IMPACT OF COLOUR ADJUSTMENT ON FLAVOUR STABILITY OF PALE LAGER BEERS WITH A RANGE OF DISTINCT COLOURING AGENTS

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ABSTRACT

The impact of colour adjustment on the flavour stability of a portfolio of locally-brewed pale lager beers with a range of colouring agents such as specialty malts, roasted barley, colouring beer and artificial caramel colorant was investigated. All brewing control parameters and beer specifications were defined and monitored under a rigorous regime in order to avoid processing factors that might interfere with or modify the two parameters under investigation.

The colour appearance parameters of the beer samples at distinct ages (fresh, forced aged and 12 month-aged) were psychophysically assessed by means of sensory viewing method (magnitude estimation) by an expert panel of the Colour Imaging Group at the Department of Colour Science, University of Leeds. Likewise, the aforementioned samples were physically measured by tele-spectroradiometry and digital imaging system at two different environments. Significant differences between the beer samples at same- and distinct ageing conditions were detected in terms of lightness, colourfulness, hue angle, opacity and clarity, although all of the samples were colour-adjusted to the same colour units according to conventional procedures (EBC colour units). In addition, good agreement between the sensory viewing (magnitude estimation) method and tele-spectroradiometry was observed. In contrast, some discrepancies between the aforementioned methodologies and the digital imaging technology were detected.

Flavour stability was assessed by the detection and quantification of fifteen flavour-active beer ageing compounds (10 aldehydes and 5 non-aldehydes compounds) by GC-MS using headspace-solid phase microextraction (HS-SPME) with on-fibre PFBOA [*O*-(2,3,4,5,6-pentafluorobenzyl)hydroxylamine] derivatisation for aldehydes compounds and on-fibre DVB-CAR-PDMS [divinylbenzene-carboxen-polydimethylsiloxane 50/30_m] derivatisation for non-aldehyde compounds. The results were correlated with the determination of the endogenous anti-oxidative potential (EAP) of the beer samples by electron spin resonance (ESR) using N-tert-butyl-α-(4-pyridyl)nitrone N'-oxide (POBN) and the sensory assessments provided by the I.C.B.D. sensory panel. Additionally, the quantification of organic radicals of the specialty malts, the roasted barley (whole intact kernel and milling fraction measurement) and the artificial caramel colorant were conducted by ESR.

Based on the results of this holistic approach, a colouring agent was selected for improving the flavour stability of pale lagers according to its physicochemical-, sensorial- and psychophysical effects as colour appearance.

This work is eternally dedicated to my soulmate Martina

Men of broader intellect know that there is no sharp distinction between the real and the unreal; that all things appear as they do only by virtue of the delicate individual physical and mental media through which we are made conscious of them; but the prosaic materialism of the majority condemns as madness the flashes of super-sight which penetrate the common veil of obvious empiricism.

- **Howard Phillips Lovecraft - (1890 - 1937)**

"The Tomb" June, 1917

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GLOSSARY OF ABBREVIATIONS

Abs., A	Absorbance
A.C.S.	American chemical society
Ag.	Aged
App.	Apparent
av	Visual redness-greenness hue component
a_TSR	CIECAM02 redness-greenness hue component by tele-spectroradiometry
a_DIG	CIECAM02 redness-greenness hue component by digital imaging
a*	CIELAB redness-greenness hue component
°Baume	Degrees Baume (Specific gravity unit based on assigning 10% NaCl solution a value of 10)
BBT	Bright beer tank
°BRIX	Degrees brix (Specific gravity unit based on percentage by weight of sucrose. The Brix hydrometer is usually calibrated at 17.5°C or 20°C)
BSP	Biometric service provider (Ref. Building standard institution)
BSTD	British standard
bv	Visual yellowness-blueness hue component
b_TSR	CIECAM02 yellowness-blueness hue component by tele-spectroradiometry
b_DIG	CIECAM02 yellowness-blueness hue component by digital imaging
b*	CIELAB yellowness-blueness hue component
C	Chroma (Colourfulness of an area judged as a proportion of the brightness of a similarly illuminated area that appears white or highly transmitting)
C*	CIELAC metric chroma
C.A.	CARAAMBER® malt (Weyermann Malzfabrik's product)
C.Ar.	CARAAROMA® malt (Weyermann Malzfabrik's product)
C.F.	CARAFA® Type III malt (Weyermann Malzfabrik's product)
C.F. SP.	CARAFA® Special Type III malt (Weyermann Malzfabrik's product)
C.H.	CARAHELL® malt (Weyermann Malzfabrik's product)
CI	Confidence intervals

CIECAM02	CIECAM02 Colour appearance model
CIELAB	CIE Colour space model
CIP	Clean-in-place system
Clv	Visual clarity
CT	Cylindroconical tank
CV	Coefficient of variation
D	Exact diagonal (Ref. Size's dimension)
DO	Dissolved oxygen
dBA	Sound pressure level at operator position
DIN	Deutsche Institute für Normung
DMS	Dimethylsulphide
DTFE	Delaunay tessellation field estimator (Ref. Material Specifications)
D65	Illuminant D65 (Statistical representation of an average daylight with a correlated colour temperature of approximately 6500 K) (Fairchild, 2006)
d°H	German water hardness (1°dH = 10 mg CaO/L = 1 g CaO/hL)
EBC units	Europe brewing convention colour unit [Colour unit based on the spectrophotometric absorbance of a sample at a wavelength of 430 nm in a 1-centimetre (10 mL) cuvette]
EDTA	Ethylenediamine tetraacetic acid
ER%	% Real extract in beer
ESR	Electron spin resonance spectroscopy
Fo.	Forced
Fr.	Fresh
FTU	Formazin turbidity unit
G	Brightness of iCAM colour appearance framework
GC	Gas chromatography
GFRPP	Glass fibre reinforced plastic
GM	Grand mean
G.R.P.	Glass reinforced plastic (product)
h	Hue angle (An attribute of a visual sensation according to which an area appears to be similar to one of the perceived colours: red, yellow, green, and blue, or to a combination of two of them) (Fairchild, 2006) (Ref. CIELAB, CIECAM02 and iCAM models)
H, Hc	CIECAM02 Hue quadrature (composition)
HD	High density (Ref. material specifications)

H.I.	Linner hue index (Hues which a given caramel coloring may produce. In conjunction with tinctorial strength, or the depth of a caramel coloring's colour, it describes the spectra which a solution of the coloring may produce at different dilutions and thicknesses) (Linner, 1970)
HMW	High molecular weight
hv	Visual hue angle
h_TSR	CIECAM02 hue angle by tele-spectroradiometry
h_DIG	CIECAM02 hue angle by digital imaging
IBU	International bitter units
iCAM	iCAM colour appearance framework
I.C.B.D.	International centre for brewing and distilling
IDF	International dairy federation (Ref. Nut liner; material specifications)
I.o.B.	Institute of brewing
IPT	IPT colour space; I: light-dark, P: red-green, T: yellow-blue (Fairchild and Johnson, 2007)
IUPAC	International union of pure and applied chemists
J	Lightness of CIECAM02 & iCAM colour appearance models An area exhibited more or less light relative to a reference white (Gonzalez-Miret *et al.*, 2007, Luo *et al.*, 1991a; Luo *et al.*, 1991b)
Jv	Visual lightness
J_TSR	CIECAM02 lightness by tele-spectroradiometry
J_DIG	CIECAM02 lightness by digital imaging
LMW	Low molecular weight
LPH	Litre per hour (ref. bottling specification)
L*	CIELAB lightness
°L	Degrees Lovibond (beer colour unit)
M	Arithmetic mean (ref. Statistics)
M	Colourfulness of CIECAM02 and iCAM colour appearance models. (An area exhibited more or less chromatic) (Gonzalez-Miret *et al.*, 2007, Luo *et al.*, 1991a; Luo *et al.*, 1991b). (Ref. Colour appearance)
M_TSR	CIECAM02 colourfulness by tele-spectroradiometry
M_DIG	CIECAM02 colourfulness by digital imaging
MBT	3-Methyl-2-butene-1-thiol
M.E.B.A.K.	Die Mitteleuropäische Brautechnische Analysenkommission

M.M.	Melanoidin Malt
MS	Mass spectrometry
MSD	Mass selective detector
Mv	Visual colourfulness of CIECAM02 colour appearance model
m/z	Mass/time ratio retention
N	Number of calibration data points (Ref. Linear regression)
NBR	Nitrilebutadiene rubber
n.d.	Non-detectable
n.q.	Non-quantified
Opv	Visual opacity
p.a.	Pro analysis (Product with a guarantee certificate and/or suitable for the stated analytical application)
PFBOA	*O*-(2,3,4,5,6-pentafluorobenzyl)hydroxylamine
Ph	Phases
P.M.	Pilsner malt
P.U.	Pasteurisation unit
puriss.	Extra pure
PVP	Polyvinylpyrrolidone
ºP	Degree plato
Q	CIECAM02 brightness (Ref. CIECAM02 colour appearance model)
R.B.	Roasted barley
Reag.	Reagent
Re	Reynolds number
RGB	RGB colour model (R: Red, G: Green, B: Blue)
R^2	Coefficient of determination (Ref. Linear Regression)
r_{95}	Repeatability, with 95% of probability
R_{95}	Reproducibility, with 95% of probability
s	CIECAM02 saturation
SDS-PAGE	Sodium dodecyl sulfate polyacrylamide gel electrophoresis
SCH	State clearing house (Ref. Material specifications)
S.G.	Specific gravity
SIM	Selected ion monitoring (Used term in mass spectrometry to describe the operation of the mass spectrometer in which the intensities of several specific ion beams are recorded rather than the entire mass spectrum) (IUPAC, 2007)
SIN	SINAMAR® colouring beer (Weyermann Malzfabrik's product)
SPME	Solid phase micro extraction

Sx	Standard deviation
°SRM	Degree standard reference method (ASBC colour unit based upon spectrophotometer readings at 430 nm) (Daniels, 2001)
TEFC	Totally enclosed fan cooled (Ref. equipment specifications)
%T	% Transmittance (Ref. Spectrophotometry)
VAC	Volts alternating current (Ref. Equipment specifications)
V.L.B.	Versuchs- und Lehranstalt für Brauerei in Berlin
% v/v	% volume/volume (mL/100mL)
WFQR	Weighted fair queuing rubber (Ref. Equipment specifications)
X	Red tristimulus value
Y	Green tristimulus value
Y.ID1925	Yellowness index (A measure of the tendency of materials to turn yellow upon long-term exposure to light)
Z	Blue tristimulus value
ΔE	Colour difference (Ref. CIELAB colour space)
X g	Times gravity
#301	Artificial caramel colorant; CARAMEL #301 (D.D. Williamson Product)

1. INTRODUCTION

The success of any beer in the market is based on its colour, head retention, physical stability and on the flavour and its stability. These characteristics are strongly related to each other. Consequently, if any of these variables are changed, the quality of the other characteristics and finally of the beer may be affected.

Colour is an essential feature of beer stability due to of its importance in the matrix of the beer and its interplay with the other quality characteristics mentioned above, the most important of which is flavour stability which has played an essential role in brewing science over the last sixty years.

Beer flavour stability has proven to be a difficult problem to solve. Over the last sixty years of research it has been discovered that oxygen causes detrimental effects to beer flavour stability by oxidation reactions. Brewers have considerably reduced the oxygen levels found in beer as a final product. However, the deterioration of flavour during beer ageing cannot be totally controlled. It has proven to be impossible to predict flavour stability by merely focusing on the impact of oxygen and its damage to the beer. For this reason, it is necessary to develop new reliable evaluations of beer flavour stability, not simply focusing on one specific analytical area, but on other areas such as the psychophysical properties of beer which have a stronger impact on the consumer's perception of beer.

Flavour information is communicated in three forms. The first form is found in the presentation of the product (product appearance) in the store or pub, the label and packaging. The second form is the preparation of the product itself, and lastly in the consumption of the product (Wade, 2006). Individuals associate certain flavours with specific colours, and when the colours are altered the flavour identification is changed. This deviation of flavour is normally associated with deterioration in quality (Delwiche, 2000; Wade, 2006). Therefore, the consistency of flavour and colour in beer is a variable which is not only based upon product specifications but upon the subconscious judgment of the consumer (Riese, 1997) as well as upon physiological factors (*e.g.* adaptation, enhancement, synergy and suppression masking) and psychological factors (*e.g.* expectation, habituation, halo-, contrast- and group effect) (Meilgaard, 1991).

It is quite common under industrial conditions to make colour adjustments to obtain the desired beer colour in the final product. In general, the final colour of beer is normally half lower of the original colour of cast wort. This adjustment in beer is normally an on-line operation, carried out during wort production. When the beer colour obtained is lower than the required specifications, colour adjustment can be done later as an off-line operation using colouring agents of different nature, *e.g.* throughout the initial stage of fermentation, maturation or beer polishing. This method of colour adjustment induces modification of the basic colour properties such as the value (lightness/darkness), the colourfulness, the hue and the clarity of the original colour affecting the visual perception of the final product, which can immediately be detected by the consumer.

All breweries aim to obtain sustainable and cost-effective operations as well as consistent brand products in terms of flavour profile, mouthfeel and visual appeal in order to fulfil market demands. These attributes can be affected by formation of stale flavours, undesirable cloudiness and change of colour appearance in packaged beer. Van Waesberghe (1994) states four essential points for obtaining consistent and high quality beer products in terms of flavour stability. The first is the establishment of good logistic management, protective distribution and dispensing conditions. The second is process consistency (operation management). The third is the implementation of consistent brewing ingredients and aids. The fourth is the investment of research to identify and compensate inherent risk in the brewing process itself.

1.1 Beer colour

Colour is a vital element that informs us of many characteristics of the products one consumes. As well as allowing us to express emotions and individuality, it has remarkable cultural and commercial context (NCS Digital Atlas, 2007). Therefore, it can be used as a marketing tool through mood creation and colour communication. In fact, beer brands generate high sales due to the influence of their image and culture, rather than the quality of the beer itself (Bamforth, 2004). For this reason, the range of colour is a priority parameter for any brewer in order to define his own product and to classify the beer styles across the globe. Table 1.1.1 present the colour ranges of distinct beer styles in terms of EBC colour units. These units are based on the spectrophotometric colour measurement of the beer sample free of turbidity in a 25 mm-cuvette at 430 nm wavelength (Brautechnische Analysenmethoden. Band II. Mitteleuropäische Brautechnische Analysenkommission, 2002f).

Beer colour is a visual perception attribute that depends on a visible light source, the electromagnetic spectral distribution (*ca.* 360 to 780 nm) of which is modulated by the physical and chemical properties of the beer matrix. This modulated energy is then absorbed by the rods, the long- (L), middle- (M) and short-wavelength (S) sensitive cones photoreceptor cells of human eye retina in terms of red (R), green (G) and blue (B) light and finally imaged by the neural mechanism of the visual system of the beer consumer. However, it is important to mention that the spectral responsivities of the cones overlap across the wavelength as well as the relative population ratio of the cones is broadly varied, generating inconsistency in the colour perception or inaccuracy in colour reproduction (see Fairchild, 2006; Hughes, 2008; Shellhammer, 2008). In addition, the colour perception is not only a passive and receptive process but is also dependent on the cognitive visual mechanisms of human eye such as memory colour, colour constancy across changes in illumination, discounting the illuminant and object recognition as well as on habits and hedonic appreciations (see Fairchild, 2006; Köster, 2009).

The physical and chemical properties of the beer that modulate the spectral distribution of the visible light for the colour perception are function of several light-absorbing beer matrix components of different nature such as melanoidins (also called Maillard products) caramelisation and pyrolysis products, oxidised polyphenols, riboflavin, carotenoids, anthocyanins, chlorophylls and its oxidation derivatives as well as oxidation catalysts such as metal ions. The spectrum of these beer matrix components are dependent on the specifications of the raw materials used as well as on the brewing condition processes established (Baxter and Hughes, 2001; Coultate, 2002; Daniels, 2001; Fix, 1999; Narziß, 1995; Shellhammer, 2008).

The melanoidins are the primary source of colour in beer. These coloured flavour-active nitrogen-containing compounds possess a colour range from yellow to amber (Baxter and Hughes, 2001; Daniels, 2001). They are elicited by non-enzymatic browning reactions also known as Maillard reactions mainly throughout high thermal malting and brewing processes such as the malt kilning, the malt curing, the mashing, the lautering, the wort boiling, the hot trub separation, the beer recovery by centrifuge and the beer pasteurisation. Nevertheless, low thermal processes such as the malting cereal germination, the wort cooling, the green beer fermentation, the beer maturation and the beer storage can also drive in minor extent the formation of these compounds. The colour contribution of the later processes is considerable on pale lager beer products like Pilsner, Bavarian helles, Kölsch and Dortmunder among others. In addition, the spectrum of melanoidins define the chemical composition and the sensorial attributes of the base malts, specialty malts and other brewing roasted products such as roasted barley, roasted rye, roasted wheat, etc.

Table 1.1.1 Colour ranges of distinct beer styles

([a]Daniels, 2001; [b]Dornbusch, 2000; [c]Jackson, 1993; [d]Papazian, 2006; [e]Richman, 1994; [f]Wagner, 1998)

Lager beer style	EBC colour	Colour descriptor	Ale beer style	EBC colour	Colour descriptor
[d]Light lager	3-8	very pale to pale	[d]Witbier (*Biere blanche*)	4-8	very pale to pale
[d]American lager	4-8	very pale to pale	[d]Hefeweizen/Hefeweissbier	6-18	pale to pale amber
[d]Premium lager	4-12	very pale to golden	[f]Kölsch	7-14	pale to golden
[d]Ice lager	4-16	very pale to golden	[d]Tripel	7-14	pale to golden
[b]Bavarian helles	6-10	pale to straw	[d]Belgian pale ale	7-24	pale to light copper
[c,d]German pilsner	6-12	pale to straw	[d]English pale ale	10-28	straw to copper
[d]Bohemian pilsner	6-14	pale to golden	[d]Lambic	12-26	straw to copper
[a]Dortmunder/Export	8-12	pale to straw	[d]Indian pale ale	12-28	straw to copper
[e]Maibock	9-18	straw to golden	[d]Bitter ale	16-24	golden to light copper
[c]Märzen	14-28	golden to copper	[d]Special bitter	16-28	golden to copper
[c]Oktoberfest	14-28	golden to copper	[d]Scottish light ale	16-34	golden to deep copper
[c]Vienna	16-24	golden to light copper	[d]Scottish heavy ale	20-38	golden amber to brown
[c]Smoked beer (*Rauchbier*)	32-52	deep copper to deep brown	[d]Dunkel Weissbier	20-38	golden amber to brown
[c]Steam beer	*ca.* 20	golden amber	[d]Irish red ale	22-36	light red-copper to brown
[c]Rye beer (*Roggenbier*)	40-45	brown to tawny brown	[d]Altbier	22-38	light red-copper to brown
[e]Dunkles Bock	50-78	deep brown to black	[d]Oud bruin	24-40	deep copper to brown
[e]Doppelbock	52-74	deep brown to black	[d]Dubbel	28-36	tawny copper to brown
[c]Dark lager (*Dunkles Bier*)	55-70	deep brown to black	[d]Barley wine ale	28-44	tawny copper to tawny brown

[c]Black beer (*Schwarz Bier*)	> 80	deep black	[d]Brown ale	30-44	deep copper to tawny brown
			[d]Dark mild ale	34-68	deep copper to deep brown
			[d]Imperial stout	> 40	dark copper to black
			[d]Irish dry stout	> 80	deep black

The optimal conditions for the non-enzymatic browning reactions are high temperatures (>100℃), alkaline conditions (high pH), and low aqueous activity (0.4-0.6 A_w) from the medium and no presence of oxygen is required (Baxter and Hughes, 2001; Daniels, 2001; Shellhammer, 2008). The reactants for this complex of reactions are carbonyl groups of simple sugars [*e.g.* glucose, fructose, maltose (mainly), etc.] and free amino nitrogen-groups from aminoacids which are converted into melanoidins by numerous chemical reaction pathways. In general, the sequence of these pathways is the Maillard reaction (condensation reaction between carbonyl group from aldose sugars and lateral amino groups of aminoacids), the Amadori rearrangement, the sugar dehydration [formation of reductones (*e.g.* deoxyosones) or furfurals], production of Schiff bases and the fission sugar by-products. The further reactions induce the formation of colourless flavour active compounds such furans and pyrroles. At this point, these latter compounds can be converted into melanoidins either via Strecker degradation (aldehydes formation) and aldol condensation (nitrogenous melanoidins formation) or via aldehyde-amine polymerisation (see Figure 1.1.1) (Daniels, 2001; Fix,1999; Hodge, 1953; Narziß, 1995; Shellhammer, 2008).

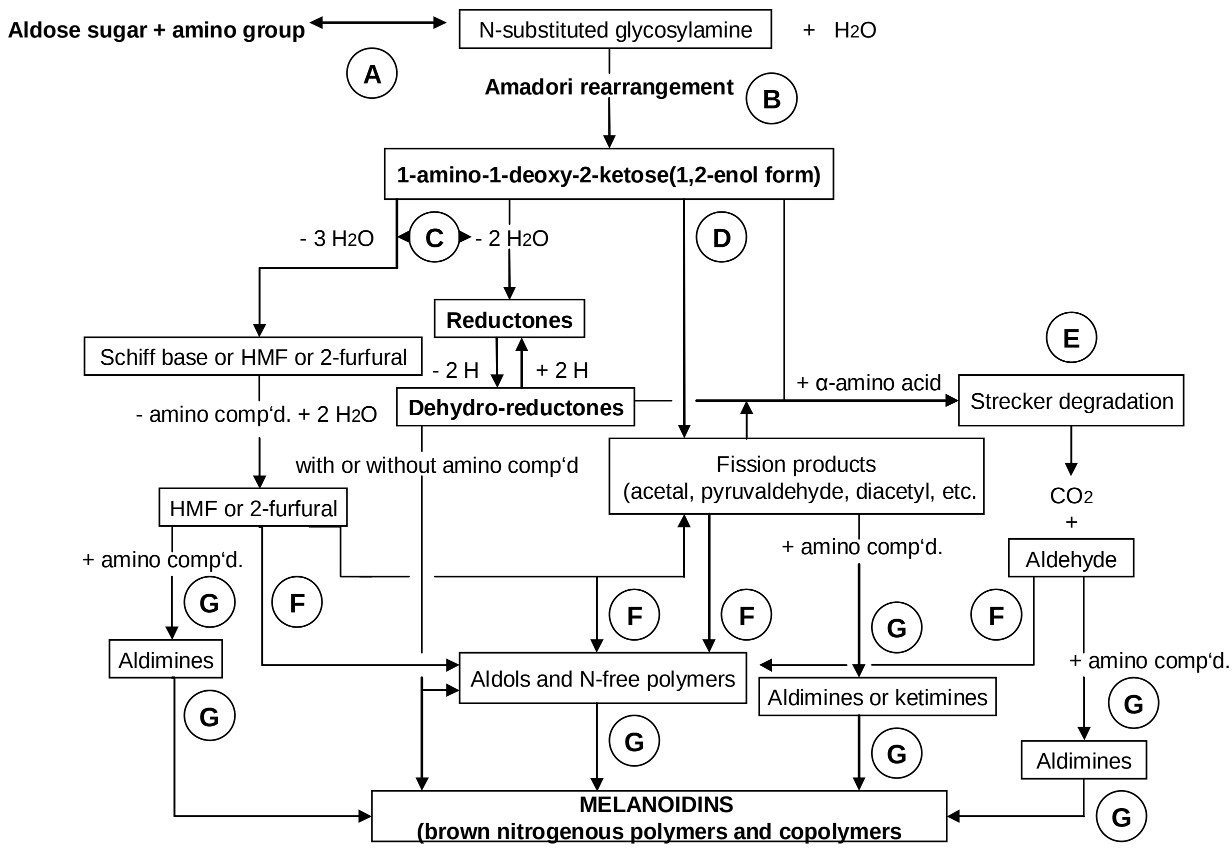

Figure 1.1.1. Maillard reactions outline (Daniels, 2001; Hodge, 1953)

A. Maillard reaction. B. Amadori rearrangement. C. Sugar dehydration. D. Fission products of sugar. E. Strecker degradation. F. Aldol condensation. G. Aldehyde-amine polymerisation and the formation of melanoidins

After the non-enzymatic browning reaction products, the oxidation of polyphenols of brewing cereal husks (*e.g.* barley, wheat, sorghum, oat etc.) and hop vegetative matter is the second mean source of colour in beer providing a colour range from red to brown (Baxter and Hughes, 2001) depending on the specific chemical structure of these compounds. Moreover, the oxidised polyphenols induce chill haze and eventually permanent beer haze as well (Daniels, 2001).

The third source of colour in beer is the caramelisation and pyrolysis reactions of sugars elicited at high temperature about 200℃ or gre ater. The caramelisation mechanism encompasses the equilibration of anomeric and ring forms, sucrose inversion to fructose and glucose, condensation reactions, intramolecular bonding, isomerisation of aldoses and ketones, dehydratation reactions, fragmentation reactions and unsaturated polymer formations. The range of products from this sort of reactions contributes to an intense red to brown colour range in beer. Technological aspects such as the heating source and technology as well as the configuration and the material specifications of the brewhouse vessels play a critical role in the spectrum of products formed. Likewise, long boiling periods, high pH and use of high gravity wort enhance the concentration levels of caramelisation and pyrolysis products (*ibid.*).

Additionally, the endogenous pigments of brewing cereals and hops such as riboflavin (vitamin B_2), carotenoids (*e.g.* carotenes and xanthophylls), hop chlorophylls (*e.g.* pheophytins), anthocyanins and melanins also contribute considerably to the colour of pale beers. These pigments are linear and cyclic compounds that present a colour range from yellow to orange (Coultate, 2002; Shellhammer, 2008). Last but not least, oxidation of metal ions (*e.g.* Fe, Cu and Mo) plays a significant role in the increase of beer colour by means of Fenton and Haber-Weiss reactions (Bamforth and Lentini, 2008; Lustig, 1993). (See the equations below).

Fenton reaction: $Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + {}^{\cdot}OH + OH^-$

(Iron) $Fe^{3+} + H_2O_2 \rightarrow Fe^{2+} + O_2^{-} + 2H^+$

Sum: $2\,H_2O_2 \xrightarrow{Fe} {}^{\cdot}OH + OH^- + O_2^- + 2H^+$

Heber-Weiss reaction: $Cu^{2+} + O_2^{-} \rightarrow Cu^+ + O_2$

(Copper) $Cu^+ + H_2O_2 \rightarrow Cu^{2+} + {}^{\cdot}OH + OH^-$

Sum: $O_2 + H_2O_2 \xrightarrow{Cu} O_2 + {}^{\cdot}OH + OH^-$

The spectrum of these beer matrix components are dependent on the specification of the raw materials used as well as on the brewing condition processes established (Baxter and Hughes, 2001; Daniels, 2001; Fix, 1999; Narziß, 1995; Shellhammer, 2008).

1.2 Beer colour measurement techniques

The colour perception of an object, such as beer, is the result of its surface properties and the integration of transmission, absorption and reflection of light over the wavelength range of 360 to 780 nm, a range which the human eye can respond to. The eye cone cells send three different signals in response to green, red and blue light in the brain, producing the perception of colours (Riese, 1997).

Different methods exist to determine colour in beer. The following colour measurement methods are used:

A) Colorimetry by visual comparison (1883)
B) Spectrophotometry (visible light region) (1950)
C) Spectrophotometry and colorimetry by CIE L*a*b* (Tristimulus method) (1995)
D) Image analysis (2002)
E) Differential spectroscopy (2005)

Colorimetry by visual comparison is based on the direct visual comparison of the colour of beer with coloured discs/glasses, ranging from 2 to 27 EBC units. The interval between two neighbouring discs is 0.5 EBC units when the colour is less than 10 EBC units and 1.0 EBC units when the EBC colour is greater than 10 (Fengxia *et al*., 2004). However, there is evidence that this method provokes problems during the process due to the variation in operator performance, ocular fatigue, variation in colour of light sources (so-called colour temperature) and discs due to ageing, and variation in the colours of new discs corrected with Illuminant C (Baxter and Hughes, 2001; Sharpe, 1992).

In 1950 the American Society of Brewing Chemists (A.S.B.C.) implemented a spectrophotometric method of measuring beer colour. This commonplace method for many breweries is based on the absorbance determination of the beer sample at wavelengths of 430 nm and 700 nm with a 10-mm light path. In 1995, the E.B.C. Analysis Committee compared E.B.C. colorimetric and spectrophotometric methods, having good repeatability in the case of EBC colorimetric method and a good reproducibility in the spectrophotometric method. It is important to point out that for both methods, beer samples must be free of any turbidity, being particularly critical for the spectrophotometric method, because at a single wavelength 430 nm, it is difficult to determine “true” colours as a single slice of transmitted light examined and exhibits errors due to back scattered light from suspended particles, when samples show temporal and dynamic changes such as slight turbidity or the light ray modifies the composition of the wort or beer matrix depending on its current oxidation state (see Fengxia *et al*., 2004).

The visual comparator and the spectrophotometric methods were found to be linearly related. The variation between these methods is low and a very good correlation has been observed for pale beers, albeit the spectrophotometric method displays higher absorbance values on dark beer samples of more than 80 EBC units, even after dilution. For this reason, the colour measurement of darkest beers could not be determined by this method. In contrast, the colour measurement of the dark beers with the use of colorimetry by visual comparator, requires dilution to obtain samples with a colour between 20 and 27 EBC units (visual comparator range). Sample dilution not only affects the intensity but also the perception of colour. For this reason, other colour measurement methods have been developed and implemented, such as the uniform CIE L*a*b* system and image analysis that offer more information of real beer colour because no dilution step is necessary (Fengxia *et al*., 2004; Smedley, 1992).

Smedley applied a method to measure beer colour based on the Tristimulus method which is well known and used in food, ceramic and paint colour industries (Smedley, 1995). This method is based on the X (red), Y (green), and Z (blue) tricolour stimulus coordinates, which are measured spectrophotometrically with a transmission of light through beer at five different wavelengths (360, 450, 540, 670, and 760 nm). These data are used to calculate the values of the Commission Internationale d l’Eclairage (CIE) L*a*b* colour space system. In this colour system *L represents the value of the colour, that is light or darkness intensity. The a* and b* values represent the red-green and the yellow-blue colour shades, respectively. These latter values together represent the hue of the colour (H). Finally, the colour difference (ΔE) to estimate EBC colour units is calculated by regression (Sharpe *et al.*, 1992; Smedley, 1992; Smedley, 1995). Figure 1.2.1 depicts the CIE L*a*b* colour space system. The repeatability coefficients of variation for L*, a* and b* and reproducibility coefficient of variation for L* were judged acceptable, but a* and b* coefficients of variation were rejected by the American Society of Brewing Chemists (A.S.B.C.) subcommittee (Beer Colour Using Tristimulus Analysis, American Society of Brewing Chemists, 2000).

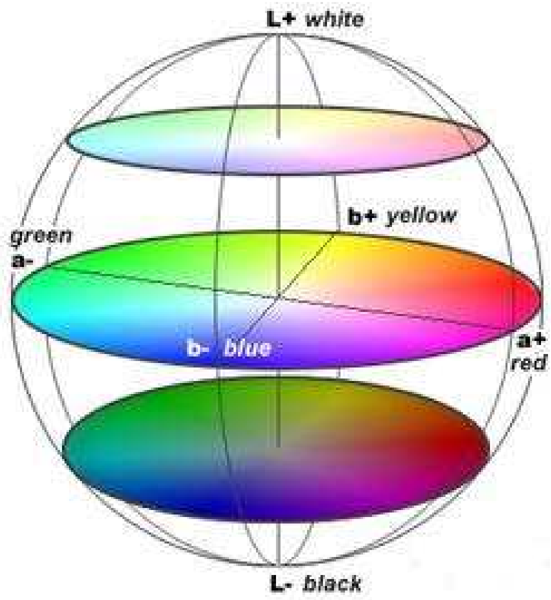

Figure 1.2.1 The CIELAB colour space

Coghe *et al.* (2003) carried out extensive research on characterising dark speciality malts on the basis of their colour evaluation and pro- and anti-oxidative activities. They discovered that the calculated L* parameter decreased with increasing EBC colour. It has been observed that for a constant EBC colour, beer produced with roasted malt always had a lower L* value. This indicates that, despite the same EBC colour, beer colour with roasted malt appears darker than beer made with colour or caramel malt (*ibid.*). Beers produced with caramel malts showed an increasingly dominant red component (+a*). The proportion of the yellow (+b*) component showed a maximum at approximately 80 EBC units for dark crystal malt beer and at 70 EBC units for roasted malt beer (*ibid.*). It was also observed that the CIE L* parameter was linearly related to anti-oxidative activity. The anti-oxidative activity was measured by reduction of Fe-dipyridyl on beer (colouring reaction). For colour and caramel malt worts, the L* parameter was negatively correlated with the reducing power. Wort made with roasted malt revealed even closer correlation to reducing power. In roasted malt wort, a* and b* parameters did not correlate with anti-oxidative activity (*ibid.*).

In 2001, Fengxia and Zhanming developed and implemented image analysis to determine beer colour successfully. Good agreement, between image analysis values and Lovibond colorimetry data was obtained (Fengxia *et al.*, 2004). This method is based on the saturation of the beer colour; a feature of the image analysis which stands for the colour of beer judged by its brightness. The saturation value was determined by using a digital camera, a scanner and developed software (*ibid.*).

The most recent method for beer colour determination is the so-called differential spectroscopy proposed in 2005 by Savel (2005). This method is confined to the ratio of absorbance between 380 nm and 580 nm of the sample against distilled water during storage at 20℃ or 45℃ or throughout pasteurisation at 60℃. Savel correlated these values as an index with wort and beer oxidation. His results become a relevant tool to detect colour shifts attesting electron transport present in the beer matrix during oxidation of active-flavour compounds (*ibid*.).

Unfortunately, the techniques described above for measuring colour in beer cannot measure the dynamic and static visual perception of the beer in the same way as its colour appearance. This is based on how the human eye perceives the colour of the beer.

1.3 Colour appearance

Colour appearance is a complex array of visual phenomena, which has not yet been considered for measuring beer colour. It extends basic colorimetry to the level of defining a specific colour perception of stimuli in a wide variety of viewing conditions such as Bezold-Brücke hue shrift (hue changes with luminance), Abney effect (hue changes with colorimetric purity), Helmholtz-Kohlrausch effect (brightness depends on luminance and chromaticity), Hunt effect (colourfulness increases with luminance), Stevens effect (contrast increases with luminance), Helson-Judd effect (hue of non-selective samples), Bartleson-Breneman equations (image contrast changes with surround), discounting the illuminant, other context and structural effects, simultaneous contrast, crispering and spreading (Fairchild, 2006). It has been quite difficult to analyse, either by psychophysical evaluations or by physical measurements, because it is a viewer-dependent variable (preference, visual and environmental characteristics) as well as a scene-dependent variable (illumination, volume, texture, and constituent materials) (Fairchild, 2006; Luo *et al.*, 1991a,b).

Beer colour appearance depends on distinct stimuli in spatial and temporal effects, as the eyes are continually moving during the perception of a stimulus (*ibid.*). One of the critical factors, which dramatically influence the beer colour appearance, is the spatial configuration of the viewing field. The spatial configuration of the viewing field consists of components of a specified image of the scene; the stimulus (*e.g.* the beer itself), the proximal field (distance between the eyes of the observer and the beer), the background (*e.g.* black or white background) and the surroundings (*e.g.* a room or pub) (Fairchild, 2006). Figure 1.3.1 shows graphically the components of the viewing field.

One of the most important phenomena involved in colour appearance is the metamerism of the colours. This is basically that different tristimulus colours appear to be the same under different viewing conditions or the same tristimulus colours appear different under distinct viewing conditions (*ibid.*). The metamerism of the colour is produced because the human eye contains only three colour receptors (cones) and each cone responds to the cumulative energy from a broad range of wavelengths. Therefore, different wavelengths of light can form visually identical colour sensations (*ibid.*). Likewise, other factors that are not considered in the determination of colour but which have a strong influence on the appearance of the beer, include the contrasts of the backgrounds, the psychological state of the viewer, the gloss and the translucency of liquids.

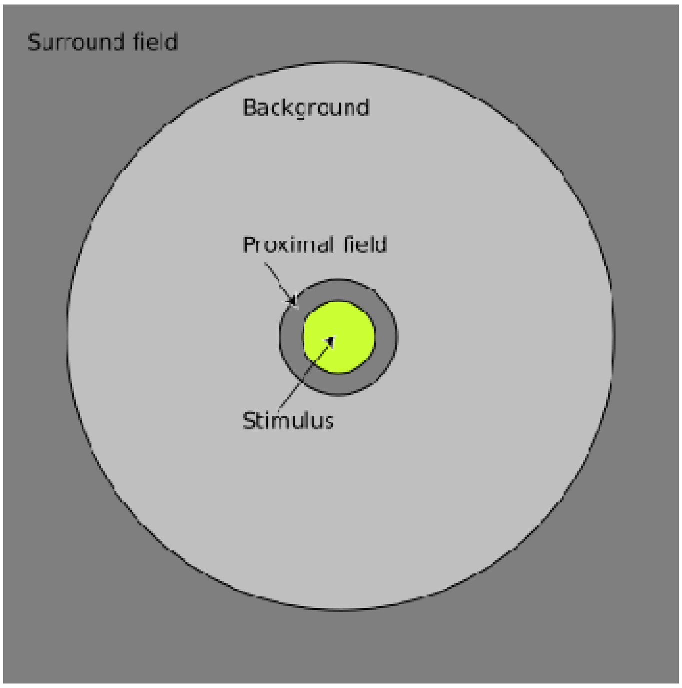

Figure 1.3.1 Description of components of the viewing field (Fairchild, 2006)

Tristimulus/CIELAB colorimeters and spectrophotometers are widely used for colour measurement but they are incapable of measuring three dimensional, non-uniform samples (Luo *et al.*, 2002) and do not consider some of the components of the viewing field as background and surround dependencies. These systems do not consider luminance-dependent effects, such as Stevens's effect (increase in perceived image contrast with luminance) and Hunt effect (increase in perceived colourfulness with luminance), neither do they provide absolute appearance attributes of brightness, and colourfulness (Fairchild, 2006).

1.3.1 The iCAM Framework

Fairchild and Johnson developed a new colour appearance framework called iCAM. In this up-dated framework is given to the colour appearance phenomena dependency, which is involved in all the aspects already mentioned, in order to measure colour appearance as the human eyes perceives it (Fairchild, 2006; Fairchild and Johnson, 2007).

This framework is based on the conversion of the image relative CIE XYZ tristimulus values (with CIE Iluminant D65) into a chromatic adaptation RGB signals to control various luminance-dependant aspects known as the Hunt effect and the Stevens effect. Afterwards, the RGB signals are converted into IPT colour space components; I:

light-dark; P: red-green, T: yellow-blue. The reason for this conversion is to predict the response compression of the human sight system. This response compression converts from physical metric signals (*e.g*. luminance) into perceptual dimensions signals (*e.g.* lightness). Finally, from the obtained IPT colour space, components are calculated image-wise predictors of lightness (J), chroma (C), hue angle (h), brightness (Q) and colourfulness (M) as the most relevant colour appearance properties (*ibid*.).

1.3.2 CIECAM02 colour appearance model

The CIECAM02 colour appearance model has been revised and proposed by the CIE Technical Committee 8-01 and is currently the most used colour appearance model for digital imaging in the food and beverage industry. This model is based on the previous CIECAM97s colour appearance model with the aim of improving its prediction performance, computational complexity and invertibility. The CIECAM02 model provides, like its analogue iCAM colour appearance framework, a perceptual attribute which correlates from a specific viewing condition *i.e.* tristimulus values of a specific object (Luo and Li, 2006; Moroney *et al.,* 2002a; Moroney *et al.*, 2002b; Moroney *et al.*, 2003).

The main components of this model are the modified chromatic adaptation transform and the D factor (degree of adaptation-discounting) for computing correlates of perceptual attributes, for instance lightness, chroma, colourfulness, hue, saturation and brightness. These modifications were based on psycho- and physiological data and other considerations that provide changes in the chromaticity and luminance of the adopted white point and non linear response compression (*ibid.*).

1.3.3 Tele-spectroradiometry

Spectroradiometry is a method of measuring the spectrum of radiation emitted by a source or object (Bentham, 1997). A tele-spectroradiometer separates by diffraction grating the radiation of an object into single component wavelength ranges of the visible spectrum (360-780 nm) with a spectral bandwidth of 5 nm and sequentially captures and measures their intensities, giving as result a record of all the spectral characteristics of the object (*ibid.*). The obtained single wavelengths are converted into tristimulus values (X,Y,Z) and subsequently into CIECAM02 colour appearance components; lightness (J), colourfulness (M), hue angle (h) and hue composition (Hc) applying the CIECAM02 formulae (CIE, 2004). Therefore, a tele-spectroradiometer generates an objective, physical measurement in radiometric units at each wavelength into more subjective photometric equivalents such as tristimulus values to CIECAM02 colour appearance predictors that indicates how the human eye perceives the radiation (illuminance quality) of the object targeted (*ibid.*). Figures 1.3.3.1 and 1.3.3.2 depict the picture and the system diagram of a Tele-spectroradiometer, respectively.

Figure 1.3.3.1 Minolta CS-1000 Tele-spectroradiometer (Minolta CS-1000 Tele-spectroradiometer, 2003)

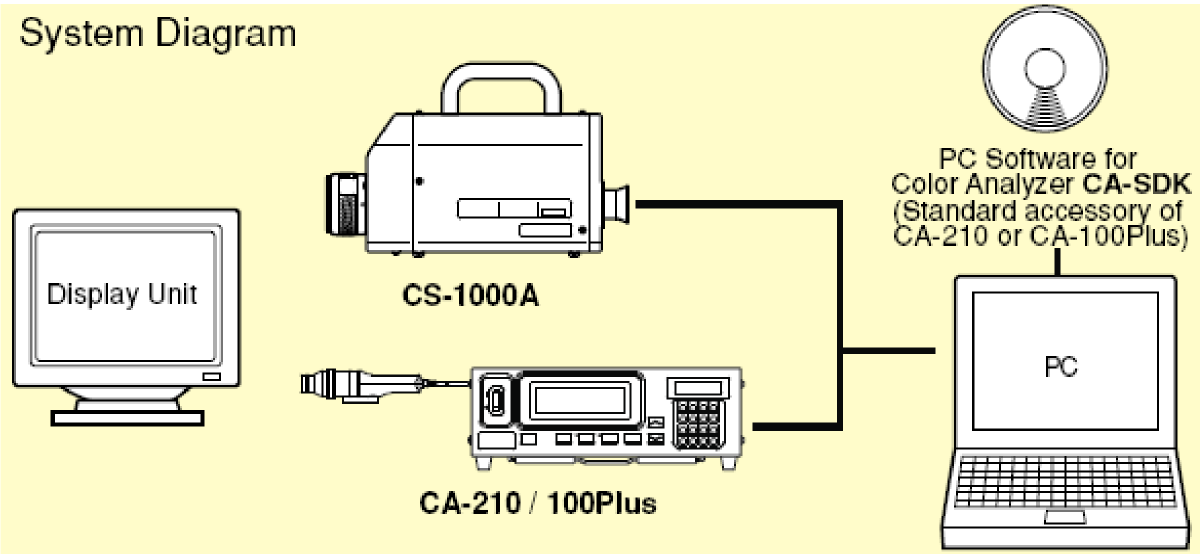

Figure 1.3.3.2 Minolta CS-1000 Tele-spectroradiometer system diagram (Minolta CS-1000 Tele-spectroradiometer, 2003)

1.3.4 DigiEye System-VeriVide®

DigiEye System-VeriVide® is a non-contact digital apparatus for measuring the total colour appearance of 2D- or 3D- objects based on the CIECAM02 colour appearance model. The apparatus includes the following hardware components: a receiving enclosure coated with a matt paint for ensuring uniformity and a diffused illumination (D65 simulator), an adjustable internal illumination by means of lamps set at 45° to the sample, a digital camera, a computer for p rocessing information relating to the image obtained by the digital camera and an image display mean (Luo *et al.*, 2002; Luo *et al.*, 2003). The computer includes four software functions: camera characterisation (colour measurement of a single pixel or a portfolio of pixels from the captured image in terms of colorimetric values), spectral reflectance function, monitor characterisation and texture profiling (*ibid.*). The calibration of the digital camera, also called camera characterisation, is carried out by converting the camera's spectral sensitivities red (R), green (G), blue (B) signals into tristimulus values (X, Y, Z). This is physically determined by taking an image under different illumination sources of a standardised reference colour chart with known tristimulus values [*e.g.* TagMacbeth Colour Checker®DC (TagMacbeth Colour Checker®DC, 2000)] and comparing the camera responses for each known colour within the chart with the tristimulus values for that colour (*ibid.*). The reason for this conversion is due to the RGB signals based on the sensor spectral sensitivity of a digital camera, being a device-dependent property. This novel technology might be a powerful tool for analysing the beer colour appearance, and will probably be the method of choice in the future of the brewing industry. Figure 1.3.4.1 depicts the DigiEye System-VeriVide® with its corresponding hardware components.

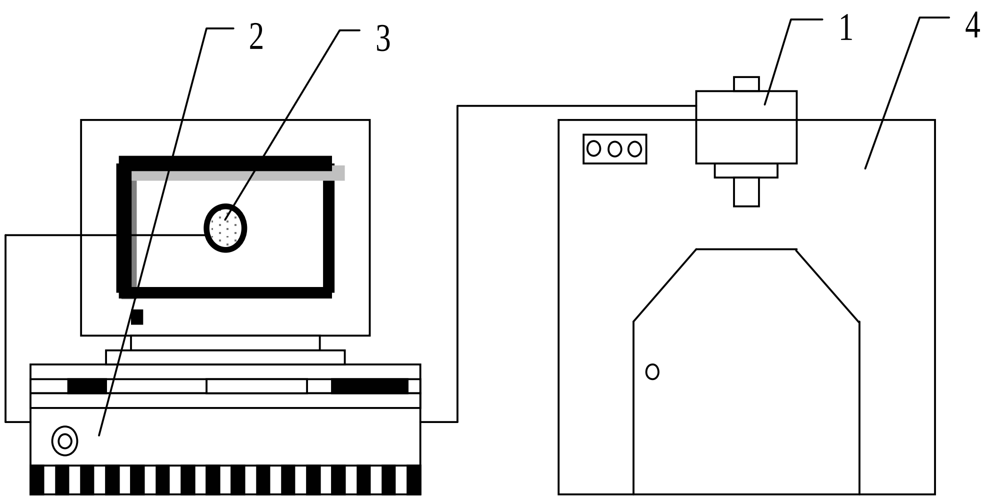

Figure 1.3.4.1 DigiEye System-VeriVide® (Luo *et al.*, 2001)
1. Digital camera, 2. Hard driver, 3. Monitor or image display means, 4. Illumination cabinet

1.4 Brewing colouring agents

The colouring agents used in brewing are specialty malts, roasted barley and caramel colorants. The advantages of specialty malts are the natural product character and their flexibility in as much as no special labelling is required. The disadvantages are an inconsistent colour and the major storage space required. In the case of caramels the relevant advantages are the high colour intensity, lower cost, exact dosage size and small storage area needed, while their disadvantages are possible special legislation labelling, usage in hot wort and when used in cold temperatures the caramels show unsatisfactory homogeneity.

1.4.1 Colour malts

This type of specialty malts is produced with a kilning programme, which starts quickly about 63℃ when the malt still has considerable moisture content, and progressively the temperature of kilning is raised to a final temperature of approximately 99℃. The intensity of drying air for kilning is much higher than that used for pilsner malt production. The higher humidity of the drying air for the production of coloured malts carries much more energy making it able to increase the temperature of the malt bed much more efficiently. The intensity of the kilning cycle and moisture content of air play a relevant role in the flavour profile and final colour of these malts (Gretenhart, 1997). However, the malting procedures can be varied depending on the physicochemical and sensorial attributes of the colour malt desired by the brewer. A particular case is the production of melanoidin malt also called "turbo Munich", Brumalt (Brühmalz) and rH-malt, in which a desirable formation of specific melanoidins in malt is induced by intensive germination at 18℃ to 20℃ for 5 to 6 days with a further carbon dioxide rest at the last 36 hours of this process stage. This latter procedure is carried out by stacking the germinated grain in uniform heaps of about 1.5 m height covered under a tarpaulin to induce production of carbon dioxide and self-heating by the grain respiration. This restrains the seedling respiration and growth but the activity of the endogenous enzymes remains intact at relative high temperatures (*ca.* 40℃ to 50℃) producing large amounts of low molecular sugars and aminoacids that participate in the formation of melanoidins across non-enzymatic browning reactions during the free drying kilning phase (*e.g.* 55℃ to 60℃ for 9 to 11 hours) and the forced drying kilning phase (*e.g.* 85℃ for 3 to 4 hours). Besides, esters and organic acids are produced but in minor extent. The withering and kilning procedures are upon the malting factory specifications but in any case the green malt is further "stewed" (*gebrüht*). These types of malt greatly promote flavour stability and mouthfeel. Besides, they have high degree of modification, excellent friability, and low hemicellulose (*e.g.* β-glucans and pentosans) levels and are highly acidic and malt aromatic. They confer a broad colour range from deep-amber to red-brown in beer (Kunze, 1999; Narziß, 1995; Weyermann Malzfabrik GmbH, 2007).

Types of colour malts include (Kunze, 1999; Weyermann Malzfabrik GmbH, 2007):

1. Pale malt [5.5-7.5 EBC]
2. Vienna malt [6-9 EBC]
3. Munich malt [Type I: 12-18 EBC, Type II: 22-28 EBC]
4. Brumalt (Brühmalz) [30-40 EBC]
5. Melanoidin malt [60-80 EBC]

1.4.2 Crystal malts (Caramel malts)

The crystal malts, also known as caramel malts, are renowned for producing saccharification formed throughout the roasting process. These malts differ from colour malts in that they are produced in roasting drums rather than kilns. The production of crystal malts differs from the roasted malts as green malt is placed on the roaster during the roasting or curing process instead of finished malt and barley in the case of roasted malts and roasted barley (Gretenhart, 1997). This method of roasting provokes the drying of the husk surface of the grain during the first part of the cycle. The grain is then treated to higher temperatures in order to maximize the activity of all the endogenous enzymes of the kernel. Once the internal part of the malt has reached a temperature between 65 to 75℃ with a moisture content of 45%, th e enzymes start to hydrolyse the malt starch. This provokes a gelatinization of malt that is followed by a subsequent saccharification (*ibid*.). After this series of reactions the malt is dried to about 5 to 6% moisture content with higher roasting temperatures from 80℃ to 145℃. In this last stage the colour and flavour are developed by non enzymatic browning reaction and caramelisation reactions (*ibid.*). The higher the roasting temperature, the more content of heterocyclic compounds are obtained. This group of compounds confers nuts-, caramel- and toffee- flavours, being in the most extreme case, a strong burnt and bitter flavour produced by a high content of pyrroles and pyrazines (*ibid.*). Finally, the crystal malt is cooled to stop any subsequent reaction. The crystal malts have the broadest range of colours and flavours of all specialty malts, and have a glassy appearance in the internal part of the kernel. The range of colour is around 2.5 EBC to over 450 EBC. Other properties of these malts are the enhancement of palatefullness and head retention due to their higher amounts of melanoidins, which interact with the hydrophobic barley malt proteins and peptides (*e.g.* LTP and Z), barley malt and hops polyphenols as well as with hop bitter substances (*e.g.* iso-α-acids, α-acids and β-fraction), hop oils derivatives and oligosaccharides (*e.g.* dextrins, β-glucans and pentosanes) forming by cross links the head foam matrix of the beer (Euston *et al*., 2008; Gretenhart, 1997).

Types of crystal malt (caramel malt) include (Weyermann Malzfabrik GmbH, 2007):

1. CARAPILS® (light crystal malt) [2.5-6.5 EBC]
2. CARAHELL® (light crystal malt) [20-30 EBC]
3. CARARED® (red crystal malt) [40-60 EBC]
4. CARAAMBER® (light crystal malt) [60-80 EBC]
5. CARAMUNICH® (dark crystal malt) [Type I: 80-100 EBC, Type II: 140-160 EBC, Type III: 170-220 EBC]
6. CARAWHEAT® (wheat crystal malt) [110-140 EBC]
7. CARARYE® (rye crystal malt) [150-200 EBC]
8. CARAAROMA® (dark crystal malt) [350-450 EBC]

1.4.3 Roasted malts and roasted cereals

These products are produced by the roasting of finished kilned malts or barley in the case of roasted barley. The roasting temperature is gradually raised throughout the process reaching a final temperature of between 220℃ to 230℃, being almost the carbonization temperature of the malt which is obtained at 248℃ (Gretenhart, 1997). The consequence of this high thermal treatment is a significant production of nitrogen containing heterocyclic compounds as pyrroles and pyrazines, which confer chocolate, coffee, burnt and astringent flavour. Likewise, during the roasting it produces phenolic acid by-products that provide smoky- and clove-like flavour in these roasted products (Gretenhart, 1997; Gruber, 2001). Type of roasted malts include (Daniels, 2001; Weyermann Malzfabrik GmbH, 2007):

1. Roasted spelt malt [450-650 EBC]
2. Roasted rye malt [500-800 EBC]
3. Roasted rye (non malted product) [500-800 EBC]
4. CARAFA® (chocolate/black malt) [Type I: 800-1000 EBC, Type II: 1100-1200 EBC, Type III: 1300-1500 EBC]
5. CARAFA® SPECIAL (dehusked chocolate/black malt) [same as CARAFA®]
6. Roasted wheat malt [800-1200 EBC]
7. Roasted barley (non malted product) [1100-1200 EBC]

1.4.4 Colouring beer (Roast malt beer)

This colouring agent has been created in a German malting company and consists in a pure extract from a beer brewed with 100% of dehusked chocolate roasted malt with a colour intensity of 1100-1200 EBC. The objective of using dehusked malt is to avoid acrid bitterness in beer that stems from the husks of barley. Hence, this colouring agent is patent named SINAMAR® derived from the latin "*Sinne Amaro*" which means "without bitterness" (Hornsey, 2008; Kunze, 1999).

The brewing of the colouring beer is based upon a mashing programme of 60 minutes at 70°C. Subsequently, there is a little hop addition during wort boiling of 60 minutes in order to guarantee the proper beer denomination according to the German purity law (Reinheitsgebot). The cast wort obtained with an original extract of 12°P is cooled down and fermented with lager yeast for a short period to obtain minimum alcohol content of 0.8-1.2% v/v in order to optimise the extract yield. Afterwards, it is extracted by means of vacuum evaporation to avoid wort pyrolysis and to eliminate the ethanol produced. The final extract content of the colouring beer is around 50°P and with a range of colour between 8,500 to 9,000 EBC with a pH range of 3.8 to 5.0 (Hornsey, 2008).

The colouring beer is normally added at the brewhouse stage during the last 10 to 15 minutes prior the end of the wort boiling depending upon the brewer's practices (*ibid.*). However, it has a great flexibility in terms of processability and can also be used for beer colour adjustment during the fermentation or post-fermentation stages (Weyermann, 2007).

1.4.5 Artificial caramel colorant

There exist four distinct types of artificial caramel colorant in the food and beverage market (Kamuf *et al*., 2003):

1) Caramel colour I (plain or spirit caramel)
2) Caramel colour II (caustic sulphite caramel)
3) Caramel colour III (ammonia or beer caramel, bakers and confectioners caramel)
4) Caramel Colour IV (sulphite-ammonia, soft drink caramel, or acid proof caramel)

The typical ingredients used to produce artificial caramel colorants are basically edible carbohydrates such as glucose, sucrose, fructose and starch degradation by-products such as inverted sugars, corn syrups, malt syrups and molasses. The production of caramels requires certain catalysts such as acids, alkalis and salts for inducing the caramelisation desired. The selection of these compounds is subject to the chemical and physicochemical properties of the substrate used (*ibid.*).

The procedure to obtain artificial caramel colorant consists in the introduction of the carbohydrate substrate into a reactor, whereby the sugars will be warmed for better mixing and subsequently the catalyst is added to induce the caramelisation reactions for several hours at a predetermined temperature and pressure conditions (Comline, 2006). The ratio of sugar substrate and catalyst, as well as the pH-time-temperature conditions vary depending on the type of caramel colorant being produced. Once the colour intensity is finally achieved the batch is immediately cooled, filtered and stored (*ibid.*).

Artificial caramel colorant for beer colour adjustment is a caramel colour III (ammonia caramel). The ammonia compounds used as catalysts for the production of this sort of colorant are hydroxides-, carbonates-, bicarbonates-, phosphates-, sulphates-, sulphites-, and bisulphites (Kamuf *et al*., 2003).

This caramel is usually a dark brown to black liquid with an aroma of burnt sugars and bitter-like taste. The selection of the artificial caramel colour depends on the isoelectric points and pHs of the artificial caramel colour and the beer to be colour adjusted (Comline, 2006). The artificial caramel product must have the same charge as the colloidal particles of the beer to be coloured, otherwise the particles of each reactant will attract each other, forming insoluble particles and precipitating into the bottom of the tank. Beer contains positively charged proteins; therefore positively charged artificial caramels are required for beer colour adjustment (Caramel products. D.D. Williamson & Co., Inc, 2007; Comline, 2006).

In the artificial caramel colorant industry the “redness” of a particular caramel colour is often measured. Linner (Caramel products. D.D. Williamson & Co., Inc., 2007) developed an equation based on spectrophotometric readings at 510 and 610 nm to determine the redness of any caramel colour also denominated hue index. Hue index is calculated as follow:

Hue Index = 10 log (Absorbance at 510 nm/ Absorbance at 610 nm)

1.5 Beer flavour stability

Beer flavour perception is a complex mechanism, which has not been fully elucidated due to the wide range of stimuli that are involved in. These are developed by the temporal transformation of physical structures and chemical compounds that active the flavour chemoreceptors of tongue, throat and nasal cavities as the beer is drunk (see Baxter and Hughes, 2001). Therefore, it is necessary to consider the entire process of flavour perception such as the release of flavour-active compounds in the mouth, the contact time between these and chemoreceptors, the subsequent neural processing of the stimuli, the overlapping effects by antagonist flavour-components, etc. In addition, there are other external factors that also influence the beer flavour perception such as the oral temperature, consumer's age, hormonal state, healthy deficiencies and genetic variations among others. However, beer flavour is reported in two general sense's impressions; aroma and taste (see Meilgaard *et al*., 2007). Several flavour-active compounds contribute to the beer aroma. For instance, such as fermentation main-, and by-products, esters, vicinal diketones, fatty acids degradation products, sulphur compounds, hop oil derivatives, Maillard products and Strecker degradation products. Table 1.5.1 shows a portfolio of significant aroma-active compounds in fresh beer reported in literature.

Beer taste is perceived in terms of sweetness, bitterness, sourness, saltiness and savoury (umami) by the specific chemoreceptors distributed in the tongue buds as well as in terms of palatefulness (body) and fizziness (irritant) by the trigeminal nerve. The sweetness in beer is provided by residual carbohydrates such fructose, glucose, sucrose, maltose, maltotriose and dextrins. In contrast, the bitterness in beer is generated by hop bitter substances, mainly iso-α-acids, but also by malt- and hops polyphenols, and yeast cells, particularly in Hefeweizen (wheat beers) (Kunze, 1999; Narziß, 1995). The sourness in beer is contributed by weak organic acids such as carbonic, acetic, propionic, tartaric lactic and succinic acids as well as those produced through the glycolysis pathway and Krebs circle such as citric, α-oxoglutaric, fumaric, L-malic, oxalacetic and pyruvic acids (Lustig, 1993; Voet and Voet, 2002). Meanwhile, the saltiness in beer is induced by inorganic anions and cations such as potassium, sodium, calcium, magnesium, chloride, sulphate, oxalate, phosphate and nitrate (Baxter and Hughes, 2001; Narziß, 1995). Last but not least, the umami taste and fizziness in beer is mainly generated by carbon dioxide and the pH of beer, while the palatefulness is contributed by the alcohol content, the residual carbohydrates (dextrins, β-glucans and gums), nitrogen compounds, bitter substance, polyphenols and phosphates (Kunze, 1999; Narziß, 1995).

A substantial body of research in beer flavour stability has been carried out over the past sixty years due to their complexity and difficulty to be solved. Nowadays, it is known that the flavour stability is not dependent on one or small number of chemical compounds but more likely on the changes in the physicochemical and sensory properties of beer. These changes of beer flavour are caused by the decrease in a desirable flavour character such as hop bitterness by degradation of trans/cis iso-α-acids (T/C ratio: 32:68) to allo-iso-α-acids,hydrated allo-iso-α-acids, acetylhumulinic acids and humulinic acids (see Jaskula *et al.*, 2007) and the increase in an undesirable flavour character (*e.g.* sweetness, ribes or catty off-flavours and diacetyl formation in lager beers) over the ageing. The variations in beer flavour are produced by several factors such as the brewing operation conditions (*e.g.* temperature, pressure, pH and oxygen levels), flavour masking, flavour failures by microbiological contamination through malting and brewing processes (*e.g.* contamination by *Lactobacillus, Pediococcus, Obesumbacterium, Enterobacter, Zymomonas, Gluconobacter, Acetobacter, Pectinatus* and wild yeasts such as *Saccharomyces, Candida, Pichia* and *Hansenula*) and taints (*e.g.* inks, metallic flavours and phenols) (Bamforth and Lentini, 2008; Baxter and Hughes, 2001; Campbell, 2003; Clapperton, 1976; Dalgliesh, 1977; Furusho *et al.*, 1999; Priest, 2003; van Vuuren and Priest, 2003; Vanderhaegen, 2006).

Nevertheless, brewers have discovered that oxygen in the singlet state, reactive oxygen species (ROS) such as hydroxyl radical ($^{\cdot}OH$) and hydroperoxyl ($^{\cdot}OOH$) from several different components of the beer matrix are the main participants in damaging the beer flavour stability, particularly when it is at too high levels in-pack. As many components of beer are oxygen sensitive, oxygen damage persists despite the rigorous oxygen control that is carried out by brewers. It is also affected by individual brewery-specific phenomena such as the sulphur dioxide (*e.g.* three forms in aqueous solution: $SO_2{\cdot}H_2O$, HSO_3^-, SO^{2-}) content in finished beer (normal values: 20 mg/L in pale lager beer after M.E.B.A.K.) (see Bamforth and Lentini, 2008; Franz and Back, 2003). In addition, previous studies have identified other relevant sources that induce damage to the beer flavour stability such as transition metal ions (*e.g.* Fenton and Haber-Weiss reactions), vicinal diketone release in beer from incompletely eliminated precursors sulphur compounds, enzymic degradation of unsaturated fatty acids (linoleic acid, mainly) into shorter chain aldehydes [*e.g.* (*E*)-2-nonenal and β-damascenone] by potentially active endogenous barley lipooxygenases (LOX) and hydroperoxides by active endogenous barley peroxidases (POD), oxidation of unsaturated fatty acid during malting and particularly during and mashing (<63℃) [*e.g.* degradation products of linoleic acid; 13-hydroperoxy-(Z,E)-9,11-octadecadiene acid (13-LOOH), 9-hydroperoxy-(Z,E)-10,12-

octadecadiene acid (9-LOOH)], oxidation of proanthocyanidins and trans-, cis isohumulones [*e.g.* mercaptan, 3-methyl-2-butene-1-thiol (MBT), methyl ketones, aldehydes and 5-methyl-4-pentenoic acid], oxidation of higher alcohols, Strecker degradation of amino acids (*e.g.* aldehydes and ketones), aldol condensations, acetal formation, binding of carbonyls by sulphur dioxide and changes in ester levels (Aerts and van Waesberghe, 2007; Bamforth and Lentini, 2008; Doderer *et al*., 1992; Griffin, 2008; Hashimoto and Kuroiwa, 1975; Kuroiwa and Hashimoto, 1961; Lustig *et al.*, 1993; Methner *et al.*, 2007; Narziß, 1995; Peppard and Halsey, 1982; Savel, 2001; van Waesberghe, 1994).

Previous studies have reported the origins of some of the main volatile compounds formed during beer storage including linear aldehydes (*e.g.* pentanal, hexanal and (*E*)-2-nonenal), Strecker aldehydes, ketones, cyclic acetals, heterocyclic Maillard products (*e.g.* 2-furfural, 5-hydroxymethylfurfural, 2-acetylfuran, 2-propionylfuran, 2,4-dimethyl-4-cyclopenten-1,3-dione), ethyl esters (*e.g.* ethyl nicotinate, diethyl oxalate, 2-ethyl phenyl acetate), furan ethers (*e.g.* 2-ethylfurfuryl ether), lactones (*e.g.* γ-nonalactone), aldehyde acetalization products (*e.g.* 2,4,5-trimethyl-1,3-dioxolane) and sulphur compounds [*e.g.* DMS, DMSO, 3-methyl-2-butene-1-thiol (MBT) and methional] (Evans *et al*., 1999; Fickert and Schieberle, 1999; Grönqvist *et al.*, 1993; Lustig, 1993; Syryn *et al*., 2007; Vanderhaegen *et al.*, 2006; Vanderhaegen *et al.*, 2007). The 2-methylpropanal, 2-methylbutanal, 3-methylbutanal, 2-phenylethanal, benzaldehyde and methional are aldehydes which are produced by Strecker degradation and their concentration increases in the presence of oxygen in beer and they are present in high quantities in beers with high alcohol content. Likewise, other carbonyl compound 3-methylbutan-2-one is also produced due to higher oxygen levels. This ketone is produced from the degradation of the carbonyl side-chain of α-acids and β-acids producing the precursor of this compound 2-methylbutyric acid (Vanderhaegen *et al.*, 2007). Other ageing components that increase by the presence of oxygen are cyclic acetals such as γ-nonalactone and 2,4,5-trimethyl-1,3-dioxolane (see Hofmann, 1998; Peppard and Halsey, 1982; Thum *et al.*, 1995). The synthesis of 2,4,5-trimethyl-1,3-dioxolane; acetal cyclic compound is originated from the condensation reaction between 2,3-butanediol (up to 280 mg/L) in beer and an aldehyde (acetaldehyde, isobutanal, 3-methyl-butanal and 2-methyl-butanal). A chemical equilibrium is produced in the beer matrix between 2,4,5-trimethyl-1,3-dioxolane, acetaldehyde and 2,3-butanediol. Thus, the increase in the acetaldehyde concentration during beer ageing generates the similar increase in the concentration of 2,4,5-trimethyl-1,3-dioxolane (Vanderhaegen *et al.*, 2006). In contrast, it has also been found that in the beer matrix certain non-oxidative reactions occur causing flavour deterioration such as re-esterifications of fatty acids, etherification, Maillard reactions, and glycoside and ester hydrolysis (Sovrano *et al*., 2006).

Table 1.5.1 Significant aroma-active compounds in fresh beer (Baxter and Hughes, 2001; Daniels, 2001; Kunze, 1999; Lustig, 1993; Meilgaard, 1975a,b; Narziß, 1995; Vanderhaegen *et al*., 2006)

Esters	ethyl acetate, iso-amyl acetate, ethyl hexanoate, ethyl octanoate, 2-phenylethyl acetate and ethyl nicotinate
Alcohols	ethanol, 1-propanol, 2-propanol, 2-methylbutanol, 3-methyl-butanol (iso-amyl alcohol), 2-phenylethanol, 4-vinylguaiacol, 1-octen-3-ol, 2-decanol, glycerol and tyrosol
Vicinal diketones and reduced derivatives	2,3-butanedione (diacetyl), 3-hydroxy-2-butanone, 2,3-butanediol, 2,3-pentanedione and 3-hydroxy-2-pentanone
Sulphur compounds	hydrogen sulphide, sulphur dioxide, carbon disulphide, methanethiol, ethylene sulphide, ethanethiol, propanethiol, dimethyl sulphide (DMS), diethyl sulphide, dimethyl disulphide, diethyl disulphide, dimethyl trisulphide, methyl thioacetate, ethyl thioacetate, methionol, methional and 3-methyl-2-butene-1-thiol (MBT)
Hop oils and oxidation derivatives	myrcene, farnesene, caryophyllene, humulene, geraniol, citral, α- and β-pinene, camphene, isobutene, ocimene, myrcene epoxide, mycernic acid, farnese epoxide, caryophyllene epoxide, humulene epoxides, humulene diepoxides, α- and β-pinene epoxide, humulol, linalool, linalool oxides, myrcenol, farnesenol, caryophyllenol, humulenol, humuladienone, geranyl acetate, citronellal, pinenol, limonene, nerol, α-terpineol, karahanenone, hop ether, cadinenes, β-selinene, muurolene, 8,9-epithiohumulene, S-methylhexanothioate
Maillard products	furaneol, maltol, isomaltol, thiophene, pyrroles, thiazoles, thiazolines, pyridines, pyrrolizines and pyrazines
Strecker degradation products	2-methylpropanal, 2-methylbutanal, 3-methylbutanal, benzaldehyde, 2-phenylethanal and methional
Oxidised lipid derivatives	oxidised triacylglycerols, myristic acid, palmitic acid, stearic acid, linolenic acid, linoleic acid, 13-hydroperoxy-(Z,E)-9,11-octadecadiene acid (13-LOOH), 9-hydroperoxy-(Z,E)-10,12-octadecadiene acid (9-LOOH) mono-, di and trihydroxy acids

Organic acids and other products	carbonic acid, butyric acid, oxalic acid, citric acid, tartaric acid, malic acid, succinic acid, D(-)-lactic acid, L(+)-lactic acid, pyruvic acid, acetic acid, fumaric acid, propionic acid and oxidised polyphenols such as flavanoids, chalcones and flavones

Therefore, it can be concluded that beer ageing cannot be avoided with the removal of oxygen, and so it is necessary to explore new ways in order to improve the shelf life of beer. Additionally, as the levels of heterocyclic compounds such as 2-furfural and 5-hydroxymethyl-2-furfural (Maillard product and thermal sugar degradation products) are increased at a linear rate with the storage temperature, they are therefore considered as heat-induced flavour damages to beer (Vanderhaegen *et al.*, 2006, Vanderhaegen *et al.* 2007). 2-Ethyl furfuryl ether is considered as an ageing indicator due to its increase during the storage time. This compound is an ether produced by acid-catalysed condensation reaction of furfuryl alcohol and ethanol.

1.6 Impact of brewing processes on colour control and beer flavour stability

It is essential for the brewer to define the operation conditions, the critical control points and the input-output streams based on the facilities and operation capacities of the brewery in order to obviate or to minimise variability on colour control and beer flavour stability generated through brewing. This situation is particularly critical due to the fact that the colour of the feed stream (wort/green beer) is increased and decreased alternately in distinct stages of the process until the product stream is obtained. Other factors that can reduce colour formation in pale lager beers are decreased malt nitrogen content, thinner husk, less husk breakage, increase of adjunct usage, lower mash pH, reduced mash time, low extraction of polyphenols, reduced hop mass, gentle boil, increased break formation, rapid chilling wort and increased yeast mass (Daniels, 2001). Likewise, the flavour stability of the final product can be remarkably affected by the ingression of oxygen as well as by the presence of oxidation’s catalysts such as metallic ions, undesirable high temperature conditions, mechanical fluid stress and light exposure.

1.6.1 Brew liquor

Brew liquor represents around 90% of the whole composition of any type of beer, being the main influence on the quality of the final product. Total hardness, carbonate hardness, calcium hardness, magnesium hardness and residual alkalinity all play a very important role on the physical-, chemical- and sensorial properties of beer. For instance, brew liquor with high residual alkalinity can induce a significant increase of colour and haze in beer by subsequent high pH during mashing and a higher production of non-enzymatic browning reactions also known as Maillard reactions as well as polyphenol solubility (Griffin, 2008; Riese, 1997). Furthermore, metallic ions such as iron (<0.2 mg/L recommended), copper (<0.15 mg/L recommended), and manganese induce important changes on final beer colour and flavour stability due to their oxidation catalyst properties. Another important ion is chloride which provides smoothness on the palate but can cause corrosion on stainless steel, and nitrates which can reduce yeast vitality during fermentation (Hackensellner, 2001). Likewise, the final beer colour is influenced significantly by the brew liquor properties based on the regulation of pH of wort and beer, as well as on the metabolic pathway regulation of the yeast and its flocculation capability.

For this reason, routine analysis of total hardness, carbonate hardness, calcium hardness, magnesium hardness and residual alkalinity of the brew liquor is strongly recommended according to Mitteleuropäische Brautechnische Analysenkommission (M.E.B.A.K.) procedures (Mitteleuropäische Brautechnische Analysenkommission, 2002a). If the residual alkalinity of the brew liquor is higher than 5°dH (German Hardness) the brew liquor would need to be decarbonised in order to get an optimal brewhouse yield (Narziß, 1995).

1.6.2 Storage of fermentable material

In microbreweries, medium size- and large breweries the barley malt and adjuncts are normally stored in grain stores or silos of reinforced concrete or steel with a hopper bottom of 40° for optimal emptying (Kunze, 19 99), while in small or pilot breweries the brewing fermentable materials are stored simply in bags or even in plastic bins in a fresh storage room.

Notwithstanding this difference of infrastructure the main target of any brewery is to store the fermentable material in a suitable place which may prevent irreversible effects on the grains that dramatically influence the quality of the raw materials and overall the core of any brewery; the brewhouse yield.

The barley variety is a relevant parameter that influences on the favour stability and the colour appearance of beer *per se*. 6-row barley provides higher levels of protein content, enzyme potential and polyphenols content than 2-row barley. These features are related to development of lipid degradation enzymes (*e.g.* lipooxygenases and peroxidases) and the higher pro-anthocyanidins levels, which are well-known to impact the colour appearance, the physical- and the flavour stability of beer. With attention to this, no- and low LOX-pro-anthocyanidins free barley (*e.g.* frilox, null-lox, -no or low hydroperoxide lyase) are currently used by brewing companies in order to yield more than 12 months physical and flavour stability (see Aerts *et al.*, 2003; Griffin, 2008; van Waesberghe, 1994).

In this stage of the process it is extremely important to control three parameters: the relative humidity of the air, the grain temperature, and the maturation process. The relative humidity of the air can provide an increase of the moisture content of the recent kilned-, roasted and not yet stored barley malt and adjuncts. The moisture content of the fermentable brewing materials normally rises from 2-3% to 4-5% during a proper storage. This has an effect on the physical chemical changes in the endosperm of the processed brewing grains which facilitates the processing during the wort production such as milling, mashing and consequently the brewhouse yield. This effect is considered in some literature as a form of maturation (Kunze, 1999; Narziß, 1995) and is induced by storing the fresh kilned malt for a period of time (four weeks minimum) right after it has been delivered from the malting plant. The moisture content of the fermentable materials must be rigorously controlled during this storage in order to avoid any retrogradation of the endogenous starch. This retrogradation could provoke serious technical problems, particularly in the grain milling and lautering, giving as a result the reduction of fermentable substrate in the produced wort. The retrogradation is the modification of rheological properties of the starch by the interaction of water molecules with the amylose fraction [*i.e*. linear polymer fraction of glucose linked mainly by α-(1, 4) bonds] over a period of time, inducing a strong and irreversible association and crystallization of this polysaccharide (Coultate, 2002). The result of this phenomenon on the brewing process is a detrimental effect on the brewhouse yield by a substantial decrease of the extraction of soluble compounds from the fermentable materials such as endogenous colouring pigments and the modification of the sugar's spectrum which interplay a critical role on the beer flavour profile. Moreover, it is important to control the moisture content of fermentable materials to prevent particularly the degradation of lipid content (*ca.* 2%) of barley pale malt by activation of lipoxygenases (LOX; LOX1 and LOX2, mainly) and peroxidases (POD) even at optimal water activity (Aw) is below 0.15-0.20, as well as Maillard reactions in minor extent and any microbiological contamination. The most common in malting and brewing is the contamination by fungus such as *Aspergillus* *clavatus, Aspergillus flavus*, *Fusarium graminearum* and *Fusarium moniliforme* which can be produced if moisture content is not maintained at optimal moisture content of barley (10-20%) and barley malt (4-5%) during storage. The species *Aspergillus* produces aflatoxines and achronotoxines [*e.g.* ochranotoxin A (OTA)] that are hazardous for the human being while the species *Fusarium* are well known for causing beer gushing (Flannigan, 2003).

1.6.3 Pre-treatment of the malt

Prior to milling, the malt or other adjuncts must be free of undesirable particles such as dust, stones, plastics, and metal objects such as screws, nuts, nails, wires, etc. which can lead to ignition, and therefore explosions, and also mechanical damage to any equipment at the brewery. In large breweries, prior to milling, the malt or adjuncts are pre-treated by passing them through destoners with integrated magnets. In microbreweries the malt is pre-treated by the malting plants before delivery to the brewery.

1.6.4 Determination of the grain bill

The malt is the core of any beer and plays a relevant role in the characteristics of the final product: the flavour, the colour, the palatefulness and the volume of alcohol, although it is possible to use adjuncts in smaller proportions for brewing. The proportion of these fermentable ingredients in the total grain bill depends on the type of beer to be produced and the characteristics that are conferred by the brewer as well as on the original gravity desired, the total brew volume, the extract potential of the fermentable ingredients to use, the loss of husk extract and the equipment efficiency (Daniel, 2001; Furukawa, 2002).

It is essential to check the malt and adjunct specifications to determine the grain bill, and to be aware of, and ensure the quality of these raw materials, which will greatly influence the brewing process and quality of the final product. Two-row barley pilsner malt is normally used as foundation malt for brewing in order to obtain homogeneous process conditions and to ensure the optimal conditions for the productions of the beers. Focusing on the beer colour and flavour stability the most substantial information provided by malt specifications is the following:

1) Screening test: Physical measurement that reflects the malt quality in terms of size homogeneity. This variable may indicate a more homogeneous availability of flavour-active and colouring components in beer. Normal values (MEBAK): Minimum. 85% (2.8 and 2.5 mm). The fraction of rejection should not be exceeded to 1.0%.

2) Thousand kernels weight: Physical measurement that reflects the malt quality in terms of weight homogeneity. This variable provides similar information as screening test. Normal values (MEBAK): 28-44 g.

3) Friability: Mechanical parameter that measures the extent of retrogradation of the malt in terms of friability and glassiness. Retrograded malt is of poor quality for brewing due to its lower availability of carbohydrates required for the wort production. The less carbohydrates source available, the less formation of colouring and flavour-active components across brewing processes. Normal values (MEBAK): Friability: >80%, Total glassiness: < 2.5%.

4) Malt modification and homogeneity: Chemical determination based on the intensity of the blue colouring reaction between fluorochrome calcofluor (Carlsberg method) or methylene blue (Heineken method) and endogenous malt β-glucans of molecular weight of about 10,000 D under U.V. light. This measurement may reflects the available amount of endogenous malt substrates which participate in the formation of colour and beer flavour. Normal values (MEBAK): Carlsberg (calcofluor) modification: 85%, homogeneity: 60%; Heineken (methylene blue) modification: 65%, homogeneity: 4%.

5) Germination capacity: Physical measurement used with particular attention on barley analysis. Notwithstanding, the malt still have some remaining germination capacity that must be controlled at optimal moisture content during its storage, otherwise a detrimental effect in terms of brewhouse yield may be caused and subsequently in the colour appearance, physical- and flavour stability of the beer. Normal values (MEBAK): 6-10%.

6) Moisture content: See section 1.6.2. Normal values (MEBAK): Pale malt: 3-5%; Dark malt:1-4%.

7) Extract fine grinding: This parameter indicates the content of the extract that is provided by the malt. This extract is formed by soluble compounds such as carbohydrates, proteins, vitamins, etc., although it mainly refers to the percentage

of fermentable carbohydrates such as monosaccharide (*e.g.* glucose, fructose, mannose and galactose) and oligosaccharides [*e.g.* sucrose, maltose, iso-maltose, maltotriose, raffinose and melobiose (lager yeast only)]. Normal values (MEBAK): >76% dry basis

8) Fine-coarse difference: This percentage difference indicates the loose extract that remains in the husk by coarse grind in comparison to fine grind. This fine-coarse difference should not exceed to 2.5% dry basis in order to achieve an optimal brewhouse yield which may be reflected in the flavour stability of the final product. Normal values (MEBAK): <1.8% dry basis.

9) pH of wort: See section 1.6.8. Normal values (MEBAK): Unboiled wort: 5.5-5.8, Cast wort: 5.3-5.6 (with biological acidification 5.0-5.4). Therefore, the pH difference is ≤0.3.

10) Wort colour and boiled wort colour: This parameter is of particular importance in this investigation. Nevertheless, pilsner and pale malts contribute with a very light colour (4 EBC) and a very light malty flavour as well (Gruber, 2001). Normal values (MEBAK): See Table 1.1.1.

11) Viscosity: This parameter reflects the hemicellulose content in wort. High viscosity in wort causes slower lautering, fitting pressure losses and turbulence. These effects induce oxidation of hot wort and increase of colour by longer vessel occupation times and intensification of wort transfer. Normal values (MEBAK): 1.5-1.6 mPa*s.

12) Soluble nitrogen: This value indicates the proteins that are extracted by the brew liquor during the wort production. These proteins are very important due to many aspects; firstly they reflect the α-amino nitrogen (FAN) content in wort, which is necessary for the optimal metabolism of the yeast during the fermentation (minimum 10-14 mg α-amino nitrogen consumed/100 mL wort). Secondly, this reflects the coagulable proteins during the wort boiling which will form the hot breaks (hot trub) by interactions of polyphenols compounds from malt husk and hops. Normal values (MEBAK): 35-45%

13) Free amino nitrogen (FAN): See soluble nitrogen. Normal values (MEBAK): Barley malt:120-160. Cast wort (12°P): 200-250. Beer (12°P): 100-120 mg/100g dry basis.

14) Diastatic power and α-amylase activity: These parameters measure the enzymatic capacity of the malt to degrade (hydrolyze) the non fermentable carbohydrate (*i.e.* starch mainly) into fermentable sugars which will be metabolised during the fermentation by the yeast. Normal values (MEBAK): 30-50 °L, 30-60 DFU.

15) Attenuation degree: The attenuation degree provides the information of how much percentage of the original gravity of the pitched wort is fermented. Thus, the higher attenuation degree obtained, the less residual extract in beer. This residual extract may participate in non-enzymatic browning and caramelisation reactions during beer storage, giving as result an increase of colour and modification of the flavour profile of the finished beer. In addition, beers with high attenuation degree provide higher amounts of fermentation products but less mouthfeel. Normal values (MEBAK): Pale malt: 77-83% (optimal <83%); Dark malt: 63-78%.

16) High molecular β-glucans: This parameter is strongly related to the modification, homogeneity and viscosity tests. In addition, high molecular β-glucans play an important role in the beer head matrix. Normal values (MEBAK): Wort: 200-800 mg/L. Beer: 10-600 mg/L.

17) Fatty materials: See section 1.5. Relevant analysis parameter in flavour stability due to its importance in the potential LOX and POD activity. Normal values (MEBAK): Unboiled wort: <100 mg/L. Cast wort: < 70 mg/L.

18) 2-Thiobarbituric acid index (TBA): Dimensionless index that reflects the lipid oxidation in wort and beer as well as the thermal intensity applied during brewing. This parameter may provide a linear relationship of its magnitude and the increase of colour by non-enzymatic browning- and caramelisation reactions as well as the formation of beer ageing markers such as 5-hydroxymethylfurfural (HMF) and 2-furfural. Normal values (MEBAK): Unboiled wort: < 22. Cast wort: < 45. Wort at whirlpool tank: < 60. Finished pale lager beer: <15.

19) Dimethyl Sulphide (DMS): See section 1.5. Normal values (MEBAK): Cast wort: <100 mg/L. Whirlpool: < 100 mg/L. Flavour threshold: 50-60 µg/L.

20) Nitrosamines: The production of nitrosamines (NOx: mainly NO and NO_2) is carried out by the heat treatment of nitrites and secondary amines from proteins

(*e.g.* dimethylamine, ethylamine, tyramine, hordeine and gramine) at direct firing during kilning and roasting. These compounds are gastric carcinogenic in humans. Normal values (MEBAK): maximum 0.8 µg/kg.

21) Relevant inorganic ions: A number of inorganic ions plays a essential role in brewing such as co-factor for yeast enzymes [*e.g.* phosphates (ATP and ADP), zinc (aldolase and alcohol dehydrogenase co-factor), magnesium (phosphohexo-isomerase and enolase co-factor), potasium, sodium and manganese]. Besides, metallic ions (*e.g.* iron, copper), magnesium and calcium affect the colour and flavour stability of beer either by oxidation catalysing or by pH regulation. See section 1.6.1. Normal values (MEBAK): Iron malt/wort: 0.1-0.6/0.1-0.27. Sodium malt/wort: 2.5-5.1/30. Potassium malt/wort: 350-360/ 550, Calcium malt/wort: 72-130/35, Manganesum malt/wort: 1.4-1.5/0.12-0.14, Zinc malt/wort: 0.3-5.3/0.1-1.08, Copper malt/wort: 0.3-0.7/0.02-0.04, Magnesium malt/wort: 70-140/100.

Another parameter to be considered in terms of beer flavour stability is the barley endogenous enzymes; lipooxygenases (*e.g.* LOX-1, LOX-2) which have been detected to have relevant influence on the oxidation of unsaturated fatty acids of malt and hops, giving cardboard-like character to beer which is a connotation of beer staling (Bamforth, 2001c; Bamforth, 2004; van Waesberghe, 1994). The second parameter to be taken into account in term of beer flavour stability is the rancidity of pre-processed adjuncts (van Waesberghe, 1994) *e.g.* rice, corn, wheat, sorghum, oat, and rye, which can also provide off-flavours in the final product.

Concerning colouring agents, specialty malts also play a critical role on the flavour stability and final colour of beer depending on the quantities used for the grain bill. A portfolio of flavour-active compounds from these raw materials such as dimethyl sulphide (DMS), aldelydes, ketones, lactones, phenols, fatty acids, pyrazines and sulphur compounds are ingressed into the wort during mashing and lautering and provide a broad range of distinct flavour profiles which normally have negative connotations for pale lager beers (*e.g.* grainy, malty, sweet, phenolic, astringent and so forth). These compounds are formed by distinct types of reactions during kilning and roasting such Strecker degradation reactions, Maillard reactions, caramelisation of sugars, thermal degradation of phenolic acids and oxygenated fatty acids among others (see Hughes, 2008).

Every brewing colouring agent has advantages and disadvantages in terms of processing. Specialty malts [colour malt, crystal (caramel) malts, roasted malts and roasted barley] as natural products do not need any special labelling but provide inconsistent colour intensity resulting in colour fluctuations of the final beer. They also require large individual storage areas (Riese, 1997).

Colouring beers are pure dehusked black malt beer extracts (Kunze, 1999) that have several advantages. For instance, they require small storage areas, do not need special labelling, can be integrated throughout the entire brewing process and provide high and consistent colour intensity (Riese, 1997). Artificial caramel colorants; caramels produced from edible carbohydrates such as glucose, sucrose, inverted sugars, corn syrups, malt syrups and molasses (Caramel products. D.D. Williamson & Co., Inc, 2007; Comline, 2006) present the same advantages as colouring beers but have the disadvantage that they will not be efficient in adjusting the beer colour in cold conditions. Therefore, it is suggested that these products must be applied exclusively at the brewhouse stage (Riese, 1997). The ratios of the distinct colouring agents in the grain bill are commonly calculated with the following conventional equation (Smedley, 1995):

$$C_1V_1 + C_2V_2 = C_3(V_1 + V_2)$$

Whereby,

C_1: Colour of the beer whose colour is to be adjusted (EBC colour units)

V_1: Volume of the beer whose colour is to be adjusted (L)

C_2: Colour of the colouring agent (EBC colour units)

V_2: Volume of the colouring agent (L)

C_3: Colour of the resulting blend (EBC colour units)

1.6.5 Milling

The malt is milled to enhance the contact area of the malt endosperm with the brew liquor during the mashing. The reduction of particle size depends completely on the selection of milling and mashing technology to be used (see Buehler *et al.*, 2003). For instance, by using conventional lautering systems a coarse/fine grist is required in which the husk of the malt or pre-processed adjuncts must be broken, while keeping its integrity almost entire, in order to create a natural filter bed, whereby a lixiviation is produced by passing through the first running and the subsequent sparging liquor additions. On the other hand, by using mashing filter systems, fine grist is required due to the operation principles, and the configuration design of these systems demand small particle size of the input to be extracted.

According to Rittinger's law (Earle, 2003; Furukawa, 2002) the energy required for size reduction means that the grinding power is directly proportional to the change in surface area, and not to the change in length. For that reason one has always to take into account the maximum rotation speed (normal value for hammer mills: 1500 rpm) and the installed motor power (normal values for hammer mills: 7.5 or 10 HP) in order to achieve a suitable mill performance. During the milling the ground material produces new superficial surface areas. Each new area unit or surface requires a determined amount of energy to be created. A great proportion of this energy is transformed into heat. This heat can provoke a re-activation of enzymatic lipid oxidation from the malt or pre-processed adjuncts. This lipid oxidation has a detrimental influence on the beer flavour stability (see Kühbeck, 2007; Richter and Sommer, 1994; van Waesberghe, 1994; Wackerbauer *et al*., 1992; Zücher, 2003).

In the last years few discussions have taken place regarding the impact of the hammer mills in terms of the beer quality and processing by the fine-disintegration generated. For instance, some brewers state that the difference in quality of malts can be compensated, while others report a commencement of lypoxygenases (LOX) and peroxydases (POD) (De Rouck *et al.*, 2005; van Waesberghe, 1994) as well as remarkable increase of hemicellulose levels (β-glucans, pentosans, mainly) by the extensive extraction produced. These polysaccharides are well known to provoke problems to the lautering process by increasing the wort viscosity as well as to produce a permanent haze in beer due to their insolubility in cold conditions causing a colloidal instability in beer (Bamforth, 2001c; Griffin, 2008). Innovative clean label brewing technology has been introduced with special attention to upstream processes by inactivation of lypooxygenases (*e.g.* LOX-1 and LOX-2) at mashing-in by using hammer mill (CO_2 protected), a premasher equipped with stripping off-system, mashing heating at >95℃ by direct live steam injection, thinbed mash filter and semi-open settling tank to prevent unnecessary thermal stress during wort clarification (Aerts and van Waesberghe, 2007; De Rouck *et al.*, 2005; van Waesberghe, 1994).

It has also been debated that using hammer mills increases the polyphenol extraction from malt and pre-processed adjuncts. Nonetheless according to recent researches (Kellner *et al*., 2005; Fumi *et al*., 2006) there is no clear difference of polyphenols content in wort by using the two different milling and lautering systems. In fact, the increase of polyphenols concentration takes place in post-brewhouse processes and is particularly affected by the ratio of malt/adjuncts of the grain bill; the more adjuncts used, the lower the levels of phenolic compounds in wort are detected (Agu, 2002; Andrew, 2004; Fumi *et al.*, 2006).

1.6.6 Mashing

The mash-in is usually performed by means of pre-mashers with a screw conveyor feeding the mash in a gentle flux on the internal walls of the mash tun. The target is to avoid, as much as possible, any pick up of oxygen throughout the operation in order to diminish lipooxygenases (LOX) and peroxydases (POD) activity (see Bamforth, 2001; Maeda, 1999; van Waesberghe, 1994).

During the mashing and boiling of the wort the major colour contribution in beer is obtained. In both processes a solid-liquid extraction is carried out in which the natural colouring pigments of the malt or adjuncts are released, as well as non-enzymatic browning reaction also referred to as Maillard reactions, caramelisation of sugars and lipid oxidation reactions (*e.g.* linoleic acid degradation to hydroperoxides) are produced due to the risk of pick up of oxygen increased by number of mash transfers to another vessels such as decoction mashing and the vessel materials such as copper which promotes oxygen radical formation. These reactions also have clear negative influence on the beer favour stability (see Bamforth and Lentini, 2008; Hughes, 2008). Therefore, mashing is a critical part of the brewing process in terms of beer colour and flavour stability.

A critical control point in this part of the brewing process is the addition of the initial brew liquor, also called brew liquor foundation, prior to the grist ingresses into the mash tun. This foundation water provides a water bed in the bottom of the tank (ca. 5% of whole brew liquor) which receives the mash-in from the pre-masher avoiding strong thermal fluctuations in the initial stage of the mashing as well as to help the suitable distribution of the mash with the brew liquor. Additionally, it is important to regulate the stirrer speed of the mash tun in order to equilibrate the temperature of the mashing. The mashing temperature must be controlled with a tolerance 0.3℃ in order to achieve the optimal enzymatic activity of the endogenous enzymes of the malt. It is also important to regulate the stirrer speed in order to prevent any shear damage that may induce an intensive release of high-molecular-weight compounds, being mainly hemicellulose (*e.g.* β-glucans and pentosans) as well as provoking protein gelation. Both cause a slow mash separation by reducing the permeability of the grain filter bed (Bamforth, 2004). Additionally, this affects the beer stability and colour.

The configuration design of the mash tun, mash cookers and mash stirrer plays a considerable role in the beer colour and flavour stability for three main reasons; the pick up of oxygen by induction of turbulence, the leaching of metallic ions (copper and iron) and the production of non-hydrolysable fines (hemicellulose's complexes) by shear force, which reduces the filterability and lixiviation during the lautering, giving as a result a poor brewhouse yield, an enhancement of viscosity and haze, and the formation of oxygen radicals (Hermann, 1999; van Waesberghe, 1994).

Another relevant critical point to be supervised is pH of the brew liquor and mash. This parameter plays an important role in the enzymatic activity [*e.g.* phytase and α-glucosidase (38-40℃); β-glucanase and pentosane (45-50℃); exopeptidases: carboxypeptidase, aminopeptidase; endopeptidases: malt endopeptidase (MEP1), lipoxygenases (LOX) and peroxydases (POD) (55-62℃); β-amylase and dextrinase limit (R enzyme or pullulanase) (62-65℃); α-amylase (70-75℃) and phosphatases (78-80℃)] and the colour pigment extraction during the mashing. The pH of mash is given by the most important ions found in brew liquor, but also buffer systems in the mashing are generated mainly by the presence of phosphates, lactates and amino acids. The calcium of water coagulates phosphates providing a mixture of salts of these ions which act as a buffer system around pH 5.7. The buffer of phosphates ends at pH 4.0-4.5, being then the pH of the wort regulated by the buffer capacity of amino acids which are amphoteric which means they can behave as bases (NH_3^+RCOOH) or as acids (NH_2RCOO^-) depending on the pH of the solution. Regarding lactates, these compounds form a very powerful buffer in the pH range of 4.4 to 4.8 (Fix, 1999; Furukawa, 2002).

Regarding different mashing methods, it is well known that decoction methods have a strong influence on the increase of colour and risk of oxidation due to the rigours transfer pumping of the decocted fraction and the high temperature programmes (≥100-103℃) in order to obtain the gelatinization of the malts or the adjuncts (Fix, 1999; Griffin, 2008).

Last but not least, there are brewhouse (mashing-lautering-boiling) additives such as hop-, tree-galls (*Rhus semialata*) and leaves (*Rhus coriara*) gallotannins with an addition range of 2-4 g/hL can improve the beer flavour stability by chelating metal cations (*e.g.* copper and iron) preventing Fenton’s and Habber-Weiss reactions and Strecker degradation products (*e.g.* phenylacetaldehyde, furfural and benzaldehydes) as well as can enhance lautering rates by coagulating and flocculating proline and thiol (-SH) containing proteins, which in oxidised state result cross-linked proteins of high molecular weight, formation of gels and oxidised “Teig” material (Aerts *et al.*, 2003 and 2004; Goiris *et al*., 2003). In addition, it has been introduced the saturation of carbon dioxide gas (CO_2) in mash tun for the last two decades in order to reduced the atmospheric oxygen levels during mashing (see Aerts and van Waesberghe, 2007; Lustig, 1993). Nevertheless, it is important to indicate this latter method must be discussed according to international safety regulations for brewhouse operators at those process conditions.

1.6.7 Lautering/Mash filtration

After the mashing a recirculation of wort also called *vorlauf* (in German) is carried out with the objective to clarify the wort produced. During the mashing an accumulation of undesirable particles (grinded husk and hot breaks) remains in the bottom of the mash tun. These particles produce turbidity in wort, damaging the quality of the beer. The wort with a clear appearance and free of particles is taken. The time period is critical in this part of the process which should not exceed 10 min since long recirculation periods can induce oxidation of the hot wort by an intensive picking up of air during the pumping. Recommend oxygen levels during the lautering should not be higher than 0.3 mg/L (Narziß, 1992).

In this part of the process the brewer must find a balance between the palatefulness of the beer and the maximum amount of extract produced during lautering. This compromise is solved by adding the same amount of brew liquor in the sparge as used in the mash (Fix, 1999). When the brewer's intentions are to obtain a beer with a fine palatefulness it is recommended to stop the lixiviation of the spent grains once one has obtained a residual extract of 1.0°P (Fix, 1999); but if the objective is to obtain beer with a clear astringency in the background some brewers stop the lautering process once the last running has been obtained, a residual extract content of 0.5°P (Narziß, 1992). Last runnings with very low extract content contain higher amounts of undesirable compounds due to exhaustive lixiviation of the filter grain bed *i.e.* lipids, oxalates, phenolic compounds, hemicelluloses and other polysaccharides such as gums and mucilage, from the husk material. These undesirable compounds have a strong detrimental effect on the beer colour appearance, the physical- and flavour stability of the beer (see Bamforth and Lentini, 2008; Franz and Back, 2003; Stewart and Martin, 2004).

Another compromise that the brewer must find in terms of colour and beer flavour stability is the temperature of the sparge liquor. Sparge liquor with temperatures above 77°C can increase considerably the extraction of the undesirable compounds already mentioned, mainly polyphenols. The polyphenols in high concentrations in beer confer astringent flavours, as well as an increase of colour by oxidation, and participate directly in the formation of hot breaks (hot trub) and chill haze, the latter being a critical parameter on the physical beer stability (see Ward, 2007; Whitear, 1981). Last, but not least, the exhaustive lixiviation during the lautering increases the beer colour by enhancing the alkalinity of the wort (Fix, 1999), which will induce more non-enzymatic browning reactions during the wort boiling and the whirlpool rest.

1.6.8 Wort boiling

The addition of colouring beer and artificial caramel colorants can be carried out at this stage of the process. There are two traditional methods of adding caramel colorants to beer, either by ingressing caramel into the wort, typically by injecting it into the boiling brew in the copper or by metering (usually diluted) caramel into fermented beer at some stage before packaging. The rate of addition can be simply determined by calculated proportions (see Caramel products. D.D. Williamson & Co., 2007; Smedley, 1995).

In terms of beer colour and beer flavour stability there exist many essential factors to be considered in wort boiling. The first parameters to be controlled are the boiling time, thermal loading (Fix, 1999) and evaporation rate. These variables have repercussions in the increase of colour by reduction of water which increases the concentration of the original gravity of the wort. In general, the evaporation rate oscillates around 4 to 10% (Riese, 1997), which is inversely proportional to the amount of extract obtained after the wort boiling. In large breweries a higher evaporation rate of 6% (Riese, 1997) can be achieved by means of modern technology which may provide a better process optimisation.

Another extremely important parameter, and probably the most relevant in terms of beer colour and flavour stability, is the production of reductones (intermediates) and non-enzymatic browning or Maillard reactions. Some authors have reported that Maillard products also called melanoidins have red-brown hues and confer clear and rounded malty aromas (Riese, 1997). The increase of non-enzymatic browning reactions is dependent on the reactant substrates; the carbonyl groups from organic compounds being mainly carbohydrates due to the plentiful amount found in wort and the available amino groups of proteic origin (see Fig. 1.1.1) (Daniels, 2001).

Other considerations in the increase of beer colour are caramelisation, pyrolysis reactions and darkening effect by oxidation of polyphenols (Spieleder, 2007). The earlier reactions form a vast range of breakdown products by the pyrolysis of reducing sugars, being mainly higher heterocyclic compounds such as pyrroles and pyrazines as well as lower heterocyclic compounds such as furfural, and the other carbonyl compounds such as acrolein (propenal), pyruvaldehyde (2-oxopropanal) and glyoxal (ethanedial) (Coultate, 2002; Fix, 1999). These compounds contribute not only to the increase of beer colour but also to the flavour profile of the beer therefore to the flavour stability (*e.g.* reductones). The oxidation of specific group of polyphenols such as proanthocyanidins also has an important influence on the colloidal stability of the beer due to their high affinity to interact with sensitive to proteins giving as result the formation of protein-polyphenols complexes also called hot breaks or hot trub. The remaining proanthocyanidins and proteins in beer will also interact during post-brewhouse stages generating undesirable chill haze or also known as temporal turbidity which depending on the oxidation state of the beer can become eventually permanent. Additionally, they cause negative flavour attributes in pale lager beers due to their remarkable astringency. In contrast, flavonol glycosides and prenylated hop flavanoids promote positive effects in terms of flavour stability due to their high reducing power, radical scavenging and metal chelating character. Moreover, they increase the beer mouthfeel, health benefits (*e.g.* xanthohumol, rutin and 8-prenylnaringenin) and the colloidal beer stability by interaction, coagulation and flocculation with proline and thiol (-SH) containing proteins (see Aerts *et al*., 2004; Goiris *et al.*, 2005).

Another parameter to be taken into account is the pH of the wort. There is a fall of pH throughout the wort boiling which in fact is started by the mashing reactions between calcium ions (Ca^{2+}) with phosphates liberating protons (H^{+}) that decrease the pH of the medium, as well as the melanidoins formed during the non-browning enzymatic reactions which contribute in the fall of pH. This decrease of pH regulates the formation of melanoidins (Maillard products) and help the coagulation of proteins during the formation of hot breaks and stimulate the activation of the yeast enzymatic system (O'Rourke, 2002a).

The volatilization and reduction of DMS during the wort boiling also plays a particular role in the beer flavour stability. The stronger the reduction of DMS produced the greater improvement of beer flavour stability is achieved. This topic is going to be discussed in more detail later in this chapter.

The nature of the hop products and clarification agents (*e.g.* Irish moss and bentonite) to be added has a remarkable influence in terms of beer colour and flavour quality and its stability. Hop products as natural hop flowers and pellets (Type 90 or 45) provide polyphenols (*e.g.* catechin, epicatechin, xanthohumol, isoxanthohumol, etc.), sulphur compounds [*e.g.* dimethyl disulphide (DMDS), dimethyl trisulphide (DMTS) and methanthiol], glycosides, pectins, waxes and fats into the hot wort (see Roberts and Wilson, 2006). The oxidation by-products of the portfolio of compounds can lead to an increase of wort colour, therefore to the final beer colour and may influence the beer flavour stability. In contrast, pre-isomerised or non-isomerised hop extracts do not contain polyphenols and the latter undesirable compounds. Hops oils products (hop-derived sesquiterpenoid-type oxidation products contribute mouthfeel, palatefulness and synergistic effects with refer to final beer bitterness enhancing the beer flavour stability with particular attention to pale lager beers (see Jaskula *et al.*, 2007, 2009a and 2009b).

The last important parameter that must be considered in terms of beer colour and flavour stability is the wort boiling technology used at this process stage (see Morikawa *et al.*, 2003). In some breweries the wort boiling is carried out using an external boiler. This type of technology provides a high thermal loading and good evaporation rate, although it has a detrimental effect on the beer flavour stability caused by mechanical stress of the continuous pumping from the external boiler, also known as calandria, to the wort kettle (*ca.* 7-12 times at 102-106℃). The physical action of this process is the formation of the laminar flux of the wort to a turbulent one by the pumping and the forced convectional movements generated through 20 cm diameter internal pipe during the boiling.

Nowadays there exists a wide group of different wort boiling technologies that have been created merely on the compromise of reduction of energy consumption and the high quality of wort production. The wort technology plays a very important role on the beer colour and flavour stability due to the many reasons still to be mentioned, but one can emphasize the most relevant ones as the heating efficiency, the wort circulation by means of pumps (*e.g.* external and internal boilers), evaporation rate, equipment material (austenitic stainless steel or other materials of high thermal conductivity *e.g.* copper), steam generators descalers, etc.

1.6.9 Separation of hot breaks (hot trub) and hop solid residues

As mentioned previously, hot breaks are a compact mass built mainly by coagulated proteins and by a complex created by the interaction between polyphenols, coagulated proteins, carbohydrates and insoluble hop bitter substances. The polyphenols (prodelphinidin B3, prodelphinidin trimer, procyanidin B3, procyanidin trimer, (+)-catechin, (-)-epicatechin, p-coumaric acid, ferulic acid, rutin and quercetin derivatives) are sensitive to oxidation with a strong tendency to polymerization due to OH^- groups that tends to form hydrogen bridges (bonds) between the proteins, carbohydrates and bitter substances allowing their nucleation and agglomeration (see Wilkinson, 2003). In contrast, the reduction of polyphenols levels in wort at this stage of the process has an impact on beer flavour stability due to their antioxidative potential at specific concentration rates (see Aerts *et al.*, 2004). In addition, it has been observed high-temperature processes at the brewhouse stage such as wort boiling and hot break separation in a whirlpool tank can induce a relevant increase of OH- radicals due to the degradation of reductones and the formation of pro-oxidants as Maillard reaction products, which are strongly related with an increase of wort colour and decrease of OH-radical activity and sulphite by the yeast (Methner *et al.* 2008; Uchida and Ono, 2000a).

The separation of hot breaks and hop solids residues is commonly carried out by means of a whirlpool effect for 10 minutes (max); after this process the wort is left for not longer than 20 minutes to allow the hot breaks to settle at the bottom of the tank. At this stage of the process it is important not to leave the wort to rest for more than 30 minutes. Even a slight drop in temperature of the wort could generate the reactivation of dimethylsulphide precursor (DMS-P) and subsequently the formation of dimethylsulphide (DMS) at temperatures around 85℃ or lower. The DMS is a well known volatile sulphur compound which confers "cabbage-like" or "cooked vegetable" off-flavours giving as result negative effects on the beer flavour quality (see Ahvenainen *et al.*, 1979; Back *et al.*, 1997; Kunze, 1999).

The geometrical configuration design, the height-to-diameter ratio of the whirlpool tank (*i.e.* 3:1 preferred), the flat bottom slope towards the outlet (*i.e*. 2%), the inlet in the lower third to produce rotation, the outlet located at the lowest point of the whirlpool and the volumetric and linear tangential velocity are essential parameters to obtain an optimal efficiency of this solid-liquid separation process (Huige, 2004; Kunze, 1999). In addition, it is always good to periodically check the steel surface roughness (Ra) of the internal walls of the whirlpool tank and the standard machined surface finish on pumps. The reason for these checks is to guarantee the proper whirlpool effect of the wort which can be affected by a lack of smoothness of the internal contact surface causing a forced turbulence (fluid dynamics) on the hot wort and eliminating the whirlpool effect desired. The surface roughness is measured according to a measurement unit denominated "Ra" which is defined as the arithmetic mean of the absolute value of the departure of the profile from the mean line. Ra is measured in micron (μm) (Alfa Laval, 2001). In fermentation tanks this parameter is extremely critical in order to avoid any microbiological contamination. In general, a standard normal value of surface roughness for a stainless steel quality 304 or 306 is 0.8 Ra (*ibid.*).

1.6.10 Wort cooling

After the whirlpool rest, the cast wort is cooled using a plate heater exchanger at a pitching temperature of 8℃ to 12℃ for pale lager beers and 17℃ to 22℃ for ales. The cooling of cast wort must be carried out as rapidly as possible in order to prevent the formation of DMS mentioned above, which will have a direct influence on the beer flavour stability but controlling the pump pressure discharge to avoid break trub particles with carryover to the fermentation tanks. This can be optimised by sizing the cooling system and pumps in order to increase the cooling efficiency (Alfa Laval, 2001; Daniels, 1999; Griffin, 2008), as well as by controlling the temperature of the cooling agent used (*e.g.* chilled water).

1.6.11 Wort pitching

The yeast pitching rate is critical to the final beer colour as the yeast α-mannan (also called yeast gum) of the cell wall is able to retain colour provided by colouring pigments of the cooled wort, which results in a considerable reduction of colour in the final product. This retention of colour is directly proportional to the yeast biomass presented in the cast wort; the more biomass volume provided, the more contact area is generated, therefore, more colour retention is induced.

Production management of any brewery is essential to ensure the quality of brewing raw materials (*i.e.* water, fermentable materials, hops and yeast) for a quality product. The yeast particularly plays a critical role in the final beer flavour profile due to its action as biocatalyst, which will transform the substrates obtained from wort to main fermentation products and derivatives that define the beer's overall character (Bamforth, 2001d; Back and Forster, 1999). The yeast strains confer a different flavour profile into beer, in spite of the fact they may belong to the same genus and species. This depends on the concentration of main- and fermentation by-products produced by the selected yeast strain. For instance, some yeasts are able to produce higher levels of ethanol, higher alcohols (also called "Fusel oils"), esters, carbonyl compounds (aldehydes and ketones), organic acids (*e.g*. pyruvic acid, citric acid, succinic acid, etc.) and SO_2 than others (Bamforth and Lentini, 2008; Stewart *et al*.,1999; van Opstaele *et al*., 2007; van Waesberghe, 1994) (see Table 1.5.1). Likewise, the oxygen demands and SO_2 production to reduce staling compounds and flocculation ability are distinct from yeast to yeast strain (Bamforth, 2004). However, the high levels of some fermentation by-products such as acetaldehyde and pyruvic acid are considered negative in view of flavour stability due to may participate as reactants for the formation of Strecker degradation products, aldol condensation (*e.g.* nitrogen-free aldols react with amino compounds, alkimines and ketimines to form nitrogen melanoidins), aldehyde-amine polymerisation and the formation of melanoidins of high molecular weight that have no reductone groups available (Fig. 1.1.1) (see Daniels, 2001; Hodge, 1953).

It has been reported that active dry-yeast (ADY) assimilates in faster rate the free amino nitrogen (FAN) of the pitched wort in comparison to yeast propagated, but eventually the residual free amino nitrogen levels in green beers become similar. Despite of its inconsistent viability, active dry yeast can be used for several repitching without affecting the fermentation performance, phenotypic characteristics, genetic stability and final product quality once the culture has adopted the typical characteristic of the strain after the initial fermentation (see De Rouck *et al*., 2007).

Lager yeast (*i.e. Saccharomyces pastorianus*) strains used to present higher flocculation ability than the ale yeast (*i.e. Saccharomyces cerevisiae*) analogue. The yeast flocculation is regulated by a number of genes such as FLO1, FLO5, FLO8, FLO8, FLO11 and tup1. This yeast phenomena is a critical parameter in terms of beer colour and flavour stability, and influences directly the attenuation of wort and the maturation and filtration process. Strong flocculent yeast provides a good sedimentation, therefore an optimal yeast harvest can be obtained and subsequently a consistent fermentation performance can be reached. Weak or non-flocculent yeast produces low consistency by weak sedimentation generating considerable bright beer filtration problems (van der Aar, 1995).

In many large breweries, it is common to add antifoam agents at this stage of the brewing process with the aim of optimising the working capacity of the fermentation tanks (*ca.* 85-95%) (Furukawa, 2002). These agents are different in nature, being the silicon oils (*e.g.* polysiloxanes), salts (*e.g.* calcium stereate and magnesium palmitate) and hop monoglycerides, the widest used in the brewing industry due to their effectiveness at very low concentrations *i.e.* 20-80 mg/L (Pierpoint, 1988) and the accessible price. Although the antifoam agents considerably help the optimisation of the brewery their effect has an impact on the reduction of beer colour by absorbing and retaining endogenous pigments of the beer.

The selected pitching method (*i.e*. one-batch filling or multi-filling "*Drauflassen*" method) also has an impact on the beer colour and flavour stability. For instance, the "*Drauflassen*" method consists of filling just 50% to 75% of the total working capacity of the fermentation tank within a period of 8 to 12 hours, leaving the yeast to achieve the adaptation phase and the initial stage of acceleration (lag phase) of the growth curve. Afterwards the tank is filled with fresh wort (Furukawa, 2002). This method induces a very quick production of yeast biomass and optimal activity of the yeast during the primary fermentation. This higher production of biomass (*i.e.* 2 to 3 times of the pitched volume) can absorb colouring pigments of wort as aforementioned.

1.6.12 Wort aeration

The aim of this operation is to help the yeast viability, yeast alcohol tolerance, to induce optimal yeast biomass production as well as the synthesis of niacin and sterols such as lanosterol, ergosterol and zymosterol, which are essential for the synthesis of the cellular membrane of the yeast (Fix, 1999; Nielsen, 1973). The theoretical amount of oxygen for the yeast to reactivate its metabolic system is about 8-9 mg/L. In practice, the amount of air introduced into the wort is much higher because oxygen bubbles are not uniformly distributed and dissolved in the cooled wort.

The adsorption of oxygen by the yeast is dependent on the diffusional transfer of the oxygen through the gas-liquid interface that surround the air bubbles, the migration of the solution through the liquid interface that surround the cell, and the transfer of oxygen to the cell interior (Furukawa, 2002). Besides, the aeration conditions will be determined according to the fermentation filling selected (*i.e.* one-batch filling or multi-filling "*Drauflassen*" method). Intense aeration to normal gravity worts (10-13°P) at later fermentation stages (*e.g.* log phase and stationary phase) can induce the production of yeast biomass in presence of oxygen under previous anaerobic conditions (*i.e.* Pasteur effect). In contrast, intense aeration of high gravity worts (14-32°P) at initial fermentation stages (*e.g.* adaptation and lag phase) may be defective due to the production of ethanol in the presence of high fermentable sugars levels under aerobic conditions (*i.e*. Crabtree effect) (Furukawa, 2002).

1.6.13 Primary fermentation and maturation

The primary fermentation stage is controlled throughout the process by measuring the following parameters: pH factor, number of yeast population cells, fermentation temperature and extract content (specific gravity, °P), and colour of green beer. The fermentation is finished when an extract content of 1°P (SG 1.0039) to 1.5°P (SG 1.0058) higher than the attenuation limit is reached, being normally around *ca.* 4°P (SG 1.016) for standard pale lager beers depending on the attenuation limit provided by the yeast strain.

Normally the fermentation period takes about five to seven days. All the carbon dioxide produced during this stage will be released to minimise stress conditions to the yeast during the fermentation, which is already stressed by hydrostatic pressure in the fermentation tank and the auto-stress produced by other metabolites synthesized, mainly ethanol and in minor degree fermentation-by products. In addition, volatile sulphur compounds such as DMS, DMSO and mercaptans can be removed by flushing of fermentation carbon dioxide released (Narziß, 1995; Saerens *et al.*, 2008; van Laere *et al.*, 2008) .

The formation of flavour-active fermentation by-products is influenced by a myriad of factors. For instance, the production of aldehydes is induced by rapid fermentation, high fermentation temperature, high pitching rate, internal pressure of the fermentation vessel during primary fermentation, low rate aeration and microbiological contamination. Likewise, the increase of wort gravity (<13°P) worts, ferm entation temperature, free amino nitrogen, lipids in cooled wort, zinc levels, aeration rate and mechanical stress by pumping or agitation remarkably promote the formation higher alcohols and esters. In addition, it has been reported that the metabolic regulation of lipid formation have and effect in the biosynthesis of esters (Narziß 1995; Saerens *et al.*, 2008; van Laere *et al.*, 2008).

After this period the green beer is slowly cooled to 4-8°C depending the type of beer brewed. The period of time between the original fermentation temperature and the temperature at the yeast collection stage should not be less than 24 hours. Once it has reached the new set up temperature, the airlock of the fermentation tank is closed in order to obtain the optimal carbonation of the beer. The yeast is collected at this stage of the process.

After the yeast harvest, the cooling rate of the cylindroconical tank is reduced in order to increase the beer temperature. This stage is considered as the vicinal diketones (*i.e.* diacetyl and 2,3-pentanodione) reduction phase. The maximum production of CO_2 of the yeast by means of the fermentation of the residual extract contained in the green beer is obtained. The carbonation of the beer is controlled by measuring the bunging pressure which should be held at 0.8-1.0 bar (11.60-14.2 psi). Then the maturation period begins.

The reduction of vicinal diketones plays an important role on the quality of fresh beer flavour and stability. It is well known that the presence of diacetyl in concentrations up to 0.15 mg/L (flavour threshold) confers off-flavours with buttery connotations in beer, being particularly undesirable in lager beers (Fix, 1999). This brewing stage is carried out by increasing the green beer temperature from 1°C to 1 .5°C above the primary fermentation temperature. The temperature must be rigorously controlled in order to avoid excessive formation of unwanted aldehydes from the deamination, discarboxylation and reduction of aminoacids via Ehrlich mechanism, as well as ester formation by esterification of ethanol, higher alcohols and fatty acids.

The precursors of the vicinal diketones are pyruvic acid and acetaldehyde which are converted into α-acetolactic acid and α-acetohydroxybutyric acid outside the yeast cell. These latter compounds undergo a spontaneous oxidative decarboxylation to diacetyl and 2,3-pentanodione, respectively. This descarboxylation is favoured by increase of fermentation and maturation temperature, presence of oxygen, low pH of the medium (4.2-4.4) and low free amino nitrogen in wort. In contrast, this is inhibited by synthesis of valine and isoleucine by the yeast. Once the vicinal ketones are formed, the brewing yeast is capable to reabsorb them and reduced them to acetoine and hydroxypentanone and eventually to butanodiol and pentanodiol, respectively. This reduction is dependent on the increase of fermentation and maturation temperature, the yeast strain, the pitching rate, the blowing-off during maturation and the fermentation performance (*e.g.* Kräusening) (Fix, 1999; Kunze, 1999).

The beer maturation is probably one of the most important brewing stages in terms of beer flavour stability. At this point the final beer flavour profile is obtained by the interaction of different fermentation by-products and other organic and inorganic compounds from the wort presented in the beer matrix resulting in the refinement and rounding balance of the beer character and the rise of digestibility (wholesomeness). The main highlights in the beer maturation are the settling down of yeast, coarsening of protein-polyphenol complex, decrease of acetaldehyde (20-70%), volatile sulphur compounds (*e.g.* SO_2 and mercaptans), vicinal diketones (<0.15 mg/L) and aldehydes as well as the increase of esters, some higher alcohols (10-20%) and fatty acids (*e.g.* hexan-, octan-, and decan acid) (20-40%) (Candy, 1998; Griffin, 2008; Kleynhans *et al.*, 1992; Narziß, 1995). In this stage of the brewing process it is essential to control three parameters; maturation temperature, maturation time and CO_2 levels.

The beer flavour profile is dependant on the beer maturation performance (see Kleynhans *et al.*, 1992). There are several beer maturation techniques to improve the beer flavour stability. For example, the "*Kräusen*" method (cauliflower in German) which consists of the addition of green beer in primary fermentation when the yeast has reached its maximum metabolic activity of fermentation in the beer maturation process. This addition can be done between 10 to 20% of the total volume of the batch. The "*Kräusen*" state is obtained normally in a period of 60 to 72 hours after the wort pitching (in lager beer conditions). This can be visually detected by the physical aspect of the head formed in the tank which has effectively a cauliflower-shape aspect. The best way to measure this "*Kräusen*" state is by counting the yeast cells which must be around 60 to $80x10^6$ cells/mL. The "*Kräusen*" addition has many objectives but mainly it is to contribute to the increase of the sensorial properties of the beer giving a delicate and fine character, and to improve the carbonation in beer since the "*Kräusen*" has higher extract content and very active yeast cells which results in a good carbonation (Furukawa, 2002).

As already mentioned, the maturation period is a very important parameter to be defined and supervised. The maturation period for pale lager beers (11-12°P) is normally from 2 to 4 weeks. Short maturation periods produce beers with unbalanced flavour profiles, while long maturation periods may cause yeast autolysis. The yeast autolysis is an enzymatic self-destruction of the yeast cell by hydrolysis of the protoplasmic components, which the products elicited, *e.g.* aminoacids, peptides, polypeptides and organic acids, are excreted into the beer matrix. These released compounds impart off-flavours in beer as yeasty, mouldy flavours and odd bitterness as well as increase the beer pH and the colour and reduce the colloidal-, biological stability and head retention. The maturation temperature also plays an important role in the yeast autolysis; any small fluctuation of the temperature can rapidly induce this physiological phenomenon of the yeast cells (Griffin, 2008; McCabe, 1999).

1.6.14 Chill proofing and beer filtration

In terms of beer flavour stability, it is of critical importance at this stage of the process to purge and run all the maturation tank-filter-bright beer tank lines with deareated water or with beer itself in order to avoid any pick up of oxygen that can dramatically influence the beer flavour stability, and to ensure the laminar flux of the beer during the transfer to avoid constrictions through the valves, and pipe transitions and shear force which can damage suspended solid as yeast biomass and cold trub. Any turbulent flow may provide instant oxygenation to wort by agitation between the liquid and the head space of the tanks, pipes, pump inlets and outlets. The key to obtaining this laminar flux throughout the filtration is to regulate the pressure difference between the inlet and outlet of the filter and by compensating the internal pressure of the maturation tank and the bright beer tank. The internal pressure of the maturation tank should be slightly higher than the bright beer tank in order to transfer the beer slowly and gently (Candy, 1998; Furukawa, 2002).

Another issue to be considered in this stage is to obtain a clear bright beer (in the case of pale lager beers) by chillproofing. There are basically two types of haze; permanent haze and temporal haze also known as chill haze. The permanent haze can be caused by turbidities of different nature; one is chemical turbidity originated by formation of calcium oxalate also called beer stones. This calcium oxalate is formed during the fermentation by the interaction of calcium ions and oxalic acids from the malt (*ca.* 8-25 mg/L) and hops extracted during wort production. However, the addition of Gips ($CaSO_4$) or $CaCl_2$ into the mash- and sparge liquour provides a optimal precipitation of calcium oxalate previous post-wort production stages. Another turbidity involved in the permanent haze is the carbohydrate turbidity which is produced by the presence of hemicellulose, gums and mucilage which were not degraded during mashing as well as dextrins and α-mannan and β-glucan in case of beer recovery by centrifuge or by yeast autolysis (see Chlup *et al*., 2007). Biological turbidity is also involved in the permanent haze and is formed by the contamination of bacteria and wild yeast or non-flocculent brewing yeast. The temporal haze also called “chill haze” is caused by the interaction between proteins of high molecular weight (fraction of hordein from the malt) that contains a high proportion of hydrophobic amino acids that are combined with polyphenols (mainly anthocyanogens and catechins). The complex formed by this interaction is soluble at high temperature but they become insoluble in cold by formation of weak hydrogen bridges (Buggey, 2001; Lim *et al*., 1992; Mikyska *et al.*, 2002).

Chill proofing aids such as PVP, PVPP, silica gels and isinglass (*i.e. polynemoidea* and *siluridae* blender colagene) reduce the beer colour and head retention by adsorption of colouring compounds of the beer matrix such as polyphenols, melanoidins and foam active proteins such as barley protein Z (40 kDa) and barley lipid transfer protein (LTP) (9.7 kDa peptide) (see Euston *et al.,* 2008). Likewise, the excessive removal of the later compounds reduce the reductone protective effect in beer. Furthermore, antioxidants additives can be added at this stage of the process such as ascorbic acid and sodium metabisulphite (KMS), or both combined with a ratio of KMS/ascorbic acid 40:60. Their anti- or pro-oxidative effect mainly depends on the concentrations used and the oxidation state of the beer.

A quite common practice at this stage of the process among large breweries is the addition of foam stabilisers such as propylene glycol alginate (PGA), into the beer in order to compensate for the reduction of head foam by the antifoam agents. PGA is synthesized by reaction between propylene oxide and alginic acid, the latter is composed of mannuronic acid and guluronic acid residues. Its effect is based on the electrostatic interaction of carbonyl groups of the propylene glycol alginates with amino groups of glycosylated proteins, glycoproteins and hydrophobic proteins involved in the beer foam. Despite the great head foam enhancement provided by these agents, it has been reported that heavy precipitates are observed in head foam stabilised-beers stored for long periods (see Outtrup, 1991), which obviously affects the beer colour perception.

1.6.15 Beer packaging and pasteurisation

Pasteurisation induces the production of *trans*-2-nonenal. This compound is well known to confer typical stale flavours in beer. Obviously, this will have a detrimental effect on the beer flavour stability (Wackerbauer *et al.*, 2002). Likewise, the pasteurisation as a short thermal process and the natural convection movements by different gradients of temperature within the product may increase the beer colour by induction of non-enzymatic browning reactions, caramelisation reactions of some residual sugars and overall by oxidation of polyphenols.

Beer packaging performance is extremely important to beer colour and flavour stability such as air pre-evacuation and CO_2 counter-pressure settings, bowl filling procedures, jetter pressure and filler speed (Griiffin, 2008). The filling must be controlled in order to guarantee the proper headspace volume of the beer, due to possible oxidation reactions. The volume of the headspace must be a maximum of 3% of the whole capacity of the bottle with a total air below 0.06 mg/L for 0.33 L-bottles and below 0.08 mg/L for 0.5 L-bottles.

1.6.16 Packaged beer storage

This last stage of brewing is the most critical in terms of beer flavour stability. For most of the breweries it is extremely difficult in real terms to store their products in suitable conditions until they are purchased by the customers. This is due to the fact that the beer trade is mostly carried out through wholesalers, who find it impractical to offer light protection, minimum agitation and refrigeration of beer products (see Bamforth, 2004; Bamforth and Lentini, 2008) in order to prevent formation of ageing compounds, but particularly of 3-methyl-2-butene-1-thiol (MBT) and *(E)*-2-nonenal. Therefore, the packaged beers may remain stored in light at high temperatures (20-40℃ during summer) or frozen for very long periods of time (Huige, 2004; O'Connor-Cox *et al*., 1991) as well as they may be excessively agitated during transportation having an impact on the quality of the beer flavour stability. For instance, it has been observed that during the packaged beer storage there are changes of colour over time and the rate of change is highly dependant on the increase of the storage temperature. Furthermore, it has been found that this change of colour is highly correlated to sensory oxidation perceived of lager beers (Huige, 2004). Therefore, the logistics of the brewery and the wholesalers must be focused on providing isothermal storage conditions for the beer, not only for the improvement of their flavour stability but in the extension of shelf life which is translated in relevant economical savings for both partners.

In conclusion, there are several factors which directly or indirectly have influence on the beer colour and flavour stability. The influence of standard control parameters on beer colour appearance and flavour stability is shown in Table 1.6.1. Brewing is a very complex process that involves different technological fields including; biotechnology, mechanical and chemical engineering. This complexity is also presented in the final product itself; the beer. Beer contains about 600 flavour active volatile compounds that contribute directly in the flavour profile. The majority of these compounds have very low detection thresholds and any slight change in their concentrations can be immediately detected by the beer consumer (Bamforth, 2004).

The key to achieving a consistent product in terms of beer colour and flavour stability is to establish and to perform uniform brewing practices by the brewer. This sounds quite straight forward, but unfortunately brewing as a biotechnological process depends on many natural inputs such as barley, hops and particularly yeast, causing unavoidable batch-to-batch inconsistencies. Nevertheless, this can be advantageous to the brewer. For instance, it has been observed in different researches that polyphenols in beer have multifunctional properties, *e.g.* bioactively healthy functions in moderate beer drinkers (see Aerts *et al*., 2003; Aerts *et al*., 2004; Fumi *et al*., 2006), anti-oxidative properties which may improve the beer flavour stability as well as contribute to the head foam stability of the beer and therefore on the beer's visual appeal. On the other hand, polyphenols play one of the main roles in the production of chill haze in beer, affecting the colour appearance and translucency of bright beers, and beers with a high concentration of polyphenols which commonly have sharp astringent flavours in the background. In other words, brewers must always find a compromise between the advantages and disadvantages generated by the brewing procedures and quality control specifications established in order to achieve high quality products which satisfy either the local beer consumers or the global market demands.

Table 1.6.1 Influence of standard control parameters on beer colour and flavour stability

Control parameters	Influence on beer colour and flavour stability
Original gravity (°P)	Increase of colour and fermentation by-products
Alcohol in beer (% v/v)	Increase of ageing components by oxidation, esterification reactions
pH	Increase/decrease of colour
International bitterness units (IBU)	Increase of ageing components by oxidation of bitter substances Participation of beer staling (light-struck)
Head retention (sec)	Impact on the colour appearance and visual appeal
Total polyphenols (mg/L)	Increase of colour and ageing components by oxidation
Flavanoids in beer (mg/L)	Increase of colour and ageing components by oxidation
Turbidity 20℃ (EBC-formazin units)	Change on colour appearance of beer
Forcing test turbidity (Shelf-life predict) Warm days	Change on colour appearance of beer
Dissolved oxygen in bottled beer (mg/L)	Oxidation of bitter substances, fermentation main- and by-products
Iron (mg/L)	Oxidation catalyst (Heavy metal ion)
Copper (mg/L))	Oxidation catalyst (Heavy metal ion)
Nickel (mg/L)	Oxidation catalyst (Heavy metal ion)
Calcium (mg/L)	Substrate for production of oxalate
Oxalate (mg/L)	Change on colour appearance of beer
Total sulphur dioxide (SO_2) (mg/L)	Endogenous beer antioxidant
DMS (mg/L)	Endogenous off-flavour compound in beer

1.7 Previous research on the influence of colouring agents on beer flavour stability

Little research has been carried out on the influence of colouring agents on flavour stability of pale lager beers. However, contrasting findings have been reported by research focused on related issues. For instance, it has been found that the addition of melanoidins and caramel to lager beer, which was subsequently exposed to light, depressed the evolution of H_2S (one indicator of light damage) and when the colour of lager beers was increased by using a colouring agent the amount of 3-methyl-2-butene-1-thiol (MBT) formed on exposure to light was reduced (Sakuma *et al.*, 1991). Nevertheless, recent studies have indicated that melanoidins and caramelisation products of caramels promote the oxidative stability of the lager beers. This pro-oxidative effect of caramels is probably caused by the increase in levels of radicals in the Fenton reaction assay, indicating that caramel colour is able to accelerate metal-catalysed oxidation of beer (Nøddekær and Andersen, 2007).

In addition, previous research has demonstrated that dark beers brewed using varying ratios of dark malts present high concentration of the flavour-active beer ageing carbonyls such as 3-methylbutanal, 2-methylbutanal, 2-phenylethanal and iso-butanal (Forster *et al.*, 1998). Moreover, the anti-oxidative potential of specialty malts does not increase with their darkening degree. In fact, a higher anti-radical activity for the pale malts and crystal malts with intermediate browning degree per unit of colour in comparison to black malts has been noticed (Cantrell and Briggs, 1996; Sovrano *et al.*, 2006). This assumes that the role of malts on the improvement of beer flavour stability is dependant on the relationship between reducing power and colour. Besides, the low anti-radical activity of dark crystal and roasted malts might react slightly with radical species, but are able to exhibit the radical activity throughout non-radical mechanisms, giving as a result a higher reducing capacity in comparison to other specialty malts (Sovrano *et al*., 2006).

In connection to this, it has also been reported that malts roasted at temperatures above 150℃ contain a lower anti-radical activity than malts of the same colour, which were roasted at lower temperatures for a longer period of time (Coghe *et al.*, 2006). This indicates anti-radical groups are involved in the latest non-enzymatic browning reactions, which are generated at higher temperatures than 150℃. The maximum antiradical activity seems to be related to the end- roasting temperature than to a specific malt colour. This is supported by other investigations that found dark beers produced with a high ratio of dark colour malt (Munich style) showed better head retention and flavour stability in comparison to dark beers brewed with roasted malts. Additionally, dark colour malts kilned with a longer final kilning temperature (7 h) enhance flavour stability of dark lager beers in comparison to those kilned with conventional procedures (Preuß *et al*., 2001). Thus, the anti-oxidative activity of malt is certainly dependent on the time-temperature roasting programme.

1.8 Previous research on the influence of colouring agents on final beer colour and beer flavour profile

Many compounds contribute to beer colour. These compounds are classified into groups based on their nature and physicochemical properties. The most influential compounds on beer colour are the melanoidins (products of the non-enzymatic browning reactions also well-know as Maillard reactions), polyphenols, and metal cations (mainly Cu and Fe), riboflavin and carotenes in the case of pale lager beers and the resulting oxidised products caused by light exposure or heat treatment during the brewing process (Narziß, 1995; Coghe *et al*., 2003). Factors that can reduce the colour formation during the brewing of pale beers include: decreased nitrogen content in malt, increased adjunct usage, lower mash pH, reduced mash times, the use of a decoction mashing programme, reduced aeration of wort, a shortened boiling time, increased break formation, rapid chilling of wort and the clarification of finished beer (Daniels, 2001).

Approximately 250 volatile components in dark specialty malt products have been found which significantly contribute to the flavour of finished beer. The contribution of each compound is based on their flavour threshold and their synergetic effect with other flavour compounds (Coghe *et al.*, 2004). Oxygen heterocyclic components such as pyrones, furans and furanones contribute predominantly on the flavour of colour malts and light crystal malts, while nitrogen containing heterocyclic compounds such as pyrazines, pyridines and pyrroles contribute most to the flavour profile of dark crystal malts, roasted malts, and roasted barley (*ibid.*).

Melanoidins of high molecular weight are not flavour-active. A correlation between the sensory perception of the heterocyclic compounds and their stereo-chemical spatial arrangement does exist (*ibid.*). It has been observed that the planar arrangement of carbonyl, enolic hydroxyl and methyl radicals induce caramel-like flavour on oxygen heterocyclic compounds. Likewise, planar, unsaturated nitrogen heterocyclic compounds with one or two nitrogen atoms and with an acetyl group in the second position of the ring structure conferred malty, bread- and biscuit-like flavours (*ibid*.).

Previous investigations (Coghe *et al.*, 2004) demonstrated that the ageing compound 3-methylbutanal is presented in significant levels in dark worts brewed with specialty malts of 150 EBC units. These investigators found the highest levels of oxygen containing heterocyclic ageing compounds are; furfural, furfuryl alcohol, 5-methyl-2-furfural and 2-acetylfuran in dark worts (390 EBC) produced with dark crystal malts. The lower level of oxygen containing heterocyclic ageing compounds were detected in dark worts brewed with roasted malts and roasted barley. These findings suggest that these heterocyclic ageing compounds can be generated through high thermal reactions. Moreover, they detected outstanding levels of nitrogen-containing compounds such as, pyrazines and their derivatives (methylpyrazine, 2,3-dimethylpyrazine, 2,6-dimethylpyrazine, ethylpyrazine and 2-ethyl-3-methylpyrazine) in wort produced with roasted malt. This fact proves that nitrogen containing compounds require a higher thermal energy load to be formed compared to oxygen heterocyclic compounds.

In addition, previous studies (Coghe and Adriaenssens, 2004) revealed by means of fractionation using ultrafiltration and gel permeation chromatography the existence of two groups of coloured Maillard reaction products; low-molecular-weight (LMW) chromophores (<10 kDa) compounds and high-molecular-weight (HMW) compounds (>100 kDa). They found that molecular weight (MW) distribution of malt colorants is dependant on malt type and colour. In pale malts, coloured compounds were mainly of LMW, while in brown crystal malts were of LMW and HMW, and in dark crystal malts, roasted malts and roasted barley HMW compounds were obtained. They found using SDS-PAGE and gel permeation chromatography that melanoidins originating from roasted malts were of higher MW than the largest melanoidins (*ca.* 320 KDa) from other specialty malts (*ibid.*).

Another relevant findings indicated that dark wort produced with roasted malts and roasted barley presented more intensive colour in terms of EBC colour units and had the lowest CIELAB lightness L* values. They demonstrated by ethanol precipitation that these low L* values originate mainly from the HMW compounds (*ibid.*). They concluded that the mass of the LMW fraction decreased with increasing colour, due to lower extract content in wort produced with roasted malts, whereas an increase in the weight of the HMW coloured compounds is produced by conversion of LMW compounds to HMW products during heating of malt (*ibid*.).

Studies on sensory and instrumental flavour analysis of wort brewed with dark specialty malts reported that a trained tasting panel detected more intense bitter and burnt flavours as the colour of dark worts was increased, while sweet and husky flavour notes were noticed as the colour of worts were decreased. In addition, it was demonstrated that brewing with dark specialty malts considerably increased the level of 3-methylbutanal, its aldol condensation product (2-isopropyl-5-methyl-2hexenal) and heterocyclic compounds. Dark beers brewed with crystal malts are commonly associated to caramel, toffee and malty flavours. On the other hand dark beer brewed with roasted malts and roasted barley are normally related to astringent, bitter and burnt flavour such as chocolate and coffee notes (see Coghe *et al*., 2004).

Previous research (Coghe *et al.*, 2006) characterised the CIE L*a*b* values of different specialty malts in detail, indicating the CIE L*a*b* lightness parameter (L*) consistently decreased during intensive roasting, whereas the highest colour shade parameters a* and b* values are obtained at 150℃ af ter 90 min, respectively (*i.e.* after 30 to 45 min of caramelisation). These findings suggest that most of the yellow coloured chromophores (+b*) are produced before red coloured compounds (+a*). Therefore, the formation of yellow coloured Maillard compounds are obtained at lower temperature (125℃) than red coloured compounds (155℃). On the ot her hand, it was also found that pale colour specialty malts such as light crystal malt and melanoidin malt have predominantly more LMW, while black roasted malts and roasted barley have a balance of HMW and LMW compounds. This assumes that the MW of malt colorants is increased as higher heating is supplied (*ibid.*).

Additionally, these investigations also compared the evolution of the MW of coloured non- enzymatic browning reaction products at different roasting conditions, finding the rate of colour formation and type of colorant are dependent on the intensity of thermal condition roasting. Roasting temperatures of 150℃ promote coloured malts with colorants of relatively LMW, while temperatures above 150℃ tend to produce more HMW colorants (*ibid.*).

2. SCOPE AND OBJECTIVES

- To investigate the influence of a range of colouring agents on the flavour stability of pale lager beers, also known as pilsner beers, by means of a holistic analytical approach and sensory evaluation.
- To determine the optimal and suitable specialty malts or colouring agents to improve the flavour stability of pale lager beers for a given colour specification.
- To define and systematically to monitor critical control points of raw materials and every step of the brewing process in a holistic and streamlined manner, in order to avoid any possible hazard or interference of process variables on the outcomes of the investigation.
- To apply new methodologies for measuring the psychophysical properties of beer in terms of total colour appearance that emulate the true perception of the beer consumer.

3. MATERIALS, PROCEDURES AND ANALYSIS METHODS

Ten pale lager beers were brewed at the pilot brewery of the I.C.B.D. using different colouring agents including: specialty malts, roasted barley, colouring beer and artificial caramel colorant for colour adjustment. New standard brewing procedures for pale lager beers were implemented and systematically approached at the I.C.B.D. pilot brewery in order to guarantee consistent beer samples in terms of flavour stability.

The brewing procedures were defined on the basis of avoiding any critical process factors which might interfere with or modify the parameters focusing on this investigation. All brewing control parameters and beer specifications were monitored under a rigorous regime. For instance, raw materials specifications, storage of raw materials, equipment specifications, milling-, mashing-, lautering-, wort boiling-, hopping-, hot break separation-, wort cooling performance, yeast specifications, pitching rate, primary fermentation, yeast cell population, yeast viability, yeast harvest, diacetyl rest, secondary fermentation (maturation), chill proofing technique, beer filtration, packaging, pasteurisation and beer storage. The obtained worts and beers were analysed at the I.C.B.D. laboratories. The aged beers were considered as beers with a spontaneous ageing of 12 months while the forced aged samples as beers thermally treated at 60℃ for 7 days. Ten commercial pale lager beers were analysed, and the results were compared to the beers produced at I.C.B.D. pilot brewery, in order to validate and confirm real values for industrial purposes.

3.1 Production of locally-brewed pale lager beers

The beer specifications for the pale lager beers produced at the pilot brewery were based on a standard German pilsner style because it has the parameters that represent the average values in comparison to other pilsner style beers, such as Bohemian pilsner, Dutch pilsner, Scandinavian pilsner and American pale lager. Table 3.1.1 shows the beer specifications of the beer produced for the focused experimentation. Likewise, these specifications were base on the facilities and operation capacities of the pilot brewery at the I.C.B.D. in order to obviate or to minimise variability due to processing factors, as well as to simulate the typical conditions of large breweries; being the most representative conditions on the brewing field. This situation was particularly critical in the investigation due to the fact that the colour of the feed stream (wort/green beer) is increased and decreased alternately in distinct stages of the process until the product stream is obtained; beer as final product. A detailed description and specifications of the pilot brewery at I.C.B.D. are presented in Appendix D.

Table 3.1.1 Specifications of I.C.B.D. standard all-malt pale lager beer

Specifications	Values
Original specific gravity [g/mL (°P)]	1.0484 ±0.0013 (12.0 ±0.3)
Apparent final gravity [g/mL (°P)]	1.0098 ±0.0016 (2.5 ±0.4)
Alcohol content [% (v/v)]	4.8 (±0.2)
Apparent degree of attenuation (%)	76 (±3.5)
Real degree attenuation (%)	63 (±3.5)
pH	4.3 (±0.1)
International bitterness units (IBU)	22 (±2.5)
Colour (EBC)	7.5 (±0.5)
Turbidity at 20°C, 90° (EBC, FTU)	<1.0, <4.0
CO_2 content (vol)	2.5-3.0
Foam Stability (NIBEM test) (sec)	>220
Polyphenols (mg/L)	150-200
Flavanoids (mg/L)	50-70
Vicinal diketones (mg/kg)	<0.15
Total iron (mg/L)	<0.2
Total copper (mg/L)	<0.2
Total calcium (mg/L)	4-100
Oxalate (mg/L)	<20
Total sulphur dioxide (mg/L)	<10

The total volume of each brew produced in the pilot brewery was 200 litres (2 hL), which is the working capacity of the plant. Therefore all values in the latter description of procedures are based on the fixed total volume previously stated (See brew control sheets 1 to 11 of Appendix C).

Routine analysis of total hardness, carbonate hardness, calcium hardness, magnesium hardness and residual alkalinity of the brew liquor was carried out according to Mitteleuropäische Brautechnische Analysenkommission (MEBAK) procedures (Mitteleuropäische Brautechnische Analysenkommission, 2002a).

The foundation malt, specialty malts and roasted barley were pre-treated (*i.e.* cleaning, deculming and polishing) by the respective malt suppliers and then were stored in bags at a cold room at 8℃ (±2.0℃). The colourin g beer and artificial caramel colorant were refrigerated at 4℃ (±2.0℃).

The grain bill of each brew batch was designed according to the standard beer specification of Table 3.1.1, being particularly focused on the colour specifications. Thereby, all the calculations of each grain bill are made to obtain a final beer colour of 7.5 EBC (±0.5 EBC). Two-row "Optic" spring barley premium pilsen malt from Pencaitland, Scotland was used as foundation malt for all the beers produced. The barley and premium pilsen malt specifications are presented in Tables 3.1.2 and 3.1.4 according to the results of field trials harvest 2006 by the E.B.C. barley committee and the pilsen malt supplier, respectively (E.B.C barley and malt committee, 2007; Premium Pilsen Malt. Bairds Malt Ltd., 2007).

Tables 3.1.3, 3.1.5, 3.1.6 and 3.1.7 show the specifications of specialty barley malts, roasted barley, colouring beer and artificial caramel colorant used for this investigation. All values reported in the tables were also taken from the results of field trials harvest 2006-2007 by the E.B.C. barley committee and the reported specifications by the specialty malts and the other colouring agent's suppliers. Two-row "Marthe" spring barley from Bamberg, Germany was used for the production of the specialty malts, roasted barley and colouring beer. The supplier of these raw materials was Weyermann Malzfabrik GmbH, Bamberg, Germany (Weyermann Malzfabrik GmbH, 2007). The supplier of the artificial caramel was an American colorant company (D.D. Williamson & Co., Inc.) (Caramel products. D.D. Williamson & Co., Inc., 2007).

Table 3.1.2 Two-row "Optic" spring barley harvest 2006 specifications (E.B.C barley and malt committee, 2007)

Parameter	Mean (M)	Normal values (MEBAK)
Year of harvest	2007	N/A
Country of origin (E.B.C. region)	Scotland (west)	N/A
Yield (kg/10 m^2 d.m.)	8.0	N/A
Relative yield (%)	98	N/A
Grading >2.0 (%)	82.6	≥85 r_{95}: 2.1; R_{95}: 2.0-0.18m
Grading >2.5 (%)	96.9	≥90 r_{95}: 2.1; R_{95}: 2.0-0.18m
Grading <2.2 (%)	0.7	≤2 r_{95}: $0.6m^{0.6}$; R_{95}: $1.1m^{0.6}$
1000-Kernel weight (g d.m.)	43	38-40 r_{95}: 1.1; R_{95}: 1.7m
Total protein (% d.m.)	10.0	8.5-14.0 r_{95}: 0.4; R_{95}: 0.10
Germination after 3 days (%)	86	≥95 r_{95}: 6.3; R_{95}: 8.7
Extract yield (% d.m.)	83.0	77-91 r_{95}: 0.85; R_{95}: 2.0
Total nitrogen in malt (% d.m.)	1.54	≥0.5 r_{95}: 0.05; R_{95}: 0.13
Total soluble nitrogen in malt (% d.m.)	0.57	0.55-0.75 r_{95}: 0.12x0.119m; R_{95}: 0.09
Kolbach index (%)	37	35-45 r_{95}: 6.7-0.12m R_{95}: 0.13+0.08m
Viscosity 20℃ 8.6°P (cp)	1.47	1.5-1.6 r_{95}: -0.26+0.195m R_{95}: -0.62+0.5m
β-glucan (mg/L)	142	N/A
Friability (%)	92	>80 r_{95}: 15-0.14m R_{95}: 22.6-0.28m
Diastatic power yield (W.K.)	299	220-600 r_{95}: 6.6+0.036m R_{95}: 21+0.148m

Table 3.1.3 Two-row "Marthe" spring barley harvest 2006 specifications (E.B.C barley and malt committee, 2007)

Parameter	Mean (Sx)	Normal values (MEBAK)
Year of harvest	2007	N/A
Country of origin (E.B.C. region)	Scotland (west)	N/A
Yield (kg/10 m^2 d.m.)	5.9 (0.5)	N/A
Relative yield (%)	105 (5.7)	N/A
Grading >2.0 (%)	67.1 (9.0)	≥85 r_{95}: 2.1; R_{95}: 2.0-0.18m
Grading >2.5 (%)	96.3 (3.0)	≥90 r_{95}: 2.1; R_{95}: 2.0-0.18m
Grading <2.2 (%)	0.7 (0.6)	≤2 r_{95}: $0.6m^{0.6}$; R_{95}: $1.1m^{0.6}$
1000-Kernel weight (g d.m.)	41 (1.4)	38-40 r_{95}: 1.1; R_{95}: 1.7m
Total protein (% d.m.)	11.1 (1.4)	8.5-14.0 r_{95}: 0.4; R_{95}: 0.10
Germination after 3 days (%)	98(2.1)	≥95 r_{95}: 6.3; R_{95}: 8.7
Extract yield (% d.m.)	83.9 (1.1)	77-91 r_{95}: 0.85; R_{95}: 2.0
Total nitrogen in malt (% d.m.)	1.65 (0.2)	≥0.5 r_{95}: 0.05; R_{95}: 0.13
Total soluble nitrogen in malt (% d.m.)	0.72 (0.1)	0.55-0.75 r_{95}: 0.12x0.119m; R_{95}: 0.09
Kolbach index (%)	43.5 (2.9)	35-45 r_{95}: 6.7-0.12m R_{95}: 0.13+0.08m
Viscosity 20℃ 8.6°P (cp)	1.43 (0.0)	1.5- 1.6 r_{95}: -0.26+0.195m R_{95}: -0.62+0.5m
β-glucan (mg/L)	158 (59.1)	N/A
Friability (%)	94 (3.4)	>80 r_{95}: 15-0.14m R_{95}: 22.6-0.28m
Diastatic power yield (W.K.)	330 (5.9)	220-600 r_{95}: 6.6+0.036m R_{95}: 21+0.148m

Table 3.1.4 Premium pilsen malt specifications
(Premium Pilsen Malt. Bairds Malt Ltd., 2007)

Parameter	A.S.B.C.	I.o.B.	E.B.C.
Moisture content (% d.m.)	4.5 max	4.5 max	4.5 max
Extract fine grind (% d.m.)	80.5 min	305 min	80.5 min
Fine-coarse difference (% d.m.)	1-3	-	1-3
Colour (°SRM*, EBC)	1-2*	3-4	3-4
Protein content (% d.m.)	10.5 max	1.65 max	1.65 max
Soluble/ Total protein (% d.m.)	38-42	35-40	38-42
Diastatic power (°L)	60 min	60 min	185 min

Table 3.1.5 Specialty malts and roasted barley specifications
(Weyermann Malzfabrik GmbH, 2007)

Malt type	Recommended quantities (% of total grain bill)	Moisture content (%)	Extract (dry basis) (%)	Wort Colour (EBC)	Wort Colour (Lovibond)	Specific weight (kg/m^3)
CARAHELL® (Light crystal malt)	Up to 15	9.0	74.0	20-30	8.1-11.8	580-640
CARAAMBER® (Light crystal malt)	Up to 20	4.5	78.0	60-80	23-31	N/A
Melanoidin malt	Up to 20	4.5	78.0	60-80	23-31	N/A
CARAMUNICH® Type III (Dark crystal malt)	Up to 5	6.5	70.0	140-160	53-60.5	N/A
CARAAROMA® (Dark crystal malt)	Up to 20	7.0	74.0	300 400	115 150	N/A
Roasted barley	Up to 5	3.8	65.0	1000-1200	375-450	500-550
CARAFA® Type III (Roasted malt)	Up to 5	3.8	65.0	1300-1500	488-563	500-550
CARAFA® SPECIAL Type III (Dehusked roasted malt)	Up to 5	3.8	65.0	1300-1500	488-563	500-550

Table 3.1.6 Colouring beer (SINAMAR®) specifications (*ibid*.)

Specifications	Values (min-max)
Real extract (% d.m. / °BRIX)	40-50
Specific weight (g/cm^3)	1.17-1.21
Colour (EBC)	8100-8600
Colour in Lovibond (°L)	3040-3200
pH, as is	3.8-4.6
Viscosity (mPa·s)	100-800
Features	• SINAMAR® is produced solely from dehusked roasted malt . • In order to raise colour of 1 hL beer by 1 EBC, 14 g of SINAMAR® is required. • Unopened containers have a 1 year shelf-life. Once opened, contents should be used immediately and stored cool.

Table 3.1.7 Artificial caramel colorant (CARAMEL #301) specifications (Caramel products. D.D. Williamson & Co. Inc., 2007)

Specifications	Values
Type of caramel colorant	Type III (Ammonia caramel)
Colour IoB (typical)	31,500
Colour EBC (typical)	29,800
Hue index (typical) (H.I.)	5.5
Percent solid (%)	66
Specific gravity (kg/L)	1.320-1.330
Baume at 60°F (15.56°C) (°Baume)	35.2- 36.0
pH, as is	4.2-4.8
Viscosity at 68°F (20°C) (Max. cps)	4000
Colloidal charge	Positive

A series of small scale colour adjustment trials were carried out with the aim of calculating the specific amounts of specialty malts, colouring beer and artificial caramel colorant required in the grain bill of each brew to be produced at the I.C.B.D. brewery pilot plant. These preliminary colour adjustment trials were based on the consideration that beer as a final product is dependent on the combination of several living processes (*e.g.* growing of barley, malting, yeast strain and fermentation) (see Candy, 1998; Meilgaard, 2001) making impossible the exact prediction of the final beer colour by doing empirical calculations, which are widely found in the literature. The colour determination was analysed according to Tristimulus method to the corresponding beers produced at this stage, to have an overview of the anticipated colour results that would be obtained at normal up-scale. Three ratios for each colouring agent were proposed for the total grain bill according to the official specifications of suppliers (see above) (Caramel products. D.D. Williamson & Co., Inc., 2007; Premium Pilsner Malt. Bairds Malt Ltd, 2007; Weyermann Malzfabrik GmbH, 2007), these ratios were calculated with the following equation (Smedley, 1995):

$$C_1V_1 + C_2V_2 = C_3(V_1 + V_2)$$

Whereby,

C_1: Colour of the beer whose colour is to be adjusted

V_1: Volume of the beer whose colour is to be adjusted

C_2: Colour of the colouring agent

V_2: Volume of the colouring agent

C_3: Colour of the resulting blend

The proposed grain bills for each colouring agent are shown in Table 3.1.6. The beers were produced from congress mashes (Programme: 45℃ for 30 min, 62℃ for 25 min, 70℃ for 1h) using a mashing bath (CM4 Mashing B ath, Canongate Technology, Ltd. Edinburgh, Scotland) according to the Mitteleuropäische Brautechnische Analysenkommission (M.E.B.A.K.) (Brautechnische Analysenmethoden. Band II. Mitteleuropäische Brautechnische Analysenkommission, 2002s) and the European Brewing Convention (E.B.C.) (Analytica-EBC. European Brewing Convention, 1998a). These worts were boiled for 60 min and hopped (22 IBU), then subsequently cooled at 12℃ (±0.3℃) and pitched with fresh bottom fermentin g yeast (see Table 3.1.10). The primary fermentation of the trials was carried out at 12℃ (±0.3℃) for 4 days (±1 day) and the beer maturation at 4℃ (±0.3℃) for 2 weeks. The samples were then filtered with the use of filter paper (Machery, Nagel and Co.No.614 ¼) and 0.1% Lucilite TR (PVP coated-silica gel) (INEOS Silicas Limited Warrington, Cheshire) (McKeown and Thompson, 2003; Lucilite TR. INEOS Silicas Limited, 2007). Finally, the beers were pasteurised with 35 PU [18.0 min at 62℃(±0.3℃)].

The beer colour was analysed by the E.B.C. spectrophotometric method (Analytica-EBC. European Brewing Convention, 1997c) and by the Tristimulus method with the conversion of a series of defined spectrophotometric transmittances; 360 nm, 450nm, 540nm, 670nm, 760 nm, respectively according to Smedley (Sharpe *et al.*, 1992; Smedley, 1992; Smedley, 1995). Likewise, the corresponding CIE colour space units Lightness/Darkness (L*), redness-greenness hue component (a*), yellowness-blueness hue component (b*), metric chroma (C*) (Smedley, 1992; Smedley, 1995), yellowness index (Yellowness Indices. Hunter Lab, 1996), iCAM colour appearance predictors; lightness (J), chroma (C), hue angle (h), brightness (G), colourfulness (M) (Fairchild, 2006; Fairchild and Johnson, 2007) and CIECAM02 colour appearance predictors; lightness (J), chroma (C), hue angle (h), redness-greenness hue component (a), yellowness-blueness hue component (b), brightness (Q) and saturation (s) (Moroney *et al.*, 2002a; Moroney *et al.*, 2002b; Moroney and Zeng, 2003) of each sample were obtained by means of mathematical formulae using an Excel spreadsheet (Microsoft Corporation) calculator.

Table 3.1.8 Proposed grain bills for pale lager beers produced at the I.C.B.D. pilot brewery

Pale malt and colouring agents	Beer No.1 Max-Min	Beer No. 2 Max-Min	Beer No.3 Max-Min	Beer No.4 Max-Min	Beer No.5 Max-Min	Beer No.6 Max-Min	Beer No.7 Max-Min	Beer No.8 Max-Min	Beer No.9 Max-Min	Beer No.10 Max-Min
PALE MALT	82-90% 28.2-31.0 kg	94.7-96.1% 32.6-33.0 kg	94.7-96.1% 32.6-33.0 kg	97.8-98.1% 33.7-33.8 kg	98.9-99.25% 34.1-34.2 kg	99.7-99.8% 34.4-34.4 kg	99.7-99.8% 34.4-34.4 kg	99.6-99.8% 34.4-34.4 kg	99.96% 34.5 kg	99.98% 34.5 kg
CARAHELL®	10-18% 3.7-6.7 kg									
CARAAMBER®		3.9-5.3% 1.4-1.9 kg								
MELANOIDIN MALT			3.9-5.3% 1.4-1.9 kg							
CARAMUNICH® TYPE III				1.9-2.1% 720-820 g						
CARAAROMA®					0.75-1% 280-380 g					
CARAFA® TYPE III						0.2% 90 g				
CARAFA® SPECIAL TYPE III							0.2% 90 g			
ROASTED BARLEY								0.2-0.4% 90 -180 g		
SINAMAR® (Colouring beer)									0.04% 85 g	
CARAMEL# 301 (Artificial caramel)										0.02% 20 g

The grain load was comminuted by hammer milling since the wort filtration was carried out by 35 kg working capacity-mash filter (Meura 2001 Junior, 2009). The selection of this wort filtration procedure was based on the optimal process yield obtained with the mash filter technology, as well as the good extraction of colouring malt components and the reduction of oxygen pick-up obtained by the performance of the mash filter operation.

An infusion step mashing method was used for the wort production of the experimental batches. No pH correction by salts (*e.g.* Gypsum or $CaCl_2$) or acids (*e.g.* lactic or phosphoric acid) was done. The mashing programme for the standard brews is shown in Figure 3.1.1. The programme was established with attention to obtain high brewhouse yield, optimal free amino nitrogen (FAN) levels for colour enhancement via Maillard reactions and higher coagulable nitrogen (protein) levels for efficient hot breaks formation and chillproofing in order to ensure satisfactory beer physical stability. In addition, it presents similar patterns to the E.B.C and M.E.B.A.K. congress mash programme. Nevertheless, it was assumed a possible detrimental effect by lipases, lipooxygenases (*e.g.* LOX 1 and LOX 2) and peroxidases (POD) at mashing temperatures conditions below 63℃ and higher pH (>4. 2); optimal conditions to inactivate aforementioned enzymes. However, it has been observed in previous studies that the latter mashing conditions do not promote colour enhancement and colour consistency (see De Rouck, 2009). The mash-in specifications are presented in Table 3.1.7. Visual iodine tests were done according to M.E.B.A.K. method of analysis (Brautechnische Analysenmethoden. Band II. Mitteleuropäische Brautechnische Analysenkommission, 2002a) to confirm the optimal conversion of sugars.

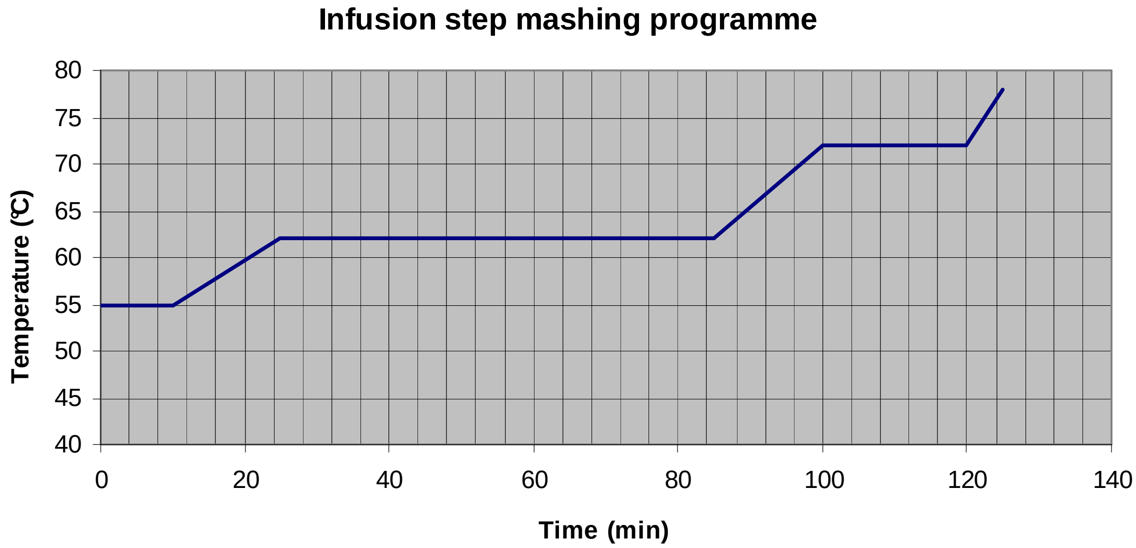

Figure 3.1.1 Infusion step mashing programme for the I.C.B.D. standard brew for pale lager beers

Table 3.1.9 Mash-in specifications

Specifications	Values
Grist composition	*See section of Results: 4.3 Preliminary colour adjustment trials and Table 4.3.3*
Brew liquor:grist ratio	2.5:1
Brew liquor volume (L)	100
Initial liquor temperature (°C)	57 ±0.5
Strike temperature (°C)	55 ±0.5
Brew liquor flow (L/hr)	420
Grist feed (kg/min)	4.0
Mash tun agitator dial setting (0-999)	350 (*ca.* 30 rpm)
Total time (min)	*ca.*6-8

The mash-in was performed by means of a conical pre-masher (304 stainless steel) with a single screw full pitch conveyor feeding the mash in a gentle flux on the internal walls of the mash tun.

Lixiviation liquor temperature was 78°C (±0.3°C) and the recirculation of wort for the initial wort clarification was achieved in less than 7 min. Minimum extract of last runnings was considered as 1°P.

The wort boiling was carried out for 60 min at 103°C (±2°C) (110 m Edinburgh-Riccarton height above sea level) with a wort recirculation of 7 to12 times an hour via external calandria. The bitterness specification of the beers was 22 International Bitterness Units (IBU). Hop dosage was performed at the beginning of the boiling process with Hallertauer-Magnum pellets (12.7% w/w α-acids), and Saaz pellets (6% w/w α-acids) were 10 minutes prior to the end of boiling. In the case of the locally-brewed beer colour-adjusted with artificial caramel colorant (CARAMEL#301), the addition of this colouring agent was conducted at this stage of the process. The separation of hot breaks (hot trub) was carried out for 10 minutes by means of a whirlpool system. The whirlpool rest time was no more than 20 min. The wort original gravity obtained was 12°P (±0.3°P).
From the cast wort weight, clip-lock bottles were taken for colour determination analysis later in the I.C.B.D. laboratories. One of the sample bottles will be used immediately for the measurement of the attenuation limit and colour according to M.E.B.A.K. (Brautechnische Analysenmethoden. Band II. Mitteleuropäische Brautechnische Analysenkommission, 2002c) and E.B.C. methods (Analytica-EBC. European Brewing

Convention, 1997d). After the whirlpool rest, the cast wort was cooled using a plate heater exchanger at a pitching temperature of 12℃ (± 0.3℃). The cooling of cast wort was done as rapidly as possible (<30 min) in order to prevent the formation of DMS mentioned above, which will have a direct influence on the beer flavour stability (see section 1.6.9). No multi-filling method was applied and no brewhouse aids such as clarification-, antifoam agents, antioxidants, zinc and yeast nutrients were used.

An active-dry bottom fermenting yeast *Saccharomyces pasterianus* “Saflager S-23” from the Versuchs-und Lehranstalt für Brauerei in Berlin (V.L.B.) laboratories was used for the cooled wort pitching (Saflager-S23. Yeast Specifications. Fermentis, 2007). The specifications of the yeast strain are presented in Table 3.1.9. First to fifth yeast generations were used for this experimentation only. Depending on the original gravity, the yeast slurry was added with a concentration of 15 to 20x10^6 yeast cells/mL with viability up to 95% to the aerated pitching wort in the cylindroconical fermentation tank. The count of pitching cells and cell’s viability (methylene blue staining method) was carried out according to M.E.B.A.K. analysis methods (Brautechnische Analysenmethoden. Band II. Mitteleuropäische Brautechnische Analysenkommission, 2002d).

Table 3.1.10 Bottom fermenting yeast “Saflager S-23” specifications (Saflager-S23. Yeast Specification. Fermentis, 2007)

Specification	**Description**
Commercial name	Saflager S-23
Yeast strain	*Saccharomyces pastorianus*
Origin	Bottom fermenting yeast is originating from the Versuchs- und Lehranstalt für Brauerei (V.L.B.), Berlin, Germany, also known under the code RH. The strain is used by Western European commercial breweries and has been reported to produce lagers with some fruity and estery notes.
Flocculation	High
Fermentation temperature	9-15℃, ideally 12℃
Final gravity	Medium
Typical analysis	Total bacteria: < 5/mL Acetic bacteria: < 1/mL Lactobacillus: < 1/mL Pediococcus: < 1/mL Wild yeast non-Saccharomyces: < 1/mL Pathogenic microorganisms: In accordance with regulation

The primary fermentation took five to seven days at 12°C (±0.3℃) and was reached with an extract content of 1°P (SG 1.0039) to 1 .5°P (SG 1.0058) higher than the attenuation limit obtained, which were *ca.* 4°P (SG 1.016). Afterwards, the green beer was slowly cooled to 4℃ (±0.3℃) with a cooling rate o f 0.1℃ per hour and the airlock of the fermentation tank was closed in order to obtain the optimal carbonation of the beer. After the yeast harvest, the cooling system of the cylindroconical tank was turned off for 48 hours with a temperature increase rate of 0.2℃/h. This stage was considered as the vicinal diketones reduction phase due to the increase of temperature favours the enzymatic reduction of diacetyl and pentanodione to acetoine and hydroxypentanone and these latter ones subsequently to butanodiol and pentanodiol by yeast, respectively (see Fix, 1999). The maximum production of CO_2 of the yeast by means of the fermentation of the residual extract contained in the green beer was obtained at this point reaching a maximum temperature of 14℃ (±0.3℃) . The carbonation of the beer was held at 0.8-1.0 bar (11.60-14.2 psi). The beer maturation was held at 2℃ (±0.3℃) and 0.8-1.0 bar for 14 days.

The beers were colloidally stabilised with 50 mg/L of Lucilite TR (PVP coated-silica gel filter aid) (McKeown and Thompson, 2003) and filtered by means of a sheet filter with the use of Carlson XE400 filter sheets (0.5 Microns) (Carlson Filtration Ltd. XE 400: Product specifications, 2007).The filtered beers were transferred into the bright beer tanks (BBT's) at 2℃ (±0.3℃). No foam stabilisers were u sed. The oxygen content was monitored at the filter inlet, at the bright beer tank and latterly in the packaged beer. The aim was to obtain a total in-package oxygen (TIPO) content in final beer of ≤0.1 mg O_2/L. Beers were bottled with previous air prevacuations by CO_2 flushing and with a filling volume tolerance of 1% and carbonated at 2.5-3.0 vol. by means of a CW250-G carbonating and counter pressure bottle filling equipment (CW250-R&D. Moravek. International Limited, 2007). No jetting injection was applied. The bottled beers were pasteurised at no more than 35 PU and stored in the dark at 4℃ (±0.5℃). The pasteurisation programme was carried out at 62℃ (±0. 3℃) for 17.5 minutes (see Table 4.5.1) according to the following formula (Narziß,1995):

$$PU = Z \times 1.393^{(T-60)}$$

The formula uses *Z* as time in minutes and *T* is the pasteurization temperature in Celsius degrees (℃).

Once the established pasteurisation units was reached a subsequent cooling was be carried out at 25℃ (±0.3℃) for 20 to 22 minute s in order to avoid any damage to the sensorial, physical and chemical properties of beer. In addition, no antioxidants and foam stabilisers were used at this final stage of the process. The period of the entire brewing for the locally-brewed beers was 25 days (±2 days). Aged beers were considered as beers with an spontaneous ageing of 12 months while the forced aged samples as beers thermally treated at 60℃ (±0.3℃) for 7 days. All the beers samples were stored in the dark at 4℃ (±0.5℃).

Several oxygen levels tests in bottled beer were carried out according to M.E.B.A.K. methods of analysis (Brautechnische Analysenmethoden. Band II. Mitteleuropäische Brautechnische Analysenkommission, 2002a) to verify the dissolved oxygen levels required and reported by the manufacturer. The determination of dissolved oxygen levels was done by means of an Orbisphere Model 3650 O_2 Logger (Model 3650 Micro O_2 Logger. Operators Manual. Orbisphere Laboratories, 1995).

3.2 Wort and beer analysis

All physical, chemical, and sensory analyses for the locally-brewed worts and beers were carried out in the I.C.B.D. laboratories according to the official methods of analysis of Mitteleuropäische Brautechnische Analysenkommision (M.E.B.A.K.) (Brautechnische Analysenmethoden. Band II. Mitteleuropäische Brautechnische Analysenkommission, 2002a-s) and the European Brewing Convention (E.B.C.) (Analytica-EBC. European Brewing Convention, 1998a-q), unless otherwise specified. Tables 3.2.1 and 3.2.2 show the proposed main and additional parameters analysed for wort and beer, respectively.

3.2.1 Analysis of bottled commercial beers

Ten commercial bottled beers were analysed according to Table 3.2.2. These beers represent typical pale lager beer produced all over the world. The aim of this selection of commercial beers was to obtain standard values of each parameter by means of comparing the outcomes from the commercial beers and use their mean values as the global product specifications for the locally-brewed beers of this investigation. The selection of these commercial beers is presented in Table 3.2.3.

Table 3.2.1 Main Analyses

Control parameters	According to
Colour (Visual comparative method) E.B.C.	M.E.B.A.K., 2002e
Colour (Spectrophotometric method 430 nm) E.B.C.	M.E.B.A.K., 2002f; E.B.C.,1998c
Colour (CIE L*a*b*/ Tristimulus values)	Smedley, 1992, 1995
Metric chroma (Chroma)	Smedley , 1992, 1995
Yellowness index (YID1925)	Hunter Lab, 1996
iCAM lightness (J)	Fairchild, 2006; Fairchild and Johnson, 2007
iCAM colourfulness (M)	Fairchild, 2006; Fairchild and Johnson, 2007
iCAM hue angle predictor (h)	Fairchild, 2006; Fairchild and Johnson, 2007
iCAM chroma predictor (C)	Fairchild, 2006; Fairchild and Johnson, 2007
iCAM brightness predictor (G)	Fairchild, 2006; Fairchild and Johnson, 2007
CIECAM02 lightness (J)	CIE, 2004; Moroney *et al.*, 2002a, 2002b, 2003
CIECAM02 colourfulness (M)	CIE, 2004; Moroney *et al.*, 2002a, 2002b, 2003
CIECAM02 hue quadrature (H, Hc)	CIE, 2004; Moroney *et al.*, 2002a, 2002b, 2003
CIECAM02 hue angle (h)	CIE, 2004; Moroney *et al.*, 2002a, 2002b, 2003
CIECAM02 redness-greenness hue component (a)	CIE, 2004; Moroney *et al.*, 2002a, 2002b, 2003
CIECAM02 yellowness-blueness hue component (b)	CIE, 2004; Moroney *et al.*, 2002a, 2002b, 2003
CIECAM02 chroma (C)	CIE, 2004; Moroney *et al.*, 2002a, 2002b, 2003
CIECAM02 brightness (Q)	CIE, 2004; Moroney *et al.*, 2002a, 2002b, 2003
CIECAM02 saturation (s)	CIE, 2004; Moroney *et al.*, 2002a, 2002b, 2003
Total flavour-active ageing compounds	Lustig, 1993; Lustig *et al.*,1999
Forcing index	Lustig, 1993; Lustig *et al.*,1999
Ageing index	Lustig, 1993; Lustig *et al.*,1999
Endogenous anti-oxidative potential (EAP)	Methner *et al*., 2007
OH-active radicals of colouring agents	Methner *et al*., 2008

Table 3.2.2 Additional Analyses (Baseline Data)

Control parameters	According to
Visual Iodine Test	M.E.B.A.K., 2002b
Final attenuation of wort and beer (%)	M.E.B.A.K., 2002c
Original gravity (by digital density meter)	M.E.B.A.K., 2002d; E.B.C.,1998b
Alcohol in beer (by distillation)	M.E.B.A.K., 2002d; E.B.C.,1998e
Real extract (by digital density meter)	M.E.B.A.K., 2002d; E.B.C.,1998f
pH	M.E.B.A.K., 2002g
Turbidity 20℃ (EBC-formazin units)	M.E.B.A.K., 2002h ; E.B.C.,1998n
Forcing test (Shelf-life prediction) Modified method according to Titze *et al.*	M.E.B.A.K., 2002i, Titze *et al.* 2007
Reducing power (%RED) (DPI method)	M.E.B.A.K., 2002j
Total polyphenols by spectrophotometry	M.E.B.A.K., 2002k; E.B.C.,1998h
Flavanoids (Anthocyanogens) by spectrophotometry	M.E.B.A.K., 2002l; E.B.C.,1998i
International bitterness units (IBU)	M.E.B.A.K., 2002m; E.B.C.,1998g
Head retention (NIBEM)	M.E.B.A.K., 2002n
CO_2% vol. (CORNING 965D)	M.E.B.A.K., 2002o; E.B.C.,1998m
Dissolved oxygen in bottled beer	M.E.B.A.K., 2002p; E.B.C.,1998o
Iron by atomic absorption spectroscopy (AAS)	E.B.C.,1998j
Copper by atomic absorption spectroscopy (AAS)	E.B.C.,1998k
Calcium by atomic absorption spectroscopy (AAS)	E.B.C., 1998l

Table 3.2.3 Commercial beers analysed

Name of commercial beer	Beer style & Country of origin
Heineken	Dutch pilsner, The Netherlands
Carlsberg	Scandinavian pilsnerr, Denmark
Becks	German pilsner, Germany
Bitburger	German pilsner, Germany
Tennents	Export-Dortmunder, Scotland (U.K.)
Budweiser	American lager, U.S.A.
Pilsner Urquell	Bohemian pilsner, Czech Republic
Corona	American lager, Mexico
Sapporo	Export-Dortmunder, Japan
Fosters	Australian lager, Australia and UK

3.2.2 Analytical measurements and sensory evaluations of beer flavour stability on locally-brewed beers

3.2.2.1 Chemical analysis of beer flavour stability: Detection of beer ageing components and determination of forcing and ageing index

An extended regime of Gas Chromatography-Mass Spectrometry (GC-MS) analysis was carried out for the detection of ageing components as aldehydes in beer by means of solid phase microextraction (SPME) with on-fibre PFBOA [*O*-(2,3,4,5,6-pentafluorobenzyl)hydroxylamine] derivatisation (Vesely *et al.*, 2003) and other ageing components as ketones, esters, lactones and heterocyclic compounds (Lustig, 1993; Lustig *et al.*,1999) with on-fibre DVB-CAR-PDMS [divinylbenzene-carboxen-polydimethylsiloxane 50/30_m] derivatisation (Saison *et al.*, 2008a) exposed to the headspace of a vial with the beer samples, respectively.

3.2.2.1.1 Detection of ageing components. Group 1: Aldehydes

Aldehydes selectively reacted with PFBOA (*O*-(2,3,4,5,6-pentafluorobenzyl)hydroxylamine) and the oxides formed were desorbed into a Gas Chromatograph (GC) and quantified by a Mass spectrometer (MS) in SIM modus (Selected Ion Monitoring) for better selectivity and sensitivity for the registration of total-ions-current. The selection of reagents, preparation of samples and chromatographic conditions are according to the method implemented by Vesely *et al.* (2003) due to its reproducibility and linearity [R^2: 0.96-0.99; CV: 4.7-5.3% and 8% for (*E*)2-nonenal]. The methodology and conditions used are summarised in Table 3.2.4.

Table 3.2.4 GC-MS analysis methodology and conditions for detection and quantification of aldehydes as beer ageing markers (Vesely *et al.*, 2003)

Stock solution	Mixture of ten standard compounds (100 µg/L each) in ethanol (5% in deionised H_2O). Preparation daily.
PFBOA Stock solution	PFBOA = *O*-(2,3,4,5,6-pentafluorobenzylhydroxylamine) (Sigma-Aldrich, Milwaukee, WI). Catalogue no. 194484-1G. Stock solution PFBOA 6 g/L (deionised H_2O). Preparation every 3 months and kept at refrigeration temperatures.
Beer samples conditions	Fresh beer samples at 4℃ (< 90 days) Forced beer samples 1 week at 60℃ (≈1 year at 20℃) Aged beer samples at 4℃ (1 year)
SPME fibre	6.5 µm poly(dimethylsiloxane)divinylbenzene (PDMS/DVB) fibre coating (Supelco, Bellefonte, PA; catalog.no.57346-U). Selected for its affinity to PFBOA-aldehyde oximes (Vesely *et al.*, 2003).
Derivatisation procedure	1. 100 µL of PFBOA solution (6 g/L) and 10 mL of deionised water are placed in a 20 mL-glass vial and sealed with a magnetic crimp cap (Gerstel, Baltimore, MD) 2. The PDMS/DVB SPME fibre is then placed in the headspace of the PFBOA solution for 10 min at 50℃ 3. The SPME fibre loaded with PFBOA solution was then exposed to the headspace of 10 mL of beer placed in a 20 mL glass vial for 60 minutes at 50℃. 4. Finally the SPME fibre was placed in the inlet of the GC/MS and the analytical run started. Compounds were desorbed from the fibre for 10 minutes, after which it was removed from the inlet.
Gas Chromatograph	HP 6890 GC coupled with Mass Selective Detector (MSD) (5972A_Agilent Technologies)
Separation column	HP5MS column, 30 m , ID 0.25 mm, film thickness 0.25 um (Agilent Technologies, Palo Alto, CA)
Carrier gas	Helium
Front inlet temperature	At 220℃
Injection mode	Splitless with purge valve set at 30 s

Oven temperature programme	40℃ for 2 min, from 40 to 140℃ at 8℃/min, from 1 40 to 250℃ at 5℃/min. Hold at 250℃ for 3 min. Total time: 39.5 min
MS-detector	Mass-selective detector Agilent 6890 (5972A, Agilent Technologies, Palo Alto, CA). The transfer line from the GC to the MSD was at 280℃. PFBOA derivatives were analysed by mass spectrometry using electron impact ionization. Fragment m/z 181 was the main fragment of all analyzed aldehydes.
MS-modus detection	To increase sensitivity of the method, all analyses were run in Single-Ion Monitoring (SIM) mode with monitoring for m/z 181.
Retention times (minutes)	pentanal (valeraldehyde):14.69 and 14.80 hexanal:16.41 and 16.50 (*E*)-2-nonenal: 23.49 and 23.79 2-methylpropanal (isobutyraldehyde):12.17 and 12.22 2-methylbutanal:13.74 and 13.81 3-methylbutanal (isovaleraldehyde):13.97 and 14.11 benzaldehyde: 20.58 and 20.70 2-phenylethanal (phenylacetaldehyde): 21.70 and 21.87 methional (3-methyl-1-thiopropanal): 18.9 and 18.94 2-furfural (furan-2-carboxaldehyde): 17.10 and 17.46

Some considerations/observations during GC-MS analysis (*ibid.*):

- Most aldehydes form two geometrical isomers (cis and trans) of the derivatives which are represented by the two peaks in the chromatogram.
- Main fragment expected value is obtained around m/z 181 for all aldehydes analysed.

For calibration purposes, the sum of the peak areas of the two geometrical isomers was used for calculations. A six-point calibration curve for ten aldehydes was measured due to a possible matrix effect expected according previous studies (Lustig, 1993; Saison *et al.*, 2008a-b; Vesely *et al.*, 2003). The calibration range was 0.1-50 µg/L, except for (*E*)-2-nonenal, where the calibration range was 0.01-5 µg/L. The matrix used for calibration solutions was a standard 5% ethanol solution, pH 4.5 in order to get an accurate quantification (Saison *et al.*, 2008a-b; Vesely *et al.*, 2003).

3.2.2.1.2 Detection of ageing compounds. Group 2: Ketones, esters, lactones and heterocyclic compounds

The solid phase microextraction (SPME) technique with on-fibre PFBOA [O-(2,3,4,5,6-pentafluorobenzyl)hydroxylamine] derivatisation (Vesely *et al.*, 2003) is unfortunately selective for detection of aldehydes only. Hence, it was necessary to use another technique which enables the suitable extraction of other relevant ageing compounds.

An alternative method for the detection and quantification of non-aldehyde beer ageing compounds has been recently proposed by Saison *et al.* (2008a). This solid phase microextraction (SPME) method has been proved to be very selective and reliable by using a specific SPME fibre coating of divinylbenzene-carboxen-polydimethylsiloxane 50/30_m (DVB-CAR-PDMS). The method is based on the previous proposal by Vesely *et al.* (2003) optimised by means of the selection of a SPME fibre [divinylbenzene-carboxen-polydimethylsiloxane 50/30_m], effect of salt addition (salting-out effect), extraction temperature and time (Saison *et al.*, 2008a). Table 3.2.5 shows the methodology and conditions applied for the detection and quantification of beer ageing compounds of non-aldehyde nature.

The calibration was carried out by the standard addition method according to previous studies (Saison *et al.*, 2008a). This was attained by addition of a calibration mixture of ethanol, containing the different target compounds at a known concentration. Tests showed compounds to be linear over expected concentration ranges of beer (see Table 3.2.8 and Saison *et al*., 2008a). The calibration standard added to the beer samples was calculated to give a concentration roughly mid point of these ranges. Peak areas for the compounds were measured in unspiked and spiked samples of each beer type, and the difference between these readings were used to calculate the actual value in the beer.

Table 3.2.5 GC-MS analysis methodology and conditions for detection and quantification of non-aldehydes as beer ageing markers (Saison *et al.*, 2008a)

Beer samples conditions	Fresh beer samples at 4℃ (< 90 days) Forced beer samples 1 week at 60 ℃ (≈1 year at 20 ℃) Aged beer samples at 4℃ (1 year)
SPME fibre	Divinylbenzene-carboxen-polydimethylsiloxane 50/30_m. (DVB-CAR-PDMS) fibre coating (Supelco, Bellefonte, PA; catalog.no.57328-U) (Saison *et al.*, 2008a).
Salt addition	Total addition: 2.0 g of NaCl (analytical grade). The salting-out effect improved in a considerable manner the extraction efficiency due to changes in polarity of beer matrix. The solubility of organic compounds (mainly hydrophobic ones) is reduced by enhancing the concentration of salt in the medium increasing salt concentration (Saison *et al*., 2008a).
Derivatisation procedure	<u>Unspiked sample</u>: 10 mL of beer was placed in a 20 mL vial and internal standard. 100 µL of ethanol and 2 g of salt was also added and the vial crimp sealed. The DVB-CAR-PDMS fibre was placed in the headspace of this solution for 35 minutes at 40℃. The SPME fibre was then placed in the inlet of the GC/MS and the analytical run started. Compounds were desorbed from the fibre for 10 minutes, after which it was removed from the inlet. <u>Spiked sample</u>: 10 mL of beer was placed in a 20 mL vial and internal standard added as per the paper (Saison *et al*., 2008a). 100 µL of ethanol, containing the calibration compounds and 2 g of salt was also added and the vial crimp sealed. The DVB-CAR-PDMS fibre was placed in the headspace of this solution for 35 minutes at 40℃. The SPME fibre was then placed in the inlet of the GC/MS and the analytical run started. Compounds were desorbed from the fibre for 10 minutes, after which it was removed from the inlet.
Gas Chromatograph	HP 6890 GC coupled with 5972 Mass Selective Detector (MSD)
Separation column	HP5MS column, 30 m, ID 0.25 mm, film thickness 0.25 um (Agilent Technologies, Palo Alto, CA)

Carrier gas	Helium
Front inlet temperature	At 220℃
Injection mode	Splitless with purge valve set at 30 s
Oven temperature programme	40℃ for 2 min, from 40 to 140℃ at 8℃/min, from 1 40 to 250℃ at 5℃/min. Hold at 250℃ for 3 min. Total time: 39.5 min
MS-detector	Mass-selective detector Agilent 6890 (5972A, Agilent Technologies, Palo Alto, CA). The transfer line from the GC to the MSD was at 280℃. PFBOA derivatives were analysed by mass spectrometry using electron impact ionization.
MS-modus detection	To increase sensitivity of the method, all analyses were run in Single-Ion Monitoring (SIM) mode with monitoring for various ions at various times (see table below).
Retention times (minutes)	For non-aldehydes ageing compounds: Solvent delay: 4 and 4 (m/z= 110) acetylfuran (Group 1): 6.4 and 5.9 (m/z= 95, 110, 67) 2-ethyl furfuryl ether (relative area) (Group 2): 7.4 ethyl nicotinate (nicotinic acid ethyl ester) (Group 3): 12.1 and 11.5 (m/z= 106, 78, 51, 123, 151) 5-hydroxymethylfurfural (Group 3): 12.5 (m/z= 97, 126, 69) 2-Phenylethyl acetate (2-phenylacetic acid ethyl ester) (Group 4): 13.28 and 12.9 (m/z= 91, 65, 164) γ-Nonalactone (Group 5): 15.4 and 15 (m/z= 85)

3.2.2.1.3 Method of validation for both GC-MS detection techniques

For both techniques applied a standard method of validation was used with the aim of obtaining optimal conditions for detection and quantification of the beer ageing components and homogenous results based on the reproducibility, statistical tools and resolution peaks reported by the authors who developed the GC-MS techniques aforementioned. The method of validation is presented in Table 3.2.6.

Table 3.2.6 Method of validation for GC-MS techniques (Vesely *et al.*, 2003)

Calculated statistical values	Mean, standard deviation, coefficient of variation and coefficient intervals for 95%
Coefficient of variation (expected)	Below 5.5%, except for (*E*)-2-nonenal. A higher coefficient of variation for (*E*)-2-nonenal is expected (*ca.* 8%) due to extremely low levels of this aldehyde in analysed beer.
Resolution peaks	A good resolution of two peaks is expected, except for 2-furfural, where a possible clustering of first peak by an uncharacterized compound can be expected.

3.2.2.1.4 Quantification of ageing compounds

Nineteen ageing compounds (11 aldehydes and 9 non-aldehyde compounds) were selected to be analysed on the entire portfolio of colour-adjusted locally-brewed beers and beer control; 16 fresh, 16 forced aged (7 days at 60℃) and 16 spontaneously aged beer samples (12 months at 4℃), respectively. These ageing components were selected according to previous studies (Eichhorn *et al.*, 1999; Lustig, 1993; Narziß *et al.*, 1999). Some of these compounds are considered as indicators of oxygenation and thermal damage of the beer matrix during brewing, packaging and storage. Tables 3.2.7 and 3.2.8 show the components analysed for this investigation as well as their thresholds in beer and flavour descriptors, respectively. The dimensionless forcing and ageing indexes were calculated according to previous investigations by Lustig (1993; Narziß *et al.*, 1999). The empirical multiplying factors used for the calculation of these indexes are based on the concentration increase of some of the quantified compounds during forcing and spontaneous beer ageing. Some of them increase at the initial ageing phase, while others at later phases. These factors compensate the very high concentrations of specific compounds such as 2-furfural and γ-nonalactone in the aged beer matrix. The use of these indexes in fresh beer is comparable to those obtained at spontaneously aged conditions, being suitable to predict the ageing state of analysed beers.

Table 3.2.7 Index numbers of ageing compounds (Lustig, 1993; Narziß *et al.*, 1999)

Index number	***Compounds***
Sum of oxygenation indicators (µg/L) (5)	2-methylpropanal (isobutyraldehyde) 2-methylbutanal 3-methylbutanal (isovaleraldehyde) benzaldehyde 2-phenylethanal (phenylacetaldehyde)
Sum of warming indicators (µg/L) (3)	2-furfural (furfural, furan-2-carboxaldehyde) ethyl nicotinate (Nicotinic acid ethyl ester) γ-nonalactone
Sum of furans (µg/L) (5)	2-furfural (furfural, furan-2-carboxaldehyde) 5-hydroxymethylfurfural 2-acetylfuran (2-furyl methyl ketone) 2-propionylfuran 2-ethyl furfuryl ether (relative area)
Other relevant ageing compounds (µg/L) (7)	pentanal (valeraldehyde) hexanal (*E*)-2-nonenal methional (3-methyl-1-thiopropanal) diethyl oxalate (oxalic acid diethyl ester) 2-phenylethyl acetate (2-phenyl acetic acid ethyl ester) 2,4,5-trimethyl-1,3-dioxolane (relative peak area)
Sum of ageing compounds (µg/L) (20)	pentanal (valeraldehyde) hexanal (*E*)-2-nonenal 2-methylpropanal (isobutyraldehyde) 2-methylbutanal 3-methylbutanal (isovaleraldehyde) benzaldehyde 2-phenylethanal (phenylacetaldehyde) methional (3-methyl-1-thiopropanal) 2-furfural (furan-2-carboxaldehyde) 5-hydroxymethylfurfural

Index number	*Compounds*
	2-acetylfuran (2-furyl methyl ketone) 2-propionylfuran ethyl nicotinate (nicotinic acid ethyl ester) diethyl oxalate (oxalic acid diethyl ester) 2-phenylethyl acetate (2-phenyl acetic acid ethyl ester) 2-ethyl furfuryl ether (relative area) γ-nonalactone 2,4-dimethyl-4-cyclopenten-1,3-dione (relative peak area) 2,4,5-trimethyl-1,3-dioxolane (relative peak area)
Forcing index (dimensionless) (7)	Total from: 2 x concentration of 3-methylbutanal (isovaleraldehyde) 0.5 x concentration of 2-phenylethanal (phenylacetaldehyde) 0.25 x concentration of 2-furfural (furan-2-carboxaldehyde) 2 x concentration of 2-acetylfuran (2-furyl methyl ketone) 2 x concentration of 2-propionylfuran 0.5 x concentration of γ-nonalactone relative peak area of 2,4,5-trimethyl-1,3-dioxolane
Ageing index (dimensionless) (11)	Total from: 2 x concentration of 3-methylbutanal (isovaleraldehyde) 0.5 x concentration of 2-phenylethanal (phenylacetaldehyde) 0.25 x concentration of 2-furfural (furan-2-carboxaldehyde) 2 x concentration of 2-acetylfuran (2-furyl methyl ketone) 4 x concentration of 2-propionylfuran concentration of diethyl oxalate (oxalic acid

Index number	*Compounds*
	diethyl ester) concentration of 2-phenylethyl acetate (2-phenyl acetic acid ethyl ester) 5 x relative peak area of 2-ethyl furfuryl ether 0.5 x concentration of γ-nonalactone 3 x relative peak area of 2,4-dimethyl-4-cyclopentene-1,3-dione relative peak area of 2,4,5-trimethyl-1,3-dioxolane

Table 3.2.8 Reported concentration levels at different ageing stages, flavour thresholds and flavour descriptors of ageing compounds of pale lager beers ([a]Lustig, 1993; [b]Meilgaard, 1975b; [c]Narziß *et al.*, 1999; [d]Saison *et al.*, 2008a; [e]Saison *et al.*, 2008b; [f]Vanderhaegen *et al.*, 2003)

Beer ageing compound	Fresh pale lager beer (μg/L)	Forced pale lager beer (μg/L)	6 Months-pale lager beer (μg/L)	12 Months-pale lager beer (μg/L)	Threshold in beer (μg/L)	Possible Sources	Flavour descriptors [a,b, c, e, f]
Linear Aldehydes							
Pentanal (Valeraldehyde)	[e]0.2 (±0.01)	[e]0.7 (±0.02)	N/A	N/A	[b]500	3	Green character, banana
Hexanal	[e]0.7 (±0.04)	[e]3.5 (±0.14)	[a]0.8 (±0.06)	[a]1 (±0.1)	[e]88	3	Bitter, vinous
(*E*)-2-Nonenal	[a]0.03 (n.q.)	[a]0.09 (n.q.)	[a]0.1 (threshold)	[a]0.1 (threshold)	[c]0.1	4	Cardboard, papery, stale
Strecker Aldehydes							
2-Methylpropanal (Isobutyraldehyde)	[e]6.7 (±0.60)	[e]39.2 (±0.47)	N/A	N/A	[e]86	1, 2	Green character, spicy, malty, banana, melon
2-Methylbutanal	[e]2.4 (±0.18)	[e]6.8 (±0.16)	[a]9.8 (±0.8)	[a]18.55 (±2.9)	[e]45	1, 2	Green character, ethery, bitter almond
3-Methylbutanal (Isovaleraldehyde)	[e]9.1 (±0.58)	[e]22.9 (±0.54)	[a]16 (±1.4)	[a]28.8 (±0.35)	[e]56	1, 2	Green character, bitter almond, cherry, malty

Benzaldehyde	[e]1.0 (±0.02)	[e]2 (±0.04)	[a]1.3 (±0.01)	[a]2.4 (±1.27)	[e]515	2	Almonds
2-Phenylethanal (Phenylacetaldehyde)	[e]13.1 (±1.74)	[e]34.8 (±2.86)	[a]29.2 (±3.15)	[a]52.1 (±5.23)	[e]105	2	Hyacinth, lilac
Methional (3-Methyl-1-thiopropanal)	[e]1 (±0.2)	[e]3 (±0.5)	[a]1.8 (±0.35)	[a]43 (±3.5)	[e]4.2	2	Cooked potato, vegetables
Maillard Reaction Products							
2-Furfural (Furan-2-carboxaldehyde)	[e]21 (±0.3)	[e]282 (±3.3)	[a]173.7 (±12.37)	[a]482 (74.5)	[e]15,157	5	Sweet, caramel, papery, husky, mouldy
5-Hydroxymethylfurfural	[b]0.1-20 x10^3	N/A	N/A	N/A	[e]35,784	5	Stale, vegetable oil
2-Acetylfuran (2-Furyl methyl ketone)	[e]9.4 (±0.40)	[e]17.2 (±0.54)	[a]13.5 (±0.77)	[a]19.7 (±1.34)	[e]513	5,6	Papery, almonds, nuts
2-Propionylfuran	[a]1.7 (±0.28)	[a]8.8 (±0.28)	[a]7.15 (±1.62)	[a]17.7 (±2.47)	N/A	5	Sweet, caramel, rum
2,4-Dimethyl-4-cyclopenten-1,3 dione	[a]3.5 (±1.80)	[a]5.4 (±2.54)	[a]7.4 (±3.63)	[a]16.7 (±5.25)	N/A	5	N/A
Ethyl esters							
Ethyl nicotinate	[e]n.d.	[e]16.9 (±0.83)	[a]56.2 (±3.74)	[a]159.4 (±11.17)	[e]4555	8	Grassy, papery

(Nicotinic acid ethyl ester)							
Diethyl oxalate (Oxalic acid diethyl ester)	[a]0.7 (±0.34)	[a]3 (±1.3)	[a]2 (±0.9)	[a]3.3 (±1.84)	[a]18000	8	N/A
Acetate esters							
2-Ethyl phenyl acetate (2-Phenyl acetic acid ethyl ester)	[a]0.7 (±0.21)	[a]1.2 (±0.21)	[a]1.6 (±0.28)	[a]3.1 (±0.15)	[a]3800	8	Hyacinth, lilac, roses, honey, apple, sweetish
Furan ethers							
2-Ethylfurfuryl ether	[d]1.1 (±0.06)	[d]9.6 (±0.42)	[a]8.2 (±1.90)	[a]26 (±2.1)	[e]11	7	Solvent-like, stale
Lactones							
γ-Nonalactone	[d]17.6 (±0.37)	[d]29.8 (±1.98)	[a]52.5 (±4.56)	[a]66.1 (±5.77)	[e]607	9	Coconuts, peach, fruity
Aldehyde acetalization products							
2,4,5-Trimethyl-1,3-dioxolane	[a]0.7 (±0.14)	[a]19 (±6.6)	[a]29 (±2.8)	[a]28.6 (±9.5)	[a]900,000	10	Vinous, plums, apples
Sum of indicators							
Sum of warm indicators	[a]51.5 (±10.60)	[a]186 (±29.7)	[a]293 (±25.5)	[a]609.5 (±112.42)			
Sum of oxygen indicators	[a]28 (±11.3)	[a]46.5 (±2.12)	[a]54.5 (±6.36)	[a]83.0 (±7.07)			
Sum of ageing	[a]93.5 (±3.53)	[a]252 (±29)	[a]372 (±17.0)	[a]729 (±135.8)			

compounds				
Indexes				
Forcing index	[a]77 (±11.3)	[a]160.5 (±0.70)	[a]228 (±5.6)	[a]371 (±24.0)
Ageing index	[a]102 (±1.4)	[a]211 (±12.7)	[a]308 (±22.6)	[a]574.5 (±68.58)

1. Lower alcohol and iso-humulone oxidation
2. Strecker degradation (Precursors: Valine → 2-methylbutanal, Leucine → 3-methylbutanal, Methionine → methional, Phenylalanine→ 2-phenylacetate)
3. Fatty acids and high alcohol oxidation
4. Aldol condensation of acetaldehyde with heptanal and unsaturated fatty acid oxidation
5. Maillard reactions (Precursors: Pentoses → 2-furfural, Hexoses → 5-hydroxymethylfurfural and 2-acetylfuran)
6. Caramelisation reactions
7. Etherifications during later ageing stages
8. Esterification between fatty acids and alcohol by Acetyl CoA regulation (Precursors: Tryptophane → ethyl nicotinate)
9. Cyclic esterification of γ-hydroxy acids
10. Acetalization of aldehydes from a condensation reaction between 2,3-butanediol and acetaldehyde

3.2.2.1.5 GC-Standards of beer ageing compounds

The GC-standards shown in Table 3.2.9 were used to detect beer ageing compounds. All GC-standards were obtained from chemical reagents suppliers except in the case of 2,4,5-trimethyl-1,3-dioxolane which was not available in the chemical market. The synthesis of 2,4,5-trimethyl-1,3-dioxolane was carried out at the I.C.B.D. laboratories according to Peppard and Halsey (1982). The purchase of others GC-standards was based on the highest purity that could be found by the chemical reagents market.

Table 3.2.9 GC-Standards of beer ageing compounds

GC-Standard	CAS number	Supplier catalogue number
Pentanal (≥97%)	110-62-3	Sigma-Aldrich®: 110132
Hexanal (≥98%)	66-25-1	Sigma-Aldrich®: 115606
(*E*)-2-Nonenal (≥97%)	1882-56-6	Sigma-Aldrich®: 255653
2-Methylpropanal (≥99%)	78-4-2	Sigma-Aldrich®: 78-4-2
2-Methylbutanal (≥95%)	96-17-3	Sigma-Aldrich®: 96-17-3
3-Methylbutanal (≥97%)	590-86-3	Sigma-Aldrich®: 146455
Benzaldehyde (≥99%)	100-52-7	Sigma-Aldrich®: B1334
2-Phenyethanal (≥90%)	122-78-1	Sigma-Aldrich®:107395
Methional (≥98%)	3862-49-3	Sigma-Aldrich®: 277460
2-Furfural (≥99%)	98-01-1	Sigma-Aldrich®: 48070
5-Hydroxymethylfurfural (≥99%)	67-47-0	Sigma-Aldrich®: H40807
2-Acetylfuran (≥99%)	1192-62-7	Acros Organics®:10255100
2-Propionylfuran (≥99%)	3194-15-8	Endeavour Speciality Chemicals®: ZFU-0010
Ethyl nicotinate (≥99%)	614-18-6	Sigma-Aldrich®: E40609
Diethyl oxalate (≥99%)	95-92-1	Alfa Aesar®: A14498
2-Ethyl phenyl acetate (≥99%)	103-45-7	AlfaAesar®: A19356
2-Ethyl furfuryl ether (≥99%)	62435-71-6	Sigma-Aldrich®: S408573
γ-Nonalactone (≥97%)	203-219-1	Sigma-Aldrich®: 292370

3.2.2.1.6 Synthesis of 2,4,5-trimethyl-1,3-dioxolane

As mentioned above the synthesis of 2,4,5-trimethyl-1,3-dioxolane was carried out following the method published by Peppard and Halsey (*ibid.*). The synthesis of this acetal cyclic compound originated from the condensation reaction between 2,3-butanediol (up to 280 mg/L) in beer and an aldehyde (acetaldehyde, isobutanal, 3-methyl-butanal and 2-methyl-butanal).

Materials:

- 2,3-butanediol puriss >99% (Sigma-Fluka, Cat. No: 18970)
- Acetaldehyde puriss >99.5% (BDH Laboratory, Cat. No: GPRT 270024L)
- Dichloromethane puriss. p.a. Reag. (ACS Sigma-Fluka, Cat. No:66740)
- Sodium hydrogen carbonate >99% (T) (Sigma-Fluka, Cat. No: 71630)
- Sodium sulphate, powder >99% A.C.S. reagent anhydrous (Sigma-Aldrich)
- Rotatory evaporator RE111 (Buchi, Switzerland)

Procedure:

10 mL acetaldehyde and 2,3-butanediol in 200 mL dichloromethane were added to a 1 L Erlenmeyer flask and treated with 1 mL of concentrated sulphuric acid. The solution volume was stirred overnight. It was treated with sodium hydrogen carbonate solution and the organic phase dried with sodium sulphate anhydrous. The dichloromethane-phase was 2 x 200 mL concentrated by means of rotatory evaporation.

Three substances with similar mass spectra are formed from this synthesis, hence it is suspected that there are three isomers of 2,4,5-trimethyl-1,3-dioxolane. The production of three isomers results from the 2,3-butanediol produced by yeast which is a mixture of the levorotatory and meso isomers. The identification of these three isomers was carried out by means of their reference spectra. The mass spectral data are shown in Table 3.2.10

Table 3.2.10 Mass spectra of 2,4,5-trimethyl-1,3-dioxolane isomers (*ibid.*)

2,4,5-trimethyl-1,3 dioxolane	Kovat index (Retention)	Mass fragments
Isomer I	737	43(100); 101(75); 44(68); 55(50); 72(45); 73(43); 45(41); 57(12); 115(9); 39(8)
Isomer II	748	43(100); 44(68); 101(59); 73(45); 45(39); 55(37); 72(36); 57(12); 115(9); 41(8)
Isomer III	760	43(100), 101(87); 44(68); 55(57); 45(45); 72(39); 57(14); 41(9); 39(8)

3.2.2.2 Endogenous anti-oxidative potential (EAP) of the locally-brewed beers and determination of organic radicals of the specialty malts (whole intact kernel and milling fraction measurement) by electromagnetic spin resonance (ESR) spectroscopy

The endogenous anti-oxidative potential of the five fresh locally-brewed beers was measured by the Technische Universität Berlin, Germany. According to Kunz *et al.* patent, this method features POBN (N-tert-butyl-α-(4-pyridyl)nitrone N'-oxide) as a spin trap instead of PBN (N-tert-butyl-α-phenylnitron) in order to avoid any distortion by the pH effect such as the increase of velocity of radical generation in a Fenton reaction system in the beer sample caused by the spin trap PBN (Kunz *et al.* 2005). Likewise, the concentration levels of organic radicals of the specialty malts and the roasted barley (whole intact kernel and milling fraction measurement) were determined by electromagnetic spin resonance (ESR) spectroscopy. Based on the patented method by Kaneda, an optimised version for solids measurement by using a novel internal standard (^{52}Cr:MgO) was used (Kaneda, 2005; Maier *et al.*, 2002). This optimised method considerably reduces the dispersion and improve considerably the quantification of the organic radicals in the whole kernels and their respective milling fractions (Methner *et al*. 2007; Methner *et al.*, 2008; Takoi *et al.*, 2003). Figures 3.2.2 show the electron spin resonance (ESR) spectroscopy unit used for this investigation. The results were correlated with the total colour appearance results of the locally-brewed beers as well as with the concentrations of the beer ageing compounds obtained by GC-MS and the sensory assessments provided by the I.C.B.D. tasting panel.

Figure 3.2.1 Electron spin resonance (ESR) spectroscopy (Methner, 2006)

3.2.2.3 Colour appearance determination of locally-brewed beers

The colour appearance analysis was carried out in collaboration of The Colour Imaging Group at the Department of Colour Science at the University of Leeds, England.

The colour appearance predictors of the locally-brewed beers were psychophysical, evaluated by the expert observer panel from the University of Leeds. Likewise, the beer samples were physically measured by using the DigiEye System-VeriVide® (Digital Camera) and a tele-spectroradiometer at two different environments following the same protocol established in the previous investigation of total colour appearance by Gonzalez-Miret *et al.* (2007) but adapted on the locally-brewed beer samples analysed. Therefore, it was necessary to introduce some modifications for the suitable performance of the complete analysis.

3.2.2.3.1 Psychophysical evaluation (sensory viewing) for total colour appearance on locally-brewed beers

The trained panel was comprised of nine expert panel observers from the department of Colour Science at University of Leeds. The observers were 6 male and 3 female aged between 21 and 40. The normal colour vision of the observers was previously screened using the Ishihara Colour Vision Test (Gonzalez-Miret *et al.*, 2007; Ishihara Colour Vision Test, 2004) in order to confirm that any of the observers might not have some colour vision deficiencies or colour blindness.

The colour appearance of the beer samples was analysed by means of a set of psychophysical evaluations using the scaling technique of magnitude estimation and categorical judgement method, respectively (Gonzalez-Miret *et al.*, 2007; Luo *et al.*, 1991a). The evaluations were carried out twice for each observer of the trained panel to obtain the optimal observer accuracy in the experiment.

The psychophysical experiment consists of evaluating the total colour appearance of the samples placing 200 mL of beer poured into a standard highball glass (240 mL capacity) exactly 1m away from the eyes of the observer into a dark room. The sample was fixed in an angle position of 90° at the Ve riVide® viewing cabinet with a diffuse D65 illumination simulator (Gonzalez-Miret *et al.*, 2007; Luo *et al.*, 2003).

The beer samples from each colour-adjusted beer were compared, based on their static visual colour intensity and their visual colour appearance properties; visual lightness (Lv), visual colourfulness (Cv), visual hue (hv), visual opacity (Opv) and clarity (Clv) (Gonzalez-Miret *et al.*, 2007, Luo *et al.*, 1991a; Luo *et al.*, 1991b). All samples were randomly ordered and presented to the observers concurrently. In tables A.4.1 and A.4.2 of Appendix A are presented the random selection of the fresh, forced and aged locally-brewed beer samples for psychophysical assessments, respectively.

For the estimation of visual lightness (Lv) the panellist observed a white background card as a reference of lightness which represents the lightness value of 100, while the blackest colour that each member of the panel could imagine represented the lightness value of zero. Finally, the lightness was measured by the panel determining the lightness as the amount of light reflected from the test samples against the reference of lightness (white background) (*ibid.*).

The assessment of visual colourfulness (Cv) was carried out using a reference of colourfulness in the viewing field which was presented to the panel. The reference of colourfulness consists in a standard reference greenish-yellow card with a NCS value of S 1060-G90Y (NCS Digital Atlas 1950, 2007) which corresponds to CIE values of L*:90, a*: -2, b*:13; these values represent the grand mean of CIE L*a*b* values obtained from the commercial pale lager beers, being considered as the standard reference of colourfulness in this investigation.

The colourfulness of the card was established with a value of 40 for the panel. Taking the greenish-yellow card as a reference the members of the panel assigned the corresponding colourfulness value of the samples. Using this method of evaluation, the members of the panel can assign the colourfulness of the values as multiples or divisors of 40. *i.e.* samples with half the colourfulness than the reference were assigned a value of 20, while samples with double colourfulness were assigned a value of 80. The colourfulness value of zero was defined as the total neutral colours, and there were no upper limit values (*ibid.*).

The evaluation of visual hue (hv) in the beer samples were carried out using four standard reference hues of red, yellow, green and blue. Samples with pure standard reference hues were established as 100%. The colours produced by the mixture of the standard reference hues, for instance orange and brown colours were reported as percentage composition of red/yellow and green/blue, respectively. The observers scored the samples against the white background only. The following equations were used to calculate the corresponding visual redness-greenness hue component (av), yellowness-blueness hue component (bv) and visual hue angle (hv) of the samples:

$$av = Mv\cos(hv)$$
$$bv = Mv\sin(hv)$$
$$hv = 0.9 * Hv$$

Two colour appearance phenomena of semi-transparent liquids were assessed on this investigation; opacity and clarity of the beer samples. Opacity is the ability of a specimen to prevent the transmission of light. The evaluation of opacity was carried out by comparing the beer sample with a highball glass containing clear liquid (distilled water) as the reference for opacity zero and another highball glass containing a black card was used as the reference for opacity 10. Therefore, the opacity of the beer was determined through a scale of 0 to 10. Clarity is the clearness of a liquid as measured by a variety of methods. The clarity of the locally-brewed beer samples was estimated using a clarity scale that was set from 10 to 0. Inverse to the opacity, a glass containing clear distilled water was set with the maximum clarity value of 10, due to it being considered as the liquid with the highest clarity, while the highball glass which contained a black card was set as the minimum clarity value of 0. Figure 3.2.3 presents the format of the experimental instructions given to the observer's panel for the psychophysical assessment of total colour appearance of the beer samples.

Figure 3.2.2 Format of the experimental instructions for the psychophysical assessment of total colour appearance

Experimental Instructions

Thank you for taking part in this visual assessment.

The aim of this session is to investigate the colour appearance of semi-transparent liquid. **Magnitude estimation method** and **categorical judgement method** will be used in this psychophysical experiment.

You will see different glasses containing coloured liquid individually in the viewing cabinet. These samples are put in the viewing cabinet of dark surround. A White/Black card is placed behind the glass. All the samples will be scaled based on the overall appearance of the glass with the liquid inside.

TWO reference samples will be shown in the viewing cabinet before and throughout the experiment.

Please note:

One glass containing clear liquid is used as the reference for **Opacity 0**. Another glass containing a black card is used as the reference for **Opacity 10**.

1. Opacity

Scale	10	9	8	7	6	5	4	3	2	1	0

2. Clarity

Scale	10	9	8	7	6	5	4	3	2	1	0

3.2.2.3.2 Physical measurements for total colour appearance on locally-brewed beers: Tele-spectroradiometry & Digital imaging method

3.2.2.3.2.1 Tele-spectroradiometry

The tele-spectroradiometric measurements of the locally-brewed beers were carried out in two different sets using a Minolta CS-1000 tele-spectroradiometer (Minolta CS-1000 Tele-spectroradiometer, 2003). Figures 3.2.4 show the apparatus specifications. The readings obtained by the tele-spectroradiometer are displayed in single wavelengths of the visible spectrum (380-780 nm) with a spectral bandwidth of 5 nm. These values were converted into tristimulus values (X,Y,Z) and subsequently into CIECAM02 colour appearance components; lightness (J), colourfulness (M), hue angle (h), hue redness-greenness component (a) and hue yellowness-blueness hue component (b) applying the CIECAM02 formulae (CIE, 2004). It is important to mention that all CIECAM02 colour appearance components are based upon the visual attributes scaled by psychophysical research (see CIE, 2004; Luo *et al.*, 1991a; Luo *et al*., 1991b; Luo *et al.*, 2002; Luo *et al.*, 2003). Therefore, they can be compared perfectly with the results of psychophysical experimentation explained above.

The first set used for the tele-spectroradiometric measurements was conducted in the same conditions as those applied during the psychophysical evaluations. Figure 3.2.5 shows a demonstration of the set for the tele-spectroradiometric determinations.

The influence of the depth on the beer colour appearance was analysed in the second set by measuring the poured beer sample into a calibrated stainless-steel cell with a symmetric white/black background and three different depths *i.e.* 30.0, 40.0 and 50.0 mm, respectively. Figure 3.2.6 shows a picture of the calibrated stainless-steel cell. Once the cell contains the beer sample, it was placed into the illumination box of the DigiEye System-VeriVide® and concurrently the colour appearance of the samples was measured. Figure 3.2.7 presents a demonstration of the second set at the illumination box of the DigiEye System-VeriVide®.

Specifications

Model	CS-1000A	CS-1000S	CS-1000T
Wavelength range	380 to 780nm		
Spectral bandwidth	5nm		
Wavelength resolution	0.9nm/pixel		
Display wavelength bandwidth	1nm		
Spectral accuracy	±0.3nm(mean wavelength:546.1nm Hg lamp)		
Acceptance angle	1° (standard and macro lens)	– – – (standard lens : 1°)	0.14° *1 (standard lens : 1°)
Display	Lvxy, Lvxy, Lvu'v', Lvu'v', LvT uv, Le (Observer can be switched between 2° and 10°)		
Data memory	Measurement data : 30 sets, Target data : 20 sets		
Minimum measuring distance *2	362mm (standard lens) 94mm (macro lens)	25mm (standard lens : 362mm)	254mm (standard lens : 362mm)
Minimum measuring area	7.9mm (standard lens) 1.15mm (macro lens)	0.45mm (standard lens : 7.9mm)	1.2mm (standard lens : 7.9mm)
Luminance display range	0.01 to 80000cd/m² (for Illuminant A)		
Accuracy (for Illuminant A, Normal Mode)	±2%±1digit x : ±0.0015 y : ±0.001 (standard and macro lens)	±2.5%±1digit x : ±0.002 y : ±0.0015 (small measuring area lens)	±2.5%±1digit x : ±0.002 y : ±0.0015 (small measuring angle lens)
	(Luminance range Standard lens : 1 to 8000cd/m² Other lens : 10 to 80000cd/m²)		
Repeatability (σ) (for Illuminant A)	Normal Mode: 0.1%+1digit, xy : 0.0002 Fast Mode: 0.1%+1digit, xy : 0.0004	(Luminance range Standard lens : 1 to 8000cd/m² Other lens : 10 to 80000cd/m²)	
	Normal Mode: 0.1%+1digit, xy : 0.0003 Fast Mode: 0.1%+1digit, xy : 0.0006	(Luminance range Standard lens : 0.5 to 1cd/m² Other lens : 5 to 10 cd/m²)	
Polarisation error	Less than 5% (400nm to 780nm)		
Integration time *3	Fast : 40msec to 15sec, Normal : 40msec to 60sec		
Power	120V~ 50Hz Type or 230V~ 60Hz Type (using AC adapter AC-A12)		
Operating temperature /humidity range	5 to 35°C relative humidity 80% or less (at 35°C) with no condensation		
Storage temperature /humidity range	0 to 45°C relative humidity 80% or less (at 35°C) with no condensation		
Interface	RS-232C		
Size (body)	146 × 148 × 256mm (5-3/4 × 5-13/16 × 10-1/16 in.)		
Weight	4.9kg (10.38 lb.) (with standard lens)	5.8kg (12.79 lb.) (with small measuring area lens)	5.9kg (13.01 IB.) (with small measuring angle lens)
Standard accessories	Standard Lens Macro Lens	Standard Lens Small Measuring Area Lens	Standard Lens Small Measuring Angle Lens
	Data Processing Software CS-S1w, ND Eyepiece Filter (for finder) CS-A1, AC Adapter AC-A12, RS-232C Cable (for IBM PC/AT 2m, 9-pin) IF-A12		
Optional accessories	Tripod CS-A3, Panhead CS-A4, White Calibration Plate CS-A5, ND Filter CS-A6 (10% / for macro lens), ND Filter CS-A7 (1% / for macro lens), RS-232C Cable (for IBM PC/AT 5m pin, for IBM PS/2 2m/5m) IF-A13 to IF-A15, Hard Case CS-A2 (Not for small measuring area lens and small measuring angle lens)		

*1 Minimum measuring distance.
*2 Distance from front end of the lens.
*3 Measurement time is twice integral time plus approx 3 seconds.

- Specifications subject to change without notice.
- Windows® is a trademark of Microsoft Corporation in the USA and other countries.
- Trademarks referred to are the property of their respective owners.

Figure 3.2.3 Specifications of Minolta CS-1000 Tele-spectroradiometer (Minolta CS-1000 Tele-spectroradiometer, 2003)

Figure 3.2.4 First set for the tele-spectroradiometric measurements (sensory viewing simulation)

Figure 3.2.5 Calibrated stainless-steel cell for measuring the influence of the depth on beer colour appearance

Figure 3.2.6 Second set for the tele-spectroradiometric measurements (influence of the depth on beer colour appearance)

3.2.2.3.2.2 Digital imaging method (DigiEye System-VeriVide®)

The total colour appearance of the locally-brewed beers was measured applying the digital imaging method by means of the DigiEye System-VeriVide®. A camera characterisation was done using TagMacbeth ColorChecker® DC (TagMacbeth ColorChecker® DC, 2000) before the digital imaging measurements. Figure 3.2.8 depicts the physical representation of the camera characterisation for the DigiEye System-VeriVide®.

The beer samples were poured into the calibrated stainless-steel cell as for the tele-spectroradiometric measurements. The digital imaging measurements were carried out five times, therefore five shoots were taken for each sample. The appropriate software for the DigiEye System-VeriVide® displayed the corresponding colour appearance predictors of the samples analysed. Figures 3.2.9 and 3.2.10 show the set for measuring the beer sample using the DigiEye System-VeriVide®.

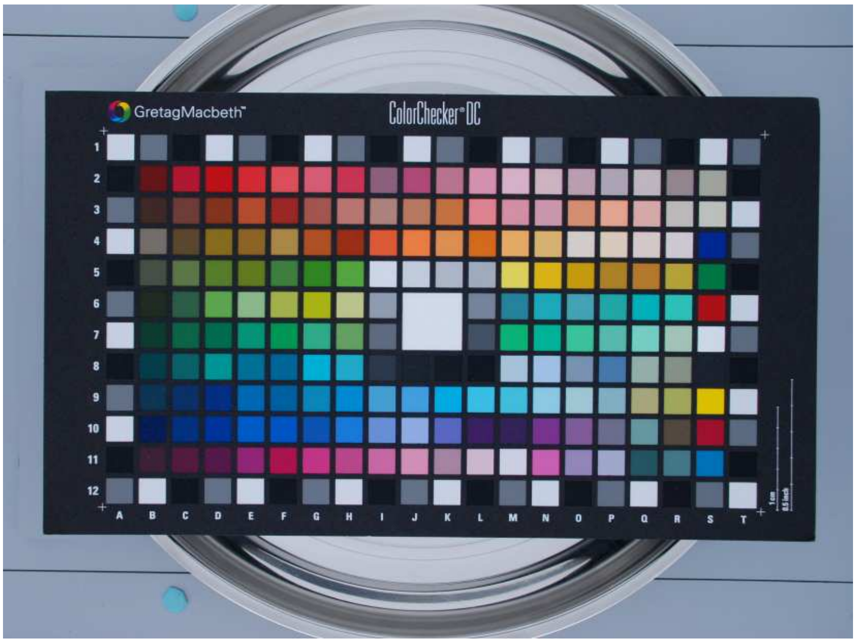

Figure 3.2.7 Camera characterisation for the DigiEye System-VeriVide® by means of TagMacbeth ColorChecker® DC chart

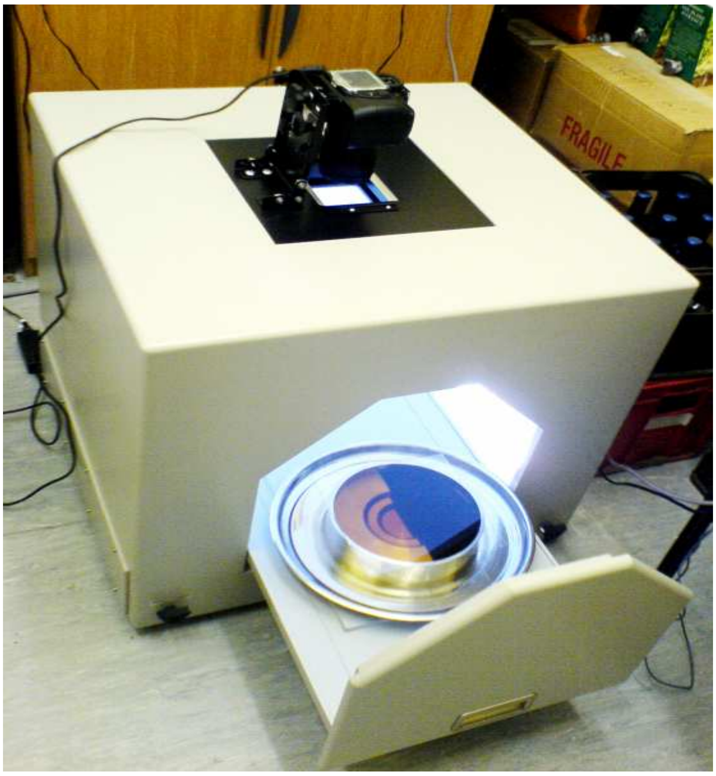

Figure 3.2.8 Set for the colour appearance measurements using DigiEye System-VeriVide® (digital imaging method) –introduction of the sample-

Figure 3.2.9 Set for the colour appearance measurements using DigiEye System-VeriVide® (digital imaging method)

3.2.2.4 Sensory evaluations of beer flavour stability

At the final stage of this investigation a series of sensory evaluations was carried out in order to link them with the analytical results previously obtained. The sensory assessment of the locally-brewed beers is of great importance. This holistic investigation focused on beer flavour stability and mimicked the realistic conditions in which all beer consumers judge the quality of the beer products. The sensory evaluation schemes were based on the official method of analysis as stated by the European Brewing Convention (E.B.C.) (Analytica-EBC. European Brewing Convention, 1997) and the Mitteleuropäische Brautechnische Analysenkommission (M.E.B.A.K.) (Brautechnische Analysenmethoden. Band II. Mitteleuropäische Brautechnische Analysenkommission, 2002a).

3.2.2.4.1 Selection of taste panel

A tasting panel of eleven members at I.C.B.D. sensory suite were trained by means of a fourteen hour-training programme based on the Institute of Brewing (I.o.B.) sensory analysis procedures as well as on those recently established by the I.C.B.D research team (Novotná, 2007).

The tasting panel comprised of five female and six male sensory assessors with an age range between 25 to 60 years old from five different nationalities and who consume beer on a regular basis (once or twice per week), respectively. This is important because flavour perception is strongly influenced by a multifaceted combination of sensations and cultural environments and the individual daily experience. Therefore, the perception response of certain chemosensory compounds by the tasters can be different from one to another (André, 2007; Delwiche, 2000). The sensory training programme is presented in Table 3.2.11.

Table 3.2.11 Training and sensory evaluation programme

Activity	Date	Duration
Introduction of beer styles I: **Ales:** Kölsch, Indian pale ale (I.P.A.), Bitter ale, Barley wine, Scotch ale, Brown ale, Irish stout and Hefeweizen (Wheat beer)	Thursday June 5th, 2008 2:30 pm	**2 hour**
Introduction of beer styles II: **Belgian beers:** Trappist (Abbey), Lambic, Witbier (Wheat beer) and Flemish red ale **Lagers:** Pilsner, Märzen, Oktoberfest, Dunkles Bier, Doppelbock	Friday June 6th, 2008 2:30 pm	**2 hour**
Training session I: Introduction of beer flavour terminology Development of sensory descriptors by tasting panel. (Use of a range of brewing raw materials, yeast strains, fresh and spontaneously aged ale and lager beers instead of chemical aids)	Monday June 16th, 2008 2:30 pm	**2 hour**
Training session II: Training with fresh commercial ale and lager beers	Tuesday June 17th, 2008 2:30 pm	**2 hour**
Training session III: Detection of beer off-flavours Training with forced aged (7 days at 60℃) and spontaneously aged (12 months at 4℃) locally-brewed pale lager beers	Wednesday June18th, 2008 2:30 pm	**2 hour**
Training session IV: Training with forced aged (7 days at 60℃) and spontaneously aged (12 months at 4℃) locally-brewed pale lager beers	Thursday June 19th and Friday June 20th, 2008 2:30 pm	**4 hour**
Total duration	N/A	**14 hours**

3.2.2.4.2 Detection and intensity of beer ageing flavour in beer colour-adjusted by the distinct colouring agents

Descriptive sensory analysis (Analytica-EBC. European Brewing Convention, 1998p; Brautechnische Analysenmethoden. Band II. Mitteleuropäische Brautechnische Analysenkommission, 2002q-r) was carried out to correlate the results obtained from the ageing compounds of the five locally-brewed beers from the second round, *i.e*. quantification of total flavour-active ageing compounds, forcing index and ageing index, as well as the endogenous anti-oxidative potential (EAP) of the beers and the –OH active radicals of the colouring agents. The main aim of this analysis was based on the agreement of the tasters to define a scale of certain attributes from the beer analysed, which define a standard beer ageing flavour. The flavour attributes for the sensory assessments of beer aroma and taste were selected according to previous studies from the I.C.B.D. research team, in which the sensory panellists identified the most relevant aroma and taste attributes that reflect the true beer flavour and its overall quality (Novotná, 2007). Non-chemical descriptors were used for the definition of ageing flavour attributes, *e.g.* "sherry" or "madeira" flavour for describing "oxidised" flavour. This method of describing the beer ageing flavour is based on the fact that the chemical names defined by the terminology of E.B.C. flavour wheel (*ibid.*) have negative connotations of chemicals e.g. solvent-like, metallic, alkaline, etc (Meilgaard, 1975; Meilgaard, 1991; Meilgaard *et al.*, 2001). Once a scale of beer ageing flavour was defined, the tasters had to estimate an intensity score for defined attribute. Because several samples were involved in the experiment and so the perception of the tasters can be altered, a modified Kelly's repertory Grid was applied (*ibid.*). This consists in presenting the beers samples in tetrads throughout the sessions. The procedure selects the first tetrad with four beers at random. A second tetrad, one beer from the first tetrad and three new ones, will then be selected at random and this is followed by the random selection of the third tetrad; one of the three new beers from tetrad two and three untested beers will be chosen. The procedure is carried out successively until all the beers have been tested but not repeated. Therefore, 5 tetrads were required to test all the locally-brewed beers of the second round.

In order to avoid any influence by dynamic visual appeal, *i.e.* the graphic description of the beer being poured into a glass, the samples were served at the same temperature and CO_2 content and poured with the same pouring technique. They were also coded with three-digit numbers chosen at random throughout the test. A numerical intensity scale from 0 to 5 was used on the assessment forms. The mean of the obtained values were calculated and plotted on spider charts. Likewise, the aforementioned values were tested by the non-parametric statistical method Friedman's Rank Sum Test (Nave, 1999). Figures 3.2.11 and 3.2.12 depict the standard forms used by the I.C.B.D. trained tasting panel for the descriptive sensory analysis of beer aroma and beer taste, respectively.

Figure 3.2.10 Standard form for the sensory assessment of beer aroma

Name: Time:
Date: Beer temperature (℃):
Sample no.:

Please evaluate the aroma attributes from the list below for each beer sample. Circle the number that reflects the most your judgement.

Beer aroma

Attribute	Scale score	Description	Observations:
Fruity	5	Extreme	
	4	Strong	
(*e.g.* citrus, apple,	3	Marked	
banana, melon, pear &	2	Noticeable	
black currant)	1	Slight	
	0	Absent	
Floral	5	Extreme	
	4	Strong	
(*e.g.* roses, perfume)	3	Marked	
	2	Noticeable	
	1	Slight	
	0	Absent	
Hoppy	5	Extreme	
	4	Strong	
(*e.g.* hops)	3	Marked	
	2	Noticeable	
	1	Slight	
	0	Absent	
Grainy	5	Extreme	
	4	Strong	
(*e.g.* wheat flour, corn	3	Marked	
grits & husky)	2	Noticeable	
	1	Slight	
	0	Absent	

Malty (*e.g.* malt, wort & bread)	5 4 3 2 1 0	Extreme Strong Marked Noticeable Slight Absent	
Sweet (*e.g.* honey, candy, jam-like, vanilla)	5 4 3 2 1 0	Extreme Strong Marked Noticeable Slight Absent	
Acetaldehyde (*e.g.* green apple & raw apple skin)	5 4 3 2 1 0	Extreme Strong Marked Noticeable Slight Absent	
Oxidised (*e.g.* papery, leathery, mouldy & catty)	5 4 3 2 1 0	Extreme Strong Marked Noticeable Slight Absent	
Acidic (*e.g.* vinegar & sour milk)	5 4 3 2 1 0	Extreme Strong Marked Noticeable Slight Absent	
Overall quality of beer aroma	5 4 3 2 1 0	Excellent Very good Good Satisfactory Poor Bad	

Figure 3.2.11 Standard form for the sensory assessment of beer taste

Name: Time:
Date: Beer temperature (℃):
Sample no.:

Please evaluate the taste attributes from the list below for each beer sample. Circle the number that reflects the most your judgement. Rinse your mouth and clean your palate by eating plain bread after each sample evaluation.

Beer taste

Attribute	Range score	Description	Observations:
Fruity	5	Extreme	
	4	Strong	
(*e.g.* citrus, apple,	3	Marked	
banana, melon, pear	2	Noticeable	
& black currant)	1	Slight	
	0	Absent	
Spicy	5	Extreme	
	4	Strong	
(*e.g.* clove, pepper &	3	Marked	
nutmeg)	2	Noticeable	
	1	Slight	
	0	Absent	
Grainy	5	Extreme	
	4	Strong	
(*e.g.* wheat flour,	3	Marked	
corn grits & husky)	2	Noticeable	
	1	Slight	
	0	Absent	
Malty	5	Extreme	
	4	Strong	
(*e.g.* malt, wort &	3	Marked	
bread)	2	Noticeable	
	1	Slight	
	0	Absent	
Sulphury	5	Extreme	
	4	Strong	
(*e.g.* rotten egg,	3	Marked	
cooked vegetable &	2	Noticeable	
drainage)	1	Slight	
	0	Absent	

Acetaldehyde (*e.g.* green apple & raw apple skin)	5 4 3 2 1 0	Extreme Strong Marked Noticeable Slight Absent	
Phenolic (*e.g.* pharmacy & hospital aroma-like)	5 4 3 2 1 0	Extreme Strong Marked Noticeable Slight Absent	
Oxidised (*e.g.* papery, leathery, mouldy & catty)	5 4 3 2 1 0	Extreme Strong Marked Noticeable Slight Absent	
Acidic (*e.g.* vinegar & sour milk)	5 4 3 2 1 0	Extreme Strong Marked Noticeable Slight Absent	
Astringent (*e.g.* harsh, tart & drying)	5 4 3 2 1 0	Extreme Strong Marked Noticeable Slight Absent	
Overall quality of beer taste	5 4 3 2 1 0	Excellent Very good Good Satisfactory Poor Bad	

3.2.2.4.3 Statistical treatment for the results of the sensory analysis

Statistical analysis of rankings was carried out using the Friedman's test method to analyse the sensory analysis data obtained and conclude whether any apparent difference exists or not between the locally-brewed beers colour-adjusted in terms of flavour stability.

The selection of this non parametric test is based on its power for the distribution-free two ways "analysis of variance" situation for data importantly non-normally distributed such as the flavour perception evaluated by the sensory panellists (see Neave, 1990). The test consists of a block experiment with each treatment appearing once in each block. The analyses are blocks; the beers are treatments. In Friedman's test, the beers are ranked from 1 to 10 within each block; afterwards the ranks for each beer are added in order to get rank-sums X_1, X_2, $X_3 \ldots X_n$. The Friedman test statistic M is defined as (*ibid.*):

$$M = \frac{12}{am(m+1)} \sum_{k=1}^{m} R_k^2 - 3a(m+1)$$

Where m: Number of treatments

a: Number of blocks

R_k: Rank sum

The research hypothesis that will be tested is whether the colouring agents for the beer colour adjustment can influence the ageing of the beer, and so in turn its flavour stability. For example, it is believed that beer produced with dark crystal malt ages quicker than beer produced with light crystal malt and that beer produced with roasted malt is quicker still. To test this research hypothesis several groups of beer samples are collected. The scores are rank ordered with superscripts, if there are ties each receives the average rank they would have received. Table 3.2.12 depicts a Friedman's test for hypothetical results.

Table 3.2.12 Friedman's test for analysis results (Example)

Ageing compound	Beer *CARAHELL®*	Beer *CARAAROMA®*	Beer *CARAFA® III*	Beer *CARAMUNICH® III*
1	4^{1}	8^{3}	12^{4}	4.25^{2}
2	4^{1}	8^{3}	16^{4}	4.75^{2}
3	$0^{11/2}$	8^{4}	4^{3}	$0^{11/2}$
4	8^{1}	16.25^{4}	16^{3}	12.75^{2}
5	8^{1}	$16^{21/2}$	32.50^{4}	$16^{21/2}$

In particular, small values are more likely under the null hypothesis, so the larger the value of *M*, the smaller the probability will be. Using mean ranks, the block-by-block rankings of the four beers (treatments) are as in the following Table 3.2.13.

Table 3.2.13 Ranking of values (Friedman's test)

Ageing compound	Beer *CARAHELL®*	Beer *CARAAROMA®*	Beer *CARAFA® III*	Beer *CARAMUNICH® III*
1	1	3	4	2
2	1	3	4	2
3	1 ½	4	3	1 ½
4	1	4	3	2
5	1	2 ½	4	2 ½
Rank sum	5 ½	16 ½	18	10

The rank-sums are later substituted by the *M* formula:

$$M = \frac{12}{5\times 4\times (4+1)}\left[\left(5\tfrac{1}{2}\right)^2 + \left(16\tfrac{1}{2}\right)^2 + 18^2 + 10^2\right] - 3\times 5\times (4+1) = 12.18$$

***M* = 12.18**

The next step is to determine the critical F value for *m*= 4 and *a*= 5 with a significance level (α) of 1% (less than one in a hundred of being wrong) for this example by looking at the table of critical values for Friedman's test, which is 9.960 in this particular case. Compare the obtained M value and the critical F value to determine whether to retain or reject the null hypothesis. If the obtained M value is larger than the critical F value, then the null hypothesis is retained. In contrast, if the obtained M value is less than or equal to the critical F value, then the null hypothesis is rejected. In conclusion of this case, the null hypothesis is rejected indicating that beer *CARAHELL®* has a better flavour stability, while beer *CARAAROMA®* and beer *CARAFA® III* are not as good.

4. RESULTS AND DISCUSSION

4.1 Analysis of commercial beers

4.1.1 Additional beer analyses

Tables A.1.1 to A.1.10 of appendix A summarise the analysis of the ten commercial beers previously selected for this investigation. The means (M) and standard deviations (Sx) of each analysis for each beer were calculated using the results. The grand means (GM) and their corresponding standard deviations (Sx) were also calculated to obtain single values which could be compared with the range of normal values reported by M.E.B.A.K (Brautechnische Analysenmethoden. Band II. Mitteleuropäische Brautechnische Analysenkommission, 2002a; Titze *et al*., 2007). The grand means (GM) and standard deviations (Sx) as well as the normal values reported by M.E.B.A.K. are summarised in Table A.1.11 of appendix A. The fundamental reason for this comparison is to confirm that the terms determined by the analyst were accurate and confirmed the established specifications for I.C.B.D. standard all-malt pale lager beer showed in Table 3.1.1. On the basis of the results of commercial beers, most of the values of each parameter determined are of normal range in accordance with M.E.B.A.K. and Titze *et al.* (*ibid.*). Furthermore, it was confirmed that the values established in Table 3.1.1 represent real standard values for pale lager beers. Some differences were found in the determinations of original gravity and pH. The grand mean values of these parameters in commercial beers were slightly lower in comparison to values reported by M.E.B.A.K. (Brautechnische Analysenmethoden. Band II. Mitteleuropäische Brautechnische Analysenkommission, 2002a) and Table 3.1.1. Nevertheless, it was not considered as a factor which can strongly influence the main experiments due to the difference between obtained and reported values being very small.

4.2 Brew Liquor Analysis

A routine water analysis was carried out in triplicate to confirm the suitable composition of brew liquor for the beer to be brewed for the investigation. The total water hardness, carbonate hardness, calcium- magnesium- hardness and residual alkalinity were also determined. These quality parameters show the main water composition required for an optimal production of pale lager beers. If the residual alkalinity is higher than 5°dH (German Hardness) (Brautechnische Analysenmetho den. Wasser: Trinkwasser und Mineralwasser, Brauwasser, Kessel(speise)wasser, Abwasser. Mitteleuropäische Brautechnische Analysenkommission, 2002b), the brew liquor will need to be decarbonised in order to get an optimal brewhouse yield (Narziß, 1995).

The results of the trials of the locally-brewed beers are reported in Table 4.2.1. The values obtained in this analysis showed that the total hardness of brew liquor is considered as water medium hard to hard according to M.E.B.A.K. (Brautechnische Analysenmethoden. Wasser: Trinkwasser und Mineralwasser, Brauwasser, Kessel(speise)wasser, Abwasser. Mitteleuropäische Brautechnische Analysenkommission, 2002a) of the pilot-brewery at I.C.B.D. Nonetheless, the residual alkalinity is lower than 5°dH, therefore is not necessary for it to be decarbonised. In spite of this result, the water analysis was determined periodically throughout the brewing of all the locally-brewed beers for this investigation in order to control the hardness and alkalinity of the brew liquor to be used.

Table 4.2.1 Brew liquor analysis of I.C.B.D. pilot brewery

Determination of total hardness

Sample No.	1	2	3
Consumption of Titriplex (mL)	2.6	2.5	2.7
Total hardness (°dH) (EDTA 0.1 M * 5.6)	14.6	14.0	15 .1
Mean (Standard Deviation)	14.6 (0.56)		
Evaluation (M.E.B.A.K.) °dH (Brautechnische Analysenmethoden. Band II. Mitteleuropäische Brautechnische Analysenkommission, 2002a)	< 7 soft 7-14 medium hard 14-21 hard > 21 very hard		

Determination of Ca^{2+} and Mg^{2+}

	Ca^{2+}			Mg^{2+}		
Sample No.	1	2	3	1	2	3
Consumption of Titriplex III (mL):	1.5	1.8	1.5	0.8	0.9	1.1
Concentration of Ca/Mg in (mg/L) (mL*40.08 for Ca^{2+} and 24.31 for Mg^{2+})	60.1	72.1	60.1	19.4	21.9	26.7
Hardness (°dH) (Factor 0.14 resp. 0.231)	8.4	10.1	8.4	4.5	5.0	6.2
Mean (Standard Deviation)	9.0 (0.97)			5.2 (0.87)		

Determination of carbonate hardness

Sample No.	1	2	3
Consumption of HCl (mL):	3.0	2.9	2.7
Carbonate hardness in °dH (mL*2.8)	8.4	8.1	7.6
Mean (Standard Deviation)	8.0 (0.43)		
Residual alkalinity °dH	4.7		
Decarbonising of water	No required! 4.7 < 5.0°dH		

4.3 Preliminary colour adjustment trials

A series of trials of colour adjustment were carried out by means of beer produced on a small scale according to the previous section “preliminary colour adjustment trials”. The determinations of E.B.C. colour, tristimulus values, C.I.E. colour space (L*, a*, b*), yellowness index, iCAM predictors (J, M, h, C, G) and CIECAM02 predictors (J, M, h, a, b, C, Q, s) were carried out with use of a spectrophotometer (Genesys 20 Thermo.Thermo Spectronic. Thermo Electron Corporation USA). The technical specifications are outlined in Table 4.3.1 (Spectronic GENESYS 20. Spectrophotometer. Thermo Fisher Scientific Inc., 2007).

Table 4.3.1 Technical specification of visible spectrophotometer (*ibid.*)

Name	Spectronic GENESYS 20 Spectrophotometer
Spectral slitwidth	8 nm
Optical system	Single-beam
Optical system grating-based	1200 lines/mm
Wavelength	Range: 325 to 1100 nm Accuracy: ± 2.0 nm
Photometric range	0 to 125% Transmittance – 0.1 to 2.5 Absorbance 0 to 1999 Concentration ± 0.1 to ± 9990 Factor
Photometric accuracy	0.003 Abs. from 0.0 to 0.3 Abs. 1.0% from 0.301 to 2.5 Abs.
Photometric noise (at 500 nm)	≤ 0.001 Abs. at 0 Abs. ≤ 0.004 Abs. at 2 Abs.
Photometric drift	0.003 Abs./hour
Stray radiant energy	< 0.1%T at 340 nm and 400 nm
Lamp source	Tungsten lamp
Lamp source lifetime	Approx. 1,000 hours
Standard interfaces	RS-232C and Centronics ports
Power requirements	100/240 V ± 10, 50/60 Hz ± 10%
Dimensions	30 cm W x 33 cm D x 19 cm H (12" W x 13" D x 7" H)

The results of the first preliminary trials of colour adjustment are presented in Tables A.2.1 to A.2.3 of appendix A. The results showed a good repeatability ($r_{95}<0.3$) of EBC colour units in each established ratio of the grain bills. Nonetheless, very high EBC colour units of the second and third proposed ratios (see Tables A.2.2 and A.2.3 of Appendix A) were observed in comparison to the EBC colour pre-established for the locally-brewed pale lager beers at I.C.B.D. pilot brewery (see Table 3.1.1). However, similar values in the first proposed ratios (see Table A.2.1 of Appendix A) were obtained. In order to confirm the correct ratios of the grain bill for each colouring agent, a series of triplicate using the ratios established in Table A.2.1 of Appendix A was repeated. Table A.2.4 to A.2.6 of Appendix A show the corresponding results of the latter analysis, which also presented similar values to the EBC colour units pre-established for the all-malt pale lager beers to be analysed in this investigation. Table 4.3.2 presents the means (M) and standard deviations (Sx) of the second trials as well as Table 4.3.3 shows the correct and final ratios of grain bills to be used for the further up-scales brews at the I.C.B.D. pilot brewery, respectively.

Variations on the tristimulus values (X, Y, Z), the C.I.E. colour space values (L*, a*, b*, C*), the iCAM predictors [*i.e.* lightness (J) and brightness (G)] and the CIECAM02 predictors [*i.e*. lightness (J), hue angle (h), redness-greenness hue component (a), brightness (Q) and saturation (s)] of the beers colour-adjusted with the distinct colouring agents were detected. Nevertheless, all the samples presented very similar EBC colour units (7.5 ±0.5 EBC). Charts B.1.1 to B.1.27 of Appendix B depict the corresponding colour appearance parameters of the beers trials.

According to the results of the preliminary beer trials, a similar trend was noticed to results reported by previous studies (Coghe *et al*., 2003). Lower CIE lightness (L*) of the beers colour-adjusted with roasted malts (CARAFA® Type III and CARAFA® SPECIAL Type III) and roasted barley was observed. Furthermore, an increase on the Tristimulus values X (red) in the beers colour-adjusted with the light crystal malt (CARAHELL®), the dark crystal malts (CARAMUNICH® Type III and CARAROMA®) and the melanoidin malt was found. Regarding the CIE a*, b* (hue), the metric chroma (C*) and the yellowness index, no clear difference was found between the samples. Regarding iCAM predictors, very similar values were detected between the lightness (J), the chroma (C) and the hue angle (h) in comparison to the corresponding lightness (L*), the chroma (C*) and the hue components (a*, b*), respectively. Low iCAM brightness (G) in the beer samples colour-adjusted with the roasted malts (CARAFA® Type III and CARAFA® SPECIAL Type III) and the roasted barley as well as with the light crystal malts (CARAHELL® and CARAAMBER®) was found. Higher iCAM brightness (G) in the beers colour-adjusted with colouring beer (SINAMAR®) and artificial colorant

(CARAMEL #301) was also observed. Finally, no clear difference was noticed between the beer samples in terms of iCAM chroma (C) and iCAM colourfulness (M).

In the case of CIECAM02 predictors, a very similar trend of the CIECAM02 lightness (J) was found in comparison to the obtained results of CIE lightness (L*) and iCAM lightness (J). Lower lightness (J) in the beers colour-adjusted with the roasted malts (CARAFA® Type III and CARAFA® SPECIAL Type III) and the roasted barley was detected. In addition, relative lower lightness (J) in beer samples colour-adjusted with light crystal malts (CARAHELL® and CARAAMBER®) was also obtained in comparison to the other beer subjects. Similarly to the iCAM results, relative lower CIECAM02 brightness (Q) in the beers colour-adjusted with roasted malts (CARAFA® Type III and CARAFA® SPECIAL Type III), roasted barley and light crystal malts (CARAHELL® and CARAAMBER®) was detected. Moreover, higher CIECAM02 brightness (G) in the beers colour-adjusted with colouring beer (SINAMAR®) and artificial caramel colorant (CARAMEL #301) was noticed.

Higher redness hue component (a) in the beers colour-adjusted with roasted malts (CARAFA® Type III and CARAFA® SPECIAL Type III) and roasted barley was observed in comparison to the beer samples colour-adjusted with light crystal malts (CARAHELL® and CARAAMBER®). In contrast, the highest CIECAM02 yellowness hue component (b) in the latter beer samples was observed. Likewise, an outstanding CIECAM02 greenness hue component (b) in the beers colour-adjusted with melanoidin malt and dark crystal malt (CARAMUNICH® Type III) was found. However, it is important to remark that all these preliminary results of colour appearance were confirmed or rejected by comparing them with the further series of colour appearance analysis of the locally-brewed beers obtained from the I.C.B.D. pilot brewery.

Table 4.3.2 Beer colour adjustment [mean and (standard deviation)]

PARAMETER	CARAHELL®	CARAAMBER®	MELANOIDIN MALT	CARAMUNICH® TYPE III	CARAAROMA®	CARAFA® TYPE III	CARAFA® SPECIAL TYPE III	ROASTED BARLEY	SINAMAR®	CARAMEL #301	PILSNER MALT
Ratio (specialty malt/ base malt) %	**10/90**	**3.9/96.1**	**3.9/96.1**	**1.9/98.1**	**0.8/99.2**	**0.8/99.2**	**0.2/99.8**	**0.2/99.8**	**0.04/99.96**	**0.02/99.98**	**100**
Ratio (specialty malt/ base malt) g	**5.20/46.80**	**2.02/49.98**	**2.02/49.98**	**0.98/51.02**	**0.39/51.61**	**0.10/51.90**	**0.10/51.90**	**0.10/51.90**	**0.02 (0.017 mL)/ 51.98**	**0.01 / 51.99**	**52.00**
Colour EBC Abs. 430 nm	0.36 (0.001)	0.37(0.002)	0.36 (0.001)	0.35 (0.000)	0.35 (0.000)	0.34 (0.000)	0.34 (0.000)	0.34 (0.000)	0.328 (0.0005)	0.32 (0.001)	0.29 (0.001)
Colour EBC	**9.0 (0.03)**	**9.2 (0.07)**	**8.9 (0.03)**	**8.7 (0.00)**	**8.7 (0.02)**	**8.6 (0.00)**	**8.4 (0.00)**	**8.6 (0.00)**	**8.2 (0.02)**	**7.9 (0.15)**	**6.9 (0.02)**
Colour tristimulus %T 360 nm	01.50 (0.100)	1.23 (0.057)	1.60 (0.100)	1.55 (0.356)	1.93 (0.152)	2.30 (0.000)	2.56 (0.057)	2.36 (0.057)	2.73 (0.057)	2.00 (0.000)	3.30 (0.057)
Colour tristimulus %T 450 nm	48.30 (0.000)	48.13 (0.057)	52.80 (0.100)	53.76 (0.057)	53.40 (0.100)	53.36 (0.057)	58.83 (0.057)	53.16 (0.115)	58.96 (0.057)	55.80 (0.000)	55.36 (0.057)
Colour tristimulus %T 540 nm	76.40 (0.100)	79.16 (0.057)	81.56 (0.115)	82.10 (0.000)	81.03 (0.057)	79.40 (0.000)	79.83 (0.057)	79.10 (0.000)	81.30 (0.100)	82.00 (0.000)	77.60 (0.000)
Colour tristimulus %T 670 nn	89.90 (0.100)	94.40 (0.000)	95.00 (0.000)	95.23 (0.057)	94.36 (0.057)	93.50 (0.000)	93.83 (0.152)	93 .00 (0.000)	93.66 (0.057)	94.83 (0.057)	90.16 (0.115)
Colour tristimulus %T 760 nm	93.30 (0.057)	98.03 (0.057)	98.26 (0.057)	98.50 (0.000)	97.53 (0.0057)	97.43 (0.0057)	97.76 (0.0057)	96.70 (0.0000)	97.00 (0.0000)	98.20 (0.0000)	93.30 (0.000)
Colour tristimulus values X (Red)	71.25 (0.039)	73.93 (0.027)	75.93 (0.042)	76.41 (0.024)	75.58 (0.025)	74.56 (0.009)	74.94 (0.068)	74.23 (0.016)	76.33 (0.042)	76.55 (0.018)	72.98 (0.042)
Colour tristimulus values Y (Green)	76.21 (0.062)	79.02 (0.040)	81.29 (0.072)	81.81 (0.015)	80.85 (0.038)	79.53 (0.006)	79.95 (0.066)	79.21 (0.011)	81.47 (0.065)	81.87 (0.011)	77.81 (0.026)

PARAMETER	CARAHELL®	CARAAMBER®	MELANOIDIN MALT	CARAMUNICH® TYPE III	CARAAROMA®	CARAFA® TYPE III	CARAFA® SPECIAL TYPE III	ROASTED BARLEY	SINAMAR®	CARAMEL #301	PILSNER MALT
Colour tristimulus values Z (Blue)	52.037 (0.012)	52.24 (0.014)	56.60 (0.061)	57.53 (0.044)	57.06 (0.106)	56.84 (0.049)	57.32 (0.047)	56.63 (0.092)	61.89 (0.033)	59.24 (0.000)	58.38 (0.052)
Colour CIELAB L*	**87.60 (0.020)**	**88.88 (0.011)**	**89.82 (0.020)**	**90.04 (0.015)**	**89.66 (0.010)**	**89.18 (0.00)**	**89.36 (0.032)**	**89.02 (0.115)**	**90.0 (0.02)**	**90.10 (0.005)**	**88.43 (0.020)**
Colour CIELAB a*	**-3.33 (0.032)**	**-3.32 (0.011)**	**-3.32 (0.011)**	**-3.48 (0.011)**	**-3.40 (0.011)**	**-3.19 (0.000)**	**-3.20 (0.005)**	**-3.21 (0.005)**	**-3.24 (0.020)**	**-3.40 (0.005)**	**-3.13 (0.017)**
Colour CIELAB b*	**14.15 (0.017)**	**15.08 (0.005)**	**15.08 (0.005)**	**13.77 (0.011)**	**13.63 (0.035)**	**13.26 (0.017)**	**13.20 (0.04)**	**13.22 (0.040)**	**11.84 (0.032)**	**13.07 (0.005)**	**12.0 (0.02)**
Colour CIELAB C* (Metric Chroma)	**14.54 (0.049)**	**15.45 (0.011)**	**15.45 (0.115)**	**14.21 (0.017)**	**14.05 (0.025)**	**13.63 (0.023)**	**13.58 (0.035)**	**13.61 (0.034)**	**12.28 (0.041)**	**13.51 (0.005)**	**12.38 (0.015)**
Yellowness Index	**47.28 (0.046)**	**48.68 (0.000)**	**45.75 (0.100)**	**45 (0.036)**	**44.84 (0.120)**	**44.24 (0.051)**	**43.97 (0.120)**	**44.17 (0.103)**	**39.38 (0.075)**	**42.97 (0.023)**	**40.52 (0.060)**
iCAM lightness J	**6.22 (0.002)**	**6.30 (0.001)**	**6.4 (0.002)**	**6.42 (0.001)**	**6.39 (0.001)**	**6.35 (0.000)**	**6.37 (0.001)**	**6.34 (0.001)**	**6.45 (0.002)**	**6.44 (0.000)**	**6.31 (0.001)**
iCAM choma C	**1.41 (0.002)**	**1.52 (0.001)**	**1.39 (0.005)**	**1.37 (0.001)**	**1.35 (0.004)**	**1.31 (0.002)**	**1.30 (0.005)**	**1.30 (0.004)**	**1.14 (0.003)**	**1.28 (0.000)**	**1.16 (0.002)**
iCAM hue angle h	**1.02 (0.002)**	**0.11 (0.001)**	**0.10 (0.002)**	**0.02 (0.000)**	**0.01 (0.001)**	**0.12 (0.000)**	**0.12 (0.000)**	**0.12 (0.000)**	**0.11 (0.002)**	**0.10 (0.000)**	**0.12 (0.002)**
iCAM brightness Q	**12.56(0.004)**	**12.73 (0.002)**	**12.93 (0.003)**	**12.98 (0.002)**	**12.91 (0.004)**	**12.83 (0.001)**	**12.87 (0.004)**	**12.81 (0.002)**	**13.03 (0.003)**	**13.01 (0.000)**	**12.76 (0.002)**
iCAM colourfulness M	**2.84 (0.004)**	**3.07 (0.002)**	**2.81 (0.011)**	**2.76 (0.003)**	**2.73 (0.008)**	**2.64 (0.004)**	**2.63 (0.009)**	**2.64 (0.010)**	**2.31 (0.007)**	**2.60 (0.002)**	**2.34 (0.004)**
CIECAM02 lightness **J**	**86.70 (0.037)**	**88.45 (0.023)**	**89.75 (0.040)**	**90.06 (0.011)**	**89.49 (0.020)**	**88.71 (0.000)**	**88.96 (0.043)**	**88.51 (0.011)**	**89.81 (0.040)**	**90.07 (0.005)**	**87.63 (0.020)**
CIECAM02 chroma **C**	**21.66 (0.037)**	**23.18 (0.011)**	**21.23 (0.087)**	**20.87 (0.028)**	**20.63 (0.060)**	**19.99 (0.034)**	**19.87 (0.065)**	**19.94 (0.063)**	**17.5 (0.062)**	**19.71 (0.115)**	**17.83 (0.030)**
CIECAM02 hue angle **h**	**89.43 (0.145)**	**89.03 (0.046)**	**89.87 (0.118)**	**90.01 (0.052)**	**89.68 (0.068)**	**88.68 (0.011)**	**88.74 (0.045)**	**88.78 (0.017)**	**89.4 (0.122)**	**89.86 (0.051)**	**88.85 (0.102)**
CIECAM02 redness-greenness hue component **a**	**0.91 (0.233)**	**1.56 (0.075)**	**0.20 (0.176)**	**0.023 (0.0392)**	**0.506 (0.113)**	**2.15 (0.024)**	**2.03 (0.070)**	**1.98 (0.036)**	**0.97 (0.202)**	**0.29 (0.070)**	**1.86 (0.164)**

PARAMETER	CARAHELL®	CARAAMBER®	MELANOIDIN MALT	CARAMUNICH® TYPE III	CARAAROMA®	CARAFA® TYPE III	CARAFA® SPECIAL TYPE III	ROASTED BARLEY	SINAMAR®	CARAMEL #301	PILSNER MALT
CIECAM02 redness-greenness hue component **b**	**99.08 (0.236)**	**98.43 (0.075)**	**99.78 (0.161)**	**99.91 (0.011)**	**99.49 (0.115)**	**97.84 (0.023)**	**97.96 (0.070)**	**98.01 (0.034)**	**99.02 (0.204)**	**99.04 (1.085)**	**98.13 (0.166)**
CIECAM02 brightness **Q**	**221.57 (0.047)**	**223.80 (0.028)**	**225.45 (0.049)**	**225.72 (0.181)**	**225.12 (0.026)**	**224.46 (0.570)**	**224.45 (0.055)**	**223.86 (0.049)**	**225.52 (0.045)**	**225.85 (0.011)**	**222.76 (0.026)**
CIECAM02 colourfulness **M**	**20.47 (0.032)**	**21.88 (0.011)**	**20.04 (0.082)**	**20.07 (0.664)**	**19.47 (0.050)**	**18.87 (0.029)**	**18.76 (0.060)**	**18.83 (0.058)**	**16.52 (0.057)**	**18.54 (0.006)**	**16.83 (0.030)**
CIECAM02 saturation **s**	**30.38 (0.023)**	**31.27 (0.005)**	**29.81 (0.061)**	**29.52 (0.017)**	**29.40 (0.040)**	**29.01 (0.023)**	**28.91 (0.040)**	**28.99 (0.046)**	**27.06 (0.042)**	**28.65 (0.006)**	**27.48 (0.025)**

Table 4.3.3 Proposed grain bills for colour adjustment determination

PARAMETER	CARAHELL®	CARAAMBER®	MELANOIDIN MALT	CARAMUNICH® TYPE III	CARAAROMA®	CARAFA® TYPE III	CARAFA® SPECIAL TYPE III	ROASTED BARLEY	SINAMAR ®	CARAMEL #301	PILSNER MALT
Raw material source	GERMAN- GROWN "MARTHE" SPRING BARLEY (2006 harvest)										
Recommended Quantities (after supplier)	Up to 15% of total grain bill (Low Gravity)	Up to 20% of total grain bill	Up to 20% of total grain bill	Up to 5% of total grain bill (pale beers)	Up to 20% of total grain bill	Up to 5% of total grain bill	Up to 5% of total grain bill	Up to 5% of total grain bill	14 g (11.9 mL) 1hL/1EBC		Up to 100% of total grain bill
Wort Colour EBC	20 min 30 max	60 min 80 max	60 min 80 max	170 min 220 max	350 min 450 max	1300 min 1500 max	1300 min 1500 max	1000 min 1300 max	8100 min 8600 max	29,800 (typical)	2.5 min 4.0 max
Wort Colour Lovibond	8.1 min 11.8 max	23 min 31 max	23 min 31 max	64 min 83 max	115 min 150 max	488 min 563 max	488 min 563 max	375 min 450 max	3040 min 3200 max		1.5 min 2.1 max
Ratio (specialty malt/ base malt) %	**10/90**	**3.9/96.1**	**3.9/96.1**	**1.9/98.1**	**0.8/99.2**	**0.2/99.8**	**0.2/99.8**	**0.2/99.8**	**0.04/99.96**	**0.02/99.98**	**100**
Ratio (specialty malt/ base malt) g	**5.20/46.80**	**2.02/49.98**	**2.02/49.98**	**0.98/51.02**	**0.39/51.61**	**0.10/51.90**	**0.10/51.90**	**0.10/51.90**	**0.02 (0.017 mL)/ 51.98**	**0.01 / 51.99**	**52.00**

4.4 Brew control sheets of locally-brewed beers

Eleven beers were brewed at the I.C.B.D. pilot brewery for the research project purposes. All beers were produced under the previous established specifications and standard brewing procedures reported in Table 3.1.1. All the beer control sheets are shown in appendix C (See brew control sheets 1 to 11 of Appendix C).

4.5 Installation of the new I.C.B.D. bottling machine (CW 250 G) and oxygen levels determination in bottled beer

A new bottling machine for the I.C.B.D. pilot brewery was installed. The specifications and the design of the new bottling machine are presented in the ensuing Table 4.5.1 and Figure 4.5.1, respectively.

Several oxygen levels tests in bottled beer were carried out according to M.E.B.A.K. methods of analysis (Brautechnische Analysenmethoden. Band II. Mitteleuropäische Brautechnische Analysenkommission, 2002a) to verify the oxygen levels required and reported by the manufacturer. The determination of oxygen levels was carried out by means of an Orbisphere Model 3650 O_2 Logger (Model 3650 Micro O_2 Logger. Operators Manual. Orbisphere Laboratories, 1995) with a flow rate of 50-180 mL/min. The values of oxygen levels in bottled beers at different bottling performance conditions are shown in Table 4.5.2.

Based on the values presented in Table 4.5.2, the lowest concentration levels of oxygen in bottled beer were obtained by performing the beer bottling with five CO_2 purges for counterpressuring (*i.e.* pre-evacuation) and the corresponding snifting at the filling tubes. Nonetheless, it is mandatory to control the oxygen levels during the whole brewing process in order to elicit the lowest possible oxygen levels at pre-bottling conditions, that is to say in bright beer tank conditions.

Table 4.5.1 New bottling machine for International Centre for Brewing and Distilling (I.C.B.D.) pilot brewery (CW250-R&D. Carbonating and Counter Pressure Bottle Filling Equipment. Moravek International Limited, 2007)

Technical Specification	Description & values
Name	CW250-G, Pilot Plant, Low volume. Carbonating and Counter Pressure Bottle Filling Equipment
Manufacturer	Moravek International Limited. Brealey Works, Station Street, Misterton. North Nottinghamshire. England. DN10 4DD. United Kingdom www.moravek.co.uk
Maximum capacity of beverage (LPH)	400
Max. CO_2 (N_2) content range - According to temperature, sugar content, set conditions and water hardness max. 10°dH (German scale) (Vols.)	0-4.5
Maximum carbonating overpressure (Mpa)	0.8
Max. CO_2 consumption (based on 1 L bottle) (kg/h)	4
Capacity of bottles (L)	0.2-2.5
Adjustable bottle height (mm)	180-340
Bottle pitch (mm)	140
Number of filling valves	2
Carbonator tank capacity (L) and pressure limits (bar)	20 (0 up to +8.0)
Filler bowl capacity (L) and pressure limits (bar)	12 (0 up to +8.0)
Maximum efficiency of saturation (%)	75
Power demand (kW)	1
Feeding (V, Hz)	3 x 400, 50
Noise level (dBA)	60 – 75
Weight (kg)	130
Dimensions (m)	0.6 x 0.6 x 2.2
DO levels (mg/L) - Depending of the original DO levels (< 0.5)	0.1 – 0.3

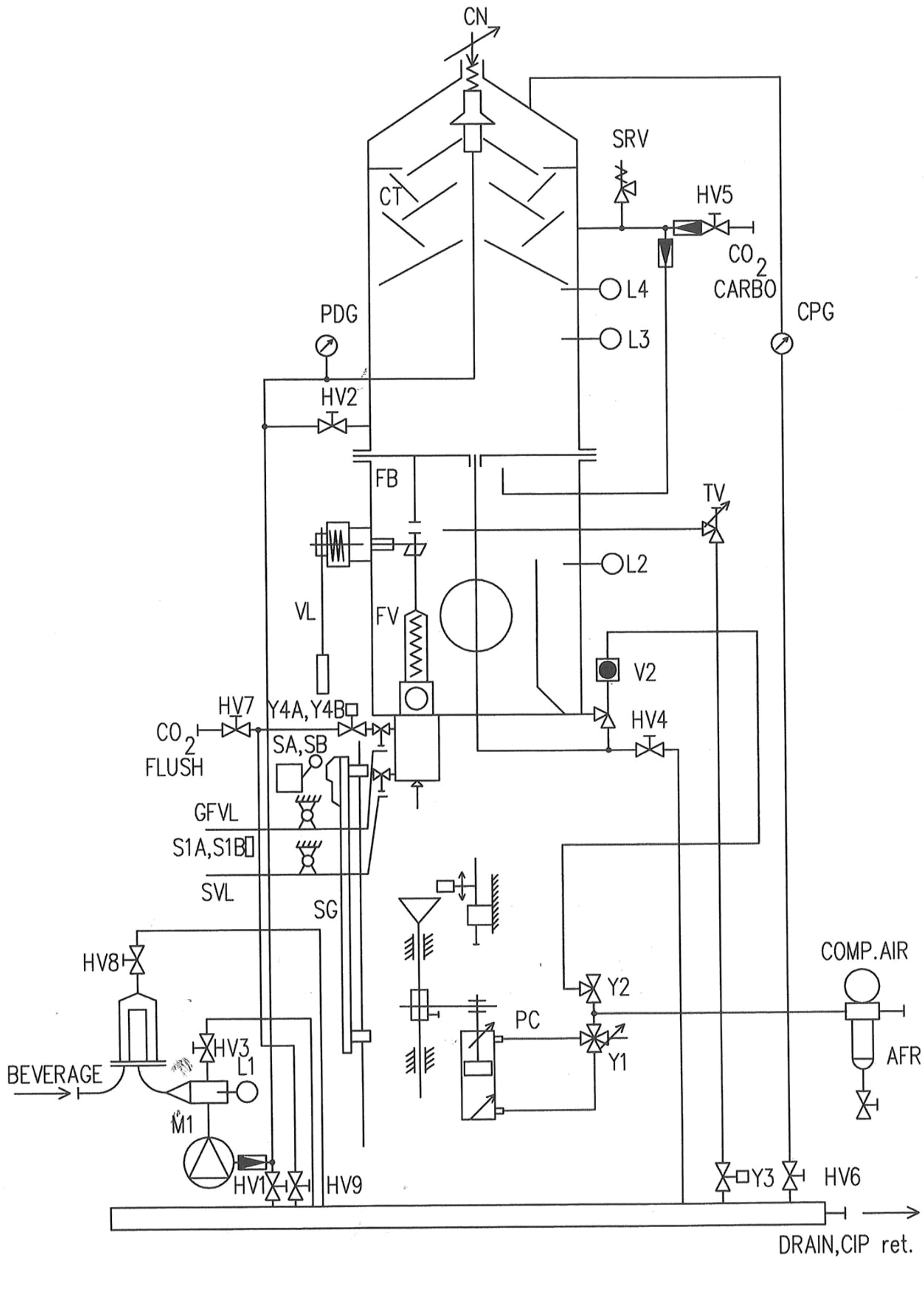

Figure 4.5.1 New bottling machine for International Centre for Brewing and Distilling (I.C.B.D.) pilot brewery (*ibid*.)

Table 4.5.2 Determination of oxygen levels in beer at different bottle filling conditions

Test description	**Sample 1 (O_2 mg/L)**	**Sample 2 (O_2 mg/L)**	**Sample 3 (O_2 mg/L)**	**Mean and Standard Deviation (Sx) (O_2 mg/L)**
Bright beer tank conditions	0.26	0.26	0.26	**0.264 (0.0005)**
4 CO_2 purges (Counterpressuring) + No final pressure release (Snifting)	0.39	0.40	0.35	0.385 (0.0264)
4 CO_2 purges (Counterpressuring) + Induced overfoaming	0.35	0.28	0.36	0.330 (0.0435)
3 CO_2 purges (Counterpressuring) + Final pressure release (Snifting)	0.28	0.28	0.27	0.281 (0.0090)
4 CO_2 purges (Counterpressuring) + Final pressure release Snifting)	0.35	0.36	0.36	0.360 (0.0051)
5 CO_2 purges (Counterpressuring) + Final pressure release Snifting)	0.24	0.25	0.26	**0.252 * (0.0136)**
6 CO_2 purges (Counterpressuring) + Final pressure release (Snifting)	0.25	0.25	0.25	0.253 (0.0025)

4.6 Analyses of locally-brewed beers

4.6.1 Additional analyses (Baseline Data)

The baseline data obtained from each fresh locally-brewed beer are presented in Tables A.3.1 to A.3.12, respectively. The majority of the outcomes were of normal range in accordance with M.E.B.A.K. and Titze *et al.* (Brautechnische Analysenmethoden. Band II. Mitteleuropäische Brautechnische Analysenkommission, 2002a-p; Titze *et al.*, 2007). Nonetheless, it is important to mention some general observations of the investigation of the beer samples.

Acceptable low levels of dissolved oxygen (*ca*. 0.2 mg/L) in all the fresh bottled beer samples were found for pilot brewery conditions but slightly higher compared to M.E.B.A.K. and industrial specifications (<0.1 mg/L) (Brautechnische Analysenmethoden. Band II. Mitteleuropäische Brautechnische Analysenkommission, 2002p). These low levels of dissolved oxygen are required for establishing the optimal conditions for any beer flavour and colour stability investigation as aforementioned, because the oxygen plays a key role in the beer ageing process. However, it is necessary to stress that oxygen is not the only critical factor that induces beer ageing. Low levels of oxygen are obtained by rigorous brewing and bottling performances of the beer samples which are carried out in keeping with the specifications and the previous conditions established in this research (see section 3.1).

Higher levels of carbon dioxide in the fresh bottled beers samples than those outlined in the M.E.B.A.K. specifications (Brautechnische Analysenmethoden. Band II. Mitteleuropäische Brautechnische Analysenkommission, 2002o) and the specifications established in Table 3.1.1 were found. However, these higher levels of carbon dioxide do not affect the physical-chemical properties and sensorial quality of the fresh beers in a relevant manner.

The reducing power of all the fresh beer samples ranged from good to very good levels according to M.E.B.A.K. specifications (Brautechnische Analysenmethoden. Band II. Mitteleuropäische Brautechnische Analysenkommission, 2002j). There was no clear distinction of the levels of reducing power between all the fresh beer samples, therefore this method was considered unsuitable as baseline marker in terms of flavour stability for the locally-brewed beers and consequently for the effects of this research.

These results contrast with previous investigations (Cantrell and Briggs, 1996), in which beers colour-adjusted with roasted malts or roasted barley presented higher reducing powers than beers colour-adjusted with other specialty malts. Likewise, these results were comparable with previous research (Coghe *et al.*, 2006) that reported the anti-oxidative activity of malt as dependent variable on the time-temperature ratio of its kilning and roasting programme. This effect was not noticed in this investigation considering that all the specialty malts used as colouring agents for colour adjustment of the locally-brewed beers were treated at different time-temperature conditions during their kilning and roasting treatment (see section 1.3).

Lower pH in all fresh beer samples was observed after M.E.B.A.K specifications (Brautechnische Analysenmethoden. Band II. Mitteleuropäische Brautechnische Analysenkommission, 2002g) but of normal range in accordance with values reported by other literature sources (Narziß, 1995). Furthermore, the results were similar to the pH values reported for the commercial beers previously analysed.

Higher turbidity (EBC-formazin units) at 20℃ and shor ter shelf life predicted by the modified forcing test method (Titze *et al.*, 2007) in the fresh beer colour-adjusted with dark crystal malt (CARAMUNICH® Type III) were noticed in comparison to the remaining fresh beer samples. The shelf life predicted for this fresh beer was significantly lower (7 warm days), and so this was the shortest shelf life reported for all the fresh locally-brewed beers. In addition, the fresh beer sample colour-adjusted with artificial caramel colorant (CARAMEL #301) and the fresh beer control (100% pilsner malt) presented a relatively short shelf life. This parameter was further monitored throughout the colour appearance analysis as it is of great significance in beer colour perception.

4.6.2 Determination of colour intensity and colour appearance by spectrophotometry (preliminary approach)

The colour intensity (*i.e.* E.B.C. colour units) and the total colour appearance (*i.e*. CIE L*a*b*, C*, yellowness index (Y.ID1925), iCAM and CIECAM02 colour appearance predictors) of the fresh locally-brewed beers were spectrophotometrically measured in keeping with the procedures applied on the colour adjustments trials (see section 3.1). The range of outcomes from each fresh locally-brewed beer specimen were analysed and compared to the other fresh beers colour-adjusted and the previous results obtained from the preliminary adjustment trials (see Charts B.2.1 to B.2.29 of Appendix B).

All E.B.C. colour units of the fresh locally-brewed beer were the same as the values established in the beer specifications (see Table 3.1.1) of normal range. The fresh beer colour-adjusted with light crystal malt (CARAHELL®) displayed the highest E.B.C. colour units, while fresh beers colour-adjusted with roasted malt (CARAFA® Type III) and melanoidin malt showed the lowest ones, respectively.

Concerning the tristimulus values (X, Y, Z), there was no clear distinction in each tristimulus parameter of all the fresh locally-brewed beers, except in the case of the fresh beer colour-adjusted with light crystal malt (CARAHELL®), in which relatively lower tristimulus values were detected.

The values reported for CIE colour space (L*a*b*) of the fresh beer samples indicated that fresh beer colour-adjusted with light crystal malt (CARAHELL®) had the lowest lightness (L*), while the fresh beer control (100% pilsner malt) obtained the highest one. Similarly, fresh beer colour-adjusted with light crystal malt (CARAHELL®) displayed the lowest redness hue component (+a*) and the highest yellowness hue component (+b*), metric chroma (C*) and yellowness index. In contrast, fresh beer colour-adjusted with dark crystal malt (CARAAROMA®) presented the lowest yellowness hue component (+b*) and metric chroma (C*). No clear difference between the remaining fresh beer samples was detected.

In the determination of colour appearance predictors of the fresh locally-brewed beers some significant features were observed. The iCAM and CIECAM02 colour appearance predictors proportionally showed very similar behaviour in all the fresh beer samples, however the colour appearance predictors obtained by using CIECAM02 colour appearance model displayed more significant differences in the samples tested. Hence, the CIECAM02 colour appearance model seemed to be more sensitive for measuring beer colour appearance against the iCAM colour appearance framework. These finding provide good arguments for choosing the CIECAM02 model as the suitable colour appearance model for this investigation.

In spite of these assumptions, it is necessary to point out that in general there was no clear distinction between the colour appearance predictors of the majority of the beer samples measured by spectrophotometry. For this reason, the total colour appearance of the fresh locally-brewed samples must be measured using other more reliable methodologies which might provide more accurate and reproducible results such as psychophysical evaluations (*i.e.* sensory viewing) and instrumental physical measurements (*i.e.* tele-spectroradiometry and DigiEye System-VeriVide®), respectively (see section 3.2.2.3).

The comparative results between the distinct iCAM and CIECAM02 colour appearance predictors of the fresh locally-brewed beers were as follows:

The fresh beer colour-adjusted with light crystal malt (CARAHELL®) presented the lowest iCAM lightness (J) and CIECAM02 lightness (J). In contrast, the fresh beer control (100% pilsner malt) showed the highest values of this colour appearance parameters. There was no sharp distinction recorded between the other fresh samples. These results contrast the conclusions of previous research (Coghe and Adrianssens, 2004) that worts and beers produced with roasted malts and roasted barley show lower levels of CIELAB lightness (L*) and consequently lower iCAM and CIECAM02 lightness (J). This effect is attributed by these researchers to the presence of high molecular weight (HMW) compounds (*ibid.*). They concluded that mass of low molecular weight (LMW) fraction decreased with increasing colour, due to lower extract content in wort produced with roasted malts, whereas an increase in the weight of the HMW coloured compounds is produced by conversion of low molecular weight (LMW) compounds to high molecular weight (HMW) products during heating of malt (*ibid.*).

Comparing, fresh beers colour-adjusted with the light crystal malt (CARAHELL®) and the dark crystal malt (CARAMUNICH® Type III) showed inversed hue angle in terms of iCAM and CIECAM02, respectively. That is, iCAM hue angle (h) obtained the highest values whereas the CIECAM02 hue angle (h) the lowest ones. This may be attributed to the independent mathematical arrangements of the colour appearance formulae for these two distinct colour appearance models.

With reference to the CIECAM02 hue components, higher redness hue component (+a) and lower yellowness hue component (+b) in the fresh beers colour-adjusted with the light crystal malt (CARAHELL®), the dark crystal malt (CARAMUNICH® Type III), the melanoidin malt and the artificial caramel colorant (CARAMEL #301) were noticed. On the other hand, certain greenness hue component (-a) and higher yellowness hue component (+b) in the fresh beer control (100% pilsner malt), the fresh beers colour-adjusted with roasted malts (CARAFA® Type III, CARAFA® SPECIAL Type III) and with the dark crystal malt (CARAAROMA) were observed. Additionally, an outstanding greenness hue component in the fresh beer colour-adjusted with melanoidin malt was found. This result is theoretically incorrect as the fresh beer sample also showed slight redness hue component (+a). According to the geometrical CIECAM02 hue arrangement the redness and the greenness hue components are spatially displayed on a same axis along the 3D-space.

The fresh beers colour-adjusted with light crystal malts (CARAHELL® and CARAAMBER®) had the lowest iCAM brightness (G) and CIECAM02 brightness (Q). Similarly, the fresh beer colour-adjusted with light crystal malt (CARAHELL®) presented the highest iCAM colourfulness (M) and CIECAM02 colourfulness (M). In contrast, the other fresh beer samples showed no clear differences in terms of the aforementioned colour appearance predictors. A hypothetical reason of these results is that the fresh beers colour-adjusted with light crystal malts (CARAHELL® and CARAAMBER®) obtained the highest colour in terms of EBC colour units, thus resulting in a decrease of brightness and an increase of colourfulness, respectively. All the fresh locally-brewed beers presented no evident distinction in terms of iCAM and CIECAM02 chroma (C) and CIECAM02 saturation (s).

In conclusion, the results revealed substantial inconsistencies in the majority of the features measured when the results are compared to the preliminary adjustment trials (see Section 4.3).

4.6.3 Main analyses

4.6.3.1 Colour appearance analysis of the locally-brewed beers

4.6.3.1.1 Determination of colour psychophysical method (sensory viewing)

Tables A.4.3 to A.4.7 of Appendix A and Charts B.3.1 to B.3.15 of Appendix B present the comparative values obtained for the fresh, the forced aged (7 days at 60℃) and the spontaneously aged (12 months at 4℃) locally-brewed beers by sensory viewing, respectively. In general, none of the colour appearance predictors evaluated by sensory viewing matched the obtained results of CIECAM02 by spectrophotometry.

Visual lightness (Lv) (fresh, forced aged and 12-month aged):

Higher visual lightness (Lv) in the fresh locally-brewed beers colour-adjusted with dark crystal malt (CARAAROMA®) and roasted malt (CARAFA® Type III) was detected in comparison to the remaining fresh beer samples, except to the fresh beer control (100% of pilsner malt). The latter displayed the highest lightness of all the fresh samples. This may be attributed to the fact that the fresh beer control was brewed without any colouring agent that contribute an increase of colour to the beer matrix.

The fresh locally-brewed beer colour-adjusted with melanoidin malt showed a slight decrease in its visual lightness. All the visual lightness results of the fresh locally-brewed beers matched the EBC and CIE L* values previously obtained in this research.

Regarding the forced aged locally-brewed beers (7 days at 60℃), all results showed very similar behaviour to the fresh ones, except in the case of the forced aged beer sample colour-adjusted with dehusked roasted malt (CARAFA® SPECIAL Type III) which displayed a slight decrease of lightness. The reason for this can be attributed to the fact that the selected forcing beer ageing (7 days at 60℃) as aggressive thermal treatment may induce non-enzymatic browning reactions (Maillard reactions), oxidation of polyphenols as well as possible caramelisation reactions in the beer matrix. All results of the forced aged locally brewed beers did not match the CIECAM02 results by spectrophotometry.

Finally, the spontaneously aged beers (12 months at 4℃) colour-adjusted with light crystal malts (CARAHELL® and CARAAMBER®), colouring beer (SINAMAR®) and melanoidin malt presented a clearly lower visual lightness than the other spontaneously aged samples. Besides, the spontaneously aged beers colour-adjusted with dehusked roasted malt (CARAFA® SPECIAL Type III) and dark crystal malt (CARAMUNICH® Type III), and the spontaneously aged beer control (100% pilsner malt) showed the highest visual lightness of the portfolio of spontaneously aged beer samples. These results suggest that light crystal malts, melanoidin malt and colouring beer might provide certain protection to the beer matrix against non-enzymatic browning reactions during ageing. These outcomes contrast with the findings reported in previous works (Coghe and Adrianssens, 2004) that worts and beers produced with high amounts of roasted malts and roasted barley presented low levels in terms of lightness, which corresponds proportionally to the concentration of high molecular weight (HMW) compounds (*ibid.*). Even though, it is important to point out that the amounts of colouring agents used on this investigation are within normal and realistic specifications according to those used for the production of pale lager beers in the beer industry, while the aforementioned results from the aforementioned previous studies were obtained from grain bills with higher levels of specialty malts which are absolutely not used in any commercial brewery.

Visual colourfulness (Cv):

The fresh locally-brewed beers colour-adjusted with light crystal malt (CARAHELL®), melanoidin malt and light crystal malt (CARAAMBER®) showed the highest colourfulness, while the fresh beer control (100% pilsner malt) showed the lowest one. In general, the obtained visual colourfulness results did not match the CIECAM02 by spectrophotometry, but the EBC colour units, the CIELAB metric chroma (C*) and the yellowness index (Y.ID1925), except the fresh locally-brewed beer colour-adjusted with melanoidin malt that showed lower EBC colour units. This result may indicate the EBC colour units do not accurately characterise the colour perception by the human eye. This may also confirm that the scientific basis of the EBC colour method by measuring the absorbance in a specific wavelength of 430 nm does not mimic the true colour perception of the beers by the consumers (see Viggiano, 2006).

In the case of the results for the forced aged locally-brewed beers (7 days at 60℃), a sudden increase of colourfulness in those forced aged beer samples colour-adjusted with roasted malt products such as (CARAFA® SPECIAL Type III), roasted barley and colouring beer (SINAMAR®) was detected. There was no clear difference between the remaining forced aged beer samples, being quite similar to the fresh ones.

Nevertheless, it is important to point out that, in general, the results of forced aged beers presented incongruity; this can be attributed to the forcing beer ageing method itself. In this connection, it is important to draw attention to the composition of the beer extract, which can play a relevant role on the development of colourfulness on pale lager beers throughout ageing. This extract is formed by 80 to 85% of residual carbohydrates, 4.5 to 5.2 % of nitrogen compounds, 3 to 5% of glycerine, 3 to 4% of minerals, 2 to 3% of hop bitter substances, polyphenols and pigments, 0.7 to 1% of organic acids and small amounts of vitamins (Narziß, 1995).

As was mentioned above, the forcing beer ageing treatment promotes Maillard reactions by inducing condensation- and subsequent breakdown reactions of residual carbohydrates in beer, being mainly dextrines, hemicelullose (*e.g*. β-glucans and pentosans), mono-, di- and trisaccharides (*e.g.* maltotriose and raffinose) with nitrogen compounds (700 to 800 mg/L) of different molecular weight such as aminoacids, peptides, oligopeptides and proteins (*e.g.* proline 60 to 100 mg/L) which are presented in the beer matrix (Kunze, 1999; and Narziß, 1995). Likewise, this effect may be the result of a higher rate of caramelisation reactions. The mechanism of caramelisation reactions is started by sugar-amino condensations and Amadori or Heyns rearrangements, subsequently degradative reactions such as sugar degradation and Strecker degradation take place, providing from colourless reactants to yellow coloured products with stronger U.V. absorption ability. Finally, aldol condensations and aldehyde-amino polymerisations are produced; those reactions generate a wide range of strong coloured compounds and pigments (Kamuf *et al.*, 2003). Additionally, oxidation of polyphenols (150 to 200 mg/L) can be produced, *e.g.* anthocyanogenes (50 to 70 mg/L) and catequins (10 to 12 mg/L), as well as oxidation of hop bitter substances or hop resins; *e.g.* non-isomerised α- acids (0.5-1.5 mg/L), β-acids mainly hupulone (1-3 mg/L), lupulone, colupulone, adlupulone and iso α-acids (isohumulones, isocohumulones, isoadhumulone). Furthermore, vitamins can also be oxidised such as vitamins B1 (Thiamin) (30 µg/L) and biotin (10µg/L), riboflavine (300 µg/L), pyridoxine (600 µg/L), panthothenic acid (1500 µg/L) and niacin (7500 µg/L) (Narziß, 1995) (see Table 1.5.1).

Concerning the spontaneously aged locally-brewed beers (12 months at 4℃), those beers colour-adjusted with light crystal malt (CARAAMBER®) and melanoidin malt showed the highest colourfulness, while the beer colour-adjusted with the dehusked roasted malt (CARAFA® SPECIAL Type III) presented the lowest one in comparison to the other samples investigated. Thus, a clear interrelation exists between the visual lightness and the visual colourfulness of the beers. This is based on the visual lightness results (read above), which can conclude that visual lightness is a colour appearance attribute which is indirectly proportional to colourfulness. Likewise, it could be possible to state that light crystal malt (CARAMBER®) and melanoidin malt promote not only protection against certain oxidation and non-enzymatic browning reaction to the beer but also contribute to higher colourfulness, which participates to the overall colour appearance of the final beer product.

Visual hue angle (hv):

The visual hue of all the fresh locally-brewed beers presented exactly the opposite behaviour to the corresponding colourfulness ones. The fresh beers colour-adjusted with light crystal malts (CARAHELL® and CARAMBER®) and melanoidin malt showed the lowest visual hue while fresh beer control (100% pilsner malt) the highest one. The visual hue obtained by sensory viewing presented the opposite trend than EBC colour units and did not match with other colour appearance predictors such as CIELAB metric chroma (C*) and yellowness index (Y.ID1925).

Similarly, the same behaviour was found in the forced aged locally-brewed beers (7 days at 60℃) in comparison to fresh ones. The for ced aged beer samples colour-adjusted with roasted malt (CARAFA® Type III), roasted barley and colouring beer (SINAMAR®) presented the lowest visual hue, while the forced aged beer control (100% pilsner malt) showed the highest one, respectively. There was no clear difference between the other forced aged samples. This may be once again attributed to the forcing beer ageing method. In general, the values were directly proportional to the lightness predictors such as CIE L* and visual lightness (Lv). Overall, the forced aged beers presented less visual hue than the fresh ones.

The spontaneously aged locally-brewed beers (12 months at 4℃) colour-adjusted with light crystal malts (CARAHELL® and CARAAMBER®), melanoidin malt and colouring beer (SINAMAR®) presented the lowest visual hue, while the spontaneously aged beer control (100% pilsner malt) obtained the highest one. According to all these results, visual lightness and visual hue of the beers are directly proportional and inversely proportional to visual colourfulness.

Visual redness-greenness hue component (av)

The fresh locally-brewed beers colour-adjusted with light crystal malts (CARAHELL® and CARAMBER®) and melanoidin malt displayed the highest visual redness-greenness hue component. All fresh samples presented positive values; therefore, the fresh samples showed redness hue component only (see Smedley, 1992 and 1995; Sharpe *et al.*, 1992). The fresh beer control (100% pilsner malt) presented the lowest redness hue component of all the fresh samples. No clear difference between the remaining fresh samples was found. In general, visual redness-greenness hue component matched the EBC values but did not match with CIE a*.

In the case of forced aged locally-brewed beers (7 days at 60 ℃), the same behaviour as visual hue (hv) was found; a sudden increase of redness hue component of forced aged beers colour-adjusted with dehusked roasted malt (CARAFA® SPECIAL Type III), roasted barley and colouring beer (SINAMAR®). The remaining forced aged samples showed the same behaviour as fresh ones. The possible reason for this effect is the forcing beer ageing treatment. The thermal treatment applied in this method may induce the production of red colouring pigments due to non enzymatic reactions as Maillard- and caramelisation reactions and polyphenols oxidation by-products.

Regarding the spontaneously aged locally-brewed beers (12 months at 4℃), there was an increase of the redness hue component on the spontaneously aged samples colour-adjusted with light crystal malts (CARAHELL® and CARAMBER®), melanoidin malt and colouring beer (SINAMAR®). On the other hand, the spontaneously aged beer control (100% pilsner malt) and the spontaneously aged beers colour-adjusted with roasted malts (CARAFA® Type III and CARAFA® SPECIAL Type III) showed the lowest redness hue component from all the portfolio of spontaneously aged samples. At this point, it is particularly of great interest to observe that light crystal malts (CARAHELL® and CARAMBER®), melanoidin malt and colouring beer (SINAMAR®) certainly have an influence on the total visual hue by providing an increase of the redness hue component on the beer matrix. This effect may be attributed to the higher amounts of low (LMW) and high (HMW) molecular weight melanoidins as well as to the oxidation of small endogenous flavanoids such as catechins, epicatechins and gallocatechins throughout the beer ageing and low molecular weight (LWM) chromophores (<1 kDa) which are also responsible for light absorption (Coghe and Adriaenssens, 2004; Coghe *et al.*, 2005; Coghe *et. al*., 2006; Coultate, 2002; Laille *et al.*, 2008).

Visual yellowness-blueness hue component (bv):

The fresh locally-brewed beers showed the same behaviour as their corresponding visual redness-greenness hue predictor (av), that means the visual yellowness-blueness hue predictor (bv) of all the fresh samples matched proportionally the EBC colour units but did not match the CIE b* and yellowness index, respectively.

Regarding forced aged locally-brewed beers (7 days at 60℃), a very similar behaviour as redness-greenness hue (av) was found. In general, there was an increase of yellowness hue component in all the forced aged beer samples, except in those colour-adjusted with artificial caramel (CARAMEL #301) and the forced aged beer control (100% pilsner malt), respectively.

As for the spontaneously aged locally-brewed beers (12 months at 4℃), there was an increase of the yellowness hue component on all the spontaneously aged beer samples, even though those spontaneously aged beers colour-adjusted with light crystal malt (CARAAMBER®), melanoidin malt, dark crystal malt (CARAMUNICH® Type III) and the spontaneously aged control beer (100% pilsner malt) presented the highest yellowness hue component. This increase of the yellowness hue component of all the spontaneously aged samples may be attributed to the fact that the majority of yellow colouring chromophores such as riboflavins, carotenoids and low molecular weight melanoidins (<10) are firstly elicited during the early formation stage of reddish components such as caramelisation products and polyphenols oxidation by-products which are induced at higher temperatures (Coghe *et al.*, 2006; Laille *et al.*, 2008).

Visual opacity (Opv):

The fresh locally-brewed beers colour-adjusted with colouring beer (SINAMAR®) and melanoidin malt showed the highest visual opacity. The fresh beer control (100% pilsner malt) showed the lowest one in comparison to the all group of fresh beer samples.

In the case of forced aged locally-brewed beers (7 days at 60℃), those beers coloured-adjusted with dehusked roasted malt (CARAFA® SPECIAL Type III) and colouring beer (SINAMAR®) presented the highest visual opacity in comparison to the other forced aged samples, while the forced aged control beer (100% pilsner malt) obtained the lowest value.

The spontaneously aged locally-brewed beers (12 months at 4℃) colour-adjusted with light crystal malt (CARAHELL®) and melanoidin malt showed the highest visual opacity of the portfolio of spontaneously aged samples, while the spontaneously aged beer control (100% pilsner malt) presented the lowest one. This increase of opacity given by the aforementioned colouring agents can be based on the fact that visual opacity is highly interrelated with the visual lightness. Melanoidins of low (LMW: <10 kDa) and mediate molecular weight (MMW: <70 kDa) provided by the light crystal malts, melanoidin malts and colouring beer may confer certain opacity and reduction of lightness on the beer matrix, which may also influence the technical shelf life of the product but at the same time may provide certain protection against oxidation and therefore to the beer flavour stability (see Coghe *et al.*, 2006; Méllote, 2008; Titze *et al*., 2007).

Visual clarity (Clv):

The visual clarity of the fresh locally-brewed beers was clearly lower on those samples colour-adjusted with light crystal malts (CARAHELL® and CARAAMBER®), colouring beer (SINAMAR®) and melanoidin malt. The beer control (100% pilsner malt) showed the highest clarity from all the investigated fresh samples.

The forced aged locally-brewed samples (7 days at 60℃) colour-adjusted with roasted malt (CARAFA® Type III) and colouring beer (SINAMAR®) showed the lower visual clarity, while the forced aged beer control (100% pilsner malt) presented the highest one.

Concerning the spontaneously aged locally-brewed beers (12 months at 4℃), the samples colour-adjusted with light crystal malts (CARAHELL® and CARAAMBER®) and melanoidin malt obtained the lowest visual clarity. The spontaneously aged beer colour-adjusted with dehusked roasted malt (CARAFA® SPECIAL Type III) and the spontaneously aged beer control (100% pilsner malt) showed the highest visual clarity in comparison to the other spontaneously aged samples.

Overall, these results suggest that the beer colour adjustment with the selection of roasted malt products may contribute to a higher visual clarity in comparison to other beer colouring agents in the market. It is worth mentioning that beer clarity plays a relevant quality role in beer judging since its interaction with the beer flavour is critical on the psychophysical perception of the beer consumer (see Finn and Evans, 2008).

4.6.3.1.2 Determination of colour appearance components by tele-spectroradiometry (TSR)

4.6.3.1.2.1 Simulation of sensory viewing (Use of highball glass)

In general, fresh and spontaneously aged (12 months at 4℃) beer samples over white background (w/bg) have a good correlation with sensory viewing but with a sharper difference between the samples. The forced aged locally-brewed samples (7 day at 60℃) showed no consistency in the results due to the thermal treatment by forcing beer ageing. Table A.4.10 and A.4.11 of Appendix A display the tristimulus values and the CIECAM02 colour appearance predictors obtained by tele-spectroradiometry (simulation of sensory viewing) for the locally-brewed beer samples at different ageing states. Table 4.6.1 shows the comparative values of CIECAM02 colour appearance predictors obtained by Minolta CS-1000 tele-spectroradiometer on high ball glass at Verivide® Illumination cabinet and sensory viewing for each of the locally-brewed beer samples.

Contrast ratio:

The powerful information obtained from the contrast ratio of the beer samples lies upon the fact that the higher the contrast ratio is presented the clearer the beer is. This is based on the following formula:

$$Contrast\_ratio = \frac{Yb}{Yw} \times 100\%$$

Where Yb: Tristimulus value Y on black background
Yw: Tristimulus value Y on white background

The fresh and spontaneously aged (12 months at 4℃) beers colour-adjusted with colouring beer (SINAMAR®) and artificial caramel colorant (CARAMEL #301) showed the highest contrast ratio, while the fresh and spontaneously aged beer control (100% pilsner malt) as well as the fresh and spontaneously aged beers colour-adjusted with dark crystal malt (CARAAROMA®), roasted barley, roasted malt (CARAFA® Type III) and dehusked roasted malt (CARAFA® SPECIAL Type III) showed the lowest one.

In the case of forced aged beers (7 days at 60℃) colour-adjusted with dehusked roasted malt (CARAFA® SPECIAL Type III) and colouring beer (SINAMAR®) showed much higher contrast ratio in comparison to the remaining forced aged samples. Moreover, the remaining forced aged samples showed no clear difference between them.

CIECAM02 lightness (J_TSR) (w/bg)

The fresh locally-brewed beers displayed good correlation with sensory viewing (Lv), EBC colour units and CIE lightness (L*). The fresh beer samples colour-adjusted with light crystal malts (CARAHELL® and CARAAMBER®) and melanoidin malt presented the lowest CIECAM02 lightness (J_TSR), while the fresh beers colour-adjusted with dark crystal malts (CARAMUNICH® Type III and CARAAROMA®) and roasted malt (CARAFA® Type III) showed the highest one.

The forced aged locally-brewed beers (7 days at 60℃) presented lower CIECAM02 lightness (J_TSR) than the fresh ones due to possible increase of colour by forcing beer ageing method. There were no clear differences between the forced aged, except in the case of the forced aged locally-brewed beer colour-adjusted with colouring beer (SINAMAR®). This beer presented a relative lower CIECAM02 lightness (J_TSR) than the other forced aged samples, while the forced aged beer control showed the highest one.

The spontaneously aged locally-brewed beers (12 months at 4℃) showed no clear difference between them. The spontaneously aged beers colour-adjusted with light crystal malt (CARAHELL®) and melanoidin malt presented slightly lower CIECAM02 lightness (J_TSR) while the spontaneously aged beer control (100% pilsner malt) showed a higher one in comparison to the other spontaneously aged samples.

CIECAM02 colourfulness (M_TSR) (w/bg):

All the colourfulness values by tele-spectroradiometry (sensory viewing simulation) were similar to the obtained visual colourfulness (Cv), EBC colour units, CIE redness-greenness hue component (a*), metric chroma (C*) and yellowness index (Y.ID1925). The colourfulness of the fresh beers colour-adjusted with light crystal malts (CARAHELL® and CARAAMBER®) and melanoidin malt were slightly higher than the other fresh samples. The fresh beer control (100% pilsner malt) showed the lowest

CIECAM02 colourfulness (M_TSR) and there was no clear difference between the remaining fresh samples. These results matched those obtained by sensory viewing, therefore a good correlation between the perception of the colour appearance by the human eye and those obtained by tele-spectroradiometry can be generated.

Concerning the forced aged locally-brewed beers (7 days at 60℃), the forced aged beer samples colour-adjusted with light crystal malts (CARAHELL® and CARAAMBER®) presented the highest CIECAM02 colourfulness (M_TSR) and the beers colour-adjusted with artificial caramel colorant (CARAMEL #301) and the forced aged beer control (100% pilsner malt) presented the lowest one in comparison to the remaining forced aged samples.

The results obtained from the spontaneously aged locally-brewed beers (12 months at 4℃) showed that the spontaneously aged beer colour-adjusted with light crystal malt (CARAAMBER®) had the highest CIECAM02 colourfulness (M_TSR) while the spontaneously aged beer control (100% pilsner malt) the lowest one. There was also no clear distinction between the remaining spontaneously aged samples.

CIECAM02 hue angle (h) (w/bg):

The fresh beer control (100% pilsner malt) and the fresh locally-brewed beers colour-adjusted with dark crystal malt (CARAAROMA®), roasted malt (CARAFA® Type III) and roasted barley presented the highest CIECAM02 hue angle (h_TSR), while that colour-adjusted with light crystal malt (CARAHELL®) showed the lowest one. These results were exactly opposite to those obtained for CIECAM02 colourfulness by tele-spectroradiometry with highball glass and visual colourfulness. This indicates a good correlation between the sensory viewing and the tele-spectroradiometry was obtained.

The forced aged locally-brewed beers (7 days at 60℃) showed very similar behaviour to the fresh ones, except the forced aged beer control (100% pilsner malt) which showed the highest CIECAM02 hue angle (h_TSR) and the forced aged beer colour-adjusted with colouring beer (SINAMAR®) showed lower values than the remaining forced aged samples.

On the spontaneously aged locally-brewed beers (12 months at 4℃), an outstanding decrease of CIECAM02 hue angle (h_TSR) of the beer colour-adjusted with crystal malt (CARAHELL®) was noticed. This can suggest that light crystal malts as colouring agents may reduce the hue of the beer during ageing.

CIECAM02 redness-greenness hue component (a_TSR) (w/bg)

The obtained results of redness-greenness hue component of all the fresh locally-brewed beer samples matched well the EBC colour units and the visual redness-greenness component (av) but did not match the CIE redness-greenness hue component (a*). In accordance with these results, it is possible to state that CIE a* is not as accurate colour appearance predictor as it was reported by previous investigations (Smedley, 1995). The fresh beers colour-adjusted with light crystal malts (CARAHELL® and CARAAMBER®) and melanoidin malt showed the highest values. The fresh beer control (100% pilsner malt) presented the lowest redness hue component. There was no clear difference between the remaining fresh beers.

The forced aged locally-brewed beers (7 days at 60℃) colour-adjusted with light crystal malt (CARAHELL®), colouring beer (SINAMAR®) and dehusked roasted barley (CARAFA® SPECIAL Type III) showed higher redness hue component (a_TSR) due to the forcing beer ageing treatment used. In general, the results obtained a very similar trend as those obtained from the visual redness (av) for the forced aged beers. All the forced aged samples had an increase of redness hue component (a_TSR) due to forcing beer ageing method in comparison to the fresh beer samples, except in the case of the forced aged beer colour- adjusted with artificial caramel colorant (CARAMEL #301).

The spontaneously aged locally-brewed beer (12 months at 4℃) colour-adjusted with crystal malt (CARAHELL®) clearly presented the highest redness hue component (a_TSR) in comparison to the other spontaneously aged beers. The spontaneously aged beer control presented the lowest redness hue component (a_TSR) and there was no clear difference between the remaining spontaneously aged samples.

CIECAM02 yellowness-blueness hue component (b_TSR) (w/bg)

The yellowness-blueness values (b) of the fresh locally brewed beers matched CIE yellowness-blueness component (b*), yellowness index (Y.ID1925) but not visual yellowness-blueness component (bv). The fresh locally-brewed beers colour-adjusted with light crystal malts (CARAHELL® and CARAAMBER®) presented the highest yellowness hue component (b_TSR) while fresh beers colour-adjusted with dehusked roasted malt (CARAFA® SPECIAL Type III) and roasted barley presented the lowest one.

The forced aged locally-brewed beers (7 days at 60℃) presented very similar yellowness hue component (b_TSR) to those obtained on fresh samples. Nevertheless, it was clearly observed a slight increase on forced aged beer colour-adjusted with light crystal malt (CARAAMBER®) as well as a slight decrease on the forced aged beer control (100% pilsner malt). It seems that light crystal malt contributes to the increase of yellowness hue component (b_TSR) in beer for a specific colour adjustment value while other colouring agents do not.

The spontaneously aged locally-brewed beers (12 months at 4℃) colour-adjusted with light crystal malts (CARAHELL® and CARAAMBER®) obtained the highest yellowness hue component (b_TSR) from all the spontaneously aged samples, while the spontaneously aged locally-brewed beer colour-adjusted with roasted barley presented the lowest one. Based on this finding, it is possible to confirm that light crystal malts definitely contributes to an enhancement of yellowness hue component (b_TSR) of the total hue of the beer matrix than any other beer colouring agent applied for colour adjustment of pale lager beers.

Table 4.6.1 Comparative values of CIECAM02 colour appearance predictors obtained by Minolta CS-1000 tele-spectroradiometer on high ball glass at Verivide® Illumination cabinet and sensory viewing for each of the locally-brewed beer samples

Sample	J	M	h	a	b	Lv	Cv	hv	av	bv	Opv	Clv
CH Fr	55.1	66.6	65.2	0.44	1.37	56.28	41.9	45.0	30.40	28.91	2.6	7.44
CH Fo	52.8	65.2	64.1	0.45	1.33	55.56	43.4	42.3	32.16	29.22	2.8	7.22
CH Ag	39.22	52.92	39.3	0.43	1.06	44.89	61.5	44.75	30.82	34.96	4.06	5.79
CA Fr	59.3	66.9	69.6	0.38	1.43	59.83	37.8	48.9	25.38	27.94	2.5	7.29
CA Fo	57.5	67.8	67.7	0.41	1.42	57.72	39.4	47.3	26.78	28.97	2.4	7.75
CA Ag	45.78	60.44	66.31	0.35	1.19	49.50	55.1	51.75	31.15	45.33	3.5	6.00
ME Fr	50.45	64.38	61.65	0.48	1.28	53.28	44.5	47.5	33.59	29.19	2.9	6.97
ME Fo	56.50	62.60	67.75	0.38	1.32	56.83	38.9	44.5	25.49	29.32	2.5	7.35
ME Ag	43.26	55.36	64.94	0.35	1.08	51.44	50.3	54.25	30.11	45.23	3.79	6.17
CM Fr	59.93	58.12	71.65	0.30	1.27	62.61	31.1	54.9	18.06	25.32	2.1	7.93
CM Fo	58.67	58.38	69.97	0.33	1.26	61.11	34.1	52.3	21.31	26.56	2.5	7.53
CM Ag	49.07	54.14	68.99	0.27	1.12	65.56	42.7	58.1	19.33	44.66	2.14	7.79
CAR Fr	64.41	58.98	75.39	0.25	1.32	66.61	28.5	60.0	16.55	23.20	2.0	8.06
CAR Fo	56.73	58.78	69.09	0.34	1.25	60.44	35.7	53.3	21.55	26.33	2.22	8.00
CAR Ag	49.22	53.55	68.94	0.26	1.11	62.28	40.2	58.15	19.79	41.77	2.37	7.65
CF Fr	63.77	58.00	74.94	0.26	1.30	65.56	30.0	60.7	16.73	24.90	2.06	8.25
CF Fo	58.95	59.39	71.59	0.31	1.29	61.17	31.1	54.0	18.31	25.20	2.25	7.97
CF Ag	46.24	53.52	67.80	0.28	1.08	56.56	45.6	60.25	18.08	41.09	2.42	7.47
CFSP Fr	56.39	55.30	69.20	0.32	1.19	58.72	34.4	59.5	21.60	26.84	2.44	7.83
CFSP Fo	52.04	59.01	64.33	0.41	1.21	53.28	42.1	46.7	30.03	29.51	3.72	5.97
CFSP Ag	49.09	53.38	68.96	0.26	1.10	67.61	40.6	55.5	16.13	38.00	2.06	7.89
RB Fr	59.25	54.60	72.42	0.28	1.20	62.17	33.5	60.5	20.64	26.39	2.08	7.72
RB Fo	55.00	61.46	67.34	0.38	1.29	56.67	39.0	48.3	27.58	27.58	2.56	7.69
RB Ag	46.60	52.06	67.10	0.29	1.05	55.11	46.7	49.5	24.83	37.87	2.42	7.57
SIN Fr	56.71	58.62	69.91	0.33	1.25	58.11	37.1	52.5	25.02	27.32	2.92	7.03
SIN Fo	49.61	59.46	62.19	0.44	1.19	56.50	41.8	45.8	31.18	27.84	3.36	6.42
SIN Ag	44.41	56.63	65.02	0.36	1.11	50.22	59.3	47.25	29.92	40.06	2.86	6.86
#301 Fr	56.69	60.07	69.31	0.34	1.28	60.78	33.7	52.3	21.42	26.02	2.58	7.53
#301 Fo	60.22	56.66	72.82	0.28	1.24	62.50	32.1	51.9	19.40	25.51	2.31	7.94
#301 Ag	47.57	53.23	67.92	0.28	1.09	58.00	46.4	56.9	21.25	39.54	2.67	7.04
PM Fr	64.35	55.58	76.12	0.23	1.25	67.33	26.9	57.9	14.78	22.42	1.75	8.56
PM Fo	65.40	49.68	76.59	0.20	1.13	71.06	23.4	57.6	10.15	21.14	2.03	8.22
PM Ag	54.83	51.45	71.99	0.20	1.11	67.44	35.1	68.4	14.80	43.97	1.88	7.83
		X	**Y**	**Z**				**Observer data**				
Black background		2.13	2.33	2.64					0	0		
White background		160.35	177.84	173.80					100.00	100.00		

4.6.3.1.2.2 Influence of depth on the determination of beer colour appearance (Use of calibrated cell)

Table A.4.12 and A.4.13 of appendix A show the mean values of the tristimulus values and the CIECAM02 colour appearance predictors obtained by the Minolta CS-1000 tele-spectroradiometer for the locally-brewed beers at the calibrated cell with different depths over black and white background, respectively.

CIECAM02 lightness (J_TSR) 50/40/30mm (w/bg):

The CIECAM02 lightness (J_TSR) obtained of the fresh locally-brewed beers presented a similar behaviour to EBC colour units, CIE L*, visual lightness (Lv), but did not match the CIECAM02 lightness (J_TSR) by simulation of sensory viewing with tele-spectroradiometry. The fresh beer control (100% pilsner malt) and the fresh beer colour-adjusted with melanoidin malt showed the highest values. The other fresh samples presented no clear difference between them.

In the case of the yellowness hue component (b_TSR) of the forced aged beers (7 days at 60℃), all the values matched the EBC colou r units and the CIE lightness (L*) but did not match either the visual lightness (Lv) or the CIECAM02 lightness (J_TSR) by simulation of sensory viewing with tele-spectroradiometry. The forced aged beer control (100% pilsner malt) showed the highest yellowness hue component (b_TSR), while the forced aged beer colour-adjusted with dark crystal malt (CARAAROMA®) and roasted malt (CARAFA® Type III) showed an outstanding decrease of it. This is attributed to the thermal treatment exposed to the samples during the forcing beer ageing.

The spontaneously aged locally-brewed beer control (100% pilsner malt) presented the highest yellowness hue component (b_TSR), while the spontaneously aged beers (12 months at 4℃) colour-adjusted with co louring beer (SINAMAR®), roasted barley and light crystal malt (CARAHELL®) presented the lowest one among the other spontaneously aged locally-brewed beers. No difference was detected between the other remaining spontaneously aged samples.

CIECAM02 colourfulness (M_TSR) 50/40/30 mm (w/bg)

The fresh and forced aged (7 days at 60℃) locally-brewed beers did not match the CIE chromatic chroma (C*), the yellowness index (Y.ID1925), the visual colourfulness (Cv), and the CIECAM02 colourfulness by sensory viewing simulation with tele-spectroradiometry (M_TSR). Nevertheless, the spontaneously aged locally-brewed beers (12 months at 4℃) showed some similarity to those results obtained from the colour measuring methods applied earlier in this investigation. The spontaneously aged beer colour-adjusted with light crystal malt (CARAAMBER®) remarkably show higher CIECAM02 colourfulness (M_TSR) than the other spontaneously aged samples analysed, while the spontaneously aged beers colour-adjusted with roasted barley and artificial colorant (CARAMEL #301) showed the lowest one.

CIECAM02 hue angle (h_TSR) 50/40/30 mm (w/bg)

The fresh locally-brewed beers colour-adjusted with roasted barley, dark crystal malt (CARAMUNICH® Type III) and artificial caramel colorant (CARAMEL #301) showed clear lower CIECAM02 hue angle (h_TSR) in comparison to the fresh remaining beers. The fresh beer control (100% pilsner malt) presented the highest CIECAM02 hue angle (h_TSR) from all the samples under investigation.

A decrease of CIECAM02 hue angle (h_TSR) of the forced aged beers (7 days at 60℃) against fresh ones was observed. Nevertheless, the results presented the same trend as the fresh samples.

The spontaneously aged beers (12 months at 4℃) colour-adjusted with dark crystal malt (CARAMUNICH® Type III) and colouring beer (SINAMAR®) showed the lowest CIECAM02 hue angle (h_TSR), while the spontaneously beer control (100% pilsner malt) presented the highest one.

The overall results matched those obtained by EBC colour units, but did not match those obtained for yellowness index (Y.ID1925), visual hue (hv) and CIECAM02 hue angle (h_TSR) by simulation of sensory viewing with tele-spectroradiometry (h). In other words, there were some inconsistencies by using this method.

CIECAM02 redness-greenness hue component (a_TSR) 50/40/30mm (w/bg):

The results of fresh locally-brewed beers did not match the CIE redness-greenness hue component (a*). Nonetheless, the results matched those obtained for EBC colour units, visual redness hue component (av) and CIECAM02 redness hue component (a_TSR) by simulation of sensory viewing with tele-spectroradiometry. The forced aged (7 day at 60℃) and spontaneously aged (12 months at 4℃) locally-brewed beers presented very similar behaviour to the fresh ones. The fresh beers colour-adjusted with light crystal malts (CARAAMBER® and CARAHELL®) and melanoidin malt showed the highest CIECAM02 redness hue component (a_TSR). Furthermore, the beer control (100% pilsner malt) at the distinct aged states showed the lowest CIECAM02 redness hue component (a_TSR) and no clear difference among the other colour-adjusted samples was observed.

CIECAM02 yellowness-blueness hue component (b_TSR) 50/40/30mm (w/bg)

The fresh beers colour-adjusted with light crystal malts (CARAHELL® and CARAAMBER®), melanoidin malt and artificial caramel (CARAMEL #301) showed the lowest CIECAM02 yellowness hue component (b_TSR). The fresh beer control (100% pilsner malt) showed the highest one between all the fresh samples.

In the case of the forced aged beers (7 days at 60℃), there was no apparent match with the previous results from the other methods used. The forced aged beer control (100% pilsner malt) presented the highest CIECAM02 yellowness hue component (b_TSR), followed by the forced aged beers colour-adjusted with dark crystal malts (CARAMUNICH® Type III and CARAAROMA®) and roasted malt (CARAFA® Type III). The forced aged beers colour-adjusted with roasted malt (CARAFA® Type III), roasted barley, colouring beer (SINAMAR®) and artificial caramel colorant (CARAMEL #301) showed a considerable reduction of the CIECAM02 yellowness hue component (b_TSR).

The results obtained for the spontaneously aged (12 months at 4℃) locally-brewed beers did not match those obtained for EBC colour units, CIE yellowness-blueness (b*), yellowness index (Y.ID1925), and visual yellowness-blueness (bv). Thus, the results did not match any colour property previously analysed.

4.6.3.1.3 Determination of colour appearance predictors by digital imaging method (DigiEye System-VeriVide®)

Tables A.4.14 to A.4.16 of appendix A present the device coordinates (RGB), tristimulus values and the mean values of CIECAM02 colour appearance predictors obtained by DigiEye System-VeriVide® (Digital Imaging) for each of the locally-brewed beer samples on cell at different depths over black/white background, respectively. In addition, table A.4.17 of appendix A displays the comparative mean values of CIECAM02 colour appearance predictors obtained by Minolta CS-1000 tele-spectroradiometer and DigiEye System-VeriVide® (Digital Imaging) for each of the beer samples on different depths over white background.

Contrast ratio:

The fresh locally-brewed beers colour-adjusted with colouring beer (SINAMAR®) and artificial caramel colorant (CARAMEL #301) showed the highest contrast ratio, while the fresh beer control (100% pilsner malt) and the fresh beers colour-adjusted with dark crystal malt (CARAAROMA®), roasted barley and roasted malts (CARAFA® Type III and CARAFA® SPECIAL Type III) presented the lowest one. The other fresh samples showed no clear distinction between them.

In the case of forced aged locally-brewed beers (7 days at 60℃), it was found that the forced aged beers coloured-adjusted with dehusked roasted malt (CARAFA® SPECIAL Type III) and colouring beer (SINAMAR®) showed much higher contrast ratio than the other forced aged beers. The remaining forced aged samples showed no clear difference between them. Therefore, no congruency could be observed.

Concerning the spontaneously aged locally brewed beers (12 months at 4℃), it was seen that the spontaneously aged beers colour-adjusted with light crystal malts (CARAHELL® and CARAAMBER®) and melanoidin malt showed much higher contrast ratio than the other spontaneously aged samples. There was no clear difference between the other spontaneously aged samples. These results matched the contrast ratios measured by simulation of sensory viewing with tele-spectroradiometry.

CIECAM02 lightness (J_DIG) 50/40/30mm (w/bg):

At this point an interesting finding was observed. CIECAM02 lightness (J_DIG) by digital imaging matched accurately the visual lightness and CIECAM02 lightness (J_TSR) by simulation of sensory viewing with tele-spectroradiometry, but the beer samples showed less sharp difference between them. This means, the values were lower in terms of magnitude than visual lightness (Lv) but maintained the same tendency.

The fresh beer control (100% pilsner malt) and the fresh beer colour-adjusted with dark crystal malt (CARAMUNICH® III) presented the highest CIECAM02 lightness (J_DIG) in comparison to the other fresh samples, as well as the fresh beers colour-adjusted with melanoidin malt, dehusked roasted malt (CARAFA® SPECIAL Type III) and artificial colorant (CARAMEL #301) showed the lowest CIECAM02 lightness (J_DIG) from all the fresh samples.

The values obtained from the forced aged locally-brewed beers (7 days at 60℃) did not match the corresponding visual lightness (Lv) and CIECAM02 lightness by simulation of sensory viewing with tele-spectroradiometry (J). The forced aged beer control (100% pilsner malt) showed the highest CIECAM02 lightness (J_DIG) while the forced aged beer colour-adjusted with dehusked roasted malt (CARAFA® SPECIAL Type III) showed the lowest one.

The spontaneously aged beers (12 months at 4℃) colour- adjusted with colouring beer (SINAMAR®) and light crystal malt (CARAHELL®) showed the lowest CIECAM02 lightness (J_DIG). The spontaneously aged beer control (100% pilsner malt) presented the highest CIECAM02 lightness (J_DIG) and there was no clear difference among the other spontaneously aged samples.

CIECAM02 colourfulness (M_DIG) 50/40/30 mm (w/bg)

The values obtained from the fresh locally-brewed beers did not match with the visual colourfulness (Lv) and the CIECAM02 colourfulness (M_TSR) by simulation of sensory viewing with tele-spectroradiometry as well as the values presented a lower magnitude than the analogue predictors. Therefore, no consistency could be attained.

The fresh beer colour-adjusted with light crystal malt (CARAAMBER®) showed the highest CIECAM02 colourfulness (M_DIG), while the fresh beers colour-adjusted with colouring beer (SINAMAR®), dehusked roasted malt (CARAFA® SPECIAL Type III) and artificial caramel (CARAMEL #301) showed the lowest one. There was no difference between the other fresh samples.

All the results for forced aged locally-brewed beers (7 days at 60℃) were very similar to the fresh beer samples. In the case of spontaneously aged locally-brewed beers (12 months at 4℃), it was observed that spontane ously aged beer colour-adjusted with light crystal malt (CARAAMBER®) and the spontaneously aged beer control (100% pilsner malt) obtained the highest CIECAM02 colourfulness (M_DIG) while the spontaneously aged beers colour-adjusted with roasted barley, artificial colorant (CARAMEL #301) and colouring beer (SINAMAR®) had the lowest one. There was no clear difference between the other spontaneously aged samples.

CIECAM02 hue angle (h_DIG) 50/40/30 mm (w/bg)

The results of the fresh locally-brewed beers did not match any other analogue predictor measured previously. The fresh beer control (100% pilsner malt) showed the highest CIECAM02 hue angle (h_DIG), while the fresh beers colour-adjusted with melanoidin malt and light crystal malt (CARAHELL®) presented the lowest one in comparison to the other fresh samples.

The forced aged beers (7 days at 60℃) colour-adjusted with roasted products (CARAFA® SPECIAL Type III and roasted barley) showed the lowest CIECAM02 hue angle (h_DIG), while the forced aged beer control (100% pilsner malt) showed the highest one. In general, as the values increase in terms of magnitude the smaller the depth of the calibrated cell.

Regarding the spontaneously aged locally-brewed beers (12 months at 4℃), the spontaneously aged beer control (100% pilsner malt) presented the highest CIECAM02 hue angle (h_DIG) while the spontaneously aged beers colour-adjusted with colouring beer (SINAMAR®) and light crystal malt (CARAHELL®) presented the lowest one. There was no clear difference between the other spontaneously aged samples.

CIECAM02 redness-greenness hue component (a_DIG) 50/40/30mm (w/bg):

The fresh locally-brewed beers colour-adjusted with light crystal malts (CARAHELL® and CARAAMBER®) and melanoidin malt showed clear higher CIECAM02 redness hue component (a_DIG) than the other fresh samples, while the fresh beer control showed the lowest one. There was no significant difference between the other fresh samples.

The forced aged (7 days at 60℃) and spontaneously aged locally-brewed beers (12 months at 4℃) presented the same trend as the fresh samples. The forced aged beers colour-adjusted with colouring beer (SINAMAR®) and artificial caramel showed the lowest CIECAM02 redness hue component (a_DIG).

CIECAM02 yellowness-blueness hue component (b_DIG) 50/40/30mm (w/bg):

The results obtained from the fresh locally-brewed beers presented no clear difference between them. Even though, the beers colour-adjusted with dehusked roasted malt (CARAFA® SPECIAL Type III) and artificial caramel colorant (CARAMEL #301) had the lowest CIECAM02 yellowness hue component (b_DIG) from all the fresh samples investigated.

The forced aged (7 days at 60℃) and spontaneously aged locally-brewed beers (12 months at 4℃) also showed no clear distinction between the other samples in terms of CIECAM02 yellowness hue component (b_DIG), but the forced aged and spontaneously aged beer colour-adjusted with dehusked roasted malt (CARAFA® SPECIAL Type III) obtained a sudden decrease, being the lowest one among all the forced aged and spontaneously aged beer samples. As a general observation, we can state that there is no match between sensory viewing, tele-spectroradiometry (simulation and depth) and digital imaging (depth) with the results obtained for CIECAM02 predictors by spectrophotometry.

There was inconsistency and incongruency for all CIECAM02 values over black background by tele-spectroradiometry as well as by digital imaging. Therefore, they might be discarded for any further physical colour appearance measurement. The CIECAM02 colourfulness (M_TSR) and hue angle (h_TSR) data by tele-spectroradiometry and digital imaging by using calibrated cell did not match those obtained by sensory viewing, EBC colour units, CIE L*a*b* and yellowness index.

Regarding the measurements of CIECAM02 colour appearance predictors by tele-spectroradiometry and digital imaging with calibrated cell, the less deep the measurement is taken (*i.e.* 30 mm) the sharper difference between samples is obtained.

4.6.3.1.4 Observer repeatability and observer accuracy of the sensory viewing assessments of the locally-brewed beers at different ageing stages

The observer repeatability and observer accuracy of the sensory viewing assessments of the locally-brewed samples were calculated by means of the square of the correlation coefficients obtained or so-called coefficients of determination (R^2) and the ratio of the standard deviation to the mean or so-called coefficient of variation (CV) between each individual observer's two data sets.

The selection of these parametric statistics is based upon the fact that the coefficient of determination (R^2) provides information of how well the regression curve approximates the real data values. Likewise, the coefficient of variation (CV) as a normalised measure of dispersion of a probability distribution of the observer data obtained, delivers a dimensionless number which is more useful in terms of comparing different values of colour appearance predictors with different magnitude scales instead of the standard deviation. Table 4.6.2 as well as Tables A.4.8 and A.4.9 of Appendix A display the observer repeatability and observer accuracy of the sensory viewing assessments of the locally-brewed beers at different ageing stages.

According to the repeatability results, large coefficients of determination (R^2) in all the colour appearance attributes of all the locally-brewed beers were detected. This means that great observer repeatability on the sensory viewing assessments was achieved. Visual lightness (Lv), visual colourfulness (Cv) and visual hue angle (hv) presented the largest coefficients of determination, while the liquid translucency attributes such as visual opacity (Opv) and visual clarity (Clv) showed a slightly lower ones. These results present the same trend as those reported by previous studies (Gonzalez-Miret *et al.*, 2007), which claimed this effect is caused by little drifts of illumination sources as well as by the geometry of the liquid container, which will induce significant modifications on the colour appearance perception of translucent colloid samples.

In the case of the observer accuracy results, smaller coefficients of determination for visual lightness (Lv), visual colourfulness (Cv), visual hue angle (hv), visual opacity (Opv) and visual clarity (Clv) were found in comparison to observer repeatability. Nonetheless, all observer accuracy values showed the same tendency to those obtained for the observer repeatability. These results are in good agreement with the previous findings from other previous investigations (Gonzalez-Miret *et al*., 2007; Luo *et al*., 1991; Melgosa *et al*., 2000). In general, it is possible to claim that the magnitude estimation experiments can effectively measure the colour appearance parameters of pale lager beers.

Table 4.6.2 Observer repeatability and accuracy of the sensory viewing assessment of the locally-brewed beers at different ageing stages

	FRESH BEERS (<1 month old) Observer repeatability		FORCED BEERS (60℃/1 week) Observer. repeatability		AGED BEERS (12 months old) Observer. repeatability	
	R^2	CV	R^2	CV	R^2	CV
Visual lightness	0.95	0.25	0.95	0.27	0.83	0.26
Visual colourfulness	0.90	0.34	0.86	0.32	0.72	0.35
Visual hue angle	0.91	0.32	0.83	0.31	0.86	0.38
Visual opacity	0.75	0.45	0.68	0.44	0.86	0.60
Visual clarity	0.74	0.16	0.77	0.18	0.73	0.22
	FRESH BEERS Observer accuracy		**FORCED BEERS Observer accuracy**		**AGED BEERS Observer accuracy**	
	R^2	CV	R^2	CV	R^2	CV
Visual lightness	0.70	0.10	0.63	0.12	0.62	0.18
Visual colourfulness	0.67	0.22	0.70	0.23	0.54	0.25
Visual hue angle	0.51	0.15	0.57	0.18	0.62	0.17
Visual opacity	**0.48**	0.30	**0.47**	0.32	0.65	0.40
Visual clarity	**0.34**	0.12	0.65	0.14	0.59	0.16

4.6.3.1.5 Comparison between the colour appearance measuring methods

Table 4.6.3 shows all the significant correlations between each colour appearance predictors evaluated by psychophysical assessments (sensory viewing method) and physical measurements (tele-spectroradiometry and digital imaging).

The results obtained in this investigation showed a large correlation between the sensory viewing assessments (magnitude estimation) and tele-spectroradiometry measurements at simulation of sensory viewing conditions (use of highball glass). This good agreement between the two colour appearance measuring methodologies matched to those reported by previous studies (Gonzalez-Miret *et al.*, 2007; Luo *et al.*, 2002).

Nonetheless, the correlations between the colour appearance physical measurements (tele-spectroradiometry and digital imaging) at calibrated cell conditions (influence of depth) did not present any good agreement, but small and medium coefficients of determination (R^2). These results showed relevant discrepancies in comparison to those obtained for the colour appearance of distinct sorts of wine reported by previous research (Gonzalez-Miret *et al.*, 2007).

This discrepancy may be caused by the different matrix composition between the portfolio of pale lager beers and wines producing significant changes on the colour appearance phenomena and the translucency of liquids. For instances, the wavelengths of the visible light are absorbed in different proportions depending upon the matrix composition of colloids, while other wavelengths are reflected back to the observer eyes or optical measurement instruments (Blevins, 2006). In addition, the colour consistency as the apparent invariance in the colour appearance of the beer does not exist in the human sight in realistic terms. This is due to the everyday life of the human eye being used to create the perception of a majority of colours as consistent matter by remembering the colours rather than looking at them carefully (Fairchild, 2006). Therefore, different colour perception is generated by the human eye, which the physical colour appearance technologies (*i.e.* tele-spectroradiometry and digital imaging) proposed in this research are not capable of producing at specific conditions such as the influence of different depths (10, 20 and 30 mm). For this reason, it is suggested to improve the characterisation of the CIECAM02 colour appearance model by having multiple mechanisms of chromatic adaptation based on the truly psychophysical perception of the colour appearance by the human eye which implies the quantification and the prediction of failure of colour consistency.

Table 4.6.3 Correlation between colour appearance predictors provided by the distinct methodologies of colour appearance measurements

Colour appearance predictors	**Correlation factor**	**Magnitude**
Lv *vs* J_TSR highball	R^2= **0.88**	**Large**
Cv *vs* M_TSR highball	R^2 = **0.56**	**Large**
hv *vs* h_TSR highball	R^2 = **0.87**	**Large**
Lv *vs* J_TSR 50/40/30 mm depth	R^2 = 0.03	None
Cv *vs* M_TSR 50/40/30 mm depth	R^2 = 0.03	None
hv *vs* h_TSR 50/40/30 mm depth	R^2 = 0.00	None
Lv *vs* J_DIG 50/40/30 mm depth	R^2 = 0.09	Small
Cv *vs* M_DIG 50/40/30 mm depth	R^2 = 0.01	None
hv *vs* h_DIG 50/40/30 mm depth	R^2 = 0.18	Small
J_TSR highball *vs* J_DIG 50/40/30 mm depth	R^2 = 0.03	None
M_TSR highball *vs* M_DIG 50/40/30 mm depth	R^2 = 0.00	None
h_TSR highball *vs* h_DIG 50/40/30 mm depth	R^2 = 0.08	None
J_TSR 50/40/30 mm depth *vs* J_DIG 50/40/30 mm depth	R^2 = 0.34	Medium
M_TSR 50/40/30 mm depth *vs* M_DIG 50/40/30 mm depth	R^2 = 0.05	None
h_TSR 50/40/30 mm depth *vs* h_DIG 50/40/30 mm depth	R^2 = 0.36	Medium
Correlation (R^2)	**Negative**	**Positive**
Small	-0.3 to -0.1	0.1 to 0.3
Medium	-0.5 to -0.3	0.3 to 0.5
Large	-1.0 to -0.5	0.5 to 1.0

4.6.3.2 Detection and quantification of ageing flavour-active aldehydes of the locally-brewed beers

The results obtained of the GC-MS analysis for the detection and quantification of the ageing flavour-active compounds of all the locally-brewed beers examined [fresh, forced aged (7 days at 60℃) and spontaneously aged (12 months at 4℃)] are presented in Tables A.5.1 to A.5.3 of Appendix A and Charts B.5.1 to B.5.30 of Appendix B. Table 4.6.4 summarises the mean of the concentration of these compounds.

The analytical approach of ageing flavour-active compounds of the first round of locally-brewed beers was focused exclusively on the detection and quantification of the flavour-active aldehydes such as beer ageing markers (see Lustig *et. al.*, 1991; Lustig, 1993; Lustig *et al*., 1993; Narziß *et al.*, 1999; Vesely *et al.*, 2003). At this point, the detection and quantification of the beer ageing flavour-active non-aldehyde compounds were discarded due to lack of consistency and certain anomalies on the GC-MS analysis carried out at the I.C.B.D. facilities. Nevertheless, this was successfully attained in later stages of this research.

In general, the concentration of the beer ageing flavour-active aldehydes of all the portfolio of the beer samples showed good agreement with previous studies (Lustig *et. al.*, 1991; Lustig, 1993; Lustig *et al*., 1993; Narziß *et al*., 1999; Saison *et al.*, 2008; Vesely *et al.*, 2003). Additionally, evident difference of concentrations was noticed between the beer samples in fresh, forced aged (7 days at 60℃) and spontaneous aged (12 months at 4℃) conditions. This difference was manif ested not only in each single beer ageing flavour-active aldehyde but also in a holistic manner. At spontaneously aged conditions (12 months at 4℃), the locally-brewed beer colour-adjusted with melanoidin malt presented the lowest concentration of aldehydes in comparison to the other beer samples while the beer colour-adjusted with light crystal malt (CARAHELL®) showed the highest concentration of aldehydes from all portfolio of the locally-brewed beers under investigation (see Table 4.6.4).

At this point, one has to bear in mind that the variation of the concentration of the beer ageing flavour-active compounds does not only depend upon the quality and composition of the brewing materials used for the production of locally-brewed beers but significantly upon the process variabilities generated through all the brewing processes (see section 1.6). Particularly, one of these variabilities is the metabolism of the brewing yeast used, which maintains a steady state rather than maintaining equilibrium in thermodynamic terms. This steady state is achieved by regulation or compensation of the concentration of intermediate products and the level of flux on the metabolic pathways of the yeast cell. According to the literature (see Voet, 2002), these precise regulation controls can be greatly affected by several metabolic mechanisms more specifically such as allosteric control (feedback regulation; regulation by substrates, products or coenzymes), covalent modification (regulation by enzymes), substrate cycles, and genetic control (regulation by protein synthesis in response to metabolic needs). For instance, previous studies (Coghe *et al.*, 2006) have demonstrated that non-enzymatic browning reaction by-products from roasted malt such as CARAFA® Type III and CARAFA® SPECIAL Type III affect the yeast cell membrane giving, as a consequence, a faster formation of acetolactate or a slower reduction of diacetyl in comparison to worts brewed with dark crystal malt such as CARAAROMA®. This is due to the fact that roasted malts promote greater oxidation of acetolactate to diacetyl than diacetyl assimilation and reduction by the yeast. Nevertheless, the outcomes reported by the latter investigations (*ibid.*) were obtained from dark worts and green beers, as well as the specialty malts ratios used on the grain bills were atypically high and unrealistic in terms of the brewing industrial specifications. Taking this into account, they were not considered as standard conditions for the purposes of this research but as analytical clues regarding the influence of the colouring agents on beer flavour stability.

A higher concentration of 2-methylpropanal, 2-methylbutanal, 3-methylbutanal and 2-phenylethanal in the fresh locally-brewed beers colour-adjusted with melanoidin malt, light crystal malts (CARAAMBER® and CARAHELL®) and artificial caramel colorant (CARAMEL #301) was detected in comparison to the remaining fresh samples. Conversely, the lowest concentration in the fresh locally-brewed beers colour-adjusted with roasted malts (CARAFA® Type III and CARAFA® SPECIAL Type III) was found. These results are in disagreement with the findings reported by Coghe *et al.* (2006). These Belgian researchers claimed that roasted malt products possess higher oxidative potential due to significant levels of functional groups with scavenging activity are lost by possible participation in polymerisation reactions, leading to the formation of high molecular weight (HMW) melanoidins, which are produced in advanced non-enzymatic browning reactions at high thermal treatment above 150℃ during roasting. Besides, Coghe *et al.* (2004) previously found that dark crystal malts (480 EBC) are prone to containing more aldehydes from non-enzymatic browning reactions or so called Maillard reactions than roasted products, such as dehusked roasted malts and roasted barley. Likewise, they discovered that 3-methylbutanal is the main Maillard aldehyde presented in dark worts brewed with dark crystal malts. 3-Methylbutanal is formed by the Strecker degradation of the aminoacid leucine, which subsequently is reduced to 3-methylbutanol during fermentation-maturation stages and finally chemically or enzymatically decarboxylated to 3-methylbutanal (*ibid*.).

Concerning the detection and quantification of benzaldyde, a higher concentration in the fresh beer samples colour-adjusted with roasted barley and colouring beer (SINAMAR®) as well as in the fresh beer control (100% pilsner malt) was found. In contrast, the lowest levels in the fresh beer samples colour-adjusted with dehusked roasted malt (CARAFA® SPECIAL Type III), light crystal malt (CARAAMBER®) and artificial caramel colorant (CARAMEL #301) were detected. These outcomes for the detection and quantification of benzaldehyde as a beer ageing marker made no distinguishable consistency between the fresh locally-brewed beers analysed due to the majority of them being colour-adjusted with colouring agents of a distinct nature presenting similar concentrations at this point. A scientific argument of this apparent similarity of beer ageing flavour-active aldehydes concentration in most of the samples is the fact that reducing compounds in wort and beer can be formed throughout any thermal treatment independently of the thermal conditions established (see Savel, 2001). Therefore, any kilning and wort boiling programme can induce at distinct degrees the formation of reducing compounds during the early Maillard reactions stages. Likewise, wort sugars can undergo conversions to reductones which can be further degraded providing oxygen-free radicals. This thermal sugars degradation can be carried out in very low thermal conditions (*ibid.*).

The fresh beer samples colour-adjusted with roasted malt products (CARAFA® Type III and CARAFA® SPECIAL Type III), melanoidin malt, and light crystal malt (CARAAMBER®) showed a higher concentration of pentanal and hexanal, while the fresh beer control (100% pilsner malt) and the fresh beer colour-adjusted with light crystal malt (CARAHELL®) showed the lowest one. In addition, the fresh beer sample colour-adjusted with dark crystal malt (CARAMUNICH® Type III) and light crystal malts (CARAAMBER® and CARAHELL®) obtained the highest concentration of methional. Conversely, the fresh beer colour-adjusted with melanoidin malt and the fresh beer control presented remarkably low methional levels in comparison to the remaining group of fresh beer samples.

Regarding the concentration of (*E*)-2-nonenal, on one hand the fresh beer control presented clearly the highest one in comparison to the other fresh beer samples. On the other hand, the fresh beer samples colour-adjusted with light crystal malts (CARAHELL® and CARAAMBER®) and artificial caramel colorant (CARAMEL #301) exhibited the lowest concentrations. This observation suggest the possibility that all colouring agents for beer colour adjustment may contribute to the reduction of (*E*)-2-nonenal levels in the beer matrix by protecting the product with colorant pigments which enhance the colour intensity of the beers products in question. Even though, light crystal malts

(CARAHELL® and CARAAMBER®) and artificial caramel colorant (CARAMEL #301) apparently promote a better protection of (*E*)-2-nonenal than the remaining the colouring agents examined.

Finally, the fresh locally-brewed beers colour-adjusted with light crystal malts (CARAHELL® and CARAAMBER®) displayed the highest concentration of 2-furfural. In contrast, the fresh locally-brewed beer colour-adjusted with colouring beer (SINAMAR®) and the fresh blank sample showed the lowest one. In accordance with previous investigations (Syryn *et al*., 2007), the increase of 2-furfural levels does not confer off-beer flavour connotations, although greatly related to intense thermal stress in beer. As well as its high concentration have a significant impact of the total concentration of flavour-active Strecker aldehydes related to beer ageing due to the concentration of 2-furfural is proportionally much higher than other Strecker aldehydes analogues (*ibid.*).

In reference to the outcomes from the forced aged locally-brewed beers (7 days at 60℃), an evident increase of all the portfolio of beer ageing flavour-active compounds examined in this investigation was observed in comparison to the fresh samples, although this increase was more remarkable in some forced aged beer samples than others.

The forced aged locally-brewed beers (7 days at 60℃) colour-adjusted with light crystal malts (CARAHELL® and CARAAMBER®) showed much higher levels of 2-methylpropanal. Conversely, the beer samples colour-adjusted with dark crystal malt (CARAAROMA®) and artificial caramel colorant (CARAMEL #301) showed the lowest ones. These results are in agreement with those found in the fresh samples and the findings published by Coghe *et al.* (2006).

A remarkable higher concentration of 2-methylbutanal, 3-methylbutanal and 2-phenylethanal in the forced aged locally-brewed beers (7 days at 60℃) colour-adjusted with light crystal malt (CARAHELL®) and colouring beer (SINAMAR®) was detected. In contrast, the forced aged beers colour-adjusted with dark crystal malt (CARAAROMA®) and roasted malt (CARAFA® Type III) exhibited the lowest concentrations of these compounds.

Concerning the presence of benzaldehyde in the forced aged locally-brewed beers (7 days at 60℃), a higher concentration of this aldehyde in the beer samples colour-adjusted with roasted products, such as dehusked roasted malt (CARAFA® SPECIAL Type III) and roasted barley was observed. Conversely, the lowest levels of benzaldehyde in the forced aged locally-brewed beers colour-adjusted with dark crystal malt (CARAAROMA®) were identified.

On the subject of the detection and quantification of pentanal and hexanal, a significant higher concentration of these flavour-active aldehydes in the forced aged locally-brewed beers (7 days at 60℃) colour-adjusted with dark crystal malt (CARAMUNICH® Type III) and dehusked roasted malt (CARAFA® SPECIAL Type III) was noticed. In contrast, there was no clear difference of concentration among the other beer samples.

Higher levels of methional in the forced aged locally-brewed beers (7 days at 60℃) colour-adjusted with roasted barley, dehusked r oasted malt (CARAFA® SPECIAL Type III) and light crystal malt (CARAHELL®) were noticed. On the other hand, relative low levels of this compound in the forced aged beer sample colour-adjusted with melanoidin malt were observed. In contrast, higher amounts of (*E*)-2-nonenal in the forced aged locally-brewed beers colour-adjusted with artificial caramel colorant (CARAMEL #301), dark crystal malt (CARAAROMA®) and roasted barley were found. Notwithstanding, low levels of (*E*)-2-nonenal in the forced aged locally brewed-beer colour-adjusted with colouring beer (SINAMAR®) were detected. This reinforced the outcomes reported by previous investigations (Bravo *et al*., 2008), which demonstrated that forcing beer ageing used in this research increases significantly the amounts of (*E*)-2-nonenal in comparison to beers at fresh storage conditions.

Additionally, the presence of 2-furfural as a beer ageing marker was clearly higher in the forced aged locally-brewed beer (7 days at 60℃) colour-adjusted with light crystal malt (CARAHELL®), while the remaining forced aged samples showed no clear difference between them. These upshots are in disagreement with those obtained in the fresh analogue beers.

On the detection and quantification of beer ageing flavour active aldehydes in spontaneously aged locally-brewed beers (12 months at 4℃), a higher concentration of all the portfolio of aldehydes was observed in comparison to fresh and forced aged (7 days at 60℃) locally-brewed beers. In addition, no mat ch of concentration of the beer ageing flavour active aldehydes was found between the forced aged and the spontaneously aged locally-brewed beers. This clearly indicates that forcing beer ageing method does not mimic the spontaneous beer ageing in realistic terms. This can be attributed to the fact that forcing beer ageing supplies intense thermal treatment that may induce and elicit higher amounts of beer ageing markers in the beer matrix than in ordinary beer storage conditions.

Moreover, the outcomes obtained in the spontaneously aged locally-brewed beers (12 months at 4℃) are also in agreement with pr evious investigations (Preuß, 2000), which claimed that the concentration of the majority of the Strecker aldehydes usually increases in the first 6 to 12 months during storage. This is ultimately derived from flavour-active aldehydes which are formed either by the oxidation of the endogenous lipids of the malt and hops which remains in final beer and/or by the Strecker degradations of residual amino acids in the final extract of the finished beer (Hughes, 2008).

The spontaneously aged locally-brewed beers (12 months at 4℃) colour-adjusted with light crystal malts (CARAHELL® and CARAAMBER®) showed an evident higher concentration of 2-methylpropanal in contrast to the remaining spontaneously aged beer samples. Conversely, the spontaneously aged beer colour-adjusted with dark crystal malt (CARAAROMA®) presented the lowest values from all the spontaneously aged locally-brewed beers analysed. Similarly, significant higher levels of 2-methylbutanal, 3-methylbutanal and 2-phenylethanal in the spontaneously aged locally-brewed beers colour-adjusted with light crystal malt (CARAHELLl®) were noticed, while the lowest concentration in spontaneously aged beer sample colour-adjusted with dark crystal malt (CARAAROMA®) was found. The results disagree with those stated by previous research (Syryn *et al.*, 2007), which reported that the concentration of the precursors of 2-methylbutanal and 3-methylbutanal (*i.e.* 2-methylbutanol and 3-methylbutanol, respectively) does not significantly change during spontaneous beer ageing. The results obtained from the spontaneously aged locally-brewed samples proved the opposite. Thus, the formation of 2-methylbutanal and 3-methylbutanal seems to increase greatly during the beer ageing. In accordance with former studies (Narziß *et al.*, 1993) 3-methylpropanal, 2-methylbutanal, 3-methylbutanal and 2-furfural present noticeable increase of concentration when significant amounts of oxygen were uptaken during the wort production. For that reason, these compounds are concerned as oxygen damage indicators.

In reference to the concentration of benzaldehyde, the spontaneously aged beer samples (12 months at 4℃) colour-adjusted with dehusked r oasted malt (CARAFA® SPECIAL Type III), artificial caramel colorant (CARAMEL #301) and roasted barley obtained noticeable higher amounts than the remaining spontaneously aged samples. Alternatively, the spontaneously aged beer colour-adjusted with dark crystal malt (CARAAROMA®) displayed the lowest concentration from all the spontaneously aged samples. Likewise, higher levels of pentanal and hexanal in the spontaneously aged locally-brewed beers colour-adjusted with dark crystal malt (CARAMUNICH® Type III) and dehusked roasted malt (CARAFA® SPECIAL Type III) were observed. Although, no sharp difference of concentration of pentanal and hexanal was found among the other spontaneously aged samples. These latter compounds are derivatives of the fatty acids and alcohols oxidation. This oxidation may be produced by the active radical groups of the dark crystal malts and roasted products such as oxidised polyphenols or pyrazines polymers. In addition, possible matrix effect may take place depending on the composition of the locally-brewed beers. Nevertheless, further research need to be carried out to prove this hypothesis.

Besides, higher levels of methional in the spontaneously aged locally-brewed beers (12 months at 4°C) colour-adjusted with dehusked roasted malt (CARAFA® SPECIAL Type III), roasted barley and light crystal malt (CARAHELL®) were observed, while relative lower levels of this compound in the spontaneously aged locally-brewed beer colour-adjusted with melanoidin malt were found. The results are in agreement with previous findings (Methner *et al.*, 2005), which exhibited that the formation rate of methional apparently rise on spontaneously aged beers of minimum 8 months old. Additionally, the latter findings pointed out that the formation of methional is more quickly increased by light exposure on spontaneously aged pale lager beers stored at room temperature (20°C) (*ibid.*).

In connection with the development of (*E*)-2-nonenal, the spontaneously aged beers (12 months at 4°C) colour-adjusted with roasted barley and artificial caramel colorant (CARAMEL #301) displayed an outstanding concentration of (*E*)-2-nonenal in relation to the other spontaneously aged locally-brewed beers. Conversely, the remaining spontaneously aged samples showed no clear difference between them.

Very high levels of 2-furfural in the spontaneously aged locally-brewed beer (12 months at 4°C) colour-adjusted with light crystal malt (CARAHELL®) were detected in comparison to the remaining spontaneously aged beer samples, which showed no clear difference between them. This detection of 2-furfural in all the spontaneously aged locally-brewed beers under investigation contrasts with the previous results (Coghe *et al.*, 2004). They indicate that dark worts brewed with high amounts of dark crystal malts with a colour of approximately 480 EBC (CARAAROMA®) showed a higher concentration of 2-furfural than dark worts brewed with light crystal malts such as CARAHELL®. Nevertheless, the obtained results of 2-furfural levels in the spontaneously aged locally-brewed beers colour-adjusted with roasted malt products matched the previous ones obtained by previous research (*ibid.*), in which lower levels of oxygen heterocyclic compounds such as 2-furfural in dark worts brewed with roasted malts were detected.

In conclusion, it was found that melanoidin malt (*ca*. 4% of total grain bill) can promote better flavour stability in pale lager beers than the other colouring agents tested due to it showed the lowest concentration of flavour-active aldehydes (beer ageing markers) in spontaneously aged beer (12 months at 4℃) in comparison to the other samples. This conclusion are in agreement with those claimed by previous studies (Preuß, 2000), which proved that the beer flavour stability of dark lager beers is increased with the use of malt processed under longer kilning procedures at lower temperature than conventional kilning and roasted conditions. This can be based on the previous investigations in specialty malts (Coghe *et al.*, 2006), which concluded that colouring pigments or compounds such as melanoidins from light colour malts are mainly of low molecular weight (LMW) (<10 kDa), while those from roasted malt products are predominantly high molecular weight (HMW) but also of low molecular weight (LMW). The size of molecular weight of the colouring pigments or compounds has great impact on the reducing power of the colouring agents and the beer itself, therefore on their endogenous anti-oxidative potential. This previous research also found that the ingress of ordinary roasted malt products in the production of dark worts, provides lower anti-radical activity than other roasted malt products kilned and roasted with longer period of time and lower temperatures than the industrial conventional methods applied for the production of roasted specialty products for brewing. In other words, they suggested that anti-radical groups are predominantly formed in the latest stages of non-enzymatic browning reactions at temperatures above 150℃. Besides, they also concluded that lower kilning temperatures such as used for the production of melanoidin malt tend to yield high levels of potential antioxidants during the early stages of non-enzymatic browning reactions and caramelisation. Likewise, noticeable levels of functional groups with radical scavenging activity as well as reducing groups are obtained during gentle and shorter kilning programmes but lost at high temperatures (>150℃) such as conventional roasting conditions due to polymerisation reactions induced, which significantly elicit high molecular weight (HWM) melanoidins and other colouring compounds such a polymerised phenolic compounds, pyrazines, among others. This cause-and-effect relationship coincides proportionally with the final colour obtained from the specialty malt products.

In accordance with all the results described and discussed above, one can claim at this stage of the research that a relevant effect of the colouring agents for beer colour adjustment is present on the concentration of all portfolios of beer ageing flavour-active compounds. This means that the colouring agents influence directly on the beer flavour stability in terms of chemical composition of the beer matrix. Likewise based on the GC-MS results obtained, it is evident that a brewer may achieve more consistent pale lager beer products in terms of flavour quality by selecting melanoidin malt (*ca*. 4% of total grain bill) as colouring agents for beer colour adjustment. Notwithstanding, it is worth pointing out that the influence of colour adjustment on the beer flavour stability with the selection of the distinct colouring agents examined in this investigation is relatively elusive by considering only the analytical regime of this research at this point. Therefore, it is essential to confirm these first conclusions with clear credentials on the sensory analysis that will be provided by the I.C.B.D. trained tasting panel in the last stage of this investigation.

Table 4.6.4 Ageing flavour-active aldehydes of locally-brewed beers (Means)

	CARAHELL®			CARAAMBER®			MELANOIDIN MALT			CARAMUNICH® TYPE III		
	FRESH	FORCED	AGED	FRESH	FORCED	AGED	FRESH	FORCED	AGED	FRESH	FORCED	AGED
Pentanal (µg/L)	0.7	1.6	2.2	0.9	1.7	2.2	0.7	1.5	2.7	0.8	3.3	4.5
Hexanal (µg/L)	0.8	2.6	4.8	1.7	2.1	3.3	1.2	1.9	3.8	1.1	4.8	8
(*E*)-2-Nonenal (µg/L)	0.0	0.01	0.04	0.0	0.01	0.04	0.0	0.01	0.03	0.00	0.01	0.03
2-Methylpropanal (µg/L)	3.8	27.2	43.2	4.1	35	49	4.9	13.3	23.7	3.3	20.8	33.5
2-Methylbutanal (µg/L)	2.7	19.6	25.4	2.9	6.1	9.6	2.5	5.2	7.7	1.6	7.7	15.9
3-Methylbutanal (µg/L)	6.3	31.1	41.4	6.7	10.5	13.3	6.2	8.8	15.8	4.2	12.7	26.3
Benzaldehyde (µg/L)	1.3	3.3	5.9	1.1	2.8	4.3	1.2	3.1	4.2	1.4	3.9	6.6
2-Phenylethanal (µg/L)	17.3	39.5	72.4	17	26.7	41.3	14.2	18.3	21.4	10.3	18.5	26.6
Methional (µg/L)	3.1	9.3	13.8	3.5	5.5	8.6	1.9	2.6	3.6	3.8	4.5	5.2
2-Furfural (µg/L)	13.8	230	371.7	12.3	69.7	106	10.4	54.3	67	10.6	71.1	150
Sum of aldehydes	49.8	364.4	**581**	50.27	160.11	237.46	43.34	109.02	**149.88**	37.13	146.99	276.99

	CARAAROMA®			CARAFA® TYPE III			CARAFA® SPECIAL TYPE III			ROASTED BARLEY		
	FRESH	FORCED	AGED	FRESH	FORCED	AGED	FRESH	FORCED	AGED	FRESH	FORCED	AGED
Pentanal (µg/L)	0.9	1.2	3.5	0.8	1.3	2.1	1.0	2.5	4.6	0.9	1.7	3.3
Hexanal (µg/L)	1.1	2.8	5.2	1.1	3.1	5.3	1.7	3.6	6.2	1.1	2.1	4.6
(*E*)-2-Nonenal (µg/L)	0.0	0.02	0.03	0.0	0.01	0.04	0.0	0.01	0.03	0.0	0.01	0.18
2-Methylpropanal (µg/L)	3.1	10.2	14.6	2.1	20	23.5	2.4	18.4	19.2	3.3	12.4	19.1
2-Methylbutanal (µg/L)	1.9	3.1	5.6	1.3	5.3	11.4	1.2	8.4	12.5	2.1	7.9	9.8
3-Methylbutanal (µg/L)	4.7	8	13.7	3	8.6	16.6	3.2	6.4	12.3	5.4	10.1	15.4
Benzaldehyde (µg/L)	1.4	1.9	3.4	1.4	3.4	7.6	1	4.7	11.3	1.8	4.9	9.3
2-Phenylethanal (µg/L)	8	12.1	15	8.4	10.5	25.4	14.6	18.1	21.2	12	20.4	37.7
Methional (µg/L)	2.6	3.5	5.1	3.0	3.6	4.2	2.5	7.5	16.5	2.2	11.1	14.3
2-Furfural (µg/L)	11.6	51.9	123	9.6	51.2	101	11.6	92.1	125.2	10	71.4	94
Sum of aldehyde	35.45	95.01	189.41	30.77	107.01	197.20	39.16	161.69	229.01	38.87	142.26	207.77

	SINAMAR®			CARAMEL #301			PILSNER MALT		
	FRESH	**FORCED**	**AGED**	**FRESH**	**FORCED**	**AGED**	**FRESH**	**FORCED**	**AGED**
Pentanal (µg/L)	0.8	1.6	2.2	0.8	1.7	3.7	0.6	1.2	2.4
Hexanal (µg/L)	1.2	2.7	4.2	1.2	3.2	6.5	1.0	2.7	5.5
(*E*)-2-Nonenal (µg/L)	0.0	0.01	0.03	0.0	0.02	0.12	0.0	0.01	0.05
2-Methylpropanal (µg/L)	3.5	18.8	22.2	3.8	10.9	26.1	3.4	17.7	30.3
2-Methylbutanal (µg/L)	2.1	11.6	16.3	2.6	7.9	17.2	2.3	6.7	11.9
3-Methylbutanal (µg/L)	4.1	19.6	23.3	6.1	12.5	30.4	5.1	13.4	23
Benzaldehyde (µg/L)	1.7	3	5	1.1	4	9.6	1.6	3.9	5.3
2-Phenylethanal (µg/L)	8.7	17.9	27.3	11.9	18.2	21.1	11.6	19.3	34.3
Methional (µg/L)	2	3.5	5.5	2.1	4.8	10.4	1.6	3.4	5.2
2-Furfural (µg/L)	7.5	58.0	63.1	9.9	88.3	125.6	9.2	59.6	76.4
Sum of aldehydes	31.61	136.86	169.25	39.57	151.46	250.75	36.43	127.25	194.27

4.6.3.3 Correlation between colour appearance predictors and the beer ageing compounds detected in locally-brewed beers at different ageing states

In order to clearly understand the influence of the colour adjustment on the beer flavour stability in analytical terms, a series of correlations between the colour appearance predictors obtained from all the locally-brewed beers using the three different methods (sensory view, tele-spectroradiometry and digital imaging) and the concentration of the beer ageing flavour-active aldehydes detected and quantified from the beer samples at this stage of the investigation was carried out. Table A.6.1 of Appendix A shows the correlation values between colour appearance predictors and beer ageing flavour-active aldehydes of the locally-brewed beers at different ageing stages *i.e.* fresh, forced aged (7 days at 60℃) and spontaneously a ged (12 months at 4℃). Likewise, Table 4.6.5 summarises the significant va lues from these correlations.

In general, more significant positive correlations between were detected colour appearance predictors and beer ageing flavour-active aldehydes in fresh locally-brewed beers in comparison to those obtained in forced aged (7 days at 60℃) and spontaneously aged samples (12 months at 4℃). Significan t positive correlation was observed between visual colourfulness (Cv) and the sum of the concentration of the flavour-active aldehydes (ageing markers), while negative correlation was found between the visual hue angle and the aforementioned sum of the concentration of the aldehydes.

In addition, the colourfulness (M_TSR) measured by tele-spectroradiometry at sensory viewing simulation conditions (highball glass) showed a significant positive correlation with the sum of the concentration of the flavour-active aldehydes in fresh locally-brewed samples. In contrast, a significant negative correlation was found between the hue angle (h_TSR) at sensory viewing simulation conditions and the sum of the concentration of the aldehydes. This similarity of results reconfirmed the strong correlation between the tele-spectroradiometry at sensory viewing simulation conditions (use of high ball glass) and the sensory viewing method (psychophysical assessment). This suggests that tele-spectroradiometry at sensory viewing conditions may be a robust and reliable analytical method for measuring the total colour appearance of beer.

Additionally, significant positive correlations were detected between the physical measurements of colour appearance by tele-spectroradiometry at calibrated cell (influence of depth) such as CIECAM02 colourfulness (M_TSR) against the sum of the concentration of the flavour-active aldehydes (ageing markers) in fresh beer. Moreover, a significant positive correlation was noticed between the hue angle (h_TSR) at sensory viewing conditions and the concentration of benzaldehyde of the fresh locally-brewed beers.

Likewise, significant positive correlations were obtained between CIECAM02 colour appearance predictors of fresh locally-brewed beers measured by digital imaging method (DigiEye System-VeriVide®) and many of the beer ageing flavour-active aldehydes in comparison to the other colour appearance methods applied in this research. A large positive correlation was shown between CIECAM02 colourfulness (M_DIG) measured by digital imaging method at calibrated cell conditions (influence of depth) and the concentration of 2-methylpropanal in the fresh locally-brewed beers. Meanwhile, several large positive correlations were detected between CIECAM02 hue angle (h_DIG) and the concentration of the majority of the beer ageing flavour-active aldehydes such as pentanal, hexanal, 2-methylbutanal, 3-methylbutanal, benzaldehyde and methional.

Few positive correlations were detected between colour appearance predictors and the concentration of the ageing flavour-active aldehydes in forced aged locally-brewed beers (7 days at 60℃). A large positive correlati on was evident between CIECAM02 lightness (J_TSR), measured by tele-spectroradiometry at sensory viewing simulation conditions, and the concentration of (*E*)-2-nonenal. This poor correlation between the colour appearance predictors and the beer ageing flavour-active aldehydes on forced aged locally-brewed beers (7 days at 60℃) ma y be attributed as previously to the thermal treatment induced during forcing beer ageing method used in this investigation, resulting in noticeable inconsistencies in terms of physical and chemical composition of the matrix of each beer sample. This corroborates once again that forcing beer ageing as an artificial beer ageing acceleration method does not mimic in realistic terms the spontaneous beer ageing at any storage conditions.

The significant correlations were detected between the colour appearance predictors and the concentration of the beer ageing flavour-active aldehydes of spontaneously aged locally-brewed beers (12 months at 4℃). A large positive correlation was detected between CIECAM02 hue angle (h_TSR) at sensory viewing simulation conditions and the sum of the concentration of the flavour-active aldehydes (ageing markers) of the spontaneously aged samples. Likewise, large positive correlations were found between CIECAM02 lightness (J_TSR) at calibrated cell conditions (influence of depth) and the concentration of 2-phenylethanal and 2-furfural.

These findings are in disagreement with previous research (Savel, 2005), which indicate a close correlation between the increase of beer colour and beer haze during ageing. In this investigation, the correlation are more significant due to the correlation between the concentration of the detected beer ageing compounds and the broad portfolio of colour appearance predictors. Nevertheless, a second round of selected locally-brewed beer was required, in order to fully ratify the existence of this relationship between the total colour appearance and beer flavour stability.

Table 4.6.5 Significant correlation values between colour appearance predictors and beer ageing flavour-active aldehydes of the locally-brewed beers at different ageing stages

Variables	Fresh beers (total 25)	Forced beers (total 3)	Aged beers (total 8)
H_DIG (cell) *vs* Pentanal	R^2 = **0.68**		
H_DIG (cell) *vs* Hexanal	R^2 = **0.68**		
J_TSR (highball) *vs* (*E*)-2-Nonenal		R^2 = **0.62**	
M_DIG (cell) *vs* 2-Methylpropanal	R^2 = **0.66**		
h_DIG (cell) *vs* 2-Methylbutanal	R^2 = **0.66**		
h_DIG (cell) *vs* 3-Methylbutanal	R^2 = **0.65**		
h_TSR (cell) *vs* Benzaldehyde	R^2 = **0.66**		
h_DIG (cell) *vs* Benzaldehyde	R^2 = **0.66**		
J_TSR (cell) *vs* 2-Phenylethanal			R^2 = **0.71**
h_DIG (cell) *vs* Methional	R^2 = **0.65**		
J_TSR (cell) *vs* 2-Furfural			R^2 = **0.80**
Cv *vs* Sum of aldehydes	R^2 = **0.65**		
hv *vs* Sum of aldehydes	R^2 = **-0.73**		
M_TSR (highball) *vs* Sum of aldehydes	R^2 = **0.77**		
h_TSR (highball) *vs* Sum of aldehydes	R^2 = **-0.62**		R^2 = **-0.90**
M_TSR (cell) *vs* Sum of aldehydes	R^2 = **0.66**		

Correlation (R^2)	**Negative**	**Positive**
Small	-0.3 to -0.1	0.1 to 0.3
Medium	-0.5 to -0.3	0.3 to 0.5
Large	-1.0 to -0.5	0.5 to 1.0

4.6.3.4 Brewing the second round of the locally-brewed beers for analytical and sensorial purposes

To confirm the previous results, a second round of locally-brewed beers [*i.e*. four colour-adjusted and one beer control (100% pilsner malt)] was brewed. At this stage, a more rigorous analytical approach and sensorial assessment was carried out on beer flavour stability. The selection of the colour agents for the colour adjustment of the beers were based on significant differences observed between the total colour appearance and the quantification of the beer ageing flavour-active aldehydes by GC-MS analysis of the wide portfolio of the first round of locally-brewed beers (see sections 4.6.3.1; 4.6.3.2). The colouring agents selected for the second round of locally-brewed beers were the following ones:

1) CARAHELL® - Light crystal malt
2) MELANOIDIN MALT
3) CARAFA® SPECIAL Type III – Dehusked roasted malt
4) CARAMEL #301 - Artificial caramel colorant

All beers were brewed, bottled and pasteurised at the I.C.B.D. pilot brewery following the same standard brewing procedures previously established in the early stage of this investigation (see section 3.1 and brew control sheets 12 to 16 of Appendix C).

Table 4.6.6 shows the average results from a triplicate approach of some additional parameters of the second round of the fresh locally-brewed beers. All the fresh locally-brewed beers were within specifications according to the normal values for pale lager beers reported by the Mitteleuropäische Brautechnische Analysenkommision (M.E.B.A.K.) (Brautechnische Analysenmethoden. Band II. Mitteleuropäische Brautechnische Analysenkommission, 2002a-p), the European Brewing Convention (E.B.C.) (Analytica-EBC. European Brewing Convention, 1998a-o). Nevertheless, all the fresh beer samples showed relatively low reducing power in comparison to the specifications of M.E.B.A.K. (Brautechnische Analysenmethoden. Band II. Mitteleuropäische Brautechnische Analysenkommission, 2002j). Additionally, significant differences were detected in the reducing power measurement of the beer samples. Fresh locally-brewed beers colour-adjusted with light crystal malt (CARAHELL®) and melanoidin malt showed satisfactory reducing power. In contrast, fresh locally-brewed beers colour-adjusted with dehusked roasted malt (CARAFA® SPECIAL Type III) and artificial caramel colorant (CARAMEL #301) as well as the blank sample (100% pilsner malt) displayed poor reducing power.

Table 4.6.6 Additional parameters of the second round of locally-brewed beers

Parameter	Carahell®	Melanoidin Malt	Carafa® Special Type III	Caramel #301	Pilsner Malt	Normal Values (MEBAK)
Original extract (ER) %	12.20	12.22	11.86	12.17	11.96	**11.7 – 12.3** r95:0.012 R95:0.080
Alcohol (%V/V)	5.15	5.20	4.97	5.16	4.91	**2.2-9.0** r95: 0.04 ± 0.004m R95: 0.04 ± 0.02m
Bitter units (IBU)	20	18	19	19	19	**10-40** r95: 0.44 ± 0.014m R95: -0.7 ± 0.18m
Colour EBC (430 nm)	7.9	7.0	7.1	7.2	4.9	**Pale beers: 7-11** r95: 0.3 R95:0.6
Turbidity EBC (20℃)	0.63	0.64	0.61	0.78	0.65	**N/A**
Head retention (NIBEM) (sec)	261	272	260	241	273	**For pale lager beers:** **< 220 bad** **> 300 very good** r95: 9 R95: 42
Dissolved oxygen (µg/L) Orbisphere	12.5	10.7	17.0	14.5	10.1	**< 30.0** r95: 15 R95: 3
CO_2 (%vol.)	3.0	3.1	2.8	3.2	3.0	**2.5 -3.0** r95: 0.09 R95: 0.08m
Total polyphenols (mg/L)	118	121	122	125	125	**73-176** r95: 4.1 R95:18 ± 0.13m
Flavanoids (mg/L)	28.3	31.0	22.3	31.4	23.6	**50-70** CV_{r95}: ±4.7% CV_{R95}: ±7.6%
Reducing Power (MEBAK) %RED	43.3	47.9	29.0	37.9	30.6	**>60 very good** **50-60 good** **45-50 satisfactory** **< 45 poor** CV_{r95}: ± 1%

Parameter	Carahell®	Melanoidin Malt	Carafa® Special Type III	Caramel #301	Pilsner Malt	Normal Values (MEBAK)
Iron (mg/L) (AAS)	0.17	0.13	0.16	0.17	0.10	**< 0.2** r95: 0.21m R95: 0.91m
Copper (mg/L) (AAS)	0.11	0.08	0.10	0.10	0.07	**< 0.2** r95: 0.45m R95: 1.71m

4.6.3.5 Endogenous anti-oxidative potential (EAP) measurement of the second round of locally-brewed beers and colouring agents by electron spin resonance (ESR) spectroscopy

In order to fully compare different methodologies for measuring the endogenous anti-oxidative potential (EAP) of the colouring agents examined in this investigation, a series of reducing power tests of the colouring beer (SINAMAR®) and artificial caramel colorant (CARAMEL #301) at distinct concentration levels (0.2% w/w and 0.4% w/w, respectively) in fresh commercial pale lager beer and in distilled water were previously carried out in collaboration with Technische Universität Berlin, Germany according to the Mitteleuropäische Brautechnische Analysenkommision (M.E.B.A.K.) (Brautechnische Analysenmethoden. Band II. Mitteleuropäische Brautechnische Analysenkommission, 2002j). All measurements were carried out by duplicate. Table 4.6.7 shows the results of the impact of the colouring beer (SINAMAR®) and the artificial caramel colorant (CARAMEL #301) as colour adjustment agents on the reducing power of beer and distilled water.

Broadly speaking, the artificial caramel colorant (CARAMEL #301) in fresh commercial pale lager beer and in distilled water at different concentrations presented a greater reducing power than the colouring beer (SINAMAR®) at the same conditions. Additionally, it was observed that both type of colouring agents have an endogenous reducing power due to the fact that they showed low but evident reducing power in normal aqueous solution (*i.e*. distilled water). In fact, it was discovered that a synergy in the reducing power is produced in the colloidal mixture of these colouring agents and fresh pale lager beer, since the values obtained from the colouring agents in fresh commercial pale lager beers were higher than the fresh commercial pale lager beer itself without the addition of colouring agent. Moreover, the results presented certain linearity between the concentration of colouring agents added and the endogenous reducing power. The colouring beer (SINAMAR®) exhibited approximately two-fold reducing power, detected at 0.4% w/w than 0.2% w/w concentration in normal aqueous solution (*i.e*. distilled water) and in fresh commercial pale lager beer. In the case of the artificial caramel colorant (CARAMEL #301) a relatively two fold reducing power was found at both established concentrations in normal aqueous solution (*i.e*. distilled water) but the reducing power gradually rose up between both concentrations in fresh commercial pale lager beer. Therefore, some rounding off questions come to mind whether the endogenous reducing power of the colouring agents follows a linear pattern with a final plateau at a specific concentration in the pale lager beer matrix. Under this assumption, it was essential to carry out further robust analysis such as endogenous anti-oxidative potential (EAP) determination as well as the detection and quantification of flavour-active relevant beer ageing compounds of the fresh, forced aged (7 days at 60℃) and spontaneously aged (12 months at 4℃) locally-brewed be ers by GC-MS analysis in order to confirm the aforementioned results.

Table 4.6.7 Impact of colouring beer and artificial colorant as colour adjustment agents on the reducing power of fresh beer and brew liquor

Samples	Reducing power (s)
Fresh pale lager beer	33.8
0.2% w/w SINAMAR® in H_2O (dist.)	10.7
0.2% w/w SINAMAR® in fresh pale lager beer	48.0
0.4% w/w SINAMAR® in H_2O (dist.)	23.3
0.4% w/w SINAMAR® in fresh pale lager beer	61.1
0.2% w/w CARAMEL #301 in H_2O (dist.)	50.7
0.2% w/w CARAMEL #301 in fresh pale lager beer	95.0
0.4% w/w CARAMEL #301 in H_2O (dist.)	91.0
0.4% w/w CARAMEL #301 in fresh pale lager beer	102.4
Evaluation (M.E.B.A.K.) % RED (Brautechnische Analysenmethoden. Band II. Mitteleuropäische Brautechnische Analysenkommission, 2002a)	**>60 Very good** **50-60 Good** **45-50 Satisfactory** **<45 Poor**

Figure 4.6.1 illustrates the endogenous anti-oxidative potential (EAP) (lag time) of the fresh locally-brewed pale lager beers. All the determinations were carried out by triplicate. The results pointed out that specialty malts as colouring agents have a negative influence on the endogenous anti-oxidative potential of the fresh pale lager beers, owing to the fact that the fresh beer colour-adjusted with artificial caramel colorant (CARAMEL #301) and the fresh beer control (100% pilsner malt) displayed the longest EAP values (118 and 78 min), respectively. These high EAP values are considered for beers of good flavour stability (70-100 min) after previous studies (Methner *et al.*, 2007 and 2008). Meanwhile, lower EAP values in the fresh locally-brewed beers colour adjusted with light crystal malt (CARAHELL®) and melanoidin malt (35 min and 27 min) were observed.

In addition, no detectable EAP value in the fresh beer colour-adjusted with dehusked roasted malt (CARAFA® SPECIAL Type III) was noticed. This means that the aforementioned fresh beer was of very poor quality in terms of flavour stability, despite the beer having almost identical parameters in comparison to its analogue samples. This result disagrees with previous investigations (Woffenden *et al.*, 2001; Coghe *et al.*, 2006). These latter investigations demonstrated that malts roasted at temperatures above 150℃ such as CARAFA® SPECIAL Type III provide a significa ntly lower anti-radical activity in comparison to other specialty malt products of same colour intensity but withered, kilned or roasted at lower temperature programmes. This result may be explained by the fact that dehusked roasted malt undergoes a high production of radicals during the roasting process, given that a sharp increase of oxidation of endogenous polyphenols and polymerisation reactions of a broad group of organic compounds of short chain, such as aldehydes and ketones, to heterocyclic compounds such as furans, pyrazines, pyrroles, just to mention few. This is where a moot point may take place, considering that the main objective of dehusking these roasted products is the reduction of polyphenols which can be released and become oxidised during the milling and the wort production, giving undesirable harsh off-flavours in the final flavour profile in beer. Nevertheless, there is also an outstanding oxidation of the internal components of the grain as no physical protection being is provided by the absence of husk.

According to previous studies (Kunz *et al*., 2008), the lowest ESR signal intensity observed with this beer, as a criteria for the radical generation, shows the typical behaviour when the endogenous anti-oxidative potential is completely consumed. After the achievement of the EAP-zero-value the ESR signal intensity decreases due to the accelerated radical generation that has already started in the beer before the measurement. Because the radicals produced in the beer at this stage can not be trapped by the spin-trap-reagent, this leads finally to a lower ESR signal intensity after the crossing of the EAP-zero-value. Besides, lower EAP values in the fresh locally-brewed beers colour- adjusted with light crystal malt (CARAHELL®) and melanoidin malt (35 min and 27 min) were observed, respectively. These values correspond to beers of poor quality flavour stability after the former investigations (Methner *et al.*, 2007 and 2008).

At this point ESR analysis of the second round of the fresh locally-brewed beers contrasted those obtained in the detection and quantification of beer ageing flavour-active aldehydes of the first round of the spontaneously aged locally-brewed beer (12 months at 4℃) by GC-MS analysis. In accordance with the previous detection and quantification of the aldehydes, the spontaneously aged locally-brewed beers colour-adjusted with crystal malts such as CARAHELL®, CARAAMBER® as well as melanoidin malt may promote better flavour stability than any other colouring agents examined in this research. In contrast, the EAP determinations of the second round of the fresh locally-brewed beers indicate that the fresh sample colour-adjusted with artificial caramel colorant (CARAMEL #301) have much better flavour stability based on its endogenous anti-oxidative potential (EAP) than any other fresh samples examined.

These discrepancies must be clarified by examination on the basis of further analysis in this investigation, such as a broader detection and quantification of beer ageing compounds of the second round of locally-brewed beers, as well as the sensory assessments of the samples by the I.C.B.D. trained tasting panel. It is complex to explain precisely the origin of this difference of results. It can be claimed that the measuring of the quality of beer products in terms of beer flavour stability can not be focused exclusively on a analytical method or technology of choice but on a holistic and complementary control quality strategy which must be based on the chemical composition of the matrix of the beer product in question and also on the sensorial flavour profile, mainly on the storage conditions of the final product, in which the logistic strategy and procedures play absolutely the main role of improvement in terms of beer flavour stability. This is the key issue in the real possibility to achieve closer and realistic agreement between the best before date stipulated on the final beer product, also known as commercial shelf life (CSL), and the period of time which the final beer products actually maintain their intrinsic physical, chemical and sensorial properties during the storage so-called technical shelf life (TSL) (see Mélotte, 2008).

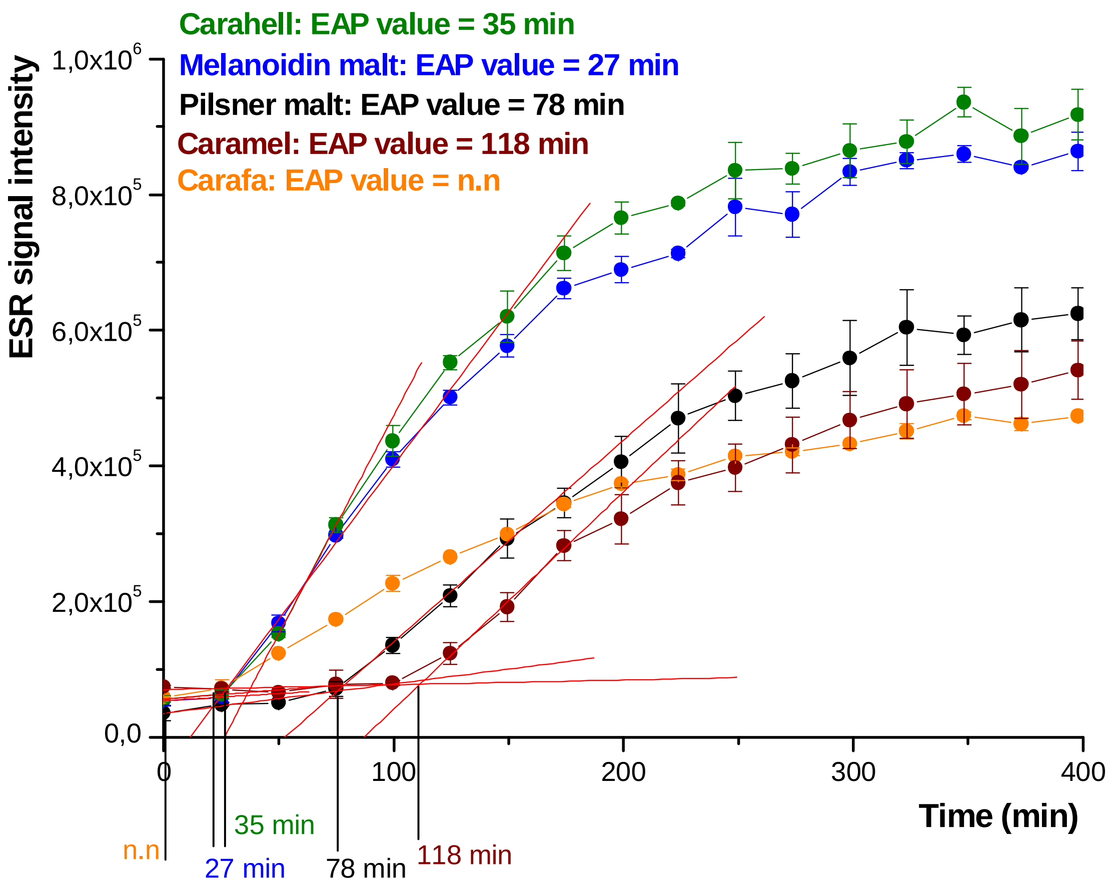

Figure 4.6.1 EAP-Determination of the second round of fresh locally-brewed beers

In order to elucidate the latter results, the sulphite concentration of the fresh locally-brewed beers was assessed after MEBAK method of analysis (Brautechnische Analysenmethoden. Band II. Mitteleuropäische Brautechnische Analysenkommission, 2002b). The results present a direct correlation to the detected EAP-value of the beers. Figure 4.6.2 shows that use of specialty malts as colouring agents leads to low sulphite content in the fresh final beer. Whereas the fresh colour-adjusted with artificial caramel colorant (CARAMEL #301) and the fresh beer control (100% pilsner malt) had a significant higher sulphite content. The differences on the sulphite production between the fresh beers colour-adjusted with specialty malts and the fresh beer control are probably due to the presence of different concentration of Maillard products in the wort. The higher amount of sulphite in fresh locally-brewed beer colour-adjusted with artificial caramel colorant (CARAMEL #301) compared to the fresh beer control may be caused by a higher input of iron ions contained in the artificial caramel colorant that was added before the fermentation. According to Samp *et al.* (2009), higher concentration levels of iron ions in the wort result in an increase in sulphite production by the yeast. Although, the acceleration of OH- radical generation is re-induced during the post-fermentation such as beer filtration, packaging, shipping and storage stages (American Society of

Brewing Chemists, 2007; Uchida, 1996; Uchida and Ono, 2000a, Uchida and Ono, 2000b). However, it is important to notice that the iron levels were higher in all the fresh colour-adjusted beers in comparison to the fresh beer control (100% pilsner malt) (see Table 4.6.6). The influence of the artificial caramel colorant addition to the wort will be discussed in detail later on in comparison to the further results of the addition to final beers.

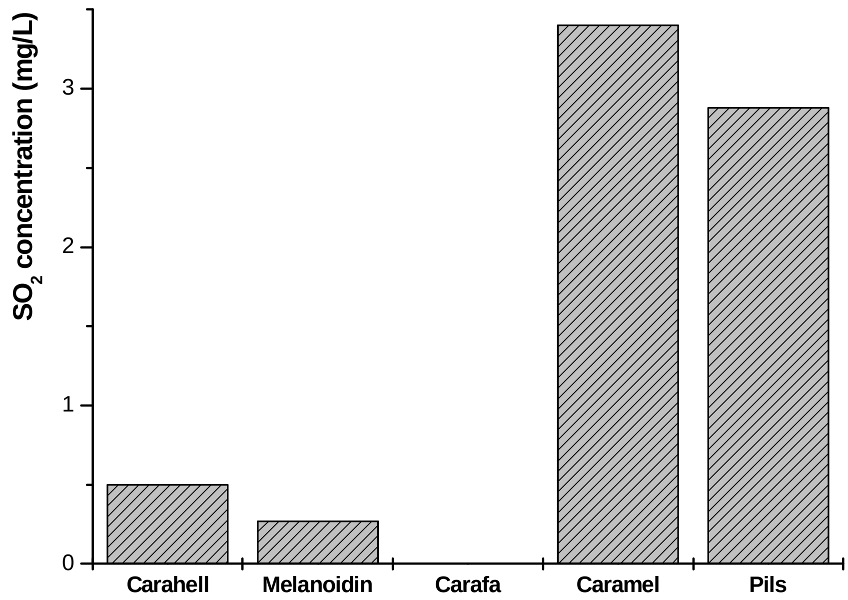

Figure 4.6.2 Sulphite concentration of fresh locally-brewed beers

The effects on beer flavour stability caused by using colouring beer (SINAMAR®) and artificial caramel colorant (CARAMEL #301) as beer colour adjustment agents were investigated by measuring the EAP values of a series of trials of different concentration levels; *i.e.* 0.83 mL/L, 1.67 mL/L, 2.50 mL/L, 3.33 mL/L and 4.14 mL/L for colouring beer (SINAMAR®) and 0.005 mL/L, 0.02 mL/L and 0.03 mL/L for artificial caramel colorant (CARAMEL #301) in an fresh all-malt commercial beer brewed according to the German purity law (Reinheitsgebot). The addition of the aforementioned colouring agents was carried out immediately right after the opening of the beer bottles and the pouring of the sample into the vials in order to avoid any ingression of oxygen at the required operational conditions for this analysis. The analysis was done by duplicate as in the previous EAP analysis.

All the EAP values of the colouring beer (SINAMAR®) trials were determined in two samples of the same beer brand but with one month of shelf life between each other (*i.e.* April, 2009 and May, 2009). All the EAP determinations of the artificial caramel colorant (CARAMEL #301) trials were done in one sample of the same beer brand used for the colouring beer. This established a comparative study between the two colouring agents in question to look at the effect of these colouring agents on final product at different age. The results of the colouring beer (SINAMAR®) trials are shown in Figures 4.6.3, 4.6.4 and 4.6.5, and the results of the artificial caramel colorant (CARAMEL #301) in Figure 4.6.6.

In general, the colouring beer (SINAMAR®) trials showed a difference between the EAP values of the two samples at all concentrations previously established for this analysis. The younger sample showed clearly twice the EAP value (lag times) than the older analogue sample. This strongly indicates that the storage conditions have a profound effect on beer flavour stability. Likewise, an evident steady downward linearity between the EAP values and the concentration of colouring beer (SINAMAR®) added was detected, although this linearity at the two highest concentrations (3.33 mL/L and 4.14 mL/L, respectively) was gradually reduced, providing closer values between them. This finding concurs with previous studies (Coghe *et al.*, 2006), in which higher molecular weight (HMW) compounds from roasted malt products [*e.g.* colouring beer (roasted beer extract)], provide greater reductive capacity but lower radical scavenging levels. Additionally, they suggested that intensive heat treatment (>150℃) during roasting on specialty malt products does not necessarily lead to more non-enzymatic browning reaction by-products with endogenous anti-oxidative activity (EAP). This phenomenon is due to the fact that a great amount of functional groups with significant scavenging ability is lost by their own ongoing polymerization at high roasting temperatures (<150℃), which subsequently promotes the f ormation of high molecular weight (HMW) melanoidins (*ibid.*).

Conversely, these results are in disagreement with the reducing power of the fresh beer according to the Mitteleuropäische Brautechnische Analysenkommision (M.E.B.A.K.) (Brautechnische Analysenmethoden. Band II. Mitteleuropäische Brautechnische Analysenkommission, 2002j) previously measured (see Table 4.6.7), in which a stronger reducing power was detected. In contrast, shorter endogenous anti-oxidative potential (EAP) values were observed in the all-malt commercial beers colour-adjusted with colouring beer at distinct concentrations. These results confirm those obtained by previous research (Coghe *et al.*, 2006; Sovrano *et al.*, 2006), which proved the reducing power of specialty malts is directly proportional to the concentration levels of melanoidins of high molecular weight (HMW) formed throughout the withering, kilning or roasting in high heat conditions, whilst scavenging activity moderately increases but eventually reaches a plateau point during the browning degree of the malt products. Hence, functional groups with significant endogenous anti-oxidative potential (EAP) in kilned and roasted malt products may react to radical species in the grain and/or beer matrix produced during withering, kilning and roasting processes, but presenting certain radical activity by means of non-radical mechanisms (Coghe *et al.*, 2006; Methner *et al.*, 2008; Sovrano *et al.*, 2006). Additionally, recent investigations pointed out that endogenous polyphenols from the grain or beer in question also participate in the endogenous anti-oxidative potential by reacting as free radical scavengers, lipooxygenase inhibitors and chelating agents (Boivin, 2008; Coghe *et al.*, 2006; Dvořáková *et al*., 2008; Sovrano *et al.*, 2006). In connection with colouring appearance phenomena, recent research (Derdelinck, 2008) has recently reported that when polyphenols react to free-radicals throughout their oxidation, cross-linkings and re-arrangements of the monomer units are promoted and subsequently random structural complex of high molecular weight with a broad red-brownish colour pigmentation range is formed. Furthermore, previous studies (Laille *et al.,* 2008) latterly reported a possible reaction pathway for the formation of the aforementioned colouring compounds originated from monomers of polyphenols. The series of reactions was elucidated as follow:

Catechin → Dehydrodi(tri)catechin B (colourless) → Dehydrodi(tri)catechin A (yellow brown) → Unknown compounds still to be identified (brown-orange compounds)

This may be an advantage of the endogenous anti-oxidative (EAP) determination by electro spin resonance (ESR) over the standard MEBAK method for measuring the reducing power of beer by spectrophotometric method in terms of a realistic flavour stability approach. A possible argument between the methods used is the scientific principle of the MEBAK method which is based on the pigmentation of the beer sample by the addition of the Tillmans reagent (2,6-Dichlorphenol-Indophenol, DPI). Colour reduction of the DPI by the endogenous reducing power of the beer is a very sensitive phenomenon. This may be affected by the chemical composition of the endogenous pigments of the colouring beer, which are likely to change the absorbance of the sample; therefore, the spectrophotometrical readings can be altered. On the other hand, Electron Spin Resonance (ESR) spectroscopy also called Electron Paramagnetic Resonance (EPR) is a non-destructive analytical method based on the indirect detection of short-lived reactive radicals (ions with unpaired electrons) such as OH- radicals in beer during the accelerated beer ageing (Andersen and Skibsted, 1998; Bright *et al.* 1993; Foster *et al*., 2001; Lustig *et al*., 1993; Wackerbauer and Hardt, 1997). The lag time value considered as the criteria for the endogenous anti-oxidative potential (EAP) of the beer is mainly based on the portfolio of reducing compounds also know as reductones found in the beer matrix such as SO_2, Maillard reaction products, polyphenols, etc. (Franz and Back, 2002; Galic *et al.*, 1994; Hayase *et al.*, 1989; Liu *et al.*, 2008; Methner, 2006; Savel, 2001). For this reason, it is strongly advised to reconsider the standard methodologies for measuring the beer flavour stability by spectrophotometrical means such as the one proposed by M.E.B.A.K.

Regarding the EAP values obtained on the fresh all-malt commercial beer colour-adjusted at distinct concentration levels with artificial caramel colorant (CARAMEL #301), similar results were obtained in comparison to the analogue trials with colouring beer (SINAMAR®). The fresh beer control (all-malt commercial without artificial colorant addition) showed twice the longer EAP values than all the analogue samples colour-adjusted. These results disagree with the determination of the endogenous anti-oxidative potential of the second round of fresh locally-brewed beers, in which longer EAP values on locally-brewed beer colour-adjusted with artificial colorant (CARAMEL #301) were detected than those on fresh beer control (100% pilsner malt) - see Figure 4.6.1. In this case for the locally-brewed beers the artificial caramel colorant (CARAMEL #301) was added at the beginning of the wort boiling and not in the final beer. The time of the addition of artificial caramel colorant (CARAMEL #301) apparently have a different influence on the endogenous anti-oxidative potential (EAP) of pale lager beers. The decrease of the EAP with the addition of caramel colorant to the final beer (Figure 5) agrees with the results reported by previous investigations (Nøddekær and Andersen, 2007). These also pointed out that melanoidins and caramelisation products of caramel colorants reduced the oxidative stability when added to lager beers. This pro-oxidative effect of caramel colour is probably caused by the acceleration of the metal-catalysed oxidation of beer and based on the reduction of Fe(III) to Fe(II) and the acceleration of the radical generation in the Fenton reaction system through Maillard products (*ibid.*).

The comparison of the results from the reducing power by M.E.B.A.K. that increase with higher artificial caramel colorant (CARAMEL #301) concentration and the decrease development of the EAP-values measured by ESR-spectroscopy, shows a negative correlation. This is an indication that the Maillard products, which are responsible for the reducing power by M.E.B.A.K., are also responsible for the accelerated consumption of the anti-oxidative potential (dependent mainly on sulphite) by the reaction system described by Nøddekær and Andersen (*ibid.*).

Against the background of this, the high EAP-value of the locally-brewed beer under addition of artificial caramel colorant (CARAMEL #301) at the beginning of wort boiling should be studied more in detail in the future in order to clarify in terms of flavour stability if is possible to reduce the negative influence of this colouring agent by its earlier addition in the brewing process and if it represents a good alternative to colour-adjust beer.

Considering all these results, there is a clear effect of the artificial caramel colorant (CARAMEL #301) on the endogenous anti-oxidative potential (EAP) of fresh beer. This does not necessarily imply an universal cause-effect relationship between the concentration of the colouring agent on the beer in question, but on the composition and the oxidation state of the matrix of both components *i.e.* colouring agent and beer in the colloidal state, which can be mainly influenced on the standard brewing procedures used, the control quality established and the storage conditions provided before its consumption. Previous studies (Cantrell and Briggs, 1996) proved that the reducing power of pale malts is variety dependent. There is a dependence of the endogenous reducing power upon the biomolecular spectrum of the grain matrix in question. The largest production of reductones is found in malts of very high colour intensity, particularly in roasted malt products such as roasted malt, roasted barley and colouring beer (roasted beer extract). However, base malts such as pilsner malt and pale malt possess the highest endogenous reducing power per EBC colour unit, giving as a consequence a more significant improvement on beer flavour stability, provided by the base malts, than the specialty malts on the grist load established, or other colouring agents applied on the beer colour adjustment, due to the small quantities used.

The fresh all-malt commercial pale lager beer colour-adjusted with artificial caramel colorant (CARAMEL #301) at concentration of 0.005 mL/L displayed normal EAP values (100 min) which was lower than those obtained on the fresh beer control (100% pilsner malt) (250 min). Thus, the artificial colorant (CARAMEL #301) at these low concentration effectively induces a moderate negative effect on the endogenous anti-oxidative potential (EAP) of the fresh all-malt pale lager beers but without damaging severely the overall beer quality in terms of flavour stability. In contrast, additions of artificial caramel colorant (CARAMEL #301) at higher concentrations levels such as 0.02 mL/L and 0.03 mL/L, promote a significant reduction of the endogenous anti-oxidative potential (EAP) (<50 min) of the fresh all-malt pale lager beer samples. Therefore, detrimental repercussions can be generated on the beer flavour stability.

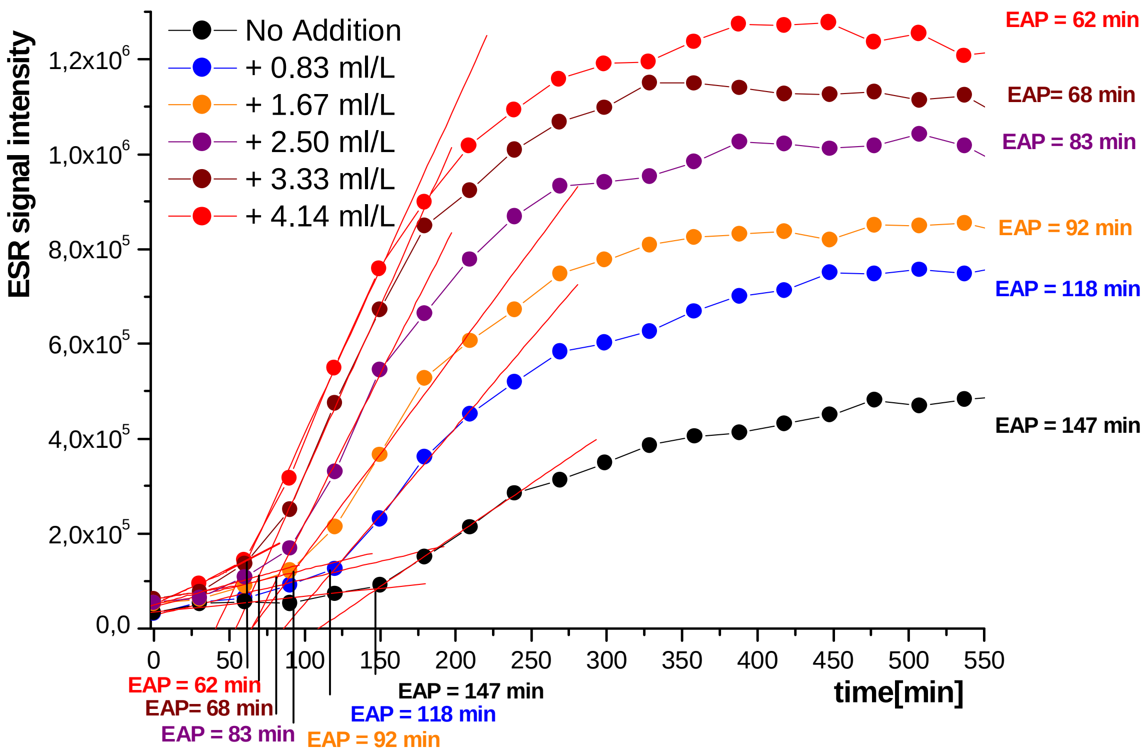

Figure 4.6.3 EAP-Determination of commercial pilsner beer colour-adjusted with colouring beer (SINAMAR®) at distinct concentration levels (Best before: April, 2009) (1)

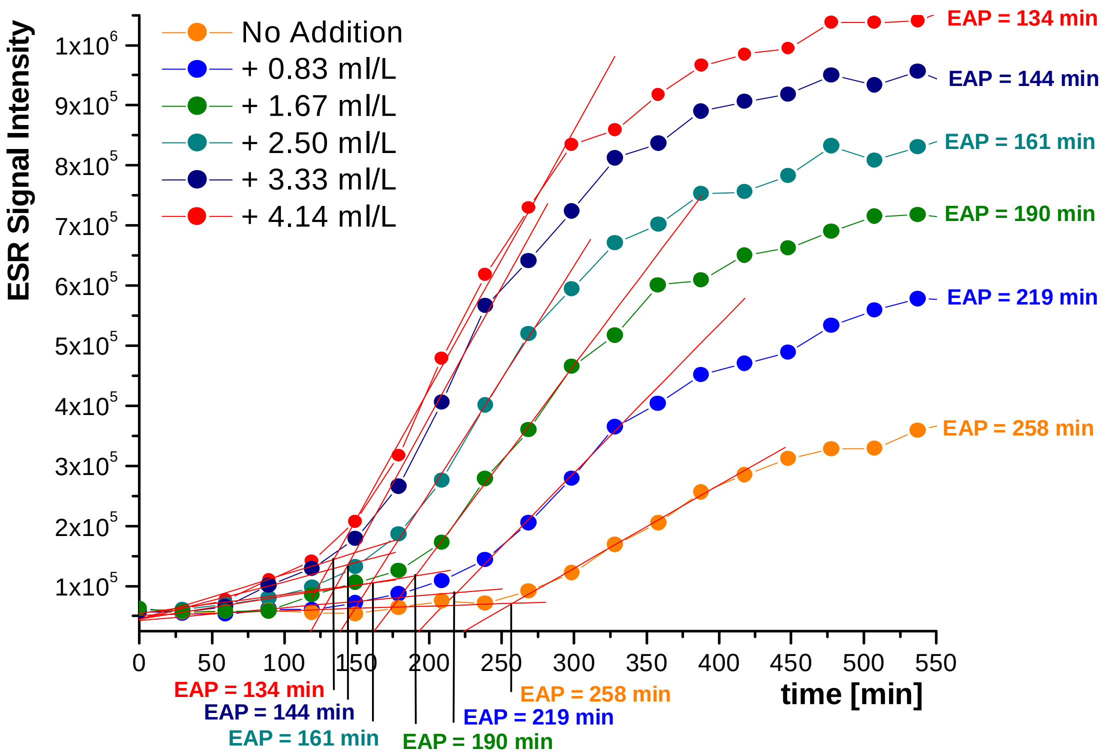

Figure 4.6.4 EAP-Determination of commercial pilsner beer colour-adjusted with colouring beer (SINAMAR®) at distinct concentration levels (Best before: May, 2009) (2)

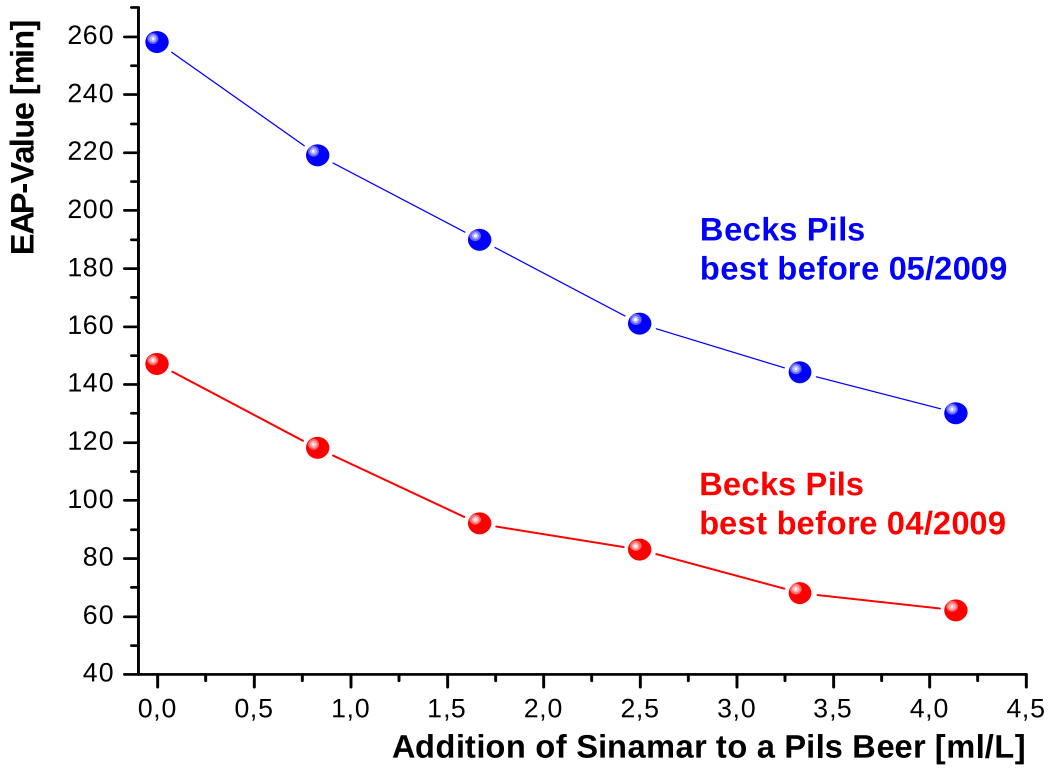

Figure 4.6.5 EAP-determination of commercial pilsner beer against addition of colouring beer (SINAMAR®) at distinct concentration levels

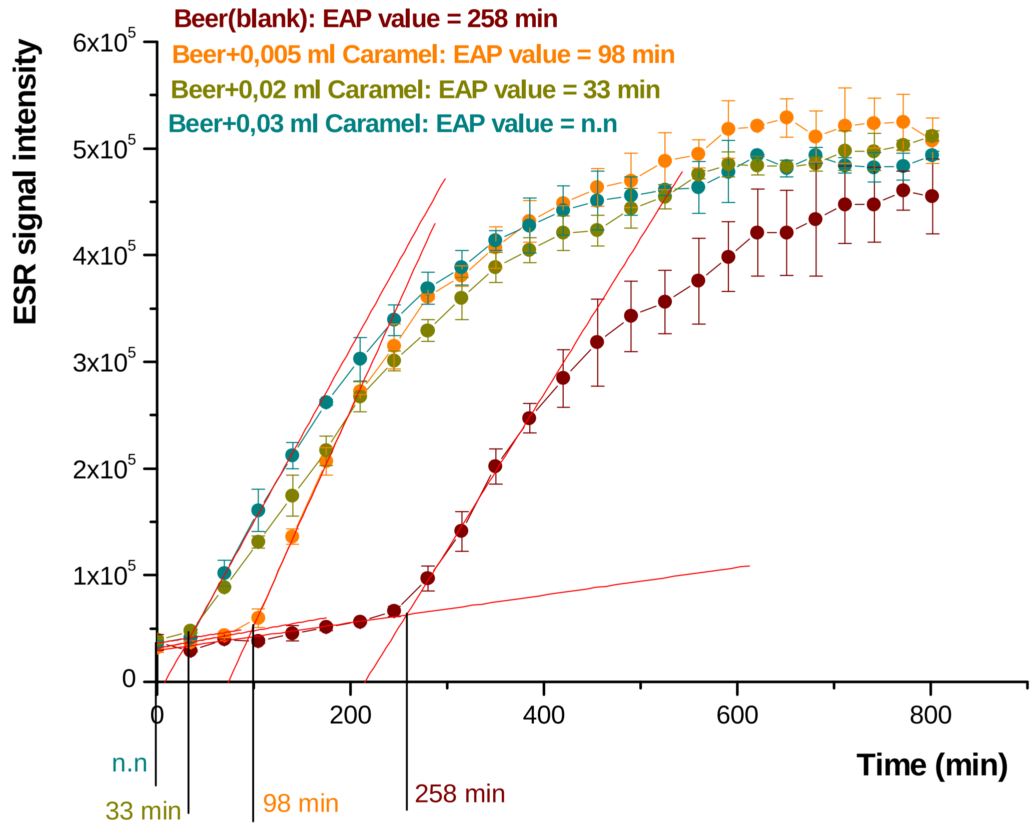

Figure 4.6.6 EAP-Determination of commercial pilsner beer colour-adjusted with artificial caramel colorant (CARAMEL #301) at distinct concentration levels

As part of the holistic approach on Electromagnetic Spin Resonance (ESR) spectroscopy for this investigation, the direct quantification of organic radicals of the whole intact kernel and the different milling fractions of the specialty malts and roasted barley were carried out. Both analyses were done in triplicate, respectively. The concentration levels of organic radicals in the whole intact kernel of each specialty malt and roasted barley are shown in Tables A.7.1 to A.7.10 of Appendix A. Figure 4.6.7 to 4.6.10 show the grand means of the concentration of organic radicals of the specialty malts, roasted barley, pilsner malt (intact whole kernels and their corresponding milling fractions) and the artificial caramel colorant (CARAMEL #301). The melanoidin malt presented the lowest concentration of organic radicals. In contrast, significant higher levels in the dehusked roasted malt (CARAFA® SPECIAL Type III) were detected. These results are in agreement with the previous analysis of reducing power (M.E.B.A.K.-method). The results also clearly indicate that pale malts such as melanoidin malt possess higher endogenous anti-oxidative potential (EAP) per EBC colour unit than dark specialty malts and other colouring agents for colouring adjustment of pale lager beers.

According to recent investigations (Methner *et al.* 2008; Methner *et al.* 2009), organic radicals in pilsner malt are mainly located in the husk-fraction of the malt and leave the wort together with the spent grain after the mashing process. Figure 4.6.8 and 4.6.10 shows however a different distribution for the specialty malts, where a higher concentration of the organic radicals in the endosperm can be detected. This suggests that the organic radicals present in the endosperm of dehusked roasted malt participate in the oxidation reactions during the mashing process in comparison to pilsner malt. This could be one reason for the negative repercussion on the endogenous anti-oxidative potential, EAP-value of the beers colour-adjusted with these malts as can be observed in Figure 4.6.1.

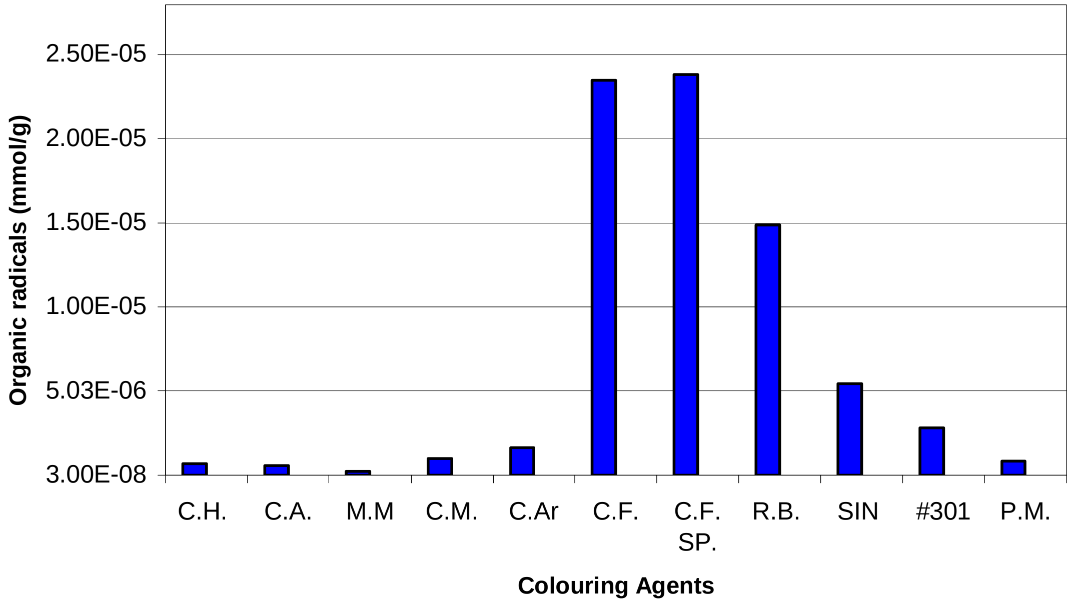

Figure 4.6.7 Organic radical concentration of colouring agents and pilsner malt (intact whole kernels)

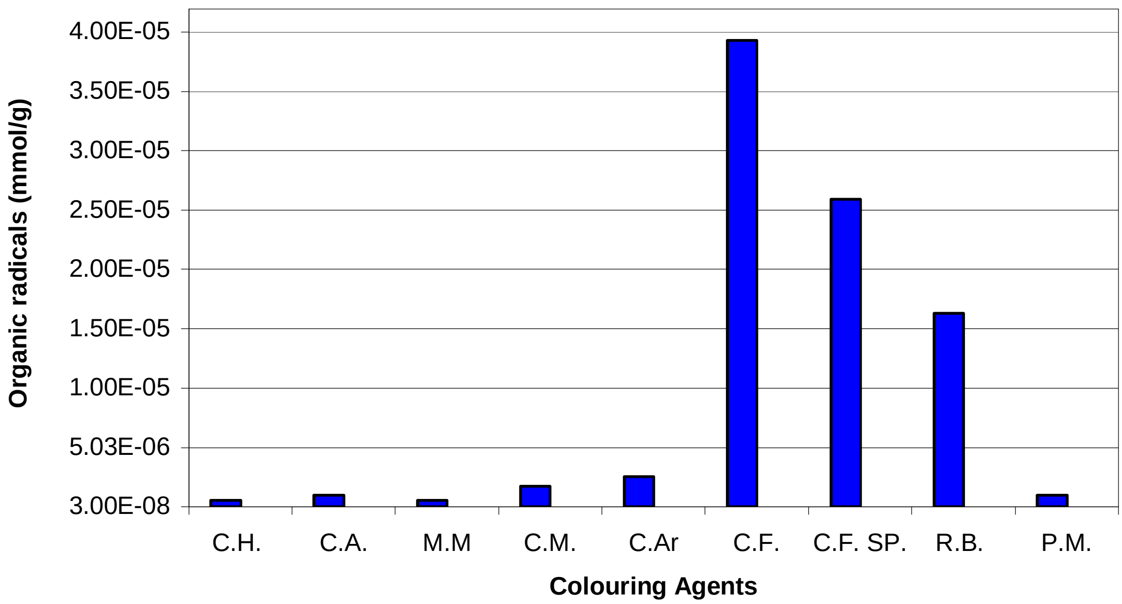

Figure 4.6.8 Organic radical concentration of specialty malts, roasted barley and pilsner malt (different milling fractions)

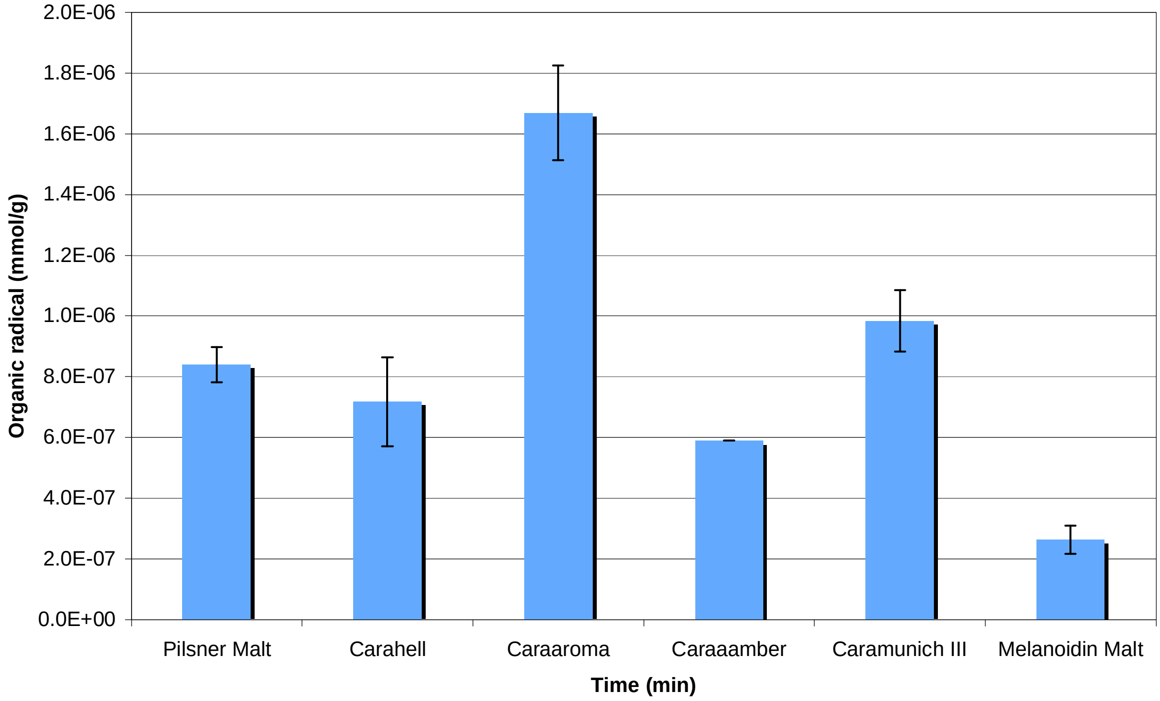

Figure 4.6.9 Organic radical concentration of crystal malts, melanoidin malt and pilsner malt (intact whole kernel)

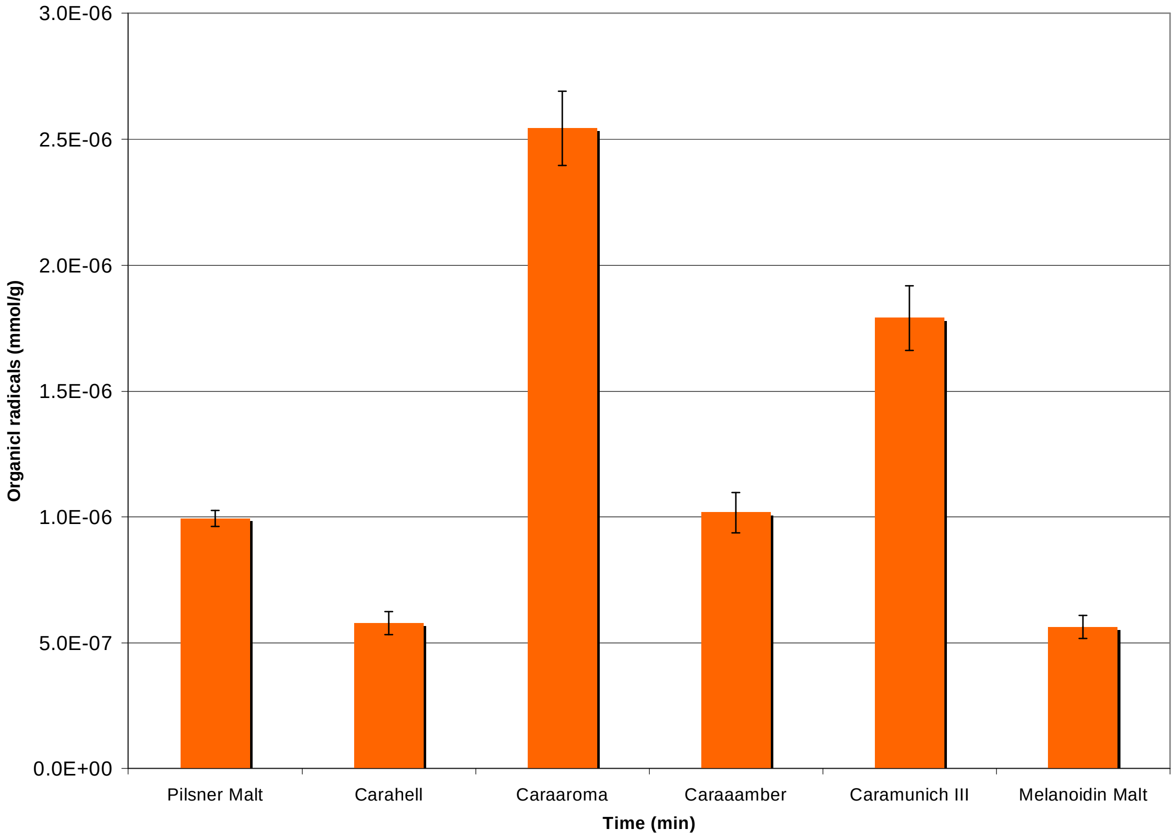

Figure 4.6.10 Organic radical concentration of crystal malts, melanoidin malt and pilsner malt (different milling fractions)

The ESR approach for this investigation indicated the addition of specialty malts or artificial caramel colorant leads to an increase in the reduction power and at the same time to a decrease in the endogenous anti-oxidative potential (EAP) of beers measured by ESR spectroscopy, mainly based on sulphite content in beer. Comparing all investigated special malt types with the blank beer, the loss of endogenous anti-oxidative potential (EAP) induces the smallest increase in beer ageing compounds during storage by using melanoidin malt for colour-adjustment. When using artificial caramel colorant (CARAMEL #301) to colour adjust beer, it should be established the moment in the process when it is added (before or after the fermentation) in order to minimize the negative influence on the oxidative stability of the final beer. Nevertheless, these assumptions must be validated with the further analytical approach such as the detection and quantification of ageing compounds by GC-MS analysis as well as the sensory analysis of the second round of the locally-brewed beers.

4.6.3.6 Detection and quantification of ageing flavour-active compounds of the second round of locally-brewed beers

In order to complete a conclusive analytical approach on the impact of the colour adjustment on the beer flavour stability with the selection of distinct colouring agents, the detection and quantification of the pre-established ageing flavour-active compounds (*i.e.* 11 aldehydes and 9 non-aldehydes compounds) of the second round of the locally-brewed pale lager beers at different ageing states, *i.e.* fresh, forced aged (7 days at 60℃) and spontaneously aged (12 months at 4℃), by GC-MS a nalysis were carried out (see Section 3.2.2.1.4). Successful detection and quantification of the majority of the ageing compounds was achieved, except for 2-propionylfuran, diethyl oxalate, 2,4-dimethyl-4-cyclopenten-1,3-dione and 2,4,5-trimethyl-1,3-dioxolane which were not detected in the beer samples. This was probably due to the selectivity, contact time and temperature of the DVB-CAR-PDMS fibre with the beer head space as well as the derivatisation procedure and the concentration of salt to induce the salting-out effect. Tables A.8.1 to A.8.3 of Appendix A and Table 4.6.8 shows the obtained data of the aforementioned GC-MS analysis.

Table 4.6.8 Ageing flavour-active compounds of the second round of the locally-brewed pale lager beers

	CARAHELL®			MELANOIDIN MALT			CARAFA® SPECIAL TYPE III		
	FRESH	FORCED	AGED	FRESH	FORCED	AGED	FRESH	FORCED	AGED
Pentanal (µg/L)	0.8	2.0	3.3	0.6	1	4.4	1.5	2.6	**7.1**
Hexanal (µg/L)	**1.2**	2.3	8.9	1.0	2.3	7.4	1.7	3.6	**12**
(*E*)-2-Nonenal (µg/L)	0.01	0.01	0.07	0.01	0.01	0.07	**0.00**	0.01	0.09
2-Methylpropanal (µg/L)	4.4	21	**57.8**	6.4	13.2	36.3	**2.2**	14.9	27.7
2-Methylbutanal (µg/L)	2.2	17.6	36.9	3.4	6.9	12.8	**1.3**	6.7	21.2
3-Methylbutanal (µg/L)	5.9	36	**54.7**	8.1	10.7	20.8	**3.6**	10.1	19.5
Benzaldehyde (µg/L)	1.5	3.6	7.4	1.3	2.5	5.8	**1**	3.4	**15.1**
2-Phenylethanal (µg/L)	8.5	30.2	**89.6**	9.5	22.5	29.6	**7.3**	17	29
Methional (µg/L)	2.8	8.6	17.1	**1.9**	2.6	6.9	2.5	8	**22.1**
2-Furfural (µg/L)	8.9	191	**582**	12.7	63.5	154	7.4	91.4	223
5-Hydroxymethylfurfural (µg/L)	0.5	0.9	**1.9**	0.5	0.6	1.6	0.4	0.7	1.3
Acetyl furan (µg/L)	12.4	14.8	**31.5**	13.1	15.9	28.6	11.7	14.4	28.6
Ethyl nicotinate (µg/L)	19.3	30.6	**63.1**	17.2	26.6	48.5	17.1	22.8	47.7
2-Phenyl ethyl acetate (µg/L)	1.7	2.6	**7.3**	0.8	2.1	5.1	0.7	2.2	6.4
2-Ethyl furfuryl ether (µg/L)	3.9	6.7	**20.8**	2.7	5.1	14.9	3.1	4.7	12
γ-Nonalactone (µg/L)	25.2	33.9	**143**	22.7	26.1	127	20.3	27.9	124
Sum of warming indicators (µg/L)	53.3	256	**788**	52.6	116	329	44.8	142	395
Sum of oxygenation indicators (µg/L)	22.6	108	**246**	28.7	55.8	105	15.5	52.1	112
Sum of ageing compounds (µg/L)	99.4	402	**1126**	102	202	503	82.1	230	596
Forcing Index	55.7	181	**434**	61.6	93.3	215	46.3	94.2	228
Ageing Index	77.2	217	**546**	75.7	121	295	62.7	120	295

	CARAMEL #301			PILSNER MALT		
	FRESH	FORCED	AGED	FRESH	FORCED	AGED
Pentanal (µg/L)	0.8	1.5	5.8	**0.6**	1.2	4.0
Hexanal (µg/L)	1.2	5.1	11.2	1.6	2.5	10.4
(*E*)-2-Nonenal (µg/L)	0.01	0.02	**0.15**	0.01	0.02	0.09
2-Methylpropanal (µg/L)	3.2	15.3	34.8	3.7	16.6	**39.8**
2-Methylbutanal (µg/L)	1.9	12.6	24.3	3.6	6.4	18.8
3-Methylbutanal (µg/L)	5.1	15.1	41.5	8.5	15.9	33.6
Benzaldehyde (µg/L)	**1**	3.4	11.5	1.1	3.8	6.9
2-Phenylethanal (µg/L)	9.1	18.8	31.4	10	17.3	41.2
Methional (µg/L)	2.4	5.3	13.4	2.1	3.1	8.2
2-Furfural (µg/L)	8.3	74.5	227	**6.5**	54.6	132
5-Hydroxymethylfurfural (µg/L)	0.4	0.7	1.3	**0.3**	0.5	1.2
Acetyl furan (µg/L)	11.6	13.2	26.4	**10.7**	12.1	20.7
Ethyl nicotinate (µg/L)	14.8	24.7	46.2	**13.4**	19.7	45.8
2-Phenyl ethyl acetate (µg/L)	0.9	1.9	5.4	**0.6**	1.6	3.9
2-Ethyl furfuryl ether (µg/L)	3.4	4.5	13.6	**2.0**	2.8	9.0
γ-Nonalactone (µg/L)	21.4	25.9	135	**19.6**	21.8	116
Sum of warming indicators (µg/L)	44.4	125	408	**39.5**	96.1	294
Sum of oxygenation indicators (µg/L)	20.3	65.4	144	26.8	60	140
Sum of ageing compounds (µg/L)	85.5	223	629	84.3	180	491
Forcing Index	50.6	97.8	276	54.8	89.3	220
Ageing Index	68.6	122	349	65.3	105	269

In general, the concentration of the entire group of ageing compounds was relatively higher than those obtained from the first round of locally-brewed beers. Most of them presented slightly lower levels but with very similar trend and good correlation to typical values for pale lager beers reported in previous investigations (Lustig, 1993; Meilgaard, 1975b; Narziß *et al.*, 1999; Saison *et al.*, 2008a; Saison *et al.*, 2008b; Vanderhaegen *et al.*, 2003). This difference of concentrations may be induced by slight process variabilities, particularly in the fermentation performance by the brewing yeast, the transfer of the green beer to the maturation tanks, the bottling, the carbonation and the pasteurisation of the two rounds of locally-brewed beers.

The highest concentration of most of the flavour-active beer ageing compounds was observed in the forced aged (7 days at 60℃) and the spontaneously aged (12 months at 4℃) locally-brewed beers colour-adjusted with light crystal malt (CARAHELL®), while the lowest one was detected in the forced aged and spontaneously aged beer colour-adjusted with melanoidin malt. Additionally, slightly higher levels of benzaldehyde, ethyl nicotinate, γ-nonalactone and oxygen indicators in all the locally-brewed beers at the different ageing stages were observed in comparison to the typical values reported in the literature (see Table 3.2.8). Furthermore, all the concentrations were below their corresponding flavour threshold values except the spontaneously aged beer sample (12 months at 4℃) colour-adjusted with artificial caramel colorant (CARAMEL #301), which showed levels of (*E*)-2-nonenal above its flavour threshold in comparison to previous studies (Saison *et al.*, 2008b). Lower levels of flavour-active beer ageing compounds in the forced aged locally-brewed beers (7 days at 60℃) were found in comparison to the spontaneously aged samples. This finding confirms that the use of forcing beer ageing method as a route to accelerate the beer ageing does not mimic spontaneous ageing in a realistic way (Syryn *et al*., 2007; Walters *et al.*, 1996, 1997a and 1997b). Besides, all the beer samples colour-adjusted presented a higher concentration of the majority of the flavour-active beer ageing compounds than the beer controls (100% pilsner malt) at fresh, forced aged (7 days at 60℃) and spontaneously aged (12 months at 4℃) conditions. This suggests that all the colouring agents used in this investigation impact the flavour stability.

In the individual detection and quantification of the ageing compounds from the fresh second round of locally-brewed beers, the highest amounts of 2-methylpropanal, 2-methylbutanal, benzaldehyde, 2-phenylethanal, (*E*)-2-nonenal, acetylfuran, the sum of ageing compounds and the forcing index were found in the fresh beer colour-adjusted with melanoidin malt, while the lowest amounts were noticed in the fresh beer sample colour-adjusted with dehusked roasted malt (CARAFA® SPECIAL Type III). Likewise, the highest amounts of 3-methylbutanal were detected in the fresh beer control (100%

pilsner malt) and the fresh locally-brewed beer colour-adjusted with melanoidin malt in comparison to the remaining samples. In contrast, the fresh locally-brewed beer colour-adjusted with dehusked roasted malt (CARAFA® SPECIAL Type III) showed the lowest levels of this compound. Besides, the fresh beer samples colour-adjusted with light crystal malt (CARAHELL®) presented the highest concentration levels of methional while the lowest ones were detected in the fresh beer colour-adjusted with melanoidin malt. Most of these compounds are basically formed by lower alcohol and iso-humulone oxidations as well as by Strecker degradation (see Table 3.2.8). In this latter reaction, some specific amino acids such as valine, leucine, methonine and phenylalanine are the primary substrate and precursor of these flavour-active aldehydes. It is possible to argue that higher amounts of these aminoacids may be found in pale malts such as light crystal malts and melanoidin malt rather than other colouring agents for beer colour adjustment such as dark crystal malts, roasted malts and artificial caramel colorants, due to the thermal treatment applied during their production (*i.e.* withering, kilning, roasting and caramelisation).

The highest amounts of 2-furfural were found in the fresh beer colour-adjusted with melanoidin malt. Conversely, the lowest amounts of this compound were observed in the fresh beer control (100% pilsner malt). Additionally, the fresh beers colour-adjusted with light crystal malt (CARAHELL®) and melanoidin malt showed a relative higher concentration of 5-hydroxymethylfurfural from all the fresh samples under investigation, while the fresh beer control presented the lowest concentration of this beer ageing and thermal treatment marker. Furthermore, the fresh beer colour-adjusted with melanoidin malt obtained the lowest concentration levels of pentanal and hexanal, while the fresh beer colour-adjusted with dehusked roasted malt (CARAFA® SPECIAL Type III) presented the highest ones.

Moreover, the highest concentration of non-carbonyl compounds such as ethyl nicotinate, 2-phenyl ethyl acetate, 2-ethyl furfuryl ether and γ-nonalactone and the sum of warming indicators was detected in the fresh beer colour-adjusted with light crystal malt (CARAHELL®) while the lowest one was found in the fresh beer colour-adjusted with dehusked roasted malt (CARAFA® SPECIAL Type III). Last but not least, the highest amount of the sum of oxygenation indicators and ageing index was noticed in the fresh beers colour-adjusted with light crystal malt (CARAHELL®) and melanoidin malt while the lowest amount of these indexes was found in the fresh beer colour-adjusted with dehusked roasted malt (CARAFA® SPECIAL Type III) and the fresh beer sample.

All these results suggest the colour adjustment of pale lager beers using light crystal malt (CARAHELL®) and melanoidin malt may provide a negative influence on the flavour stability at fresh conditions, while the dehusked roasted malt (CARAFA® SPECIAL Type III) seems to not promote deterioration at this stage in terms of concentration of flavour-active beer ageing compounds.

Concerning the quantification and detection of the flavour-active beer ageing compounds in the second round of forced aged locally-brewed beers (7 day at 60℃), the highest concentration of the majority of these compounds was found in the forced aged beer colour-adjusted with light crystal malt (CARAHELL®) while the lowest one was detected in the forced aged beer control (100% pilsner malt) and the forced aged beer colour-adjusted with dehusked roasted malt (CARAFA® SPECIAL Type III). However, the lowest amounts of pentanal, hexanal, (*E*)-2-nonenal, 2-methylpropanal, methional and benzaldehyde were noticed in the forced aged beer colour-adjusted with melanoidin malt.

In connection with the impact of the colour adjustment on the formation of these beer ageing compounds in the spontaneously aged locally-brewed beers (12 months at 4℃), the highest concentration of 2-methylpropanal, 2-methyllbutanal, 3-mehylbutanal, 2-phenylethanal, 2-furfural, 5-hydroxymethylfurfural, ethyl nicotinate, 2-phenylacetate, 2-ethyl furfuryl ether, γ-nonalactone, sum of warming indicators, sum of oxygenation indicators, sum of ageing compounds, forcing index and ageing index was observed in the spontaneously aged locally-brewed beers colour-adjusted with light crystal malt (CARAHELL®), while the lowest one of most of these compounds were detected in the spontaneously aged beer colour-adjusted with melanoidin malt.

Conversely, the lowest concentration of pentanal, hexanal, benzaldehyde and methional was detected in the second round of spontaneously aged locally-brewed beers (12 months at 4℃) colour-adjusted with melanoidin mal t and some of them in light crystal malt (CARAHELL®), while the highest levels were found in the analogue spontaneously aged samples colour-adjusted with dehusked roasted malt (CARAFA® SPECIAL Type III) and artificial caramel colorant (CARAMEL #301). In addition, the highest concentration of (*E*)-2-nonenal was detected in the spontaneously aged locally-brewed beer colour-adjusted with artificial caramel colorant (CARAMEL #301), while the lowest one was noticed in those spontaneously aged samples colour-adjusted with light crystal malt (CARAHELL®) and melanoidin malt. This suggests that light crystal malts and melanoidin malt as colouring agents for beer colour-adjustment may contribute to the improvement of the beer flavour stability in terms of concentration levels of (*E*)-2-nonenal during ageing.

In conclusion, at this stage, all the colouring agents induced higher amounts of flavour-active compounds than pilsner malt (base malt). Notwithstanding, considering that all pale lager beers must necessarily being colour-adjusted in order to obtain an attractive visual appeal, melanoidin malt as colouring agent for beer colour-adjustment seems to confer positive effects on the flavour stability of pale lager beers in terms of formation of flavour-active of different nature. The majority of the flavour-active compounds appeared in lower concentrations in the locally-brewed beers colour-adjusted with this specialty malt, particularly at the spontaneously aged stage (12 months at 4°C). The results are also in agreement with the reducing power analysis (see Table 4.6.6). These findings support the hypothesis that melanoidin malts may promote outstanding levels of reductones-melanoidins in comparison to the other colouring agents under investigation, which diminish the formation of undesirable flavour-active aldehydes by reducing or donating electrons to active organic radicals (radical scavenging) (see Savel, 2001). However, this must be finally confirmed through the corresponding sensory assessments of the second round of locally-brewed beer samples and the corresponding correlations of all the parameters under investigation.

4.6.3.7 Sensory evaluations of the locally-brewed beers at different ageing states

4.6.3.7.1 Detection and intensity of beer ageing flavour in beer colour-adjusted by the distinct colouring agents

The sensory evaluations of the second round of the five locally-brewed beers at different aged states, *i.e.* fresh, forced (7 days at 60°C) and spontaneously aged (12 months at 4°C), were carried out twice by the trained tasting panel of the I.C.B.D., Heriot-Watt University according to the methodology previously established for this investigation (see section 3.2.2.4).

As mentioned earlier in the description of this research approach, the non-parametric statistical method Friedman's test was applied for the statistical data treatment at this stage of the research (see section 3.2.2.4.3) with the aim of detecting a clear sensory difference between the samples. The hypothesis of the sensory assessments tested was whether the second round of the five locally-brewed beers has not the same quality of flavour stability in terms of the overall beer quality and the ageing attributes of the beer aroma and beer taste. The statistical approach was designed for ten and eleven numbers of treatments (*i.e.* ten ageing aroma attributes and eleven ageing taste attributes) as well as for five numbers of blocks (*i.e.* five locally-brewed beer samples) with a significance level (α) of 5% (less than one in twenty of being wrong).

All the results of the sensory evaluations of the second round of the locally-brewed beers colour-adjusted at different aged stages are displayed in Tables A.9.1 to A.9.15 of Appendix A. All the corresponding grand mean values, the ranking of values and Friedman's test of the sensory evaluations are exhibited on Tables 4.6.9 to 4.6.11, respectively. The results indicated the locally-brewed beers have not the same flavour (aroma and taste) quality and shown statistically significant differences between them. The aroma and taste profiles of the beer samples are depicted by the entire group of the beer samples at different aged stages in Figures 4.6.11 to 4.6.16, as well as by the individual beer sample examined in Figures 4.6.17 to 4.6.26.

In general, significant differences in the flavour profiles of the beer samples were detected at different ageing states by the I.C.B.D. trained sensory panel. The flavour profiles of the beer samples were not sharply distinct but clearly detectable in accordance with the I.C.B.D. trained tasting panel. This observation may be attributed by the fact that the flavour perception of the consumer or trained panellist is highly affected by several psychological factors such as the expectation and the logical errors provided by pre-conceptions of characteristic beer flavours as well as halo effects by individual personal preference for some attributes more than others generated by the tasting panellist's mind (Bennett *et al*., 2005; Lelièvre *et al*., 2008; Meilgaard *et al.*, 2007; Mejholm and Martens, 2006). According to the analytical parameters obtained for each locally-brewed beer analysed, all the samples showed relatively similar profile, making this more difficult for the tasting panellists to detect a specific magnitude of the effect of the colouring agent on the beer flavour stability of the sample tested, which is the direct function of the physicochemical properties of the ageing flavour compounds in question. Some of them are detected by the first breath after swallowing through the direct gas phase transfer of the beer volatiles and their partition effect, while others by the tasting buds of the tongue (Hodgson *et al*., 2005). Additionally, the perception of the beer ageing flavour is recognized by the human being through a multifaceted combination of chemosensory compounds of different molecular range, but particularly of low molecular weight (LMW) (Schönberger *et al*., 2002) as well as through sensations and the cultural environment that the individual experiences daily (André, 2007; Delwiche, 2000). Last but not least, beer flavour stability must be assessed not only by the intensity of the beer ageing flavour attributes but rather on the precise time when the beer consumer detected the aged character based upon their own personal concepts (see Bamforth, 2004).

The fresh locally-brewed beer colour-adjusted with melanoidin malt showed the highest overall flavour quality (aroma and taste) and scored “good” to “very good”, as well as presenting the lowest oxidised flavour (aroma and taste), and the lowest astringent taste, respectively. Nevertheless, it was very similarly scored to the other fresh analogue beers colour-adjusted with different other colouring agents. In contrast, the fresh beer sample colour-adjusted with light crystal malt (CARAHELL®) presented the lowest floral, hoppy and fruity aroma as well as the lowest overall taste quality. Additionally, it displayed the highest sulphury and oxidised taste. These results are in disagreement with statements reported by previous studies (Gruber, 2001), in which beers brewed with light crystal malts such as CARAHELL® can contribute to the improvement of beer flavour stability by providing neutral flavours, which was exactly the opposite of what this investigation obtained. In contrast, the fresh analogue beer colour-adjusted with artificial caramel colorant (CARAMEL #301) obtained a higher malty and marked fruity aroma than the other samples. According to previous investigations (Coghe, 2004; Gretenhart, 1997) remarked malty flavours are strongly related with beer ageing compounds of oxygen heterocyclic nature such as furans. Furthermore, the fresh locally-brewed beer colour-adjusted with roasted malt (CARAFA® SPECIAL Type III) was rated the lowest acetaldehyde taste, while the fresh beer control (100% pilsner malt) was scored with the highest acetaldehyde and phenolic taste, but with the lowest scores in all the other beer ageing flavour descriptors, particularly in sulphur taste in comparison to the other beer samples. In addition, all the fresh samples present considerable differences of oxidised taste, notwithstanding all of them were brewed and stored under the same specifications and conditions (see Section 3.1). This agrees with previous studies (Angelino *et al.*, 1999; Greenhoff and Wheeler, 1981) which demonstrated the perception of oxidised flavour (*i.e.* (*E*)-2-nonenal, cardboard, papery) in beer left to fluctuate during the first six months.

With the forced aged locally-brewed beers (7 days at 60℃), clear inconsistencies were observed in comparison to the flavour profile of the spontaneously aged beers (12 months at 4℃). This confirms the GC-MS results that the forcing beer ageing method used in this investigation as an ageing accelerating method does not adequately mimic natural beer ageing. This is in agreement with all the previous results of this research and work reported by others (Walters *et al.*, 1996, 1997a and 1997b). Nonetheless, all the forced aged beer samples were scored from satisfactory to good in terms of overall flavour quality (aroma and taste) by the sensory panellists. Higher sweet, hoppy, floral, fruity and acidic aromas as well as the highest overall aroma quality were scored in the forced aged beer sample colour-adjusted with light crystal malt (CARAHELL®) by the sensory panel. In contrast, the forced aged beer colour-adjusted with artificial caramel colorant (CARAMEL #301) obtained the lowest values of all the descriptors of beer ageing flavour, except in acetaldehyde and oxidised levels, which had a noticeable acetaldehyde intensity and oxidised hints. Coincidently, these two forced aged samples presented the highest overall taste quality from all the forced aged samples examined, although both showed remarkable differences on their taste profile. For instance, on one hand the forced aged beer sample colour-adjusted with light crystal malt (CARAHELL®) scored the highest fruity taste but the lowest oxidised and acidic taste from all the forced aged samples. On the other hand, the forced aged sample colour-adjusted with artificial caramel colorant (CARAMEL #301) was considered as the forced aged beer with the lowest flavour in terms of all the beer ageing attributes but with the highest astringent flavour in comparison to all the portfolio of forced aged samples. Moreover, the forced aged beer control (100% pilsner malt) and the forced aged sample colour-adjusted with melanoidin malt were indicated to have the highest oxidised flavour and the lowest overall flavour quality of all the forced aged beers. Likewise, the forced aged locally-brewed beer colour-adjusted with melanoidin malt presented the most intensive phenolic, spicy and sulphury taste but the less intensive astringency from all the forced aged samples. The intensive phenolic taste can be related to previous investigations (Vanderhaegen *et al.*, 2007) observations, which point out that phenolic, solvent-like flavours are formed by furfuryl ethyl ether during the beer ageing.

The spontaneously aged locally-brewed sample (12 months at 4℃) colour-adjusted with melanoidin malt presented the highest preference by the panellists on the overall flavour quality (aroma and taste). Also, significant lower acidic, acetaldehyde, sweet, malty and grainy aromas were found in this spontaneously aged beer sample. In contrast, the spontaneously beer sample colour-adjusted with light crystal malt (CARAHELL®) showed the lowest overall flavour quality stressed by the lowest hoppy, floral and sweet aroma but had the highest oxidised and acidic taste. The low hoppy aroma and high acidic taste presented by the aforementioned sample are in agreement with some previous observations (Narziß *et al.*, 1993), which confirm that there is a loss of hoppy aroma that sometimes turns to harsh and acidic flavours. Clearly, this spontaneously aged sample presented the poorest quality in terms of flavour stability among all the spontaneously aged samples under investigation. In contrast, the lowest overall taste quality and the highest astringent taste were noticed in spontaneously aged locally-brewed beer colour-adjusted with light crystal malt (CARAHELL®). The spontaneously beer control generated relatively higher acidic taste than all the spontaneously aged beer colour-adjusted. While, the spontaneously aged beer sample colour-adjusted with artificial caramel colorant (CARAMEL#301) generated the most intensive sulphury, malty, and grainy taste.

Looking individually at the locally-brewed beers at different ageing conditions, the fresh beer sample colour adjusted with light crystal malt (CARAHELL®) presented slightly more intense hoppy aroma and less intense phenolic and grainy taste than its forced and aged beer analogues. Conversely, the forced aged beer sample (7 days at 60℃) presented much higher values in all the descriptors of the beer ageing aroma profile and the overall flavour quality (aroma and taste) than the fresh and spontaneously aged (12 months at 4℃) versions. Additionally, the spontaneously aged version showed slightly stronger hints of oxidised, floral, grainy, malty and acidic aroma as well as more intense astringent, oxidised, phenolic and acetaldehyde taste than the fresh and forced aged versions. The spontaneously aged beer sample obtained very similar overall aroma quality as the fresh one but the poorest overall taste quality and the less intensive fruity and sulphury notes.

The fresh locally-brewed beer colour-adjusted with melanoidin malt displayed the lowest oxidised, malty, grainy, hoppy aroma, but no clear difference in taste to their forced aged (7 days at 60℃) and spontaneously aged (12 months at 4℃) versions. Meanwhile, the spontaneously aged beer sample obtained less intense acetaldehyde aroma but very similar overall flavour quality (aroma and taste) as its fresh analogue beer. Moreover, the most intense oxidised, acidic, malty and grainy aroma as well as spicy, sulphury and oxidised taste and the poorest overall flavour (aroma and taste) were observed in the forced aged beer sample. These outcomes are in disagreement with those obtained by previous research (Greenhoff and Wheeler, 1981), in which is claimed that pale lager beers become sweeter, more astringent and more solvent-like (phenolic) as well as less fruity, malty and sulphury during the ageing process. It can be argued that the heat treatment throughout the forcing can provoke radical changes in the beer matrix by the induction of caramelisation and non-enzymatic reactions, which subsequently may provide higher malty, sulphury, fruity and spicy flavour attributes on the final beer flavour profile.

The fresh and spontaneously aged beer (12 months at 4°C) samples colour-adjusted with dehusked roasted malt (CARAFA® SPECIAL Type III) presented the highest overall flavour quality (aroma and taste) as well as more intense sweet, grainy aroma, and lowest acidic aroma hints were found in the fresh version. This is in agreement with previous investigations, which demonstrated a positive correlation of beer freshness with sweet, grainy flavour attributes as well as by using an addition of roasted malt products at lower concentrations than 1% w/w, a satisfactory beer colour adjustment and no negative effect on flavour stability can be achieved. In contrast, papery, musty, and skunky flavour attributes are linked with beer staling (Preuß *et al.*, 2001; Techakriengkrai *et al.*, 2006). Besides, it has been found that high additions of roasted products such as roasted barley in the grist load can induce a negative influence not only on the beer flavour stability but in the physical stability of the beer such as reduction of head retention (Walker and Westwood, 1992). Therefore, it is important to emphasize that the ratio between colouring agent and total grist load plays an essential role on the flavour stability of any beer in question, but particularly on pale lager beers. In addition, slightly lower oxidised and acetaldehyde taste in this sample were obtained. On the other hand, the lowest overall aroma quality and remarkably higher oxidised, acetaldehyde and grainy flavour (aroma and taste) in forced beer were noticed. Likewise, the higher hoppy and sweet aromas and more noticeable phenolic, acetaldehyde, sulphury and malty tastes in aged beer were detected in the forced and fresh analogues.

In the flavour profile of the locally-brewed beers colour-adjusted with artificial caramel colorant (CARAMEL#301), the highest overall flavour quality (aroma and taste) and the most intense fruity, floral, malty and acidic aromas were noticed in the fresh version. Likewise, this one presented the less intense grainy, sulphury and phenolic aromas. Conversely, the most intense oxidised, acetaldehyde and grainy aromas were discerned in the forced aged beer (7 days at 60℃), but no clear difference found in the taste profile among the other beer samples. Furthermore, the most intense hoppy and sweet aromas and the most intense malty, sulphury and phenolic taste were observed in the spontaneously aged version (12 months at 4℃). This is in agreement with some literature (Griffin, 2008; Narziß, 1995), in which it is stated that malty, bready and sweet flavour attributes appear during the beer ageing by the increase of by-products of non-enzymatic browning reactions as well as of Strecker degradation of aminoacids and decarboxilation of higher alcohols produced during the beer fermentation and maturation.

Finally, there was no clear difference of overall aroma quality among the fresh, forced aged (7 days at 60℃) and spontaneously aged (12 m onths at 4℃) locally-brewed beer control (100% pilsner malt). Nevertheless, the fresh beer control showed a clear higher preference by the panellist in terms of overall taste quality. Also, it presented slightly higher acetaldehyde flavour (aroma and taste), as well as less intense oxidised, grainy, hoppy and acidic aromas but lower values of beer ageing taste descriptors in comparison to its forced aged and spontaneously aged beers. In contrast, the forced aged beer sample displayed the lowest overall flavour quality (aroma and taste) as well as the most intense malty and grainy aromas and sulphury, spicy and oxidised taste. Regarding, the spontaneously aged beer version, less intense sweet aroma and sulphury taste as well as slightly more acidic taste were detected than the fresh and forced aged beers.

Table 4.6.9 Grand mean values and Friedman test of the sensory evaluations of the second round of fresh locally-brewed beers

GRAND MEAN VALUES

Beer Aroma	CH Fr	MM Fr	CFSP Fr	C#301 Fr	PM Fr
Fruity	**2.50**	2.53	2.40	**2.95**	2.65
Floral	**1.15**	2.05	1.90	2.20	1.80
Hoppy	**1.50**	1.20	0.90	1.35	1.00
Grainy	1.30	1.15	1.05	1.60	1.05
Malty	1.15	1.15	1.43	**1.93**	1.35
Sweet	2.35	2.38	1.90	2.35	2.05
Acetaldehyde	1.50	1.85	1.70	2.15	2.30
Oxidised	1.15	**0.40**	1.23	0.85	1.05
Acidic	1.05	0.85	0.40	1.20	1.05
Overall quality	**2.40**	**3.53**	2.90	3.00	2.90

Beer Taste	CH Fr	MM Fr	CFSP Fr	C#301 Fr	PM Fr
Fruity	2.25	2.20	2.18	1.85	1.90
Spicy	1.90	1.75	1.55	1.90	1.50
Grainy	1.25	1.70	1.70	1.20	1.30
Malty	1.50	1.85	1.80	1.93	1.30
Sulphury	**1.75**	1.20	1.10	1.25	0.75
Acetaldehyde	1.75	1.90	1.20	**1.80**	**2.35**
Phenolic	1.20	1.35	1.25	1.45	**1.65**
Oxidised	**1.70**	**1.25**	1.55	1.45	1.20
Acidic	1.55	1.43	1.15	1.40	1.40
Astrigent	2.40	**1.55**	2.40	2.35	2.18
Overall quality	**2.40**	**3.48**	2.85	3.03	2.75

RANKING OF VALUES (Friedman's Test)

Beer Aroma	CH Fr	MM Fr	CFSP Fr	C#301 Fr	PM Fr
Fruity	2	3	1	5	4
Floral	1	4	3	5	2
Hoppy	5	3	1	4	2
Grainy	4	3	1.5	5	1.5
Malty	1.5	1.5	3	4	2
Sweet	4	5	1	3	2
Acetaldehyde	1	3	2	4	5
Oxidised	4	1	5	2	3
Acidic	4	2	1	5	3
Overall quality	1	4	2.5	5	2.5
Rank Sum	**27.5**	**29.5**	**21**	**42**	**27**

Beer Taste	CH Fr	MM Fr	CFSP Fr	C#301 Fr	PM Fr
Fruity	5	4	3	1	2
Spicy	4.5	3	2	4.5	1
Grainy	2	4.5	4.5	1	3
Malty	2	4	3	5	1
Sulphury	5	3	2	4	1
Acetaldehyde	2	4	1	3	5
Phenolic	1	3	2	4	5
Oxidised	5	2	4	3	1
Acidic	5	4	1	2.5	2.5
Astrigent	4.5	1	4.5	3	2

Overall quality	1	5	3	4	2
Rank Sum	**37**	**37.5**	**30**	**35**	**25.5**

Beer Aroma (Fresh)

$$M = 12 / am(m+1) * \sum_{k=1}^{m} R_k^2 - 3a(m+1)$$

Where
m: Number of Treatments
a: Number of Blocks

$M= \{12 / [10 \times 5 \times (5+1)] \times (27.5^2 + 29.5^2 + 21^2 + 42^2 + 27^2)\} - [3 \times 10 \times (5+1)]$

M= 2.42

F (m=10, a=5, α=0.05) = 9.49

Conclusion: The samples have not the same quality of ageing aroma

Beer Taste (Fresh)

$$M = 12 / am(m+1) * \sum_{k=1}^{m} R_k^2 - 3a(m+1)$$

Where
m: Number of Treatments
a: Number of Blocks

$M= \{12 / [11 \times 5 \times (5+1)] \times (37^2 + 37.5^2 + 30^2 + 35^2 + 25.5^2)\} - [3 \times 11 \times (5+1)]$

M= 1.82

F (m=11, a=5, α=0.05) = 9.49

Conclusion: The samples have not the same quality of ageing taste

Table 4.6.10 Grand mean values and Friedman test of the sensory evaluations of the second round of forced aged (7 days at 60℃) lo cally-brewed beers

GRAND MEAN VALUES

Beer Aroma	CH Fo	MM Fo	CFSP Fo	C#301 Fo	PM Fo
Fruity	**2.95**	2.30	2.53	2.53	2.55
Floral	**2.25**	1.75	1.75	1.75	1.95
Hoppy	**1.95**	1.50	0.85	0.85	1.35
Grainy	**1.35**	2.05	1.85	1.85	1.85
Malty	2.00	1.70	1.60	1.60	1.95
Sweet	**3.05**	2.28	2.08	2.08	2.10
Acetaldehyde	2.05	1.85	2.35	**2.35**	1.90
Oxidised	1.50	1.65	1.95	**1.95**	1.75
Acidic	**1.65**	1.25	1.00	1.00	1.25
Overall quality	**2.80**	2.25	2.30	2.30	2.63

Beer Taste	CH Fo	MM Fo	CFSP Fo	C#301 Fo	PM Fo
Fruity	**2.70**	2.10	1.90	1.90	1.80
Spicy	1.60	**2.20**	1.50	1.50	1.80
Grainy	1.70	1.80	2.00	2.00	1.60
Malty	1.75	1.85	1.80	1.80	1.93
Sulphury	2.05	**2.25**	1.35	1.35	1.90
Acetaldehyde	1.80	1.80	1.70	1.70	1.75
Phenolic	1.70	**2.33**	1.25	1.25	1.63
Oxidised	**1.55**	**2.15**	2.05	2.05	**2.30**
Acidic	**1.45**	1.45	1.15	1.15	1.60
Astrigent	2.20	**1.80**	**2.50**	**2.50**	2.35
Overall quality	**2.65**	**2.00**	2.35	**2.35**	**1.63**

RANKING OF VALUES (Friedman's Test)

Beer Aroma	CH Fo	MM Fo	CFSP Fo	C#301 Fo	PM Fo
Fruity	4	1	2.5	2.5	3
Floral	5	2	2	2	4
Hoppy	5	4	1.5	1.5	3
Grainy	1	5	2.5	2.5	2.5
Malty	5	3	1.5	1.5	4
Sweet	5	4	1.5	1.5	3
Acetaldehyde	3	1	4.5	4.5	2
Oxidised	1	2	4.5	4.5	3
Acidic	5	3.5	1.5	1.5	3.5
Overall quality	5	1	2.5	2.5	4
Rank Sum	**39**	**26.5**	**24.5**	**24.5**	**32**

Beer Taste	CH Fo	MM Fo	CFSP Fo	C#301 Fo	PM Fo
Fruity	4	3	2.5	2.5	1
Spicy	3	5	1.5	1.5	4
Grainy	2	3	4.5	4.5	1
Malty	1	4	2.5	2.5	5
Sulphury	4	5	1.5	1.5	3
Acetaldehyde	4.5	4.5	1.5	1.5	3
Phenolic	4	5	1.5	1.5	3
Oxidised	1	4	2.5	2.5	5
Acidic	3.5	3.5	1.5	1.5	5
Astrigent	2	1	4.5	4.5	3
Overall quality	5	2	3.5	3.5	1

Rank Sum	34	40	27.5	27.5	34

Beer Aroma [Forced aged (7 days at 60℃)]

$$M = 12 / am\,(m+1) * \sum_{k=1}^{m} R_k^2 - 3\,a\,(m+1)$$

Where
m: Number of Treatments
a: Number of Blocks

$$M = \{12 / [10 \times 5 \times (5+1)] \times (39^2 + 26.5^2 + 24.5^2 + 24.5^2 + 32^2)\} - [3 \times 10 \times (5+1)]$$

M= -2.09

F (m=10, a=5, α=0.05) = 9.49

Conclusion: The samples have not the same quality of ageing aroma

Beer Taste [Forced aged (7 days at 60℃)]

$$M = 12 / am\,(m+1) * \sum_{k=1}^{m} R_k^2 - 3\,a\,(m+1)$$

Where
m: Number of Treatments
a: Number of Blocks

$$M = \{12 / [11 \times 5 \times (5+1)] \times (34^2 + 40^2 + 27.5^2 + 27.5^2 + 34^2)\} - [3 \times 11 \times (5+1)]$$

M= -2.78

F (m=11, a=5, α=0.05) = 9.49

Conclusion: The samples have not the same quality of ageing taste

Table 4.6.11 Grand mean values and Friedman test of the sensory evaluations of the second round of spontaneously aged (12 months at 4℃) locally-brewed beers

GRAND MEAN VALUES

Beer Aroma	CH Ag	MM Ag	CFSP Ag	C#301 Ag	PM Ag
Fruity	2.33	2.20	2.33	2.40	2.30
Floral	**1.75**	1.90	1.90	1.85	2.05
Hoppy	**1.10**	1.75	1.63	1.70	1.45
Grainy	1.55	**1.20**	1.38	1.30	1.40
Malty	1.85	**1.45**	1.29	1.28	1.45
Sweet	**2.05**	**2.15**	2.50	2.55	2.40
Acetaldehyde	1.88	**1.45**	1.65	1.50	1.95
Oxidised	**1.75**	1.05	0.75	0.85	**1.70**
Acidic	**1.40**	**0.75**	0.80	0.80	**1.25**
Overall quality	**2.40**	**3.45**	2.60	2.85	2.75

Beer Taste	CH Ag	MM Ag	CFSP Ag	C#301 Ag	PM Ag
Fruity	1.70	1.90	2.00	2.00	2.05
Spicy	1.75	1.60	1.63	1.63	1.45
Grainy	1.50	1.40	1.75	**1.75**	1.65
Malty	1.55	1.70	2.35	**2.35**	1.95
Sulphury	1.30	1.15	1.75	**1.75**	1.30
Acetaldehyde	2.15	1.50	1.90	1.90	2.05
Phenolic	1.90	0.95	1.75	1.75	1.80
Oxidised	2.05	1.20	1.80	1.80	2.15
Acidic	1.55	0.80	1.25	1.25	**1.95**
Astrigent	**2.80**	1.80	2.30	2.30	2.40
Overall quality	**2.00**	**3.35**	2.30	2.45	2.15

RANKING OF VALUES (Friedman's Test)

Beer Aroma	CH Ag	MM Ag	CFSP Ag	C#301 Ag	PM Ag
Fruity	2.5	4	2.5	3	1
Floral	1	3.5	3.5	2	5
Hoppy	1	5	3	4	2
Grainy	5	1	3	2	4
Malty	5	3.5	2	1	3.5
Sweet	1	2	4	5	3
Acetaldehyde	4	3	2	1	5
Oxidised	5	3	1	2	4
Acidic	5	1	2.5	2.5	4
Overall quality	1	5	4	3	2
Rank Sum	**30.5**	**31**	**27.5**	**25.5**	**33.5**

Beer Taste	CH Ag	MM Ag	CFSP Ag	C#301 Ag	PM Ag
Fruity	1	2	3.5	3.5	5
Spicy	5	2	3.5	3.5	1
Grainy	2	1	4.5	4.5	3
Malty	1	2	4.5	4.5	3
Sulphury	2.5	1	4.5	4.5	2.5
Acetaldehyde	5	1	2.5	2.5	4
Phenolic	5	1	2.5	2.5	4
Oxidised	4	1	2.5	2.5	5
Acidic	4	1	2.5	2.5	5
Astrigent	5	1	2.5	2.5	4
Overall quality	1	5	3.5	3.5	2

Rank Sum	**35.5**	**18**	**36.5**	**36.5**	**38.5**

Beer Aroma [Spontaneously aged (12 months at 4℃)]

$$M = 12 / am\,(m+1) * \sum_{k=1}^{m} R_k^2 - 3\,a\,(m+1)$$

Where
m: Number of Treatments
a: Number of Blocks

$$M = \{12 / [10 \times 5 \times (5+1)] \times (30.5^2 + 31^2 + 27.5^2 + 25.5^2 + 33.5^2)\} - [3 \times 10 \times (5+1)]$$

M= -3.2

F (m=10, a=5, α=0.05) = 9.49

Conclusion: The samples have not the same quality of ageing aroma

Beer Taste [Spontaneously aged (12 months at 4℃)]

$$M = 12 / am\,(m+1) * \sum_{k=1}^{m} R_k^2 - 3\,a\,(m+1)$$

Where
m: Number of Treatments
a: Number of Blocks

$$M = \{12 / [11 \times 5 \times (5+1)] \times (35.5^2 + 18^2 + 36.5^2 + 36.5^2 + 38.5^2)\} - [3 \times 11 \times (5+1)]$$

M= 8.31

F (m=11, a=5, α=0.05) = 9.49

Conclusion: The samples have not the same quality of ageing taste

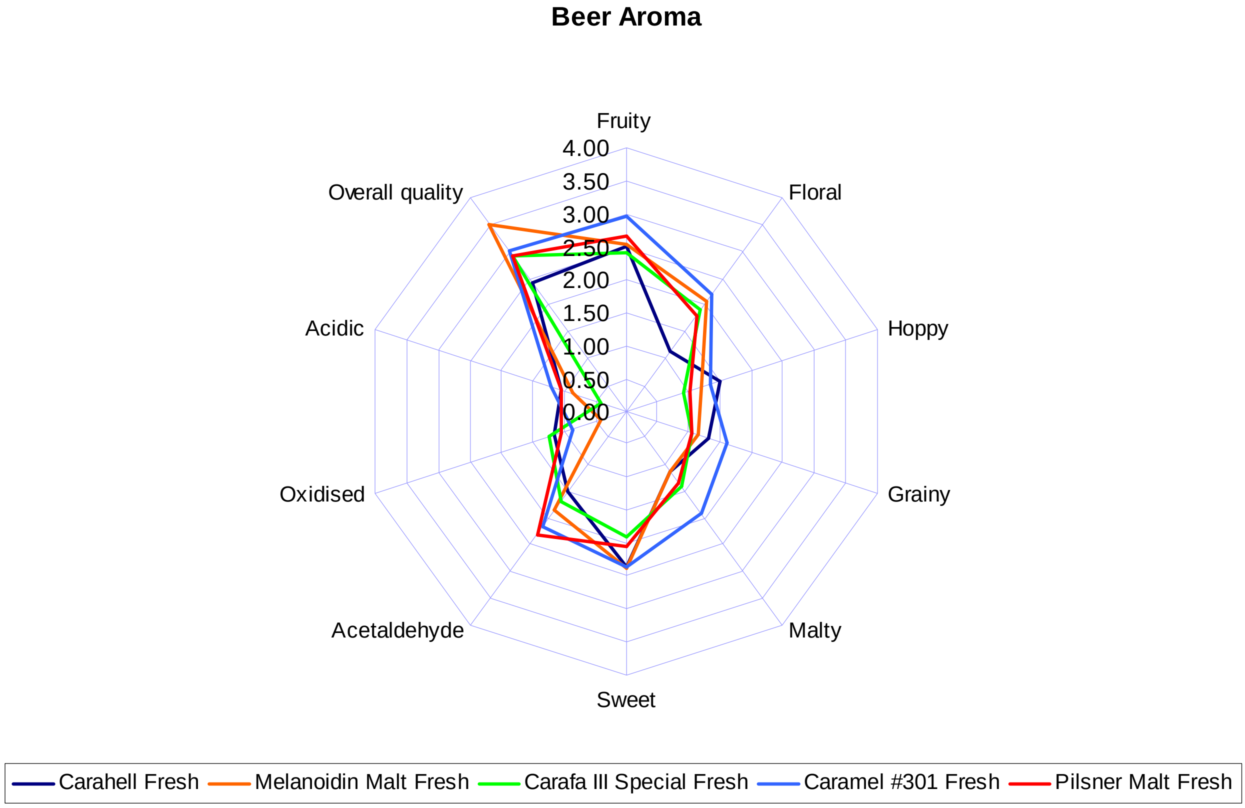

Figure 4.6.11 Aroma profile of the second round of fresh locally-brewed beers

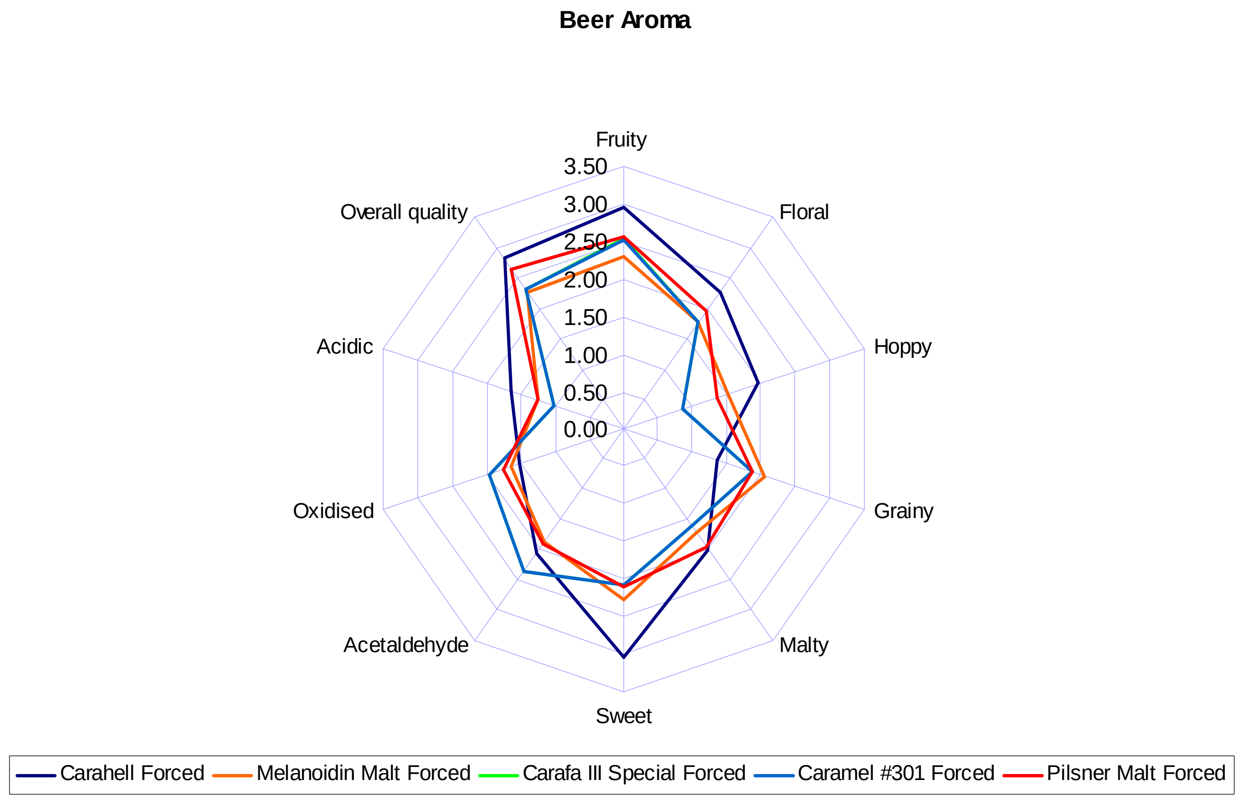

Figure 4.6.12 Aroma profile of the second round of forced aged (7 days at 60℃) locally-brewed beers

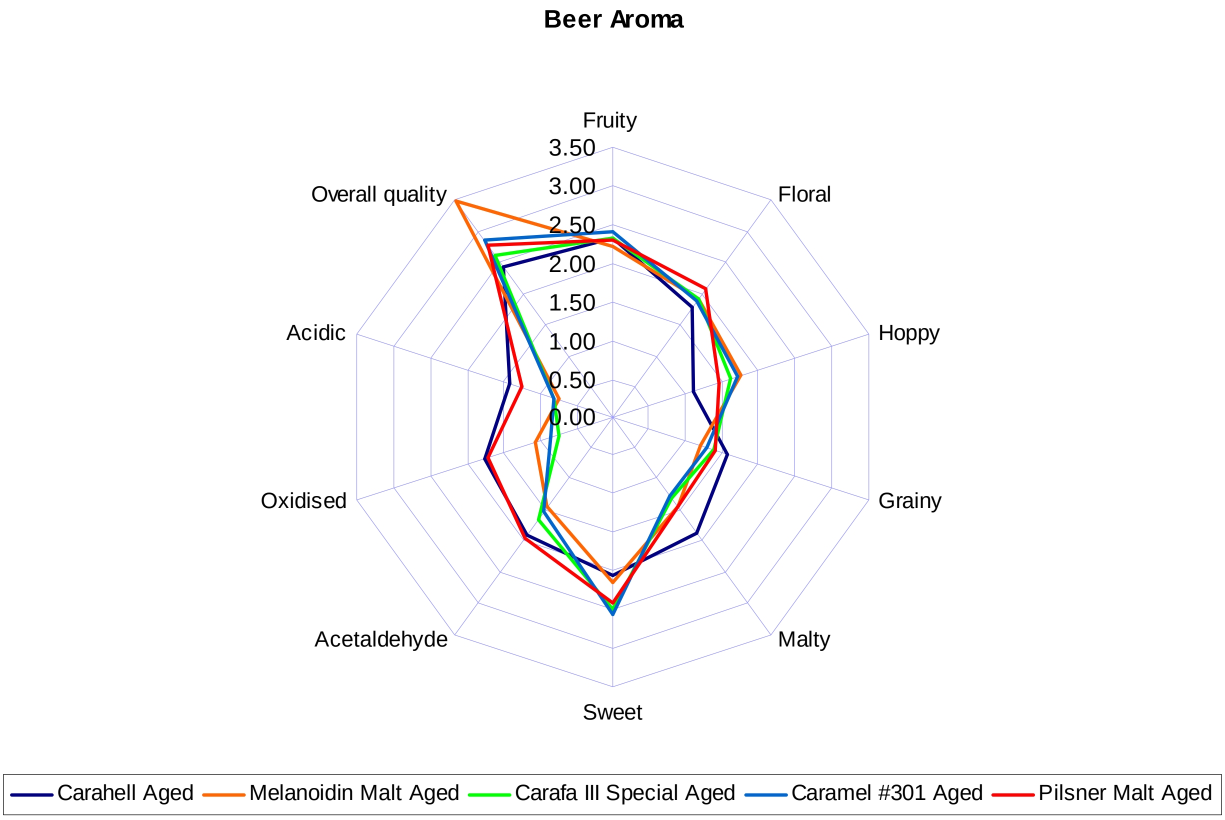

Figure 4.6.13 Aroma profile of the second round of spontaneously aged (12 months at 4℃) locally-brewed beers

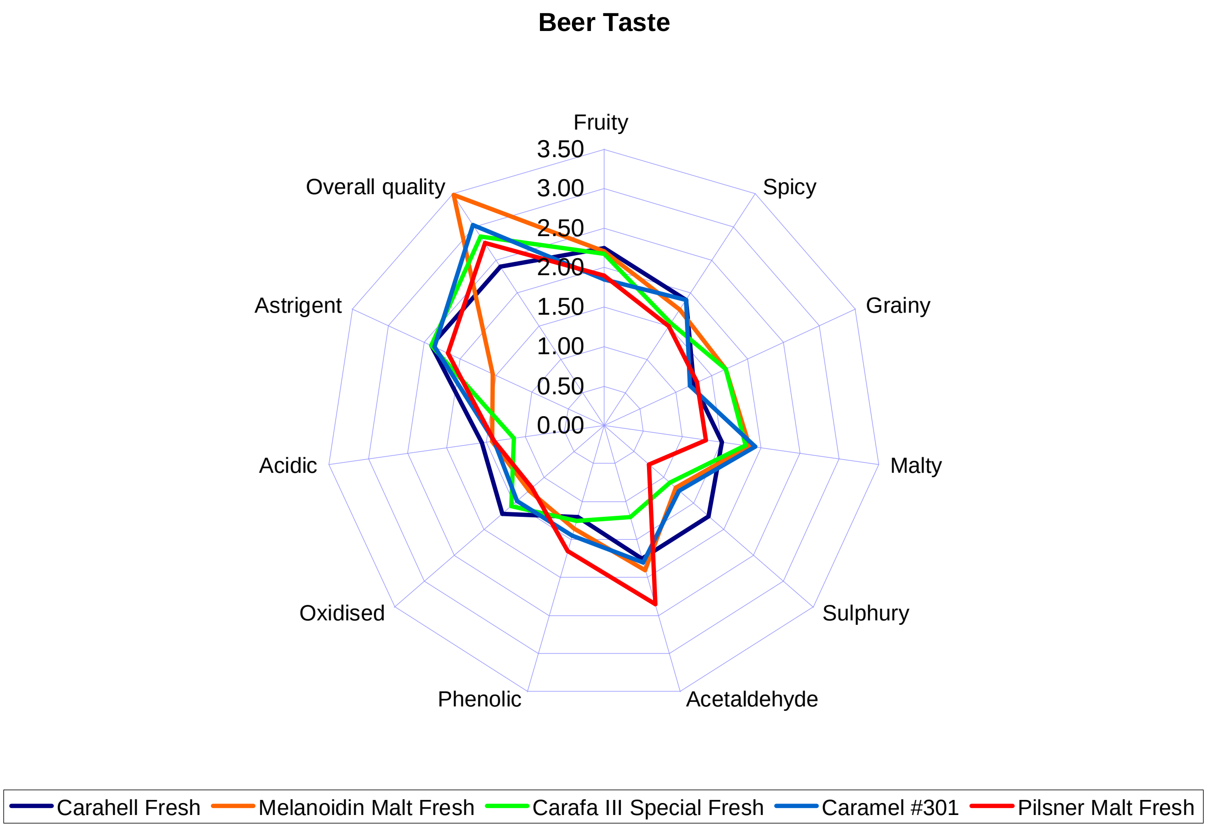

Figure 4.6.14 Taste profile of the second round of fresh locally-brewed beers

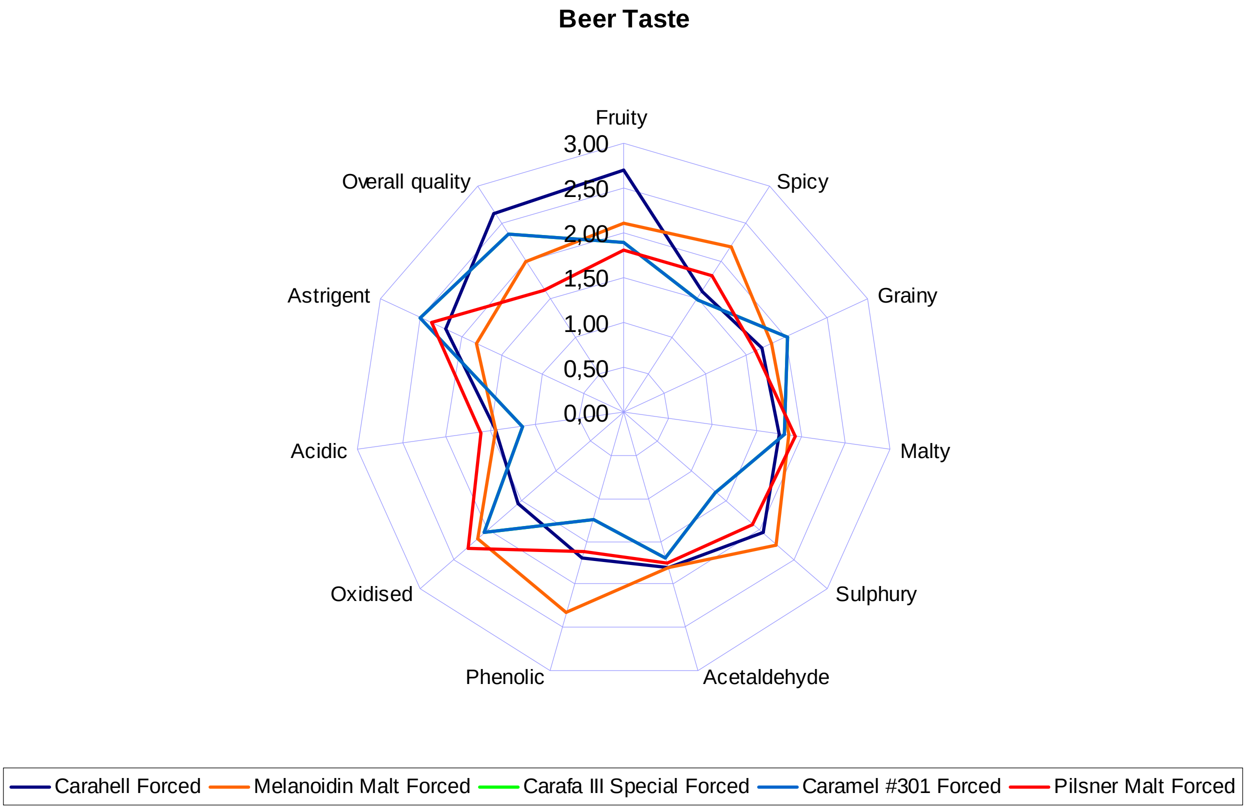

Figure 4.6.15 Taste profile of the second round of forced aged (7days at 60℃) locally-brewed beers

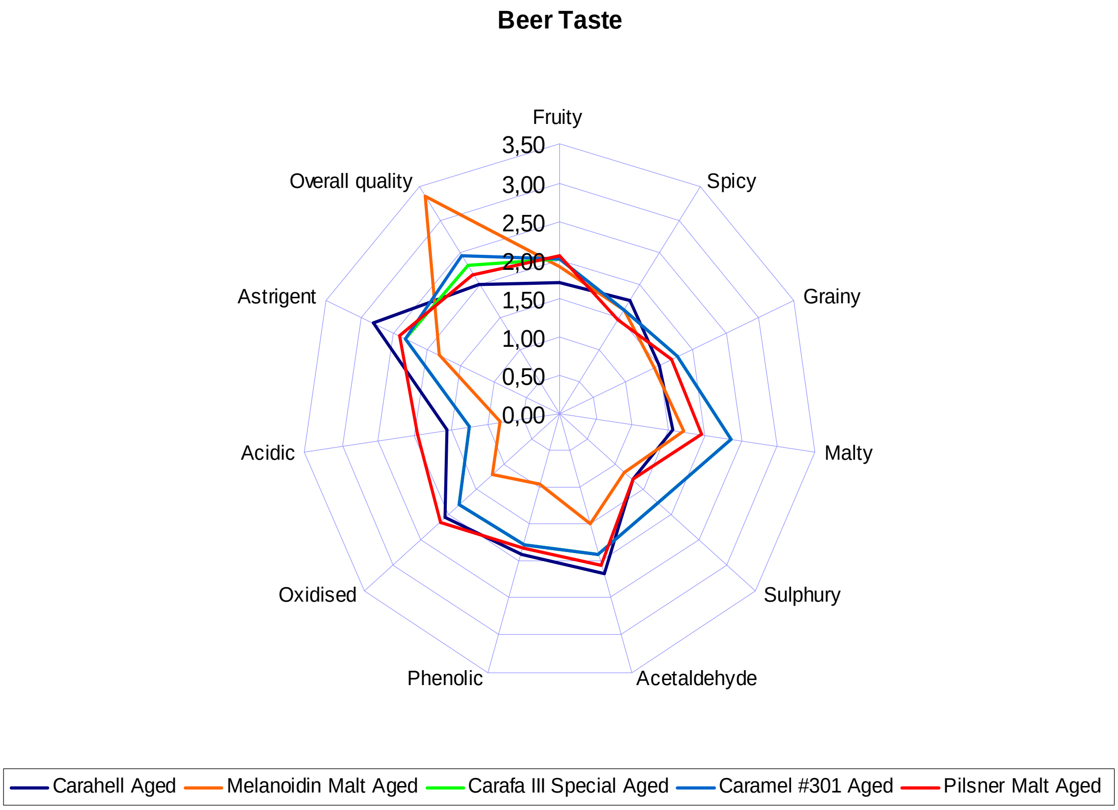

Figure 4.6.16 Taste profile of the second round of spontaneously aged (12 months at 4℃) locally-brewed beers

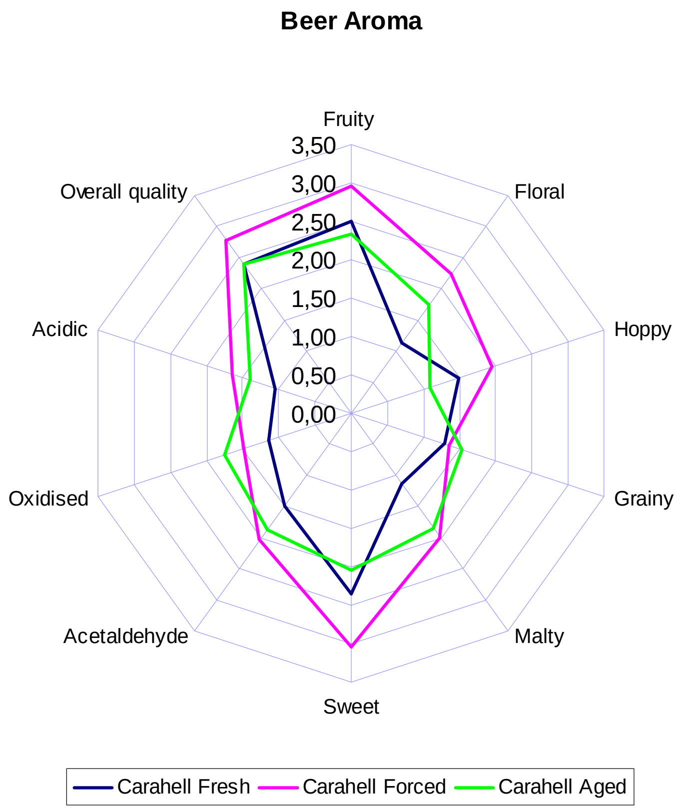

Figure 4.6.17 Aroma profile of the second round of locally-brewed beers colour-adjusted with light crystal malt (CARAHELL®)

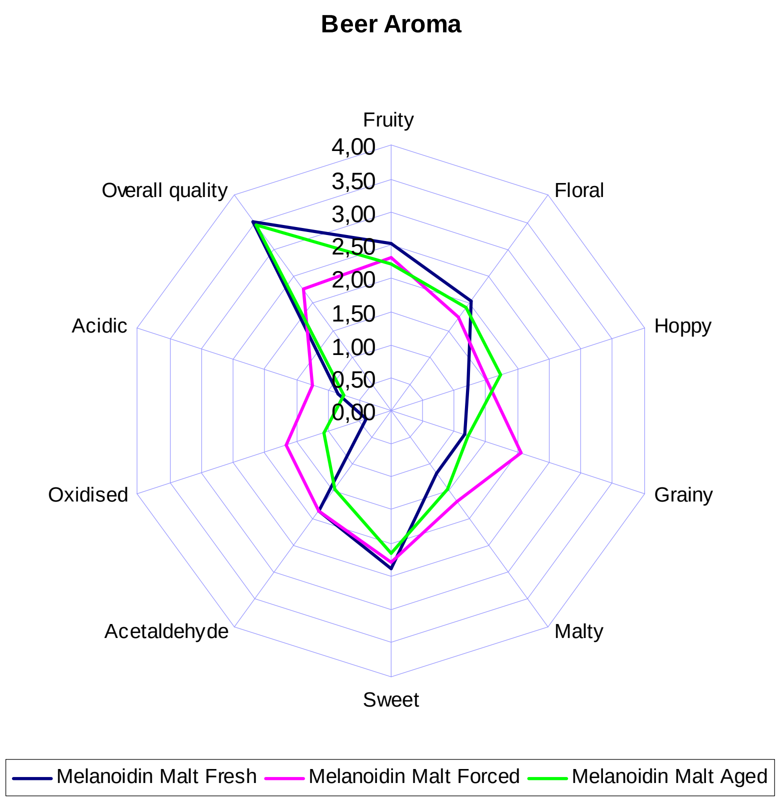

Figure 4.6.18 Aroma profile of the second round of locally-brewed beers colour-adjusted with melanoidin malt

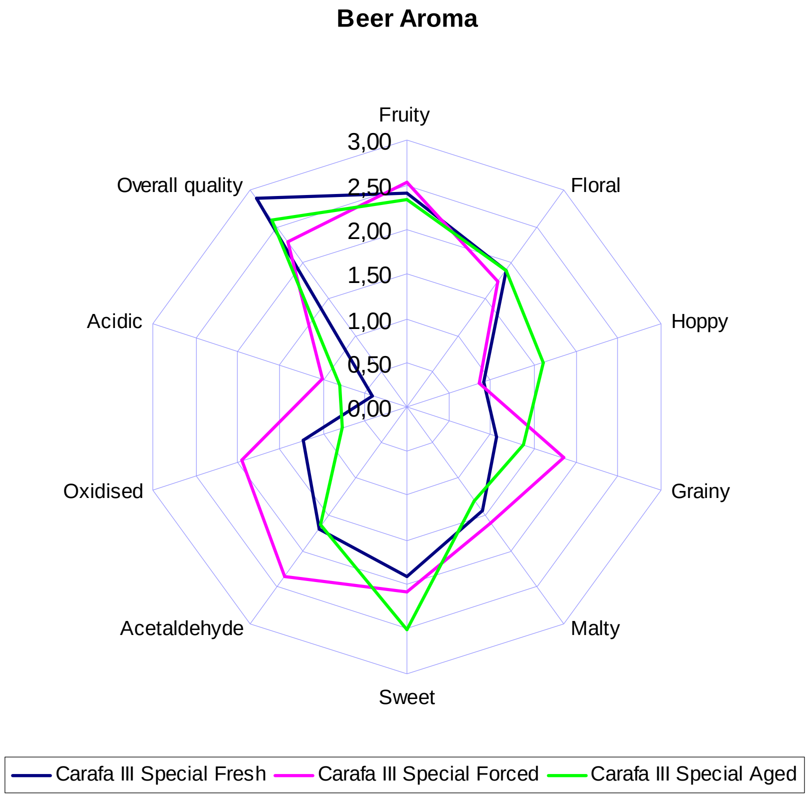

Figure 4.6.19 Aroma profile of the second round of locally-brewed beers colour-adjusted with dehusked roasted malt (CARAFA® SPECIAL Type III)

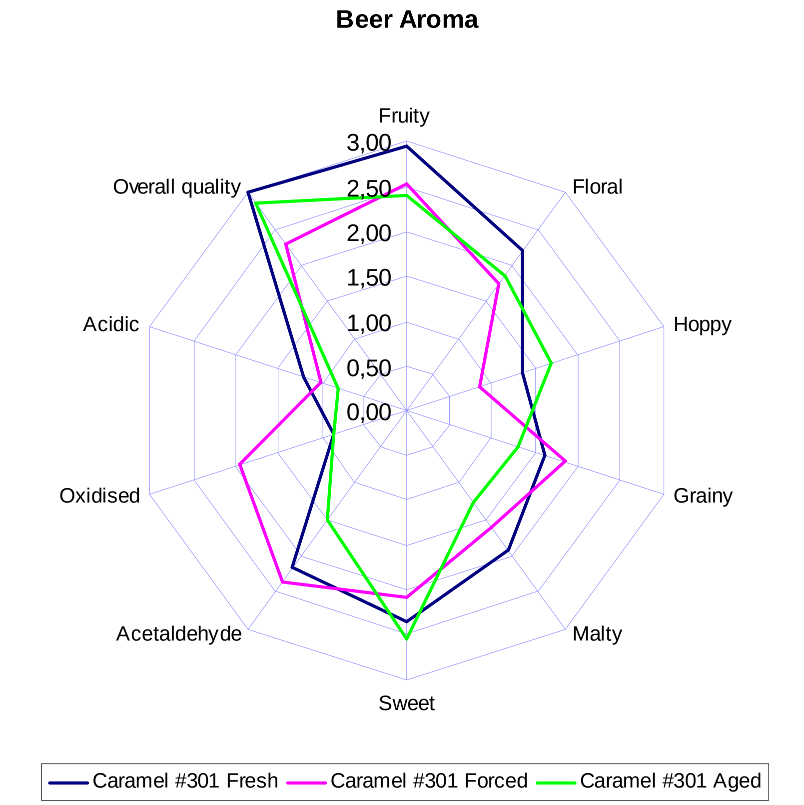

Figure 4.6.20 Aroma profile of the second round of locally-brewed beers colour-adjusted with artificial caramel colorant (CARAMEL #301)

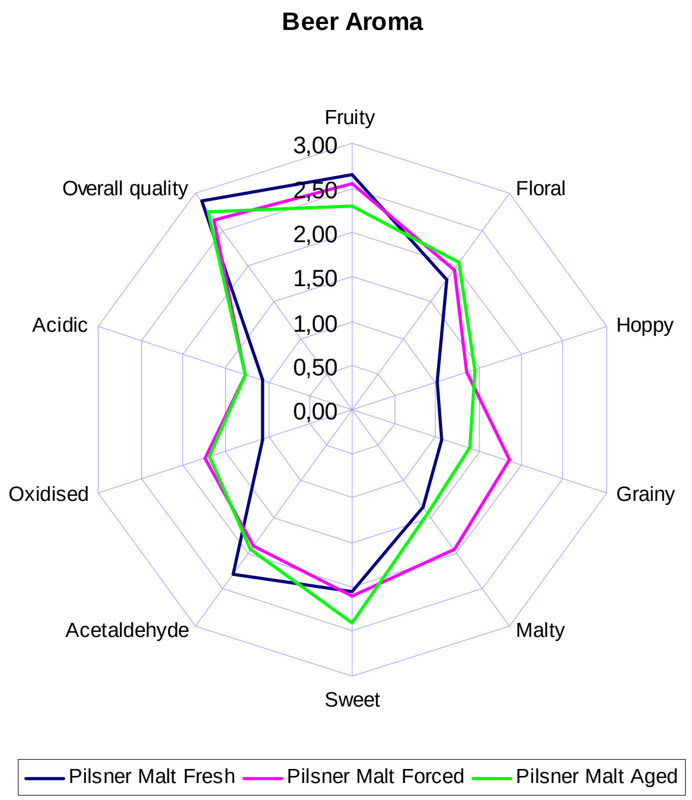

Figure 4.6.21 Aroma profile of the second round of locally-brewed beers (beer controls)

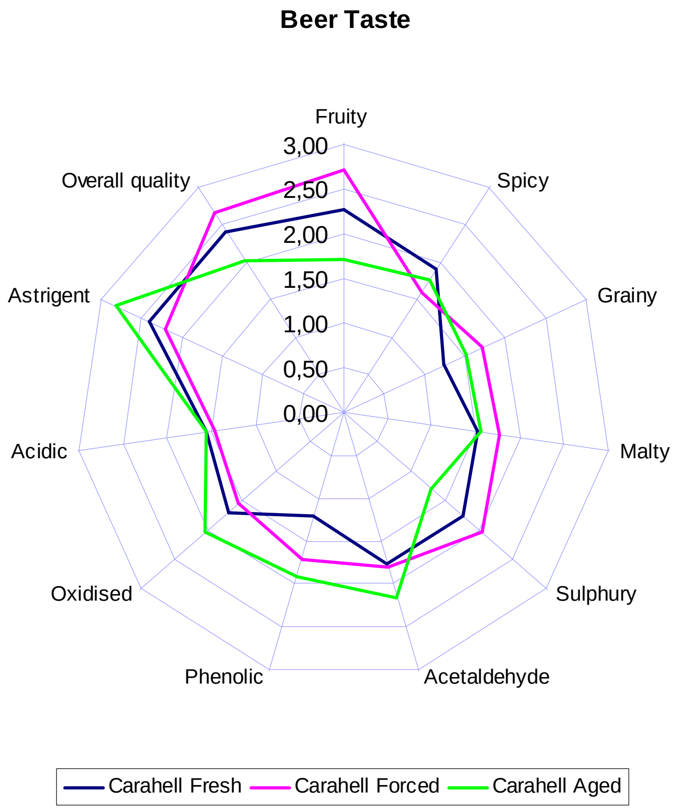

Figure 4.6.22 Taste profile of the second round of locally-brewed beers colour-adjusted with light crystal malt (CARAHELL®)

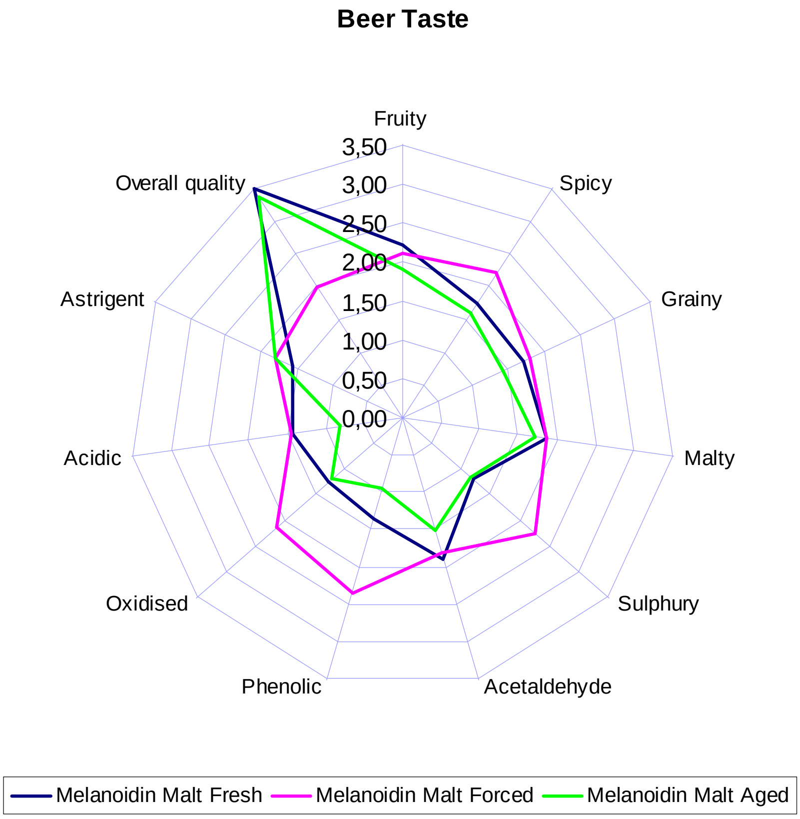

Figure 4.6.23 Taste profile of the second round of locally-brewed beers colour-adjusted with melanoidin malt

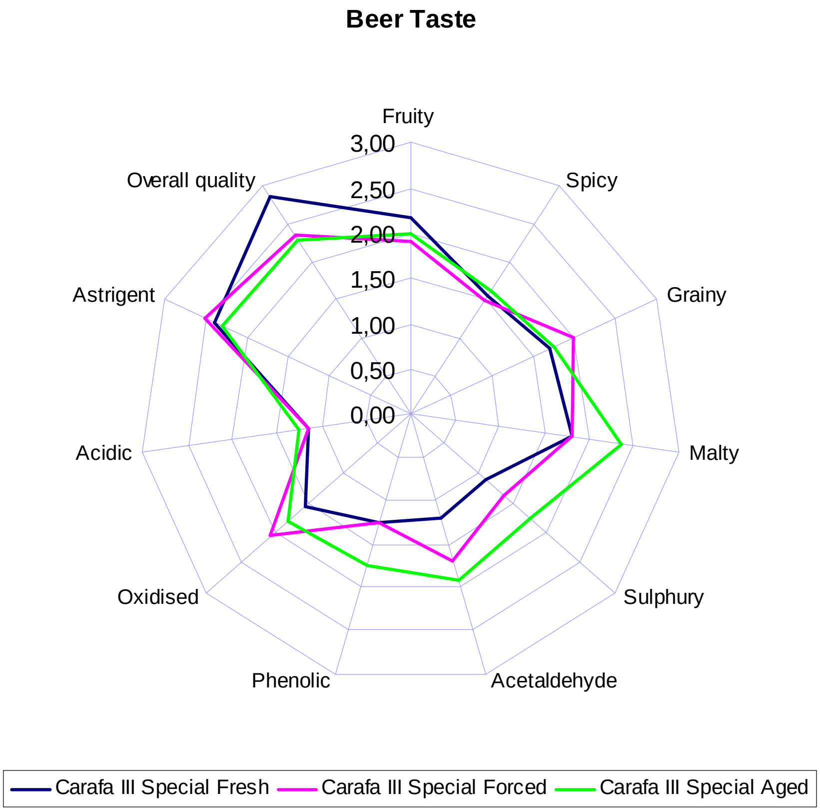

Figure 4.6.24 Taste profile of the second round of locally-brewed beers colour-adjusted with dehusked roasted malt (CARAFA® SPECIAL Type III)

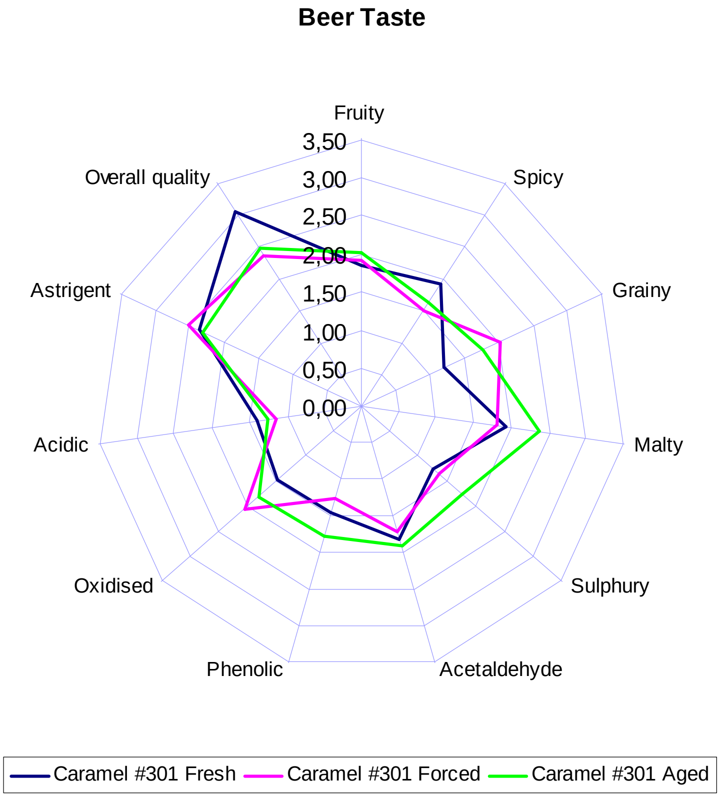

Figure 4.6.25 Taste profile of the second round of locally-brewed beers colour-adjusted with artificial caramel colorant (CARAMEL #301)

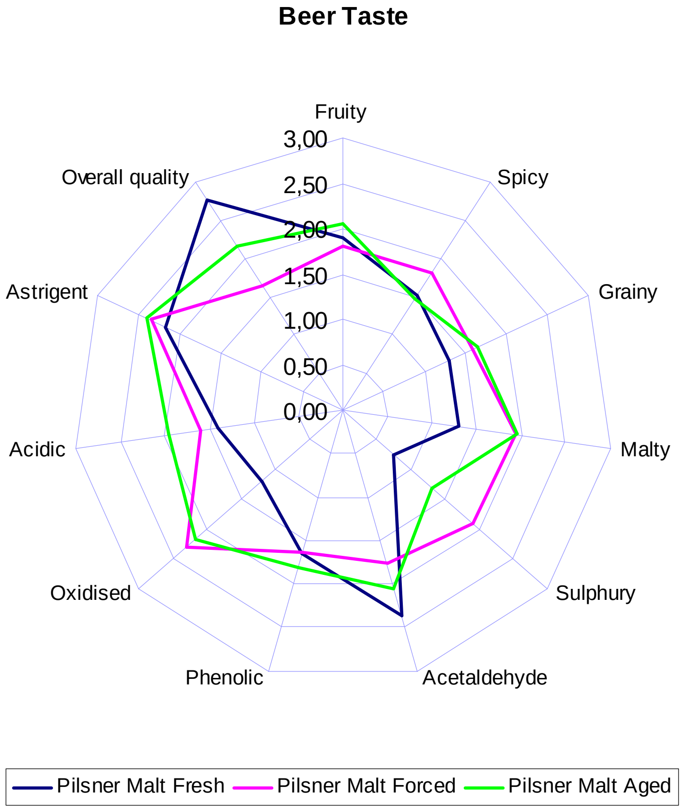

Figure 4.6.26 Taste profile of the second round of locally-brewed beers (beer controls)

4.6.3.8 Comparative analysis between analytical results and sensory evaluations of the second round of locally-brewed beers

4.6.3.8.1 Comparison between intensity of beer ageing flavour and endogenous anti-oxidative potential (EAP) of the second round of locally-brewed beers

A series of correlations between the flavour profiles of the locally-brewed beers at different age stages and the endogenous anti-oxidative potential (EAP) of the fresh locally-brewed beers was carried out with the aim of exploring the relationship between the sensory profile of the pale lager beer samples and their analytical flavour instability in terms of endogenous anti-oxidative potential (EAP). The results of these correlations were compared to the previous ones obtained between the flavour profile of the colour-adjusted beers in question and their corresponding detected and quantified beer ageing flavour-active compounds in order to find a possible linkage which may provide the true connection between the both psychophysical responses under investigation (*i.e.* colour appearance and the beer flavour, respectively) and their technological application for the better elucidation and the improvement of flavour stability of pale lager beer products. Table 4.6.12 shows the concerning correlation data of this section.

Summing up, large positive correlations were noticed between the endogenous anti-oxidative potential (EAP) of the fresh locally-brewed beers against the fruity, grainy, malty, acetaldehyde and acidic aroma profile at fresh conditions. In addition, a large positive correlation was observed between the EAP values of the fresh beer samples against the fruity aroma profile at forced aged conditions (7 days at 60℃). In contrast, large positive correlations were found between EAP values of the fresh locally-brewed beers against the acetaldehyde and phenolic taste profile, while large negative correlations were also detected between the aforementioned EAP values against the fruity and grainy taste profile at spontaneously aged conditions (12 months at 4℃). The reason for these results may be explained by the fact that a degradation of acetate esters, which confers the main pleasant fruity attributes in the overall fresh beer flavour (aroma and taste) and masking effects on spontaneously aged beer flavour, takes place besides the formation of flavour-active beer ageing compounds during ageing (see Saison *et al*., 2008b; Vanderhaegen *et al*., 2006). In addition, the deterioration of bitterness in beer is gradually produced by the degradation of hop bitter compounds during ageing. Some of the derivatives elicited by this degradation are aldehydes and fatty acids such as 2- and 3-methylbutyric acids. These fatty acids undergo esterification producing ethyl esters with low flavour thresholds, which are particularly considered as detrimental on the quality of the beer flavour (see Saison *et al*., 2008b).

Table 4.6.12 Comparison between intensity of beer ageing flavour and endogenous anti-oxidative potential (EAP) of the second round of locally-brewed beers

	FRESH	FORCED	AGED
Aroma Variables	**EAP (min)**	**EAP (min)**	**EAP (min)**
Fruity	**0.97**	-0.03	**0.55**
Floral	0.35	-0.07	0.16
Hoppy	0.33	-0.24	0.12
Grainy	**0.70**	0.07	-0.12
Malty	**0.72**	0.00	-0.25
Sweet	0.36	-0.26	0.41
Acetaldehyde	**0.75**	0.12	-0.02
Oxidised	-0.13	0.26	0.09
Acidic	**0.84**	-0.21	0.06
Overall Quality	-0.01	0.03	0.04
Taste Variables	**EAP (min)**	**EAP (min)**	**EAP (min)**
Fruity	**-0.89**	-0.31	0.34
Spicy	0.32	-0.20	-0.31
Grainy	**-0.78**	-0.02	0.35
Malty	-0.02	0.24	0.27
Sulphury	-0.19	-0.25	0.20
Acetaldehyde	**0.57**	-0.30	0.21
Phenolic	**0.67**	-0.29	0.26
Oxidised	-0.28	0.24	0.29
Acidic	0.36	-0.01	0.31
Astrigent	0.17	0.34	0.10
Overall Quality	0.01	-0.21	-0.15

Marked correlations are significant at $p<0.05$

4.6.3.8.2 Comparison between intensity of beer ageing flavour *versus* total beer ageing compounds, forcing index and ageing index of the second round of locally-brewed beers

Finally, a comparison between the flavour profile and the concentration levels of the ageing flavour-active markers of the locally-brewed samples at different ageing stages was carried out using the individual correlations of these aforementioned variables. Table 4.6.13 presents the concerning correlation data of this statistical analysis.

In summary, several large correlations were noticed between some beer ageing markers against the majority of the beer ageing flavour attributes of the locally-brewed beers at different aged conditions, *i.e.* fresh, forced aged (7 days at 60℃) and spontaneously aged (12 months at 4℃). Even though, th e investigated compounds were found at sub-threshold concentrations and their corresponding flavour descriptors did not necessarily correspond to those ones reported in the literature (Lustig, 1993; Meilgaard, 1975b; Narziß *et al.*, 1999; Saison *et al.*, 2008; Vanderhaegen *et al.*, 2003) (see Table 3.2.8). This may be explained by the fact that the non-linearity of the human perception on beer flavour is strongly influenced by the matrix and the synergetic effects generated by the great portfolio of the flavour congenerics contained on the beer matrix itself even at sub-threshold levels as well as by masking effects produced by beer esters (see Saison *et al*., 2008b). According to the flavour interaction hypothesis by Meilgaard (1975a), strong synergetic effects can be produced by flavour-active compounds with similar sensorial attributes even at sub-threshold levels. In contrast, antagonist interactions and/or partially compensations are elicited by flavour-active compounds with independent or partially similar flavour properties. Likewise, recent investigations (Saison *et al.*, 2008b) suggested that individual threshold levels of flavour-active ageing compounds in beer must be considered as indicative rather than absolute, due to the flavour interaction between the broad ranges of the compounds at sub-threshold concentrations. Therefore, it is possible to argue that the present results were affected by the broad range of flavour interaction phenomena cited above.

Several correlation results between individual flavour-active compounds and the flavour attributes reported by the tasting panel are in agreement with the flavour descriptors reported in previous studies (Saison *et al.*, 2008b; Techakriengkrai *et al.*, 2006) (see Table 3.2.8). Nevertheless, the comparative discussion of the parameters investigated was exclusively focused on the correlation values between the quantified beer ageing compounds and the overall flavour quality (aroma and taste) of the locally-brewed beers at the different ageing stages, *i.e.* fresh, forced aged (7 days at 60℃) and spontaneously aged (12 months at 4℃). This decision is based on the fact that this investigation project was not designed on the characterisation and contribution of the ageing compounds to the beer flavour according to their thresholds but to their holistic impact. However, the obtained data provides significant information in terms of beer flavour stability. For instance, a large positive correlation was noticed between the concentration of 2-furfural and the overall quality flavour (aroma and taste) profile of the fresh locally-brewed beers. Although this latter beer ageing marker does not confer remarkable flavour attributes in aged beer but stands for a relevant beer ageing marker after previous studies (see Malfliet *et al.*, 2008). In contrast, large negative correlations were observed between the concentration levels of methional and 2-phenyl ethyl acetate against the overall flavour quality (aroma and taste). This data may suggest, according to the flavour descriptors of the aforementioned compounds, that the sulphury and floral hints conferred by methional and 2-phenyl ethyl acetate provide a negative contribution in the overall flavour quality (aroma and taste) of fresh pale lager beers. In this sense, the sweet and caramel hints conferred by 2-furfural give a positive contribution in the overall flavour quality (aroma and taste) of the pale lager beer in question. Nevertheless, it is relevant to emphasize that linear correlation does not necessarily imply causation but may provide reliable indicators of a defined cause.

Concerning the forced aged locally-brewed beers (7 days at 60℃), a series of incongruencies between the correlations was found. These are based on the fact that large positive correlations were detected between the concentration of the most of the beer ageing compounds and the overall flavour quality (aroma and taste) of the forced aged beer in question. This abnormal data may be caused due to the forcing beer ageing method itself, which induce higher amounts of Maillard and caramelisation products due to the thermal treatment. These products may elicit a masking effect in the forced aged beer matrix which disables the tasting panellist's perception of typical aged flavours in beer. Additionally, all the results obtained from forced aged beers do not mimic either the psychophysical- (*i.e.* colour appearance) or chemical properties (*i.e.* ageing chemical composition) as well as sensorial attributes of the spontaneously aged pale lager beers.

Finally, large negative correlations were noticed between the concentration of 2-methylbutanal, 2-phenylethanal, methional, 2-furfural, sum of warming indicators, sum of oxygenation indicators, sum of ageing compounds, forcing index and ageing index against the aroma profile of the spontaneously aged locally-brewed beers (12 months at 4℃). Additionally, large negative correlations were obtained between the concentration of 2-methylbutanal, 3-methylbutanal and sum of oxygenation indicators. This difference in amounts of compounds and indexes perceived between the flavour profile (aroma and taste) of the spontaneously aged beer samples is caused by the higher receptor sensitivity of the olfactory system via the posterior nares than the gustation chemical sense of the sensory panellists (see Meilgaard *et al.*, 2007). However, it was clearly observed that the concentration of the Strecker aldehydes such as 2-methylbutanal, 3-methylbutanal and 2-phenylethanal as well as the fatty acid and/or high alcohol oxidation product such as the linear aldehyde hexanal is essential contributor of beer ageing flavour. In other words, the higher concentration of these flavour-active compounds the poorer the overall flavour (aroma and taste) quality of the beer. These results are in agreement with recent publications (Malfliet *et al*., 2008; Saison *et al*., 2008b; Syryn *et al*., 2007). According to the findings of these previous studies, Strecker aldehydes such as 3-methylbutanal and methional remarkably contribute to the spontaneously aged beer flavour. Other Strecker aldehydes such as 2-methylpropanal and 2-phenylethanal as well as a Maillard product such as 5-hydroxymethylfurfural contributes to the beer ageing flavour but to a lesser extent. In conclusion, interesting data was ascertained in this final section of the investigation, but further work must be carried out in order to elucidate properly the real contribution of the flavour-active compounds to the flavour of pale lager beers at different aged stages.

Table 4.6.13 Comparison between intensity of beer ageing flavour *versus* total beer ageing components, forcing index and ageing index of the second round of locally-brewed beers

FRESH

	Variables	Pentanal	Hexanal	(*E*)-2-Nonenal	2-Methylpropanal	2-Methylbutanal	3-Methylbutanal
Beer Aroma	**Fruity**	-0.45	-0.23	**0.67**	-0.13	0.06	0.07
	Floral	0.01	0.04	-0.07	-0.07	0.06	-0.02
	Hoppy	-0.46	**-0.77**	0.40	0.38	-0.06	0.03
	Grainy	-0.23	-0.48	0.36	-0.06	-0.33	-0.28
	Malty	0.14	0.19	0.19	-0.58	-0.43	-0.45
	Sweet	**-0.68**	**-0.97**	0.42	**0.69**	0.24	0.31
	Acetaldehyde	-0.44	0.19	**0.64**	-0.13	0.48	0.44
	Oxidised	0.59	**0.75**	-0.14	-0.81	-0.55	-0.54
	Acidic	**-0.81**	-0.52	**0.92**	0.27	0.40	0.46
	Overall Quality	-0.24	-0.30	-0.13	0.49	0.43	0.36
Beer Taste	**Fruity**	0.30	-0.23	**-0.65**	0.38	-0.17	-0.15
	Spicy	-0.30	**-0.77**	0.20	0.31	-0.24	-0.17
	Grainy	0.44	0.11	**-0.80**	0.21	-0.03	-0.09
	Malty	0.31	-0.30	-0.50	0.02	-0.47	-0.50
	Sulphury	0.03	-0.56	-0.14	0.22	-0.42	-0.33
	Acetaldehyde	**-0.90**	-0.26	**0.90**	0.43	**0.88**	**0.89**
	Phenolic	-0.52	0.22	**0.71**	-0.05	**0.63**	0.59
	Oxidised	0.54	0.03	-0.39	-0.37	**-0.81**	**-0.75**
	Acidic	**-0.81**	**-0.74**	**0.70**	**0.62**	0.46	0.55
	Astrigent	0.53	0.57	-0.02	-0.86	**-0.71**	**-0.68**
	Overall Quality	-0.22	-0.38	-0.17	0.49	0.32	0.27

Marked correlations are significant at $p<0.05$

FRESH

	Variables	Benzaldehyde	2-Phenylethanal	Methional	2-Furfural	5-Hydroxy methylfurfural	Acetyl furan
Beer Aroma	**Fruity**	-0.46	0.51	-0.14	-0.15	0.06	-0.37
	Floral	**-0.76**	0.18	**-0.67**	0.15	-0.13	-0.12
	Hoppy	**0.63**	0.20	0.40	0.36	**0.77**	0.44
	Grainy	-0.04	0.12	0.29	0.08	**0.60**	0.07
	Malty	**-0.75**	-0.02	0.08	-0.39	-0.03	-0.48
	Sweet	0.55	0.46	-0.07	**0.67**	**0.78**	**0.60**
	Acetaldehyde	**-0.71**	**0.68**	-0.59	-0.32	**-0.60**	**-0.67**
	Oxidised	-0.13	**-0.55**	**0.78**	**-0.86**	-0.40	-0.58
	Acidic	0.14	**0.75**	-0.03	0.01	0.17	-0.16
	Overall Quality	-0.29	0.34	**-0.90**	**0.62**	0.04	0.32
Beer Taste	**Fruity**	**0.75**	-0.51	0.27	0.50	0.46	**0.75**
	Spicy	0.48	0.05	0.36	0.44	**0.89**	0.53
	Grainy	-0.02	-0.40	-0.40	0.45	0.01	0.46
	Malty	-0.23	-0.35	-0.12	0.49	**0.60**	0.49
	Sulphury	**0.76**	-0.34	**0.66**	0.35	**0.85**	**0.63**
	Acetaldehyde	0.04	**0.96**	-0.50	-0.01	-0.36	-0.31
	Phenolic	-0.57	**0.76**	-0.58	-0.35	**-0.70**	**-0.70**
	Oxidised	0.40	**-0.74**	**0.95**	-0.17	0.51	0.22
	Acidic	**0.69**	0.61	0.07	0.33	0.42	0.29
	Astrigent	-0.23	-0.51	**0.85**	**-0.82**	-0.16	-0.56
	Overall Quality	-0.25	0.28	**-0.83**	**0.68**	0.19	0.41

Marked correlations are significant at $p<0.05$

FRESH

	Variables	Ethyl nicotinate	2-Phenyl ethyl acetate	2-Ethyl furfuryl ether	γ-Nonalactone	Sum of warm indicators	Sum of oxygen indicators
Beer Aroma	**Fruity**	**-0.62**	-0.20	0.01	-0.20	-0.38	0.08
	Floral	**-0.61**	**-0.83**	-0.42	**-0.65**	-0.42	-0.01
	Hoppy	0.45	**0.79**	**0.70**	**0.85**	**0.64**	0.18
	Grainy	-0.02	0.32	**0.60**	0.33	0.15	-0.17
	Malty	-0.55	-0.34	0.13	-0.44	-0.53	-0.46
	Sweet	0.28	0.48	0.40	**0.72**	**0.65**	0.49
	Acetaldehyde	**-0.98**	**-0.73**	**-0.70**	**-0.72**	**-0.78**	0.33
	Oxidised	0.07	0.27	0.27	-0.13	-0.37	**-0.67**
	Acidic	-0.31	0.26	0.07	0.28	-0.01	0.49
	Overall Quality	-0.30	**-0.69**	-0.54	-0.34	0.01	0.42
Beer Taste	**Fruity**	**0.92**	0.54	0.39	**0.63**	**0.79**	-0.05
	Spicy	0.46	**0.68**	**0.78**	**0.77**	**0.65**	0.01
	Grainy	0.28	-0.38	-0.26	-0.18	0.23	-0.06
	Malty	0.18	-0.17	0.36	0.03	0.28	-0.35
	Sulphury	**0.85**	**0.93**	**0.92**	**0.94**	**0.82**	-0.18
	Acetaldehyde	-0.57	-0.17	**-0.59**	-0.10	-0.26	**0.83**
	Phenolic	**-0.95**	**-0.66**	**-0.79**	**-0.67**	**-0.77**	0.46
	Oxidised	**0.72**	**0.79**	**0.92**	0.59	0.43	**-0.68**
	Acidic	0.20	**0.62**	0.24	**0.71**	0.48	**0.63**
	Astrigent	0.01	0.33	0.48	-0.06	-0.35	**-0.77**
	Overall Quality	-0.21	**-0.61**	-0.39	-0.25	0.10	0.36

Marked correlations are significant at $p<0.05$

FRESH

	Variables	Sum of ageing compounds	Forcing Index	Ageing Index
Beer Aroma	**Fruity**	-0.27	-0.07	-0.07
	Floral	-0.39	-0.14	-0.44
	Hoppy	**0.63**	0.38	**0.81**
	Grainy	0.06	-0.10	0.29
	Malty	**-0.64**	**-0.60**	-0.48
	Sweet	**0.75**	**0.66**	**0.87**
	Acetaldehyde	-0.51	0.00	-0.47
	Oxidised	**-0.56**	**-0.73**	-0.48
	Acidic	0.22	0.40	0.42
	Overall Quality	0.14	0.39	-0.02
Beer Taste	**Fruity**	**0.63**	0.26	0.50
	Spicy	0.55	0.24	**0.73**
	Grainy	0.12	0.06	-0.13
	Malty	0.05	-0.18	0.04
	Sulphury	**0.62**	0.14	**0.74**
	Acetaldehyde	0.15	**0.61**	0.19
	Phenolic	-0.43	0.11	-0.41
	Oxidised	0.09	-0.44	0.21
	Acidic	**0.69**	**0.71**	**0.82**
	Astrigent	-0.59	**-0.80**	-0.41
	Overall Quality	0.19	0.37	0.06

Marked correlations are significant at $p<0.05$

FORCED AGED (7 days at 60℃)

	Variables	Pentanal	Hexanal	(*E*)-2-Nonenal	2-Methylpropanal	2-Methylbutanal	3-Methylbutanal
Beer Aroma	**Fruity**	0.45	-0.18	-0.17	**0.98**	**0.82**	**0.93**
	Floral	0.11	-0.54	-0.09	**0.96**	**0.71**	**0.95**
	Hoppy	-0.26	**-0.82**	-0.24	**0.64**	0.48	**0.76**
	Grainy	-0.42	0.22	0.24	**-0.98**	**-0.86**	**-0.96**
	Malty	-0.20	**-0.72**	0.19	**0.78**	0.38	**0.75**
	Sweet	0.15	-0.51	-0.46	**0.83**	**0.80**	**0.93**
	Acetaldehyde	**0.70**	**0.85**	-0.15	-0.04	0.20	-0.13
	Oxidised	0.29	**0.83**	0.26	-0.58	-0.45	**-0.71**
	Acidic	-0.11	**-0.74**	-0.24	**0.79**	**0.61**	**0.87**
	Overall Quality	0.07	-0.52	0.12	**0.93**	0.57	**0.87**
Beer Taste	**Fruity**	0.17	-0.45	-0.56	**0.75**	**0.80**	**0.88**
	Spicy	**-0.74**	**-0.61**	-0.02	-0.43	-0.44	-0.28
	Grainy	0.47	**0.81**	-0.33	-0.47	-0.05	-0.46
	Malty	**-0.61**	-0.26	**0.69**	-0.44	**-0.76**	-0.52
	Sulphury	-0.58	**-0.87**	-0.13	0.18	0.05	0.33
	Acetaldehyde	-0.44	**-0.84**	-0.28	0.34	0.26	0.50
	Phenolic	**-0.64**	**-0.72**	-0.21	-0.18	-0.16	0.01
	Oxidised	-0.46	0.13	0.58	**-0.78**	**-0.90**	**-0.86**
	Acidic	-0.59	**-0.84**	0.31	0.30	-0.08	0.32
	Astrigent	0.57	**0.67**	0.33	0.18	0.09	-0.04
	Overall Quality	**0.64**	0.28	**-0.66**	0.48	**0.77**	0.55

Marked correlations are significant at $p<0.05$

FORCED AGED (7 days at 60℃)

	Variables	Benzaldehyde	2-Phenylethanal	Methional	2-Furfural	5-Hydroxy methylfurfural	Acetyl furan
Beer Aroma	**Fruity**	**0.64**	**0.66**	**0.74**	**0.90**	**0.73**	-0.12
	Floral	0.47	**0.77**	0.44	**0.82**	0.56	-0.04
	Hoppy	-0.07	**0.86**	0.05	**0.63**	0.40	0.36
	Grainy	-0.55	**-0.74**	**-0.74**	**-0.94**	**-0.79**	0.01
	Malty	0.44	0.56	0.04	0.50	0.15	-0.20
	Sweet	0.08	**0.97**	0.51	**0.93**	**0.80**	0.41
	Acetaldehyde	0.31	-0.31	**0.62**	0.10	0.33	-0.17
	Oxidised	0.15	**-0.86**	-0.01	-0.59	-0.38	-0.41
	Acidic	0.10	**0.89**	0.22	**0.75**	0.52	0.27
	Overall Quality	**0.63**	0.59	0.33	**0.67**	0.36	-0.27
Beer Taste	**Fruity**	-0.05	**0.98**	0.53	**0.93**	**0.85**	0.53
	Spicy	**-0.73**	0.11	**-0.76**	-0.38	-0.42	0.44
	Grainy	-0.23	-0.36	0.32	-0.16	0.19	0.20
	Malty	0.03	**-0.60**	**-0.83**	**-0.78**	**-0.95**	-0.49
	Sulphury	-0.43	**0.60**	-0.40	0.18	0.00	0.44
	Acetaldehyde	-0.39	**0.77**	-0.20	0.40	0.23	0.53
	Phenolic	**-0.72**	0.42	-0.55	-0.06	-0.12	**0.60**
	Oxidised	-0.15	**-0.86**	**-0.78**	**-0.98**	**-0.97**	-0.40
	Acidic	0.05	0.31	-0.47	0.03	-0.30	-0.11
	Astrigent	**0.79**	-0.48	0.47	-0.01	0.01	-0.71
	Overall Quality	0.04	0.58	**0.86**	**0.79**	**0.95**	0.43

Marked correlations are significant at $p<0.05$

FORCED AGED (7 days at 60℃)

	Variables	Ethyl nicotinate	2-Phenyl ethyl acetate	2-Ethyl furfuryl ether	γ-Nonalactone	Sum of warm indicators	Sum of oxygen indicators
Beer Aroma	**Fruity**	0.49	**0.64**	0.53	**0.72**	**0.87**	**0.91**
	Floral	0.51	0.56	0.48	**0.60**	**0.80**	**0.91**
	Hoppy	**0.63**	0.53	0.54	0.50	**0.63**	**0.74**
	Grainy	-0.59	**-0.71**	**-0.62**	**-0.78**	**-0.92**	**-0.94**
	Malty	0.20	0.21	0.12	0.22	0.47	**0.67**
	Sweet	**0.84**	**0.83**	**0.82**	**0.85**	**0.93**	**0.94**
	Acetaldehyde	-0.06	0.12	0.08	0.21	0.10	-0.09
	Oxidised	**-0.64**	-0.52	-0.55	-0.49	**-0.60**	**-0.70**
	Acidic	**0.65**	**0.60**	0.59	**0.60**	**0.75**	**0.85**
	Overall Quality	0.27	0.35	0.24	0.40	**0.64**	**0.80**
Beer Taste	**Fruity**	**0.91**	**0.89**	**0.90**	**0.90**	**0.94**	**0.91**
	Spicy	0.04	-0.20	-0.08	-0.31	-0.35	-0.27
	Grainy	0.01	0.07	0.12	0.09	-0.13	-0.38
	Malty	**-0.79**	**-0.85**	**-0.87**	**-0.91**	**-0.80**	**-0.60**
	Sulphury	0.40	0.20	0.27	0.13	0.20	0.32
	Acetaldehyde	0.59	0.42	0.48	0.35	0.42	0.51
	Phenolic	0.34	0.10	0.22	0.00	-0.03	0.03
	Oxidised	**-0.86**	**-0.92**	**-0.90**	**-0.97**	**-0.99**	**-0.90**
	Acidic	-0.04	-0.14	-0.16	-0.19	0.01	0.24
	Astrigent	-0.45	-0.21	-0.34	-0.10	-0.05	-0.07
	Overall Quality	**0.76**	**0.84**	**0.85**	**0.90**	**0.81**	**0.62**

Marked correlations are significant at $p<0.05$

FORCED AGED (7 days at 60℃)

	Variables	Sum of ageing compounds	Forcing Index	Ageing Index
Beer Aroma	**Fruity**	**0.89**	**0.90**	**0.86**
	Floral	**0.82**	**0.89**	**0.85**
	Hoppy	**0.65**	**0.74**	**0.73**
	Grainy	**-0.94**	**-0.94**	**-0.92**
	Malty	0.49	**0.61**	0.55
	Sweet	**0.94**	**0.97**	**0.98**
	Acetaldehyde	0.08	-0.06	-0.04
	Oxidised	**-0.61**	**-0.71**	**-0.70**
	Acidic	**0.77**	**0.85**	**0.83**
	Overall Quality	**0.67**	**0.75**	**0.69**
Beer Taste	**Fruity**	**0.94**	**0.96**	**0.97**
	Spicy	-0.35	-0.26	-0.24
	Grainy	-0.16	-0.31	-0.25
	Malty	**-0.79**	**-0.69**	**-0.73**
	Sulphury	0.21	0.32	0.32
	Acetaldehyde	0.42	0.53	0.53
	Phenolic	-0.03	0.06	0.09
	Oxidised	**-0.99**	**-0.95**	**-0.97**
	Acidic	0.03	0.18	0.13
	Astrigent	-0.04	-0.11	-0.15
	Overall Quality	**0.80**	**0.70**	**0.74**

Marked correlations are significant at $p<0.05$

SPONTANEOUSLY AGED (12 months at 4°C)

	Variables	Pentanal	Hexanal	(*E*)-2-nonenal	2-Methylpropanal	2-Methylbutanal	3-Methylbutanal
Beer Aroma	**Fruity**	0.36	**0.76**	0.64	0.01	0.57	0.52
	Floral	0.10	0.21	0.06	-0.51	**-0.72**	-0.55
	Hoppy	**0.64**	0.13	0.40	**-0.89**	**-0.83**	**-0.76**
	Grainy	-0.36	0.19	-0.32	**0.71**	**0.87**	**0.70**
	Malty	**-0.81**	-0.56	-0.53	**0.96**	**0.68**	**0.67**
	Sweet	**0.79**	**0.87**	**0.63**	**-0.77**	-0.30	-0.33
	Acetaldehyde	-0.50	0.14	-0.34	0.56	0.47	0.46
	Oxidised	**-0.89**	-0.38	-0.32	**0.83**	0.44	**0.61**
	Acidic	**-0.74**	-0.14	-0.30	**0.85**	**0.66**	**0.72**
	Overall Quality	-0.01	-0.55	0.11	-0.41	**-0.82**	-0.58
Beer Taste	**Fruity**	0.59	0.59	0.46	**-0.83**	**-0.69**	-0.59
	Spicy	-0.05	-0.19	-0.20	0.48	**0.71**	0.47
	Grainy	**0.72**	**0.99**	0.53	-0.52	0.07	-0.05
	Malty	**0.90**	**0.88**	0.57	**-0.79**	-0.24	-0.36
	Sulphury	**0.85**	**0.89**	0.50	-0.54	0.14	-0.07
	Acetaldehyde	-0.22	0.46	0.02	0.53	**0.78**	**0.71**
	Phenolic	0.05	**0.68**	0.18	0.30	**0.72**	**0.60**
	Oxidised	-0.18	0.53	0.09	0.40	**0.62**	**0.60**
	Acidic	-0.34	0.37	0.03	0.38	0.39	0.47
	Astrigent	-0.30	0.30	-0.07	**0.67**	**0.91**	**0.80**
	Overall Quality	0.07	-0.58	-0.02	-0.40	**-0.73**	**-0.60**

Marked correlations are significant at $p<0.05$

SPONTANEOUSLY AGED (12 months at 4℃)

	Variables	Benzaldehyde	2-Phenylethanal	Methional	2-Furfural	5-Hydroxy methylfurfural	Acetyl furan
Beer Aroma	**Fruity**	**0.60**	0.13	0.52	0.27	-0.28	-0.06
	Floral	-0.11	-0.59	-0.49	**-0.83**	**-0.73**	**-0.90**
	Hoppy	0.28	**-0.96**	-0.27	**-0.83**	**-0.65**	-0.25
	Grainy	0.03	**0.85**	0.51	**0.79**	0.44	0.20
	Malty	-0.56	**0.95**	0.03	**0.83**	**0.90**	0.45
	Sweet	**0.72**	**-0.69**	0.23	-0.58	**-0.92**	-0.52
	Acetaldehyde	-0.22	**0.62**	0.10	0.37	0.15	-0.31
	Oxidised	**-0.69**	**0.75**	-0.29	0.45	0.49	-0.18
	Acidic	-0.44	**0.85**	0.01	**0.62**	0.48	-0.07
	Overall Quality	-0.40	**-0.61**	**-0.72**	**-0.64**	-0.14	-0.13
Beer Taste	**Fruity**	0.37	**-0.85**	-0.19	**-0.89**	**-0.99**	**-0.79**
	Spicy	0.17	**0.59**	0.57	**0.84**	**0.74**	**0.95**
	Grainy	**0.81**	-0.37	0.50	-0.25	**-0.75**	-0.38
	Malty	**0.85**	**-0.68**	0.39	-0.49	**-0.84**	-0.31
	Sulphury	**0.94**	-0.36	**0.68**	-0.09	**-0.55**	0.02
	Acetaldehyde	0.15	**0.65**	0.44	0.57	0.11	-0.11
	Phenolic	0.41	0.46	0.58	0.46	-0.09	-0.13
	Oxidised	0.14	0.50	0.32	0.37	-0.08	-0.34
	Acidic	-0.10	0.41	0.03	0.17	-0.14	-0.56
	Astrigent	0.10	**0.81**	0.51	**0.77**	0.35	0.15
	Overall Quality	-0.30	-0.55	-0.54	-0.51	-0.01	0.12

Marked correlations are significant at $p<0.05$

SPONTANEOUSLY AGED (12 months at 4℃)

	Variables	Ethyl nicotinate	2-Phenyl ethyl acetate	2-Ethyl furfuryl ether	γ-Nonalactone	Sum of warm indicators	Sum of oxygen indicators
Beer Aroma	**Fruity**	0.02	0.23	-0.01	0.34	0.27	0.33
	Floral	**-0.76**	**-0.88**	**-0.92**	**-0.97**	**-0.84**	**-0.64**
	Hoppy	**-0.85**	-0.48	-0.56	-0.46	**-0.82**	**-0.92**
	Grainy	**0.73**	0.53	0.41	0.39	**0.77**	**0.85**
	Malty	**0.93**	0.49	**0.77**	0.57	**0.83**	**0.87**
	Sweet	**-0.77**	-0.36	**-0.74**	-0.45	-0.59	-0.55
	Acetaldehyde	0.39	-0.01	-0.03	-0.12	0.35	0.57
	Oxidised	0.56	-0.06	0.26	0.10	0.44	**0.69**
	Acidic	**0.66**	0.16	0.33	0.23	**0.61**	**0.82**
	Overall Quality	-0.50	-0.52	-0.21	-0.31	**-0.63**	**-0.67**
Beer Taste	**Fruity**	**-0.96**	**-0.74**	**-0.97**	**-0.81**	**-0.90**	**-0.79**
	Spicy	**0.78**	**0.94**	**0.91**	**0.92**	**0.85**	**0.61**
	Grainy	-0.47	-0.09	-0.55	-0.24	-0.26	-0.22
	Malty	**-0.69**	-0.17	**-0.61**	-0.32	-0.49	-0.54
	Sulphury	-0.33	0.22	-0.26	0.06	-0.09	-0.20
	Acetaldehyde	0.46	0.28	0.13	0.24	0.56	**0.72**
	Phenolic	0.28	0.28	0.01	0.20	0.44	0.57
	Oxidised	0.26	0.06	-0.09	0.02	0.35	0.57
	Acidic	0.13	-0.22	-0.26	-0.21	0.15	0.44
	Astrigent	**0.67**	0.49	0.39	0.46	**0.76**	**0.86**
	Overall Quality	-0.37	-0.29	-0.05	-0.17	-0.49	**-0.63**

Marked correlations are significant at $p<0.05$

SPONTANEOUSLY AGED (12 months at 4℃)

	Variables	Sum of ageing compounds	Forcing Index	Ageing Index
Beer Aroma	**Fruity**	0.29	0.33	0.27
	Floral	**-0.82**	**-0.80**	**-0.85**
	Hoppy	**-0.84**	**-0.84**	**-0.80**
	Grainy	**0.79**	**0.77**	**0.72**
	Malty	**0.83**	**0.83**	**0.83**
	Sweet	-0.57	-0.56	**-0.61**
	Acetaldehyde	0.38	0.38	0.31
	Oxidised	0.47	0.51	0.47
	Acidic	**0.64**	**0.66**	**0.61**
	Overall Quality	**-0.65**	**-0.62**	-0.55
Beer Taste	**Fruity**	**-0.88**	**-0.87**	**-0.91**
	Spicy	**0.82**	**0.78**	**0.83**
	Grainy	-0.23	-0.24	-0.30
	Malty	-0.48	-0.50	-0.53
	Sulphury	-0.09	-0.11	-0.14
	Acetaldehyde	0.59	**0.61**	0.53
	Phenolic	0.48	0.48	0.40
	Oxidised	0.39	0.41	0.32
	Acidic	0.20	0.23	0.14
	Astrigent	**0.79**	**0.79**	**0.73**
	Overall Quality	-0.52	-0.52	-0.44

Marked correlations are significant at $p<0.05$

5. CONCLUSIONS

Novel techniques for measuring the total colour appearance of beer were introduced and applied in this investigation in order to quantify the truly dynamic and static visual perception of the beer by the human eye. These techniques included sensory viewing (psychophysical assessment), tele-spectroradiometry and digital imaging (non-contact physical measurements). Advantages over conventional measuring techniques for beer colour were obtained by applying these novel techniques in terms of colour appearance parameters such as lightness, colourfulness, hue angle, opacity and clarity of the beer subjects. The impact of colour adjustment on flavour stability of pale lager beers with a range of colouring agents such as specialty malts, roasted barley, colouring beer and artificial caramel colorant was investigated. Based on these results, a colouring agent for improving the flavour stability of pale lagers was selected according to its physical and chemical effects as well as by its impact on sensorial and psychophysical responses such as flavour and colour appearance.

Standard brewing procedures for pale lagers beers were implemented and systematically approached at the I.C.B.D. pilot brewery in order to guarantee consistent pale lager beer samples in terms of flavour stability. The procedures were defined on the basis of avoiding any critical process factors which might interfere with, or modify, the parameters focusing on this investigation. All brewing control parameters and beer specifications were monitored under a rigorous regime. The investigation was focused on ten pale lager beers brewed at the pilot brewery of the I.C.B.D. using different colouring agents including: specialty malts, roasted barley, colouring beer and artificial caramel colorant for colour adjustment. The locally-brewed beers were analysed and sensory assessed at different aged conditions such as fresh, forced aged (7 days at 60℃) and spontaneously aged (12 months at 4℃). All t he analytical and sensory results for the forced aged beer samples presented great inconsistencies in comparison to the fresh and spontaneously aged samples. Additionally, it was demonstrated that forcing beer ageing method as artificial accelerating beer ageing used in this investigation (7 days at 60℃) does not truly mimic the spontaneous beer ageing of pale lager beers due to the thermal treatment applied for this method modifies the psychophysical- (*i.e.* colour appearance), physical- and chemical composition as well the sensorial attributes of the pale lager subjects. This is in agreement with previous studies (Synryn *et al*., 2007; Walters *et al.*, 1996, 1997a and 1997b).

Concerning the determination of colour by conventional measurement techniques (*i.e.* colorimetry by visual comparison and spectrophotometry) and another proposed by previous investigations such as CIE L*a*b* and iCAM, all the locally-brewed beers presented the same EBC colour according to established specifications. In contrast, inconsistent results for CIE L*a*b* and iCAM parameters were detected in accordance with the psychophysical assessments (*i.e.* sensory viewing) by the expert observer panel. Therefore, the latter colour measurement techniques were rejected for measuring the colour parameters of the samples under investigation.

On the assessment of colour appearance by psychophysical method (sensory viewing), a large observer repeatability was obtained for all the colour appearance parameters such as lightness, colourfulness, hue angle, opacity and clarity, while relative smaller observer accuracy was noticed in comparison to the corresponding repeatability of the experiment. The results showed good agreement with previous studies (Gonzalez-Miret *et al*., 2007).

In general, the broad range of results indicated that light coloured malts such as light crystal malts (CARAHELL® and CARAAMBER®) and melanoidin malt as colouring agents for colour adjustment of pale lager beers promote higher colourfulness (Cv, M_TSR, M_DIG), redness hue component (+av, a_TSR, a_DIG) and yellowness hue component (+b). They contribute to lower lightness (Lv, J_TSR, J_DIG) and visual clarity (Clv) than all the colouring agents used in this investigation. In contrast, dark coloured malts such as dark crystal malts (CARAMUNICH® Type III) and roasted malts (CARAFA® Type III and CARAFA® SPECIAL Type III) presented the opposite behaviour. This effect is proportionally increased during beer ageing. These outcomes contrast previous investigations (Coghe and Adrianssens, 2004).

Regarding the instrumental measurement of colour appearance, tele-spectroradiometry (TSR) at sensory viewing conditions showed good agreement with all the colour appearance parameters assessed by psychophysical evaluations (*i.e.* sensory viewing). Conversely, tele-spectroradiometry (calibrated cell) and digital imaging (DigiEye System-VeriVide®) presented some discrepancies with the estimation of the colour appearance attributes provided by the expert observer panel. These results contrast with previous investigations (Gonzalez-Miret *et al.*, 2007). Therefore, further work is suggested in terms of colour characterisation on the latter instrumental methodologies.

In connection with the analytical approach of beer flavour stability, slightly higher levels of benzaldehyde, ethyl nicotinate, γ-nonalactone and sum of oxygenation indicators in all the locally-brewed beers at fresh and spontaneously aged conditions (12 months at 4℃) were observed in comparison to the typic al level range reported in the literature (Lustig, 1993; Meilgaard, 1975b; Narziß *et al.*, 1999; Saison *et al.*, 2008a; Saison *et al.*, 2008b; Vanderhaegen *et al.*, 2003). Furthermore, all the concentrations of the detected and quantified ageing compounds were below their corresponding flavour threshold values, except the spontaneously aged beer sample colour-adjusted with artificial caramel colorant (CARAMEL #301) that showed levels of (*E*)-2-nonenal above its flavour threshold.

Concerning the individual quantification and detection of each beer ageing compounds, a lower concentration of the majority of the flavour-active compounds in the locally-brewed beer colour-adjusted with melanoidin malt was detected in comparison to the other beer samples, particularly at the spontaneously aged state (12 months at 4℃). Conversely, higher levels of the majority of the beer ageing compounds in the fresh and spontaneously aged locally-brewed beers colour-adjusted with light crystal malt (CARAHELL®) were observed. In addition, a higher concentration of some ageing compounds in the other beer samples was also noticed but without clear consistency in comparison to these latter specialty malts. In summary, melanoidin malt, as colouring agent for beer colour-adjustment, apparently promotes positive effects on the flavour stability of pale lager beers in terms of formation of flavour-active beer ageing compounds as well as in terms warming and oxygenation indicators. This positive effect may be laid upon the remarkable levels of reductones (enediol function groups) from intermediates and melanoidins of low (LMW) and medium (MMW) molecular weight in comparison to other investigated specialty malts and beer colouring agents, that slow down the formation of flavour-active ageing compounds by means of reduction or donation of electrons to active organic radicals (see Savel, 2001).

These observations on the GC-MS analysis were also confirmed on the direct quantification of organic radicals in the whole grain and milling fractions of the specialty malts by Electro Spin Resonance (ESR) spectroscopy. The outcomes indicated that melanoidin malt presented the lowest levels of active organic radicals, while roasted products such as roasted malts (CARAFA® Type III and CARAFA® SPECIAL Type III) and roasted barley showed the highest ones. Moreover, no detectable endogenous anti-oxidative potential (EAP) value was observed in the beer colour-adjusted with dehusked roasted malt (CARAFA® SPECIAL Type III). Also, the highest EAP value was noticed in the fresh beer control (100% pilsner malt) in comparison to all the fresh samples under investigation. This indicates that base malts such as pilsner malts and pale malts have higher endogenous anti-oxidative potential (EAP) per EBC colour unit than the specialty malts and colouring agents for colouring adjustment of pale lager beers. Therefore, from the analytical point of view, the addition of specialty malt or caramel colorant leads to an increase in the reducing power and at the same time to a decrease in the endogenous anti-oxidative potential of beers measured by ESR spectroscopy. This effect is mainly based on sulphite content of the beers. In addition, the loss of endogenous anti-oxidative potential of the pale lager beers colour-adjusted with melanoidin malt induces the smallest increase in flavour-active ageing compounds during storage. Likewise, the colour adjustment of pale lager beers using caramel colorant should be carried out during wort boiling in order to minimize its negative influence on the oxidative stability of the final beer.

Finally, all the observations stated above were conclusively confirmed by the sensory evaluations of the locally-brewed beers under investigation. The most remarkable results of the sensory analysis showed that the fresh and spontaneously aged (12 months at 4℃) locally-brewed beer colour-adjusted with melanoidin malt showed the highest overall flavour quality (aroma and taste) with a score of good to very good and presented the lowest oxidised flavour (aroma and taste) and the lowest astringent taste. Moreover, the fresh and spontaneously aged beer sample colour-adjusted with light crystal malt (CARAHELL®) presented the lowest floral, hoppy and fruity aroma and also the lowest overall taste quality as well as the highest sulphury, astringent and oxidised taste.

In conclusion, from an analytical and sensorial point of view, melanoidin malt as colouring agent for the colour adjustment of pale lager beers appears to positively enhance the quality of beer in terms of flavour stability and colour appearance phenomena. The use of this raw material could evoke sustainable and commercial benefits such as upgrading of materials by initial processing, optimisation of material yield and inventory management [*ca*. 4% of total grain bill for a final beer colour of 7.5 EBC (±0.5)]. A significant contribution can be carried out for the production of more consistent pale lager beer products in terms of world-class market and enhanced flexibility in terms of logistics and planning.

In reference to the most significant results from the multiple correlations between the parameters analysed in this investigation, significant positive correlations were detected between colour appearance predictors and beer ageing flavour-active aldehydes in the first round of the fresh locally-brewed beers in comparison to those obtained in forced aged (7 days at 60℃) and spontaneously aged (12 months at 4℃)

samples. Significant positive correlation was observed between colourfulness (Cv, M_TSR and M_DIG) and the sum of the flavour-active aldehydes (ageing markers) and 2-methylpropanal, while negative correlation was detected between the hue angle (hv, h_TSR and h_DIG) and the sum of aldehydes. A large positive correlation was noticed between CIECAM02 hue angle (h_TSR) at sensory viewing simulation conditions and the sum of the flavour-active aldehydes (ageing markers) of the first round of the spontaneously aged samples. Likewise, large positive correlations were found between CIECAM02 hue angle (h_DIG) at calibrated cell conditions (influence of depth) by digital imaging and the concentration levels of pentanal, hexanal, 2-methylbutanal, 3-methylbutanal, benzaldehyde and methional. Additionally, a large positive correlation was evident between CIECAM02 lightness (J_TSR), measured by tele-spectroradiometry, and the concentration levels of (*E*)-2-nonenal, 2-phenylethanal and 2-furfural. The outcomes are in disagreement with previous studies (Savel, 2005).

In addition, large positive correlations were observed between the endogenous anti-oxidative potential (EAP) of the second round of the fresh locally-brewed beers against the fruity, grainy, malty, acetaldehyde and acidic aroma profile. Moreover, large positive correlations were found between EAP values of the second round of the fresh locally-brewed beers against the acetaldehyde and phenolic taste profile. In contrast, large negative correlations were also detected between the EAP values against the fruity and grainy taste profile at spontaneously aged conditions (12 months at 4℃). This behaviour is may be stressed by the degradation of acetate esters, which confers the main pleasant fruity attributes and masking effects on the aged beer flavour, and by the gradual deterioration of bitterness in aged beer related with the degradation of hop bitter compounds during ageing (see Saison *et al*., 2008b; Vanderhaegen *et al*., 2006).

Furthermore, significant positive correlation was noticed between the concentration of 2-furfural and the overall quality flavour (aroma and taste) profile of the second round of the fresh locally-brewed beers. In contrast, large negative correlations were observed between the concentration of methional and 2-phenyl ethyl acetate against the overall flavour quality (aroma and taste). This data may suggest, according to the flavour descriptors of the aforementioned compounds, that the sulphury and floral hints conferred by methional and 2-phenyl ethyl acetate provide a negative contribution in the overall flavour quality (aroma and taste) of fresh pale lager beers. Additionally, large negative correlations were found between the concentration of some flavour-active beer ageing markers such as 2-methylbutanal, methional, 2-furfural and sum of oxygenation indicators against the overall flavour quality (aroma and taste) of the second round of fresh and spontaneously aged (12 months at 4°C) locally-brewed beers. These results are in agreement with recent investigations (Malfliet *et al*., 2008; Saison *et al*., 2008b; Syryn *et al*., 2007).

Notwithstanding these conclusions, it is essential to point out that the establishment and performance of uniform brewing procedures as well as the monitoring of all input and output streams and critical control points are the key priority in order to obtain consistent beer products in terms of flavour and physical stability. It is strongly recommended to apply this principle for any industrial and research purpose. This is based on the fact that brewing as biotechnological process depends on diverse natural inputs such as brew liquour, barley malt, adjuncts, hops and particularly specific yeast strains, which cause unavoidable batch-to-batch inconsistencies. Brewers must always find a compromise between the advantages and disadvantages generated by the brewing procedures and quality control specifications in order to achieve high quality products that satisfy both the local beer costumers and the global market demands.

6. FUTURE WORK

- Improvement of the colour characterisation of digital imaging technology (DigiEye System-VeriVide®) in order to mimic the truly colour perception by the human eye in a consistent manner.

- Holistic evaluation of measuring colour appearance on beer products by tele-spectroradiometry and digital imaging technology (DigiEye System-VeriVide®) at on-line industrial conditions in order to validate the outcomes of this present investigation with the focus on applying and implementing a new colour appearance technology that confronts directly the realistic needs of the beer global market as well as to displace the conventional and obsolete measuring techniques for beer colour used at present.

- Further research to confirm the positive effects of the melanoidin malt on the beer quality in terms colour appearance and flavour stability at industrial conditions in order to impose new logistic and planning trends on upgrading materials by initial processing, optimisation of material yield and inventory management.

- Studies on visual lightness, hue and clarity of beer as novel methodology on the prediction of beer flavour stability. New strategies in the areas of production and quality assurance can be created by implementing an integrated multi-parametric innovation on this field.

- Further investigations on the essential role of the Strecker aldehydes; 2-methylbutanal, 3-methylbutanal and 2-phenylethanal as well as the fatty acid and high alcohol oxidation product; hexanal on the development of ageing flavours of pale lager beers, respectively. Potential benefits can be made out of this issue on elucidation of the chemical transformations of the beer matrix throughout the ageing.

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8. APPENDIXES

APPENDIX A. Tables

Table A.1.1 Beer Analyses: Becks Bier 5% vol. alcohol

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
Sp. Gravity (S 20/20) Beer	1.0098	1.0097	1.0090	1.0098	1.0099	1.0096	0.00036	**1.00585 - 1.01175** r95:N/A R95: N/A
App. Extract (EA) %	2.50	2.48	2.30	2.51	2.53	2.467	0.0926	**1.5 – 3.0** r95:0.012 R95:0.080
Sp. Gravity (S 20/20) Alcohol	0.9929	0.9933	0.9935	0.9933	0.9931	0.9932	0.000228	**0.99675 – 0.98770** r95: N/A R95: N/A
Alcohol (mas%)	3.90	3.69	3.56	3.69	3.80	3.728	0.1283	**1.75-7.20** r95: 0.03 ± 0.005m R95: 0.03 ± 0.02m
Alcohol (vol%)	4.90	4.64	4.48	4.64	4.78	4.688	0.1591	**2.2-9.0** r95: 0.04 ± 0.004m R95: 0.04 ± 0.02m
Sp. Gravity (S 20/20) Real extract	1.0143	1.0142	1.0147	1.0144	1.0146	1.01444	0.000207	**1.01175- 1.02370** r95: N/A R95: N/A
Real extract (ER) %	3.65	3.62	3.75	3.80	3.72	3.709	0.0725	**3.0-6.0** r95:0.02m R95: 0.02m
Original Gravity (OG) %	11.01	10.61	10.49	10.77	10.90	10.756	0.2106	**7.0-12.0** r95: 0.07 R95: 0.19
pH	3.88	3.90	3.90	3.91	3.91	3.90	0.0122	**Pils: 4.3-4.6** r95:0.02 R95:0.13
Bitter units	A275: 0.552 IBU: 27.6 ≈ 28	A275: 0.554 IBU: 27.7 ≈ 28	A275: 0.555 IBU: 27.75 ≈ 28	A275: 0.556 IBU: 27.8 ≈ 28	A275: 0.557 IBU: 27.8 ≈ 28	A275: 0.55 IBU:27.7 ≈28	A275: 0.00 IBU: 0.096	**A275: 0.200-0.800** **IBU: 10-40** r95: 0.44 ± 0.014m R95: -0.7 ± 0.18m
Colour Visual Comp. EBC/Lovibond	8.5	8.5	8.0	8.5	8.5	8.4	0.22	**Pale beers: 7-11 EBC** r95: 0.4 R95: 1.8
Colour (430 nm) EBC	A430: 0.319 EBC: 8.0	A430: 0.319 EBC: 8.0	A430: 0.319 EBC: 8.0	A430: 0.320 EBC: 8.00	A430: 0.320 EBC: 8.00	A430: 0.31 EBC: 8.0	A430: 0.00 EBC: 0.00	**Pale beers: 7-11 EBC** r95: 0.3 R95:0.6

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
Colour Tristimulus %T 360 nm	1.1	1.1	1.1	1.1	1.0	1.08	0.045	
Colour Tristimulus %T 450 nm	60.2	60.2	60.5	61.6	61.4	60.78	0.672	
Colour Tristimulus %T 540 nm	84.8	85.4	85.6	85.6	85.6	85.40	0.346	
Colour Tristimulus %T 670 nm	96.6	96.6	96.9	97.0	97.2	96.86	0.260	
Colour Tristimulus %T 760 nm	98.7	98.7	98.9	98.9	99.2	98.88	0.204	
Colour Tristimulus Values **X (Red)**	79.031	79.305	79.538	79.735	79.768	79.475	0.3099	
Colour Tristimulus Values **Y (Green)**	84.616	85.036	85.265	85.395	85.415	85.145	0.3324	
Colour Tristimulus Values **Z (Blue)**	63.291	63.377	63.660	64.593	64.414	63.867	0.6002	
Colour CIELAB L*	91.24	91.37	91.47	91.56	91.58	91.44	0.141	**96.63 *, 93.83**** r95: 0.55 R95: 2.26
Colour CIELAB a*	-3.52	-3.63	-3.62	-3.55	-3.54	-3.57	0.049	**-2.04 *, 7.83**** r95: 0.19 R95: 0.56
Colour CIELAB b*	12.32	12.51	12.47	12.15	12.23	12.33	0.153	**14.39 *, 32.97**** r95: 1.01 R95: 2.20
Colour CIELAB C* (Metric Chroma)	12.89	13.09	12.99	12.66	12.73	12.87	0.178	
Yellowness Index	40.26	40.37	40.26	39.33	39.60	39.96	0.467	
iCAM Lightness **J**	6.54	6.55	6.56	6.57	6.57	6.563	0.0130	
iCAM Chroma **C**	1.20	1.21	1.21	1.17	1.18	1.198	0.0177	
iCAM Angle Hue **h**	0.094	0.085	0.086	0.090	0.092	0.0894	0.0038	
iCAM Brightness **Q**	13.22	13.25	13.27	13.29	13.29	13.262	0.0264	
iCAM Colourfulness **M**	2.43	2.46	2.45	2.37	2.39	2.422	0.0035	
CIECAM02 Lightness **J**	91.66	91.89	92.03	92.10	92.12	91.963	0.1903	Repeat.****: r^2: 0.84 CV:19 Reprod. ****: r^2: 0.88 CV:17

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
CIECAM02 Chroma **C**	18.41	18.61	18.54	17.97	18.10	18.326	0.2789	
CIECAM02 redness-greenness **a**	-0.004	-0.008	-0.008	-0.006	-0.005	-0.0062	0.0017	
CIECAM02 yellowness-blueness **b**	0.038	0.388	0.387	0.375	0.378	0.3132	0.1539	
CIECAM02 Angle Hue **h**	90.66	91.26	91.18	90.96	90.83	90.979	0.2448	
CIECAM02 Hue composition **H**	101.28	102.42	102.27	101.84	101.60	101.882	0.4694	Repeat.****: r^2: 0.99 CV: 8 Reprod.****: r^2: 0.99 CV:10
CIECAM02 **Hc (Red)**	0	0	0	0	0	0.000	0.0000	
CIECAM02 **Hc (Yellow)**	98.72	97.58	97.72	98.15	98.39	98.112	0.4703	
CIECAM02 **Hc (Green)**	1.27	2.41	2.27	1.84	1.60	1.878	0.4703	
CIECAM02 **Hc (Blue)**	0	0	0	0	0	0.000	0.0000	
CIECAM02 Brightness **Q**	227.83	228.12	228.29	228.38	228.40	228.204	0.2364	
CIECAM02 Colourfulness **M**	17.37	17.56	17.50	16.96	17.08	17.294	0.2628	Repeat.****: r^2: 0.72 CV: 30 Reprod.****: r^2: 0.67 CV:37
CIECAM02 Saturation **s**	27.61	27.75	27.69	27.25	27.35	27.53	0.2186	
Turbidity 20℃ EBC	0.273	0.260	0.266	0.262	0.260	0.2642	0.0054	**N/A** r95: 0.05 R95:0.20
Shelf Life Prediction Forcing method EBC (modified according to Titze *et al.*, 2007) (60℃,24 h/ 0℃, 24h/ 20℃) EBC-formazin units/ Warm days	Blank: 0.273 EBC: 2.13 W. days: 12	Blank: 0.260 EBC: 2.65 W. days: 11	Blank: 0.266 EBC: 3.11 W. days: 11	Blank: 0.262 EBC: 2.89 W. days: 12	Blank: 0.260 EBC: 2.76 W. days: 11	Blank: 0.26 EBC: 2.71 W. days: 11.4	Blank: 0.00 EBC: 0.36 W. days: 0.547	
NIBEM	Sec: 251 10: 97 20: 175 30: 251	Sec: 247 10: 97 20: 175 30: 247	Sec: 256 10: 87 20: 170 30: 256	Sec: 260 10: 93 20:182 30: 260	Sec: 261 10: 96 20: 182 30: 261	Sec: 255 10: 94 20: 176.8 30: 255	Sec: 5.95 10: 4.24 20: 5.17 30: 5.96	**For lager beers: Bad: < 220 s Very Good: > 300 s** r95: 9 R95:42
CO_2 % vol.	2.7	2.7	2.6	2.7	2.6	2.66	0.055	**Vol %: 2.5 -3.0** r95: 0.09

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
								R95:0.08m
Dissolved oxygen (mg/L) (Orbisphere DO)	0.178	0.163	0.195	0.188	0.192	0.1832	0.0130	**< 0.3** r95:0.15 mg/L R95: 0.3 mg/L
Total polyphenols (mg/L)	A820: 0.113 Polyθ: 185.32	A820: 0.114 Polyθ: 186.96	A820: 0.116 Polyθ: 190.24	A820: 0.117 Polyθ: 191.88	A820: 0.118 Polyθ: 193.52	A820: 0.11 Polyθ: 189.58	A820: 0.00 Polyθ: 3.400	**A820: 0.091-0.121 Polyθ:73-176** r95:4.1 R95: 18 ± 0.13m
Flavanoids (mg/L)	AB640: 0.650 AS640: 0.699 Flav: 16.41	AB640: 0.650 AS640: 0.700 Flav: 16.75	AB640: 0.650 AS640: 0.700 Flav: 16.75	AB640: 0.650 AS640: 0.700 Flav: 16.75	AB640: 0.650 AS640: 0.701 Flav: 17.08	AB640: 0.650 AS640: 0.700 Flav: 16.74	AB640: 0.000 AS640: 0.000 Flav: 0.236	**Flav: 50-70** CV_{r95}: ± 4.7% CV_{R95}: ± 7.6%
Iron (mg/L) **Factor** (Spectrophotometry-Phenantroline)	Aliquot 0.0 mL 2.5 mL 5.0 mL 10.0mL 20.0mL 30.0mL	Concentrat. 0.0 ppm 0.25 ppm 0.50 ppm 1.00 ppm 2.00 ppm 3.00 ppm	Absorb. A505:0.828 A505:0.916 A505:1.000 A505:1.190 A505:1.555 A505:1.942	Graph curve Factor F*: 0.3714				
Iron (mg/L) **Samples** (Spectrophotometry-Phenantroline)	A505: 0.931 Fe(II): 0.345	A505: 0.933 Fe(II): 0.346	A505: 0.934 Fe(II): 0.346	A505: 0.932 Fe(II): 0.346	A505: 0.932 Fe(II): 0.346	A505: 0.93 Fe(II): 0.34	A505: 0.00 Fe(II): 0.00	**Fe(II): < 0.2 Recommend.** r95: 0.21m R95: 0.91m
Copper (mg/L) **Samples** (Atomic Absorption Spectrometry)	A324.7: 0.136	A324.7: 0.239	A324.7: 0.344	A324.7: 0.545	A324.7: 0.778 Cu (II): 0.124			**Cu (II): < 0.2 Recommend.** r95: 0.45m R95: 1.71m
Calcium (mg/L) **Samples** (Atomic Absorption Spectrometry)	A423.0: 0.095	A423.0: 0.107	A423.0: 0.114	A423.0: 0.125	A423.0: 0.131 Ca (II): 28.5			**Ca (II): 4 -100 Recommend.** CV_{ST95}: ±13.3% CV_{Sr95}: ± 2.4% CV_{Sb95}: ±9.2%
Reducing Power (MEBAK) %RED	62.3	63.6	63.3	61.4	61.8	62.48	0.9471	**> 60 very good 50-60 good 45-50 satisfactory < 45 poor** CV_{r95}: ± 1%

Table A.1.2 Beer Analyses: Bitburger Bier 5% vol. Alcohol

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
Sp. Gravity (S 20/20) Beer	1.0092	1.0093	1.0093	1.0093	1.0093	1.00928	0.00004	**1.00585 - 1.01175** r95:N/A R95: N/A
App. extract (EA) %	2.35	2.38	2.38	2.38	2.38	2.376	0.0112	**1.5 – 3.0** r95:0.012 R95:0.080
Sp. Gravity (S 20/20) Alcohol	0.9934	0.9934	0.9935	0.9932	0.9931	0.99332	0.00016	**0.99675 – 0.98770** r95: N/A R95: N/A
Alcohol (mas%)	3.63	3.63	3.56	3.74	3.80	3.672	0.9628	**1.75-7.20** r95: 0.03 ± 0.005m R95: 0.03 ± 0.02m
Alcohol (vol%)	4.56	4.56	4.48	4.70	4.78	4.616	0.1212	**2.2-9.0** r95: 0.04 ± 0.004m R95: 0.04 ± 0.02m
Sp. Gravity (S 20/20) Real extract	1.0184	1.0186	1.0188	1.0185	1.0186	1.01858	0.00014	**1.01175-1.02370** r95: N/A R95: N/A
Real extract (ER) %	4.680	4.730	4.780	4.705	4.730	4.725	0.0371	**3.0-6.0** r95:0.02m R95: 0.02m
Original Gravity (OG) %	11.51	11.56	11.48	11.73	11.87	11.63	0.165	**7.0-12.0** r95: 0.07 R95: 0.19
pH	3.99	4.05	4.07	4.08	4.09	4.056	0.0397	**Pils: 4.3-4.6** r95:0.02 R95:0.13
Bitter units	A275: 0.515 IBU: 25.75 ≈ 26	A275: 0.518 IBU: 25.9 ≈ 26	A275: 0.498 IBU: 24.9 ≈ 25	A275: 0.502 IBU: 25.1 ≈ 25	A275: 0.498 IBU: 24.9 ≈ 25	A275: 0.50 IBU: ≈ 25.31	A275: 0.00 IBU: ≈ 0.480	**A275: 0.200-0.800** **IBU: 10-40** r95: 0.44 ± 0.014m R95: -0.7 ± 0.18m
Colour Visual Comp. EBC/Lovibond	8.0	8.0	8.0	8.0	8.0	8.00	0.0000	**Pale beers: 7-11 EBC** r95: 0.4 R95: 1.8
Colour (430 nm) EBC	A430: 0.321 EBC: 8.02	A430: 0.309 EBC: 7.97	A430: 0.321 EBC: 8.02	A430: 0.320 EBC: 8.00	A430: 0.323 EBC: 8.07	A430: 0.31 EBC: 8.01	A430: 0.00 EBC: 0.03	**Pale beers: 7-11 EBC** r95: 0.3 R95:0.6
Colour Tristimulus %T 360 nm	0.8	0.8	0.8	0.7	0.8	0.78	0.045	
Colour Tristimulus %T 450 nm	59.6	59.6	59.2	60.0	60.5	59.78	0.492	

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
Colour Tristimulus %T 540 nm	84.6	85.2	85.2	85.4	85.4	85.16	0.328	
Colour Tristimulus %T 670 nm	96.3	96.5	96.5	96.7	96.7	96.58	0.228	
Colour Tristimulus %T 760 nm	98.6	99.2	98.8	98.8	98.8	98.88	0.228	
Colour Tristimulus Values **X (Red)**	78.746	79.086	79.025	79.299	79.376	79.106	0.2482	
Colour Tristimulus Values **Y (Green)**	84.356	84.816	84.775	85.035	85.085	84.813	0.2890	
Colour Tristimulus Values **Z (Blue)**	62.725	62.810	62.471	63.168	63.602	62.955	0.4395	
Colour CIELAB L*	91.11	91.27	91.24	91.36	91.40	91.276	0.1132	**96.63 *, 93.83**** r95: 0.55 R95: 2.26
Colour CIELAB a*	-3.56	-3.64	-3.66	-3.64	-3.61	-3.622	0.0389	**-2.04 *, -7.83**** r95: 0.19 R95: 0.56
Colour CIELAB b*	12.53	12.66	12.78	12.59	12.43	12.598	0.1321	**14.39 *, 32.97**** r95: 1.01 R95: 2.20
Colour CIELAB C* (Metric Chroma)	13.03	13.17	13.29	13.11	12.95	13.11	0.1303	
Yellowness Index	40.66	40.85	41.20	40.62	40.17	40.70	0.3746	
iCAM Lightness **J**	6.53	6.54	6.54	6.55	6.56	6.547	0.0105	
iCAM Chroma **C**	1.22	1.23	1.25	1.27	1.21	1.21	0.056	
iCAM Angle Hue **h**	0.091	0.085	0.083	0.085	0.086	0.0860	0.0030	
iCAM Brightness **Q**	13.20	13.23	13.22	13.24	13.25	13.233	0.0211	
iCAM Colourfulness **M**	2.46	2.49	2.52	2.47	2.44	2.479	0.0030	
CIECAM02 Lightness **J**	91.51	91.77	91.75	91.90	91.92	91.772	0.1638	Repeat.****: r^2: 0.84 CV:19 Reprod. ****: r^2: 0.88 CV:17
CIECAM02 Chroma **C**	18.65	18.87	19.09	18.75	18.48	18.768	0.2298	
CIECAM02 redness-greenness **a**	-0.005	-0.008	-0.009	-0.008	-0.007	-0.0074	0.0015	

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
CIECAM02 yellowness-blueness **b**	0.389	0.394	0.399	0.391	0.386	0.3918	0.0049	
CIECAM02 Angle Hue **h**	90.81	91.24	91.29	91.24	91.17	91.153	0.1948	
CIECAM02 Hue composition **H**	101.55	102.38	102.48	102.37	102.24	102.172	0.4497	Repeat.****: r^2: 0.99 CV: 8 Reprod.****: r^2: 0.99 CV:10
CIECAM02 **Hc (Red)**	0	0	0	0	0	0.00	0.000	
CIECAM02 **Hc (Yellow)**	98.44	97.61	97.51	97.62	97.75	97.786	0.3754	
CIECAM02 **Hc (Green)**	1.55	2.38	2.48	2.37	2.24	2.204	0.3754	
CIECAM02 **Hc (Blue)**	0	0	0	0	0	0.00	0.000	
CIECAM02 Brightness **Q**	227.64	227.97	227.94	228.13	228.16	227.968	0.2070	
CIECAM02 Colourfulness **M**	17.61	17.81	18.02	17.70	17.44	17.716	0.2173	Repeat.****: r^2: 0.72 CV: 30 Reprod.****: r^2: 0.67 CV:37
CIECAM02 Saturation **s**	27.81	27.95	28.11	27.85	27.65	27.874	0.1705	
Turbidity 20℃ EBC	0.32	0.31	0.30	0.32	0.31	0.311	0.0066	**N/A** r95: 0.05 R95:0.20
Shelf Life Prediction Forcing method EBC (modified according to Titze et al., 2007) (60℃,24 h/ 0℃, 24h/ 20℃) EBC-formazin units/ Warm days	Blank: 0.316 EBC: 2.8 W. days: 12	Blank: 0.313 EBC: 2.8 W. days: 12	Blank: 0.302 EBC: 2.9 W. days: 12	Blank: 0.318 EBC: 2.5 W. days: 12	Blank: 0.307 EBC: 2.8 W. days: 13	Blank: 0.31 EBC: 2.80 W. days: 12.2	Blank: 0.00 EBC: 0.16 W. days: 0.447	
NIBEM	Sec: 276 10: 103 20: 194 30: 276	Sec: 260 10: 92 20: 182 30: 260	Sec: 261 10: 90 20: 190 30: 261	Sec: 273 10: 92 20: 183 30: 273	Sec: 261 10: 90 20: 182 30: 261	Sec: 266 10: 93.4 20:186.2 30: 266.2	Sec: 7.66 10: 5.45 20: 5.49 30: 7.66	**For lager beers: Bad:<220sec Very Good: > 300 sec** r95: 9 R95:42
CO_2 % vol.	2.6	2.5	2.5	2.5	2.4	2.5	0.007	**Vol %: 2.5 -3.0** r95: 0.09 R95:0.08m
Dissolved oxygen (mg/L) (Orbisphere DO)	0.286	0.314	0.276	0.303	0.272	0.2902	0.0179	**< 0.3** r95:0.15 mg/L R95: 0.3 mg/L
Total	A820:	A820:	A820:	A820:	A820:	A820:	A820:	**A820: 0.091-**

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
polyphenols (mg/L)	0.133 Polyθ: 185.32	0.114 Polyθ: 186.96	0.116 Polyθ: 190.24	0.117 Polyθ: 191.88	0.118 Polyθ: 193.52	0.11 Polyθ: 189.584	0.00 Polyθ: 3.4007	**0.121** **Polyθ:73-176** r95:4.1 R95: 18 ± 0.13m
Flavanoids (mg/L)	AB640: 0.650 AS640: 0.718 Flav: 22.78	AB640: 0.650 AS640: 0.722 Flav: 24.12	AB640: 0.650 AS640: 0.722 Flav: 24.12	AB640: 0.650 AS640: 0.723 Flav: 24.45	AB640: 0.650 AS640: 0.722 Flav: 24.12	AB640: 0.650 AS640: 0.721 Flav: 23.9	AB640: 0.000 AS640: 0.002 Flav:0.65	**Flav: 50-70** CV_{r95}: ± 4.7% CV_{R95}: ± 7.6%
Iron (mg/L) **Factor** (Spectrophotometry-Phenantroline)	Aliquot 0.0 mL 2.5 mL 5.0 mL 10.0mL 20.0mL 30.0mL	Concentrat. 0.0 ppm 0.25 ppm 0.50 ppm 1.00 ppm 2.00 ppm 3.00 ppm	Absorb. A505:0.828 A505:0.916 A505:1.000 A505:1.190 A505: .555 A505:1.942	Graph curve Factor F*: 0.3714				
Iron (mg/L) **Samples** (Spectrophotometry-Phenantroline)	A505: 0.926 Fe(II): 0.343	A505: 0.927 Fe(II): 0.344	A505: 0.927 Fe(II): 0.344	A505: 0.927 Fe(II): 0.344	A505: 0.927 Fe(II): 0.344	A505: 0.9268 Fe(II): 0.3438	A505: 0.00044 Fe(II):0.00044	**Fe(II): < 0.2** **Recommend. values** r95: 0.21m R95: 0.91m
Copper (mg/L) **Samples** (Atomic Absorption Spectrometry)	A324.7: 0.197	A324.7: 0.242	A324.7: 0.337	A324.7: 0.510	A324.7: 0.76 Cu(II): 0.144			**Cu (II): < 0.2** **Recommend. values** r95: 0.45m R95: 1.71m
Calcium (mg/L) **Samples** (Atomic Absorption Spectrometry)	A423.0: 0.099	A423.0: 0.108	A423.0: 0.116	A423.0: 0.127	A423.0: 0.136 Ca(II): 27.61			**Ca (II): 4 -100** **Recommend. values** CV_{ST95}: ±13.3% CV_{Sr95}: ± 2.4% CV_{Sb95}: ±9.2 %
Reducing Power (MEBAK) %RED	70.9	72.1	71.6	69.8	71.8	71.24	0.918	**> 60 very good** **50-60 good** **45-50 satisfactory** **< 45 poor** CV_{r95}: ± 1%

Table A.1.3 Beer Analyses: Budweiser Beer 5 % vol. alcohol

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
Sp. Gravity (S 20/20) Beer	1.0068	1.0066	1.0065	1.0066	1.0066	1.00662	0.000109	**1.00585 - 1.01175** r95:N/A R95: N/A
App. extract (EA) %	1.74	1.69	1.66	1.69	1.69	1.698	0.0280	**1.5 – 3.0** r95:0.012 R95:0.080
Sp. Gravity (S 20/20) Alcohol	0.9935	0.9938	0.9937	0.9939	0.9933	0.99364	0.000240	**0.99675 – 0.98770** r95: N/A R95: N/A
Alcohol (mas%)	3.56	3.40	3.45	3.34	3.69	3.488	0.1388	**1.75-7.20** r95: 0.03 ± 0.005m R95: 0.03 ± 0.02m
Alcohol (vol%)	4.48	4.28	4.34	4.20	4.64	4.388	0.1741	**2.2-9.0** r95: 0.04 ± 0.004m R95: 0.04 ± 0.02m
Sp. Gravity (S 20/20) Real extract	1.0125	1.0129	1.0129	1.0128	1.0120	1.01262	0.000383	**1.01175-1.02370** r95: N/A R95: N/A
Real extract (ER) %	3.19	3.29	3.29	3.27	3.07	3.22	0.097	**3.0-6.0** r95:0.02m R95: 0.02m
Original Gravity (OG) %	9.95	9.75	9.85	9.62	10.06	9.846	0.1707	**7.0-12.0** r95: 0.07 R95: 0.19
pH	3.78	3.83	3.84	3.84	3.84	3.826	0.0261	**Pils: 4.3-4.6** r95:0.02 R95:0.13
Bitter units	A275: 0.162 IBU: 8.1 ≈ 8	A275: 0.159 IBU: 7.9 ≈ 8	A275: 0.161 IBU: 8	A275: 0.163 IBU: 8.1 ≈ 8	A275: 0.160 IBU: 8	A275: 0.16 IBU: 8.02	A275: 0.00 IBU: 0.08	**A275: 0.200-0.800 IBU: 10-40** r95: 0.44 ± 0.014m R95: -0.7 ± 0.18m
Colour Visual Comp. EBC/Lovibond	6.0	6.5	6.0	6.5	6.0	6.2	0.273	**Pale beers: 7-11 EBC** r95: 0.4 R95: 1.8
Colour (430 nm) EBC	A430: 0.253 EBC: 6.3	A430: 0.257 EBC: 6.4	A430: 0.260 EBC: 6.5	A430: 0.255 EBC: 6.4	A430: 0.251 EBC: 6.3	A430: 0.25 EBC: 6.4	A430: 0.00 EBC: 0.08	**Pale beers: 7-11 EBC** r95: 0.3 R95:0.6
Colour Tristimulus %T 360 nm	2.3	2.3	2.3	2.3	2.4	2.32	0.045	
Colour Tristimulus %T 450 nm	67.2	67.0	67.0	66.5	66.5	66.84	0.321	

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
Colour Tristimulus %T 540 nm	89.0	89.0	89.1	89.1	88.9	89.02	0.084	
Colour Tristimulus %T 670 nm	97.9	97.8	97.8	97.8	97.8	97.82	0.0447	
Colour Tristimulus %T 760 nm	99.7	99.3	99.9	100.0	99.3	99.64	0.328	
Colour Tristimulus Values **X (Red)**	82.445	82.382	82.428	82.353	82.263	82.3745	0.7202	
Colour Tristimulus Values **Y (Green)**	88.516	88.476	88.546	88.496	88.356	88.4785	0.7303	
Colour Tristimulus Values **Z (Blue)**	69.945	69.775	69.789	69.365	69.346	69.6443	0.2716	
Colour CIELAB L*	92.77	92.74	92.76	92.73	92.69	92.738	0.0311	**96.63 *, 93.83**** r95: 0.55 R95: 2.26
Colour CIELAB a*	-3.78	-3.80	-3.82	-3.84	-3.80	-3.808	0.0228	**-2.04 *, -7.83**** r95: 0.19 R95: 0.56
Colour CIELAB b*	11.17	11.22	11.24	11.38	11.34	11.27	0.087	**14.39 *, 32.97**** r95: 1.01 R95: 2.20
Colour CIELAB C* (Metric Chroma)	11.79	11.85	11.87	12.01	11.96	11.896	0.0882	
Yellowness Index	35.45	35.58	35.61	32.03	35.97	34.928	1.6314	
iCAM Lightness **J**	6.99	6.69	6.99	6.69	6.69	6.816	0.1668	
iCAM Chroma **C**	1.055	1.061	1.063	1.079	1.075	1.0666	0.0100	
iCAM Hue Angle **h**	0.063	0.061	0.060	0.059	0.062	0.0610	0.0015	
iCAM Brightness **Q**	13.54	13.53	13.53	13.52	13.51	13.530	0.0074	
iCAM Colourfulness **M**	2.13	2.14	2.14	2.18	2.17	2.156	0.0203	
CIECAM02 Lightness **J**	93.84	93.82	93.86	93.83	93.75	93.82	0.0418	Repeat.****: r^2: 0.84 CV:19 Reprod. ****: r^2: 0.88 CV:17
CIECAM02 Chroma **C**	16.26	16.36	16.39	16.64	16.57	16.444	0.1566	
CIECAM02 redness-greenness **a**	-0.018	-0.018	-0.019	-0.019	-0.018	-0.0184	0.0005	

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
CIECAM02 yellowness-blueness **b**	0.336	0.338	0.339	0.344	0.343	0.34	0.0033	
CIECAM02 Angle Hue **h**	93.06	93.16	93.26	93.29	93.08	93.17	0.1034	
CIECAM02 Hue composition **H**	105.79	105.98	106.17	106.22	105.83	105.998	0.1940	Repeat.****: r^2: 0.99 CV: 8 Reprod. ****: r^2: 0.99 CV:10
CIECAM02 **Hc (Red)**	0	0	0	0	0	0.000	0.0000	
CIECAM02 **Hc (Yellow)**	94.20	94.01	93.82	93.77	94.16	93.992	0.1940	
CIECAM02 **Hc (Green)**	5.79	5.98	6.17	6.22	5.83	5.998	0.1940	
CIECAM02 **Hc (Blue)**	0	0	0	0	0	0.000	0.0000	
CIECAM02 Brightness **Q**	230.53	230.50	230.54	230.51	230.42	230.5	0.0474	
CIECAM02 Colourfulness **M**	15.35	15.44	15.47	15.71	15.64	15.522	0.1485	Repeat.****: r^2: 0.72CV: 30 Reprod.****: r^2: 0.67 CV:37
CIECAM02 Saturation **s**	25.80	25.88	25.90	26.10	26.05	25.946	0.1248	
Turbidity 20℃ EBC	0.264	0.268	0.261	0.262	0.258	0.2626	0.0037	**N/A** r95: 0.05 R95:0.20
Shelf Life Prediction Forcing method EBC (modified according to Titze et al., 2007) (60℃,24 h/ 0℃, 24h/ 20℃) EBC-formazin units/ Warm days	Blank: 0.264 EBC: 2.14 W. days: 7	Blank: 0.268 EBC: 2.67 W. days: 8	Blank: 0.261 EBC: 2.23 W. days: 8	Blank: 0.262 EBC: 2.11 W. days: 8	Blank: 0.258 EBC: 2.76 W. days: 8	Blank: 0.26 EBC: 2.38 W. days: 7.8	Blank: 0.27 EBC: 0.31 W. days : 0.447	
NIBEM	Sec: 225 10: 74 20: 147 30: 225	Sec: 226 10: 73 20: 150 30: 226	Sec: 217 10: 60 20: 142 30: 217	Sec: 218 10: 71 20: 144 30: 218	Sec: 222 10: 72 20: 140 30: 222	Sec:221.6 10: 70 20: 144.6 30: 221.6	Sec: 4.03 10: 5.70 20: 3.55 30: 4.037	**For lager beers: Bad: < 220sec Very Good: > 300 sec** r95: 9 R95:42
CO_2 % vol.	2.5	2.3	2.2	2.3	2.3	2.32	0.01025	**Vol %: 2.5 -3.0** r95: 0.09 R95:0.08m
Dissolved oxygen (mg/L) (Orbisphere DO)	0.122	0.189	0.134	0.144	0.156	0.149	0.0256	**< 0.3** r95:0.15 mg/L R95: 0.3 mg/L
Total polyphenols	A820: 0.192	A820: 0.194	A820: 0.193	A820: 0.194	A820: 0.195	A820: 0.19	A820: 0.00	**A820: 0.091-0.121**

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
(mg/L)	Polyθ: 314.88	Polyθ: 318.16	Polyθ: 316.52	Polyθ: 318.16	Polyθ: 319.80	Polyθ: 316.52	Polyθ: 317.50	**Polyθ:73-176** r95:4.1 R95: 18 ± 0.13m
Flavanoids (mg/L)	AB640: 0.650 AS640: 0.762 Flav: 37.52	AB640: 0.650 AS640: 0.762 Flav: 37.52	AB640: 0.650 AS640: 0.762 Flav: 37.52	AB640: 0.650 AS640: 0.762 Flav: 37.52	AB640: 0.650 AS640: 0.762 Flav: 37.52	AB640: 0.650 AS640: 0.762 Flav: 37.52	AB640: 0.000 AS640: 0.000 Flav: 0.000	**Flav: 50-70** CV_{r95}: ± 4.7% CV_{R95}: ± 7.6%
Iron (mg/L) **Factor** (Spectrophotometry-Phenantroline)	Aliquot 0.0 mL 2.5 mL 5.0 mL 10.0mL 20.0mL 30.0mL	Concentrat. 0.0 ppm 0.25 ppm 0.50 ppm 1.00 ppm 2.00 ppm 3.00 ppm	Absorb. A505:0.828 A505:0.916 A505:1.000 A505:1.190 A505:1.555 A505:1.942	Graph curve Factor F*: 0.3714				
Iron (mg/L) **Samples** (Spectrophotometry-Phenantroline)	A505: 0.928 Fe(II): 0.344	A505: 0.928 Fe(II): 0.344	A505: 0.928 Fe(II): 0.344	A505: 0.928 Fe(II): 0.344	A505: 0.928 Fe(II): 0.344	A505: 0.92 Fe(II): 0.34	A505: 0.00 Fe(II): 0.00	**Fe(II): < 0.2 Recommend. values** r95: 0.21m R95: 0.91m
Copper (mg/L) **Samples** (Atomic Absorption Spectrometry)	A324.7: 0.123	A324.7: 0.251	A324.7: 0.377	A324.7: 0.588	A324.7: 0.739 Cu (II): 0.143			**Cu (II): < 0.2 Recommend. values** r95: 0.45m R95: 1.71m
Calcium (mg/L) **Samples** (Atomic Absorption Spectrometry)	A423.0: 0.075	A423.0: 0.082	A423.0: 0.092	A423.0: 0.105	A423.0: 0.108 Ca (II): 22.11			**Ca (II): 4 -100 Recommend. values** CV_{ST95}: ±13.3% CV_{Sr95}: ± 2.4% CV_{Sb95}: ±9.2 %
Reducing Power (MEBAK) % RED	86.7	85.4	86.1	85.9	86.8	86.18	0.5805	**> 60 very good 50-60 good 45-50 satisfactory < 45 poor** CV_{r95}: ± 1%

Table A.1.4 Beer Analyses: Carlsberg Beer 4% vol. alcohol

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
Sp. Gravity (S 20/20) Beer	1.0099	1.0090	1.0098	1.0098	1.0091	1.00952	0.000432	**1.00585 - 1.01175** r95:N/A R95: N/A
App. extract (EA) %	2.53	2.30	2.51	2.51	2.33	2.437	0.109959	**1.5 – 3.0** r95:0.012 R95:0.080
Sp. Gravity (S 20/20) Alcohol	0.9940	0.9937	0.9933	0.9936	0.9935	0.9936	0.993620	**0.99675 – 0.98770** r95: N/A R95: N/A
Alcohol (mas%)	3.28	3.45	3.69	3.52	3.56	3.50	0.150831	**1.75-7.20** r95: 0.03 ± 0.005m R95: 0.03 ± 0.02m
Alcohol (vol%)	4.12	4.34	4.64	4.42	4.48	4.40	0.191312	**2.2-9.0** r95: 0.04 ± 0.004m R95: 0.04 ± 0.02m
Sp. Gravity (S 20/20) Real extract	1.0148	1.0146	1.0146	1.0144	1.0144	1.01456	0.000167	**1.01175-1.02370** r95: N/A R95: N/A
Real extract (ER) %	3.77	3.72	3.72	3.67	3.67	3.715	0.0423	**3.0-6.0** r95:0.02m R95: 0.02m
Original Gravity (OG) %	10.00	10.26	10.70	10.34	10.43	10.346	0.2547	**7.0-12.0** r95: 0.07 R95: 0.19
pH	3.91	3.91	3.91	3.91	3.92	3.912	0.00447	**Pils: 4.3-4.6** r95:0.02 R95:0.13
Bitter units	A275: 0.324 IBU: 16.2 ≈ 16	A275: 0.321 IBU: 16.05 ≈ 16	A275: 0.321 IBU: 16.05 ≈ 16	A275: 0.319 IBU:15.95 ≈ 16	A275: 0.320 IBU: 16	A275: 0.32 IBU:16.05 ≈16	A275: 0.00 IBU: 0.0935	**A275: 0.200-0.800 IBU: 10-40** r95: 0.44 ± 0.014m R95: -0.7 ± 0.18m
Colour Visual Comp. EBC/Lovibond	8.0	8.0	8.0	8.0	8.5	8.1	0.2236	**Pale beers: 7-11 EBC** r95: 0.4 R95: 1.8
Colour (430 nm) EBC	A430: 0.337 EBC: 8.42	A430: 0.339 EBC: 8.47	A430: 0.341 EBC: 8.52	A430: 0.342 EBC: 8.55	A430: 0.338 EBC: 9.70	A430: 0.33 EBC: 8.73	A430: 0.00 EBC: 0.54	**Pale beers: 7-11 EBC** r95: 0.3 R95:0.6
Colour Tristimulus %T 360 nm	0.8	0.7	0.7	0.8	0.8	0.76	0.054	
Colour Tristimulus %T 450 nm	57.4	57.0	57.2	57.0	57.5	57.22	0.228	

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
Colour Tristimulus %T 540 nm	85.5	85.5	85.5	85.5	85.5	85.48	0.045	
Colour Tristimulus %T 670 nm	97.1	97.1	96.9	97.0	97.0	96.98	0.084	
Colour Tristimulus %T 760 nm	99.6	99.6	99.6	99.6	99.6	99.60	0.00000	
Colour Tristimulus Values **X (Red)**	79.086	79.024	78.990	78.994	79.069	79.032	0.4358	
Colour Tristimulus Values **Y (Green)**	84.925	84.885	84.865	84.865	84.915	84.891	0.0278	
Colour Tristimulus Values **Z (Blue)**	60.987	60.638	60.808	60.648	61.072	60.830	1.9606	
Colour CIELAB L*	91.27	91.24	91.22	91.23	91.26	91.244	0.0207	**96.63 *, 93.83**** r95: 0.55 R95: 2.26
Colour CIELAB a*	-3.74	-3.76	-3.77	-3.77	-3.75	3.758	0.0130	**-2.04 *, -7.83**** r95: 0.19 R95: 0.56
Colour CIELAB b*	13.43	13.56	13.48	13.55	13.39	13.48	0.074	**14.39 *, 32.97**** r95: 1.01 R95: 2.20
Colour CIELAB C* (Metric Chroma)	13.94	14.07	14.00	14.06	13.91	13.99	0.071	
Yellowness Index	43.07	43.44	43.18	43.39	42.95	43.206	0.2081	
iCAM Lightness **J**	6.53	6.53	6.53	6.53	6.54	6.532	0.0032	
iCAM Chroma **C**	1.32	1.33	1.33	1.34	1.32	1.328	0.0074	
iCAM Hue Angle **h**	0.081	0.079	0.078	0.079	0.080	0.079	0.0011	
iCAM Brightness **Q**	13.20	13.19	13.19	13.19	13.20	13.20	0.005	
iCAM Colourfulness **M**	2.67	2.70	2.68	2.70	2.66	2.685	0.0168	
CIECAM02 Lightness **J**	91.85	91.83	91.81	91.81	91.84	91.828	0.0178	Repeat.****: r^2: 0.84 CV:19 Reprod.****: r^2: 0.88 CV:17
CIECAM02 Chroma **C**	20.22	20.44	20.32	20.43	20.15	20.312	0.1275	
CIECAM02 redness-greenness **a**	-0.010	-0.010	-0.011	-0.011	-0.010	-0.0104	0.0005	

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
CIECAM02 yellowness-blueness **b**	0.424	0.429	0.426	0.428	0.422	0.425	0.0028	
CIECAM02 Angle Hue **h**	91.36	91.41	91.53	91.48	91.41	91.438	0.0668	
CIECAM02 Hue composition **H**	102.59	102.70	102.93	102.82	102.70	102.748	0.1302	Repeat.****: r^2: 0.99 CV: 8 Reprod. ****: r^2: 0.99 CV:10
CIECAM02 **Hc (Red)**	0	0	0	0	0	0.00	0.000	
CIECAM02 **Hc (Yellow)**	97.40	97.29	97.06	97.17	97.29	97.242	0.1302	
CIECAM02 **Hc (Green)**	2.59	2.70	2.93	2.82	2.70	2.748	0.1302	
CIECAM02 **Hc (Blue)**	0	0	0	0	0	0.00	0.000	
CIECAM02 Brightness **Q**	228.07	228.04	228.02	228.02	228.06	228.042	0.0228	
CIECAM02 Colourfulness **M**	19.08	19.29	19.18	19.28	19.02	19.17	0.1195	Repeat.****: r^2: 0.72 CV: 30 Reprod.****: r^2: 0.67 CV:37
CIECAM02 Saturation **s**	28.92	29.09	29.00	29.08	28.88	28.994	0.0937	
Turbidity 20℃ EBC	0.303	0.312	0.312	0.312	0.316	0.311	0.0047	**N/A** r95: 0.05 R95:0.20
Shelf Life Prediction Forcing method EBC (modified according to Titze et al., 2007) (60℃,24 h/ 0℃, 24h/ 20℃) EBC-formazin units/ Warm days	Blank: 0.303 EBC: 2.674 W. days: 9	Blank: 0.312 EBC: 2.787 W. days: 9	Blank: 0.312 EBC: 2.210 W. days: 9	Blank: 0.312 EBC: 2.777 W. days: 10	Blank: 0.316 EBC: 2.831 W. days: 10	Blank: 0.311 EBC: 2.6558 W. days: 9.4	Blank: 0.0047 EBC: 0.25576 W. days: 0.547	
NIBEM	Sec: 304 10: 107 20: 213 30: 304	Sec: 295 10: 101 20: 200 30: 295	Sec: 298 10: 104 20: 207 30: 298	Sec: 299 10: 110 20: 211 30: 299	Sec: 295 10: 103 20: 203 30: 295	Sec: 298 10: 105 20: 206.8 30: 298.2	Sec: 3.70 10: 3.53 20: 4.83 30: 3.70	**For lager beers: Bad: < 220sec Very Good: > 300 sec** r95: 9 R95:42
CO_2 % vol.	2.6	2.6	2.5	2.5	2.2	2.48	0.1643	**Vol %: 2.5 -3.0** r95: 0.09 R95:0.08m
Dissolved oxygen (mg/L) (Orbisphere DO)	0.444	0.432	0.381	0.417	0.436	0.422	0.0249	**< 0.3** r95:0.15 mg/L R95: 0.3 mg/L
Total	A820:	A820:	A820:	A820:	A820:	A820:	A820:	**A820:**

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
polyphenols (mg/L)	0.119 Polyθ: 195.16	0.119 Polyθ: 195.16	0.119 Polyθ: 195.16	0.120 Polyθ: 196.80	0.120 Polyθ: 196.80	0.11 Polyθ: 195.816	0.00 Polyθ: 0.8982	**0.091-0.121** **Polyθ:73-176** r95:4.1 R95: 18 ± 0.13m
Flavanoids (mg/L)	AB640: 0.650 AS640: 0.747 Flav: 32.49	AB640: 0.650 AS640: 0.747 Flav: 32.49	AB640: 0.650 AS640: 0.747 Flav: 32.49	AB640: 0.650 AS640: 0.751 Flav: 33.83	AB640: 0.650 AS640: 0.746 Flav: 32.16	AB640: 0.650 AS640: 0.7476 Flav: 32.6	AB640: 0.000 AS640: 0.0019 Flav: 0.58	**Flav: 50-70** CV_{r95}: ± 4.7% CV_{R95}: ± 7.6%
Iron (mg/L) **Factor** (Spectrophotometry-Phenantroline)	Aliquot 0.0 mL 2.5 mL 5.0 mL 10.0mL 20.0mL 30.0mL	Concentrat. 0.0 ppm 0.25 ppm 0.50 ppm 1.00 ppm 2.00 ppm 3.00 ppm	Absorb. A505:0.828 A505:0.916 A505:1.000 A505:1.190 A505:1.555 A505:1.942	Graph curve Factor F*: 0.3714				
Iron (mg/L) **Samples** (Spectrophotometry-Phenantroline)	A505: 0.935 Fe(II): 0.347	A505: 0.935 Fe(II): 0.347	A505: 0.935 Fe(II): 0.347	A505: 0.932 Fe(II): 0.346	A505: 0.933 Fe(II): 0.346	A505: 0.93 Fe(II): 0.34	A505: 0.00 Fe(II): 0.00	**Fe(II): < 0.2** **Recommend. values** r95: 0.21m R95: 0.91m
Copper (mg/L) **Samples** (Atomic Absorption Spectrometry)	A324.7: 0.111	A324.7: 0.237	A324.7: 0.387	A324.7: 0.501	A324.7: 0.719 Cu (II): 0.143			**Cu (II): < 0.2** **Recommend. values** r95: 0.45m R95: 1.71m
Calcium (mg/L) **Samples** (Atomic Absorption Spectrometry)	A423.0: 0.097	A423.0: 0.112	A423.0: 0.120	A423.0: 0.128	A423.0: 0.136 Ca (II): 27.97			**Ca (II): 4 -100** **Recommend. values** CV_{ST95}: ±13.3% CV_{Sr95}: ± 2.4% CV_{Sb95}: ±9.2%
Reducing Power (MEBAK) % RED	55.1	53.2	51.6	53.4	52.2	53.10	1.337	**> 60 very good** **50-60 good** **45-50 satisfactory** **< 45 poor** CV_{r95}: ± 1%

Table A.1.5 Beer Analyses: Corona Exportación 5% vol. alcohol

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
Sp. Gravity (S 20/20) Beer	1.0118	1.0120	1.0122	1.0122	1.0131	1.01226	0.000497	**1.00585 - 1.01175** r95:N/A R95: N/A
App. extract (EA) %	3.02	3.07	3.12	3.12	3.35	3.133	0.1261	**1.5 – 3.0** r95:0.012 R95:0.080
Sp. Gravity (S 20/20) Alcohol	0.9942	0.9940	0.9944	0.9942	0.9938	0.99412	0.000228	**0.99675 – 0.98770** r95: N/A R95: N/A
Alcohol (mas%)	3.16	3.28	3.05	3.16	3.40	3.21	0.133791	**1.75-7.20** r95: 0.03 ± 0.005m R95: 0.03 ± 0.02m
Alcohol (vol%)	3.98	4.12	3.84	3.98	4.28	4.04	0.166733	**2.2-9.0** r95: 0.04 ± 0.004m R95: 0.04 ± 0.02m
Sp. Gravity (S 20/20) Real extract	1.0165	1.0160	1.0160	1.0163	1.0163	1.01622	0.000193	**1.01175-1.02370** r95: N/A R95: N/A
Real extract (ER) %	4.20	4.08	4.08	4.15	4.15	4.132	0.0490	**3.0-6.0** r95:0.02m R95: 0.02m
Original Gravity (OG) %	10.19	10.29	9.87	10.15	10.59	10.216	0.232436	**7.0-12.0** r95: 0.07 R95: 0.19
pH	4.09	4.00	4.00	4.12	4.12	4.066	0.0615	**Pils: 4.3-4.6** r95:0.02 R95:0.13
Bitter units	A275: 0.320 IBU: 16	A275: 0.323 IBU: 16.15 ≈ 16	A275: 0.323 IBU: 16.15 ≈ 16	A275: 0.327 IBU: 16.35 ≈ 16	A275: 0.327 IBU: 16.35 ≈ 16	A275: 0.32 IBU:16.20 ≈16	A275: 0.00 IBU: 0.15	**A275: 0.200-0.800** **IBU: 10-40** r95: 0.44 ± 0.014m R95: -0.7 ± 0.18m
Colour Visual Comp. EBC/Lovibond	7.0	7.0	7.0	7.0	7.0	7.0	0.00	**Pale beers: 7-11 EBC** r95: 0.4 R95: 1.8
Colour (430 nm) EBC	A430: 0.319 EBC: 7.97	A430: 0.319 EBC: 7.97	A430: 0.319 EBC: 7.97	A430: 0.320 EBC: 8.00	A430: 0.320 EBC: 8.00	A430: 0.31 EBC: 7.98	A430: 0.00 EBC: 0.01	**Pale beers: 7-11 EBC** r95: 0.3 R95:0.6
Colour Tristimulus %T 360 nm	2.8	2.9	2.8	2.9	2.9	2.86	0.054	
Colour Tristimulus %T 450 nm	59.4	59.5	59.0	59.0	59.8	59.34	0.343	

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
Colour Tristimulus %T 540 nm	88.6	88.4	88.0	88.0	88.8	88.36	0.357	
Colour Tristimulus %T 670 nm	98.1	97.8	98.0	97.8	98.1	97.96	0.151	
Colour Tristimulus %T 760 nm	99.9	99.7	99.7	99.0	99.9	99.64	0.371	
Colour Tristimulus Values **X (Red)**	81.165	80.994	80.798	80.735	81.318	81.002	2.5223	
Colour Tristimulus Values **Y (Green)**	87.495	87.306	87.015	86.975	87.675	87.293	0.3022	
Colour Tristimulus Values **Z (Blue)**	63.319	63.385	62.894	62.903	63.696	63.239	0.3421	
Colour CIELAB L*	92.20	92.12	92.04	92.01	92.27	92.129	0.1093	**96.63 *, 93.83**** r95: 0.55 R95: 2.26
Colour CIELAB a*	-4.06	-4.05	-3.98	-4.00	-4.07	-4.032	0.0396	**-2.04 *, -7.83**** r95: 0.19 R95: 0.56
Colour CIELAB b*	13.37	13.28	13.38	13.36	13.28	13.334	0.0497	**14.39 *, 32.97**** r95: 1.01 R95: 2.20
Colour CIELAB C* (Metric Chroma)	13.97	13.88	13.96	13.95	13.89	13.93	0.0418	
Yellowness Index	42.02	41.78	42.23	42.15	41.70	41.976	0.2298	
iCAM Lightness **J**	6.62	6.62	6.65	6.60	6.63	6.616	0.011	
iCAM Chroma **C**	1.31	1.30	1.31	1.31	1.30	1.308	0.0060	
iCAM Angle Hue **h**	0.057	0.057	0.063	0.061	0.055	0.0586	0.0032	
iCAM Brightness **Q**	13.38	13.37	13.34	13.34	13.39	13.369	0.0213	
iCAM Colourfulness **M**	2.653	2.631	2.656	2.651	2.631	2.644	0.0123	
CIECAM02 Lightness **J**	93.30	93.19	93.03	93.01	93.40	93.186	0.1689	Repeat.****: r^2: 0.84 CV:19 Reprod. ****: r^2: 0.88 CV:17
CIECAM02 Chroma **C**	20.12	19.97	20.12	20.10	19.97	20.056	0.0789	
CIECAM02 redness-greenness **a**	-0.022	-0.022	-0.019	-0.020	-0.023	0.0212	0.0016	

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
CIECAM02 yellowness-blueness **b**	0.421	0.417	0.421	0.420	0.417	0.419	0.0020	
CIECAM02 Angle Hue **h**	93.02	93.05	92.61	92.75	93.16	92.918	0.2288	
CIECAM02 Hue composition **H**	105.72	105.78	104.95	105.21	105.97	105.526	0.4274	Repeat.****: r^2: 0.99 CV: 8 Reprod. ****: r^2: 0.99 CV:10
CIECAM02 **Hc (Red)**	0	0	0	0	0	0.000	0.0000	
CIECAM02 **Hc (Yellow)**	94.27	94.21	95.04	94.78	94.02	94.464	0.4274	
CIECAM02 **Hc (Green)**	5.72	5.78	4.95	5.21	5.97	5.526	0.4274	
CIECAM02 **Hc (Blue)**	0	0	0	0	0	0.000	0.0000	
CIECAM02 Brightness **Q**	229.86	229.72	229.53	229.50	229.98	229.719	0.2083	
CIECAM02 Colourfulness **M**	18.99	18.85	18.99	18.97	18.85	18.931	0.0747	Repeat.****: r^2: 0.72 CV: 30 Reprod.****: r^2: 0.67 CV:37
CIECAM02 Saturation **s**	28.74	28.64	28.76	28.75	28.63	28.704	0.0634	
Turbidity 20℃ EBC	0.295	0.296	0.282	0.294	0.279	0.2892	0.00804	**N/A** r95: 0.05 R95:0.20
Shelf Life Prediction Forcing method EBC (modified according to Titze et al., 2007) (60℃,24 h/ 0℃, 24h/ 20℃) EBC-formazin units/ Warm days	Blank: 0.295 EBC: 2.89 W. days: 11	Blank: 0.296 EBC: 2.221 W. days: 11	Blank: 0.282 EBC: 2.003 W. days: 11	Blank: 0.294 EBC: 2.785 W. days: 11	Blank: 0.279 EBC: 2.113 W. days: 11	Blank: 0.28 EBC: 2.40 W. days: 11.0	Blank: 0.00 EBC: 0.40 W. days: 0.00	
NIBEM	Sec: 195 10: 64 20: 132 30: 195	Sec: 193 10: 63 20: 131 30: 193	Sec: 195 10: 64 20: 132 30: 195	Sec: 187 10: 50 20: 125 30: 187	Sec:191 10: 50 20: 128 30: 191	Sec:192.2 10: 58.2 20:128.83 30:192.20	Sec: 2.99 10: 7.49 20: 3.31 30: 2.99	**For lager beers: Bad: < 220sec Very Good: > 300 sec** r95: 9 R95:42
CO_2 % vol.	2.3	2.3	2.3	2.3	2.2	2.28	0.0447	**Vol %: 2.5 -3.0** r95: 0.09 R95:0.08m
Dissolved oxygen (mg/L) (Orbisphere DO)	0.098	0.087	0.112	0.105	0.093	0.099	0.0098	**< 0.3** r95:0.15 mg/L R95: 0.3 mg/L
Total	A820:	A820:	A820:	A820:	A820:	A820:	A820:	**A820: 0.091-**

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
polyphenols (mg/L)	0.080 Polyθ: 131.20	0.080 Polyθ: 131.20	0.083 Polyθ: 136.12	0.083 Polyθ: 136.12	0.081 Polyθ: 132.84	0.08 Polyθ: 133.496	0.00 Polyθ: 2.4871	**0.121** **Polyθ:73-176** r95:4.1 R95: 18 ± 0.13m
Flavanoids (mg/L)	AB640: 0.650 AS640: 0.685 Flav: 11.72	AB640: 0.650 AS640: 0.690 Flav: 13.40	AB640: 0.650 AS640: 0.690 Flav: 13.40	AB640: 0.650 AS640: 0.690 Flav: 13.40	AB640: 0.650 AS640: 0.690 Flav: 13.40	AB640: 0.650 AS640: 0.689 Flav:13.1	AB640: 0.000 AS640: 0.002 Flav: 0.75	**Flav: 50-70** CV_{r95}: ± 4.7% CV_{R95}: ± 7.6%
Iron (mg/L) **Factor** (Spectrophotometry-Phenantroline)	Aliquot 0.0mL 2.5mL 5.0mL 10.0mL 20.0mL 30.0mL	Concentrat. 0.0ppm 0.25ppm 0.50ppm 1.00ppm 2.00ppm 3.00 ppm	Absorb, A505:0.828 A505:0.916 A505:1.000 A505:1.190 A505:1.555 A505:1.942	Graph curve Factor F*: 0.3714				
Iron (mg/L) **Samples** (Spectrophotometry-Phenantroline)	A505: 0.808 Fe(II): 0.300	A505: 0.808 Fe(II): 0.300	A505: 0.808 Fe(II): 0.300	A505: 0.808 Fe(II): 0.300	A505: 0.802 Fe(II): 0.297	A505: 0.8068 Fe(II): 0.2994	A505: 0.0026 Fe(II): 0.0013	**Fe(II): < 0.2** **Recommend. values** r95: 0.21m R95: 0.91m
Copper (mg/L) **Samples** (Atomic Absorption Spectrometry)	A324.7: 0.180	A324.7: 0.210	A324.7: 0.359	A324.7: 0.537	A324.7: 0.750 Cu (II): 0.154			**Cu (II): < 0.2** **Recommend. values** r95: 0.45m R95: 1.71m
Calcium (mg/L) **Samples** (Atomic Absorption Spectrometry)	A423.0: 0.066	A423.0: 0.078	A423.0: 0.084	A423.0: 0.099	A423.0: 0.104 Ca (II): 18.27			**Ca (II): 4 -100** **Recommend. values** CV_{ST95}: ±13.3% CV_{Sr95}: ± 2.4% CV_{Sb95}: ±9.2%
Reducing Power (MEBAK) % RED	72.5	75.6	74.8	74.2	74.8	74.38	1.1627	**> 60 very good** **50-60 good** **45-50 satisfactory** **< 45 poor** CV_{r95}: ± 1%

Table A.1.6 Beer Analyses: Foster's Beer 4% vol. alcohol

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
Sp. Gravity (S 20/20) Beer	1.0116	1.0116	1.0118	1.0118	1.0114	1.01164	0.000167	**1.00585 - 1.01175** r95:N/A R95: N/A
App. extract (EA) %	2.96	2.96	3.02	3.02	2.91	2.976	0.0426	**1.5 – 3.0** r95:0.012 R95:0.080
Sp. Gravity (S 20/20) Alcohol	0.9935	0.9932	0.9935	0.9935	0.9930	0.99336	0.000216	**0.99675 – 0.98770** r95: N/A R95: N/A
Alcohol (mas%)	3.56	3.74	3.56	3.56	3.87	3.658	0.1418	**1.75-7.20** r95: 0.03 ± 0.005m R95: 0.03 ± 0.02m
Alcohol (vol%)	4.48	4.70	4.48	4.48	4.86	4.60	0.173781	**2.2-9.0** r95: 0.04 ± 0.004m R95: 0.04 ± 0.02m
Sp. Gravity (S 20/20) Real extract	1.0134	1.0134	1.0134	1.0132	1.0134	1.01336	0.000089	**1.01175-1.02370** r95: N/A R95: N/A
Real extract (ER) %	3.42	3.42	3.42	3.37	3.42	3.411	0.0223	**3.0-6.0** r95:0.02m R95: 0.02m
Original Gravity (OG) %	10.17	10.50	10.17	10.12	10.74	10.34	0.2701	**7.0-12.0** r95: 0.07 R95: 0.19
pH	3.97	4.11	4.22	4.22	4.22	4.148	0.1103	**Pils: 4.3-4.6** r95:0.02 R95:0.13
Bitter units	A275: 0.310 IBU:15.5 ≈ 16	A275: 0.316 IBU:15.8 ≈ 16	A275: 0.310 IBU:15.5 ≈ 16	A275: 0.333 IBU:16.5 ≈ 16	A275: 0.320 IBU:16	A275: 0.31 IBU:15.86 ≈16	A275: 0.00 IBU: 0.415	**A275: 0.200-0.800** **IBU: 10-40** r95: 0.44 ± 0.014m R95: -0.7 ± 0.18m
Colour Visual Comp. EBC/Lovibond	12	12	12	12	11.5	11.9	0.2236	**Pale beers: 7-11 EBC** r95: 0.4 R95: 1.8
Colour (430 nm) EBC	A430: 0.441 EBC: 11.02	A430: 0.443 EBC: 11.07	A430: 0.443 EBC: 11.07	A430: 0.444 EBC: 11.1	A430: 0.443 EBC: 11.07	A430: 0.44 EBC:11.0	A430: 0.44 EBC: 0.00	**Pale beers: 7-11 EBC** r95: 0.3 R95:0.6
Colour Tristimulus %T 360 nm	1.7	1.7	1.7	1.7	1.7	1.7	0.00	
Colour Tristimulus %T 450 nm	43.0	43.8	43.0	43.6	42.9	43.26	0.409	

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
Colour Tristimulus %T 540 nm	74.1	74.8	74.0	74.2	74.0	74.22	0.334	
Colour Tristimulus %T 670 nm	91.0	91.4	91.1	91.5	91.1	91.22	0.216	
Colour Tristimulus %T 760 nm	95.2	95.3	95.7	96.1	95.7	95.6	0.360	
Colour Tristimulus Values **X (Red)**	69.76	70.33	69.75	70.06	69.73	69.92	2.630	
Colour Tristimulus Values **Y (Green)**	74.29	74.94	74.24	74.52	74.23	74.444	0.3009	
Colour Tristimulus Values **Z (Blue)**	47.23	48.01	47.21	47.75	47.132	47.469	0.3897	
Colour CIELAB L*	86.88	87.15	86.87	87.02	86.86	86.956	0.1266	**96.63 *, 93.83**** r95: 0.55 R95: 2.26
Colour CIELAB a*	-3.00	-3.05	-2.96	-2.92	-2.97	-2.98	0.0484	**-2.04 *, -7.83**** r95: 0.19 R95: 0.56
Colour CIELAB b*	15.68	15.55	15.66	15.51	15.70	15.62	0.0845	**14.39 *, 32.97**** r95: 1.01 R95: 2.20
Colour CIELAB C* (Metric Chroma)	15.96	15.84	15.94	15.79	15.98	15.902	0.0825	
Yellowness Index	52.80	52.22	52.84	52.41	52.94	52.642	0.3101	
iCAM Lightness **J**	6.11	6.14	6.17	6.13	6.16	6.147	0.0244	
iCAM Chroma **C**	1.58	1.57	1.58	1.57	1.59	1.583	0.0092	
iCAM Angle Hue **h**	0.128	0.125	0.130	0.134	0.130	0.129	0.0032	
iCAM Brightness **Q**	12.36	12.41	12.36	12.38	12.35	12.376	0.0247	
iCAM Colourfulness **M**	3.21	3.18	3.21	3.17	3.21	3.199	0.0190	
CIECAM02 Lightness **J**	85.59	85.99	85.56	85.74	85.56	85.688	0.1845	Repeatability****: r^2: 0.84 CV:19 Reproducibility ****: r^2: 0.88 CV:17
CIECAM02 Chroma **C**	24.33	24.09	24.31	24.03	24.37	24.226	0.1545	
CIECAM02 redness-	0.019	0.018	0.021	0.022	0.021	0.020	0.0016	

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
greenness **a**								
CIECAM02 yellowness-blueness **b**	0.510	0.505	0.509	0.504	0.511	0.5078	0.00311	
CIECAM02 Angle Hue **h**	87.76	87.95	87.61	87.39	87.63	87.668	0.2062	
CIECAM02 Hue composition **H**	96.36	96.66	96.11	95.75	96.15	96.206	0.3354	Repeat.****: r^2: 0.99 CV: 8 Reprod. ****: r^2: 0.99 CV:10
CIECAM02 **Hc (Red)**	3.63	3.33	3.88	4.24	3.84	3.784	0.3354	
CIECAM02 **Hc (Yellow)**	96.36	96.66	96.11	95.75	96.15	96.206	0.3354	
CIECAM02 **Hc (Green)**	0	0	0	0	0	0.000	0.0000	
CIECAM02 **Hc (Blue)**	0	0	0	0	0	0.000	0.0000	
CIECAM02 Brightness **Q**	220.16	220.67	220.13	220.35	220.12	220.287	0.2345	
CIECAM02 Colourfulness **M**	22.96	22.73	24.31	22.68	23.00	23.136	0.6709	Repeat.****: r^2: 0.72 CV: 30 Reprod.****: r^2: 0.67 CV:37
CIECAM02 Saturation **s**	32.29	32.10	32.28	32.08	32.33	32.216	0.1167	
Turbidity 20 ℃ EBC	0.624	0.624	0.622	0.628	0.614	0.6224	0.00517	**N/A** r95: 0.05 R95:0.20
Shelf Life Prediction Forcing method EBC (modified according to Titze et al., 2007) (60℃,24 h/ 0℃, 24h/ 20℃) EBC-formazin units/ Warm days	Blank: 0.624 EBC: 2.54 W. days: 6	Blank: 0.624 EBC: 2.68 W. days: 5	Blank: 0.622 EBC: 2.48 W. days: 5	Blank: 0.628 EBC: 2.56 W. days: 5	Blank: 0.614 EBC: 2.59 W. days: 6	Blank: 0.62 EBC: 2.57 W. days: 5.4	Blank: 0.00 EBC: 0.07 W. days: 0.547	
NIBEM	Sec: 311 10: 117 20: 222 30: 311	Sec: 300 10: 120 20: 217 30: 300	Sec: 301 10: 112 20: 212 30: 301	Sec: 317 10: 124 20: 225 30: 317	Sec: 307 10: 120 20: 227 30: 307	Sec: 307 10: 118.6 20: 220.6 30: 307.2	Sec: 7.08 10: 3.979 20: 6.107 30: 7.085	**For lager beers: Bad: < 220sec Very Good: > 300 sec** r95: 9 R95:42
CO_2% vol.	2.9	2.9	2.8	2.9	2.9	2.88	0.4472	**Vol %: 2.5 -3.0** r95: 0.09 R95:0.08m
Dissolved oxygen (mg/L) (Orbisphere DO)	0.300	0.321	0.312	0.367	0.324	0.3248	0.02537	**< 0.3** r95:0.15 mg/L R95: 0.3 mg/L

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
Total polyphenols (mg/L)	A820: 0.065 Polyθ: 106.60	A820: 0.071 Polyθ: 121.36	A820: 0.072 Polyθ: 118.08	A820: 0.073 Polyθ: 119.72	A820: 0.072 Polyθ: 118.08	A820: 0.07 Polyθ: 116.76	A820: 0.00 Polyθ: 5.844	**A820: 0.091-0.121** **Polyθ: 73-176** r95:4.1 R95: 18 ± 0.13m
Flavanoids (mg/L)	AB640: 0.650 AS640: 0.698 Flav: 16.08	AB640: 0.650 AS640: 0.702 Flav: 17.42	AB640: 0.650 AS640: 0.702 Flav: 17.42	AB640: 0.650 AS640: 0.702 Flav: 17.42	AB640: 0.650 AS640: 0.703 Flav: 17.75	AB640: 0.650 AS640: 0.7014 Flav: 17.1	AB640: 0.000 AS640: 0.0019 Flav: 0.60	**Flav: 50-70** CV_{r95}: ± 4.7% CV_{R95}: ± 7.6%
Iron (mg/L) **Factor** (Spectrophotometry-Phenantroline)	Aliquot 0.0 mL 2.5 mL 5.0 mL 10.0mL 20.0mL 30.0mL	Concentrat. 0.0 ppm 0.25 ppm 0.50 ppm 1.00 ppm 2.00 ppm 3.00 ppm	Absorb.: A505:0.828 A505:0.916 A505:1.000 A505:1.190 A505:1.555 A505:1.942	Graph curve Factor F*: 0.3714				
Iron (mg/L) **Samples** (Spectrophotometry-Phenantroline)	A505: 0.998 Fe(II): 0.370	A505: 0.996 Fe(II): 0.369	A505: 0.994 Fe(II): 0.369	A505: 0.989 Fe(II): 0.367	A505: 0.996 Fe(II): 0.369	A505: 0.99 Fe(II): 0.36	A505: 0.00 Fe(II): 0.00	**Fe(II): < 0.2** **Recommend. values** r95: 0.21m R95: 0.91m
Copper (mg/L) **Samples** (Atomic Absorption Spectrometry)	A324.7: 0.181	A324.7: 0.285	A324.7: 0.387	A324.7: 0.591	A324.7: 0.733 Cu (II): 0.178			**Cu (II): < 0.2** **Recommend. values** r95: 0.45m R95: 1.71m
Calcium (mg/L) **Samples** (Atomic Absorption Spectrometry)	A423.0: 0.066	A423.0: 0.078	A423.0: 0.084	A423.0: 0.099	A423.0: 0.104 Ca(II): 18.27			**Ca (II): 4 -100** **Recommend. values** CV_{ST95}: ±13.3% CV_{Sr95}: ± 2.4% CV_{Sb95}: ±9.2%
Reducing Power (MEBAK) % RED	48.7	49.2	49.5	48.2	50.2	49.16	0.7635	**> 60 very good** **50-60 good** **45-50 satisfactory** **< 45 poor** CV_{r95}: ± 1%

Table A.1.7 Beer Analyses: Heineken Beer 5% vol. alcohol

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
Sp. Gravity (S 20/20) Beer	1.0092	1.0095	1.0097	1.0093	1.0097	1.00948	0.000228	**1.00585 - 1.01175** r95:N/A R95: N/A
App. extract (EA) %	2.35	2.43	2.48	2.38	2.48	2.42	0.058	**1.5 – 3.0** r95:0.012 R95:0.080
Sp. Gravity (S 20/20) Alcohol	0.9933	0.9933	0.9936	0.9929	0.9927	0.99316	0.000357	**0.99675 – 0.98770** r95: N/A R95: N/A
Alcohol (mas%)	3.69	3.69	3.52	3.92	4.04	3.772	0.2065	**1.75-7.20** r95: 0.03 ± 0.005m R95: 0.03 ± 0.02m
Alcohol (vol%)	4.64	4.64	4.42	4.92	5.08	4.74	0.2600	**2.2-9.0** r95: 0.04 ± 0.004m R95: 0.04 ± 0.02m
Sp. Gravity (S 20/20) Real extract	1.0187	1.0192	1.0192	1.0193	1.0186	1.0190	0.000324	**1.01175-1.02370** r95: N/A R95: N/A
Real extract (ER) %	4.75	4.88	4.88	4.90	4.73	4.83	0.081	**3.0-6.0** r95:0.02m R95: 0.02m
Original Gravity (OG) %	11.69	11.81	11.54	12.25	12.30	11.918	0.3401	**7.0-12.0** r95: 0.07 R95: 0.19
pH	4.05	4.05	4.05	4.10	4.08	4.063	0.0230	**Pils: 4.3-4.6** r95:0.02 R95:0.13
Bitter units	A275: 0.379 IBU: 18.95 ≈ 19	A275: 0.378 IBU: 18.9 ≈ 19	A275: 0.383 IBU: 19.15 ≈ 19	A275: 0.382 IBU: 19.10 ≈ 19	A275: 0.383 IBU: 19.15 ≈ 19	A275: 0.38 IBU:19.05 ≈19	A275: 0.00 IBU: 0.104	**A275: 0.200-0.800 IBU: 10-40** r95: 0.44 ± 0.014m R95: -0.7 ± 0.18m
Colour Visual Comp. EBC/Lovibond	7.0	7.0	7.0	7.5	7.5	7.2	0.2738	**Pale beers: 7-11 EBC** r95: 0.4 R95: 1.8
Colour (430 nm) EBC	A430: 0.300 EBC: 7.50	A430: 0.288 EBC: 7.20	A430: 0.299 EBC: 7.47	A430: 0.304 EBC: 7.60	A430: 0.302 EBC: 7.55	A430: 0.29 EBC: 7.46	A430: 0.00 EBC: 0.14	**Pale beers: 7-11 EBC** r95: 0.3 R95:0.6
Colour Tristimulus %T 360 nm	1.1	1.1	1.0	1.1	1.1	1.08	0.044	
Colour Tristimulus %T 450 nm	60.2	60.3	60.3	60.2	60.9	60.38	0.294	

Analysis	Beer 1	Beer 2	Beer 3	Beer 4	Beer 5	Mean	Standard Deviation (Sx)	Normal Values
Colour Tristimulus %T 540 nm	86.2	86.4	86.2	86.2	86.7	86.34	86.316	
Colour Tristimulus %T 670 nm	97.0	97.0	97.0	97.1	97.1	97.04	0.054	
Colour Tristimulus %T 760 nm	99.2	99.9	99.5	99.5	99.6	99.54	0.025	
Colour Tristimulus Values **X (Red)**	79.80	79.90	79.81	79.83	80.16	79.90	0.1524	
Colour Tristimulus Values **Y (Green)**	85.67	85.85	85.68	85.69	86.11	85.80	0.2065	
Colour Tristimulus Values **Z (Blue)**	63.49	63.60	63.56	63.49	64.15	63.66	0.2864	
Colour CIELAB L*	91.59	91.64	91.60	91.60	91.75	91.631	0.0811	**96.63 *, 93.83**** r95: 0.55 R95: 2.26
Colour CIELAB a*	-3.74	-3.77	-3.73	-3.72	-3.78	-3.748	0.0258	**-2.04 *, -7.83**** r95: 0.19 R95: 0.56
Colour CIELAB b*	12.68	12.69	12.65	12.69	12.57	12.656	0.0507	**14.39 *, 32.97**** r95: 1.01 R95: 2.20
Colour CIELAB C* (Metric Chroma)	13.22	13.24	13.19	13.22	13.13	13.20	0.0430	
Yellowness Index	40.66	40.61	40.59	40.70	40.18	40.548	0.2101	
iCAM Lightness **J**	6.57	6.58	6.57	6.57	6.58	6.57	0.004	
iCAM Chroma **C**	1.23	1.23	1.23	1.23	1.24	1.237	0.0053	
iCAM Angle Hue **h**	0.078	0.075	0.078	0.079	0.072	0.0764	0.0028	
iCAM Brightness **Q**	13.28	13.29	13.28	13.28	13.32	13.294	0.0147	
iCAM Colourfulness **M**	2.49	2.49	2.49	2.49	2.46	2.489	0.0125	
CIECAM02 Lightness **J**	92.26	92.34	92.27	92.27	92.51	92.33	0.1055	Repeat.****: r^2: 0.84 CV:19 Reprod. ****: r^2: 0.88 CV:17
CIECAM02 Chroma **C**	18.91	18.93	18.87	18.92	18.72	18.907	0.2262	
CIECAM02 redness-greenness **a**	2.49	2.49	2.49	2.49	2.46	2.489	0.0125	

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
CIECAM02 yellowness-blueness **b**	0.26	0.34	0.27	0.27	0.51	0.33	0.1055	
CIECAM02 Angle Hue **h**	88.91	88.93	88.87	88.92	88.72	88.907	0.2262	
CIECAM02 Hue composition **H**	92.26	92.34	92.27	92.27	92.51	92.33	0.0125	Repeat.****: r^2: 0.99 CV: 8 Reprod. ****: r^2: 0.99 CV:10
CIECAM02 **Hc (Red)**	2.49	2.49	2.49	2.49	2.46	2.487	0.0125	
CIECAM02 **Hc (Yellow)**	98.91	98.93	98.87	98.92	98.72	98.907	0.2262	
CIECAM02 **Hc (Green)**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
CIECAM02 **Hc (Blue)**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
CIECAM02 Brightness **Q**	18.91	18.93	18.87	18.92	18.72	18.907	0.2262	
CIECAM02 Colourfulness **M**	22.49	22.49	22.49	22.49	22.46	22.489	0.0125	Repeat.****: r^2: 0.72 CV: 30 Reprod.****: r^2: 0.67 CV:37
CIECAM02 Saturation **s**	27.95	27.95	27.91	27.95	27.78	27.908	0.0736	
Turbidity 20℃ EBC	0.415	0.397	0.422	0.408	0.405	0.4094	0.0095	**N/A** r95: 0.05 R95:0.20
Shelf Life Prediction Forcing method EBC (modified according to Titze et al., 2007) (60℃,24 h/ 0℃, 24h/ 20℃) EBC-formazin units/ Warm days	Blank: 0.415 EBC: 2.13 W. days: 10	Blank: 0.397 EBC: 2.09 W. days: 10	Blank: 0.422 EBC: 2.22 W. days: 11	Blank: 0.408 EBC: 2.13 W. days: 10	Blank: 0.405 EBC: 2.45 W. days: 11	Blank: 0.40 EBC: 2.20 W. days: 10.4	Blank: 0.00 EBC: 0.14 W. days: 0.547	
NIBEM	Sec: 244 10: 81 20: 161 30: 244	Sec: 242 10: 82 20: 165 30: 242	Sec: 242 10: 81 20: 163 30: 242	Sec: 243 10: 81 20: 163 30: 243	Sec: 252 10: 84 20: 167 30: 252	Sec: 244 10: 81.8 20: 163.8 30: 244.6	Sec: 4.21 10: 1.30 20: 2.28 30: 4.22	**For lager beers: Bad: < 220sec Very Good: > 300 sec** r95: 9 R95:42
CO_2 % vol.	2.4	2.5	2.3	2.3	2.3	2.36	0.089	**Vol %: 2.5 -3.0** r95: 0.09 R95:0.08m
Dissolved oxygen (mg/L) (Orbisphere DO)	0.072	0.068	0.083	0.071	0.059	0.0706	0.0086	**< 0.3** r95:0.15 mg/L R95: 0.3 mg/L
Total	A820:	A820:	A820:	A820:	A820:	A820:	A820:	**A820: 0.091-**

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
polyphenols (mg/L)	0.113 Polyθ: 185.32	0.117 Polyθ: 191.88	0.116 Polyθ: 190.24	0.116 Polyθ: 190.24	0.116 Polyθ: 190.24	0.11 Polyθ: 188.584	0.00 Polyθ: 2.4871	**0.121** **Polyθ: 73-176** r95:4.1 R95: 18 ± 0.13m
Flavanoids (mg/L)	AB640: 0.650 AS640: 0.708 Flav: 19.43	AB640: 0.650 AS640: 0.708 Flav: 19.43	AB640: 0.650 AS640: 0.708 Flav: 19.43	AB640: 0.650 AS640: 0.708 Flav: 19.43	AB640: 0.650 AS640: 0.707 Flav: 19.09	AB640: 0.650 AS640: 0.7078 Flav: 19.3	AB640: 0.000 AS640: 0.0004 Flav: 0.15	**Flav: 50-70** CV_{r95}: ± 4.7% CV_{R95}: ± 7.6%
Iron (mg/L) **Factor** (Spectrophotometry-Phenantroline)	Aliquot 0.0 mL 2.5 mL 5.0 mL 10.0mL 20.0mL 30.0mL	Concentrat. 0.00 ppm 0.25 ppm 0.50 ppm 1.00 ppm 2.00 ppm 3.00 ppm	Absorb.: A505:0.828 A505:0.916 A505:1.000 A505:1.190 A505:1.555 A505:1.942	Graph curve Factor F*: 0.3714				
Iron (mg/L) **Samples** (Spectrophotometry-Phenantroline)	A505: 0.922 Fe(II): 0.342	A505: 0.922 Fe(II): 0.342	A505: 0.922 Fe(II): 0.342	A505: 0.922 Fe(II): 0.342	A505: 0.922 Fe(II): 0.342	A505: 0.92 Fe(II): 0.34	A505: 0.00 Fe(II): 0.00	**Fe(II): < 0.2** **Recommend. values** r95: 0.21m R95: 0.91m
Copper (mg/L) **Samples** (Atomic Absorption Spectrometry)	A324.7: 0.147	A324.7: 0.249	A324.7: 0.361	A324.7: 0.576	A324.7: 0.751 Cu (II): 0.134			**Cu (II): < 0.2** **Recommend. values** r95: 0.45m R95: 1.71m
Calcium (mg/L) **Samples** (Atomic Absorption Spectrometry)	A423.0: 0.093	A423.0: 0.104	A423.0: 0.112	A423.0: 0.123	A423.0: 0.128 Ca (II): 27.91			**Ca (II): 4 -100** **Recommend. values** CV_{ST95}: ±13.3% CV_{Sr95}: ± 2.4% CV_{Sb95}: ±9.2 %
Reducing Power (MEBAK) % RED	67.5	67.9	67.4	67.8	68.4	67.80	0.393	**> 60 very good** **50-60 good** **45-50 satisfactory** **< 45 poor** CV_{r95}: ± 1%

Table A.1.8 Beer Analyses: Pilsner Urquell 4.4%vol. alcohol

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
Sp. Gravity (S 20/20) Beer	1.0132	1.0135	1.0135	1.0136	1.0135	1.01346	0.000151	**1.00585 - 1.01175** r95:N/A R95: N/A
App. extract (EA) %	3.37	3.40	3.40	3.47	3.40	3.423	0.0402	**1.5 – 3.0** r95:0.012 R95:0.080
Sp. Gravity (S 20/20) Alcohol	0.9928	0.9930	0.9930	0.9932	0.9937	0.9931	0.99314	**0.99675 – 0.98770** r95: N/A R95: N/A
Alcohol (mas%)	3.98	3.87	3.87	3.74	3.45	3.782	0.2041	**1.75-7.20** r95: 0.03 ± 0.005m R95: 0.03 ± 0.02m
Alcohol (vol%)	5.00	4.86	4.86	4.70	4.34	4.752	0.2536	**2.2-9.0** r95: 0.04 ± 0.004m R95: 0.04 ± 0.02m
Sp. Gravity (S 20/20) Real extract	1.0197	1.0189	1.0190	1.0197	1.0194	1.01934	0.000378	**1.01175-1.02370** r95: N/A R95: N/A
Real extract (ER) %	5.01	4.80	4.83	5.00	4.93	4.915	0.0849	**3.0-6.0** r95:0.02m R95: 0.02m
Original Gravity (OG) %	12.45	12.09	12.02	11.43	11.91	11.985	0.3294	**7.0-12.0** r95: 0.07 R95: 0.19
pH	4.30	4.28	4.30	4.30	4.32	4.30	0.0141	**Pils: 4.3-4.6** r95:0.02 R95:0.13
Bitter units	A275: 0.835 IBU: 41.75 ≈ 42	A275: 0.840 IBU: 42	A275: 0.845 IBU: 42.25 ≈ 42	A275: 0.846 IBU: 44.8 ≈45	A275: 0.844 IBU: 42.2 ≈ 42	A275: 0.84 IBU: 42.6	A275: 0.00 IBU: 1.11	**A275: 0.200-0.800** **IBU: 10-40** r95: 0.44 ± 0.014m R95: -0.7 ± 0.18m
Colour Visual Comp. EBC/Lovibond	15.5	15.5	15.5	15.5	15.5	15.5	0.0000	**Pale beers: 7-11 EBC** r95: 0.4 R95: 1.8
Colour (430 nm) EBC	A430: 0.558 EBC: 13.95	A430: 0.558 EBC: 13.95	A430: 0.559 EBC: 13.97	A430: 0.559 EBC: 13.97	A430: 0.560 EBC: 14.00	A430: 0.55 EBC: 13.9	A430: 0.00 EBC: 0.02	**Pale beers: 7-11 EBC** r95: 0.3 R95:0.6
Colour Tristimulus %T 360 nm	0.1	0.1	0.1	0.1	0.1	0.10	0.000	
Colour Tristimulus %T 450 nm	39.6	39.4	39.3	39.3	39.4	39.40	0.122	

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
Colour Tristimulus %T 540 nm	63.9	63.7	63.6	63.8	64.0	63.80	0.158	
Colour Tristimulus %T 670 nm	95.4	95.1	95.1	95.1	94.8	95.10	0.212	
Colour Tristimulus %T 760 nm	98.9	98.9	98.8	98.9	98.8	98.86	0.054	
Colour Tristimulus Values **X (Red)**	65.98	65.76	65.70	65.79	65.80	65.810	0.1201	
Colour Tristimulus Values **Y (Green)**	67.68	67.46	67.38	67.52	67.61	67.535	0.1186	
Colour Tristimulus Values **Z (Blue)**	42.73	42.54	42.44	42.47	42.58	42.555	0.1171	
Colour CIELAB L*	84.98	84.87	84.84	84.89	84.89	84.89	0.0522	**96.63 *, 93.83**** r95: 0.55 R95: 2.26
Colour CIELAB a*	-0.39	-0.39	-0.37	-0.42	-0.50	-0.414	0.0512	**-2.04 *, -7.83**** r95: 0.19 R95: 0.56
Colour CIELAB b*	15.35	15.36	15.38	15.42	15.40	15.382	0.0286	**14.39 *, 32.97**** r95: 1.01 R95: 2.20
Colour CIELAB C* (Metric Chroma)	15.35	15.37	15.39	15.43	15.41	15.39	0.0316	
Yellowness Index	57.84	57.93	58.03	58.04	57.81	57.93	0.1055	
iCAM Lightness **J**	5.88	5.87	5.86	5.87	5.87	5.875	0.0046	
iCAM Chroma **C**	1.622	1.623	1.625	1.628	1.623	1.6242	0.0023	
iCAM Angle Hue **h**	0.292	0.291	0.292	0.289	0.284	0.2896	0.0033	
iCAM Brightness **Q**	11.88	11.86	11.85	11.86	11.87	11.870	0.0095	
iCAM Colourfulness **M**	3.27	3.27	3.28	3.29	3.28	3.282	0.0056	
CIECAM02 Lightness **J**	81.70	81.55	81.50	81.59	81.64	81.596	0.0776	Repeatability****: r^2: 0.84 CV:19 Reproducibility ****: r^2: 0.88 CV:17
CIECAM02 Chroma **C**	24.36	24.39	24.43	24.48	24.41	24.41	0.0450	
CIECAM02 redness-	0.122	0.122	0.122	0.120	0.117	0.1206	0.0021	

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
greenness **a**								
CIECAM02 yellowness-blueness **b**	0.501	0.501	0.502	0.503	0.502	0.5018	0.0008	
CIECAM02 Angle Hue **h**	76.27	76.32	76.26	76.49	76.82	76.432	0.2357	
CIECAM02 Hue composition **H**	78.16	78.23	78.14	78.50	79.01	78.408	0.3660	Repeat.****: r^2: 0.99 CV: 8 Reprod. ****: r^2: 0.99 CV:10
CIECAM02 **Hc (Red)**	21.83	21.76	21.85	21.49	20.98	21.582	0.3660	
CIECAM02 **Hc (Yellow)**	78.16	78.23	78.14	78.50	79.01	78.408	0.3660	
CIECAM02 **Hc (Green)**	0	0	0	0	0	0.000	0.0000	
CIECAM02 **Hc (Blue)**	0	0	0	0	0	0.000	0.0000	
CIECAM02 Brightness **Q**	215.09	214.90	214.84	214.95	215.02	214.96	0.0982	
CIECAM02 Colourfulness **M**	22.99	23.02	23.06	23.10	24.41	23.316	0.6129	Repeat.****: r^2: 0.72 CV: 30 Reprod.****: r^2: 0.67 CV:37
CIECAM02 Saturation **s**	32.69	32.73	32.76	32.78	32.73	32.738	0.03420	
Turbidity 20 ℃ EBC	0.39	0.39	0.41	0.40	0.38	0.398	0.0078	**N/A** r95: 0.05 R95:0.20
Shelf Life Prediction Forcing method EBC (modified according to Titze et al., 2007) (60℃,24 h/ 0℃, 24h/ 20℃) EBC-formazin units/ Warm days	Blank: 0.398 EBC: 2.78 W. days: 10	Blank: 0.397 EBC: 2.64 W. days: 10	Blank: 0.410 EBC: 2.75 W. days: 10	Blank: 0.400 EBC: 2.71 W. days: 10	Blank: 0.388 EBC: 2.69 W. days: 10	Blank: 0.39 EBC: 2.71 W. days: 10.0	Blank: 0.00 EBC: 0.05 W. days: 0.00	
NIBEM	Sec: 253 10: 85 20: 171 30: 253	Sec: 256 10: 91 20: 177 30: 256	Sec: 263 10: 92 20: 175 30: 263	Sec: 262 10: 92 20: 181 30: 262	Sec: 254 10: 80 20: 175 30: 254	Sec: 257 10: 88.0 20: 175.8 30: 257.6	Sec: 4.61 10: 5.33 20: 3.63 30: 4.61	**For lager beers: Bad: < 220sec Very Good: > 300 sec** r95: 9 R95:42
CO_2 % vol.	2.2	1.8	1.8	1.9	1.8	1.90	0.173	**Vol %: 2.5 -3.0** r95: 0.09 R95:0.08m
Dissolved oxygen (mg/L) (Orbisphere DO)	0.645	0.671	0.632	0.620	0.677	0.649	0.0245	**< 0.3** r95:0.15 mg/L R95: 0.3 mg/L

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
Total polyphenols (mg/L)	A820: 0.169 Polyθ: 277.16	A820: 0.171 Polyθ: 280.44	A820: 0.169 Polyθ: 277.16	A820: 0.167 Polyθ: 273.88	A820: 0.169 Polyθ: 277.16	A820: 0.16 Polyθ: 277.16	A820: 0.00 Polyθ: 2.3193	**A820: 0.091-0.121** **Polyθ: 73-176** r95:4.1 R95: 18 ± 0.13m
Flavanoids (mg/L)	AB640: 0.650 AS640: 0.706 Flav: 18.76	AB640: 0.650 AS640: 0.705 Flav: 18.42	AB640: 0.650 AS640: 0.705 Flav: 18.42	AB640: 0.650 AS640: 0.705 Flav: 18.42	AB640: 0.650 AS640: 0.704 Flav: 18.09	AB640: 0.650 AS640: 0.705 Flav: 18.42	AB640: 0.0000 AS640: 0.0007 Flav: 18.42	**Flav: 50-70** CV_{r95}: ± 4.7% CV_{R95}: ± 7.6%
Iron (mg/L) **Factor** (Spectrophotometry-Phenantroline)	Aliquot 0.0 mL 2.5 mL 5.0 mL 10.0mL 20.0mL 30.0mL	Concentrat. 0.00 ppm 0.25 ppm 0.50 ppm 1.00 ppm 2.00 ppm 3.00 ppm	Absorb.: A505:0.828 A505:0.916 A505:1.000 A505:1.190 A505:1.555 A505:1.942	Graph curve Factor F*: 0.3714				
Iron (mg/L) **Samples** (Spectrophotometry-Phenantroline)	A505: 0.997 Fe(II): 0.370	A505: 0.997 Fe(II): 0.370	A505: 0.999 Fe(II): 0.371	A505: 0.999 Fe(II): 0.371	A505: 0.999 Fe(II): 0.371	A505: 0.99 Fe(II): 0.37	A505: 0.00 Fe(II): 0.00	**Fe(II): < 0.2** **Recommend. values** r95: 0.21m R95: 0.91m
Copper (mg/L) **Samples** (Atomic Absorption Spectrometry)	A324.7: 0.151	A324.7: 0.204	A324.7: 0.308	A324.7: 0.522	A324.7: 0.752 Cu (II): 0.116			**Cu (II): < 0.2** **Recommend. values** r95: 0.45m R95: 1.71m
Calcium (mg/L) **Samples** (Atomic Absorption Spectrometry)	A423.0: 0.081	A423.0: 0.089	A423.0: 0.095	A423.0: 0.106	A423.0: 0.111 Ca (II): 27.20			**Ca (II): 4 -100** **Recommend. values** CV_{ST95}: ±13.3% CV_{Sr95}: ± 2.4% CV_{Sb95}: ±9.2%
Reducing Power (MEBAK) % RED	47.0	47.2	46.8	46.6	46.9	46.90	0.2336	**> 60 very good** **50-60 good** **45-50 satisfactory** **< 45 poor** CV_{r95}: ± 1%

Table A.1.9 Beer Analyses: Sapporo Beer Premium Lager 4.7% vol. alcohol

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
Sp. Gravity (S 20/20) Beer	1.0092	1.0090	1.0090	1.0095	1.0095	1.00924	0.000250	**1.00585 - 1.01175** r95:N/A R95: N/A
App. Extract (EA) %	2.35	2.30	2.30	2.43	2.43	2.366	0.0637	**1.5 – 3.0** r95:0.012 R95:0.080
Sp. Gravity (S 20/20) Alcohol	0.9934	0.9936	0.9934	0.9933	0.9935	0.99344	0.000114	**0.99675 – 0.98770** r95: N/A R95: N/A
Alcohol (mas%)	3.63	3.52	3.63	3.69	3.56	3.606	0.0595	**1.75-7.20** r95: 0.03 ± 0.005m R95: 0.03 ± 0.02m
Alcohol (vol%)	4.56	4.42	4.56	4.64	4.48	4.532	0.0843	**2.2-9.0** r95: 0.04 ± 0.004m R95: 0.04 ± 0.02m
Sp. Gravity (S 20/20) Real extract	1.0154	1.0153	1.0154	1.0152	1.0152	1.0153	0.0001	**1.01175-1.02370** r95: N/A R95: N/A
Real extract (ER) %	3.92	3.90	3.92	3.87	3.87	3.901	0.025	**3.0-6.0** r95:0.02m R95: 0.02m
Original Gravity (OG) %	10.79	10.56	10.79	10.85	10.61	10.72	0.1268	**7.0-12.0** r95: 0.07 R95: 0.19
pH	4.30	4.30	4.31	4.30	4.30	4.302	0.0044	**Pils: 4.3-4.6** r95:0.02 R95:0.13
Bitter units	A275: 0.344 IBU: 17.20 ≈ 17	A275: 0.338 IBU: 16.9 ≈ 17	A275: 0.348 IBU: 17.4 ≈ 17	A275: 0.340 IBU: 17	A275: 0.352 IBU: 17.6 ≈ 17	A275: 0.34 IBU:17.22 ≈17	A275: 0.00 IBU: 0.286	**A275: 0.200-0.800** **IBU: 10-40** r95: 0.44 ± 0.014m R95: -0.7 ± 0.18m
Colour Visual Comp. EBC/Lovibond	10.0	10.0	10.5	10.0	10.0	10.1	0.2236	**Pale beers: 7-11 EBC** r95: 0.4 R95: 1.8
Colour (430 nm) EBC	A430: 0.431 EBC: 10.7	A430: 0.433 EBC: 10.8	A430: 0.433 EBC: 10.8	A430: 0.431 EBC: 10.7	A430: 0.430 EBC: 10.7	A430: 0.43 EBC: 10.7	A430: 0.00 EBC: 0.03	**Pale beers: 7-11 EBC** r95: 0.3 R95:0.6
Colour Tristimulus %T 360 nm	0.5	0.5	0.5	0.5	0.5	0.5	0.000	
Colour Tristimulus %T 450 nm	47.3	47.1	47.0	46.8	47.4	47.12	0.2387	

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
Colour Tristimulus %T 540 nm	78.8	77.9	78.6	78.8	78.8	78.58	0.3898	
Colour Tristimulus %T 670 nm	92.7	92.4	93.0	93.0	93.0	92.82	0.2683	
Colour Tristimulus %T 760 nm	98.4	98.6	98.6	98.3	98.5	98.48	0.1303	
Colour Tristimulus Values **X (Red)**	73.08	72.54	73.04	73.10	73.19	72.995	0.2568	
Colour Tristimulus Values **Y (Green)**	78.34	77.63	78.23	78.35	78.41	78.201	0.3204	
Colour Tristimulus Values **Z (Blue)**	51.43	51.13	51.15	51.00	51.51	51.249	0.2159	
Colour CIELAB L*	88.48	88.23	88.46	88.49	88.54	88.44	0.1210	**96.63 *, 93.83**** r95: 0.55 R95: 2.26
Colour CIELAB a*	-3.52	-3.39	-3.46	-3.51	-3.48	-3.472	0.0516	**-2.04 *, -7.83**** r95: 0.19 R95: 0.56
Colour CIELAB b*	15.21	15.09	15.30	15.41	15.20	15.24	0.1198	**14.39 *, 32.97**** r95: 1.01 R95: 2.20
Colour CIELAB C* (Metric Chroma)	15.61	15.46	15.69	15.80	15.59	15.63	0.1258	
Yellowness Index	49.81	49.78	50.20	50.41	49.83	50.006	0.2834	
iCAM Lightness **J**	6.27	6.25	6.26	6.27	6.27	6.267	0.0101	
iCAM Chroma **C**	1.53	1.51	1.54	1.55	1.53	1.534	0.0135	
iCAM Angle Hue **h**	0.097	0.105	0.101	0.098	0.100	0.1002	0.0031	
iCAM Brightness **Q**	12.67	12.62	12.66	12.66	12.68	12.663	0.0203	
iCAM Colourfulness **M**	3.09	3.06	3.11	3.13	3.09	3.099	0.0272	
CIECAM02 Lightness **J**	88.01	87.59	87.96	88.03	88.06	87.93	0.1935	Repeat.****: r^2: 0.84 CV:19 Reprod. ****: r^2: 0.88 CV:17
CIECAM02 Chroma **C**	23.45	23.24	23.59	23.78	23.41	23.494	0.2028	
CIECAM02 redness-greenness **a**	-5.17 E-05	0.004	0.002	0.0007	0.001	0.0015	0.0015	

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
CIECAM02 yellowness-blueness **b**	0.492	0.487	0.495	0.499	0.491	0.492	0.0044	
CIECAM02 Angle Hue **h**	90.00	89.44	89.70	89.91	89.79	89.768	0.2160	
CIECAM02 Hue composition **H**	100.01	99.09	99.50	99.85	99.66	99.622	0.3542	Repeat.****: r^2: 0.99 CV: 8 Reprod. ****: r^2: 0.99 CV:10
CIECAM02 **Hc (Red)**	0	0	0	0	0	0.000	0.0000	
CIECAM02 **Hc (Yellow)**	99.98	99.09	99.50	99.85	99.66	99.616	0.3461	
CIECAM02 **Hc (Green)**	0.01	0.90	0.49	0.14	0.33	0.374	0.3461	
CIECAM02 **Hc (Blue)**	0	0	0	0	0	0.0	0.00	
CIECAM02 Brightness **Q**	223.25	222.72	223.18	223.27	223.31	223.146	0.2427	
CIECAM02 Colourfulness **M**	22.13	22.33	22.27	22.45	22.10	22.176	0.1951	Repeat.****: r^2: 0.72 CV:30 Reprod.****: r^2: 0.67 CV:37
CIECAM02 Saturation **s**	31.48	31.38	31.59	31.71	31.46	31.52	0.1281	
Turbidity 20 ℃ EBC	0.343	0.344	0.347	0.343	0.329	0.341	0.0070	**N/A** r95: 0.05 R95:0.20
Shelf Life Prediction Forcing method EBC (modified according to Titze et al., 2007) (60℃,24 h/ 0℃, 24h/ 20℃) EBC-formazin units/ Warm days	Blank: 0.343 EBC: 2.98 W. days: 7	Blank: 0.344 EBC: 3.03 W. days: 7	Blank: 0.347 EBC: 3.15 W. days: 7	Blank: 0.343 EBC: 2.77 W. days: 7	Blank: 0.329 EBC: 2.84 W. days: 7	Blank: 0.34 EBC: 2.95 W. days: 7.0	Blank: 0.00 EBC: 0.14 W. days: 0.00	
NIBEM	Sec: 274 10: 95 20: 187 30: 274	Sec: 290 10: 103 20: 201 30: 290	Sec: 295 10: 100 20: 201 30: 295	Sec: 292 10: 102 20: 201 30: 292	Sec: 293 10: 97 20: 197 30: 293	Sec: 288 10: 99.4 20: 197.4 30: 288.8	Sec: 8.46 10: 3.361 20: 6.066 30: 8.467	**For lager beers: Bad: < 220sec Very Good: > 300 sec** r95: 9 R95:42
CO_2% vol.	3.0	2.6	2.6	2.8	2.5	2.7	0.2	**Vol %: 2.5 -3.0** r95: 0.09 R95:0.08m
Dissolved oxygen (mg/L) (Orbisphere DO)	0.498	0.465	0.467	0.483	0.483	0.479	0.0135	**< 0.3** r95:0.15 mg/L R95: 0.3 mg/L
Total polyphenols	A820: 0.170	A820: 0.173	A820: 0.173	A820: 0.174	A820: 0.172	A820: 0.17	A820: 0.00	**A820: 0.091-0.121**

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
(mg/L)	Polyθ: 278.80	Polyθ: 283.72	Polyθ: 283.72	Polyθ: 285.36	Polyθ: 282.08	Polyθ: 282.73	Polyθ: 2.4871	**Polyθ:73-176** r95:4.1 R95: 18 ± 0.13m
Flavanoids (mg/L)	AB640: 0.650 AS640: 0.714 Flav: 21.44	AB640: 0.650 AS640: 0.714 Flav: 21.44	AB640: 0.650 AS640: 0.713 Flav: 21.10	AB640: 0.650 AS640: 0.712 Flav: 20.77	AB640: 0.650 AS640: 0.713 Flav: 21.10	AB640: 0.650 AS640: 0.7134 Flav:21.1	AB640: 0.000 AS640: 0.0005 Flav: 0.28	**Flav: 50-70** CV_{r95}: ± 4.7% CV_{R95}: ± 7.6%
Iron (mg/L) **Factor** (Spectrophotometry-Phenantroline)	Aliquot 0.0 mL 2.5 mL 5.0 mL 10.0mL 20.0mL 30.0mL	Concentrat. 0.00 ppm 0.25 ppm 0.50 ppm 1.00 ppm 2.00 ppm 3.00 ppm	Absorb. A505:0.828 A505:0.916 A505:1.000 A505:1.190 A505:1.555 A505:1.942	Graph curve Factor F*: 0.3714				
Iron (mg/L) **Samples** (Spectrophotometry-Phenantroline)	A505: 0.972 Fe(II): 0.361	A505: 0.971 Fe(II): 0.360	A505: 0.971 Fe(II): 0.360	A505: 0.972 Fe(II): 0.361	A505: 0.972 Fe(II): 0.361	A505: 0.97 Fe(II): 0.36	A505: 0.00 Fe(II): 0.00	**Fe(II): < 0.2 Recommend. values** r95: 0.21m R95: 0.91m
Copper (mg/L) **Samples** (Atomic Absorption Spectrometry)	A324.7: 0.168	A324.7: 0.279	A324.7: 0.384	A324.7: 0.590	A324.7: 0.701 Cu (II): 0.210			**Cu (II): < 0.2 Recommend. values** r95: 0.45m R95: 1.71m
Calcium (mg/L) **Samples** (Atomic Absorption Spectrometry)	A423.0: 0.104	A423.0: 0.115	A423.0: 0.127	A423.0: 0.134	A423.0: 0.141 Ca (II): 29.55			**Ca (II): 4 -100 Recommend. values** CV_{ST95}: ±13.3% CV_{Sr95}: ± 2.4% CV_{Sb95}: ±9.2%
Reducing Power (MEBAK) % RED	54.3	53.4	53.8	54.1	52.9	53.70	0.561	**> 60 very good** **50-60 good** **45-50 satisfactory** **< 45 poor** CV_{r95}: ± 1%

Table A.1.10 Beer Analyses: Tennents Beer 4% vol. alcohol

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
Sp. Gravity (S 20/20) Beer	1.0082	1.0086	1.0085	1.0087	1.0084	1.00848	0.000192	**1.00585 - 1.01175** r95:N/A R95: N/A
App. extract (EA) %	2.10	2.20	2.17	2.22	2.15	2.172	0.0488	**1.5 – 3.0** r95:0.012 R95:0.080
Sp. Gravity (S 20/20) Alcohol	0.9943	0.9946	0.9944	0.9944	0.9945	0.99444	0.000114	**0.99675 – 0.98770** r95: N/A R95: N/A
Alcohol (mas%)	3.12	2.94	3.05	3.05	3.00	3.032	0.0668	**1.75-7.20** r95: 0.03 ± 0.005m R95: 0.03 ± 0.02m
Alcohol (vol%)	3.92	3.70	3.84	3.84	3.78	3.828	0.0794	**2.2-9.0** r95: 0.04 ± 0.004m R95: 0.04 ± 0.02m
Sp. Gravity (S 20/20) Real extract	1.0142	1.0143	1.0144	1.0142	1.0142	1.01426	0.000089	**1.01175-1.02370** r95: N/A R95: N/A
Real extract (ER) %	3.62	3.64	3.67	3.62	3.62	3.639	0.0223	**3.0-6.0** r95:0.02m R95: 0.02m
Original Gravity (OG) %	9.56	9.24	9.48	9.43	9.34	9.41	0.124	**7.0-12.0** r95: 0.07 R95: 0.19
pH	3.95	3.95	3.97	3.96	3.96	3.958	0.0083	**Pils: 4.3-4.6** r95:0.02 R95:0.13
Bitter units	A275: 0.496 IBU: 24.8 ≈ 25	A275: 0.497 IBU: 24.85 ≈ 25	A275: 0.498 IBU: 24.9 ≈ 25	A275: 0.506 IBU: 25.3 ≈ 25	A275: 0.504 IBU: 25.2 ≈ 25	A275: 0.50 IBU:25.01 ≈25	A275: 0.00 IBU: 0.224	**A275: 0.200-0.800** **IBU: 10-40** r95: 0.44 ± 0.014m R95: -0.7 ± 0.18m
Colour Visual Comp. EBC/Lovibond	10.5	10.5	10.5	10.5	10.5	10.5	0.00	**Pale beers: 7-11 EBC** r95: 0.4 R95: 1.8
Colour (430 nm) EBC	A430: 0.410 EBC: 10.25	A430: 0.410 EBC: 10.25	A430: 0.410 EBC: 10.25	A430: 0.409 EBC: 10.22	A430: 0.408 EBC: 10.22	A430: 0.40 EBC: 10.2	A430: 0.00 EBC: 0.01	**Pale beers: 7-11 EBC** r95: 0.3 R95:0.6
Colour Tristimulus %T 360 nm	1.0	1.0	1.0	1.0	1.0	1.0	0.00	
Colour Tristimulus %T 450 nm	48.8	48.1	48.8	48.0	48.4	48.42	0.376	

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
Colour Tristimulus %T 540 nm	73.5	73.5	73.8	73.0	74.3	73.62	0.763	
Colour Tristimulus %T 670 nm	95.7	95.9	96.1	96.4	95.9	96.00	0.264	
Colour Tristimulus %T 760 nm	97.5	98.1	97.4	98.2	97.9	97.82	0.356	
Colour Tristimulus Values **X (Red)**	71.86	71.82	72.12	71.73	72.23	71.956	0.2118	
Colour Tristimulus Values **Y (Green)**	75.38	75.35	75.67	75.09	75.94	75.491	0.3266	
Colour Tristimulus Values **Z (Blue)**	52.00	51.40	52.04	51.25	51.77	51.694	0.3541	
Colour CIELAB L*	87.90	87.88	88.03	87.84	88.08	87.946	0.1033	**96.63 *, 93.83**** r95: 0.55 R95: 2.26
Colour CIELAB a*	-1.97	-1.98	-1.98	-1.82	-2.13	-1.976	0.1096	**-2.04 *, -7.83**** r95: 0.19 R95: 0.56
Colour CIELAB b*	13.86	14.12	13.95	14.09	14.17	14.038	0.1287	**14.39 *, 32.97**** r95: 1.01 R95: 2.20
Colour CIELAB C* (Metric Chroma)	14.00	14.26	14.09	14.21	14.33	14.178	0.1325	
Yellowness Index	48.90	46.68	49.10	49.93	49.47	48.816	1.2568	
iCAM Lightness **J**	6.19	6.19	6.20	6.18	6.21	6.195	0.0117	
iCAM Chroma **C**	1.40	1.43	1.41	1.44	1.44	1.428	0.014	
iCAM Angle Hue **h**	0.20	0.20	0.20	0.21	0.19	0.206	0.0078	
iCAM Brightness **Q**	12.51	12.50	12.53	12.48	12.54	12.518	0.0231	
iCAM Colourfulness **M**	2.84	2.90	2.86	2.90	2.91	2.88	0.029	
CIECAM02 Lightness **J**	86.35	86.34	86.53	86.19	86.68	86.418	0.1896	Repeat.****: r^2: 0.84 CV:19 Reprod. ****: r^2: 0.88 CV:17
CIECAM02 Chroma **C**	21.16	21.61	21.30	21.59	21.66	21.464	0.2207	
CIECAM02 redness-greenness **a**	0.059	0.059	0.059	0.065	0.053	0.059	0.0042	

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
CIECAM02 yellowness-blueness **b**	0.443	0.453	0.446	0.452	0.454	0.4496	0.00482	
CIECAM02 Angle Hue **h**	82.39	82.54	82.46	81.71	83.29	82.47	0.561	
CIECAM02 Hue composition **H**	87.74	87.98	87.86	86.67	89.17	87.764	0.9511	Repeat.****: r^2: 0.99 CV: 8 Reprod. ****: r^2: 0.99 CV:10
CIECAM02 **Hc (Red)**	12.25	12.01	12.13	13.32	10.82	12.106	0.8885	
CIECAM02 **Hc (Yellow)**	87.74	87.98	87.86	86.67	89.17	87.884	0.8885	
CIECAM02 **Hc (Green)**	0	0	0	0	0	0.00	0.000	
CIECAM02 **Hc (Blue)**	0	0	0	0	0	0.00	0.000	
CIECAM02 Brightness **Q**	221.13	221.12	221.36	220.94	221.56	221.222	0.2406	
CIECAM02 Colourfulness **M**	19.97	20.39	20.11	21.59	20.45	20.502	0.6394	Repeat.****: r^2: 0.72 CV: 30 Reprod.****: r^2: 0.67 CV:37
CIECAM02 Saturation **s**	30.05	30.37	30.14	30.37	30.38	30.262	0.1557	
Turbidity 20 ℃ EBC	0.35	0.32	0.32	0.32	0.32	0.329	0.0118	**N/A** r95: 0.05 R95:0.20
Shelf Life Prediction Forcing method EBC (modified according to Titze et al., 2007) (60℃,24 h/ 0℃, 24h/ 20℃) EBC-formazin units/ Warm days	Blank: 0.350 EBC: 3.45 W. days: 8	Blank: 0.327 EBC: 3.23 W. days: 8	Blank: 0.328 EBC: 3.44 W. days: 8	Blank: 0.322 EBC: 3.11 W. days: 8	Blank: 0.321 EBC: 3.21 W. days: 8	Blank: 0.32 EBC: 3.29 W. days: 8.0	Blank: 0.01 EBC: 0.15 W. days: 0.00	
NIBEM	Sec: 273 10: 100 20: 186 30: 273	Sec: 280 10: 97 20: 196 30: 280	Sec: 267 10: 87 20: 172 30: 267	Sec: 290 10: 105 20: 200 30: 290	Sec: 272 10: 101 20: 180 30: 272	Sec: 276 10: 98.0 20: 186.8 30: 276.4	Sec: 8.90 10: 6.78 20: 10.24 30: 8.90	**For lager beers: Bad: < 220sec Very Good: > 300 sec** r95: 9 R95:42
CO_2% vol.	2.5	2.6	2.5	2.3	2.3	2.44	0.1341	**Vol %: 2.5 -3.0** r95: 0.09 R95:0.08m
Dissolved oxygen (mg/L) (Orbisphere DO)	0.56	0.589	0.621	0.577	0.564	0.5836	0.02308	**< 0.3** r95:0.15 mg/L R95: 0.3 mg/L
Total	A820:	A820:	A820:	A820:	A820:	A820:	A820:	**A820: 0.091-**

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
polyphenols (mg/L)	0.077 Polyθ: 126.28	0.075 Polyθ: 123.00	0.077 Polyθ: 126.28	0.077 Polyθ: 126.28	0.077 Polyθ: 126.28	0.07 Polyθ: 125.62	0.00 Polyθ: 1.466	**0.121** **Polyθ: 73-176** r95:4.1 R95: 18 ± 0.13m
Flavanoids (mg/L)	AB640: 0.650 AS640: 0.705 Flav: 18.42	AB640: 0.650 AS640: 0.705 Flav: 18.42	AB640: 0.650 AS640: 0.705 Flav: 18.42	AB640: 0.650 AS640: 0.705 Flav: 18.42	AB640: 0.650 AS640: 0.705 Flav: 18.42	AB640: 0.650 AS640: 0.705 Flav:18.4	AB640: 0.000 AS640: 0.000 Flav: 0.00	**Flav: 50-70** CV_{r95}: ± 4.7% CV_{R95}: ± 7.6%
Iron (mg/L) **Factor** (Spectrophotometry-Phenantroline)	Aliquot 0.0 mL 2.5 mL 5.0 mL 10.0mL 20.0mL 30.0mL	Concentrat. 0.00 ppm 0.25 ppm 0.50 ppm 1.00 ppm 2.00 ppm 3.00 ppm	Absorb.: A505:0.828 A505:0.916 A505:1.000 A505:1.190 A505:1.555 A505:1.942	Graph curve Factor F*: 0.3714				
Iron (mg/L) **Samples** (Spectrophotometry-Phenantroline)	A505: 0.957 Fe(II): 0.355	A505: 0.957 Fe(II): 0.355	A505: 0.962 Fe(II): 0.357	A505: 0.959 Fe(II): 0.356	A505: 0.924 Fe(II): 0.343	A505: 0.95 Fe(II): 0.35	A505: 0.01 Fe(II): 0.00	**Fe(II): < 0.2** **Recommend. values** r95: 0.21m R95: 0.91m
Copper (mg/L) **Samples** (Atomic Absorption Spectrometry)	A324.7: 0.116	A324.7: 0.224	A324.7: 0.338	A324.7: 0.540	A324.7: 0.742 Cu (II): 0.116			**Cu (II): < 0.2** **Recommend. values** r95: 0.45m R95: 1.71m
Calcium (mg/L) **Samples** (Atomic Absorption Spectrometry)	A423.0: 0.101	A423.0: 0.110	A423.0: 0.119	A423.0: 0.127	A423.0: 0.137 Ca (II): 29.94			**Ca (II): 4 -100** **Recommend. values** CV_{ST95}: ±13.3% CV_{Sr95}: ± 2.4% CV_{Sb95}: ±9.2%
Reducing Power (MEBAK) % RED	52.3	53.6	54.6	55.6	55.8	54.38	1.456	**> 60 very good** **50-60 good** **45-50 satisfactory** **< 45 poor** CV_{r95}: ± 1%

A.1.11 Pale lager beer parameters (Commercial beers)

Parameter	***Grand mean of analysed commercial beers***	***Standard Deviation (Sx)***	***Normal Values***
Sp. Gravity (S 20/20) Beer	1.00995	0.001978	**1.00585 -1.01175** r95:N/A R95: N/A
App. extract (EA)%	2.54	0.500	**1.5 – 3.0** r95:0.012 R95:0.080
Sp. Gravity (S 20/20) Alcohol	0.99353	0.000435	**0.99675 – 0.98770** r95: N/A R95: N/A
Alcohol (mas%)	3.54	0.248	**1.75-7.20** r95: 0.03 ± 0.005m R95: 0.03 ± 0.02m
Alcohol (vol%)	4.46	0.312	**2.2-9.0** r95: 0.04 ± 0.004m R95: 0.04 ± 0.02m
Sp. Gravity (S 20/20) Real extract	1.01576	0.002420	**1.01175-1.02370** r95: N/A R95: N/A
Real extract (ER)%	4.02	0.607	**3.0-6.0** r95:0.02m R95: 0.02m
Original Gravity (OG)%	10.71	0.874	**7.0-12.0** r95: 0.07 R95: 0.19
pH	4.04	0.162	**Pils: 4.3-4.6** r95:0.02 R95:0.13
Bitter units	A275: 0.4247 IBU:21.30 ≈ 21	A275: 0.18696 IBU: 9.46	**A275: 0.200- 0.800** **IBU: 10-40** r95: 0.44 ± 0.014m R95: -0.7 ± 0.18m
Colour Visual Comp. EBC/Lovibond	9.24	2.677	**Pale beers: 7-11 EBC** r95: 0.4 R95: 1.8
Colour (430 nm) EBC	A430: 0.369 EBC: 9.26	A430: 0.0901 EBC: 2.244	**Pale beers: 7-11 EBC** r95: 0.3 R95:0.6
Colour Tristimulus %T 360 nm	1.21	0.842	
Colour Tristimulus %T 450 nm	54.25	9.007	

Parameter	*Grand mean of analysed commercial beers*	*Standard Deviation (Sx)*	*Normal Values*
Colour Tristimulus %T 540 nm	80.99	8.204	
Colour Tristimulus %T 670 nm	95.83	2.205	
Colour Tristimulus %T 760 nm	98.69	1.238	
Colour Tristimulus Values **X (Red)**	76.15	5.554	
Colour Tristimulus Values **Y (Green)**	77.90	7.425	
Colour Tristimulus Values **Z (Blue)**	57.71	8.794	
Colour CIELAB L*	89.86	2.620	**96.63 *, 93.83**** r95: 0.55 R95: 2.26
Colour CIELAB a*	-2.38	2.423	**-2.04 *, -7.83 **** r95: 0.19 R95: 0.56
Colour CIELAB b*	13.59	1.459	**14.39 *, 32.97**** r95: 1.01 R95: 2.20
Colour CIELAB C* (Metric Chroma)	14.01	1.307	
Yellowness Index	45.07	7.013	
iCAM Lightness **J**	6.41	0.281	
iCAM Chroma **C**	1.35	0.184	
iCAM Angle Hue **h**	0.117	0.0742	
iCAM Brightness **Q**	12.94	0.545	
iCAM Colourfulness **M**	2.73	0.371	
CIECAM02 Lightness **J**	89.65	4.022	Repeatability****: r^2: 0.84 CV:19 Reproducibility ****: r^2: 0.88 CV:17
CIECAM02 Chroma **C**	20.64	2.704	
CIECAM02 redness-greenness **a**	0.019	0.0419	
CIECAM02 yellowness-blueness **b**	0.423	0.0664	
CIECAM02 Angle Hue **h**	88.78	5.348	
CIECAM02 Hue composition **H**	98.37	8.808	Repeatability****: r^2: 0.99 CV: 8

Parameter	***Grand mean of analysed commercial beers***	***Standard Deviation (Sx)***	***Normal Values***
			Reproducibility ****: r^2: 0.99 CV:10
CIECAM02 **Hc (Red)**	3.747	7.350	
CIECAM02 **Hc (Yellow)**	94.02	6.371	
CIECAM02 **Hc (Green)**	2.21	2.243	
CIECAM02 **Hc (Blue)**	0.00	0.000	
CIECAM02 Brightness **Q**	225.27	5.102	
CIECAM02 Colourfulness **M**	19.55	2.647	Repeatability****: r^2: 0.72 CV: 30 Reproducibility****: r^2: 0.67 CV:37
CIECAM02 Saturation **s**	29.36	2.234	
Turbidity 20℃ EBC	0.353	0.1064	**N/A** r95: 0.05 R95:0.20
Shelf Life Prediction Forcing method EBC (modified according to Titze *et al.*, 2007) (60℃,24 h/ 0℃, 24h/ 20℃) EBC-formazin units/ Warm days	Blank: 0.353 EBC: 2.67 Warm days: 9.2	Blank: 0.1065 EBC: 0.319 Warm days: 2.156	
NIBEM	Sec: 260.78 10: 90.64 20: 178.76 30: 260.78	Sec: 35.209 10: 17.324 20: 27.689 30: 35.209	**For lager beers:** **Bad: < 220 sec** **Very Good: > 300 sec** r95: 9 R95:42
CO_2% vol.	P (psi): 1.16 T (℃): 11.38 Vol%: 2.45	P (psi): 0.256 T (℃): 1.397 Vol%: 0.269	**Vol %: 2.5 -3.0** r95: 0.09 R95:0.08m
Dissolved oxygen (mg/L) (Orbisphere DO)	0.325	0.2036	**< 0.3** r95:0.15 mg/L R95: 0.3 mg/L
Total polyphenols (mg/L)	A820: 0.1233 Polyθ: 201.58	A820:0.0425 Polyθ: 69.600	**A820: 0.091-0.121** **Polyθ: 73-176**

Parameter	***Grand mean of analysed commercial beers***	***Standard Deviation (Sx)***	***Normal Values***
			r95:4.1 R95: 18 ± 0.13m
Flavanoids (mg/L)	AB640: 0.650 AS640: 0.715 Flav: 21.84	AB640: 0.000 AS640: 0.0227 Flav: 7.617	**Flav: 50-70** CV_{r95}: ± 4.7% CV_{R95}: ± 7.6%
Iron (mg/L) **Samples** (Spectrophotometry-Phenantroline)	A505: 0.936 Fe(II): 0.347	A505: 0.0536 Fe(II): 0.0204	**Fe(II): < 0.2 Recommended values** r95: 0.21m R95: 0.91m
Copper (mg/L) **Samples** (Atomic Absorption Spectrometry)	A324.7: 0.742 Cu (II): 0.146	A324.7: 0.0216 Cu (II): 0.0291	**Cu (II): < 0.2 Recommended values** r95: 0.45m R95: 1.71m
Calcium (mg/L) **Samples** (Atomic Absorption Spectrometry)	A423.0: 0.092 Ca (II): 25.74	A423.0: 0.056 Ca (II): 4.476	**Ca (II): 4 -100 Recommended values** CV_{ST95}: ±13.3% CV_{Sr95}: ± 2.4% CV_{Sb95}: ±9.2 %
Reducing Power (MEBAK) % RED	61.93	12.720	**> 60 very good** **50-60 good** **45-50 satisfactory** **< 45 poor** CV_{r95}: ± 1%

The normal values are reported according to Brautechnische Analysenmethoden. Band II. Mitteleuropäische Brautechnische Analysenkommission (M.E.B.A.K.) (2002), except; * according to American Society of Brewing Chemist. Report of Subcommittee on Wort and Beer. Colour Using Tristimulus Analysis (2000), ** according to Smedley (1992, 1995), *** according to Lustig (193, 1999), and **** according to Gonzalez-Miret *et al.* (2007); Luo *et al*. (1991a, 1991b)

Table A.2.1 Beer colour adjustment trial no. 1

PARAMETER	CARAHELL®	CARAAMBER®	MELANOIDIN MALT	CARAMUNICH® TYPE III	CARAAROMA®	CARAFA ® TYPE III	CARAFA SPECIAL® TYPE III	ROASTED BARLEY	SINAMAR ®	CARAMEL #301	PILSNER MALT
Raw material source	GERMAN- GROWN "MARTHE" SPRING BARLEY (2006 harvest)										
Recommended Quantities	Up to 15% of total grain bill (Low Gravity) Up to 30% of total grain bill(High Gravity)	Up to 20% of total grain bill	Up to 20% of total grain bill	Up to 5% of total grain bill (pale beers)	Up to 20% of total grain bill	Up to 5% of total grain bill	Up to 5% of total grain bill	Up to 5% of total grain bill	14 g (11.9 mL) 1hL/1EBC		Up to 100% of total grain bill
Wort Colour EBC	20 min 30 max	60 min 80 max	60 min 80 max	170 min 220 max	350 min 450 max	1300 min 1500 max	1300 min 1500 max	1000 min 1300 max	8100 min 8600 max	29,800 (typical)	2.5 min 4.0 max
Wort Colour Lovibond	8.1 min 11.8 max	23 min 31 max	23 min 31 max	64 min 83 max	115 min 150 max	488 min 563 max	488 min 563 max	375 min 450 max	3040 min 3200 max		1.5 min 2.1 max
Ratio (specialty malt/ base malt) %	**10/90**	**3.9/96.1**	**3.9/96.1**	**1.9/98.1**	**0.8/99.2**	**0.8/99.2**	**0.2/99.8**	**0.2/99.8**	**0.04/99.96**	**0.02/99.98**	**100**
Ratio (specialty malt/ base malt) kg	**5.20/46.80**	**2.02/49.98**	**2.02/49.98**	**0.98/51.02**	**0.39/51.61**	**0.10/51.90**	**0.10/51.90**	**0.10/51.90**	**0.02 (0.017 mL)/ 51.98**	**0.01 / 51.99**	**52.00**
Colour EBC Abs. 430 nm	0.368	0.373	0.363	0.341	0.345	0.343	0.335	0.343	0.358	0.321	0.270
Colour EBC	**9.20**	**9.32**	**9.07**	**8.52**	**8.62**	**8.57**	**8.37**	**8.57**	**8.95**	**8.02**	**6.75**

PARAMETER	CARAHELL®	CARAAMBER®	MELANOIDIN MALT	CARAMUNICH® TYPE III	CARAAROMA®	CARAFA ® TYPE III	CARAFA SPECIAL® TYPE III	ROASTED BARLEY	SINAMAR ®	CARAMEL #301	PILSNER MALT
Colour Tristimulus %T 360 nm	1.40	0.8	1.3	1.7	1.9	2.5	2.4	2.4	2.6	2.2	2.9
Colour Tristimulus %T 450 nm	45.2	47.7	53.3	53.0	53.3	53.5	53.7	52.8	58.7	55.5	55.9
Colour Tristimulus %T 540 nm	72.1	78.8	83.1	80.7	81.4	79.8	79.6	78.8	81.6	81.9	78.0
Colour Tristimulus %T 670 nn	85.4	93.8	95.3	94.9	94.6	93.6	94.1	93.8	93.2	94.6	91.6
Colour Tristimulus %T 760 nm	92.5	97.5	98.0	98.2	97.5	97.4	97.6	96.5	96.6	98.6	94.1
Colour Tristimulus Values X (Red)	67.36	73.50	76.80	75.54	75.81	74.80	74.89	74.29	76.27	76.37	73.69
Colour Tristimulus Values Y (Green)	71.99	78.60	82.47	80.68	81.148	79.85	79.82	79.11	81.55	81.71	78.43
Colour Tristimulus Values Z (Blue)	48.78	51.80	57.21	56.65	57.03	57.02	57.16	56.28	61.70	58.99	58.84
Colour CIELAB L*	**85.68**	**88.68**	**90.23**	**89.64**	**89.77**	**89.29**	**89.34**	**89.06**	**89.98**	**90.03**	**88.77**
Colour CIELAB a*	**-3.21**	**-3.36**	**-3.71**	**-3.30**	**-3.45**	**-3.25**	**-3.13**	**-3.06**	**-3.38**	**-3.43**	**-3.01**
Colour CIELAB b*	**14.06**	**15.14**	**14.14**	**13.75**	**13.75**	**13.29**	**13.22**	**13.34**	**11.96**	**13.13**	**12.01**
Colour CIELAB C* (Metric Chroma)	**14.43**	**15.50**	**14.62**	**14.14**	**14.18**	**13.68**	**13.59**	**13.69**	**12.43**	**13.57**	**12.38**
Yellow Index	**47.94**	**49.83**	**45.66**	**45.40**	**45.08**	**44.19**	**44.19**	**44.79**	**39.51**	**43.10**	**40.74**
iCAM Lightness J	**6.06**	**6.28**	**6.43**	**6.38**	**6.39**	**6.36**	**6.36**	**6.33**	**6.47**	**6.43**	**6.33**
iCAM Choma C	**1.39**	**1.52**	**1.40**	**1.36**	**1.36**	**1.31**	**1.30**	**1.32**	**1.15**	**1.29**	**1.16**

PARAMETER	CARAHELL®	CARAAMBER®	MELANOIDIN MALT	CARAMUNICH® TYPE III	CARAAROMA®	CARAFA ® TYPE III	CARAFA SPECIAL® TYPE III	ROASTED BARLEY	SINAMAR ®	CARAMEL #301	PILSNER MALT
iCAM Hue h	**0.111**	**0.108**	**0.084**	**0.113**	**0.101**	**0.116**	**0.124**	**0.130**	**0.101**	**0.102**	**0.131**
iCAM Brightness Q	**12.25**	**12.69**	**13.00**	**12.90**	**12.93**	**12.85**	**12.85**	**12.80**	**13.02**	**12.99**	**12.80**
iCAM Colourfulness M	**2.28**	**3.08**	**2.84**	**2.76**	**2.75**	**2.65**	**2.64**	**2.67**	**2.33**	**2.60**	**2.356**
CIECAM02 Lightness **J**	**84.07**	**88.19**	**90.43**	**89.41**	**88.66**	**88.89**	**88.89**	**88.48**	**89.85**	**89.98**	**88.02**
CIECAM02 Chroma **C**	**21.64**	**23.28**	**21.51**	**20.81**	**25.34**	**20.04**	**19.92**	**20.14**	**17.71**	**19.73**	**17.84**
CIECAM02 redness-greenness **a**	**0.0071**	**0.0067**	**-0.0078**	**0.0069**	**0.0008**	**0.0075**	**0.0119**	**0.0149**	**-0.0012**	**0.0002**	**0.0127**
CIECAM02 yellowness- blueness **b**	**0.448**	**0.489**	**0.451**	**0.437**	**0.436**	**0.419**	**0.417**	**0.421**	**0.368**	**0.413**	**0.371**
CIECAM02 Angle Hue **h**	**89.08**	**89.21**	**91.00**	**89.08**	**89.89**	**88.96**	**88.36**	**87.97**	**90.19**	**89.96**	**88.03**
CIECAM02 Hue composition **H**	**98.51**	**98.71**	**101.91**	**98.51**	**99.82**	**98.31**	**97.32**	**96.69**	**100.37**	**99.93**	**96.79**
CIECAM02 **Hc (Red)**	**1.48**	**1.28**	**0**	**1.48**	**0.174**	**1.68**	**2.67**	**3.30**	**0**	**0.065**	**3.20**
CIECAM02 **Hc (Yellow)**	**98.51**	**98.71**	**98.08**	**98.51**	**99.82**	**98.31**	**97.32**	**96.69**	**99.62**	**99.93**	**96.79**
CIECAM02 **Hc (Green)**	**0**	**0**	**1.91**	**0**	**0**	**0**	**0**	**0**	**0.37**	**0**	**0**

PARAMETER	CARAHELL®	CARAAMBER®	MELANOIDIN MALT	CARAMUNICH® TYPE III	CARAAROMA®	CARAFA ® TYPE III	CARAFA SPECIAL® TYPE III	ROASTED BARLEY	SINAMAR ®	CARAMEL #301	PILSNER MALT
CIECAM02 **Hc (Blue)**	0	0	0	0	0	0	0	0	0	0	0
CIECAM02 Brightness **Q**	218.20	223.48	226.30	225.01	225.34	224.37	224.37	223.84	225.57	225.74	223.26
CIECAM02 Colourfulness **M**	20.42	23.28	21.51	19.64	19.66	18.92	18.80	19.01	16.72	18.63	16.84
CIECAM02 Saturation **s**	30.59	31.36	29.95	29.55	29.54	29.03	28.94	29.14	27.22	28.72	27.46

Table A.2.2 Beer colour adjustment trial no. 2

PARAMETER	CARAHELL®	CARAAMBER®	MELANOIDIN MALT	CARAMUNICH® TYPE III	CARAAROMA®	CARAFA ® TYPE III	CARAFA SPECIAL® TYPE III	ROASTED BARLEY	SINAMAR ®	CARAMEL #301	PILSNER MALT
Raw material source	GERMAN- GROWN “MARTHE” SPRING BARLEY (2006 harvest)										
Recommended Quantities	Up to 15% of total grain bill (Low Gravity) Up to 30% of total grain bill(High Gravity)	Up to 20% of total grain bill	Up to 20% of total grain bill	Up to 5% of total grain bill (pale beers)	Up to 20% of total grain bill	Up to 5% of total grain bill	Up to 5% of total grain bill	Up to 5% of total grain bill	14 g (11.9 mL) 1hL/1EBC		Up to 100% of total grain bill
Wort Colour EBC	20 min 30 max	60 min 80 max	60 min 80 max	170 min 220 max	350 min 450 max	1300 min 1500 max	1300 min 1500 max	1000 min 1300 max	8100 min 8600 max	29,800 (typical)	2.5 min 4 .0 max
Wort Colour Lovibond	8.1 min 11.8 max	23 min 31 max	23 min 31 max	64 min 83 max	115 min 150 max	488 min 563 max	488 min 563 max	375 min 450 max	3040 min 3200 max		1.5 min 2.1 max
Ratio (specialty malt/ base malt) %	**14/86**	**4.6/95.4**	**4.6/95.4**	**2/98**	**2/98**	**0.2/99.8**	**0.2/99.8**	**0.25/99.75**	**0.04/99.96**	**0.02/99.98**	**100**
Ratio (specialty malt/ base malt) kg	**7.28/44.74**	**2.38/49.61**	**2.38/49.61**	**1.03/50.96**	**0.45/51.54**	**0.10/51.90**	**0.10/51.90**	**0.12/51.87**	**0.02 (0.017 mL)/ 51.98**	**0.01 / 51.99**	**52.00**
Colour EBC Abs. 430 nm	0.517	0.648	0.717	0.550	0.755	0.389	0.337	0.349	0.355	0.330	0.282
Colour EBC	**12.92**	**16.20**	**17.92**	**13.75**	**18.87**	**14.72**	**8.42**	**8.72**	**8.87**	**8.25**	**7.05**
Colour Tristimulus	0.8	0.9	0.0	0.1	0.0	2.3	2.5	2.4	2.6	2.1	2.8

PARAMETER	CARAHELL®	CARAAMBER®	MELANOIDIN MALT	CARAMUNICH® TYPE III	CARAAROMA®	CARAFA ® TYPE III	CARAFA SPECIAL® TYPE III	ROASTED BARLEY	SINAMAR ®	CARAMEL #301	PILSNER MALT
%T 360 nm											
Colour Tristimulus %T 450 nm	26.9	33.4	28.2	33.9	26.8	53.7	54.4	52.8	58.5	55.3	58.6
Colour Tristimulus %T 540 nm	66.4	69.9	66.6	72.1	65.8	78.9	80.1	79.2	81.6	81.3	75.5
Colour Tristimulus %T 670 nn	77.4	91.9	89.3	94.3	91.4	92.9	94.7	94.3	94.8	96.4	92.0
Colour Tristimulus %T 760 nm	88.0	96.8	95.5	98.4	97.7	97.7	98.2	96.2	96.8	99.0	95.0
Colour Tristimulus Values X (Red)	59.42	66.67	63.53	68.51	63.63	74.19	75.42	74.64	76.76	76.65	73.08
Colour Tristimulus Values Y (Green)	64.58	70.56	67.21	72.63	66.93	79.10	80.36	79.49	81.84	81.63	77.03
Colour Tristimulus Values Z (Blue)	32.3842	38.4114	33.4419	39.0725	32.1408	57.0513	57.8360	56.3406	61.5378	58.7324	60.7718
Colour CIELAB L*	**81.52**	**85.34**	**83.72**	**86.26**	**83.77**	**89.01**	**89.59**	**89.22**	**90.21**	**90.16**	**88.49**
Colour CIELAB a*	**-4.20**	**-2.53**	**-2.47**	**-2.67**	**-2.07**	**-3.15**	**-3.12**	**-3.08**	**-3.19**	**-3.10**	**-2.31**
Colour CIELAB b*	**19.93**	**18.80**	**20.35**	**19.24**	**21.04**	**13.01**	**13.13**	**13.46**	**12.13**	**13.21**	**10.70**
Colour CIELAB C* (Metric Chroma)	**20.37**	**18.97**	**20.50**	**19.42**	**21.14**	**13.39**	**13.50**	**13.80**	**12.54**	**13.57**	**10.95**
Yellow Index	**64.62**	**63.24**	**68.24**	**63.72**	**70.78**	**43.60**	**43.84**	**45.05**	**40.34**	**43.92**	**37.82**
iCAM Lightness J	**5.66**	**5.92**	**5.76**	**5.99**	**5.74**	**6.34**	**6.38**	**6.34**	**6.45**	**6.42**	**6.31**
iCAM Choma C	**2.02**	**1.94**	**2.11**	**1.99**	**2.19**	**1.28**	**1.29**	**1.33**	**1.17**	**1.30**	**1.20**

PARAMETER	CARAHELL®	CARAAMBER®	MELANOIDIN MALT	CARAMUNICH® TYPE III	CARAAROMA®	CARAFA ® TYPE III	CARAFA SPECIAL® TYPE III	ROASTED BARLEY	SINAMAR ®	CARAMEL #301	PILSNER MALT
iCAM Hue h	0.046	0.143	0.136	0.136	0.151	0.122	0.126	0.129	0.119	0.129	0.199
iCAM Brightness Q	11.45	11.96	11.65	12.10	11.60	12.81	12.90	12.82	13.04	12.98	12.75
iCAM Colourfulness M	4.09	3.93	4.26	4.03	4.43	2.58	2.62	2.69	2.38	2.64	2.07
CIECAM02 Lightness **J**	79.29	83.38	81.25	84.69	81.13	88.44	89.22	88.71	90.06	89.98	87.21
CIECAM02 Chroma **C**	32.41	29.88	32.74	30.55	33.95	19.57	19.74	20.32	17.97	19.83	15.60
CIECAM02 redness-greenness **a**	-0.033	0.038	0.038	0.034	0.053	0.010	0.012	0.014	0.007	0.013	0.036
CIECAM02 yellowness- blueness **b**	0.664	0.627	0.683	0.643	0.709	0.409	0.413	0.426	0.375	0.416	0.322
CIECAM02 Angle Hue **h**	92.84	86.45	86.80	86.91	85.71	88.53	88.26	88.02	88.90	88.08	83.59
CIECAM02 Hue composition **H**	105.39	94.23	94.81	94.99	93.05	97.61	97.17	96.77	98.21	96.88	89.65
CIECAM02 **Hc (Red)**	0	5.76	5.18	5.00	6.94	2.38	2.82	3.22	1.78	3.11	10.34
CIECAM02 **Hc (Yellow)**	94.60	94.23	94.81	94.99	93.05	97.61	97.17	96.77	98.21	96.88	89.65
CIECAM02 **Hc (Green)**	5.39	0	0	0	0	0	0	0	0	0	0

PARAMETER	CARAHELL®	CARAAMBER®	MELANOIDIN MALT	CARAMUNICH® TYPE III	CARAAROMA®	CARAFA ® TYPE III	CARAFA SPECIAL® TYPE III	ROASTED BARLEY	SINAMAR ®	CARAMEL #301	PILSNER MALT
CIECAM02 **Hc (Blue)**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
CIECAM02 Brightness **Q**	**211.90**	**217.30**	**214.51**	**219.00**	**214.35**	**223.80**	**224.78**	**224.13**	**225.83**	**225.74**	**222.23**
CIECAM02 Colourfulness **M**	**30.59**	**28.20**	**30.90**	**28.84**	**32.04**	**18.47**	**18.63**	**19.18**	**16.96**	**18.72**	**14.72**
CIECAM02 Saturation **s**	**37.99**	**36.02**	**37.95**	**36.29**	**38.66**	**28.73**	**28.79**	**29.25**	**27.41**	**28.79**	**25.74**

Table A.2.3 Beer colour adjustment trial no. 3

PARAMETER	CARAHELL®	CARAAMBER®	MELANOIDIN MALT	CARAMUNICH® TYPE III	CARAAROMA®	CARAFA ® TYPE III	CARAFA SPECIAL® TYPE III	ROASTED BARLEY	SINAMAR ®	CARAMEL #301	PILSNER MALT
Raw material source	GERMAN- GROWN "MARTHE" SPRING BARLEY (2006 harvest)										
Recommended Quantities	Up to 15% of total grain bill (Low Gravity) Up to 30% of total grain bill(High Gravity)	Up to 20% of total grain bill	Up to 20% of total grain bill	Up to 5% of total grain bill (pale beers)	Up to 20% of total grain bill	Up to 5% of total grain bill	Up to 5% of total grain bill	Up to 5% of total grain bill	14 g (11.9 mL) 1hL/1EBC		Up to 100% of total grain bill
Wort Colour EBC	20 min 30 max	60 min 80 max	60 min 80 max	170 min 220 max	350 min 450 max	1300 min 1500 max	1300 min 1500 max	1000 min 1300 max	8100 min 8600 max	29,800 (typical)	2.5 min 4.0 max
Wort Colour Lovibond	8.1 min 11.8 max	23 min 31 max	23 min 31 max	64 min 83 max	115 min 150 max	488 min 563 max	488 min 563 max	375 min 450 max	3040 min 3200 max		1.5 min 2.1 max
Ratio (specialty malt/ base malt) %	**18/82**	**5.3/94.7**	**5.3/94.7**	**2.1/97.9**	**1/99**	**0.2/99.8**	**0.2/99.8**	**0.3/99.7**	**0.04/99.96**	**0.02/99.98**	**100**
Ratio (specialty malt/ base malt) kg	**9.36/42.64**	**2.75/49.25**	**2.75/49.25**	**1.09/50.91**	**0.52/51.48**	**0.10/51.90**	**0.10/51.90**	**0.15/51.85**	**0.02 (0.017 mL)/ 51.98**	**0.01 / 51.99**	**52.00**
Colour EBC Abs. 430 nm	0.759	1.016	0.927	1.120	1.020	0.389	0.335	0.349	0.357	0.341	0.286
Colour EBC	**18.97**	**25.40**	**23.17**	**28.00**	**25.5**	**14.72**	**8.37**	**8.72**	**8.92**	**8.52**	**7.15**
Colour Tristimulus	0.6	0.8	0.0	0.0	0.0	2.3	2.5	2.4	2.6	2.1	2.5

PARAMETER	CARAHELL®	CARAAMBER®	MELANOIDIN MALT	CARAMUNICH® TYPE III	CARAAROMA®	CARAFA ® TYPE III	CARAFA SPECIAL® TYPE III	ROASTED BARLEY	SINAMAR ®	CARAMEL #301	PILSNER MALT
%T 360 nm											
Colour Tristimulus %T 450 nm	19.7	16.6	19.1	18.4	16.6	53.8	53.7	53.3	58.1	53.8	53.9
Colour Tristimulus %T 540 nm	54.9	57.9	57.5	52.2	56.1	78.5	79.8	78.8	81.5	84.8	78.6
Colour Tristimulus %T 670 nn	72.6	88.9	85.9	84.4	87.7	93.8	94.1	94.6	93.0	96.2	94.8
Colour Tristimulus %T 760 nm	85.1	96.6	93.2	92.4	95.8	98.6	97.8	96.6	95.8	99.2	95.5
Colour Tristimulus Values X (Red)	51.53	57.70	56.91	539.00	56.47	74.31	74.99	74.63	76.075	77.9615	74.6959
Colour Tristimulus Values Y (Green)	54.85	59.89	59.26	55.15	58.39	79.01	79.96	79.32	81.38	83.8966	79.2875
Colour Tristimulus Values Z (Blue)	24.61	22.43	24.42	23.07	23.35	57.07	57.19	56.70	61.18	57.9586	57.1981
Colour CIELAB L*	**77.00**	**80.57**	**80.12**	**78.40**	**79.88**	**89.07**	**89.38**	**89.22**	**89.89**	**90.76**	**89.95**
Colour CIELAB a*	**-2.69**	**-1.13**	**-1.34**	**-0.24**	**-0.87**	**-2.95**	**-3.17**	**-2.93**	**-3.41**	**-3.88**	**-2.84**
Colour CIELAB b*	**20.95**	**24.88**	**23.07**	**22.27**	**24.48**	**12.96**	**13.26**	**13.24**	**12.11**	**14.33**	**13.01**
Colour CIELAB C* (Metric Chroma)	**21.12**	**24.90**	**23.11**	**22.27**	**24.50**	**13.30**	**13.63**	**13.56**	**12.58**	**14.84**	**13.32**
Yellow Index	**72.67**	**83.61**	**79.23**	**80.69**	**83.68**	**43.81**	**44.21**	**44.64**	**39.96**	**45.71**	**44.11**
iCAM Lightness J	**5.25**	**5.39**	**5.40**	**5.24**	**5.34**	**6.34**	**6.36**	**6.34**	**6.43**	**6.48**	**6.34**
iCAM Choma C	**2.13**	**2.60**	**2.40**	**2.33**	**2.56**	**1.28**	**1.31**	**1.31**	**1.17**	**1.42**	**1.28**

PARAMETER	CARAHELL®	CARAAMBER®	MELANOIDIN MALT	CARAMUNICH® TYPE III	CARAAROMA®	CARAFA ® TYPE III	CARAFA SPECIAL® TYPE III	ROASTED BARLEY	SINAMAR ®	CARAMEL #301	PILSNER MALT
iCAM Hue h	0.108	0.160	0.163	0.212	0.171	0.139	0.122	0.140	0.099	0.074	0.148
iCAM Brightness Q	10.60	10.90	10.91	10.60	10.79	12.81	12.86	12.82	13.01	13.09	12.82
iCAM Colourfulness M	4.31	5.25	4.85	4.71	5.17	2.58	2.64	2.65	2.36	2.88	2.60
CIECAM02 Lightness **J**	72.74	76.55	76.06	73.29	75.53	88.41	88.97	88.62	89.75	91.26	88.60
CIECAM02 Chroma **C**	34.47	41.12	37.95	36.88	40.53	19.47	19.98	19.94	17.99	21.82	19.54
CIECAM02 redness-greenness **a**	0.017	0.076	0.071	0.113	0.086	0.018	0.010	18.82	-0.002	-0.013	0.0232
CIECAM02 yellowness- blueness **b**	0.698	0.844	0.779	0.750	0.830	0.407	0.418	2.98	0.374	0.458	0.409
CIECAM02 Angle Hue **h**	88.54	84.84	84.72	81.36	84.07	87.41	88.55	87.27	90.35	91.72	86.75
CIECAM02 Hue composition **H**	97.62	91.64	91.46	86.12	90.41	95.78	97.64	95.55	100.67	103.29	94.71
CIECAM02 **Hc (Red)**	2.37	8.35	8.53	13.87	9.58	4.21	2.35	4.44	0	0	5.28
CIECAM02 **Hc (Yellow)**	97.62	91.64	91.46	86.12	90.41	95.78	97.64	95.55	99.32	96.70	94.71
CIECAM02 **Hc (Green)**	0	0	0	0	0	0	0	0	0.678	3.292	0

PARAMETER	CARAHELL®	CARAAMBER®	MELANOIDIN MALT	CARAMUNICH® TYPE III	CARAAROMA®	CARAFA ® TYPE III	CARAFA SPECIAL® TYPE III	ROASTED BARLEY	SINAMAR ®	CARAMEL #301	PILSNER MALT
CIECAM02 **Hc (Blue)**	0	0	0	0	0	0	0	0	0	0	0
CIECAM02 Brightness **Q**	202.97	208.21	207.54	203.73	206.82	223.76	224.47	224.02	225.44	227.33	223.99
CIECAM02 Colourfulness **M**	32.54	38.81	35.82	34.81	38.25	18.38	18.85	18.82	16.98	20.59	18.45
CIECAM02 Saturation **s**	40.04	43.17	41.54	41.33	43.01	28.66	28.98	28.98	27.44	30.09	28.70

Table A.2.4 Beer colour adjustment trial no. 1

PARAMETER	CARAHELL®	CARAAMBER®	MELANOIDIN MALT	CARAMUNICH® TYPE III	CARAAROMA®	CARAFA ® TYPE III	CARAFA SPECIAL® TYPE III	ROASTED BARLEY	SINAMAR ®	CARAMEL #301	PILSNER MALT
Raw material source	GERMAN- GROWN "MARTHE" SPRING BARLEY (2006 harvest)										
Recommended Quantities	Up to 15% of total grain bill (Low Gravity) Up to 30% of total grain bill(High Gravity)	Up to 20% of total grain bill	Up to 20% of total grain bill	Up to 5% of total grain bill (pale beers)	Up to 20% of total grain bill	Up to 5% of total grain bill	Up to 5% of total grain bill	Up to 5% of total grain bill	14 g (11.9 mL) 1hL/1EBC		Up to 100% of total grain bill
Wort Colour EBC	20 min 30 max	60 min 80 max	60 min 80 max	170 min 220 max	350 min 450 max	1300 min 1500 max	1300 min 1500 max	1000 min 1300 max	8100 min 8600 max	29,800 (typical)	2.5 min 4.0 max
Wort Colour Lovibond	8.1 min 11.8 max	23 min 31 max	23 min 31 max	64 min 83 max	115 min 150 max	488 min 563 max	488 min 563 max	375 min 450 max	3040 min 3200 max		1.5 min 2.1 max
Ratio (specialty malt/ base malt) %	**10/90**	**3.9/96.1**	**3.9/96.1**	**1.9/98.1**	**0.8/99.2**	**0.8/99.2**	**0.2/99.8**	**0.2/99.8**	**0.04/99.96**	**0.02/99.98**	**100**
Ratio (specialty malt/ base malt) kg	**5.20/46.80**	**2.02/49.98**	**2.02/49.98**	**0.98/51.02**	**0.39/51.61**	**0.10/51.90**	**0.10/51.90**	**0.10/51.90**	**0.02 (0.017 mL)/ 51.98**	**0.01 / 51.99**	**52.00**
Colour EBC Abs. 430 nm	0.359	0.364	0.359	0.347	0.347	0.343	0.336	0.345	0.329	0.323	0.277
Colour EBC	**8.97**	**9.10**	**8.97**	**8.67**	**8.67**	**8.57**	**8.40**	**8.62**	**8.22**	**8.07**	**6.92**
Colour Tristimulus	1.6	1.3	1.7	2.0	2.1	2.3	2.5	2.4	2.8	2.0	3.3

PARAMETER	CARAHELL®	CARAAMBER®	MELANOIDIN MALT	CARAMUNICH® TYPE III	CARAAROMA®	CARAFA ® TYPE III	CARAFA SPECIAL® TYPE III	ROASTED BARLEY	SINAMAR ®	CARAMEL #301	PILSNER MALT
%T 360 nm											
Colour Tristimulus %T 450 nm	48.3	48.1	52.7	53.8	53.5	53.4	53.8	53.1	58.9	55.8	55.4
Colour Tristimulus %T 540 nm	76.3	79.2	81.7	82.1	81.1	79.4	79.9	79.1	81.4	82.0	77.6
Colour Tristimulus %T 670 nn	89.9	94.4	95.0	95.3	94.3	93.5	94.0	93.0	93.7	94.9	90.3
Colour Tristimulus %T 760 nm	93.4	98.0	98.3	98.5	97.6	97.5	97.8	96.7	97.0	98.2	93.3
Colour Tristimulus Values X (Red)	71.2064	73.9498	75.9845	76.4352	75.6122	74.5668	75.0206	74.2246	76.3803	76.5608	73.0291
Colour Tristimulus Values Y (Green)	76.1420	79.0474	81.3776	81.8276	80.8987	79.5401	80.0297	79.2004	81.5307	81.8784	77.8438
Colour Tristimulus Values Z (Blue)	52.0311	52.2470	56.5446	57.5639	57.1762	56.8682	57.2983	56.5805	61.8676	59.2462	58.4041
Colour CIELAB L*	**87.58**	**88.89**	**89.85**	**90.06**	**89.67**	**89.18**	**89.40**	**89.02**	**90.03**	**90.11**	**88.46**
Colour CIELAB a*	**-3.31**	**-3.33**	**-3.50**	**-3.47**	**-3.42**	**-3.19**	**-3.20**	**-3.21**	**-3.26**	**-3.40**	**-3.11**
Colour CIELAB b*	**14.13**	**15.09**	**14.04**	**13.77**	**13.60**	**13.25**	**13.24**	**13.25**	**11.88**	**13.08**	**11.98**
Colour CIELAB C* (Metric Chroma)	**14.51**	**15.46**	**14.04**	**14.20**	**14.03**	**13.62**	**13.62**	**13.63**	**12.33**	**13.52**	**12.38**
Yellow Index	**47.26**	**49.68**	**45.86**	**44.99**	**44.71**	**44.21**	**44.09**	**44.23**	**39.47**	**42.98**	**40.55**
iCAM Lightness J	**6.214**	**6.300**	**6.402**	**6.423**	**6.393**	**6.353**	**6.370**	**6.341**	**6.448**	**6.438**	**6.316**
iCAM Choma C	**1.406**	**1.521**	**1.397**	**1.366**	**1.346**	**1.308**	**1.308**	**1.308**	**1.147**	**1.286**	**1.160**

PARAMETER	CARAHELL®	CARAAMBER®	MELANOIDIN MALT	CARAMUNICH® TYPE III	CARAAROMA®	CARAFA ® TYPE III	CARAFA SPECIAL® TYPE III	ROASTED BARLEY	SINAMAR ®	CARAMEL #301	PILSNER MALT
iCAM Hue h	0.108	0.110	0.099	0.100	0.103	0.120	0.119	0.118	0.112	0.104	0.122
iCAM Brightness Q	12.556	12.730	12.935	12.978	12.919	12.836	12.872	12.812	13.030	13.008	12.763
iCAM Colourfulness M	2.840	3.073	2.823	2.760	2.721	2.644	2.643	2.643	2.318	2.60	2.343
CIECAM02 Lightness **J**	86.65	88.46	89.80	90.07	89.51	88.71	89.01	88.50	89.85	90.08	87.65
CIECAM02 Chroma **C**	21.62	23.19	21.33	20.84	20.57	19.97	19.94	19.98	17.57	19.64	17.82
CIECAM02 redness-greenness **a**	0.005	0.007	-8.78E-05	-0.0003	0.0017	0.0096	0.0094	0.0088	0.0032	0.0014	0.0081
CIECAM02 yellowness- blueness **b**	0.451	0.488	0.447	0.437	0.431	0.418	0.417	0.418	0.365	0.411	0.369
CIECAM02 Angle Hue **h**	89.33	89.06	90.01	89.95	89.76	88.67	88.70	88.79	89.49	89.90	88.73
CIECAM02 Hue composition **H**	98.91	98.47	100.02	99.93	99.62	97.83	97.89	98.03	99.17	99.67	97.94
CIECAM02 **Hc (Red)**	1.08	1.52	0	0.068	0.378	2.16	2.10	1.96	0.824	0.322	2.05
CIECAM02 **Hc (Yellow)**	98.91	98.47	99.97	99.93	99.62	97.83	97.89	98.03	99.17	99.67	97.94
CIECAM02 **Hc (Green)**	0	0	0.021	0	0	0	0	0	0	0	0

PARAMETER	CARAHELL®	CARAAMBER®	MELANOIDIN MALT	CARAMUNICH® TYPE III	CARAAROMA®	CARAFA ® TYPE III	CARAFA SPECIAL® TYPE III	ROASTED BARLEY	SINAMAR ®	CARAMEL #301	PILSNER MALT
CIECAM02 **Hc (Blue)**	0	0	0	0	0	0	0	0	0	0	0
CIECAM02 Brightness **Q**	221.52	223.82	225.51	225.84	225.15	224.14	224.51	223.88	225.57	225.86	222.79
CIECAM02 Colourfulness **M**	20.41	21.89	20.13	20.84	19.42	18.85	18.82	18.86	16.58	18.54	16.82
CIECAM02 Saturation **s**	30.35	31.27	29.88	29.51	29.37	29.00	28.95	29.02	27.11	28.65	27.48

Table A.2.5 Beer color adjustment trial no. 2

PARAMETER	CARAHELL®	CARAAMBER®	MELANOIDIN MALT	CARAMUNICH® TYPE III	CARAAROMA®	CARAFA ® TYPE III	CARAFA SPECIAL® TYPE III	ROASTED BARLEY	SINAMAR ®	CARAMEL #301	PILSNER MALT
Raw material source	GERMAN- GROWN "MARTHE" SPRING BARLEY (2006 harvest)										
Recommended Quantities	Up to 15% of total grain bill (Low Gravity) Up to 30% of total grain bill(High Gravity)	Up to 20% of total grain bill	Up to 20% of total grain bill	Up to 5% of total grain bill (pale beers)	Up to 20% of total grain bill	Up to 5% of total grain bill	Up to 5% of total grain bill	Up to 5% of total grain bill	14 g (11.9 mL) 1hL/1EBC		Up to 100% of total grain bill
Wort Colour EBC	20 min 30 max	60 min 80 max	60 min 80 max	170 min 220 max	350 min 450 max	1300 min 1500 max	1300 min 1500 max	1000 min 1300 max	8100 min 8600 max	29,800 (typical)	2.5 min 4.0 max
Wort Colour Lovibond	8.1 min 11.8 max	23 min 31 max	23 min 31 max	64 min 83 max	115 min 150 max	488 min 563 max	488 min 563 max	375 min 450 max	3040 min 3200 max		1.5 min 2.1 max
Ratio (specialty malt/ base malt) %	**10/90**	**3.9/96.1**	**3.9/96.1**	**1.9/98.1**	**0.8/99.2**	**0.8/99.2**	**0.2/99.8**	**0.2/99.8**	**0.04/99.96**	**0.02/99.98**	
Ratio (specialty malt/ base malt) kg	**5.20/46.80**	**2.02/49.98**	**2.02/49.98**	**0.98/51.02**	**0.39/51.61**	**0.10/51.90**	**0.10/51.90**	**0.10/51.90**	**0.02 (0.017 mL)/ 51.98**	**0.01 / 51.99**	**52.00**
Colour EBC Abs. 430 nm	0.360	0.368	0.357	0.347	0.348	0.343	0.336	0.344	0.328	0.323	0.278
Colour EBC	**8.76**	**9.22**	**8.92**	**8.67**	**8.70**	**8.57**	**8.40**	**8.62**	**8.21**	**8.07**	**6.95**
Colour Tristimulus %T	1.4	1.3	1.6	1.8	1.9	2.3	2.6	2.4	2.7	2.0	3.4

PARAMETER	CARAHELL®	CARAAMBER®	MELANOIDIN MALT	CARAMUNICH® TYPE III	CARAAROMA®	CARAFA ® TYPE III	CARAFA SPECIAL® TYPE III	ROASTED BARLEY	SINAMAR ®	CARAMEL #301	PILSNER MALT
360 nm											
Colour Tristimulus %T 450 nm	48.3	48.1	52.8	53.8	53.4	53.3	53.8	53.1	59.0	55.8	55.4
Colour Tristimulus %T 540 nm	76.4	79.2	81.5	82.1	81.0	79.4	79.8	79.1	81.2	82.0	77.6
Colour Tristimulus %T 670 nn	90.0	94.4	95.0	95.2	94.4	93.5	93.8	93.0	93.7	94.8	90.1
Colour Tristimulus %T 760 nm	93.4	98.0	98.2	98.5	97.5	97.4	97.7	96.7	97.0	98.2	93.3
Colour Tristimulus Values X (Red)	71.28	73.94	75.90	76.39	75.57	74.55	74.91	74.22	76.30	76.52	72.96
Colour Tristimulus Values Y (Green)	76.23	79.04	81.24	81.80	80.83	79.53	79.92	79.20	81.40	81.85	77.80
Colour Tristimulus Values Z (Blue)	52.026	52.247	56.591	57.544	57.057	56.783	57.293	56.580	61.914	59.246	58.413
Colour CIELAB L*	**87.62**	**88.89**	**89.81**	**90.04**	**89.66**	**89.18**	**89.35**	**89.02**	**89.99**	**90.10**	**88.43**
Colour CIELAB a*	**-3.32**	**-3.33**	**-3.45**	**-3.49**	**-3.40**	**-3.19**	**-3.20**	**-3.21**	**-3.22**	**-3.41**	**-3.14**
Colour CIELAB b*	**14.16**	**15.09**	**13.97**	**13.77**	**13.63**	**13.28**	**13.20**	**13.25**	**11.82**	**13.07**	**11.96**
Colour CIELAB C* (Metric Chroma)	**14.55**	**15.46**	**14.40**	**14.20**	**14.05**	**13.66**	**13.58**	**13.63**	**12.25**	**13.51**	**12.37**
Yellow Index	**47.34**	**49.68**	**45.75**	**44.97**	**44.85**	**44.30**	**43.98**	**44.23**	**39.35**	**42.94**	**40.45**
iCAM Lightness J	**6.21**	**6.30**	**6.39**	**6.42**	**6.39**	**6.35**	**6.36**	**6.34**	**6.44**	**6.43**	**6.31**

PARAMETER	CARAHELL®	CARAAMBER®	MELANOIDIN MALT	CARAMUNICH® TYPE III	CARAAROMA®	CARAFA ® TYPE III	CARAFA SPECIAL® TYPE III	ROASTED BARLEY	SINAMAR ®	CARAMEL #301	PILSNER MALT
iCAM Choma C	1.41	1.52	1.39	1.36	1.35	1.31	1.30	1.30	1.14	1.28	1.15
iCAM Hue h	0.107	0.110	0.102	0.099	0.105	0.119	0.119	0.118	0.115	0.103	0.119
iCAM Brightness Q	12.56	12.73	12.92	12.97	12.91	12.83	12.86	12.81	13.02	13.00	12.76
iCAM Colourfulness M	2.84	3.07	2.80	2.75	2.72	2.65	2.63	2.64	2.30	2.59	2.33
CIECAM02 Lightness **J**	86.71	88.46	89.73	90.05	89.48	88.71	88.94	88.50	89.77	90.07	87.62
CIECAM02 Chroma **C**	21.68	23.19	21.21	20.84	20.62	20.03	19.88	19.98	17.45	19.84	17.80
CIECAM02 redness-greenness **a**	0.0049	0.0079	0.0014	-0.0003	0.0027	0.0095	0.0091	0.0088	0.0046	0.0008	0.0070
CIECAM02 yellowness- blueness **b**	0.452	0.488	0.445	0.437	0.432	0.419	0.416	0.418	0.363	0.411	0.369
CIECAM02 Angle Hue **h**	89.37	89.06	89.81	90.04	89.63	88.69	88.74	88.79	89.26	89.87	88.89
CIECAM02 Hue composition **H**	98.98	98.47	99.70	100.08	99.40	97.87	97.95	98.03	98.79	97.79	98.20
CIECAM02 **Hc (Red)**	1.01	1.52	0.297	0	0.593	2.12	2.04	1.96	1.20	0.201	1.79
CIECAM02 **Hc (Yellow)**	98.98	98.47	99.70	99.91	99.40	97.87	97.95	98.03	98.79	99.79	98.20

PARAMETER	CARAHELL®	CARAAMBER®	MELANOIDIN MALT	CARAMUNICH® TYPE III	CARAAROMA®	CARAFA ® TYPE III	CARAFA SPECIAL® TYPE III	ROASTED BARLEY	SINAMAR ®	CARAMEL #301	PILSNER MALT
CIECAM02 **Hc (Green)**	**0**	**0**	**0**	**0.084**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
CIECAM02 **Hc (Blue)**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
CIECAM02 Brightness **Q**	**221.59**	**223.82**	**225.42**	**225.830**	**225.11**	**224.13**	**224.42**	**223.88**	**225.48**	**225.84**	**222.75**
CIECAM02 Colourfulness **M**	**20.46**	**21.89**	**20.02**	**19.67**	**19.46**	**18.90**	**18.77**	**18.86**	**16.47**	**18.53**	**16.80**
CIECAM02 Saturation **s**	**30.39**	**31.27**	**29.80**	**29.51**	**29.40**	**29.04**	**28.92**	**29.02**	**27.03**	**28.64**	**27.46**

Table A.2.6 Beer colour adjustment trial no. 3

PARAMETER	CARAHELL®	CARAAMBER®	MELANOIDIN MALT	CARAMUNICH® TYPE III	CARAAROMA®	CARAFA ® TYPE III	CARAFA SPECIAL® TYPE III	ROASTED BARLEY	SINAMAR ®	CARAMEL #301	PILSNER MALT
Raw material source	GERMAN- GROWN “MARTHE” SPRING BARLEY (2006 harvest)										
Recommended Quantities	Up to 15% of total grain bill (Low Gravity) Up to 30% of total grain bill(High Gravity)	Up to 20% of total grain bill	Up to 20% of total grain bill	Up to 5% of total grain bill (pale beers)	Up to 20% of total grain bill	Up to 5% of total grain bill	Up to 5% of total grain bill	Up to 5% of total grain bill	14 g (11.9 mL) 1hL/1EBC		Up to 100% of total grain bill
Wort Colour EBC	20 min 30 max	60 min 80 max	60 min 80 max	170 min 220 max	350 min 450 max	1300 min 1500 max	1300 min 1500 max	1000 min 1300 max	8100 min 8600 max	29,800 (typical)	2.5 min 4.0 max
Wort Colour Lovibond	8.1 min 11.8 max	23 min 31 max	23 min 31 max	64 min 83 max	115 min 150 max	488 min 563 max	488 min 563 max	375 min 450 max	3040 min 3200 max		1.5 min 2.1 max
Ratio (specialty malt/ base malt) %	**10/90**	**3.9/96.1**	**3.9/96.1**	**1.9/98.1**	**0.8/99.2**	**0.8/99.2**	**0.2/99.8**	**0.2/99.8**	**0.04/99.96**	**0.02/99.98**	**100**
Ratio (specialty malt/ base malt) kg	**5.20/46.80**	**2.02/49.98**	**2.02/49.98**	**0.98/51.02**	**0.39/51.61**	**0.10/51.90**	**0.10/51.90**	**0.10/51.90**	**0.02 (0.017 mL)/ 51.98**	**0.01 / 51.99**	**52.00**
Colour EBC Abs. 430 nm	0.361	0.368	0.357	0.347	0.348	0.343	0.335	0.345	0.329	0.321	0.279
Colour EBC	**9.02**	**9.22**	**8.92**	**8.67**	**8.70**	**8.57**	**8.37**	**8.62**	**8.22**	**7.80**	**6.97**
Colour Tristimulus	1.5	1.2	1.5	2.0	1.8	2.3	2.6	2.3	2.7	2.0	3.3

PARAMETER	CARAHELL®	CARAAMBER®	MELANOIDIN MALT	CARAMUNICH® TYPE III	CARAAROMA®	CARAFA ® TYPE III	CARAFA SPECIAL® TYPE III	ROASTED BARLEY	SINAMAR ®	CARAMEL #301	PILSNER MALT
%T 360 nm											
Colour Tristimulus %T 450 nm	48.3	48.1	52.9	53.7	53.3	53.4	53.9	53.3	59.0	55.8	55.3
Colour Tristimulus %T 540 nm	76.5	79.1	81.5	82.1	81.0	79.4	79.8	79.1	81.3	82.0	77.6
Colour Tristimulus %T 670 nn	89.8	94.4	95.0	95.2	94.4	93.5	93.7	93.0	93.6	94.9	90.1
Colour Tristimulus %T 760 nm	93.3	98.0	98.3	98.5	97.5	97.4	97.8	96.7	97.0	98.2	93.3
Colour Tristimulus Values X (Red)	71.26	73.90	75.91	76.38	75.56	74.56	74.89	74.25	76.31	76.56	72.94
Colour Tristimulus Values Y (Green)	76.26	78.97	81.25	81.79	80.82	79.54	79.91	79.22	81.45	81.87	77.79
Colour Tristimulus Values Z (Blue)	52.04	52.22	56.66	57.47	56.96	56.86	57.37	56.74	61.92	59.24	58.31
Colour CIELAB L*	**87.61**	**88.87**	**89.82**	**90.03**	**89.65**	**89.18**	**89.34**	**89.04**	**90.00**	**90.11**	**88.42**
Colour CIELAB a*	**-3.37**	**-3.31**	**-3.45**	**-3.49**	**-3.40**	**-3.19**	**-3.21**	**-3.20**	**-3.25**	**-3.40**	**-3.14**
Colour CIELAB b*	**14.16**	**15.08**	**13.95**	**13.79**	**13.67**	**13.25**	**13.16**	**13.18**	**11.83**	**13.08**	**12.00**
Colour CIELAB C* (Metric Chroma)	**14.56**	**15.44**	**14.37**	**14.23**	**14.08**	**13.62**	**13.55**	**13.57**	**12.27**	**13.52**	**12.40**
Yellow Index	**47.26**	**49.68**	**45.66**	**45.04**	**44.95**	**44.21**	**43.85**	**44.05**	**39.33**	**42.98**	**40.56**
iCAM Lightness J	**6.21**	**6.29**	**6.39**	**6.42**	**6.39**	**6.35**	**6.36**	**6.34**	**6.44**	**6.43**	**6.31**
iCAM Choma C	**1.40**	**1.51**	**1.38**	**1.36**	**1.35**	**1.30**	**1.29**	**1.30**	**1.14**	**1.28**	**1.16**

PARAMETER	CARAHELL®	CARAAMBER®	MELANOIDIN MALT	CARAMUNICH® TYPE III	CARAAROMA®	CARAFA ® TYPE III	CARAFA SPECIAL® TYPE III	ROASTED BARLEY	SINAMAR ®	CARAMEL #301	PILSNER MALT
iCAM Hue h	0.104	0.112	0.102	0.099	0.105	0.120	0.118	0.119	0.112	0.104	0.119
iCAM Brightness Q	12.56	12.72	12.93	12.97	12.91	12.83	12.86	12.81	13.02	13.00	12.75
iCAM Colourfulness M	2.84	3.07	2.80	2.76	2.73	2.64	2.62	2.62	2.30	2.60	2.34
CIECAM02 Lightness **J**	86.72	88.42	89.73	90.05	89.47	88.71	88.93	88.52	89.80	90.08	87.61
CIECAM02 Chroma **C**	21.69	23.17	21.16	20.89	20.69	19.97	19.81	19.87	17.48	19.64	17.86
CIECAM02 redness-greenness **a**	0.0031	0.0086	0.0014	-0.0003	0.0025	0.0096	0.0087	0.0089	0.0034	0.0014	0.0069
CIECAM02 yellowness- blueness **b**	0.452	0.487	0.444	0.438	0.433	0.418	0.414	0.415	0.363	0.411	0.370
CIECAM02 Angle Hue **h**	89.60	88.98	89.80	90.04	89.66	88.67	88.79	88.76	89.45	89.80	88.92
CIECAM02 Hue composition **H**	99.35	98.34	99.68	100.08	99.45	97.83	98.03	97.97	99.11	99.67	98.25
CIECAM02 **Hc (Red)**	0.646	1.655	0.313	0	0.549	2.164	1.961	2.022	0.883	0.322	1.747
CIECAM02 **Hc (Yellow)**	99.35	98.34	99.68	99.91	99.45	97.83	98.03	97.97	99.11	99.67	98.25
CIECAM02 **Hc (Green)**	0	0	0	0.086	0	0	0	0	0	0	0

PARAMETER	CARAHELL®	CARAAMBER®	MELANOIDIN MALT	CARAMUNICH® TYPE III	CARAAROMA®	CARAFA ® TYPE III	CARAFA SPECIAL® TYPE III	ROASTED BARLEY	SINAMAR ®	CARAMEL #301	PILSNER MALT
CIECAM02 **Hc (Blue)**	0	0	0	0	0	0	0	0	0	0	0
CIECAM02 Brightness **Q**	221.61	223.77	225.43	225.82	225.10	224.14	224.41	223.89	225.51	225.86	222.74
CIECAM02 Colourfulness **M**	20.47	21.87	19.97	19.71	19.52	18.85	18.70	18.76	16.50	18.54	16.86
CIECAM02 Saturation **s**	30.39	31.26	29.76	29.54	29.45	29.00	28.87	28.94	27.05	28.65	27.51

Table A.2.7 Beer colour adjustment (mean & standard deviation values)

PARAMETER	CARAHELL®	CARAAMBER®	MELANOIDIN MALT	CARAMUNICH® TYPE III	CARAAROMA®	CARAFA® TYPE III	CARAFA® SPECIAL TYPE III	ROASTED BARLEY	SINAMAR®	CARAMEL #301	PILSNER MALT
Ratio (specialty malt/ base malt) %	**10/90**	**3.9/96.1**	**3.9/96.1**	**1.9/98.1**	**0.8/99.2**	**0.8/99.2**	**0.2/99.8**	**0.2/99.8**	**0.04/99.96**	**0.02/99.98**	**100**
Ratio (specialty malt/ base malt) kg	**5.20/46.80**	**2.02/49.98**	**2.02/49.98**	**0.98/51.02**	**0.39/51.61**	**0.10/51.90**	**0.10/51.90**	**0.10/51.90**	**0.02 (0.017 mL)/ 51.98**	**0.01 / 51.99**	**52.00**
Colour EBC Abs. 430 nm	0.360 (0.001)	0.366 (0.002)	0.357 (0.001)	0.347 (0.000)	0.347 (0.0005)	0.343 (0.000)	0.335 (0.0005)	0.344 (0.000)	0.328 (0.0005)	0.322 (0.0011)	0.2780 (0.001)
Colour EBC	**8.996 (0.025)**	**9.180 (0.069)**	**8.936 (0.028)**	**8.670 (0.000)**	**8.690 (0.017)**	**8.570 (0.000)**	**8.390 (0.000)**	**8.620 (0.000)**	**8.216 (0.0173)**	**7.980 (0.1558)**	**6.946 (0.0251)**
Colour Tristimulus %T 360 nm	01.50 (0.100)	1.23 (0.057)	1.60 (0.100)	1.55 (0.356)	1.93 (0.152)	2.30 (0.000)	2.56 (0.057)	2.36 (0.057)	2.73 (0.057)	2.00 (0.000)	3.30 (0.057)
Colour Tristimulus %T 450 nm	48.30 (0.000)	48.13 (0.057)	52.80 (0.100)	53.76 (0.057)	53.40 (0.100)	53.36 (0.057)	58.83 (0.057)	53.16 (0.115)	58.96 (0.057)	55.80 (0.000)	55.36 (0.057)
Colour Tristimulus %T 540 nm	76.4 (0.100)	79.16 (0.057)	81.56 (0.115)	82.10 (0.000)	81.03 (0.057)	79.40 (0.000)	79.83 (0.057)	79.10 (0.000)	81.30 (0.100)	82.00 (0.000)	77.60 (0.000)
Colour Tristimulus %T 670 nn	89.9 (0.100)	94.4 (0.000)	95.00 (0.000)	95.23 (0.057)	94.36 (0.057)	93.50 (0.000)	93.83 (0.152)	93 .00 (0.000)	93.66 (0.057)	94.83 (0.057)	90.16 (0.115)
Colour Tristimulus %T 760 nm	93.3 (0.057)	98.03 (0.057)	98.26 (0.057)	98.50 (0.000)	97.53 (0.0057)	97.43 (0.0057)	97.76 (0.0057)	96.70 (0.0000)	97.00 (0.0000)	98.20 (0.0000)	93.30 (0.000)
Colour Tristimulus Values X (Red)	71.25 (0.038)	73.93 (0.027)	75.93 (0.042)	76.40 (0.024)	75.58 (0.025)	74.56 (0.008)	74.94 (0.067)	74.23 (0.016)	76.33 (0.041)	76.55 (0.018)	72.9818 (0.0418)
Colour Tristimulus Values Y (Green)	76.21 (0.062)	79.02 (0.040)	81.29 (0.072)	81.81 (0.015)	80.85 (0.038)	79.53 (0.005)	79.95 (0.066)	79.20 (0.011)	81.46 (0.065)	81.87 (0.011)	77.8140 (0.0262)

PARAMETER	CARAHELL®	CARAAMBER®	MELANOIDIN MALT	CARAMUNICH® TYPE III	CARAAROMA®	CARAFA® TYPE III	CARAFA® SPECIAL TYPE III	ROASTED BARLEY	SINAMAR®	CARAMEL #301	PILSNER MALT
Colour Tristimulus Values Z (Blue)	52.035 (0.012)	52.23 (0.013)	56.60 (0.061)	57.52 (0.044)	57.06 (0.106)	56.83 (0.048)	57.32 (0.04)	56.63 (0.092)	61.89 (0.033)	59.24 (0.00)	58.379 (0.0520)
Colour CIELAB L*	**87.60 (0.020)**	**88.883 (0.011)**	**89.82 (0.020)**	**90.043 (0.015)**	**89.66 (0.01)**	**89.18 (0.000)**	**89.363 (0.032)**	**89.02 (0.115)**	**90-00 (0.020)**	**90.10 (0.005)**	**88.436 (0.020)**
Colour CIELAB a*	**-3.33 (0.032)**	**-3.32 (0.011)**	**-3.32 (0.011)**	**-3.48 (0.011)**	**-3.40 (0.011)**	**-3.19 (0.000)**	**-3.20 (0.005)**	**-3.20 (0.005)**	**-3.24 (0.020)**	**-3.40 (0.005)**	**-3.13 (0.017)**
Colour CIELAB b*	**14.15 (0.017)**	**15.08 (0.005)**	**15.08 (0.005)**	**13.77 (0.011)**	**13.63 (0.035)**	**13.26 (0.017)**	**13.20 (0.04)**	**13.22 (0.040)**	**11.84 (0.032)**	**13.07 (0.005)**	**11.98 (0.02)**
Colour CIELAB C* (Metric Chroma)	**14.54 (0.049)**	**15.45 (0.011)**	**15.45 (0.115)**	**14.21 (0.017)**	**14.05 (0.025)**	**13.63 (0.023)**	**13.58 (0.035)**	**13.61 (0.034)**	**12.28 (0.041)**	**13.51 (0.005)**	**12.383 (0.015)**
Yellowness Index	**47.28 (0.042)**	**48.68 (0.000)**	**45.75 (0.100)**	**45 (0.036)**	**44.83 (0.120)**	**44.24 (0..051)**	**43.97 (0.120)**	**44.17 (0.103)**	**39.38 (0.075)**	**42.966(0.023)**	**40.52 (0.060)**
iCAM Lightness J	**6.21 (0.002)**	**6.29 (0.001)**	**6.4 (0.001)**	**6.42 (0.001)**	**6.39 (0.001)**	**6.35 (0.000)**	**6.36 (0.002)**	**6.34 (0.001)**	**6.44 (0.002)**	**6.43 (0.000)**	**6.3150 (0.0010)**
iCAM Choma C	**1.40 (0.002)**	**1.52 (0.001)**	**1.39 (0.005)**	**1.36 (0.001)**	**1.35 (0.004)**	**1.30 (0.002)**	**1.30 (0.005)**	**1.30 (0.004)**	**1.14 (0.003)**	**1.28 (0.000)**	**1.1593 (0.0020)**
iCAM Hue h	**1.016 (0.0020)**	**0.1106 (0.0011)**	**0.1010 (0.0017)**	**0.0993 (0.0005)**	**0.01043 (0.0011)**	**0.1196 (0.0005)**	**0.1186 (0.0005)**	**0.1183 (0.0005)**	**0.1130 (0.0017)**	**0.1036 (0.0005)**	**0.120 (0.0017)**
iCAM Brightness Q	**12.56 (0.003)**	**12.72 (0.002)**	**12.93 (0.003)**	**12.97 (0.002)**	**12.91 (0.004)**	**12.83 (0.001)**	**12.86 (0.003)**	**12.81 (0.002)**	**13.02 (0.003)**	**13.00 (0.000)**	**12.76 (0.0025)**
iCAM Colourfulness M	**2.84 (0.004)**	**3.07 (0.002)**	**2.811 (0.010)**	**2.76 (0.003)**	**2.72 (0.008)**	**2.64 (0.004)**	**2.63 (0.009)**	**2.63 (0.008)**	**2.30 (0.007)**	**2.59 (0.001)**	**2.3423 (0.0040)**
CIECAM02 Lightness **J**	**86.69 (0.037)**	**88.44 (0.023)**	**89.75 (0.040)**	**90.05 (0.011)**	**89.48 (0.020)**	**88.71 (.000)**	**88.96 (0.043)**	**88.50 (0.011)**	**89.80 (0.040)**	**90.07 (0.005)**	**87.626 (0.020)**
CIECAM02 Chroma **C**	**21.66 (0.037)**	**23.18 (0.011)**	**21.23 (0.087)**	**20.85 (0.028)**	**20.62 (0.060)**	**19.99 (0.034)**	**19.87 (0.065)**	**19.943 (0.063)**	**17.5 (0.062)**	**19.70 (0.115)**	**17.826 (0.030)**
CIECAM02 redness- greenness **a**	**0.004 (0.0010)**	**0.007 (0.0008)**	**0.0009 (0.0008)**	**-0.0003 (0.0000)**	**0.0023 (0.0005)**	**0.0095(0.0000)**	**0.0090 (0.0003)**	**0.0088 (0.0000)**	**0.0037 (0.0007)**	**0.0012 (0.0003)**	**0.0073 (0.0006)**
CIECAM02 yellowness-	**0.451 (0.0005)**	**0.487 (0.0005)**	**0.445 (0.0013)**	**0.437 (0.0005)**	**0.432 (0.001)**	**0.418 (0.0005)**	**0.415 (0.0015)**	**0.417 (0.0017)**	**0.363 (0.0011)**	**0.411 (0.0000)**	**0.3693 (0.0005)**

PARAMETER	CARAHELL®	CARAAMBER®	MELANOIDIN MALT	CARAMUNICH® TYPE III	CARAAROMA®	CARAFA® TYPE III	CARAFA® SPECIAL TYPE III	ROASTED BARLEY	SINAMAR®	CARAMEL #301	PILSNER MALT
blueness **b**											
CIECAM02 Angle Hue **h**	89.43 (0.145)	89.03 (0.046)	89.87 (0.118)	90.01 (0.051)	89.68 (0.068)	88.67 (0.01)	88.74 (0.04)	88.78 (0.017)	89.4 (0.122)	89.85 (0.051)	88.846 (0.1021)
CIECAM02 Hue composition **H**	99.08 (0.236)	98.42 (0.075)	99.8 (0.1907)	100.03 (0.086)	99.49 (0.115)	97.84 (0.023)	97.95 (0.070)	98.01 (0.034)	99.02 (0.204)	99.04 (1.085)	98.13 (0.166)
CIECAM02 **Hc (Red)**	0.91 (0.233)	1.56 (0.075)	0.20 (0.176)	0.02 (0.039)	0.50 (0.113)	2.14 (0.024)	2.03 (0.069)	1.98 (0.035)	0.96 (0.202)	0.281 (0.069)	1.862 (0.1639)
CIECAM02 **Hc (Yellow)**	99.08 (0.236)	98.42 (0.075)	99.78 (0.161)	99.91 (0.011)	99.49 (0.115)	97.84 (0.023)	97.95 (0.070)	98.01 (0.034)	99.02 (0.204)	99.04 (1.085)	98.13 (0.166)
CIECAM02 **Hc (Green)**	0.000 (0.000)	0.000 (0.0000)	0.007 (0.121)	0.0286 (0.0496	0.000 (0.0000)	0.000 (0.0000)	0.000 (0.0000)	0.000 (0.0000)	0.000 (0.0000)	0.000 (0.0000)	0.000 (0.0000)
CIECAM02 **Hc (Blue)**	0.000 (0.000)	0.000 (0.0000)	0.000 (0.0000)	0.000 (0.0000)	0.000 (0.0000)	0.000 (0.0000)	0.000 (0.0000)	0.000 (0.0000)	0.000 (0.0000)	0.000 (0.0000)	0.000 (0.0000)
CIECAM02 Brightness **Q**	221.57 (0.047)	223.80 (0.028)	225.45 (0.049)	225.72 (0.181)	225.12 (0.026)	224.46 (0.570)	224.44 (0.055)	223.85 (0.049)	225.52 (0.045)	225.85 (0.011)	222.76 (0.026)
CIECAM02 Colourfulness **M**	20.46 (0.03)	21.88 (0.011)	20.04 (0.081)	20.07 (0.664)	19.46 (0.050)	18.86 (0.028)	18.76 (0.060)	18.82 (0.057)	16.51 (0.056)	18.53 (0.005)	16.82 (0.030)
CIECAM02 Saturation **s**	30.37 (0.023)	31.26 (0.005)	29.81 (0.061)	29.52 (0.017)	29.40 (0.040)	29.013 (0.023)	28.91 (0.040)	28.99 (0.046)	27.06 (0.041)	28.64 (0.005)	27.48 (0.025)

Table A.2.8 Proposed grain bills for colour adjustment determination

PARAMETER	CARAHELL®	CARAAMBER®	MELANOIDIN MALT	CARAMUNICH®TYPE III	CARAAROMA®	CARAFA® TYPE III	CARAFA® SPECIAL TYPE III	ROASTED BARLEY	SINAMAR ®	CARAMEL #301	PILSNER MALT
Raw material source	GERMAN- GROWN “MARTHE” SPRING BARLEY (2006 harvest)										
Recommended Quantities	Up to 15% of total grain bill (Low Gravity) Up to 30% of total grain bill(High Gravity)	Up to 20% of total grain bill	Up to 20% of total grain bill	Up to 5% of total grain bill (pale beers)	Up to 20% of total grain bill	Up to 5% of total grain bill	Up to 5% of total grain bill	Up to 5% of total grain bill	14 g (11.9 mL) 1hL/1EBC		Up to 100% of total grain bill
Wort Colour EBC	20 min 30 max	60 min 80 max	60 min 80 max	170 min 220 max	350 min 450 max	1300 min 1500 max	1300 min 1500 max	1000 min 1300 max	8100 min 8600 max	29,800 (typical)	2.5 min 4.0 max
Wort Colour Lovibond	8.1 min 11.8 max	23 min 31 max	23 min 31 max	64 min 83 max	115 min 150 max	488 min 563 max	488 min 563 max	375 min 450 max	3040 min 3200 max		1.5 min 2.1 max
Ratio (specialty malt/ base malt) %	**10/90**	**3.9/96.1**	**3.9/96.1**	**1.9/98.1**	**0.8/99.2**	**0.2/99.2**	**0.2/99.8**	**0.2/99.8**	**0.04/99.96**	**0.02/99.98**	**100**
Ratio (specialty malt/ base malt) kg	**5.20/46.80**	**2.02/49.98**	**2.02/49.98**	**0.98/51.02**	**0.39/51.61**	**0.10/51.90**	**0.10/51.90**	**0.10/51.90**	**0.02 (0.017 mL)/ 51.98**	**0.01 / 51.99**	**52.00**

Table A.3.1 CARAHELL®

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
Sp. Gravity (S 20/20) Beer	1.0076	1.0076	1.0075	1.0075	1.0075	1.00754	0.000054	**1.00585 - 1.01175** r95:N/A R95: N/A
App. Extract (EA) %	1.95	1.95	1.93	1.93	1.93	1.938	0.010954	**1.5 – 3.0** r95:0.012 R95:0.080
Sp. Gravity (S 20/20) Alcohol	0.99280	0.99280	0.99286	0.99288	0.99288	0.992848	0.004380	**0.99675 – 0.98770** r95: N/A R95: N/A
Alcohol (mas%)	3.98	3.98	3.95	3.95	3.95	3.962	0.01643	**1.75-7.20** r95: 0.03 ± 0.005m R95: 0.03 ± 0.02m
Alcohol (vol%)	5.00	5.00	4.96	4.96	4.96	4.976	0.02190	**2.2-9.0** r95: 0.04 ± 0.004m R95: 0.04 ± 0.02m
Sp. Gravity (S 20/20) Real extract	1.0155	1.0156	1.0155	1.0159	1.0155	1.01560	0.00017	**1.01175-1.02370** r95: N/A R95: N/A
Real extract (ER) %	3.96	3.98	3.96	4.06	3.96	3.984	0.0433	**3.0-6.0** r95:0.02m R95: 0.02m
Original Gravity (OG) %	12.22	12.22	12.22	12.23	12.22	12.224	0.0054	**7.0-12.0** r95: 0.07 R95: 0.19
pH	4.18	4.18	4.19	4.20	4.19	4.188	0.00876	**Pils: 4.3-4.6** r95:0.02 R95:0.13
Bitter units	A275: 0.4201 IBU: 21.00 ≈ 21	A275: 0.431 IBU: 21.55 ≈ 21	A275: 0.428 IBU: 21.40 ≈ 21	A275: 0.424 IBU: 21.20 ≈ 21	A275: 0.421 IBU: 21.05 ≈ 21	A275: 0.4248 IBU: 21.2 ≈ 21	A275: 0.0046 IBU: 0.23	**A275: 0.200-0.800 IBU: 10-40** r95: 0.44 ± 0.014m R95: -0.7 ± 0.18m
Colour Visual Comp. EBC/Lovibond	7.5	7.5	7.5	7.5	7.5	7.50	0.000	**Pale beers: 7-11 EBC** r95: 0.4 R95: 1.8
Colour (430 nm) EBC	A430: 0.365 EBC: 7.875	A430: 0.365 EBC: 7.875	A430: 0.365 EBC: 7.875	A430: 0.367 EBC: 7.925	A430: 0.367 EBC: 7.925	A430: 0.3858 EBC: 7.89	A430: 0.0010 EBC: 0.02	**Pale beers: 7-11 EBC** r95: 0.3 R95:0.6
Colour Tristimulus %T 360 nm	1.09	1.07	1.05	1.07	1.04	1.064	0.0194	
Colour Tristimulus	29.81	29.83	29.81	29.90	29.80	29.83	0.0406	

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
%T 450 nm								
Colour Tristimulus %T 540 nm	61.82	61.90	61.73	61.87	61.85	61.834	0.0650	
Colour Tristimulus %T 670 nm	89.71	89.67	89.57	89.72	89.63	89.66	0.0616	
Colour Tristimulus %T 760 nm	92.17	92.16	92.07	92.17	92.17	92.148	0.0438	
Colour Tristimulus ∑ x/k	652.475	652.753	651.555	652.889	652.322	652.398	0.5218	
Colour Tristimulus ∑ y/k	677.587	678.116	676.627	678.073	677.630	677.606	0.5994	
Colour Tristimulus ∑ z/k	361.769	362.048	361.592	362.631	361.673	361.942	0.4215	
Colour Tristimulus Values **X (Red)**	61.73	61.76	61.65	61.77	61.72	61.732	0.0496	
Colour Tristimulus Values **Y (Green)**	64.11	64.16	64.02	64.16	64.12	64.117	0.0567	
Colour Tristimulus Values **Z (Blue)**	34.23	34.25	34.21	34.31	34.22	34.248	0.0396	
Colour CIELAB L*	82.77	82.78	82.72	82.79	82.76	82.769	0.0260	**96.63 *, 93.83**** r95: 0.55 R95: 2.26
Colour CIELAB a*	-1.201	-1.225	-1.200	-1.207	-1.221	-1.2108	0.0115	**-2.04 *, -7.83 **** r95: 0.19 R95: 0.56
Colour CIELAB b*	18.61	18.61	18.58	18.58	18.61	18.602	0.0193	**14.39 *, 32.97**** r95: 1.01 R95: 2.20
Colour CIELAB C* (Metric Chroma)	18.65	18.65	18.62	18.62	18.65	18.617	0.0363	
Yellowness Index	66.66	66.61	66.61	66.55	66.64	66.607	0.0313	
iCAM Lightness **J**	5.68	5.68	5.67	5.68	5.68	5.68	0.002	
iCAM Chroma **C**	1.94	1.94	1.94	1.94	1.94	1.944	0.0018	
iCAM Angle Hue **h**	0.208	0.207	0.208	0.208	0.207	0.2078	0.0006	
iCAM Brightness **Q**	11.47	11.48	11.47	11.48	11.47	11.47	0.004	
iCAM	3.93	3.93	3.92	3.92	3.93	3.929	0.0036	

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
Colourfulness **M**								
CIECAM02 Lightness **J**	79.31	79.34	79.25	79.34	79.31	79.319	0.0374	Repeat.****: r^2: 0.84 CV:19 Reprod. ****: r^2: 0.88 CV:17
CIECAM02 Chroma **C**	29.89	29.89	29.84	29.83	29.90	29.874	0.0296	
CIECAM02 redness-greenness **a**	0.088	0.089	0.088	0.087	0.087	0.0881	0.0008	
CIECAM02 yellowness-blueness **b**	0.620	0.620	0.618	0.618	0.620	0.6196	0.00068	
CIECAM02 Angle Hue **h**	81.90	81.99	81.89	81.90	81.98	81.937	0.0475	
CIECAM02 Hue composition **H**	86.97	86.11	86.95	86.97	87.09	86.822	0.4017	Repeat.****: r^2: 0.99 CV: 8 Reprod. ****: r^2: 0.99 CV:10
CIECAM02 **Hc (Red)**	13.02	12.88	13.04	13.02	12.90	12.977	0.0735	
CIECAM02 **Hc (Yellow)**	86.97	87.11	86.95	86.97	87.04	87.013	0.0648	
CIECAM02 **Hc (Green)**	0.0000	0.0000	0.0000	0.0000	0.0000	0.00000	0.000000	
CIECAM02 **Hc (Blue)**	0.0000	0.0000	0.0000	0.0000	0.0000	0.00000	0.000000	
CIECAM02 Brightness **Q**	211.93	211.98	211.85	211.85	211.94	211.91	0.055	
CIECAM02 Colourfulness **M**	28.21	28.21	28.17	28.17	29.90	28.53	0.763	Repeat.****: r^2: 0.72 CV: 30 Reprod.****: r^2: 0.67 CV:37
CIECAM02 Saturation **s**	36.48	36.48	36.46	36.46	36.49	36.478	0.0119	
Turbidity 20℃ EBC	0.62	0.66	0.62	0.65	0.60	0.63	0.0244	**N/A** r95: 0.05 R95:0.20
Shelf Life Prediction Forcing method EBC (modified according to Titze *et al.*, 2007) (60℃,24 h/ 0℃, 24h/ 20℃) EBC-formazin units/ Warm days	Blank: 0.626 EBC: 2.78 W. days: 12	Blank: 0.664 EBC: 2.23 W. days: 12	Blank: 0.621 EBC: 2.88 W. days: 12	Blank: 0.655 EBC: 2.31 W. days: 12	Blank: 0.608 EBC: 2.46 W. days: 12	Blank: 0.6348 EBC: 2.53 W. days: 12.0	Blank: 0.02370 EBC: 0.28 W. days: 0.00	
NIBEM	Sec: 261 10: 87 20: 172	Sec: 255 10: 84 20: 168	Sec: 266 10: 90 20: 174	Sec: 264 10: 87 20: 170	Sec: 260 10: 87 20: 168	Sec: 261 10: 87 20: 170.4	Sec: 4.20 10: 2.12 20: 2.60	**For lager beers:** **Bad: < 220 sec Very Good: > 300 sec**

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
	30: 261	30: 255	30:266	30: 264	30: 260	30: 261.2	30: 4.207	r95: 9 R95:42
CO_2% vol.	3.15	3.19	3.01	3.00	2.99	3.068	0.094	**Vol %: 2.5 -3.0** r95: 0.09 R95:0.08m
Dissolved oxygen (mg/L) (Orbisphere DO)	0.151	0.137	0.163	0.091	0.086	0.1256	0.03513	**< 0.3** r95:0.15 mg/L R95: 0.3 mg/L
Total polyphenols (mg/L)	A820: 0.180 Polyθ: 147.60	A820: 0.184 Polyθ: 150.88	A820: 0.184 Polyθ: 150.88	A820: 0.188 Polyθ: 154.16	A820: 0.182 Polyθ: 149.24	A820: 0.1836 Polyθ: 150.552	A820: 0.0029 Polyθ: 2.4325	**A820: 0.091-0.121 Polyθ: 73-176** r95:4.1 R95: 18 ± 0.13m
Flavanoids (mg/L)	AB640: -0.053 AS640: 0.031 Flav: 28.14	AB640: -0.053 AS640: 0.031 Flav: 28.14	AB640: -0.053 AS640: 0.032 Flav: 28.47	AB640: -0.053 AS640: 0.032 Flav: 28.47	AB640: -0.053 AS640: 0.031 Flav: 28.14	AB640: -0.053 AS640: 0.0314 Flav:28.2	AB640: 0.000 AS640 : 0.0005 Flav: 0.18	**Flav: 50-70** CV_{r95}: ± 4.7% CV_{R95}: ± 7.6%
Iron (mg/L) **Samples** (Atomic Absorption Spectrometry)	A248.3: 0.187	A248.3: 0.244	A248.3: 0.389	A248.3: 0.594	A248.3: 0.781 Fe (II): 0.169			**Fe(II): < 0.2 Recommend. values** r95: 0.21m R95: 0.91m
Copper (mg/L) **Samples** (Atomic Absorption Spectrometry)	A324.7: 0.114	A324.7: 0.225	A324.7: 0.332	A324.7: 0.533	A324.7: 0.752 Cu (II): 0.111			**Cu (II): < 0.2 Recommend. values** r95: 0.45m R95: 1.71m
Calcium (mg/L) **Samples** (Atomic Absorption Spectrometry)	A423.0: 0.080	A423.0: 0.110	A423.0: 0.120	A423.0: 0.128	A423.0: 0.137 Ca (II): 0.180			**Ca (II): 4 -100 Recommend. values** CV_{ST95}: ±13.3% CV_{Sr95}: ±2.4% CV_{Sb95}: ±9.2 %
Reducing Power (MEBAK) %RED	69.7	71.1	70.2	68.7	72.8	70.5	1.5508	**> 60 very good 50-60 good 45-50 satisfactory < 45 poor** CV_{r95}: ± 1%
2-Methylpropanal (µg/L)	3.84	3.78				3.81	0.0424	**Fresh: 6.68 (±0.60) *** 2 weeks 40℃: 39.15 (±0.47)**
2-Methylbutanal (µg/L)	2.62	2.74				2.68	0.0848	**Fresh: 18.6 ***** CV(%): 7.8 CI(abs): 1.0 CI(%): 5.6 **Forced: 19.6**

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
								******* CV(%): 7.0 CI(abs): 1.0 CI(%): 5.0 **6-Months: 9.8 ***** **1-Year: 20.6 *****
3-Methylbutanal (µg/L)	6.27	6.38				6.325	0.0777	**Fresh: 10.5 ***** CV(%): 4.0 CI(abs): 0.3 CI(%): 2.9 **Forced: 13.9 ***** CV(%): 5.7 CI(abs): 0.6 CI(%): 4.1 **6-Months: 16.1 ***** **1-Year: 29.0 *****
Benzaldehyde (µg/L)	1.38	1.29				1.335	0.0636	**Fresh: 0.96 (±0.02) ***** **Forced: 0.0 ***** CV(%): 0.0 CI(abs): 0.0 CI(%): 0.0 **6-Months: 1.8 ***** **1-Year: 3.3 *****
2-Phenylethanal (µg/L)	17.46	17.11				17.285	0.2474	**Fresh: 21.5 ***** CV(%): 10.3 CI(abs): 1.6 CI(%): 7.4 **Forced: 38.3 ***** CV(%): 5.3 CI(abs): 1.5 CI(%): 3.8 **6-Months: 32.2 ***** **1-Year: 55.8 *****
2-Furfural (µg/L)	13.64	14.06				13.85	0.2969	**Fresh: 7.1***** CV(%): 7.5 CI(abs): 0.4 CI(%): 5.4 **Forced: 110.8 ***** CV(%): 4.7 CI(abs): 3.8 CI(%): 3.4 **6-Months: 164.9 ***** **1-Year: 534.5 *****
Pentanal (µg/L)	0.71	0.68				0.695	0.0212	**Fresh: 1.9 ***** CV(%): N/A CI(abs): N/A CI(%): N/A **Forced: 4.5***** CV(%): N/A CI(abs): N/A

Analysis	Beer 1	Beer 2	Beer 3	Beer 4	Beer 5	Mean	Standard Deviation (Sx)	Normal Values
								CI(%): N/A **6-Months:4.9 ***** **1-Year: N/A**
Hexanal (µg/L)	0.74	0.81				0.775	0.0494	**Fresh: 0.75 ***** CV(%): 6.22 CI(abs): N/A CI(%): N/A **Forced: N/A ***** CV(%): N/A CI(abs): N/A CI(%): N/A **6-Months: 0.8 ***** **1-Year: 1.0 *****
Methional (µg/L)	3.04	3.11				3.075	0.0494	**Fresh: 1.07(±0.19) ***** CV(%): N/A CI(abs): N/A CI(%): N/A **2weeks 40℃: 3.03** **6-Months: N/A ***** **1-Year: N/A**
(*E*)-2-nonenal (µg/L)	0.0023	0.0026				0.00245	0.000212	**Fresh: no quantifiable** **2 weeks 40℃: 0.070 (±0.09) *****

The normal values are reported according to Brautechnische Analysenmethoden. Band II. Mitteleuropäische Brautechnische Analysenkommission (M.E.B.A.K.) (2002), except; * according to American Society of Brewing Chemist. Report of Subcommittee on Wort and Beer. Colour Using Tristimulus Analysis (2000), ** according to Smedley (1992, 1995), *** according to Lustig (1993); Saison *et al.* (2008), **** according to Gonzalez-Miret *et al.* (2007); Luo *et al*. (1991a, 1991b)

Table A.3.2 CARAAMBER®

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
Sp. Gravity (S 20/20) Beer	1.0079	1.0078	1.0078	1.0077	1.0077	1.00778	0.000883	**1.00585 - 1.01175** r95:N/A R95: N/A
App. Extract (EA) %	2.03	2.0	2.0	1.98	1.98	1.998	0.0204	**1.5 – 3.0** r95:0.012 R95:0.080
Sp. Gravity (S 20/20) Alcohol	0.99303	0.99301	0.99303	0.99302	0.99802	0.993022	0.00008	**0.99675 – 0.98770** r95: N/A R95: N/A
Alcohol (mas%)	3.85	3.87	3.85	3.85	3.85	3.854	0.00894	**1.75-7.20** r95: 0.03 ± 0.005m R95: 0.03 ± 0.02m
Alcohol (vol%)	4.84	4.86	4.84	4.84	4.84	4.844	0.00894	**2.2-9.0** r95: 0.04 ± 0.004m R95: 0.04 ± 0.02m
Sp. Gravity (S 20/20) Real extract	1.0144	1.0144	1.0144	1.0145	1.0144	1.01442	0.000044	**1.01175-1.02370** r95: N/A R95: N/A
Real extract (ER) %	3.68	3.68	3.68	3.70	3.68	3.684	0.0089	**3.0-6.0** r95:0.02m R95: 0.02m
Original Gravity (OG) %	12.33	12.37	12.33	12.35	12.33	12.342	0.0178	**7.0-12.0** r95: 0.07 R95: 0.19
pH	4.13	4.14	4.14	4.15	4.15	4.142	0.0083	**Pils: 4.3-4.6** r95:0.02 R95:0.13
Bitter units	A275: 0.463 IBU: 23.18 ≈ 23	A275: 0.468 IBU: 23.40 ≈ 23	A275: 0.464 IBU: 23.23 ≈ 23	A275: 0.462 IBU: 23.11 ≈ 23	A275: 0.461 IBU: 23.09 ≈ 23	A275: 0.4640 IBU: 23.2 ≈ 23	A275: 0.0024 IBU: 0.12	**A275: 0.200-0.800** **IBU: 10-40** r95: 0.44 ± 0.014m R95: -0.7 ± 0.18m
Colour Visual Comp. EBC/Lovibond	7.0	7.0	7.0	7.0	7.0	7.00	0.000	**Pale beers: 7-11 EBC** r95: 0.4 R95: 1.8
Colour (430 nm) EBC	A430: 0.308 EBC: 7.7	A430: 0.309 EBC: 7.7	A430: 0.309 EBC: 7.7	A430: 0.309 EBC: 7.7	A430: 0.309 EBC: 7.7	A430: 0.3088 EBC: 7.72	A430: 0.0004 EBC:0.01	**Pale beers: 7-11 EBC** r95: 0.3 R95:0.6
Colour Tristimulus %T 360 nm	1.15	1.14	1.15	1.16	1.12	1.144	0.1516	
Colour Tristimulus %T 450 nm	49.31	49.32	49.39	49.39	49.39	49.36	0.04123	

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
Colour Tristimulus %T 540 nm	80.99	80.91	80.99	81.01	81.01	80.982	0.0414	
Colour Tristimulus %T 670 nm	90.31	90.25	90.26	90.69	90.31	90.364	0.1843	
Colour Tristimulus %T 760 nm	93.31	93.30	93.33	93.35	93.35	93.328	0.0228	
Colour Tristimulus ∑ x/k	778.24	777.49	778.02	779.58	778.28	778.325	0.7720	
Colour Tristimulus ∑ y/k	796.06	840.58	841.27	842.32	841.52	832.356	20.2978	
Colour Tristimulus ∑ z/k	535.12	565.44	566.24	566.29	566.24	559.871	13.8359	
Colour Tristimulus Values **X (Red)**	73.62	73.56	73.61	73.76	73.64	73.644	0.0737	
Colour Tristimulus Values **Y (Green)**	79.60	79.53	79.60	79.70	79.62	79.616	0.0542	
Colour Tristimulus Values **Z (Blue)**	53.51	53.50	53.58	53.58	53.58	53.553	0.0388	
Colour CIELAB L*	88.74	88.71	88.74	88.81	88.75	88.754	0.03501	**96.63 *, 93.83**** r95: 0.55 R95: 2.26
Colour CIELAB a*	-4.14	-4.14	-4.15	-4.09	-4.14	-4.137	0.0220	**-2.04 *, -7.83 **** r95: 0.19 R95: 0.56
Colour CIELAB b*	14.73	14.71	14.70	14.73	14.71	14.719	0.0151	**14.39 *, 32.97**** r95: 1.01 R95: 2.20
Colour CIELAB C* (Metric Chroma)	15.30	15.28	15.27	15.29	15.28	15.290	0.0116	
Yellowness Index	47.12	47.08	47.02	47.20	47.05	47.098	0.0678	
iCAM Lightness **J**	6.32	6.32	6.32	6.32	6.32	6.326	0.0019	
iCAM Chroma **C**	1.46	1.46	1.46	1.46	1.46	1.463	0.0019	
iCAM Angle Hue **h**	0.052	0.052	0.052	0.056	0.052	0.0531	0.00167	
iCAM Brightness **Q**	12.78	12.77	12.78	12.78	12.78	12.78	0.003	
iCAM Colourfulness **M**	2.96	2.95	2.95	2.96	2.95	2.957	0.0040	

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
CIECAM02 Lightness **J**	88.68	88.64	88.68	88.74	88.69	88.691	0.0381	Repeatability****: r^2: 0.84 CV:19 Reproducibility****: r^2: 0.88 CV:17
CIECAM02 Chroma **C**	22.73	22.69	22.67	22.71	22.69	22.70	0.0213	
CIECAM02 redness-greenness **a**	-0.025	-0.025	-0.025	-0.023	-0.025	-0.0252	0.00091	
CIECAM02 yellowness-blueness **b**	0.473	0.472	0.471	0.473	0.472	0.4725	0.00059	
CIECAM02 Angle Hue **h**	93.10	93.08	93.13	92.85	93.11	93.057	0.1141	
CIECAM02 Hue composition **H**	105.86	105.82	105.91	105.40	105.88	105.781	0.2123	Repeat.****: r^2: 0.99 CV: 8 Reprod. ****: r^2: 0.99 CV:10
CIECAM02 **Hc (Red)**	0.00	0.00	0.00	0.00	0.00	0.000	0.0000	
CIECAM02 **Hc (Yellow)**	94.13	94.17	94.08	94.59	94.11	94.218	0.2123	
CIECAM02 **Hc (Green)**	5.86	5.88	5.91	5.40	5.88	5.793	0.2168	
CIECAM02 **Hc (Blue)**	0.00	0.00	0.00	0.00	0.00	0.000	0.0000	
CIECAM02 Brightness **Q**	224.10	224.05	224.09	224.18	224.11	224.110	0.0481	
CIECAM02 Colourfulness **M**	21.45	21.41	21.40	21.44	21.41	21.428	0.0201	Repeat.****: r^2: 0.72 CV: 30 Reprod.****: r^2: 0.67 CV:37
CIECAM02 Saturation **s**	30.94	30.91	30.90	30.92	30.91	30.922	0.0134	
Turbidity 20℃ EBC	0.77	0.76	0.75	0.76	0.76	0.7628	0.0098	**N/A** r95: 0.05 R95:0.20
Shelf Life Prediction Forcing method EBC (modified according to Titze *et al.*, 2007) (60℃,24 h/ 0℃, 24h/ 20℃) EBC-formazin units/ Warm days	Blank: 0.771 EBC: 2.49 W. days: 11	Blank: 0.760 EBC: 2.47 W. days: 11	Blank: 0.759 EBC: 2.77 W. days: 11	Blank: 0.763 EBC: 2.50 W. days: 11	Blank: 0.761 EBC: 2.43 W. days: 11	Blank: 0.7628 EBC: 2.53 W. days: 11.0	Blank: 0.0098 EBC: 0.13 W. days: 0.000	
NIBEM	Sec: 243 10: 74 20: 165 30: 243	Sec: 249 10: 77 20:174 30: 249	Sec: 244 10: 71 20: 161 30: 244	Sec: 238 10: 66 20: 157 30: 238	Sec: 240 10: 68 20: 159 30: 240	Sec: 243 10: 71.2 2: 163.2 30: 243	Sec: 4.20 10: 4.438 20: 6.723 30: 4.207	**For lager beers: Bad: < 220 sec Very Good: > 300 sec** r95: 9 R95:42

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
CO_2% vol.	3.34	3.27	3.38	3.32	3.30	3.322	0.0414	**Vol %: 2.5 - 3.0** r95: 0.09 R95:0.08m
Dissolved oxygen (mg/L) (Orbisphere DO)	0.078	0.089	0.092	0.074	0.079	0.0824	0.0770	**< 0.3** r95:0.15 mg/L R95: 0.3 mg/L
Total polyphenols (mg/L)	A820: 0.199 Polyθ: 163.1	A820: 0.195 Polyθ: 159.9	A820: 0.193 Polyθ: 158.3	A820: 0.196 Polyθ: 160.7	A820: 0.190 Polyθ: 155.8	A820: 0.1946 Polyθ: 159.732	A820: 0.00336 Polyθ: 3.02808	**A820: 0.091-0.121** **Polyθ: 73-176** r95:4.1 R95: 18 ± 0.13m
Flavanoids (mg/L)	AB640: -0.053 AS640: 0.037 Flav: 3.01	AB640: -0.053 AS640: 0.037 Flav: 30.15	AB640: -0.053 AS640: 0.0380 Flav: 30.48	AB640: -0.053 AS640: 0.037 Flav: 30.15	AB640: -0.053 AS640: 0.038 Flav: 30.48	AB640: -0.03 AS640: . 0.0374 Flav: 30.2	AB640: 0.000 AS640: 0.0005 Flav: 0.18	**Flav: 50-70** CV_{r95}: ± 4.7% CV_{R95}: ± 7.6%
Iron (mg/L) **Samples** (Atomic Absorption Spectrometry)	A248.3: 0.113	A248.3: 0.290	A248.3: 0.331	A248.3: 0.518	A248.3: 0.703 Fe (II): 0.160			**Fe(II): < 0.2 Recommend. values** r95: 0.21m R95: 0.91m
Copper (mg/L) **Samples** (Atomic Absorption Spectrometry)	A324.7: 0.182	A324.7: 0.256	A324.7: 0.336	A324.7: 0.542	A324.7: 0.765 Cu (II): 0.164			**Cu (II): < 0.2 Recommend. values** r95: 0.45m R95: 1.71m
Calcium (mg/L) **Samples** (Atomic Absorption Spectrometry)	A423.0: 0.067	A423.0: 0.103	A423.0: 0.112	A423.0: 0.138	A423.0: 0.145 Ca (II): 1.094			**Ca (II): 4 -100 Recommend. values** CV_{ST95}: ±13.3% CV_{Sr95}: ± 2.4% CV_{Sb95}: ±9.2%
Reducing Power (MEBAK) %RED	66.0	66.7	65.8	65.1	67.2	66.16	0.8142	**> 60 very good** **50-60 good** **45-50 satisfactory** **< 45 poor** CV_{r95}: ± 1%
2-Methylpropanal (µg/L)	4.07	4.11				4.09	0.0282	**Fresh: 6.68 (±0.60) ***** **2 weeks 40℃: 39.15 (±0.47)**
2-Methylbutanal (µg/L)	2.88	2.91				2.895	0.0212	**Fresh: 18.6 ***** CV(%): 7.8 CI(abs): 1.0 CI(%): 5.6 **Forced: 19.6 ***** CV(%): 7.0 CI(abs): 1.0 CI(%): 5.0 **6-Months:**

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
								9.8 *** **1-Year: 20.6 *****
3-Methylbutanal (µg/L)	6.64	6.79				6.765	0.0353	**Fresh: 10.5 ***** CV(%): 4.0 CI(abs): 0.3 CI(%): 2.9 **Forced: 13.9 ***** CV(%): 5.7 CI(abs): 0.6 CI(%): 4.1 **6-Months: 16.1 ***** **1-Year: 29.0 *****
Benzaldehyde (µg/L)	1.11	1.08				1.095	0.0212	**Fresh: 0.96 (±0.02) ***** **Forced: 0.0 ***** CV(%): 0.0 CI(abs): 0.0 CI(%): 0.0 **6-Months: 1.8 ***** **1-Year: 3.3 *****
2-Phenylethanal (µg/L)	17.16	16.81				16.985	0.2474	**Fresh: 21.5 ***** CV(%): 10.3 CI(abs): 1.6 CI(%): 7.4 **Forced: 38.3 ***** CV(%): 5.3 CI(abs): 1.5 CI(%): 3.8 **6-Months: 32.2 ***** **1-Year: 55.8 *****
2-Furfural (µg/L)	12.50	12.17				12.335	0.2333	**Fresh: 7.1***** CV(%): 7.5 CI(abs): 0.4 CI(%): 5.4 **Forced: 110.8 ***** CV(%): 4.7 CI(abs): 3.8 CI(%): 3.4 **6-Months: 164.9 ***** **1-Year: 534.5 *****
Pentanal (µg/L)	1.00	0.94				0.97	0.0424	**Fresh: 1.9 ***** CV(%): N/A CI(abs): N/A CI(%): N/A **Forced: 4.5***** CV(%): N/A CI(abs): N/A CI(%): N/A **6-Months:4.9 ***** **1-Year: N/A**

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
Hexanal (µg/L)	1.75	1.68				1.715	0.0494	**Fresh: 0.75 ***** CV(%): 6.22 CI(abs): N/A CI(%): N/A **Forced: N/A ***** CV(%): N/A CI(abs): N/A CI(%): N/A **6-Months: 0.8 ***** **1-Year: 1.0 *****
Methional (µg/L)	3.55	3.39				3.47	0.1131	**Fresh: 1.07(±0.19) ***** CV(%): N/A CI(abs): N/A CI(%): N/A **2weeks 40℃: 3.03** **6-Months: N/A ***** **1-Year: N/A**
(*E*)-2-nonenal (µg/L)	0.0021	0.0024				0.00225	0.000212	**Fresh: no quantifiable 2 weeks 40℃: 0.070 (±0.09) *****

The normal values are reported according to Brautechnische Analysenmethoden. Band II. Mitteleuropäische Brautechnische Analysenkommission (M.E.B.A.K.) (2002), except; * according to American Society of Brewing Chemist. Report of Subcommittee on Wort and Beer. Colour Using Tristimulus Analysis (2000), ** according to Smedley (1992, 1995), *** according to Lustig (1993); Saison *et al.* (2008), **** according to Gonzalez-Miret *et al.* (2007); Luo *et al.* (1991a, 1991b)

Table A.3.3 MELANOIDIN MALT

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
Sp. Gravity (S 20/20) Beer	1.0080	1.0081	1.0081	1.0081	1.0080	1.00806	0.000547	**1.00585 - 1.01175** r95:N/A R95: N/A
App. Extract (EA) %	2.06	2.08	2.08	2.08	2.06	2.072	0.000109	**1.5 – 3.0** r95:0.012 R95:0.080
Sp. Gravity (S 20/20) Alcohol	0.99297	0.99297	0.99297	0.99297	0.99297	0.992970	0.000000	**0.99675 – 0.98770** r95: N/A R95: N/A
Alcohol (mas%)	3.88	3.88	3.88	3.88	3.88	3.880	0.0000	**1.75-7.20** r95: 0.03 ± 0.005m R95: 0.03 ± 0.02m
Alcohol (vol%)	4.88	4.88	4.88	4.88	4.88	4.880	0.0000	**2.2-9.0** r95: 0.04 ± 0.004m R95: 0.04 ± 0.02m
Sp. Gravity (S 20/20) Real extract	1.0151	1.0148	1.0149	1.0149	1.0148	1.0149	0.00012	**1.01175-1.02370** r95: N/A R95: N/A
Real extract (ER) %	3.82	3.78	3.80	3.80	3.78	3.796	0.01673	**3.0-6.0** r95:0.02m R95: 0.02m
Original Gravity (OG) %	12.03	12.01	12.02	12.03	12.01	12.02	0.001	**7.0-12.0** r95: 0.07 R95: 0.19
pH	4.06	4.06	4.07	4.07	4.09	4.07	0.0122	**Pils: 4.3-4.6** r95:0.02 R95:0.13
Bitter units	A275: 0.4177 IBU: 20.88 ≈ 21	A275: 0.4154 IBU: 20.77 ≈ 21	A275: 0.4185 IBU: 20.92 ≈ 21	A275: 0.42000 IBU: 21.00 ≈ 21	A275: 0.4179 IBU: 20.89 ≈ 21	A275: 0.4479 IBU:20.89 ≈ 21	A275: 0.0016 IBU: 0.0831	**A275: 0.200-0.800** **IBU: 10-40** r95: 0.44 ± 0.014m R95: -0.7 ± 0.18m
Colour Visual Comp. EBC/Lovibond	6.5	6.5	6.5	6.5	6.5	6.50	0.000	**Pale beers: 7-11 EBC** r95: 0.4 R95: 1.8
Colour (430 nm) EBC	A430: 0.269 EBC: 6.72	A430: 0.265 EBC: 6.62	A430: 0.264 EBC: 6.60	A430: 0.264 EBC: 6.60	A430: 0.265 EBC: 6.62	A430: 0.2654 EBC: 6.63	A430: 0.0021 EBC: 0.05	**Pale beers: 7-11 EBC** r95: 0.3 R95:0.6
Colour Tristimulus %T 360 nm	2.13	2.09	2.11	2.11	2.09	2.106	0.0167	
Colour Tristimulus %T 450 nm	52.82	52.52	52.82	52.80	52.84	52.76	0.1349	

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
Colour Tristimulus %T 540 nm	83.83	83.07	83.49	83.51	83.53	83.486	0.29958	
Colour Tristimulus %T 670 nm	98.03	98.58	98.98	98.01	98.03	98.166	0.1413	
Colour Tristimulus %T 760 nm	99.51	99.19	99.54	99.54	99.56	99.468	0.1564	
Colour Tristimulus ∑ x/k	882.45	821.61	825.48	822.25	822.47	818.856	9.3976	
Colour Tristimulus ∑ y/k	880.04	877.47	881.73	879.83	880.06	879.829	1.5246	
Colour Tristimulus ∑ z/k	601.85	598.43	601.77	601.62	601.99	601.133	1.5172	
Colour Tristimulus Values **X (Red)**	77.82	77.74	78.11	77.80	77.82	77.861	0.1428	
Colour Tristimulus Values **Y (Green)**	82.27	83.03	83.43	83.25	83.27	83.252	0.1440	
Colour Tristimulus Values **Z (Blue)**	56.94	56.62	56.94	56.92	56.96	56.881	0.1436	
Colour CIELAB L*	90.69	90.66	90.83	90.69	90.70	90.716	0.0652	**96.63 *, 93.83**** r95: 0.55 R95: 2.26
Colour CIELAB a*	-3.46	-3.32	-3.34	-3.46	-3.46	-3.411	0.0719	**-2.04 *, -7.83 **** r95: 0.19 R95: 0.56
Colour CIELAB b*	14.54	14.59	14.59	14.54	14.53	14.561	0.0313	**14.39 *, 32.97**** r95: 1.01 R95: 2.20
Colour CIELAB C* (Metric Chroma)	14.94	14.96	14.97	14.94	14.94	14.956	0.0148	
Yellowness Index	47.13	47.56	47.49	47.14	47.11	47.287	0.2181	
iCAM Lightness **J**	6.45	6.44	6.46	6.45	6.45	6.457	0.0049	
iCAM Chroma **C**	1.45	1.46	1.46	1.45	1.45	1.461	0.0051	
iCAM Angle Hue **h**	0.104	0.114	0.114	0.104	0.105	0.1087	0.0052	
iCAM Brightness **Q**	13.05	13.03	13.05	13.04	13.05	13.048	0.0101	
iCAM Colourfulness **M**	2.94	2.96	2.96	2.94	2.94	2.953	0.0104	

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
CIECAM02 Lightness **J**	90.95	90.83	91.07	90.94	90.95	90.952	0.0968	Repeat.****: r^2: 0.84 CV:19 Reprod. ****: r^2: 0.88 CV:17
CIECAM02 Chroma **C**	22.11	22.19	22.19	22.12	22.10	22.146	0.0438	
CIECAM02 redness-greenness **a**	0.0034	0.0091	0.0086	0.0034	0.0034	0.00558	0.002990	
CIECAM02 yellowness-blueness **b**	0.466	0.469	0.469	0.467	0.466	0.4678	0.001284	
CIECAM02 Angle Hue **h**	89.57	88.88	88.93	89.58	89.57	89.312	0.3662	
CIECAM02 Hue composition **H**	99.31	98.17	98.26	99.31	99.31	98.877	0.5973	Repeat.****: r^2: 0.99 CV: 8 Reprod. ****: r^2: 0.99 CV:10
CIECAM02 **Hc (Red)**	0.686	1.820	1.730	0.685	0.687	1.122	0.5973	
CIECAM02 **Hc (Yellow)**	99.31	98.17	98.26	99.31	99.31	98.877	0.5973	
CIECAM02 **Hc (Green)**	0.00	0.00	0.00	0.00	0.00	0.000	0.0000	
CIECAM02 **Hc (Blue)**	0.00	0.00	0.00	0.00	0.00	0.000	0.0000	
CIECAM02 Brightness **Q**	226.95	226.80	227.09	226.94	226.95	226.951	0.1047	
CIECAM02 Colourfulness **M**	20.87	20.94	20.94	20.87	20.86	20.913	0.0415	Repeat.****: r^2: 0.72 CV: 30 Reprod.****: r^2: 0.67 CV:37
CIECAM02 Saturation **s**	30.32	30.39	30.37	30.33	30.32	30.349	0.0309	
Turbidity 20℃ EBC	0.5	0.7	0.6	0.7	0.7	0.64	0.008	**N/A** r95: 0.05 R95:0.20
Shelf Life Prediction Forcing method EBC (modified according to Titze *et al.*, 2007) (60℃,24 h/ 0℃, 24h/ 20℃) EBC-formazin units/ Warm days	Blank: 0.589 EBC: 2.00 W. days: 13	Blank: 0.761 EBC: 2.07 W. days: 13	Blank: 0.690 EBC: 2.13 W. days: 13	Blank: 0.732 EBC: 2.12 W. days: 12	Blank: 0.776 EBC: 2.11 W. days: 13	Blank: 0.7096 EBC: 2.09 W. days: 12.8	Blank: 0.07496 EBC: 0.05 W. days: 0.447	
NIBEM	Sec: 271 10: 96 20: 187 30: 271	Sec: 277 10: 103 20: 192 30: 277	Sec: 275 10: 97 20: 188 30: 275	Sec: 269 10: 96 20: 185 30: 269	Sec: 271 10: 98 20: 193 30: 271	Sec: 272 10: 98 20: 189 30: 272	Sec: 3.28 10: 2.91 20: 3.39 30: 3.28	**For lager beers: Bad: < 220 sec Very Good: > 300 sec** r95: 9 R95:42
CO_2% vol.	3.08	3.15	3.19	3.08	3.05	3.11	0.0578	**Vol %: 2.5 -**

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
								3.0 r95: 0.09 R95:0.08m
Dissolved oxygen (mg/L) (Orbisphere DO)	0.113	0.108	0.100	0.121	0.097	0.1078	0.00973	**< 0.3** r95:0.15 mg/L R95: 0.3 mg/L
Total polyphenols (mg/L)	A820: 0.203 Polyθ: 166.46	A820: 0.204 Polyθ: 167.28	A820: 0.202 Polyθ: 165.64	A820: 0.202 Polyθ: 165.64	A820: 0.201 Polyθ: 164.82	A820: 0.20 Polyθ: 165.96	A820: 0.00 Polyθ: 0.934	**A820: 0.091-0.121** **Polyθ: 73-176** r95:4.1 R95: 18 ± 0.13m
Flavanoids (mg/L)	AB640: -0.053 AS640: 0.041 Flav: 31.49	AB640: -0.053 AS640: 0.040 Flav: 31.15	AB640: -0.053 AS640: 0.040 Flav: 31.15	AB640: -0.053 AS640: 0.039 Flav: 30.82	AB640: -0.053 AS640: 0.039 Flav: 30.82	AB640: -0.053 AS640: 0.0398 Flav:31.1	AB640: 0.000 AS640: 0.0008 Flav:0.28	**Flav: 50-70** CV_{r95}: ± 4.7% CV_{R95}: ± 7.6%
Iron (mg/L) **Samples** (Atomic Absorption Spectrometry)	A248.3: 0.135	A248.3: 0.223	A248.3: 0.339	A248.3: 0.552	A248.3: 0.713 Fe (II): 0.135			**Fe(II): < 0.2 Recommend. values** r95: 0.21m R95: 0.91m
Copper (mg/L) **Samples** (Atomic Absorption Spectrometry)	A324.7: 0.145	A324.7: 0.280	A324.7: 0.341	A324.7: 0.546	A324.7: 0.779 Cu (II): 0.146			**Cu (II): < 0.2 Recommend. values** r95: 0.45m R95: 1.71m
Calcium (mg/L) **Samples** (Atomic Absorption Spectrometry)	A423.0: 0.098	A423.0: 0.122	A423.0: 0.138	A423.0: 0.142	A423.0: 0.153 Ca (II): 2.12			**Ca (II): 4 -100 Recommend. values** CV_{ST95}: ±13.3% CV_{Sr95}:± 2.4% CV_{Sb95}: ±9.2%
Reducing Power (MEBAK) %RED	67.4	68.6	68.4	67.8	68.1	68.06	0.4774	**> 60 very good 50-60 good** **45-50 satisfactory** **< 45 poor** CV_{r95}: ± 1%
2-Methylpropanal (µg/L)	4.99	4.75				4.87	0.169	**Fresh: 6.68 (±0.60) ***** **2 weeks 40℃: 39.15 (±0.47)**
2-Methylbutanal (µg/L)	2.5	2.61				2.55	0.077	**Fresh: 18.6 ***** CV(%): 7.8 CI(abs): 1.0 CI(%): 5.6 **Forced: 19.6 ***** CV(%): 7.0 CI(abs): 1.0 CI(%): 5.0 **6-Months: 9.8 ***** **1-Year: 20.6 *****

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
3-Methylbutanal (µg/L)	6.28	6.22				6.25	0.042	**Fresh: 10.5 ***** CV(%): 4.0 CI(abs): 0.3 CI(%): 2.9 **Forced: 13.9 ***** CV(%): 5.7 CI(abs): 0.6 CI(%): 4.1 **6-Months: 16.1 ***** **1-Year: 29.0 *****
Benzaldehyde (µg/L)	1.16	1.33				1.24	0.120	**Fresh: 0.96 (±0.02) ***** **Forced: 0.0 ***** CV(%): 0.0 CI(abs): 0.0 CI(%): 0.0 **6-Months: 1.8 ***** **1-Year: 3.3 *****
2-Phenylethanal (µg/L)	14.27	14.06				14.16	0.148	**Fresh: 21.5 ***** CV(%): 10.3 CI(abs): 1.6 CI(%): 7.4 **Forced: 38.3 ***** CV(%): 5.3 CI(abs): 1.5 CI(%): 3.8 **6-Months: 32.2 ***** **1-Year: 55.8 *****
2-Furfural (µg/L)	10.31	10.55				10.43	0.1697	**Fresh: 7.1***** CV(%): 7.5 CI(abs): 0.4 CI(%): 5.4 **Forced: 110.8 ***** CV(%): 4.7 CI(abs): 3.8 CI(%): 3.4 **6-Months: 164.9 ***** **1-Year: 534.5 *****
Pentanal (µg/L)	0.71	0.64				0.67	0.049	**Fresh: 1.9 ***** CV(%): N/A CI(abs): N/A CI(%): N/A **Forced: 4.5***** CV(%): N/A CI(abs): N/A CI(%): N/A **6-Months:4.9 ***** **1-Year: N/A**
Hexanal (µg/L)	1.17	1.3				1.23	0.091	**Fresh: 0.75 ***** CV(%): 6.22 CI(abs): N/A

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
								CI(%): N/A **Forced: N/A ***** CV(%): N/A CI(abs): N/A CI(%): N/A **6-Months: 0.8 ***** **1-Year: 1.0 *****
Methional (µg/L)	1.85	1.97				1.91	0.084	**Fresh: 1.07(±0.19) ***** CV(%): N/A CI(abs): N/A CI(%): N/A **2weeks 40℃: 3.03** **6-Months: N/A ***** **1-Year: N/A**
(*E*)-2-nonenal (µg/L)	0.0054	0.0058				0.0056	0.00028	**Fresh: no quantifiable** **2 weeks 40℃: 0.070 (±0.09) *****

The normal values are reported according to Brautechnische Analysenmethoden. Band II. Mitteleuropäische Brautechnische Analysenkommission (M.E.B.A.K.) (2002), except; * according to American Society of Brewing Chemist. Report of Subcommittee on Wort and Beer. Colour Using Tristimulus Analysis (2000), ** according to Smedley (1992, 1995), *** according to Lustig (1993); Saison *et al.* (2008), **** according to Gonzalez-Miret *et al.* (2007); Luo *et al*. (1991a, 1991b)

Table A.3.4 CARAMUNICH® TYPE III

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
Sp. Gravity (S 20/20) Beer	1.0089	1.0089	1.0089	1.0088	1.0090	1.00890	0.000700	**1.00585 - 1.01175** r95:N/A R95: N/A
App. Extract (EA) %	2.28	2.28	2.28	2.26	2.31	2.282	0.0178	**1.5 – 3.0** r95:0.012 R95:0.080
Sp. Gravity (S 20/20) Alcohol	0.99287	0.99287	0.99285	0.99286	0.99286	0.992862	0.000008	**0.99675 – 0.98770** r95: N/A R95: N/A
Alcohol (mas%)	3.95	3.95	3.96	3.96	3.96	3.956	0.00547	**1.75-7.20** r95: 0.03 ± 0.005m R95: 0.03 ± 0.02m
Alcohol (vol%)	4.96	4.96	4.98	4.98	4.98	4.972	0.01095	**2.2-9.0** r95: 0.04 ± 0.004m R95: 0.04 ± 0.02m
Sp. Gravity (S 20/20) Real extract	1.0153	1.0152	1.0153	1.0153	1.0155	1.02268	0.01639	**1.01175-1.02370** r95: N/A R95: N/A
Real extract (ER) %	3.91	3.88	3.91	3.91	3.96	3.914	0.02880	**3.0-6.0** r95:0.02m R95: 0.02m
Original Gravity (OG) %	11.75	11.74	11.78	11.77	11.73	11.754	0.02073	**7.0-12.0** r95: 0.07 R95: 0.19
pH	4.01	4.02	4.01	4.03	4.02	4.018	0.0083	**Pils: 4.3-4.6** r95:0.02 R95:0.13
Bitter units	A275: 0.4292 IBU: 21.46 ≈ 21	A275: 0.4284 IBU: 21.42 ≈ 21	A275: 0.4275 IBU: 21.37 ≈ 21	A275: 0.4271 IBU: 21.35 ≈ 21	A275: 0.4250 IBU: 21.25 ≈ 21	A275: 0.4274 IBU: 21.3 ≈ 21	A275: 0.0015 IBU: 0.07	**A275: 0.200-0.800** **IBU: 10-40** r95: 0.44 ± 0.014m R95: -0.7 ± 0.18m
Colour Visual Comp. EBC/Lovibond	7.0	7.0	7.0	7.0	7.0	7.00	0.000	**Pale beers: 7-11 EBC** r95: 0.4 R95: 1.8
Colour (430 nm) EBC	A430: 0.306 EBC: 7.65	A430: 0.308 EBC: 7.7	A430: 0.307 EBC: 7.675	A430: 0.306 EBC: 7.65	A430: 0.307 EBC: 7.675	A430: 0.3068 EBC:7.67	A430: 0.0008 EBC: 0.02	**Pale beers: 7-11 EBC** r95: 0.3 R95:0.6
Colour Tristimulus %T 360 nm	1.18	1.16	1.17	1.18	1.18	1.174	0.0089	
Colour Tristimulus %T 450 nm	64.61	64.63	64.58	64.56	64.52	64.58	0.04301	

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
Colour Tristimulus %T 540 nm	81.54	81.84	81.50	81.41	81.39	81.546	0.2020	
Colour Tristimulus %T 670 nm	97.93	97.94	97.89	97.77	97.81	97.868	0.0749	
Colour Tristimulus %T 760 nm	99.65	99.62	99.51	99.54	99.54	99.612	0.1391	
Colour Tristimulus ∑ x/k	825.20	822.63	824.92	823.18	825.06	824.202	1.2013	
Colour Tristimulus ∑ y/k	893.83	890.98	893.56	890.90	893.70	892.597	1.5123	
Colour Tristimulus ∑ z/k	591.54	589.34	591.17	590.63	591.71	590.880	0.9536	
Colour Tristimulus Values **X (Red)**	78.08	77.84	78.05	77.89	78.07	77.989	0.1137	
Colour Tristimulus Values **Y (Green)**	84.57	84.30	84.55	84.30	84.56	84.460	0.1432	
Colour Tristimulus Values **Z (Blue)**	55.97	55.76	55.93	55.88	55.99	55.911	0.0902	
Colour CIELAB L*	90.81	90.70	90.80	90.73	90.81	90.774	0.0518	**96.63 *, 93.83**** r95: 0.55 R95: 2.26
Colour CIELAB a*	-4.36	-4.35	-4.36	-4.29	-4.36	-4.345	0.0286	**-2.04 *, -7.83 **** r95: 0.19 R95: 0.56
Colour CIELAB b*	15.41	15.40	15.41	15.35	15.40	15.398	0.0261	**14.39 *, 32.97**** r95: 1.01 R95: 2.20
Colour CIELAB C* (Metric Chroma)	16.01	16.01	16.02	15.94	16.00	16.000	0.0324	
Yellowness Index	48.02	48.06	48.03	47.99	47.98	48.021	0.0315	
iCAM Lightness **J**	6.57	6.53	6.52	6.52	6.52	6.536	0.0210	
iCAM Chroma **C**	0.84	1.01	1.00	1.00	1.00	0.976	0.0733	
iCAM Angle Hue **h**	0.219	0.179	0.185	0.186	0.186	0.191	0.0160	
iCAM Brightness **Q**	13.28	13.20	13.18	13.18	13.18	13.207	0.0424	
iCAM Colourfulness **M**	1.70	2.05	2.03	2.03	2.03	1.973	0.1484	

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
CIECAM02 Lightness **J**	91.06	90.93	90.77	90.72	90.71	90.843	0.1538	Repeat.****: r^2: 0.84 CV:19 Reprod. ****: r^2: 0.88 CV:17
CIECAM02 Chroma **C**	12.71	15.29	15.19	15.15	15.17	14.705	1.1157	
CIECAM02 redness-greenness **a**	0.0338	0.0273	0.0297	0.0297	0.0300	0.0301	0.00233	
CIECAM02 yellowness-blueness **b**	0.261	0.318	0.315	0.314	0.315	0.3049	0.02461	
CIECAM02 Angle Hue **h**	82.62	85.09	84.61	84.60	84.55	84.298	0.9627	
CIECAM02 Hue composition **H**	88.10	92.04	91.29	91.27	91.19	90.78	1.535	Repeat.****: r^2: 0.99 CV: 8 Reprod. ****: r^2: 0.99 CV:10
CIECAM02 **Hc (Red)**	11.89	7.95	8.70	8.72	8.80	9.216	1.5353	
CIECAM02 **Hc (Yellow)**	88.10	92.04	91.29	91.27	91.19	90.783	1.5353	
CIECAM02 **Hc (Green)**	0.00	0.00	0.00	0.00	0.00	0.000	0.0000	
CIECAM02 **Hc (Blue)**	0.00	0.00	0.00	0.00	0.00	0.000	0.0000	
CIECAM02 Brightness **Q**	227.09	226.93	226.72	226.66	226.65	226.814	0.1919	
CIECAM02 Colourfulness **M**	11.99	14.43	14.33	14.30	14.32	13.88	1.0531	Repeat.****: r^2: 0.72 CV: 30 Reprod.****: r^2: 0.67 CV:37
CIECAM02 Saturation **s**	22.98	25.21	25.14	25.12	25.13	24.723	0.9718	
Turbidity 20℃ EBC	0.937	0.944	0.932	0.939	0.934	0.9372	0.0046	**N/A** r95: 0.05 R95:0.20
Shelf Life Prediction Forcing method EBC (modified according to Titze *et al.*, 2007) (60℃,24 h/ 0℃, 24h/ 20℃) EBC-formazin units/ Warm days	Blank: 0.608 EBC: 2.43 W. days: 7	Blank: 0.606 EBC: 2.40 W. days: 7	Blank: 0.606 EBC: 2.46 W. days: 7	Blank: 0.606 EBC: 2.40 W. days: 7	Blank: 0.607 EBC: 2.49 W. days: 7	Blank: 0.606 EBC: 2.43 W. days: 7.0	Blank: 0.0008 EBC: 0.03 W. days: 0.00	
NIBEM	Sec: 289 10: 101 20: 193 30: 284	Sec: 285 10: 106 20: 190 30: 285	Sec: 289 10: 104 20: 196 30: 289	Sec: 288 10: 101 20: 190 30: 288	Sec: 278 10: 97 20: 185 30: 278	Sec: 285 10: 101.8 20: 190.8 30: 284.8	Sec: 4.32 10: 3.42 20: 4.08 30: 4.32	**For lager beers: Bad: < 220 sec Very Good: > 300 sec** r95: 9 R95:42
CO_2% vol.	3.13	3.13	2.95	3.02	3.04	3.054	0.077	**Vol %: 2.5 -**

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
								3.0 r95: 0.09 R95:0.08m
Dissolved oxygen (mg/L) (Orbisphere DO)	0.073	0.063	0.079	0.086	0.073	0.074	0.0084	**< 0.3** r95:0.15 mg/L R95: 0.3 mg/L
Total polyphenols (mg/L)	A820: 0.180 Polyθ: 147.6	A820: 0.189 Polyθ: 154.98	A820: 0.189 Polyθ: 154.98	A820: 0.184 Polyθ: 150.88	A820: 0.180 Polyθ: 147.6	A820: 0.1844 Polyθ: 151.208	A820: 0.0095 Polyθ: 3.6945	**A820: 0.091-0.121** **Polyθ: 73-176** r95:4.1 R95: 18 ± 0.13m
Flavanoids (mg/L)	AB640: -0.053 AS640: 0.041 Flav: 31.49	AB640: -0.053 AS640: 0.041 Flav: 31.49	AB640: -0.053 AS640: 0.041 Flav: 31.49	AB640: -0.053 AS640: 0.041 Flav: 31.49	AB640: -0.053 AS640: 0.041 Flav: 31.49	AB640: -0.053 AS640: 0.041 Flav:31.4	AB640: 0.000 AS640: 0.000 Flav: 0.00	**Flav: 50-70** CV_{r95}: ± 4.7% CV_{R95}: ± 7.6%
Iron (mg/L) **Samples** (Atomic Absorption Spectrometry)	A248.3: 0.146	A248.3: 0.219	A248.3: 0.307	A248.3: 0.545	A248.3: 0.749 Fe (II): 0.121			**Fe(II): < 0.2** **Recommend. values** r95: 0.21m R95: 0.91m
Copper (mg/L) **Samples** (Atomic Absorption Spectrometry)	A324.7: 0.143	A324.7: 0.229	A324.7: 0.338	A324.7: 0.542	A324.7: 0.770 Cu (II): 0.125			**Cu (II): < 0.2** **Recommend. values** r95: 0.45m R95: 1.71m
Calcium (mg/L) **Samples** (Atomic Absorption Spectrometry)	A423.0: 0.053	A423.0: 0.063	A423.0: 0.103	A423.0: 0.126	A423.0: 0.137 Ca (II): 0.573			**Ca (II): 4 -100** **Recommend. values** CV_{ST95}: ±13.3% CV_{Sr95}:± 2.4% CV_{Sb95}: ±9.2%
Reducing Power (MEBAK) %RED	61.8	62.9	62.3	61.7	62.3	62.20	0.479	**> 60 very good** **50-60 good** **45-50 satisfactory** **< 45 poor** CV_{r95}: ± 1%
2-Methylpropanal (µg/L)	3.33	3.36				3.34	0.021	**Fresh: 6.68 (±0.60) ***** **2 weeks 40℃: 39.15 (±0.47)**
2-Methylbutanal (µg/L)	1.52	1.66				1.59	0.098	**Fresh: 18.6 ***** CV(%): 7.8 CI(abs): 1.0 CI(%): 5.6 **Forced: 19.6 ***** CV(%): 7.0 CI(abs): 1.0 CI(%): 5.0 **6-Months: 9.8 ***** **1-Year: 20.6 *****

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
3-Methylbutanal (µg/L)	4.20	4.22				4.21	0.014	**Fresh: 10.5 ***** CV(%): 4.0 CI(abs): 0.3 CI(%): 2.9 **Forced: 13.9 ***** CV(%): 5.7 CI(abs): 0.6 CI(%): 4.1 **6-Months: 16.1 ***** **1-Year: 29.0 *****
Benzaldehyde (µg/L)	1.50	1.28				1.39	0.155	**Fresh: 0.96 (±0.02) ***** **Forced: 0.0 ***** CV(%): 0.0 CI(abs): 0.0 CI(%): 0.0 **6-Months: 1.8 ***** **1-Year: 3.3 *****
2-Phenylethanal (µg/L)	10.20	10.48				10.34	0.198	**Fresh: 21.5 ***** CV(%): 10.3 CI(abs): 1.6 CI(%): 7.4 **Forced: 38.3 ***** CV(%): 5.3 CI(abs): 1.5 CI(%): 3.8 **6-Months: 32.2 ***** **1-Year: 55.8 *****
2-Furfural (µg/L)	10.30	10.88				10.59	0.410	**Fresh: 7.1***** CV(%): 7.5 CI(abs): 0.4 CI(%): 5.4 **Forced: 110.8 ***** CV(%): 4.7 CI(abs): 3.8 CI(%): 3.4 **6-Months: 164.9 ***** **1-Year: 534.5 *****
Pentanal (µg/L)	0.83	0.74				0.78	0.063	**Fresh: 1.9 ***** CV(%): N/A CI(abs): N/A CI(%): N/A **Forced: 4.5***** CV(%): N/A CI(abs): N/A CI(%): N/A **6-Months:4.9 ***** **1-Year: N/A**
Hexanal (µg/L)	1.00	1.12				1.06	0.084	**Fresh: 0.75 ***** CV(%): 6.22 CI(abs): N/A

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
								CI(%): N/A **Forced: N/A ***** CV(%): N/A CI(abs): N/A CI(%): N/A **6-Months: 0.8 ***** **1-Year: 1.0 *****
Methional (µg/L)	3.91	3.72				3.81	0.134	**Fresh: 1.07(±0.19) ***** CV(%): N/A CI(abs): N/A CI(%): N/A **2weeks 40℃: 3.03** **6-Months: N/A ***** **1-Year: N/A**
(*E*)-2-nonenal (µg/L)	0.0025	0.0029				0.0027	0.00028	**Fresh: no quantifiable** **2 weeks 40℃: 0.070 (±0.09) *****

The normal values are reported according to Brautechnische Analysenmethoden. Band II. Mitteleuropäische Brautechnische Analysenkommission (M.E.B.A.K.) (2002), except; * according to American Society of Brewing Chemist. Report of Subcommittee on Wort and Beer. Colour Using Tristimulus Analysis (2000), ** according to Smedley (1992, 1995), *** according to Lustig (1993); Saison *et al.* (2008), **** according to Gonzalez-Miret *et al.* (2007); Luo *et al.* (1991a, 1991b)

Table A.3.5 CARAAROMA®

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
Sp. Gravity (S 20/20) Beer	1.0091	1.0092	1.0092	1.0092	1.0091	1.00916	0.000054	**1.00585 - 1.01175** r95:N/A R95: N/A
App. Extract (EA) %	2.34	2.36	2.36	2.36	2.34	2.352	0.0109	**1.5 – 3.0** r95:0.012 R95:0.080
Sp. Gravity (S 20/20) Alcohol	0.99306	0.99304	0.99305	0.99305	0.99305	0.99305	0.000007	**0.99675 – 0.98770** r95: N/A R95: N/A
Alcohol (mas%)	3.84	3.84	3.84	3.84	3.84	3.84	0.000	**1.75-7.20** r95: 0.03 ± 0.005m R95: 0.03 ± 0.02m
Alcohol (vol%)	4.82	4.82	4.82	4.82	4.82	4.82	0.000	**2.2-9.0** r95: 0.04 ± 0.004m R95: 0.04 ± 0.02m
Sp. Gravity (S 20/20) Real extract	1.0155	1.0155	1.0155	1.0152	1.0153	1.0154	0.00141	**1.01175-1.02370** r95: N/A R95: N/A
Real extract (ER) %	3.96	3.96	3.96	3.88	3.91	3.934	0.0371	**3.0-6.0** r95:0.02m R95: 0.02m
Original Gravity (OG) %	11.83	11.83	11.86	11.83	11.85	11.84	0.014	**7.0-12.0** r95: 0.07 R95: 0.19
pH	3.99	4.00	4.00	4.01	4.00	4.00	0.007	**Pils: 4.3-4.6** r95:0.02 R95:0.13
Bitter units	A275: 0.4024 IBU: 20.12 ≈ 20	A275: 0.4003 IBU: 20.01 ≈ 20	A275: 0.3978 IBU: 19.89 ≈ 20	A275: 0.3999 IBU: 19.99 ≈ 20	A275: 0.4011 IBU: 20.05 ≈ 20	A275: 0.4003 IBU: 20.0 ≈ 20	A275: 0.0969 IBU: 0.0846	**A275: 0.200-0.800** **IBU: 10-40** r95: 0.44 ± 0.014m R95: -0.7 ± 0.18m
Colour Visual Comp. EBC/Lovibond	6.5	6.5	6.5	6.5	6.5	6.50	0.000	**Pale beers: 7-11 EBC** r95: 0.4 R95: 1.8
Colour (430 nm) EBC	A430: 0.276 EBC: 6.9	A430: 0.277 EBC: 6.92	A430: 0.277 EBC: 6.92	A430: 0.279 EBC: 6.97	A430: 0.280 EBC: 7.0	A430: 0.2778 EBC: 6.98	A430: 0.00164 EBC: 0.04	**Pale beers: 7-11 EBC** r95: 0.3 R95:0.6
Colour Tristimulus %T 360 nm	0.92	0.94	0.94	0.94	0.93	0.944	0.0270	
Colour Tristimulus %T 450 nm	51.33	51.13	51.31	51.31	51.37	51.294	0.0345	

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
Colour Tristimulus %T 540 nm	86.26	85.98	86.24	85.88	86.25	86.122	0.1789	
Colour Tristimulus %T 670 nm	95.73	95.46	95.64	95.69	95.69	95.742	0.1259	
Colour Tristimulus %T 760 nm	97.82	98.60	98.78	98.78	98.82	98.36	0.518	
Colour Tristimulus ∑ x/k	838.96	832.77	830.64	829.76	829.74	832.336	3.8814	
Colour Tristimulus ∑ y/k	882.87	880.21	877.17	876.23	876.12	878.524	2.9427	
Colour Tristimulus ∑ z/k	748.41	704.27	703.24	702.94	702.55	712.287	20.206	
Colour Tristimulus Values **X (Red)**	79.38	78.80	78.59	78.51	78.51	78.762	0.3670	
Colour Tristimulus Values **Y (Green)**	83.54	83.28	83.00	82.91	82.90	83.129	0.2785	
Colour Tristimulus Values **Z (Blue)**	70.81	66.64	66.54	66.51	66.47	67.399	1.9121	
Colour CIELAB L*	91.40	91.43	91.05	91.01	91.01	91.185	0.2180	**96.63 *, 93.83**** r95: 0.55 R95: 2.26
Colour CIELAB a*	-2.27	-2.58	-2.51	-2.51	-2.50	-2.477	0.1202	**-2.04 *, -7.83 **** r95: 0.19 R95: 0.56
Colour CIELAB b*	9.14	10.63	10.56	10.54	10.55	10.290	0.6390	**14.39 *, 32.97**** r95: 1.01 R95: 2.20
Colour CIELAB C* (Metric Chroma)	9.42	10.94	10.86	10.84	10.85	10.584	0.6485	
Yellowness Index	31.77	36.28	36.22	36.17	36.22	35.337	1.9415	
iCAM Lightness **J**	6.48	6.47	6.48	6.47	6.48	6.481	0.0045	
iCAM Chroma **C**	1.54	1.54	1.54	1.53	1.54	1.544	0.0027	
iCAM Angle Hue **h**	0.045	0.0460	0.0454	0.0495	0.0454	0.0463	0.00176	
iCAM Brightness **Q**	13.10	13.08	13.10	13.08	13.10	13.095	0.0091	
iCAM Colourfulness **M**	3.12	3.12	3.12	3.11	3.12	3.121	0.0055	

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
CIECAM02 Lightness **J**	91.63	91.48	91.62	91.48	91.63	91.571	0.0818	Repeat.****: r^2: 0.84 CV:19 Reprod. ****: r^2: 0.88 CV:17
CIECAM02 Chroma **C**	23.78	23.78	23.79	23.66	23.76	23.757	0.0501	
CIECAM02 redness-greenness **a**	-0.0306	-0.0304	-0.0307	-0.0282	-0.0307	-0.03012	0.001080	
CIECAM02 yellowness-blueness **b**	0.498	0.498	0.499	0.496	0.498	0.4983	0.00096	
CIECAM02 Angle Hue **h**	93.52	93.49	93.52	93.26	93.53	93.466	0.1161	
CIECAM02 Hue composition **H**	106.63	106.58	106.65	106.15	106.66	106.539	0.2160	Repeat.****: r^2: 0.99 CV: 8 Reprod. ****: r^2: 0.99 CV:10
CIECAM02 **Hc (Red)**	0.00	0.00	0.00	0.00	0.00	0.000	0.0000	
CIECAM02 **Hc (Yellow)**	93.36	93.41	93.34	93.84	93.33	93.460	0.2160	
CIECAM02 **Hc (Green)**	6.63	6.58	6.65	6.15	6.66	6.539	0.2160	
CIECAM02 **Hc (Blue)**	0.00	0.00	0.00	0.00	0.00	0.000	0.0000	
CIECAM02 Brightness **Q**	227.80	227.60	227.78	227.60	227.79	227.720	0.1017	
CIECAM02 Colourfulness **M**	22.44	22.44	22.45	22.34	22.42	22.423	0.0473	Repeat.***: r^2: 0.72 CV: 30 Reprod.****: r^2: 0.67 CV:37
CIECAM02 Saturation **s**	31.38	31.40	31.39	31.32	31.37	31.380	0.0297	
Turbidity 20℃ EBC	0.599	0.606	0.602	0.602	0.602	0.6022	0.0024	**N/A** r95: 0.05 R95:0.20
Shelf Life Prediction Forcing method EBC (modified according to Titze *et al.*, 2007) (60℃,24 h/ 0℃, 24h/ 20℃) EBC-formazin units/ Warm days	Blank: 0.599 EBC: 2.87 W. days: 11	Blank: 0.606 EBC: 2.96 W. days: 11	Blank: 0.602 EBC: 3.23 W. days: 11	Blank: 0.602 EBC: 2.80 W. days: 11	Blank: 0.602 EBC: 2.74 W. days: 11	Blank: 0.6022 EBC: 2.92 W. days: 11.0	Blank: 0.0024 EBC: 0.18 W. days: 0.00	
NIBEM	Sec: 242 10: 80 20: 166 30: 242	Sec: 236 10: 84 20: 171 30: 236	Sec: 239 10: 78 20: 169 30: 239	Sec: 233 10: 81 20: 165 30: 233	Sec: 244 10: 84 20: 172 30: 244	Sec: 239 10: 81.4 20: 168.6 30: 239	Sec: 4.43 10: 2.60 20: 3.04 30: 4.43	**For lager beers: Bad: < 220 sec Very Good: > 300 sec** r95: 9 R95:42
CO_2% vol.	2.87	2.88	2.83	2.90	2.85	2.866	0.0270	**Vol %: 2.5 -**

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
								3.0 r95: 0.09 R95:0.08m
Dissolved oxygen (mg/L) (Orbisphere DO)	0.081	0.088	0.084	0.097	0.089	0.0878	0.0064	**< 0.3** r95:0.15 mg/L R95: 0.3 mg/L
Total polyphenols (mg/L)	A820: 0.182 Polyθ: 148.42	A820: 0.181 Polyθ: 148.42	A820: 0.188 Polyθ: 154.16	A820: 0.188 Polyθ: 154.16	A820: 0.182 Polyθ: 149.24	A820: 0.1842 Polyθ: 150.88	A820: 0.0034 Polyθ: 3.012	**A820: 0.091-0.121** **Polyθ: 73-176** r95:4.1 R95: 18 ± 0.13m
Flavanoids (mg/L)	AB640: -0.053 AS640: 0.030 Flav: 27.80	AB640: -0.053 AS640: 0.034 Flav: 29.14	AB640: -0.053 AS640: 0.033 Flav: 28.81	AB640: -0.053 AS640: 0.034 Flav: 29.14	AB640: -0.053 AS640: 0.032 Flav: 28.47	AB640: -0.053 AS640: 0.0326 Flav: 28.6	AB640: 0.000 AS640: 0.0016 Flav: 0.56	**Flav: 50-70** CV_{r95}: ± 4.7% CV_{R95}: ± 7.6%
Iron (mg/L) **Samples** (Atomic Absorption Spectrometry)	A248.3: 0.134	A248.3: 0.216	A248.3: 0.365	A248.3: 0.530	A248.3: 0.707 Fe (II): 0.146			**Fe(II): < 0.2** **Recommend. values** r95: 0.21m R95: 0.91m
Copper (mg/L) **Samples** (Atomic Absorption Spectrometry)	A324.7: 0.115	A324.7: 0.225	A324.7: 0.330	A324.7: 0.532	A324.7: 0.743 Cu (II): 0.114			**Cu (II): < 0.2** **Recommend. values** r95: 0.45m R95: 1.71m
Calcium (mg/L) **Samples** (Atomic Absorption Spectrometry)	A423.0: 0.052	A423.0: 0.080	A423.0: 0.117	A423.0: 0.128	A423.0: 0.184 Ca (II): 2.16			**Ca (II): 4 -100** **Recommend. values** CV_{ST95}: ±13.3% CV_{Sr95}: ± 2.4% CV_{Sb95}: ±9.2%
Reducing Power (MEBAK) %RED	59.6	59.2	59.5	59.8	60.2	59.66	0.37148	**> 60 very good** **50-60 good** **45-50 satisfactory** **< 45 poor** CV_{r95}: ± 1%
2-Methylpropanal (µg/L)	3.09	3.12				3.105	0.0212	**Fresh: 6.68 (±0.60) ***** **2 weeks 40℃: 39.15 (±0.47)**
2-Methylbutanal (µg/L)	1.87	1.95				1.91	0.0565	**Fresh: 18.6 ***** CV(%): 7.8 CI(abs): 1.0 CI(%): 5.6 **Forced: 19.6 ***** CV(%): 7.0 CI(abs): 1.0 CI(%): 5.0 **6-Months: 9.8 ***** **1-Year: 20.6**

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
								***
3-Methylbutanal (µg/L)	4.69	4.76				4.725	0.0494	**Fresh: 10.5 ***** CV(%): 4.0 CI(abs): 0.3 CI(%): 2.9 **Forced: 13.9 ***** CV(%): 5.7 CI(abs): 0.6 CI(%): 4.1 **6-Months: 16.1 ***** **1-Year: 29.0 *****
Benzaldehyde (µg/L)	1.49	1.28				1.385	0.1485	**Fresh: 0.96 (±0.02) ***** **Forced: 0.0 ***** CV(%): 0.0 CI(abs): 0.0 CI(%): 0.0 **6-Months: 1.8 ***** **1-Year: 3.3 *****
2-Phenylethanal (µg/L)	7.95	8.16				8.055	0.1485	**Fresh: 21.5 ***** CV(%): 10.3 CI(abs): 1.6 CI(%): 7.4 **Forced: 38.3 ***** CV(%): 5.3 CI(abs): 1.5 CI(%): 3.8 **6-Months: 32.2 ***** **1-Year: 55.8 *****
2-Furfural (µg/L)	10.68	12.58				11.63	1.3435	**Fresh: 7.1***** CV(%): 7.5 CI(abs): 0.4 CI(%): 5.4 **Forced: 110.8 ***** CV(%): 4.7 CI(abs): 3.8 CI(%): 3.4 **6-Months: 164.9 ***** **1-Year: 534.5 *****
Pentanal (µg/L)	1.02	0.81				0.915	0.1484	**Fresh: 1.9 ***** CV(%): N/A CI(abs): N/A CI(%): N/A **Forced: 4.5***** CV(%): N/A CI(abs): N/A CI(%): N/A **6-Months:4.9 ***** **1-Year: N/A**
Hexanal (µg/L)	1.02	1.22				1.12	0.1414	**Fresh: 0.75 *****

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
								CV(%): 6.22 CI(abs): N/A CI(%): N/A **Forced: N/A ***** CV(%): N/A CI(abs): N/A CI(%): N/A **6-Months: 0.8 ***** **1-Year: 1.0 *****
Methional (µg/L)	2.65	2.56				2.605	0.0636	**Fresh: 1.07(±0.19) ***** CV(%): N/A CI(abs): N/A CI(%): N/A **2weeks 40℃: 3.03** **6-Months: N/A ***** **1-Year: N/A**
(*E*)-2-nonenal (µg/L)	0.0042	0.0048				0.0045	0.00042	**Fresh: no quantifiable** **2 weeks 40℃: 0.070 (±0.09) *****

The normal values are reported according to Brautechnische Analysenmethoden. Band II. Mitteleuropäische Brautechnische Analysenkommission (M.E.B.A.K.) (2002), except; * according to American Society of Brewing Chemist. Report of Subcommittee on Wort and Beer. Colour Using Tristimulus Analysis (2000), ** according to Smedley (1992, 1995), *** according to Lustig (1993); Saison *et al.* (2008), **** according to Gonzalez-Miret *et al.* (2007); Luo *et al*. (1991a, 1991b)

Table A.3.6 CARAFA® TYPE III

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
Sp. Gravity (S 20/20) Beer	1.0086	1.0087	1.0086	1.0086	1.0086	1.00862	0.00004	**1.00585 - 1.01175** r95:N/A R95: N/A
App. Extract (EA) %	2.21	2.23	2.21	2.21	2.21	2.216	0.0089	**1.5 – 3.0** r95:0.012 R95:0.080
Sp. Gravity (S 20/20) Alcohol	0.99299	0.99299	0.99298	0.99298	0.99299	0.992986	0.000005	**0.99675 – 0.98770** r95: N/A R95: N/A
Alcohol (mas%)	3.87	3.87	3.88	3.88	3.87	3.874	0.0054	**1.75-7.20** r95: 0.03 ± 0.005m R95: 0.03 ± 0.02m
Alcohol (vol%)	4.86	4.86	4.88	4.88	4.86	4.868	0.0109	**2.2-9.0** r95: 0.04 ± 0.004m R95: 0.04 ± 0.02m
Sp. Gravity (S 20/20) Real extract	1.0157	1.0157	1.0156	1.0156	1.0156	1.01564	0.000054	**1.01175- 1.02370** r95: N/A R95: N/A
Real extract (ER) %	4.01	4.01	3.98	3.98	3.98	3.992	0.0164	**3.0-6.0** r95:0.02m R95: 0.02m
Original Gravity (OG)%	12.17	12.17	12.19	12.19	12.17	12.178	0.0109	**7.0-12.0** r95: 0.07 R95: 0.19
pH	3.99	4.01	3.98	3.98	4.00	3.992	0.0130	**Pils: 4.3-4.6** r95:0.02 R95:0.13
Bitter units	A275: 0.4683 IBU: 23.41 ≈ 23	A275: 0.4677 IBU: 23.38 ≈ 23	A275: 0.4713 IBU: 23.56 ≈ 23	A275: 0.4692 IBU: 23.46 ≈ 23	A275: 0.4705 IBU: 23.52 ≈ 23	A275: 0.4694 IBU:23.47 ≈ 23	A275: 0.0015 IBU: 0.74	**A275: 0.200- 0.800** **IBU: 10-40** r95: 0.44 ± 0.014m R95: -0.7 ± 0.18m
Colour Visual Comp. EBC/Lovibond	6.5	6.5	6.5	6.5	6.5	6.50	0.000	**Pale beers: 7-11 EBC** r95: 0.4 R95: 1.8
Colour (430 nm) EBC	A430: 0.277 EBC: 6.2	A430: 0.277 EBC: 6.2	A430: 0.277 EBC: 6.2	A430: 0.277 EBC: 6.2	A430: 0.277 EBC: 6.2	A430: 0.277 EBC: 6.2	A430: 0.0000 EBC: 0.00	**Pale beers: 7-11 EBC** r95: 0.3 R95:0.6
Colour Tristimulus %T 360 nm	1.43	1.48	1.44	1.45	1.44	1.448	0.0192	
Colour Tristimulus %T 450 nm	51.31	52.75	53.05	52.40	52.74	52.45	0.6775	

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
Colour Tristimulus %T 540 nm	86.35	86.04	86.16	86.19	86.01	86.15	0.1354	
Colour Tristimulus %T 670 nm	98.69	98.43	98.54	98.55	98.43	98.618	0.1896	
Colour Tristimulus %T 760 nm	99.86	99.73	99.84	99.82	99.11	99.752	0.1441	
Colour Tristimulus ∑ x/k	835.60	835.65	837.11	836.26	835.51	836.035	0.6688	
Colour Tristimulus ∑ y/k	900.57	899.36	900.80	900.36	899.13	900.048	0.7502	
Colour Tristimulus ∑ z/k	591.84	604.34	607.17	601.39	604.16	601.785	5.9186	
Colour Tristimulus Values **X (Red)**	79.06	79.07	79.21	79.13	79.05	79.108	0.0635	
Colour Tristimulus Values **Y (Green)**	85.216	85.10	85.23	85.19	85.07	85.016	0.0710	
Colour Tristimulus Values **Z (Blue)**	56.00	57.18	57.45	56.90	57.16	56.943	0.5599	
Colour CIELAB L*	91.26	91.26	91.32	91.29	91.26	91.283	0.0284	**96.63 *, 93.83**** r95: 0.55 R95: 2.26
Colour CIELAB a*	-4.01	-3.90	-3.89	-3.43	-3.90	-3.929	0.0473	**-2.04 *, -7.83 **** r95: 0.19 R95: 0.56
Colour CIELAB b*	15.62	15.07	15.00	15.22	15.07	15.200	0.2478	**14.39 *, 32.97**** r95: 1.01 R95: 2.20
Colour CIELAB C* (Metric Chroma)	16.12	15.57	15.50	15.72	15.57	15.700	0.2515	
Yellowness Index	49.10	47.70	47.50	48.08	47.71	48.022	0.6392	
iCAM Lightness **J**	6.50	6.51	6.51	6.51	6.50	6.509	0.0044	
iCAM Chroma **C**	1.57	1.51	1.50	1.53	1.51	1.52	0.0282	
iCAM Angle Hue **h**	0.071	0.076	0.076	0.074	0.076	0.075	0.0023	
iCAM Brightness **Q**	13.14	13.15	13.16	13.15	13.15	13.153	0.0090	
iCAM Colourfulness **M**	3.185	3.05	3.04	3.09	3.05	3.088	0.0570	

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
CIECAM02 Lightness **J**	92.06	91.9938	92.0719	92.0496	91.9812	92.03226	0.041884	Repeat.****: r^2: 0.84 CV:19 Reprod. ****: r^2: 0.88 CV:17
CIECAM02 Chroma **C**	24.01	23.06	22.94	23.32	23.05	23.279	0.4340	
CIECAM02 redness-greenness **a**	-0.015	-0.012	-0.012	-0.013	-0.012	-0.0133	0.00144	
CIECAM02 yellowness-blueness **b**	0.507	0.486	0.484	0.492	0.486	0.491	0.0093	
CIECAM02 Angle Hue **h**	91.78	91.98	91.47	91.57	91.46	91.656	0.2232	
CIECAM02 Hue composition **H**	103.39	102.82	102.81	103.00	102.79	102.967	0.2541	Repeat.****: r^2: 0.99 CV: 8 Reprod. ****: r^2: 0.99 CV:10
CIECAM02 **Hc (Red)**	0.00	0.00	0.00	0.00	0.00	0.000	0.0000	
CIECAM02 **Hc (Yellow)**	96.60	97.17	97.18	96.99	97.20	95.972	2.7243	
CIECAM02 **Hc (Green)**	3.39	2.82	2.81	3.00	2.79	2.967	0.2541	
CIECAM02 **Hc (Blue)**	0.00	0.00	0.00	0.00	0.00	0.000	0.0000	
CIECAM02 Brightness **Q**	228.33	228.24	228.34	228.31	228.23	228.293	0.0519	
CIECAM02 Colourfulness **M**	22.66	21.76	21.65	22.01	21.76	21.97	0.4096	Repeat.****: r^2: 0.72 CV: 30 Reprod.****: r^2: 0.67 CV:37
CIECAM02 Saturation **s**	31.50	30.88	30.79	31.05	30.88	31.023	0.2863	
Turbidity 20℃ EBC	0.608	0.606	0.606	0.606	0.607	0.606	0.0008	**N/A** r95: 0.05 R95:0.20
Shelf Life Prediction Forcing method EBC (modified according to Titze *et al.*, 2007) (60℃,24 h/ 0℃, 24h/ 20℃) EBC-formazin units/ Warm days	Blank: 0.937 EBC: 2.63 W. days: 9	Blank: 0.944 EBC: 2.78 W. days: 9	Blank: 0.932 EBC: 2.14 W. days: 10	Blank: 0.939 EBC: 2.00 W. days: 10	Blank: 0.934 EBC: 2.22 W. days: 10	Blank: 0.9372 EBC: 2.35 W. days: 9.6	Blank: 0.0046 EBC: 0.33 W. days: 0.547	
NIBEM	Sec: 217 10: 66 20: 154 30: 217	Sec: 222 10: 64 20: 163 30: 222	Sec: 226 10: 70 20: 167 30: 226	Sec: 219 10: 66 20: 150 30: 219	Sec: 222 10: 69 20: 167 30: 222	Sec: 221 10: 67 20: 180.2 30: 221	Sec: 3.42 10: 2.49 20: 7.79 30: 3.42	**For lager beers: Bad: < 220 sec Very Good: > 300 sec** r95: 9 R95:42
CO_2% vol.	3.12	2.97	3.08	3.08	3.01	3.052	0.0605	**Vol %: 2.5 -**

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
								3.0 r95: 0.09 R95:0.08m
Dissolved oxygen (mg/L) (Orbisphere DO)	0.179	0.191	0.204	0.188	0.195	0.1919	0.0098	**< 0.3** r95:0.15 mg/L R95: 0.3 mg/L
Total polyphenols (mg/L)	A820: 0.196 Polyθ: 160.72	A820: 0.196 Polyθ: 160.72	A820: 0.198 Polyθ: 162.36	A820: 0.198 Polyθ: 162.36	A820: 0.195 Polyθ: 159.9	A820: 0.1966 Polyθ: 161.212	A820: 0.00134 Polyθ: 1.1001	**A820: 0.091-0.121 Polyθ: 73-176** r95:4.1 R95: 18 ± 0.13m
Flavanoids (mg/L)	AB640: -0.053 AS640: 0.019 Flav: 24.12	AB640: -0.053 AS640: 0.016 Flav: 23.11	AB640: -0.053 AS640: 0.017 Flav: 23.45	AB640: -0.053 AS640: 0.018 Flav: 23.78	AB640: -0.053 AS640: 0.018 Flav: 23.78	AB640: -0.053 AS640: 0.0176 Flav: 23.6	AB640: 0.000 AS640: 0.0011 Flav: 0.38	**Flav: 50-70** CV_{r95}: ± 4.7% CV_{R95}: ± 7.6%
Iron (mg/L) **Samples** (Atomic Absorption Spectrometry)	A248.3: 0.122	A248.3: 0.208	A248.3: 0.391	A248.3: 0.533	A248.3: 0.722 Fe (II): 0.135			**Fe(II): < 0.2 Recommend. values** r95: 0.21m R95: 0.91m
Copper (mg/L) **Samples** (Atomic Absorption Spectrometry)	A324.7: 0.122	A324.7: 0.213	A324.7: 0.530	A324.7: 0.583	A324.7: 0.783 Cu (II): 0.099			**Cu (II): < 0.2 Recommend. values** r95: 0.45m R95: 1.71m
Calcium (mg/L) **Samples** (Atomic Absorption Spectrometry)	A423.0: 0.106	A423.0: 0.118	A423.0: 0.136	A423.0: 0.148	A423.0: 0.155 Ca (II): 2.382			**Ca (II): 4 -100 Recommend. values** CV_{ST95}: ±13.3% CV_{Sr95}: ± 2.4% CV_{Sb95}: ±9.2%
Reducing Power (MEBAK) %RED	52.7	52.4	53.0	52.7	52.5	52.66	0.23021	**> 60 very good 50-60 good 45-50 satisfactory < 45 poor** CV_{r95}: ± 1%
2-Methylpropanal (µg/L)	2.14	2.13				2.135	0.0070	**Fresh: 6.68 (±0.60) *** 2 weeks 40℃: 39.15 (±0.47)**
2-Methylbutanal (µg/L)	1.21	1.46				1.335	0.1767	**Fresh: 18.6 ***** CV(%): 7.8 CI(abs): 1.0 CI(%): 5.6 **Forced: 19.6 ***** CV(%): 7.0 CI(abs): 1.0 CI(%): 5.0 **6-Months: 9.8 *****

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
								1-Year: 20.6 ***
3-Methylbutanal (μg/L)	2.98	3.01				2.995	0.0212	**Fresh: 10.5 ***** CV(%): 4.0 CI(abs): 0.3 CI(%): 2.9 **Forced: 13.9 ***** CV(%): 5.7 CI(abs): 0.6 CI(%): 4.1 **6-Months: 16.1 ***** **1-Year: 29.0 *****
Benzaldehyde (μg/L)	1.33	1.44				1.385	0.0777	**Fresh: 0.96 (±0.02) ***** **Forced: 0.0 ***** CV(%): 0.0 CI(abs): 0.0 CI(%): 0.0 **6-Months: 1.8 ***** **1-Year: 3.3 *****
2-Phenylethanal (μg/L)	8.50	8.31				8.405	0.1343	**Fresh: 21.5 ***** CV(%): 10.3 CI(abs): 1.6 CI(%): 7.4 **Forced: 38.3 ***** CV(%): 5.3 CI(abs): 1.5 CI(%): 3.8 **6-Months: 32.2 ***** **1-Year: 55.8 *****
2-Furfural (μg/L)	9.77	9.43				9.6	0.2404	**Fresh: 7.1***** CV(%): 7.5 CI(abs): 0.4 CI(%): 5.4 **Forced: 110.8 ***** CV(%): 4.7 CI(abs): 3.8 CI(%): 3.4 **6-Months: 164.9 ***** **1-Year: 534.5 *****
Pentanal (μg/L)	0.73	0.81				0.77	0.0565	**Fresh: 1.9 ***** CV(%): N/A CI(abs): N/A CI(%): N/A **Forced: 4.5***** CV(%): N/A CI(abs): N/A CI(%): N/A **6-Months:4.9 ***** **1-Year: N/A**
Hexanal (μg/L)	1.08	0.93				1.005	0.1060	**Fresh: 0.75**

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
								******* CV(%): 6.22 CI(abs): N/A CI(%): N/A **Forced: N/A ***** CV(%): N/A CI(abs): N/A CI(%): N/A **6-Months: 0.8 *** 1-Year: 1.0 *****
Methional (µg/L)	3.00	3.09				3.045	0.0636	**Fresh: 1.07(±0.19) ***** CV(%): N/A CI(abs): N/A CI(%): N/A **2weeks 40℃: 3.03 6-Months: N/A *** 1-Year: N/A**
(*E*)-2-nonenal (µg/L)	0.0032	0.0036				0.0034	0.00028	**Fresh: no quantifiable 2 weeks 40℃: 0.070 (±0.09) *****

The normal values are reported according to Brautechnische Analysenmethoden. Band II. Mitteleuropäische Brautechnische Analysenkommission (M.E.B.A.K.) (2002), except; * according to American Society of Brewing Chemist. Report of Subcommittee on Wort and Beer. Colour Using Tristimulus Analysis (2000), ** according to Smedley (1992, 1995), *** according to Lustig (1993); Saison *et al.* (2008), **** according to Gonzalez-Miret *et al.* (2007); Luo *et al*. (1991a, 1991b)

Table A.3.7 CARAFA® SPECIAL TYPE III

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
Sp. Gravity (S 20/20) Beer	1.0084	1.0085	1.0084	1.0084	1.0084	1.00842	0.000044	**1.00585 - 1.01175** r95:N/A R95: N/A
App. Extract (EA) %	2.16	2.18	2.16	2.16	2.16	2.164	0.0089	**1.5 – 3.0** r95:0.012 R95:0.080
Sp. Gravity (S 20/20) Alcohol	0.99307	0.99307	0.99307	0.99307	0.99306	0.993068	0.0000044	**0.99675 – 0.98770** r95: N/A R95: N/A
Alcohol (mas%)	3.82	3.82	3.82	3.82	3.82	3.82	0.000	**1.75-7.20** r95: 0.03 ± 0.005m R95: 0.03 ± 0.02m
Alcohol (vol%)	4.80	4.80	4.80	4.80	4.80	4.80	0.000	**2.2-9.0** r95: 0.04 ± 0.004m R95: 0.04 ± 0.02m
Sp. Gravity (S 20/20) Real extract	1.0155	1.0156	1.0156	1.0156	1.0152	0.01550	0.00017	**1.01175-1.02370** r95: N/A R95: N/A
Real extract (ER) %	3.96	3.98	3.98	3.98	3.98	3.956	0.0433	**3.0-6.0** r95:0.02m R95: 0.02m
Original Gravity (OG) %	12.17	12.18	12.18	12.18	12.17	12.176	0.0054	**7.0-12.0** r95: 0.07 R95: 0.19
pH	3.97	3.97	3.98	3.99	3.97	3.976	0.0089	**Pils: 4.3-4.6** r95:0.02 R95:0.13
Bitter units	A275: 0.422 IBU: 21.11 ≈ 21	A275: 0.4183 IBU: 20.91 ≈ 21	A275: 0.4176 IBU: 20.88 ≈ 21	A275: 0.4144 IBU: 20.72 ≈ 21	A275: 0.4215 IBU: 21.07 ≈ 21	A275: 0.4188 IBU:20.94 ≈ 21	A275: 0.0031 IBU: 0.15	**A275: 0.200-0.800** **IBU: 10-40** r95: 0.44 ± 0.014m R95: -0.7 ± 0.18m
Colour Visual Comp. EBC/Lovibond	6.5	6.5	6.5	6.5	6.5	6.5	0.00	**Pale beers: 7-11 EBC** r95: 0.4 R95: 1.8
Colour (430 nm) EBC	A430: 0.284 EBC: 7.1	A430: 0.284 EBC: 7.1	A430: 0.284 EBC: 7.1	A430: 0.286 EBC:7.1	A430: 0.286 EBC:7.1	A430: 0.2848 EBC:7.1	A430: 0.0010 EBC: 0.02	**Pale beers: 7-11 EBC** r95: 0.3 R95:0.6
Colour Tristimulus %T 360 nm	1.54	1.55	1.51	1.55	1.51	1.532	0.0204	
Colour Tristimulus %T 450 nm	55.90	54.93	54.96	54.91	55.02	55.144	0.42465	

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
Colour Tristimulus %T 540 nm	88.52	88.47	88.51	88.47	88.54	88.502	0.0311	
Colour Tristimulus %T 670 nm	98.36	98.32	98.37	98.31	98.37	98.346	0.0288	
Colour Tristimulus %T 760 nm	99.25	99.20	99.24	99.19	99.24	99.224	0.0270	
Colour Tristimulus ∑ x/k	852.43	850.51	850.92	850.45	851.16	831.780	42.4447	
Colour Tristimulus ∑ y/k	920.89	919.41	919.85	919.37	920.13	930.347	23.8214	
Colour Tristimulus ∑ z/k	636.37	627.61	627.90	627.43	628.48	623.541	9.6701	
Colour Tristimulus Values **X (Red)**	80.66	80.47	80.51	80.47	80.540	78.706	4.0162	
Colour Tristimulus Values **Y (Green)**	87.13	86.99	87.04	86.99	87.06	84.248	6.2097	
Colour Tristimulus Values **Z (Blue)**	60.21	59.38	59.41	59.37	59.47	59.001	0.9151	
Colour CIELAB L*	91.98	91.89	91.91	91.81	91.92	91.075	1.8654	**96.63 *, 93.83**** r95: 0.55 R95: 2.26
Colour CIELAB a*	-4.21	-4.25	-4.25	-4.25	-4.25	-3.442	1.8199	**-2.04 *, -7.83 **** r95: 0.19 R95: 0.56
Colour CIELAB b*	14.50	14.79	14.80	14.80	14.78	13.972	1.8481	**14.39 *, 32.97**** r95: 1.01 R95: 2.20
Colour CIELAB C* (Metric Chroma)	15.10	15.39	15.40	15.40	15.34	14.452	2.1157	
Yellowness Index	45.23	46.04	46.05	46.06	46.00	45.238	1.7948	
iCAM Lightness **J**	6.58	6.57	6.58	6.57	6.58	6.581	0.0044	
iCAM Chroma **C**	1.44	1.47	1.47	1.47	1.47	1.471	0.0151	
iCAM Angle Hue **h**	0.0531	0.0515	0.0515	0.0514	0.0513	0.05176	0.000753	
iCAM Brightness **Q**	13.31	13.29	13.29	13.29	13.29	13.297	0.0089	
iCAM Colourfulness **M**	2.91	2.98	2.98	2.98	2.98	2.972	0.0305	

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
CIECAM02 Lightness **J**	93.11	93.04	93.06	93.04	93.23	93.101	0.0817	Repeat.****: r^2: 0.84 CV:19 Reprod. ****: r^2: 0.88 CV:17
CIECAM02 Chroma **C**	22.10	22.62	22.62	22.63	22.60	22.519	0.2314	
CIECAM02 redness-greenness **a**	-0.025	-0.026	-0.026	-0.026	-0.026	-0.026	0.0005	
CIECAM02 yellowness-blueness **b**	0.464	0.475	0.475	0.475	0.475	0.4734	0.0050	
CIECAM02 Angle Hue **h**	93.15	93.21	93.21	93.22	93.23	93.210	0.0333	
CIECAM02 Hue composition **H**	105.95	106.08	106.07	106.09	106.11	106.064	0.0618	Repeat.****: r^2: 0.99 CV: 8 Reprod. ****: r^2: 0.99 CV:10
CIECAM02 **Hc (Red)**	0.00	0.00	0.00	0.00	0.00	0.000	0.0000	
CIECAM02 **Hc (Yellow)**	94.04	93.91	93.92	93.90	93.08	93.774	0.3911	
CIECAM02 **Hc (Green)**	5.95	6.08	6.07	6.09	6.11	6.064	0.0061	
CIECAM02 **Hc (Blue)**	0.00	0.00	0.00	0.00	0.00	0.000	0.0000	
CIECAM02 Brightness **Q**	229.63	229.54	229.57	229.54	229.59	229.56	0.0436	
CIECAM02 Colourfulness **M**	20.86	21.35	21.35	21.36	21.33	21.255	0.2184	Repeat.****: r^2: 0.72 CV: 30 Reprod.****: r^2: 0.67 CV:37
CIECAM02 Saturation **s**	30.14	30.50	30.50	30.50	30.48	30.427	0.1592	
Turbidity 20℃ EBC	0.608	0.617	0.618	0.615	0.617	0.615	0.00406	**N/A** r95: 0.05 R95:0.20
Shelf Life Prediction Forcing method EBC (modified according to Titze *et al.*, 2007) (60℃,24 h/ 0℃, 24h/ 20℃) EBC-formazin units/ Warm days	Blank: 0.608 EBC: 2.13 W. days: 10	Blank: 0.617 EBC: 2.65 W. days: 10	Blank: 0.618 EBC: 3.11 W. days: 9	Blank: 0.615 EBC: 2.89 W. days: 9	Blank: 0.617 EBC: 2.76 W. days: 9	Blank: 0.615 EBC: 2.71 W. days: 9.4	Blank: 0.00406 EBC: 0.36 W. days: 0.547	
NIBEM	Sec: 260 10: 94 20: 184 30: 260	Sec: 257 10: 94 20: 177 30: 257	Sec: 255 10: 97 20: 179 30: 255	Sec: 264 10: 97 20: 189 30: 264	Sec: 268 10: 93 20: 193 30: 268	Sec: 261 10: 95 20: 184.4 30: 261	Sec: 5.26 10: 1.870 20: 6.693 30: 5.263	**For lager beers: Bad: < 220 sec Very Good: > 300 sec** r95: 9 R95:42
CO_2% vol.	2.88	2.94	2.88	2.84	2.87	2.882	0.0363	**Vol %: 2.5 -**

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
								3.0 r95: 0.09 R95:0.08m
Dissolved oxygen (mg/L) (Orbisphere DO)	0.167	0.172	0.161	0.189	0.156	0.169	0.01270	**< 0.3** r95:0.15 mg/L R95: 0.3 mg/L
Total polyphenols (mg/L)	A820: 0.198 Polyθ: 162.36	A820: 0.198 Polyθ: 162.36	A820: 0.197 Polyθ: 161.54	A820: 0.196 Polyθ: 160.72	A820: 0.196 Polyθ: 160.72	A820: 0.197 Polyθ: 161.54	A820: 0.001 Polyθ: 0.821	**A820: 0.091-0.121** **Polyθ: 73-176** r95:4.1 R95: 18 ± 0.13m
Flavanoids (mg/L)	AB640: -0.053 AS640: 0.013 Flav: 22.11	AB640: -0.053 AS640: 0.013 Flav: 22.11	AB640: -0.053 AS640: 0.014 Flav: 22.44	AB640: -0.053 AS640: 0.014 Flav: 22.44	AB640: -0.053 AS640: 0.014 Flav: 22.44	AB640: -0.053 AS640:0.0136 Flav: 22.311	AB640:0.0000 AS640:0.0005 Flav: 0.18348	**Flav: 50-70** CV_{r95}: ± 4.7% CV_{R95}: ± 7.6%
Iron (mg/L) **Samples** (Atomic Absorption Spectrometry)	A248.3: 0.127	A248.3: 0.251	A248.3: 0.347	A248.3: 0.524	A248.3: 0.692 Fe (II): 0.158			**Fe(II): < 0.2** **Recommend. values** r95: 0.21m R95: 0.91m
Copper (mg/L) **Samples** (Atomic Absorption Spectrometry)	A324.7: 0.110	A324.7: 0.217	A324.7: 0.323	A324.7: 0.536	A324.7: 0.748 Cu (II): 0.104			**Cu (II): < 0.2** **Recommend. values** r95: 0.45m R95: 1.71m
Calcium (mg/L) **Samples** (Atomic Absorption Spectrometry)	A423.0: 0.116	A423.0: 0.132	A423.0: 0.146	A423.0: 0.152	A423.0: 0.169 Ca (II): 2.625			**Ca (II): 4 -100** **Recommend. values** CV_{ST95}: ±13.3% CV_{Sr95}: ± 2.4% CV_{Sb95}: ±9.2%
Reducing Power (MEBAK) % RED	58.4	57.1	57.7	57.3	57.7	57.64	0.4979	**> 60 very good** **50-60 good** **45-50 satisfactory** **< 45 poor** CV_{r95}: ± 1%
2-Methylpropanal (µg/L)	2.33	2.4				2.365	0.0494	**Fresh: 6.68 (±0.60) ***** **2 weeks 40℃: 39.15 (±0.47)**
2-Methylbutanal (µg/L)	1.13	1.31				1.22	0.1272	**Fresh: 18.6 ***** CV(%): 7.8 CI(abs): 1.0 CI(%): 5.6 **Forced: 19.6 ***** CV(%): 7.0 CI(abs): 1.0 CI(%): 5.0 **6-Months: 9.8 *****

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
								1-Year: 20.6 ***
3-Methylbutanal (µg/L)	3.26	3.15				3.205	0.0777	**Fresh: 10.5 ***** CV(%): 4.0 CI(abs): 0.3 CI(%): 2.9 **Forced: 13.9 ***** CV(%): 5.7 CI(abs): 0.6 CI(%): 4.1 **6-Months: 16.1 ***** **1-Year: 29.0 *****
Benzaldehyde (µg/L)	1.1	0.99				1.045	0.0777	**Fresh: 0.96 (±0.02) ***** **Forced: 0.0 ***** CV(%): 0.0 CI(abs): 0.0 CI(%): 0.0 **6-Months: 1.8 ***** **1-Year: 3.3 *****
2-Phenylethanal (µg/L)	14.41	14.72				14.565	0.2192	**Fresh: 21.5 ***** CV(%): 10.3 CI(abs): 1.6 CI(%): 7.4 **Forced: 38.3 ***** CV(%): 5.3 CI(abs): 1.5 CI(%): 3.8 **6-Months: 32.2 ***** **1-Year: 55.8 *****
2-Furfural (µg/L)	11.32	11.95				11.635	0.4454	**Fresh: 7.1***** CV(%): 7.5 CI(abs): 0.4 CI(%): 5.4 **Forced: 110.8 ***** CV(%): 4.7 CI(abs): 3.8 CI(%): 3.4 **6-Months: 164.9 ***** **1-Year: 534.5 *****
Pentanal (µg/L)	1.21	0.76				0.985	0.3182	**Fresh: 1.9 ***** CV(%): N/A CI(abs): N/A CI(%): N/A **Forced: 4.5***** CV(%): N/A CI(abs): N/A CI(%): N/A **6-Months:4.9 ***** **1-Year: N/A**
Hexanal (µg/L)	1.65	1.7				1.675	0.0353	**Fresh: 0.75**

Analysis	Beer 1	Beer 2	Beer 3	Beer 4	Beer 5	Mean	Standard Deviation (Sx)	Normal Values
								*** CV(%): 6.22 CI(abs): N/A CI(%): N/A **Forced: N/A ***** CV(%): N/A CI(abs): N/A CI(%): N/A **6-Months: 0.8 *** 1-Year: 1.0 *****
Methional (µg/L)	11.32	11.95				11.635	0.4454	**Fresh: 1.07(±0.19) ***** CV(%): N/A CI(abs): N/A CI(%): N/A **2weeks 40℃: 3.03 6-Months: N/A *** 1-Year: N/A**
(*E*)-2-nonenal (µg/L)	0.0053	0.0058				0.00555	0.000353	**Fresh: no quantifiable 2 weeks 40℃: 0.070 (±0.09) *****

The normal values are reported according to Brautechnische Analysenmethoden. Band II. Mitteleuropäische Brautechnische Analysenkommission (M.E.B.A.K.) (2002), except; * according to American Society of Brewing Chemist. Report of Subcommittee on Wort and Beer. Colour Using Tristimulus Analysis (2000), ** according to Smedley (1992, 1995), *** according to Lustig (1993); Saison *et al.* (2008), **** according to Gonzalez-Miret *et al.* (2007); Luo *et al*. (1991a, 1991b)

Table A.3.8 ROASTED BARLEY

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
Sp. Gravity (S 20/20) Beer	1.0088	1.0089	1.0089	1.0089	1.0089	1.00888	0.000044	**1.00585 - 1.01175** r95:N/A R95: N/A
App. Extract (EA) %	2.26	2.28	2.28	2.28	2.28	2.276	0.0089	**1.5 – 3.0** r95:0.012 R95:0.080
Sp. Gravity (S 20/20) Alcohol	0.99301	0.99302	0.99302	0.99302	0.99303	0.99302	0.000007	**0.99675 – 0.98770** r95: N/A R95: N/A
Alcohol (mas%)	3.87	3.85	3.85	3.85	3.87	3.858	0.0109	**1.75-7.20** r95: 0.03 ± 0.005m R95: 0.03 ± 0.02m
Alcohol (vol%)	4.86	4.84	4.84	4.84	4.86	4.848	0.0109	**2.2-9.0** r95: 0.04 ± 0.004m R95: 0.04 ± 0.02m
Sp. Gravity (S 20/20) Real extract	1.0148	1.0148	1.0148	1.0148	1.0148	1.01480	0.00000	**1.01175-1.02370** r95: N/A R95: N/A
Real extract (ER) %	3.78	3.78	3.78	3.78	3.78	3.78	0.000	**3.0-6.0** r95:0.02m R95: 0.02m
Original Gravity (OG) %	12.10	12.10	12.10	12.10	12.08	12. 096	0.0088	**7.0-12.0** r95: 0.07 R95: 0.19
pH	4.10	4.09	4.09	4.10	4.10	4.096	0.0054	**Pils: 4.3-4.6** r95:0.02 R95:0.13
Bitter units	A275: 0.398 IBU: 19.90 ≈ 20	A275: 0.381 IBU: 19.06 ≈ 19	A275: 0.384 IBU: 19.21 ≈ 19	A275: 0.382 IBU: 19.14 ≈ 19	A275: 0.381 IBU: 19.09 ≈ 19	A275: 0.385 IBU:19.28 ≈ 19	A275: 0.007 IBU: 0.35	**A275: 0.200-0.800 IBU: 10-40** r95: 0.44 ± 0.014m R95: -0.7 ± 0.18m
Colour Visual Comp. EBC/Lovibond	6.5	6.5	6.5	6.5	6.5	6.50	0.000	**Pale beers: 7-11 EBC** r95: 0.4 R95: 1.8
Colour (430 nm) EBC	A430: 0.260 EBC: 7.0	A430: 0.261 EBC: 7.025	A430: 0.262 EBC: 7.05	A430: 0.269 EBC: 7.225	A430: 0.269 EBC: 7.225	A430: 0.2642 EBC: 7.105	A430: 0.0044 EBC: 0.1109	**Pale beers: 7-11 EBC** r95: 0.3 R95:0.6
Colour Tristimulus %T 360 nm	1.44	1.43	1.46	1.44	1.46	1.446	0.0134	
Colour Tristimulus	63.98	63.98	63.95	63.92	63.93	63.952	0.0277	

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
%T 450 nm								
Colour Tristimulus %T 540 nm	88.30	88.30	88.25	88.25	88.23	88.263	0.0294	
Colour Tristimulus %T 670 nm	97.99	97.99	97.98	97.98	97.97	97.982	0.0083	
Colour Tristimulus %T 760 nm	98.78	98.76	98.75	98.76	98.74	98.758	0.0148	
Colour Tristimulus ∑ x/k	862.91	862.90	862.54	862.53	862.42	926.74	0.2812	
Colour Tristimulus ∑ y/k	927.04	927.04	926.62	926.59	926.43	926.74	0.2812	
Colour Tristimulus ∑ z/k	708.38	708.37	708.06	707.77	707.85	708.090	0.2858	
Colour Tristimulus Values **X (Red)**	81.65	81.65	81.62	81.61	81.60	81.629	0.0209	
Colour Tristimulus Values **Y (Green)**	87.72	87.72	87.68	87.67	87.68	87.695	0.0221	
Colour Tristimulus Values **Z (Blue)**	67.03	67.02	66.99	66.97	66.97	67.001	0.0271	
Colour CIELAB L*	92.42	92.42	92.40	92.40	92.40	92.410	0.0096	**96.63 *, 93.83**** r95: 0.55 R95: 2.26
Colour CIELAB a*	-3.81	-3.81	-3.81	-3.81	-3.80	-3.813	0.0038	**-2.04 *, -7.83 **** r95: 0.19 R95: 0.56
Colour CIELAB b*	12.00	12.00	12.00	12.01	12.00	12.005	0.0038	**14.39 *, 32.97**** r95: 1.01 R95: 2.20
Colour CIELAB C* (Metric Chroma)	12.59	12.59	12.59	12.60	12.59	12.595	0.0038	
Yellowness Index	38.14	38.14	38.15	38.18	38.16	38.159	0.0157	
iCAM Lightness **J**	6.65	6.65	6.65	6.65	6.65	6.65	0.000	
iCAM Chroma **C**	1.15	1.15	1.15	1.15	1.15	1.154	0.0004	
iCAM Angle Hue **h**	0.067	0.067	0.068	0.068	0.068	0.0681	0.00033	
iCAM Brightness **Q**	13.45	13.45	13.44	13.44	13.44	13.449	0.0015	
iCAM	2.33	2.33	2.33	2.33	2.33	2.332	0.0008	

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
Colourfulness **M**								
CIECAM02 Lightness **J**	93.41	93.41	93.39	93.39	93.38	93.400	0.0148	Repeat.****: r^2: 0.84 CV:19 Reprod. ****: r^2: 0.88 CV:17
CIECAM02 Chroma **C**	17.71	17.71	17.71	17.72	17.71	17.718	0.0064	
CIECAM02 redness-greenness **a**	-0.0166	-0.0166	-0.0163	-0.0163	-0.0162	-0.0164	0.000187	
CIECAM02 yellowness-blueness **b**	0.368	0.368	0.368	0.369	0.368	0.3688	0.00015	
CIECAM02 Angle Hue **h**	92.57	92.57	92.53	92.54	92.52	92.552	0.0231	
CIECAM02 Hue composition **H**	104.88	104.88	104.81	104.81	104.79	104.840	0.0441	Repeat.****: r^2: 0.99 CV: 8 Reprod. ****: r^2: 0.99 CV:10
CIECAM02 **Hc (Red)**	0.00	0.00	0.00	0.00	0.00	0.000	0.0000	
CIECAM02 **Hc (Yellow)**	95.11	95.11	95.18	95.18	95.20	95.15	0.0441	
CIECAM02 **Hc (Green)**	4.88	4.88	4.81	4.81	4.79	4.84	0.044	
CIECAM02 **Hc (Blue)**	0.00	0.00	0.00	0.00	0.00	0.000	0.0000	
CIECAM02 Brightness **Q**	230.00	230.00	229.97	229.97	229.96	229.984	0.0182	
CIECAM02 Colourfulness **M**	16.72	16.72	16.71	16.72	16.72	16.723	0.0040	Repeat.****: r^2: 0.72 CV: 30 Reprod.****: r^2: 0.67 CV:37
CIECAM02 Saturation **s**	29.96	26.96	26.96	26.97	26.96	27.566	1.3403	
Turbidity 20℃ EBC	0.582	0.573	0.576	0.578	0.580	0.5778	0.0034	**N/A** r95: 0.05 R95:0.20
Shelf Life Prediction Forcing method EBC (modified according to Titze *et al.*, 2007) (60℃,24 h/ 0℃, 24h/ 20℃) EBC-formazin units/ Warm days	Blank: 0.582 EBC: 2.22 W. days: 9	Blank: 0.573 EBC: 2.29 W. days: 9	Blank: 0.576 EBC: 2.44 W. days: 9	Blank: 0.578 EBC: 2.27 W. days: 9	Blank: 0.580 EBC: 2.36 W. days: 9	Blank: 0.5778 EBC: 2.32 W. days: 9.0	Blank: 0.0034 EBC:0.08 W. days: 0.00	
NIBEM	Sec: 247 10: 90 20: 172	Sec: 249 10: 94 20: 170	Sec: 253 10: 99 20: 176	Sec: 241 10: 84 20: 165	Sec: 246 10: 89 20: 172	Sec: 247 10: 91.2 20: 171	Sec: 4.38 10: 5.63 20: 4.38	**For lager beers: Bad: < 220 sec Very Good: > 300 sec** r95: 9 R95:42

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
	30: 247	30: 249	30: 253	30: 241	30: 246	30: 247	30: 4.38	
CO_2% vol.	2.93	2.93	3.00	2.86	3.06	2.956	0.0763	**Vol %: 2.5 - 3.0** r95: 0.09 R95:0.08m
Dissolved oxygen (m/L) (Orbisphere DO)	0.155	0.198	0.153	0.161	0.150	0.1334	0.0050	**< 0.3** r95:0.15 mg/L R95: 0.3 mg/L
Total polyphenols (mg/L)	A820: 0.204 Polyθ: 167.28	A820: 0.204 Polyθ: 167.28	A820: 0.206 Polyθ: 168.92	A820: 0.207 Polyθ: 169.74	A820: 0.204 Polyθ: 167.28	A820: 0.205 Polyθ: 168.1	A820: 0.0014 Polyθ: 1.1596	**A820: 0.091-0.121** **Polθ: 73-176** r95:4.1 R95: 18 ± 0.13m
Flavanoids (mg/L)	AB640: -0.053 AS640: 0.018 Flav: 23.78	AB640: -0.053 AS640: 0.018 Flav: 23.78	AB640: -0.053 AS640: 0.018 Flav: 23.78	AB640: -0.053 AS640: 0.017 Flav: 23.45	AB640: -0.053 AS640: 0.017 Flav: 23.45	AB640: -0.053 AS640: 0.0176 Flav: 23.6	AB640: 0.000 AS640: 0.0005 Flav: 0.18	**Flav: 50-70** CV_{r95}: ± 4.7% CV_{R95}: ± 7.6%
Iron (mg/L) **Samples** (Atomic Absorption Spectrometry)	A248.3: 0.116	A248.3: 0.201	A248.3: 0.328	A248.3: 0.518	A248.3: 0.708 Fe (II): 0.115			**Fe(II): < 0.2 Recommend. values** r95: 0.21m R95: 0.91m
Copper (mg/L) **Samples** (Atomic Absorption Spectrometry)	A324.7: 0.117	A324.7: 0.222	A324.7: 0.316	A324.7: 0.521	A324.7: 0.728 Cu (II): 0.0114			**Cu (II): < 0.2 Recommend. values** r95: 0.45m R95: 1.71m
Calcium (mg/L) **Samples** (Atomic Absorption Spectrometry)	A423.0: 0.103	A423.0: 0.114	A423.0: 0.128	A423.0: 0.139	A423.0: 0.154 Ca (II): 2.625			**Ca (II): 4 -100 Recommend. values** CV_{ST95}: ±13.3% CV_{Sr95}: ± 2.4% CV_{Sb95}: ±9.2%
Reducing Power (MEBAK) %RED	64.7	65.6	65.0	64.4	65.8	65.10	0.5916	**> 60 very good** **50-60 good** **45-50 satisfactory** **< 45 poor** CV_{r95}: ± 1%
2-Methylpropanal (µg/L)	3.34	3.37				3.355	0.0212	**Fresh: 6.68 (±0.60) ***** **2 weeks 40℃: 39.15 (±0.47)**
2-Methylbutanal (µg/L)	2.06	2.14				2.1	0.05	**Fresh: 18.6 ***** CV(%): 7.8 CI(abs): 1.0 CI(%): 5.6 **Forced: 19.6 ***** CV(%): 7.0

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
								CI(abs): 1.0 CI(%): 5.0 **6-Months: 9.8 ***** **1-Year: 20.6 *****
3-Methylbutanal (µg/L)	5.34	5.38				5.36	0.028	**Fresh: 10.5 ***** CV(%): 4.0 CI(abs): 0.3 CI(%): 2.9 **Forced: 13.9 ***** CV(%): 5.7 CI(abs): 0.6 CI(%): 4.1 **6-Months: 16.1 ***** **1-Year: 29.0 *****
Benzaldehyde (µg/L)	1.73	1.84				1.785	0.0777	**Fresh: 0.96 (±0.02) ***** **Forced: 0.0 ***** CV(%): 0.0 CI(abs): 0.0 CI(%): 0.0 **6-Months: 1.8 ***** **1-Year: 3.3 *****
2-Phenylethanal (µg/L)	12.10	11.91				12.005	0.1343	**Fresh: 21.5 ***** CV(%): 10.3 CI(abs): 1.6 CI(%): 7.4 **Forced: 38.3 ***** CV(%): 5.3 CI(abs): 1.5 CI(%): 3.8 **6-Months: 32.2 ***** **1-Year: 55.8 *****
2-Furfural (µg/L)	9.63	10.36				9.995	0.5161	**Fresh: 7.1***** CV(%): 7.5 CI(abs): 0.4 CI(%): 5.4 **Forced: 110.8 ***** CV(%): 4.7 CI(abs): 3.8 CI(%): 3.4 **6-Months: 164.9 ***** **1-Year: 534.5 *****
Pentanal (µg/L)	0.93	0.95				0.94	0.0141	**Fresh: 1.9 ***** CV(%): N/A CI(abs): N/A CI(%): N/A **Forced: 4.5***** CV(%): N/A CI(abs): N/A CI(%): N/A **6-Months:4.9**

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
								***** 1-Year: N/A**
Hexanal (µg/L)	1.06	1.12				1.09	0.0424	**Fresh: 0.75 ***** CV(%): 6.22 CI(abs): N/A CI(%): N/A **Forced: N/A ***** CV(%): N/A CI(abs): N/A CI(%): N/A **6-Months: 0.8 ***** **1-Year: 1.0 *****
Methional (µg/L)	2.19	2.28				2.235	0.0636	**Fresh: 1.07(±0.19) ***** CV(%): N/A CI(abs): N/A CI(%): N/A **2weeks 40℃: 3.03** **6-Months: N/A ***** **1-Year: N/A**
(*E*)-2-nonenal (µg/L)	0.0026	0.0028				0.0027	0.00014	**Fresh: no quantifiable** **2 weeks 40℃: 0.070 (±0.09) *****

The normal values are reported according to Brautechnische Analysenmethoden. Band II. Mitteleuropäische Brautechnische Analysenkommission (M.E.B.A.K.) (2002), except; * according to American Society of Brewing Chemist. Report of Subcommittee on Wort and Beer. Colour Using Tristimulus Analysis (2000), ** according to Smedley (1992, 1995), *** according to Lustig (1993); Saison *et al.* (2008), **** according to Gonzalez-Miret *et al.* (2007); Luo *et al*. (1991a, 1991b)

Table A.3.9 SINAMAR®

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
Sp. Gravity (S 20/20) Beer	1.0094	1.0094	1.0094	1.0095	1.0094	1.00942	0.000044	**1.00585 - 1.01175** r95:N/A R95: N/A
App. Extract (EA) %	2.41	2.41	2.41	2.44	2.41	2.416	0.0134	**1.5 – 3.0** r95:0.012 R95:0.080
Sp. Gravity (S 20/20) Alcohol	0.99322	0.99322	0.99317	0.99314	0.99314	0.993178	0.000040	**0.99675 – 0.98770** r95: N/A R95: N/A
Alcohol (mas%)	3.74	3.74	3.77	3.79	3.79	3.766	0.0250	**1.75-7.20** r95: 0.03 ± 0.005m R95: 0.03 ± 0.02m
Alcohol (vol%)	4.70	4.70	4.74	4.76	4.76	4.732	0.0303	**2.2-9.0** r95: 0.04 ± 0.004m R95: 0.04 ± 0.02m
Sp. Gravity (S 20/20) Real extract	1.0159	1.0156	1.0156	1.0156	1.0157	1.01568	0.00013	**1.01175-1.02370** r95: N/A R95: N/A
Real extract (ER) %	4.06	3.98	3.98	3.98	4.01	4.002	0.0349	**3.0-6.0** r95:0.02m R95: 0.02m
Original Gravity (OG) %	12.22	12.23	12.24	12.22	12.22	12.226	0.0089	**7.0-12.0** r95: 0.07 R95: 0.19
pH	4.25	4.25	4.25	4.25	4.25	4.25	0.000	**Pils: 4.3-4.6** r95:0.02 R95:0.13
Bitter units	A275: 0.4445 IBU: 22.22 ≈ 22	A275: 0.4447 IBU: 22.23 ≈ 22	A275: 0.4447 IBU: 22.23 ≈ 22	A275: 0.4448 IBU: 22.24 ≈ 22	A275: 0.4447 IBU: 22.23 ≈ 22	A275: 0.4446 IBU:22.23 ≈ 22	A275: 0.0001 IBU: 0.00	**A275: 0.200-0.800 IBU: 10-40** r95: 0.44 ± 0.014m R95: -0.7 ± 0.18m
Colour Visual Comp. EBC/Lovibond	7.0	7.0	7.0	7.0	7.0	7.0	0.00	**Pale beers: 7-11 EBC** r95: 0.4 R95: 1.8
Colour (430 nm) EBC	A430: 0.295 EBC: 7.375	A430: 0.295 EBC: 7.375	A430: 0.295 EBC: 7.375	A430: 0.295 EBC: 7.375	A430: 0.295 EBC: 7.375	A430: 0.295 EBC: 7.375	A430: 0.0000 EBC: 0.0000	**Pale beers: 7-11 EBC** r95: 0.3 R95:0.6
Colour Tristimulus %T 360 nm	1.08	1.04	1.04	1.04	1.01	1.042	0.0248	
Colour Tristimulus	62.46	62.53	62.54	62.25	62.54	62.474	0.1335	

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
%T 450 nm								
Colour Tristimulus %T 540 nm	86.37	86.53	86.53	86.24	86.56	86.446	0.13722	
Colour Tristimulus %T 670 nm	96.90	97.02	97.00	97.77	97.05	97.148	0.3522	
Colour Tristimulus %T 760 nm	99.82	99.86	99.88	99.70	99.90	99.832	0.07944	
Colour Tristimulus ∑ x/k	847.41	848.69	848.64	849.39	849.03	848.635	0.7484	
Colour Tristimulus ∑ y/k	908.87	910.38	910.35	909.51	910.73	909.971	0.7591	
Colour Tristimulus ∑ z/k	691.48	692.30	692.39	689.36	692.86	691.682	1.3882	
Colour Tristimulus Values **X (Red)**	80.18	80.30	80.30	80.37	80.33	80.301	0.0705	
Colour Tristimulus Values **Y (Green)**	86.00	86.14	86.14	86.06	86.17	86.105	0.0717	
Colour Tristimulus Values **Z (Blue)**	65.43	65.50	65.51	65.23	65.56	65.449	0.1313	
Colour CIELAB L*	91.76	91.82	91.82	91.85	91.83	91.819	0.0315	**96.63 *, 93.83**** r95: 0.55 R95: 2.26
Colour CIELAB a*	-3.67	-3.68	-3.68	-3.55	-3.68	-3.655	0.0575	**-2.04 *, -7.83 **** r95: 0.19 R95: 0.56
Colour CIELAB b*	12.03	12.05	12.05	12.13	12.04	12.063	0.0398	**14.39 *, 32.97**** r95: 1.01 R95: 2.20
Colour CIELAB C* (Metric Chroma)	12.58	12.60	12.60	12.64	12.59	12.605	0.0229	
Yellowness Index	38.69	38.71	38.70	39.19	38.68	38.799	0.2224	
iCAM Lightness **J**	6.59	6.60	6.60	6.59	6.60	6.602	0.0026	
iCAM Chroma **C**	1.15	1.16	1.16	1.17	1.16	1.163	0.0057	
iCAM Angle Hue **h**	0.0800	0.0791	0.0789	0.0915	0.0791	0.08172	0.00548	
iCAM Brightness **Q**	13.33	13.34	13.34	13.33	13.34	13.33	0.0052	
iCAM	2.34	2.34	2.34	2.37	2.34	2.350	0.0116	

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
Colourfulness **M**								
CIECAM02 Lightness **J**	92.44	92.52	92.52	92.49	92.54	92.504	0.0391	Repeat.****: r^2: 0.84 CV:19 Reprod. ****: r^2: 0.88 CV:17
CIECAM02 Chroma **C**	17.78	17.81	17.80	17.92	17.79	17.823	0.0559	
CIECAM02 redness-greenness **a**	-0.0111	-0.0115	-0.0116	-0.0059	-0.0115	-0.0103	0.00247	
CIECAM02 yellowness-blueness **b**	0.370	0.371	0.370	0.374	0.370	0.371	0.0016	
CIECAM02 Angle Hue **h**	91.72	91.77	91.79	90.90	91.78	91.596	0.3857	
CIECAM02 Hue composition **H**	103.27	103.38	103.41	101.73	103.39	103.042	0.7308	Repeat.****: r^2: 0.99 CV: 8 Reprod. ****: r^2: 0.99 CV:10
CIECAM02 **Hc (Red)**	0.00	0.00	0.00	0.00	0.00	0.000	0.0000	
CIECAM02 **Hc (Yellow)**	96.72	96.61	96.58	98.26	96.60	96.9574	0.7308	
CIECAM02 **Hc (Green)**	3.27	3.38	3.41	1.73	3.39	3.042	0.7308	
CIECAM02 **Hc (Blue)**	0.00	0.00	0.00	0.00	0.00	0.000	0.0000	
CIECAM02 Brightness **Q**	228.79	228.90	228.89	228.86	228.92	228.877	0.0484	
CIECAM02 Colourfulness **M**	16.78	16.81	16.80	16.91	16.79	16.822	0.0527	Repeat.****: r^2: 0.72 CV: 30 Reprod.****: r^2: 0.67 CV:37
CIECAM02 Saturation **s**	27.08	27.10	27.09	27.18	27.08	27.11	0.042	
Turbidity 20 ℃ EBC	0.694	0.684	0.675	0.682	0.688	0.6846	0.00705	**N/A** r95: 0.05 R95:0.20
Shelf Life Prediction Forcing method EBC (modified according to Titze *et al.*, 2007) (60℃,24 h/ 0℃, 24h/ 20℃) EBC-formazin units/ Warm days	Blank: 0.694 EBC: 2.457 W. days: 11	Blank: 0.684 EBC: 2.391 W. days: 11	Blank: 0.675 EBC: 2.569 W. days: 11	Blank: 0.682 EBC: 2.466 W. days: 11	Blank: 0.688 EBC: 2.445 W. days: 11	Blank: 0.6846 EBC: 2.4656 W. days: 11.0	Blank: 0.00705 EBC: 0.06472 W. days: 0.00	
NIBEM	Sec: 254 10: 90 20: 175	Sec: 255 10: 97 20: 180	Sec: 259 10: 99 20: 181	Sec: 255 10: 95 20: 183	Sec: 252 10: 90 20: 171	Sec: 255 10: 94.2 20: 178	Sec: 2.55 10: 4.086 20: 4.898	**For lager beers: Bad: < 220 sec Very Good: > 300 sec** r95: 9 R95:42

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
	30: 254	30: 255	30: 259	30: 255	30: 252	30: 255	30: 2.549	
CO_2% vol.	2.93	2.93	3.00	2.86	3.06	2.956	0.0763	**Vol %: 2.5 - 3.0** r95: 0.09 R95:0.08m
Dissolved oxygen (mg/L) (Orbisphere DO)	0.115	0.113	0.115	0.117	0.119	0.1158	0.00228	**< 0.3** r95:0.15 mg/L R95: 0.3 mg/L
Total polyphenols (mg/L)	A820: 0.218 Polyθ: 178.76	A820: 0.219 Polyθ: 179.58	A820: 0.216 Polyθ: 177.12	A820: 0.219 Polyθ: 179.58	A820: 0.219 Polyθ: 179.58	A820: 0.2182 Polyθ: 178.924	A820: 0.0013 Polyθ: 1.0691	**A820: 0.091-0.121** **Polyθ: 73-176** r95:4.1 R95: 18 ± 0.13m
Flavanoids (mg/L)	AB640: -0.053 AS640: 0.045 Flav: 32.83	AB640: -0.053 AS640: 0.045 Flav: 32.83	AB640: -0.053 AS640: 0.047 Flav: 33.50	AB640: -0.053 AS640: 0.045 Flav: 32.83	AB640: -0.053 AS640: 0.045 Flav: 32.83	AB640: -0.053 AS640: 0.0454 Flav: 32.964	AB640: 0.000 AS640: 0.0008 Flav: 0.29963	**Flav: 50-70** CV_{r95}: ± 4.7% CV_{R95}: ± 7.6%
Iron (mg/L) **Samples** (Atomic Absorption Spectrometry)	A248.3: 0.112	A248.3: 0.233	A248.3: 0.334	A248.3: 0.501	A248.3: 0.701 Fe (II): 0.092			**Fe(II): < 0.2 Recommend. values** r95: 0.21m R95: 0.91m
Copper (mg/L) **Samples** (Atomic Absorption Spectrometry)	A324.7: 0.103	A324.7: 0.199	A324.7: 0.304	A324.7: 0.533	A324.7: 0.742 Cu (II): 0.088			**Cu (II): < 0.2 Recommend. values** r95: 0.45m R95: 1.71m
Calcium (mg/L) **Samples** (Atomic Absorption Spectrometry)	A423.0: 0.062	A423.0: 0.087	A423.0: 0.118	A423.0: 0.143	A423.0: 0.162 Ca (II): 1.088			**Ca (II): 4 -100 Recommend. values** CV_{ST95}: ±13.3% CV_{Sr95}: ± 2.4% CV_{Sb95}: ±9.2%
Reducing Power (MEBAK) % RED	57.9	57.3	57.9	57.3	57.7	57.62	0.30331	**> 60 very good** **50-60 good** **45-50 satisfactory** **< 45 poor** CV_{r95}: ± 1%
2-Methylpropanal (μg/L)	3.50	3.51				3.505	0.007	**Fresh: 6.68 (±0.60) ***** **2 weeks 40°C: 39.15 (±0.47)**
2-Methylbutanal (μg/L)	2.01	2.11				2.06	0.070	**Fresh: 18.6 ***** CV(%): 7.8 CI(abs): 1.0 CI(%): 5.6 **Forced: 19.6 *****

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
								CV(%): 7.0 CI(abs): 1.0 CI(%): 5.0 **6-Months: 9.8 ***** **1-Year: 20.6 *****
3-Methylbutanal (µg/L)	4.06	4.11				4.085	0.0353	**Fresh: 10.5 ***** CV(%): 4.0 CI(abs): 0.3 CI(%): 2.9 **Forced: 13.9 ***** CV(%): 5.7 CI(abs): 0.6 CI(%): 4.1 **6-Months: 16.1 ***** **1-Year: 29.0 *****
Benzaldehyde (µg/L)	1.70	1.64				1.67	0.042	**Fresh: 0.96 (±0.02) ***** **Forced: 0.0 ***** CV(%): 0.0 CI(abs): 0.0 CI(%): 0.0 **6-Months: 1.8 ***** **1-Year: 3.3 *****
2-Phenylethanal (µg/L)	8.58	8.86				8.72	0.198	**Fresh: 21.5 ***** CV(%): 10.3 CI(abs): 1.6 CI(%): 7.4 **Forced: 38.3 ***** CV(%): 5.3 CI(abs): 1.5 CI(%): 3.8 **6-Months: 32.2 ***** **1-Year: 55.8 *****
2-Furfural (µg/L)	7.50	7.54				7.52	0.028	**Fresh: 7.1***** CV(%): 7.5 CI(abs): 0.4 CI(%): 5.4 **Forced: 110.8 ***** CV(%): 4.7 CI(abs): 3.8 CI(%): 3.4 **6-Months: 164.9 ***** **1-Year: 534.5 *****
Pentanal (µg/L)	0.85	0.74				0.795	0.077	**Fresh: 1.9 ***** CV(%): N/A CI(abs): N/A CI(%): N/A **Forced: 4.5***** CV(%): N/A CI(abs): N/A CI(%): N/A

Analysis	Beer 1	Beer 2	Beer 3	Beer 4	Beer 5	Mean	Standard Deviation (Sx)	Normal Values
								6-Months:4.9 *** **1-Year: N/A**
Hexanal (µg/L)	1.14	1.25				1.195	0.077	**Fresh: 0.75 ***** CV(%): 6.22 CI(abs): N/A CI(%): N/A **Forced: N/A ***** CV(%): N/A CI(abs): N/A CI(%): N/A **6-Months: 0.8 ***** **1-Year: 1.0 *****
Methional (µg/L)	3.21	2.85				3.03	0.254	**Fresh: 1.07(±0.19) ***** CV(%): N/A CI(abs): N/A CI(%): N/A **2weeks 40℃: 3.03** **6-Months: N/A ***** **1-Year: N/A**
(*E*)-2-nonenal (µg/L)	0.0039	0.0034				0.00365	0.00035	**Fresh: no quantifiable** **2 weeks 40℃: 0.070 (±0.09) *****

The normal values are reported according to Brautechnische Analysenmethoden. Band II. Mitteleuropäische Brautechnische Analysenkommission (M.E.B.A.K.) (2002), except; * according to American Society of Brewing Chemist. Report of Subcommittee on Wort and Beer. Colour Using Tristimulus Analysis (2000), ** according to Smedley (1992, 1995), *** according to Lustig (1993); Saison *et al.* (2008), **** according to Gonzalez-Miret *et al.* (2007); Luo *et al*. (1991a, 1991b

Table A.3.10 CARAMEL #301

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
Sp. Gravity (S 20/20) Beer	1.0094	1.0093	1.0094	1.0094	1.0094	1.00938	0.000447	**1.00585 - 1.01175** r95:N/A R95: N/A
App. Extract (EA) %	2.41	2.39	2.41	2.41	2.41	2.406	0.0089	**1.5 – 3.0** r95:0.012 R95:0.080
Sp. Gravity (S 20/20) Alcohol	0.99285	0.99288	0.99287	0.99288	0.99287	0.99287	0.0000712	**0.99675 – 0.98770** r95: N/A R95: N/A
Alcohol (mas%)	3.96	3.93	3.95	3.93	3.95	3.944	0.0134	**1.75-7.20** r95: 0.03 ± 0.005m R95: 0.03 ± 0.02m
Alcohol (vol%)	4.98	4.94	4.96	4.94	4.96	4.956	0.0167	**2.2-9.0** r95: 0.04 ± 0.004m R95: 0.04 ± 0.02m
Sp. Gravity (S 20/20) Real extract	1.0160	1.0160	1.0161	1.0163	1.0161	1.0161	0.00012	**1.01175-1.02370** r95: N/A R95: N/A
Real extract (ER) %	4.08	4.08	4.11	4.11	4.11	4.098	0.0164	**3.0-6.0** r95:0.02m R95: 0.02m
Original Gravity (OG) %	12.27	12.28	12.28	12.27	12.27	12.274	0.0054	**7.0-12.0** r95: 0.07 R95: 0.19
pH	4.17	4.18	4.16	4.16	4.16	4.166	0.0090	**Pils: 4.3-4.6** r95:0.02 R95:0.13
Bitter units	A275: 0.4417 IBU: 22.08 ≈ 22	A275: 0.4438 IBU: 22.19 ≈ 22	A275: 0.4419 IBU: 22.09 ≈ 22	A275: 0.4499 IBU: 22.14 ≈ 22	A275: 0.4513 IBU: 22.56 ≈ 22	A275: 0.4457 IBU:22.21 ≈ 22	A275: 0.0041 IBU: 0.19	**A275: 0.200-0.800 IBU: 10-40** r95: 0.44 ± 0.014m R95: -0.7 ± 0.18m
Colour Visual Comp. EBC/Lovibond	6.5	6.5	6.5	6.5	6.5	6.50	0.000	**Pale beers: 7-11 EBC** r95: 0.4 R95: 1.8
Colour (430 nm) EBC	A430: 0.286 EBC: 7.15	A430: 0.287 EBC: 7.175	A430: 0.287 EBC: 7.175	A430: 0.287 EBC: 7.175	A430: 0.286 EBC: 7.15	A430: 0.2866 EBC: 7.165	A430: 0.0005 EBC: 0.0013	**Pale beers: 7-11 EBC** r95: 0.3 R95:0.6
Colour Tristimulus %T 360 nm	1.04	1.02	1.00	1.02	1.01	1.018	0.0148	
Colour Tristimulus	64.89	64.78	64.68	64.70	64.70	64.75	0.0871	

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
%T 450 nm								
Colour Tristimulus %T 540 nm	84.88	84.76	84.60	84.70	84.69	84.726	0.1033	
Colour Tristimulus %T 670 nm	98.85	98.80	98.51	98.76	98.74	98.732	0.1310	
Colour Tristimulus %T 760 nm	99.92	99.91	99.97	99.91	99.95	99.932	0.0268	
Colour Tristimulus ∑ x/k	850.69	849.76	847.84	849.21	849.09	849.325	1.0397	
Colour Tristimulus ∑ y/k	904.51	903.40	901.51	902.79	902.67	902.988	1.0990	
Colour Tristimulus ∑ z/k	710.98	709.80	708.64	708.99	708.96	709.478	0.9458	
Colour Tristimulus Values **X (Red)**	80.49	80.40	80.22	80.35	80.34	80.366	0.0984	
Colour Tristimulus Values **Y (Green)**	85.58	85.48	85.30	85.42	85.41	85.442	0.10241	
Colour Tristimulus Values **Z (Blue)**	67.27	67.16	67.05	67.08	67.08	67.133	0.0895	
Colour CIELAB L*	91.90	91.86	91.78	91.84	91.83	91.848	0.0441	**96.63 *, 93.83**** r95: 0.55 R95: 2.26
Colour CIELAB a*	-3.038	-3.027	-3.036	-3.024	-3.025	-3.03	0.0065	**-2.04 *, -7.83 **** r95: 0.19 R95: 0.56
Colour CIELAB b*	11.18	11.19	11.17	11.20	11.19	11.343	0.3505	**14.39 *, 32.97**** r95: 1.01 R95: 2.20
Colour CIELAB C* (Metric Chroma)	11.58	11.39	11.57	11.60	11.59	11.551	0.0892	
Yellowness Index	37.06	37.11	37.05	37.15	37.14	37.114	0.0406	
iCAM Lightness **J**	6.60	6.59	6.59	6.59	6.59	6.597	0.0034	
iCAM Chroma **C**	1.070	1.071	1.068	1.072	1.072	1.071	0.0015	
iCAM Angle Hue **h**	0.135	0.136	0.135	0.137	0.136	0.1364	0.00066	
iCAM Brightness **Q**	13.34	13.33	13.32	13.32	13.32	13.33	0.007	
iCAM	2.16	2.16	2.15	2.16	2.16	2.164	0.0031	

Analysis	Beer 1	Beer 2	Beer 3	Beer 4	Beer 5	Mean	Standard Deviation (Sx)	Normal Values
Colourfulness **M**								
CIECAM02 Lightness **J**	92.25	92.19	92.08	92.15	92.15	92.167	0.0607	Repeat.****: r^2: 0.84 CV:19 Reprod. ****: r^2: 0.88 CV:17
CIECAM02 Chroma **C**	16.21	16.22	16.19	16.24	16.23	16.22	0.018	
CIECAM02 redness-greenness **a**	0.011	0.012	0.011	0.012	0.012	0.0118	0.00031	
CIECAM02 yellowness-blueness **b**	0.338	0.338	0.338	0.339	0.339	0.3386	0.00044	
CIECAM02 Angle Hue **h**	88.03	87.95	88.04	87.93	87.94	87.983	0.0498	
CIECAM02 Hue composition **H**	96.79	96.67	96.81	96.64	96.65	96.715	0.0808	Repeat.****: r^2: 0.99 CV: 8 Reprod. ****: r^2: 0.99 CV:10
CIECAM02 **Hc (Red)**	3.20	3.32	3.18	3.35	3.34	3.284	0.0808	
CIECAM02 **Hc (Yellow)**	96.79	96.67	96.81	96.64	96.65	96.715	0.0806	
CIECAM02 **Hc (Green)**	0.00	0.00	0.00	0.00	0.00	0.000	0.0000	
CIECAM02 **Hc (Blue)**	0.00	0.00	0.00	0.00	0.00	0.000	0.0000	
CIECAM02 Brightness **Q**	228.56	228.49	228.35	228.44	228.44	228.46	0.075	
CIECAM02 Colourfulness **M**	15.30	15.31	16.19	15.33	15.32	15.495	0.3929	Repeat.****: r^2: 0.72 CV: 30 Reprod.****: r^2: 0.67 CV:37
CIECAM02 Saturation **s**	25.87	25.89	25.87	25.90	25.90	25.890	0.0148	
Turbidity 20℃ EBC	0.783	0.775	0.772	0.772	0.777	0.7888	0.0045	**N/A** r95: 0.05 R95:0.20
Shelf Life Prediction Forcing method EBC (modified according to Titze *et al.*, 2007) (60℃,24 h/ 0℃, 24h/ 20℃) EBC-formazin units/ Warm days	Blank: 0.783 EBC: 2.683 W. days: 9	Blank: 0.775 EBC: 2.557 W. days: 9	Blank: 0.772 EBC: 2.656 W. days: 8	Blank: 0.772 EBC: 2.113 W. days: 8	Blank: 0.777 EBC: 2.681 W. days: 8	Blank: 0.7888 EBC: 2.538 W. days: 8.4	Blank: 0.0045 EBC: 0.24309 W. days: 0.547	
NIBEM	Sec: 237 10: 81 20: 161	Sec: 244 10: 85 20: 161	Sec: 247 10: 90 20: 166	Sec: 242 10: 89 20: 164	Sec: 239 10: 86 20: 157	Sec: 242 10: 86.2 20: 161.8	Sec: 3.96 10: 3.56 20: 3.42	**For lager beers: Bad: <220 sec Very Good: > 300 sec** r95: 9 R95:42

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
	30: 237	30: 244	30: 247	30: 242	30: 239	30: 242	30: 3.96	
CO_2% vol.	3.20	3.17	3.21	3.14	3.23	3.19	0.0353	**Vol %: 2.5 - 3.0** r95: 0.09 R95:0.08m
Dissolved oxygen (mg/L) (Orbisphere DO)	0.137	0.144	0.131	0.152	0.163	0.1454	0.0425	**< 0.3** r95:0.15 mg/L R95: 0.3 mg/L
Total polyphenols (mg/L)	A820: 0.190 Polyθ: 155.8	A820: 0.190 Polyθ: 155.8	A820: 0.199 Polyθ: 163.18	A820: 0.190 Polyθ: 155.80	A820: 0.199 Polyθ: 163.18	A820: 0.1936 Polyθ: 158.75	A820: 0.00492 Polyθ: 4.0421	**A820: 0.091-0.121 Polyθ: 73-176** r95:4.1 R95: 18 ± 0.13m
Flavanoids (mg/L)	AB640: -0.053 AS640: 0.040 Flav: 31.15	AB640: -0.053 AS640: 0.041 Flav: 31.49	AB640: -0.053 AS640: 0.041 Flav: 31.49	AB640: -0.053 AS640: 0.040 Flav: 31.15	AB640: -0.053 AS640: 0.042 Flav: 31.82	AB640: -0.053 AS640: 0.0408 Flav:31.4	AB640: 0.000 AS640: 0.0008 Flav: 0.28	**Flav: 50-70** CV_{r95}: ± 4.7% CV_{R95}: ± 7.6%
Iron (mg/L) **Samples** (Atomic Absorption Spectrometry)	A248.3: 0.187	A248.3: 0.244	A248.3: 0.389	A248.3: 0.594	A248.3: 0.781 Fe (II): 0.169			**Fe(II): < 0.2 Recommend. values** r95: 0.21m R95: 0.91m
Copper (mg/L) **Samples** (Atomic Absorption Spectrometry)	A324.7: 0.119	A324.7: 0.215	A324.7: 0.319	A324.7: 0.525	A324.7: 0.731 Cu (II): 0.106			**Cu (II): < 0.2 Recommend. values** r95: 0.45m R95: 1.71m
Calcium (mg/L) **Samples** (Atomic Absorption Spectrometry)	A423.0: 0.072	A423.0: 0.112	A423.0: 0.127	A423.0: 0.134	A423.0: 0.140 Ca (II): 1.451			**Ca (II): 4 -100 Recommend. values** CV_{ST95}: ±13.3% CV_{Sr95}: ± 2.4% CV_{Sb95}: ±9.2%
Reducing Power (MEBAK) %RED	68.4	68.1	68.4	68.3	67.4	68.12	0.4207	**> 60 very good 50-60 good 45-50 satisfactory < 45 poor** CV_{r95}: ± 1%
2-Methylpropanal (μg/L)	3.74	3.88				3.81	0.098	**Fresh: 6.68 (±0.60) *** 2 weeks 40℃: 39.15 (±0.47)**
2-Methylbutanal (μg/L)	2.54	2.61				2.57	0.049	**Fresh: 18.6 ***** CV(%): 7.8 CI(abs): 1.0 CI(%): 5.6 **Forced: 19.6 *****

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
								CV(%): 7.0 CI(abs): 1.0 CI(%): 5.0 **6-Months: 9.8 ***** **1-Year: 20.6 *****
3-Methylbutanal (µg/L)	5.96	6.16				6.06	0.141	**Fresh: 10.5 ***** CV(%): 4.0 CI(abs): 0.3 CI(%): 2.9 **Forced: 13.9 ***** CV(%): 5.7 CI(abs): 0.6 CI(%): 4.1 **6-Months: 16.1 ***** **1-Year: 29.0 *****
Benzaldehyde (µg/L)	1.22	1.00				1.11	0.155	**Fresh: 0.96 (±0.02) ***** **Forced: 0.0 ***** CV(%): 0.0 CI(abs): 0.0 CI(%): 0.0 **6-Months: 1.8 ***** **1-Year: 3.3 *****
2-Phenylethanal (µg/L)	11.95	11.87				11.91	0.056	**Fresh: 21.5 ***** CV(%): 10.3 CI(abs): 1.6 CI(%): 7.4 **Forced: 38.3 ***** CV(%): 5.3 CI(abs): 1.5 CI(%): 3.8 **6-Months: 32.2 ***** **1-Year: 55.8 *****
2-Furfural (µg/L)	10.05	9.86				9.95	0.134	**Fresh: 7.1***** CV(%): 7.5 CI(abs): 0.4 CI(%): 5.4 **Forced: 110.8 ***** CV(%): 4.7 CI(abs): 3.8 CI(%): 3.4 **6-Months: 164.9 ***** **1-Year: 534.5 *****
Pentanal (µg/L)	0.86	0.81				0.83	0.035	**Fresh: 1.9 ***** CV(%): N/A CI(abs): N/A CI(%): N/A **Forced: 4.5***** CV(%): N/A CI(abs): N/A CI(%): N/A

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
								6-Months:4.9 *** **1-Year: N/A**
Hexanal (µg/L)	1.21	1.18				1.195	0.0212	**Fresh: 0.75 ***** CV(%): 6.22 CI(abs): N/A CI(%): N/A **Forced: N/A ***** CV(%): N/A CI(abs): N/A CI(%): N/A **6-Months: 0.8 ***** **1-Year: 1.0 *****
Methional (µg/L)	2.10	2.13				2.115	0.0212	**Fresh: 1.07(±0.19) ***** CV(%): N/A CI(abs): N/A CI(%): N/A **2weeks 40℃: 3.03** **6-Months: N/A ***** **1-Year: N/A**
(*E*)-2-nonenal (µg/L)	0.0020	0.0026				0.0023	0.00042	**Fresh: no quantifiable** **2 weeks 40℃: 0.070 (±0.09) *****

The normal values are reported according to Brautechnische Analysenmethoden. Band II. Mitteleuropäische Brautechnische Analysenkommission (M.E.B.A.K.) (2002), except; * according to American Society of Brewing Chemist. Report of Subcommittee on Wort and Beer. Colour Using Tristimulus Analysis (2000), ** according to Smedley (1992, 1995), *** according to Lustig (1993); Saison *et al.* (2008), **** according to Gonzalez-Miret *et al.* (2007); Luo *et al*. (1991a, 1991b)

Table A.3.11 PILSNER MALT

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
Sp. Gravity (S 20/20) Beer	1.0091	1.0092	1.0092	1.0093	1.0092	1.0092	0.000070	**1.00585 - 1.01175** r95:N/A R95: N/A
App. Extract (EA) %	2.34	2.36	2.36	2.39	2.36	2.362	0.0178	**1.5 – 3.0** r95:0.012 R95:0.080
Sp. Gravity (S 20/20) Alcohol	0.99299	0.99300	0.99300	0.99299	0.99300	0.992996	0.000005	**0.99675 – 0.98770** r95: N/A R95: N/A
Alcohol (mas%)	3.87	3.87	3.87	3.87	3.87	3.87	0.000	**1.75-7.20** r95: 0.03 ± 0.005m R95: 0.03 ± 0.02m
Alcohol (vol%)	4.86	4.86	4.86	4.86	4.86	4.86	0.000	**2.2-9.0** r95: 0.04 ± 0.004m R95: 0.04 ± 0.02m
Sp. Gravity (S 20/20) Real extract	1.0156	1.0156	1.0156	1.0156	1.0156	1.0156	0.0000	**1.01175-1.02370** r95: N/A R95: N/A
Real extract (ER) %	3.98	3.98	3.98	3.98	3.98	3.98	0.000	**3.0-6.0** r95:0.02m R95: 0.02m
Original Gravity (OG) %	11.79	11.79	11.79	11.79	11.79	11.79	0.000	**7.0-12.0** r95: 0.07 R95: 0.19
pH	3.95	3.92	3.92	3.92	3.92	3.926	0.0134	**Pils: 4.3-4.6** r95:0.02 R95:0.13
Bitter units	A275: 0.3888 IBU: 19.44 ≈ 19	A275: 0.3805 IBU: 19.02 ≈ 19	A275: 0.3809 IBU: 19.04 ≈ 19	A275: 0.3822 IBU: 19.11 ≈ 19	A275: 0.3829 IBU: 19.14 ≈ 19	A275: 0.3829 IBU:19.15 ≈ 19	A275: 0.0030 IBU: 0.1631	**A275: 0.200-0.800 IBU: 10-40** r95: 0.44 ± 0.014m R95: -0.7 ± 0.18m
Colour Visual Comp. EBC/Lovibond	4.5	4.5	4.5	4.5	4.5	4.50	0.000	**Pale beers: 7-11 EBC** r95: 0.4 R95: 1.8
Colour (430 nm) EBC	A430: 0.195 EBC: 4.8	A430: 0.195 EBC: 4.8	A430: 0.195 EBC:4.8	A430: 0.196 EBC:4.9	A430: 0.196 EBC:4.9	A430: 0.1954 EBC: 4.88	A430: 0.0005 EBC: 0.00	**Pale beers: 7-11 EBC** r95: 0.3 R95:0.6
Colour Tristimulus %T 360 nm	3.43	3.43	3.43	3.44	3.44	3.434	0.0054	

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
Colour Tristimulus %T 450 nm	67.67	67.85	67.91	67.63	67.88	67.788	0.1285	
Colour Tristimulus %T 540 nm	90.54	90.65	90.68	90.40	90.61	90.636	0.1582	
Colour Tristimulus %T 670 nm	99.26	99.31	99.32	99.09	99.25	99.246	0.0923	
Colour Tristimulus %T 760 nm	99.99	99.98	99.99	99.98	100.02	99.926	0.0527	
Colour Tristimulus ∑ x/k	885.78	885.32	885.59	883.02	884.97	884.941	1.1153	
Colour Tristimulus ∑ y/k	952.42	951.31	951.62	948.77	950.92	951.014	1.3682	
Colour Tristimulus ∑ z/k	747.33	748.66	749.24	746.32	748.87	748.086	1.222	
Colour Tristimulus Values **X (Red)**	83.81	83.77	83.79	83.55	83.74	83.736	0.1053	
Colour Tristimulus Values **Y (Green)**	90.12	90.01	90.04	89.77	89.98	89.988	0.1295	
Colour Tristimulus Values **Z (Blue)**	70.71	70.84	70.89	70.61	70.86	70.786	0.1158	
Colour CIELAB L*	93.37	93.35	93.36	93.25	93.33	93.335	0.0461	**96.63 *, 93.83**** r95: 0.55 R95: 2.26
Colour CIELAB a*	-3.91	-3.86	-3.86	-3.85	-3.86	-3.872	0.0233	**-2.04 *, -7.83 **** r95: 0.19 R95: 0.56
Colour CIELAB b*	11.42	11.34	11.33	11.34	11.32	11.353	0.0404	**14.39 *, 32.97**** r95: 1.01 R95: 2.20
Colour CIELAB C* (Metric Chroma)	12.07	11.98	11.97	11.98	11.96	11.996	0.0454	
Yellowness Index	35.86	35.70	35.66	35.74	35.64	35.725	0.0897	
iCAM Lightness **J**	6.74	6.74	6.74	6.73	6.74	6.745	0.0039	
iCAM Chroma **C**	1.084	1.075	1.073	1.075	1.072	1.076	0.0045	
iCAM Angle Hue **h**	0.054	0.058	0.058	0.059	0.058	0.0578	0.00177	
iCAM Brightness	13.63	13.63	13.63	13.61	13.62	13.628	0.0079	

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
Q								
iCAM Colourfulness **M**	2.190	2.17	2.16	2.17	2.16	2.174	0.0091	
CIECAM02 Lightness **J**	94.75	94.69	94.71	94.56	94.67	94.682	0.0723	Repeat.****: r^2: 0.84 CV:19 Reprod. ****: r^2: 0.88 CV:17
CIECAM02 Chroma **C**	16.69	16.54	16.52	16.54	16.50	16.563	0.0741	
CIECAM02 redness-greenness **a**	-0.021	-0.020	-0.020	-0.019	-0.020	-0.020	0.0007	
CIECAM02 yellowness-blueness **b**	0.346	0.342	0.342	0.343	0.342	0.3433	0.0015	
CIECAM02 Angle Hue **h**	93.62	93.37	93.39	93.32	93.38	93.423	0.1142	
CIECAM02 Hue composition **H**	106.82	106.37	106.41	106.28	106.39	106.459	0.2111	Repeat.****: r^2: 0.99 CV: 8 Reprod. ****: r^2: 0.99 CV:10
CIECAM02 **Hc (Red)**	0.00	0.00	0.00	0.00	0.00	0.000	0.0000	
CIECAM02 **Hc (Yellow)**	93.17	93.62	93.58	93.71	93.60	93.54	0.2111	
CIECAM02 **Hc (Green)**	6.82	6.37	6.41	6.28	6.39	6.459	0.2113	
CIECAM02 **Hc (Blue)**	0.00	0.00	0.00	0.00	0.00	0.000	0.0000	
CIECAM02 Brightness **Q**	231.64	231.57	231.59	231.41	231.55	231.557	0.0884	
CIECAM02 Colourfulness **M**	15.75	15.61	15.59	15.62	16.58	15.833	0.4233	Repeat.****: r^2: 0.72 CV:30 Reprod.****: r^2: 0.67 CV:37
CIECAM02 Saturation **s**	26.08	25.96	25.95	25.98	25.94	25.983	0.0559	
Turbidity 20℃ EBC	0.663	0.651	0.648	0.657	0.646	0.652	0.00812	**N/A** r95: 0.05 R95:0.20
Shelf Life Prediction Forcing method EBC (modified according to Titze *et al.*, 2007) (60℃,24 h/ 0℃, 24h/ 20℃) EBC-formazin units/ Warm days	Blank: 0.663 EBC:2.79 W. days: 8	Blank: 0.651 EBC: 2.76 W. days: 8	Blank: 0.648 EBC: 2.80 W. days: 8	Blank: 0.657 EBC: 2.77 W. days: 8	Blank: 0.646 EBC: 2.82 W. days: 8	Blank: 0.652 EBC: 2.79 W. days: 8.0	Blank:0.00812 EBC: 0.02 W. days: 0.0	
NIBEM	Sec: 273 10: 103	Sec: 276 10: 109	Sec: 269 10: 97	Sec: 273 10: 106	Sec: 276 10: 107	Sec: 273.4	Sec: 2.885	**For lager beers: Bad: < 220 sec Very Good:**

Analysis	***Beer 1***	***Beer 2***	***Beer 3***	***Beer 4***	***Beer 5***	***Mean***	***Standard Deviation (Sx)***	***Normal Values***
	20: 193 30: 273	20: 197 30: 276	20: 186 30: 269	20: 197 30: 273	20: 194 30: 276	10: 104.4 20: 193.4 30: 273.4	10: 4.66 20: 4.50 30: 2.88	**> 300 sec** r95: 9 R95:42
CO_2% vol.	3.09	2.95	2.99	2.97	2.96	2.992	0.0567	**Vol %: 2.5 - 3.0** r95: 0.09 R95:0.08m
Dissolved oxygen (mg/L) (Orbisphere DO)	0.084	0.075	0.077	0.079	0.079	0.0188	0.00334	**< 0.3** r95:0.15 mg/L R95: 0.3 mg/L
Total polyphenols (mg/L)	A820: 0.165 Polyθ: 135.3	A820: 0.165 Polyθ: 135.3	A820: 0.166 Polyθ: 136.12	A820: 0.160 Polyθ: 131.2	A820: 0.164 Polyθ: 134.48	A820: 0.164 Polyθ: 134.48	A820:0.00 234 Polyθ: 1.9230	**A820: 0.091-0.121** **Polyθ: 73-176** r95:4.1 R95: 18 ± 0.13m
Flavanoids (mg/L)	AB640: -0.053 AS640: 0.018 Flav: 23.78	AB640: -0.053 AS640: 0.018 Flav: 23.78	AB640: -0.053 AS640: 0.018 Flav: 23.78	AB640: -0.053 AS640: 0.017 Flav: 23.45	AB640: -0.053 AS640: 0.017 Flav: 23.45	AB640: -0.053 AS640: 0.0176 Flav: 23.6	AB640: -0.053 AS640: 0.0005 Flav: 0.18	**Flav: 50-70** CV_{r95}: ± 4.7% CV_{R95}: ± 7.6%
Iron (mg/L) **Samples** (Atomic Absorption Spectrometry)	A248.3: 0.110	A248.3: 0.248	A248.3: 0.313	A248.3: 0.511	A248.3: 0.724 Fe (II): 0.102			**Fe(II): < 0.2 Recommend. values** r95: 0.21m R95: 0.91m
Copper (mg/L) **Samples** (Atomic Absorption Spectrometry)	A324.7: 0.106	A324.7: 0.210	A324.7: 0.311	A324.7: 0.516	A324.7: 0.715 Cu (II): 0.102			**Cu (II): < 0.2 Recommend. values** r95: 0.45m R95: 1.71m
Calcium (mg/L) **Samples** (Atomic Absorption Spectrometry)	A423.0: 0.050	A423.0: 0.088	A423.0: 0.119	A423.0: 0.124	A423.0: 0.139 Ca (II): 0.791			**Ca (II): 4 -100 Recommend. values** CV_{ST95}: ±13.3% CV_{Sr95}: ± 2.4% CV_{Sb95}: ±9.2%
Reducing Power (MEBAK) %RED	55.7	54.9	55.3	55.1	55.6	55.32	0.334	**> 60 very good** **50-60 good** **45-50 satisfactory** **< 45 poor** CV_{r95}: ± 1%

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
2-Methylpropanal (μg/L)	3.38	3.42				3.4	0.028	**Fresh: 6.68 (±0.60) ***** **2 weeks 40℃: 39.15 (±0.47)**
2-Methylbutanal (μg/L)	2.35	2.2				2.27	0.106	**Fresh: 18.6 ***** CV(%): 7.8 CI(abs): 1.0 CI(%): 5.6 **Forced: 19.6 ***** CV(%): 7.0 CI(abs): 1.0 CI(%): 5.0 **6-Months: 9.8 ***** **1-Year: 20.6 *****
3-Methylbutanal (μg/L)	5.13	5.11				5.12	0.014	**Fresh: 10.5 ***** CV(%): 4.0 CI(abs): 0.3 CI(%): 2.9 **Forced: 13.9 ***** CV(%): 5.7 CI(abs): 0.6 CI(%): 4.1 **6-Months: 16.1 ***** **1-Year: 29.0 *****
Benzaldehyde (μg/L)	1.76	1.54				1.65	0.155	**Fresh: 0.96 (±0.02) ***** **Forced: 0.0 ***** CV(%): 0.0 CI(abs): 0.0 CI(%): 0.0 **6-Months: 1.8 ***** **1-Year: 3.3 *****
2-Phenylethanal (μg/L)	11.72	11.51				11.615	0.1485	**Fresh: 21.5 ***** CV(%): 10.3 CI(abs): 1.6 CI(%): 7.4 **Forced: 38.3 ***** CV(%): 5.3 CI(abs): 1.5 CI(%): 3.8 **6-Months: 32.2 ***** **1-Year: 55.8 *****
2-Furfural (μg/L)	8.91	9.42				9.165	0.3606	**Fresh: 7.1***** CV(%): 7.5 CI(abs): 0.4 CI(%): 5.4 **Forced: 110.8 ***** CV(%): 4.7 CI(abs): 3.8 CI(%): 3.4 **6-Months:**

Analysis	*Beer 1*	*Beer 2*	*Beer 3*	*Beer 4*	*Beer 5*	*Mean*	*Standard Deviation (Sx)*	*Normal Values*
								164.9 * 1-Year: 534.5 *****
Pentanal (µg/L)	0.57	0.69				0.63	0.848	**Fresh: 1.9 ***** CV(%): N/A CI(abs): N/A CI(%): N/A **Forced: 4.5***** CV(%): N/A CI(abs): N/A CI(%): N/A **6-Months:4.9 ***** **1-Year: N/A**
Hexanal (µg/L)	0.96	0.99				0.975	0.0212	**Fresh: 0.75 ***** CV(%): 6.22 CI(abs): N/A CI(%): N/A **Forced: N/A ***** CV(%): N/A CI(abs): N/A CI(%): N/A **6-Months: 0.8 ***** **1-Year: 1.0 *****
Methional (µg/L)	1.67	1.51				1.59	0.113	**Fresh: 1.07(±0.19) ***** CV(%): N/A CI(abs): N/A CI(%): N/A **2weeks 40℃: 3.03** **6-Months: N/A ***** **1-Year: N/A**
(*E*)-2-nonenal (µg/L)	0.0063	0.0068				0.00655	0.00035	**Fresh: no quantifiable** **2 weeks 40℃: 0.070 (±0.09) *****

The normal values are reported according to Brautechnische Analysenmethoden. Band II. Mitteleuropäische Brautechnische Analysenkommission (M.E.B.A.K.) (2002), except; * according to American Society of Brewing Chemist. Report of Subcommittee on Wort and Beer. Colour Using Tristimulus Analysis (2000), ** according to Smedley (1992, 1995), *** according to Lustig (1993); Saison *et al.* (2008), **** according to Gonzalez-Miret *et al.* (2007); Luo *et al*. (1991a, 1991b)

Table A.3.12 Pale Lager Beer Parameters (Locally-brewed beers)

Parameter	*Grand mean of produced beers (GM)*	*Standard Deviation (Sx)*	*Normal Values*
Sp. Gravity (S 20/20) Beer	1.008670	0.0006495	**1.00585 -1.01175** r95:N/A R95: N/A
App. extract (EA) %	2.22	0.165	**1.5 – 3.0** r95:0.012 R95:0.080
Sp. Gravity (S 20/20) Alcohol	0.992988	0.0000991	**0.99675 – 0.98770** r95: N/A R95: N/A
Alcohol (mas%)	3.87	0.060	**1.75-7.20** r95: 0.03 ± 0.005m R95: 0.03 ± 0.02m
Alcohol (vol%)	4.87	0.075	**2.2-9.0** r95: 0.04 ± 0.004m R95: 0.04 ± 0.02m
Sp. Gravity (S 20/20) Real extract	1.01603	0.002256	**1.01175-1.02370** r95: N/A R95: N/A
Real extract (ER) %	3.92	0.119	**3.0-6.0** r95:0.02m R95: 0.02m
Original Gravity (OG) %	12.08	0.205	**7.0-12.0** r95: 0.07 R95: 0.19
pH	4.07	0.105	**Pils: 4.3-4.6** r95:0.02 R95:0.13
Bitter units	21.27	1.438	**A275: 0.200- 0.800** **IBU: 10-40** r95: 0.44 ± 0.014m R95: -0.7 ± 0.18m
Colour Visual Comp. EBC/Lovibond	6.54	0.756	**Pale beers: 7-11 EBC** r95: 0.4 R95: 1.8
Colour (430 nm) EBC	6.98	0.840	**Pale beers: 7-11 EBC** r95: 0.3 R95:0.6
Colour Tristimulus 360 nm	1.486	0.7270	
Colour Tristimulus 450 nm	55.853	10.8119	

Parameter	*Grand mean of produced beers (GM)*	*Standard Deviation (Sx)*	*Normal Values*
Colour Tristimulus 540 nm	83.522	7.9067	
Colour Tristimulus 670 nm	96.533	3.3546	
Colour Tristimulus 760 nm	98.212	2.7640	
Colour Tristimulus ∑ x/k	825.780	68.7886	
Colour Tristimulus ∑ y/k	880.184	74.1522	
Colour Tristimulus ∑ z/k	628.070	108.1059	
Colour Tristimulus Values **X (Red)**	77.621	5.8424	
Colour Tristimulus Values **Y (Green)**	83.006	6.7993	
Colour Tristimulus Values **Z (Blue)**	59.482	10.1944	
Colour CIELAB L*	90.54	2.821	**96.63 *, 93.83**** r95: 0.55 R95: 2.26
Colour CIELAB a*	-3.40	0.090	**-2.04 *, -7.83 **** r95: 0.19 R95: 0.56
Colour CIELAB b*	13.60	2.432	**14.39 *, 32.97**** r95: 1.01 R95: 2.20
Colour CIELAB C* (Metric Chroma)	14.03	2.378	
Yellowness Index	44.31	9.035	
iCAM Lightness **J**	6.47	0.284	
iCAM Chroma **C**	1.35	0.287	
iCAM Angle Hue **h**	0.098	0.0570	
iCAM Brightness **Q**	13.07	0.574	
iCAM Colourfulness **M**	2.73	0.586	
CIECAM02 Lightness **J**	90.84	4.126	Repeatability****: r^2: 0.84 CV:19 Reproducibility ****: r^2: 0.88 CV:17
CIECAM02 Chroma **C**	20.66	4.469	
CIECAM02 redness-greenness **a**	-0.0006	0.03474	

Parameter	*Grand mean of produced beers (GM)*	*Standard Deviation (Sx)*	*Normal Values*
CIECAM02 yellowness-blueness **b**	0.43186	0.09388	
CIECAM02 Angle Hue **h**	90.23	3.958	
CIECAM02 Hue composition **H**	100.81	6.780	Repeatability****: r^2: 0.99 CV: 8 Reproducibility ****: r^2: 0.99 CV:10
CIECAM02 **Hc (Red)**	2.42	4.484	
CIECAM02 **Hc (Yellow)**	94.22	3.230	
CIECAM02 **Hc (Green)**	3.24	2.835	
CIECAM02 **Hc (Blue)**	0.00	0.00	
CIECAM02 Brightness **Q**	226.75	5.285	
CIECAM02 Colourfulness **M**	17.77	6.561	Repeatability****: r^2: 0.72 CV: 30 Reproducibility****: r^2: 0.67 CV:37
CIECAM02 Saturation **s**	29.26	3.393	
Turbidity 20℃ EBC	0.68	0.107	**N/A** r95: 0.05 R95:0.20
Shelf Life Prediction Forcing method EBC (modified according to Titze *et al.*, 2007) (60℃,24 h/ 0℃, 24h/ 20℃) EBC-formazin units/ Warm days	Blank: 0.681 EBC: 2.52 Warm days: 9.8	Blank: 0.1070 EBC: 0.237 Warm days: 1.84	
NIBEM	Sec: 254.50 10: 89.09 20: 177.34 30: 254.50	Sec: 18.424 10: 12.276 20: 11.134 30: 18.424	**For lager beers:** **Bad: < 220 sec** **Very Good: > 300 sec** r95: 9 R95:42
CO_2 %vol.	3.04	0.134	**Vol %: 2.5 -3.0** r95: 0.09 R95:0.08m
Dissolved oxygen (mg/L) (Orbisphere DO)	0.1138	0.04787	**< 0.3** r95:0.15 mg/L R95: 0.3 mg/L
Total polyphenols	158.30	11.550	**A820: 0.091-0.121**

Parameter	*Grand mean of produced beers (GM)*	*Standard Deviation (Sx)*	*Normal Values*
(mg/L)			**Polyθ: 73-176** r95:4.1 R95: 18 ± 0.13m
Flavanoids (mg/L)	27.95	3.910	**Flav: 50-70** CV_{r95}: ± 4.7% CV_{R95}: ± 7.6%
Iron (mg/L) (Atomic Absorption Spectrometry)	0.136	0.0266	**Fe(II): < 0.2** **Recommended values** r95: 0.21m R95: 0.91m
Copper (mg/L) (Atomic Absorption Spectrometry)	0.106	0.0384	**Cu (II): < 0.2** **Recommended values** r95: 0.45m R95: 1.71m
Calcium (mg/L) (Atomic Absorption Spectrometry)	1.553	0.8682	**Ca (II): 4 -100** **Recommended values** CV_{ST95}: ±13.3% CV_{Sr95}: ± 2.4% CV_{Sb95}: ±9.2 %
Reducing Power (MEBAK) %RED	62.10	5.906	**> 60 very good** **50-60 good** **45-50 satisfactory** **< 45 poor** CV_{r95}: ± 1%
2-Methylpropanal (µg/L)	3.43	0.757	**Fresh: N/A ***** CV(%): N/A CI(abs): N/A CI(%): N/A **Forced: N/A ***** CV(%): N/A CI(abs): N/A CI(%): N/A **6-Months: N/A ***** **1-Year: N/A *****
2-Methylbutanal (µg/L)	2.12	0.555	**Fresh: 18.6 ***** CV(%): 7.8 CI(abs):1.0 CI(%): 5.6 **Forced: 19.6 ***** CV(%): 7.0 CI(abs): 1.0 CI(%): 5.0 **6-Months: 9.8 ***** **1-Year: 20.6 *****
3-Methylbutanal (µg/L)	5.00	1.277	**Fresh: 10.5 ***** CV(%): 4.0 CI(abs): 0.3 CI(%): 2.9 **Forced: 13.9 *****

Parameter	***Grand mean of produced beers (GM)***	***Standard Deviation (Sx)***	***Normal Values***
			CV(%): 5.7 CI(abs): 0.6 CI(%): 4.1 **6-Months: 16.1 ***** **1-Year: 29.0 *****
Benzaldehyde (μg/L)	1.37	0.246	**Fresh: 0.0 ***** CV(%): 0.0 CI(abs): 0.0 CI(%): 0.0 **Forced: 0.0 ***** CV(%): 0.0 CI(abs): 0.0 CI(%): 0.0 **6-Months: 1.8 ***** **1-Year: 3.3 *****
2-Phenylethanal (μg/L)	12.18	3.253	**Fresh: 21.5 ***** CV(%): 10.3 CI(abs): 1.6 CI(%): 7.4 **Forced: 38.3 ***** CV(%): 5.3 CI(abs): 1.5 CI(%): 3.8 **6-Months: 32.2 ***** **1-Year: 55.8 *****
2-Furfural (μg/L)	10.61	1.704	**Fresh: 7.1***** CV(%): 7.5 CI(abs): 0.4 CI(%): 5.4 **Forced: 110.8 ***** CV(%): 4.7 CI(abs): 3.8 CI(%): 3.4 **6-Months: 164.9 ***** **1-Year: 534.5 *****
Pentanal (μg/L)	0.82	0.122	**Fresh: 4 ***** CV(%): N/A CI(abs): N/A CI(%): N/A **Forced: 4.5***** CV(%): N/A CI(abs): N/A CI(%): N/A **6-Months:N/A** **1-Year: N/A**
Hexanal (μg/L)	1.18	0.282	**Fresh: 0.75 ***** CV(%): 6.22 CI(abs): N/A CI(%): N/A **Forced: N/A ***** CV(%): N/A CI(abs): N/A CI(%): N/A **6-Months: 0.8 *****

Parameter	*Grand mean of produced beers (GM)*	*Standard Deviation (Sx)*	*Normal Values*
			1-Year: 1.0 ***
Methional (µg/L)	2.66	0.683	**Fresh: 0.5 ***** CV(%): N/A CI(abs): N/A CI(%): N/A **Forced: N/A** CV(%): N/A CI(abs): N/A CI(%): N/A **6-Months: 1.8 ***** **1-Year: N/A**
(*E*)-2-nonenal (µg/L)	0.00378	0.001530	**0.11 ***** CV(%): 14.5 CI(abs): 0.0 CI(%): 10.9

The normal values are reported according to Brautechnische Analysenmethoden. Band II. Mitteleuropäische Brautechnische Analysenkommission (M.E.B.A.K.) (2002), except; * according to American Society of Brewing Chemist. Report of Subcommittee on Wort and Beer. Colour Using Tristimulus Analysis (2000), ** according to Smedley (1992, 1995), *** according to Lustig (193, 1999), and **** according to Gonzalez-Miret *et al.* (2007); Luo *et al*. (1991a, 1991b)

Table A.4.1 Random selection of the fresh and forced aged beer samples for psychophysical assessments

	Observer 1	Observer 2	Observer 3
1	'Caramunich III Malt (C.M.) Forced'	'Carahell Malt (C.H.) Forced'	'Carafa III (C.F.) Fresh'
2	'Pilsner Malt (P.M.) Fresh'	'Caraaroma Malt (C.Ar.) Fresh'	'Melanoidin Malt (M.M.) Forced'
3	'Roasted Barley (R.B.) Fresh'	'Caramel #301 (#301) Forced'	'Caramunich III Malt (C.M.) Fresh'
4	'Carahell Malt (C.H.) Forced'	'Caraamber Malt (C.A.) Fresh'	'Caraaroma Malt (C.Ar.) Fresh'
5	'Pilsner Malt (P.M.) Forced'	'Melanoidin Malt (M.M.) Fresh'	'Melanoidin Malt (M.M.) Fresh'
6	'Roasted Barley (R.B.) Forced'	'Caramunich III Malt (C.M.) Forced'	'Carafa III Especial (C.F.SP.) Fresh'
7	'Caramel #301 (#301) Fresh'	'SINAMAR (SIN) Fresh'	'Caraamber Malt (C.Amb.) Forced'
8	'Caraaroma Malt (C.Ar.) Forced'	'Caraamber Malt (C.A.) Forced'	'SINAMAR (SIN) Fresh'
9	'Caramunich III Malt (C.M.) Fresh'	'Caramunich III Malt (C.M.) Fresh'	'Carahell Malt (C.H.) Forced'
10	'Caraamber Malt (C.A.) Forced'	'Pilsner Malt (P.M.) Forced'	'Caraaroma Malt (C.Ar.) Forced'
11	'Caraamber Malt (C.A.) Fresh'	'Carafa III Especial (C.F.SP.) Forced'	'Roasted Barley (R.B.) Forced'
12	'Carafa III (C.F.) Fresh'	'Carafa III (C.F.) Fresh'	'Caramel #301 (#301) Forced'
13	'Carafa III Especial (C.F.SP.) Forced'	'Carafa III Especial (C.F.SP.) Fresh'	'Pilsner Malt (P.M.) Forced'
14	'Melanoidin Malt (M.M.) Forced'	'Roasted Barley (R.B.) Forced'	'Caramunich III Malt (C.M.) Forced'
15	'Carafa III (C.F.) Forced'	'Melanoidin Malt (M.M.) Forced'	'Carafa III (C.F.) Forced'
16	'Caraaroma Malt (C.Ar.) Fresh'	'SINAMAR (SIN) Forced'	'Caraamber Malt (C.A.) Fresh'
17	'Melanoidin Malt (M.M.) Fresh'	'Pilsner Malt (P.M.) Fresh'	'Pilsner Malt (P.M.) Fresh'
18	'Caramel #301 (#301) Forced'	'Caraaroma Malt (C.Ar.) Forced'	'Caramel #301 (#301) Fresh'
19	'SINAMAR (SIN) Forced'	'Carahell Malt (C.H.) Fresh'	'Carahell Malt (C.H.) Fresh'
20	'Carafa III Especial (C.F.SP.) Fresh'	'Caramel #301 (#301) Fresh'	'Roasted Barley (R.B.) Fresh'
21	'SINAMAR (SIN) Fresh'	'Roasted Barley (R.B.) Fresh'	'Carafa III Especial (C.F.SP.) Forced'
22	'Carahell Malt (C.H.) Fresh'	'Carafa III (C.F.) Forced'	'SINAMAR (SIN) Forced'
	Observer 4	**Observer 5**	**Observer 6**
1	'Caramel #301 (#301) Fresh'	'Caraamber Malt (C.A.) Forced'	'Carafa III Especial (C.F.SP.) Forced'
2	'Pilsner Malt (P.M.) Forced'	'Carafa III (C.F.) Fresh'	'Caraaroma Malt (C.Ar.) Forced'
3	'Pilsner Malt (P.M.) Fresh'	'Caraamber Malt (C.A.) Fresh'	'Caramunich III Malt (C.M.) Forced'
4	'Carahell Malt (C.H.) Forced'	'Melanoidin Malt (M.M.) Forced'	'Carahell Malt (C.H.) Fresh'
5	'Melanoidin Malt (M.M.) Forced'	'SINAMAR (SIN) Forced'	'Pilsner Malt (P.M.) Fresh'
6	'Caraamber Malt (C.A.) Fresh'	'Caraaroma Malt (C.Ar.) Fresh'	'Carafa III (C.F.) Forced'
7	'Carahell Malt (C.H.) Fresh'	'Caramunich III Malt (C.M.) Fresh'	'Carahell Malt (C.H.) Forced'
8	'Caraaroma Malt (C.A.) Fresh'	'Roasted Barley (R.B.) Forced'	'Carafa III (C.F.) Fresh'
9	'Carafa III (C.F.) Forced'	'Carafa III Especial (C.F.SP.) Forced'	'Caramel #301 (#301) Fresh'
10	'SINAMAR (SIN) Fresh'	'SINAMAR (SIN) Fresh'	'Melanoidin Malt (M.M.) Fresh'
11	'Caraamber Malt (C.A.) Forced'	'Caraaroma Malt (C.Ar.) Forced'	'Caramel #301 (#301) Forced'
12	'Carafa III (C.F.) Fresh'	'Roasted Barley (R.B.) Fresh'	'Melanoidin Malt (M.M.) Forced'
13	'Caramunich III Malt (C.M.) Forced'	'Pilsner Malt (P.M.) Fresh'	'Caraaroma Malt (C.Ar.) Fresh'

14	'Carafa III Especial (C.F.SP.) Forced'	'Caramel #301 (#301) Fresh'	'Pilsner Malt (P.M.) Forced'
15	'Carafa III Especial (C.F.SP.) Fresh'	'Carafa III Especial (C.F.SP.) Fresh'	'Caraamber Malt (C.A.) Forced'
16	'Caraaroma Malt (C.Ar.) Forced'	'Pilsner Malt (P.M.) Forced'	'Roasted Barley (R.B.) Fresh'
17	'Melanoidin Malt (M.M.) Fresh'	'Caramunich III Malt (C.M.) Forced'	'Caraamber Malt (C.A.) Fresh'
18	'Roasted Barley (R.B.) Fresh'	'Carahell Malt (C.H.) Forced'	'SINAMAR (SIN) Forced'
19	'Caramunich III Malt (C.M.) Fresh'	'Caramel #301 (#301) Forced'	'Caramunich III Malt (C.M.) Fresh'
20	'SINAMAR (SIN) Forced'	'Carahell Malt (C.H.) Fresh'	'Carafa III Especial (C.F.SP.) Fresh'
21	'Roasted Barley (R.B.) Forced'	'Melanoidin Malt (M.M.) Fresh'	'Roasted Barley (R.B.) Forced'
22	'Caramel #301 (#301) Forced'	'Carafa III (C.F.) Forced'	'SINAMAR (SIN) Fresh'
	Observer 7	**Observer 8**	**Observer 9**
1	'Pilsner Malt (P.M.) Fresh'	'Carahell Malt (C.H.) Fresh'	'SINAMAR (SIN) Fresh'
2	'Caramel #301 (#301) Forced'	'Caramunich III Malt (C.M.) Forced'	'SINAMAR (SIN) Forced'
3	'Carafa III Especial (C.F.SP.) Fresh'	'Caraaroma Malt (C.Ar.) Fresh'	'Melanoidin Malt (M.M.) Fresh'
4	'Carafa III Especial (C.F.SP.) Forced'	'Melanoidin Malt (M.M.) Fresh'	'Pilsner Malt (P.M.) Forced'
5	'Caraaroma Malt (C.A.) Forced'	'Carafa III (C.F.) Forced'	'Caramel #301 (#301) Forced'
6	'Melanoidin Malt (M.M.) Forced'	'SINAMAR (SIN) Fresh'	'Roasted Barley (R.B.) Fresh'
7	'Pilsner Malt (P.M.) Forced'	'Caraamber Malt (C.A.) Forced'	'Carafa III (C.F.) Forced'
8	'Carahell Malt (C.H.) Fresh'	'Pilsner Malt (P.M.) Fresh'	'Roasted Barley (R.B.) Forced'
9	'SINAMAR (SIN) Fresh'	'Caraaroma Malt (C.Ar.) Forced'	'Caraaroma Malt (C.Ar.) Forced'
10	'Caraamber Malt (C.A.) Forced'	'Caramel #301 (#301) Forced'	'Caraaroma Malt (C.Ar.) Fresh'
11	'Caramunich III Malt (C.M.) Fresh'	'Carafa III Especial (C.F.SP.) Fresh'	'Melanoidin Malt (M.M.) Forced'
12	'Caramel #301 (#301) Fresh'	'Carahell Malt (C.H.) Forced'	'Caraamber Malt (C.A.) Fresh'
13	'SINAMAR (SIN) Forced'	'Caramel #301 (#301) Fresh'	'Caraamber Malt (C.A.) Forced'
14	'Roasted Barley (R.B.) Fresh'	'SINAMAR (SIN) Forced'	'Caramel #301 (#301) Fresh'
15	'Carafa III (C.F.) Forced'	'Carafa III (C.F.) Fresh'	'Carahell Malt (C.H.) Fresh'
16	'Roasted Barley (R.B.) Forced'	'Caramunich III Malt (C.M.) Fresh'	'Caramunich III Malt (C.M.) Fresh'
17	'Caraaroma Malt (C.A.) Fresh'	'Melanoidin Malt (M.M.) Forced'	'Carahell Malt (C.H.) Forced'
18	'Caraamber Malt (C.A.) Fresh'	'Carafa III Especial (C.F.SP.) Forced'	'Carafa III Especial (C.F.SP.) Fresh'
19	'Melanoidin Malt (M.M.) Fresh'	'Pilsner Malt (P.M.) Forced'	'Pilsner Malt (P.M.) Fresh'
20	'Carafa III (C.F.) Fresh'	'Caraamber Malt (C.A.) Fresh'	'Carafa III (C.F.) Fresh'
21	'Caramunich III Malt (C.M.) Forced'	'Roasted Barley (R.B.) Forced'	'Caramunich III Malt (C.M.) Forced'
22	'Carahell Malt (C.H.) Forced'	'Roasted Barley (R.B.) Fresh'	'Carafa III Especial (C.F.SP.) Forced'

Table A.4.2 Random selection of the spontaneously aged locally-brewed beers for psychophysical assessments

	Observer 1	Observer 2	Observer 3
1	‘Roasted Barley (R.B.) Aged’	’SINAMAR (SIN) Aged’	‘Carafa III Especial (C.F.SP.) Aged’
2	‘Carafa III Especial (C.F.SP.) Aged’	’Caramel #301 (#301) Aged’	‘Carafa III (C.F.) Aged’
3	’Melanoidin Malt (M.M.) Aged’	’Caraamber Malt (C.A.) Aged’	‘Roasted Barley (R.B.) Aged’
4	’Caraamber Malt (C.A.) Aged’	’Caramunich III Malt (C.M.) Aged’	‘Caraaroma Malt (C.Ar.) Aged’
5	’Caramunich III Malt (C.M.) Aged’	‘Carahell Malt (C.H.) Aged’	’SINAMAR (SIN) Aged’
6	’Caraaroma Malt (C.Ar.) Aged’	‘Caraaroma Malt (C.Ar.) Aged’	‘Carahell Malt (C.H.) Aged’
7	’Carahell Malt (C.H.) Aged’	‘Carafa III Especial (C.F.SP.) Aged’	’Pilsner Malt (P.M.) Aged’
8	’SINAMAR (SIN) Aged’	’Pilsner Malt (P.M.) Aged’	’Caramunich III Malt (C.M.) Aged’
9	’Carafa III (C.F.) Aged’	‘Roasted Barley (R.B.) Aged’	’Melanoidin Malt (M.M.) Aged’
10	’Caramel #301 (#301) Aged	’Melanoidin Malt (M.M.) Aged’	’Caramel #301 (#301) Aged’
11	’Pilsner Malt (P.M.) Aged’	‘Carafa III (C.F.) Aged’	’Caraamber Malt (C.A.) Aged’
	Observer 4	**Observer 5**	**Observer 6**
1	‘Carafa III Especial (C.F.SP.) Aged’	‘Roasted Barley (R.B.) Aged’	‘Carafa III (C.F.) Aged’
2	’SINAMAR (SIN) Aged’	’Caramunich III Malt (C.M.) Aged’	’Caramel #301 (#301) Aged’
3	’Roasted Barley (R.B.) Aged’	‘Carafa III Especial (C.F.SP.) Aged’	’Melanoidin Malt (M.M.) Aged’
4	‘Caraaroma Malt (C.Ar.) Aged’	’Melanoidin Malt (M.M.) Aged’	’Pilsner Malt (P.M.) Aged’
5	’Caramunich III Malt (C.M.) Aged’	’SINAMAR (SIN) Aged’	‘Roasted Barley (R.B.) Aged’
6	’Melanoidin Malt (M.M.) Aged’	’Caraamber Malt (C.A.) Aged’	’Caramunich III Malt (C.M.) Aged’
7	’Caraamber Malt (C.A.) Aged’	‘Caraaroma Malt (C.Ar.) Aged’	’SINAMAR (SIN) Aged’
8	’Pilsner Malt (P.M.) Aged’	‘Carafa III (C.F.) Aged’	‘Caraaroma Malt (C.Ar.) Aged’
9	’Caramel #301 (#301) Aged’	’Caramel #301 (#301) Aged’	’Caraamber Malt (C.A.) Aged’
10	‘Carahell Malt (C.H.) Aged’	’Pilsner Malt (P.M.) Aged’	‘Carafa III Especial (C.F.SP.) Aged’
11	‘Carafa III (C.F.) Aged’	‘Carahell Malt (C.H.) Aged’	‘Carahell Malt (C.H.) Aged’
	Observer 7	**Observer 8**	**Observer 9**
1	‘Caraamber Malt (C.A.) Aged’	’Roasted Barley (R.B.) Aged’	’Melanoidin Malt (M.M.) Aged’
2	’Pilsner Malt (P.M.) Aged’	‘Carahell Malt (C.H.) Aged’	“Carafa III (C.F.) Aged’
3	’Caramunich III Malt (C.M.) Aged’	‘Carafa III Especial (C.F.SP.) Aged’	‘Caraaroma Malt (C.Ar.) Aged’
4	‘Carafa III Especial (C.F.SP.) Aged’	‘Caraaroma Malt (C.Ar.) Aged’	’Caraamber Malt (C.A.) Aged’
5	’Roasted Barley (R.B.) Aged’	’Melanoidin Malt (M.M.) Aged’	Carafa III Especial (C.F.SP.) Aged’
6	‘Caraaroma Malt (C.Ar.) Aged’	’Caraamber Malt (C.A.) Aged’	’Caramunich III Malt (C.M.) Aged’
7	’SINAMAR (SIN) Aged’	’SINAMAR (SIN) Aged’	’SINAMAR (SIN) Aged’
8	’Melanoidin Malt (M.M.) Aged’	’Caramunich III Malt (C.M.) Aged’	‘Carahell Malt (C.H.) Aged’
9	‘Carafa III (C.F.) Aged’	6‘Carafa III (C.F.) Aged’	’Roasted Barley (R.B.) Aged’
10	’Caramel #301 (#301) Aged’	’Pilsner Malt (P.M.) Aged’	’Pilsner Malt (P.M.) Aged’
11	‘Carahell Malt (C.H.) Aged’	’Caramel #301 (#301) Aged’	’Caramel #301 (#301) Aged’

	Observer 10
1	‘Carafa III (C.F.) Aged’
2	‘Carahell Malt (C.H.) Aged’
3	’Caramunich III Malt (C.M.) Aged’
4	’Caraamber Malt (C.A.) Aged’
5	’Melanoidin Malt (M.M.) Aged’
6	‘Carafa III Especial (C.F.SP.) Aged’
7	‘Caraaroma Malt (C.Ar.) Aged’
8	’Roasted Barley (R.B.) Aged’
9	’Pilsner Malt (P.M.) Aged’
10	’Caramel #301 (#301) Aged’
11	’SINAMAR (SIN) Aged’

Table A.4.3 Visual lightness (Lv) data of the fresh, forced aged and spontaneously aged locally-brewed beers

Lightness

	Obs1	Obs2	Obs3	Obs4	Obs5	Obs6	Obs7	Obs8	Obs9	Mean	Sx	r_{95}
CH Fr	78	60	35	40	60	70	50	50	58	55.7	13.6	0.94
CH Fo	74	70	30	35	55	70	50	40	56	53.3	16.1	0.94
CH Ag	76	40	30	30	30	52	70	50	40	46.4	17.2	0.77
CA Fr	83	60	40	50	60	75	55	50	62	59.4	13.1	0.89
CA Fo	80	60	40	40	60	70	55	40	55	55.6	14.0	0.96
CA Ag	82	40	40	60	40	50	60	50	40	51.3	14.2	0.79
MM Fr	80	60	30	35	55	70	50	40	56	52.9	16.2	0.96
MM Fo	78	60	35	45	55	75	55	40	56	55.4	14.5	0.93
MM Ag	80	40	40	30	55	53	70	60	50	53.1	15.6	0.85
CM Fr	90	80	40	50	60	75	57	50	60	62.4	16.1	0.96
CM Fo	85	80	40	50	65	75	57	40	58	61.1	16.5	0.95
CM Ag	92	60	50	60	70	58	70	65	60	65.0	11.9	0.86
CAR Fr	93	85	45	55	65	80	60	50	58	65.7	16.6	0.92
CAR Fo	85	65	40	40	65	80	60	40	55	58.9	16.9	0.96
CAR Ag	88	60	50	60	70	62	80	60	50	64.4	12.8	0.85
CF Fr	92	80	45	50	70	80	57	60	55	65.4	15.9	0.96
CF Fo	90	65	30	45	65	75	57	50	56	59.2	17.4	0.96
CF Ag	88	50	30	50	40	55	60	65	50	54.2	16.3	0.68
CFSP Fr	85	65	40	45	60	75	60	40	55	58.3	15.4	0.99
CFSP Fo	75	60	40	35	55	70	52	35	52	52.7	14.3	0.97
CFSP Ag	90	60	40	50	80	60	90	79	60	67.7	17.8	0.76
RB Fr	89	80	45	50	60	75	52	50	58	62.1	15.5	0.99
RB Fo	83	65	40	45	65	70	60	40	55	58.1	14.6	0.96
RB Ag	85	60	50	30	40	62	40	63	40	52.2	16.9	0.71
SIN Fr	76	80	40	40	55	70	50	50	55	57.3	14.8	0.93
SIN Fo	80	60	40	35	70	75	55	40	55	56.7	16.2	0.98
SIN Ag	90	50	40	40	50	58	50	60	40	53.1	15.7	0.95
#301 Fr	87	70	40	45	65	75	57	50	58	60.8	15.0	0.96
#301 Fo	92	70	40	50	60	75	60	40	55	60.2	16.9	0.91
#301 Ag	94	50	50	40	70	56	50	65	40	57.2	17.1	0.90
PM Fr	92	85	45	55	70	75	65	60	60	67.4	14.8	0.91
PM Fo	96	85	50	60	75	80	60	70	58	70.4	14.9	0.95
PM Ag	98	75	50	60	80	60	80	68	50	69.0	15.8	0.98

CH Fr	85	70	35	35	60	70	57	50	50	56.9	16.6
CH Fo	80	90	35	40	55	70	55	40	55	57.8	18.9
CH Ag	68	40	40	30	30	52	40	50	40	43.3	11.9
CA Fr	85	80	40	45	60	75	55	40	62	60.2	17.0
CA Fo	82	70	45	45	60	70	65	40	62	59.9	14.0
CA Ag	74	45	30	40	40	55	50	55	40	47.7	12.8
MM Fr	75	70	30	35	50	70	55	40	58	53.7	16.3
MM Fo	84	80	35	45	55	75	55	40	55	58.2	17.7
MM Ag	76	40	40	40	50	55	50	57	40	49.8	12.0
CM Fr	90	85	45	45	65	75	60	40	60	62.8	17.9
CM Fo	90	75	40	45	60	75	60	50	55	61.1	16.2
CM Ag	85	60	50	60	80	60	80	70	50	66.1	13.2
CAR Fr	90	85	45	50	80	80	60	60	58	67.6	16.4
CAR Fo	83	75	40	50	70	80	65	40	55	62.0	16.5
CAR Ag	90	60	50	50	75	56	60	60	40	60.1	14.8

CF Fr	93	75	40	50	75	75	65	60	58	65.7	15.8
CF Fo	88	70	40	45	75	75	60	60	55	63.1	15.4
CF Ag	92	50	50	40	70	58	60	60	50	58.9	15.1
CFSP Fr	90	70	40	45	60	75	60	40	52	59.1	17.0
CFSP Fo	75	60	40	40	55	70	55	30	60	53.9	14.7
CFSP Ag	87	70	50	70	80	58	80	63	50	67.6	13.4
RB Fr	85	80	45	55	60	75	55	50	55	62.2	14.2
RB Fo	80	75	30	40	60	75	55	30	52	55.2	19.1
RB Ag	83	60	50	60	60	56	50	63	40	58.0	11.8
SIN Fr	85	75	45	40	60	70	55	40	60	58.9	15.8
SIN Fo	80	65	35	35	70	75	60	35	52	56.3	17.9
SIN Ag	87	50	30	30	35	52	50	52	40	47.3	17.5
#301 Fr	80	75	40	40	65	75	62	50	60	60.8	14.9
#301 Fo	88	90	45	50	65	75	60	50	60	64.8	16.4
#301 Ag	94	50	50	40	65	60	70	60	40	58.8	16.8
PM Fr	95	90	50	50	75	80	65	40	60	67.2	19.1
PM Fo	97	90	50	60	80	80	68	60	60	71.7	15.8
PM Ag	90	70	50	60	70	58	80	65	50	65.9	13.3
r^2	0.75	0.86	0.57	0.54	0.76	0.95	0.49	0.79	0.80		

Table A.4.4 Visual colourfulness (Cv) data of the fresh, forced aged and spontaneously aged locally-brewed beers

Colourfulness

	Obs1	Obs2	Obs3	Obs4	Obs5	Obs6	Obs7	Obs8	Obs9	Mean	Sx	r_{95}
CH Fr	30	55	45	50	50	30	30	50	35	41.7	10.3	0.83
CH Fo	30	50	50	50	60	30	30	60	35	43.9	12.7	0.92
CH Ag	79	40	70	80	85	48	70	30	40	60.2	20.7	0.95
CA Fr	20	50	45	45	45	30	25	50	35	38.3	11.2	0.93
CA Fo	20	45	40	50	50	35	30	50	30	38.9	10.8	0.86
CA Ag	60	50	70	40	80	45	60	30	60	55.0	15.4	0.45
ME Fr	38	50	45	50	60	35	30	60	38	45.1	10.7	0.96
ME Fo	30	45	45	45	50	25	25	50	30	38.3	10.6	0.91
ME Ag	43	40	60	70	70	35	60	15	20	45.9	20.5	0.98
CM Fr	17	30	35	40	45	25	23	50	15	31.1	12.3	0.94
CM Fo	30	30	40	45	45	25	23	50	25	34.8	10.3	0.95
CM Ag	27	30	50	60	70	42	50	20	30	42.1	16.7	0.84
CAR Fr	20	30	35	40	40	20	20	40	20	29.4	9.5	0.81
CAR Fo	20	45	40	40	40	20	50	60	25	37.8	13.7	0.70
CAR Ag	35	40	40	40	40	40	50	15	40	37.8	9.4	0.76
CF Fr	15	35	35	40	35	25	20	50	15	30.0	12.0	0.96
CF Fo	15	40	40	45	45	25	20	40	15	31.7	12.7	0.95
CF Ag	50	30	50	60	80	38	80	10	20	46.4	24.6	0.57
CFSP Fr	15	40	35	45	45	25	20	60	20	33.9	15.0	0.94
CFSP Fo	34	45	45	45	55	25	25	60	45	42.1	12.1	0.69
CFSP Ag	32	40	80	60	20	38	40	20	30	40.0	19.3	0.39
RB Fr	13	35	30	40	50	30	25	40	25	32.0	10.8	0.74
RB Fo	20	45	45	45	50	35	20	50	35	38.3	11.7	0.78
RB Ag	38	40	50	60	70	45	50	20	40	45.9	14.2	0.74
SIN Fr	35	30	35	45	60	35	27	50	25	38.0	11.5	0.85
SIN Fo	38	55	50	45	45	25	20	60	40	42.0	13.1	0.98
SIN Ag	55	45	85	70	80	45	70	30	50	58.9	18.3	0.93
#301 Fr	16	45	40	45	45	25	20	50	25	34.6	12.9	0.93
#301 Fo	20	30	35	40	45	25	20	50	20	31.7	11.5	0.94
#301 Ag	30	30	70	70	20	35	60	25	40	42.2	19.4	0.50
PM Fr	17	30	35	40	35	20	15	40	15	27.4	10.7	0.98
PM Fo	12	30	25	35	30	20	15	30	20	24.1	7.8	0.81
PM Ag	22	20	40	40	40	40	50	15	30	33.0	11.8	0.78

CH Fr	20	50	45	45	60	35	20	60	45	42.2	14.8
CH Fo	35	50	40	50	60	35	22	60	35	43.0	12.8
CH Ag	70	50	70	80	85	45	80	35	50	62.8	18.0
CA Fr	17	50	40	40	50	30	23	60	25	37.2	14.5
CA Fo	30	45	40	45	55	35	20	60	30	40.0	12.7
CA Ag	64	45	60	80	70	38	70	30	40	55.2	17.4
MM Fr	40	55	40	50	60	35	25	60	30	43.9	12.9
MM Fo	30	50	40	40	55	30	25	60	25	39.4	13.1
MM Ag	44	50	70	80	80	38	70	30	30	54.7	20.6
CM Fr	20	30	35	45	40	25	15	50	20	31.1	12.2
CM Fo	20	30	35	45	50	25	20	50	25	33.3	12.2
CM Ag	45	50	50	60	60	40	50	25	20	45	13.3
CAR Fr	15	30	30	35	30	25	15	40	28	27.6	8.3
CAR Fo	17	35	35	45	40	20	20	60	30	33.6	13.8

CAR Ag	35	40	50	60	30	38	70	20	40	43.8	14.9
CF Fr	15	35	40	35	35	25	15	50	20	30.0	12.0
CF Fo	20	35	40	40	40	25	15	40	20	30.6	10.4
CF Ag	34	50	50	80	40	35	60	23	40	47.7	16.9
CFSP Fr	15	45	35	40	50	30	25	50	25	35.0	12.2
CFSP Fo	32	60	40	50	50	35	27	60	25	42.1	13.4
CFSP Ag	35	80	40	70	50	35	60	20	30	47	18.7
RB Fr	25	30	45	40	50	30	20	40	35	35.0	9.7
RB Fo	37	45	40	50	50	30	20	60	25	39.7	13.0
RB Ag	38	50	50	50	65	42	80	23	40	47.3	16.0
SIN Fr	20	40	35	50	55	35	20	50	20	36.1	13.9
SIN Fo	37	50	45	45	45	30	20	60	42	41.6	11.5
SIN Ag	58	85	70	80	80	45	70	35	50	62.8	16.7
#301 Fr	20	40	40	35	40	25	15	50	30	32.8	11.2
#301 Fo	12	30	40	40	45	30	25	50	20	32.4	12.4
#301 Ag	37	70	50	80	70	38	60	30	50	53	16.4
PM Fr	12	25	35	40	35	20	15	40	15	26.3	11.3
PM Fo	10	25	30	25	30	20	10	30	25	22.8	7.9
PM Ag	30	40	50	60	40	30	50	15	30	39	13.0
r^2	0.86	0.74	0.73	0.75	0.62	0.88	0.88	0.95	0.66		

Table A.4.5 Visual hue (hv) data of the fresh, forced aged and spontaneously aged locally-brewed beers

Hue Angle (0-360)

	Obs1	Obs2	Obs3	Obs4	Obs5	Obs6	Obs7	Obs8	Obs9	Mean	Sx	r_{95}
CH Fr	63	27	40.5	36	31.5	67.5	31.5	54	54	45.0	14.9	0.90
CH Fo	54	36	36	27	27	67.5	31.5	45	54	42.0	14.1	0.93
CH Ag	18	49.5	72	27	54	54	63	58.5	27	47.0	18.6	0.77
CA Fr	63	36	36	31.5	36	72	36	49.5	67.5	47.5	15.9	0.88
CA Fo	63	31.5	45	31.5	36	63	31.5	54	63	46.5	14.4	0.83
CA Ag	27	49.5	76.5	45	67.5	54	72	54	54	55.5	15.1	0.83
MM Fr	36	27	36	27	27	63	31.5	49.5	58.5	39.5	14.0	0.94
MM Fo	54	31.5	45	31.5	31.5	72	36	49.5	67.5	46.5	15.6	0.83
MM Ag	27	49.5	81	36	72	58.5	72	63	54	57.0	17.6	0.74
CM Fr	76.5	54	45	45	36	67.5	36	49.5	76.5	54.0	15.9	0.99
CM Fo	67.5	36	45	40.5	36	72	31.5	54	72	50.5	16.3	0.73
CM Ag	36	67.5	84.6	36	76.5	70.2	108	63	36	64.2	24.8	0.88
CAR Fr	72	36	36	45	31.5	72	36	54	76.5	51.0	18.1	0.93
CAR Fo	72	36	45	36	36	72	36	49.5	72	50.5	16.8	0.85
CAR Ag	29.7	54	85.5	54	81	67.5	108	63	45	65.3	23.5	0.94
CF Fr	79.2	45	58.5	45	45	72	36	54	81	57.3	16.5	0.97
CF Fo	67.5	45	45	45	40.5	67.5	36	54	76.5	53.0	14.2	0.69
CF Ag	27	54	85.5	36	99	67.5	108	58.5	54	65.5	27.4	0.89
CFSP Fr	72	45	45	40.5	36	67.5	36	49.5	76.5	52.0	15.8	0.92
CFSP Fo	54	27	36	31.5	27	67.5	36	49.5	58.5	43.0	14.8	0.68
CFSP Ag	36	63	81	36	81	72	99	67.5	54	65.5	21.0	0.93
RB Fr	81	45	36	45	36	67.5	36	54	72	52.5	17.1	0.94
RB Fo	58.5	31.5	36	36	31.5	63	36	49.5	63	45.0	13.5	0.94
RB Ag	22.5	54	85.5	45	67.5	63	54	58.5	36	54.0	18.3	0.66
SIN Fr	27	45	45	36	36	63	36	49.5	72	45.5	14.3	0.66
SIN Fo	31.5	36	36	27	36	72	36	49.5	54	42.0	14.1	0.90
SIN Ag	31.5	54	85.5	36	63	54	72	54	27	53.0	19.2	0.85
#301 Fr	72	36	45	45	36	72	36	54	63	51.0	14.9	0.96
#301 Fo	78.3	45	36	45	36	72	36	54	81	53.7	18.6	0.95
#301 Ag	31.5	54	85.5	36	72	72	108	54	45	62.0	24.7	0.99
PM Fr	82.8	36	27	49.5	45	72	27	54	94.5	54.2	24.2	0.88
PM Fo	96.3	63	27	45	45	72	63	49.5	81	60.2	21.1	0.83
PM Ag	45	63	88.2	54	94.5	72	117	63	54	72.3	23.3	0.99

CH Fr	54	18	36	31.5	36	63	36	45	63	42.5	15.1
CH Fo	54	27	36	31.5	27	63	36	45	63	42.5	14.4
CH Ag	15.3	45	63	27	58.5	54	108	45	36	50.2	26.5
CA Fr	58.5	45	45	31.5	27	63	40.5	45	76.5	48.0	15.6
CA Fo	54	31.5	45	45	27	63	36	49.5	81	48.0	16.7
CA Ag	18	49.5	63	36	67.5	63	108	49.5	45	55.5	25.0
MM Fr	36	36	45	27	27	63	36	45	67.5	42.5	14.4
MM Fo	67.5	45	54	45	27	63	36	45	81	51.5	16.7
MM Ag	28.8	45	67.5	36	63	67.5	108	49.5	36	55.7	24.3
CM Fr	72	54	45	45	36	67.5	36	49.5	81	54.0	16.1
CM Fo	63	36	45	40.5	31.5	67.5	63	49.5	72	52.0	14.8
CM Ag	36	63	72	54	99	67.5	108	67.5	54	69.0	22.4
CAR Fr	76.5	36	54	58.5	36	72	36	54	81	56.0	17.7
CAR Fo	58.5	27	45	31.5	40.5	72	54	49.5	81	51.0	17.7

CAR Ag	31.5	58.5	76.5	36	99	67.5	117	54	36	64.0	29.5
CF Fr	78.3	36	54	49.5	36	72	36	49.5	82.8	54.9	18.5
CF Fo	63	36	54	45	40.5	67.5	63	54	72	55.0	12.5
CF Ag	58.5	49.5	72	36	99	72	108	54	54	67.0	23.5
CFSP Fr	76.5	27	45	45	36	67.5	36	49.5	70.2	50.3	17.3
CFSP Fo	36	27	40.5	31.5	31.5	63	63	45	72	45.5	16.4
CFSP Ag	40.5	54	85.5	45	99	67.5	117	63	45	68.5	26.7
RB Fr	67.5	45	45	45	36	63	36	49.5	76.5	51.5	14.3
RB Fo	54	27	45	40.5	27	63	36	45	67.5	45.0	14.4
RB Ag	31.5	54	81	45	67.5	67.5	108	54	27	59.5	25.1
SIN Fr	63	45	45	31.5	36	63	36	49.5	76.5	49.5	15.1
SIN Fo	36	27	45	31.5	36	63	36	45	54	41.5	11.4
SIN Ag	27	49.5	72	27	63	58.5	108	49.5	27	53.5	26.4
#301 Fr	72	36	45	45	36	67.5	27	49.5	72	50.0	16.8
#301 Fo	79.2	36	45	45	36	63	36	49.5	76.5	51.8	17.1
#301 Ag	36	54	81	36	76.5	72	108	54	36	61.5	24.9
PM Fr	81	27	54	45	45	72	36	54	81	55.0	19.3
PM Fo	99	45	54	54	45	72	63	54	94.5	64.5	20.1
PM Ag	40.5	63	85.5	45	99	72	117	58.5	54	70.5	25.6
r^2	0.87	0.83	0.89	0.57	0.97	0.62	0.88	0.71	0.87		

Table A.4.6 Visual opacity (Opv) data of the fresh, forced aged and spontaneously aged locally-brewed beers

Opacity

	Obs1	Obs2	Obs3	Obs4	Obs5	Obs6	Obs7	Obs8	Obs9	Mean	Sx	r_{95}
CH Fr	3	5	4	1	2	2	2	1	2	2.4	1.3	0.68
CH Fo	3	5	4	2	3	2	4	2	2	3.0	1.1	0.58
CH Ag	4.5	4	3	7	3	2.5	2	4	5	3.9	1.5	0.86
CA Fr	2	5	2	1	1	2	4	2	1.5	2.3	1.3	0.80
CA Fo	3	4	4	1	1	2	3	2	2	2.4	1.1	0.57
CA Ag	3.5	3	3	6	4	2	2	3	5	3.5	1.3	0.90
MM Fr	3	5	4	2	2	2	4	2	3	3.0	1.1	0.92
MM Fo	2	5	4	1	2	2	3	2	1.5	2.5	1.3	0.61
MM Ag	4.5	3	3	5	3	2.5	3	3	6	3.7	1.2	0.90
CM Fr	2	4	1	2	2	2	3	1	2	2.1	0.9	0.88
CM Fo	2	5	3	2	2	2	4	2	2.5	2.7	1.1	0.88
CM Ag	4	1	1	3	1	1	1	2	2	1.8	1.1	0.67
CAR Fr	2	4	1	1	3	2	3	1	2	2.1	1.1	0.62
CAR Fo	2.5	4	4	1	2	2	2	2	1.5	2.3	1.0	0.40
CAR Ag	4	2	1	6	1	1	2	2	3	2.4	1.7	0.80
CF Fr	1.5	5	1	2	2	2	3	1	2.5	2.2	1.2	0.79
CF Fo	2	5	2	1	2	2	3	1	2	2.2	1.2	0.80
CF Ag	3.5	2	1	7	1	1	1	2	3	2.4	2.0	0.91
CFSP Fr	3	5	3	4	2	2	2	2	2.5	2.8	1.1	0.41
CFSP Fo	4	6	6	1	4	2	4	3	4	3.8	1.6	0.56
CFSP Ag	2.5	2	1	5	1	0.5	1	2	3	2.0	1.4	0.92
RB Fr	3	4	2	1	1	2	4	1	1.5	2.2	1.2	0.87
RB Fo	4	5	3	1	3	2	3	2	1	2.7	1.3	0.81
RB Ag	4	1	1	4	1	1	3	3	4	2.4	1.4	0.84
SIN Fr	4	5	4	2	4	2	4	2	2.5	3.3	1.1	0.71
SIN Fo	4	5	5	4	3	2	3	2	3.5	3.5	1.1	0.77
SIN Ag	3	2	2	4	1	1.5	1	3	6	2.6	1.6	0.89
#301 Fr	3.5	5	3	2	1	2	3	2	2.5	2.7	1.1	0.85
#301 Fo	3	5	3	2	2	2	3	1	1.5	2.5	1.2	0.62
#301 Ag	4	2	1	7	1	1	2	3	8	3.2	2.6	0.83
PM Fr	1.5	3	2	1	2	2	2	1	1.5	1.8	0.6	0.67
PM Fo	4	4	1	1	3	2	2	1	1.5	2.2	1.2	0.84
PM Ag	2	1	1	4	1	1	1	2	3	1.8	1.1	0.99

CH Fr	2	4	5	3	2	2	3	2	2	2.8	1.1
CH Fo	4	4	3	3	1	2	3	2	1.5	2.6	1.1
CH Ag	4.5	3	3	7	4	2.5	3	4	7	4.2	1.7
CA Fr	2	6	4	2	2	2	3	2	1.5	2.7	1.4
CA Fo	2	4	2	2	2	2	3	2	1.5	2.3	0.8
CA Ag	4	2	3	6	4	1.5	3	2	6	3.5	1.7
MM Fr	3	5	3	2	2	2	4	2	2	2.8	1.1
MM Fo	2	4	2	2	3	2	4	2	2	2.6	0.9
MM Ag	4.8	3	3	7	3	1.5	3	4	6	3.9	1.7
CM Fr	2	4	1	3	1	2	3	1	2	2.1	1.1
CM Fo	2	4	3	2	2	2	3	1	1.5	2.3	0.9
CM Ag	3	2	2	5	1	1.5	2	2	4	2.5	1.3
CAR Fr	2	3	1	2	1	2	3	1	2	1.9	0.8
CAR Fo	2	5	1	2	1	2	3	2	1	2.1	1.3
CAR Ag	1.7	2	2	5	1	1	2	3	3	2.3	1.2
CF Fr	2	4	2	1	1	2	2	1	2	1.9	0.9

CF Fo	2	4	3	2	1	2	3	1	2.5	2.3	1.0
CF Ag	2	2	2	7	1	1	0	3	4	2.4	2.1
CFSP Fr	2	4	2	1	2	2	3	1	1.5	2.1	1.0
CFSP Fo	4	5	5	4	3	3	3	3	3	3.7	0.9
CFSP Ag	2	1	2	6	1	1	1	2	3	2.1	1.6
RB Fr	2	3	2	1	2	2	4	1	1	2.0	1.0
RB Fo	2	6	4	1	2	2	3	1	1	2.4	1.7
RB Ag	2.5	1	2	5	1	1	2	3	4	2.4	1.4
SIN Fr	2	5	2	2	3	2	3	2	2	2.6	1.0
SIN Fo	2.5	5	6	2	3	2	3	2	3.5	3.2	1.4
SIN Ag	3.5	2	3	7	1	1.5	1	3	6	3.1	2.1
#301 Fr	3	5	3	2	2	2	2	1	2.5	2.5	1.1
#301 Fo	2	3	2	1	2	2	3	2	2	2.1	0.6
#301 Ag	2	2	1	5	1	1	1	3	3	2.1	1.4
PM Fr	1	3	1	2	2	2	2	1	1.5	1.7	0.7
PM Fo	3.5	4	1	1	1	2	2	1	1.5	1.9	1.1
PM Ag	1.8	1	1	5	1	1	1	2	4	2.0	1.5
r^2	0.57	0.87	0.63	0.79	0.60	0.81	0.72	0.78	0.74		

Table A.4.7 Visual clarity (Clv) data of the fresh, forced aged and spontaneously aged locally-brewed beers

Clarity

	Obs1	Obs2	Obs3	Obs4	Obs5	Obs6	Obs7	Obs8	Obs9	Mean	Sx	r_{95}
CH Fr	7.5	5	6	9	8	8	4	9	8.5	7.2	1.8	0.62
CH Fo	7.5	5	6	8	8	9	4	8	8.5	7.1	1.7	0.76
CH Ag	7.7	7	4	3	5	7	8	5	5	5.7	1.7	0.77
CA Fr	8.5	5	8	8	9	8	4	8	8	7.4	1.7	0.73
CA Fo	8	6	6	9	9	8	6	8	8	7.6	1.2	0.83
CA Ag	6.5	7	8	6	3	7.5	7	5	5	6.1	1.6	0.72
MM Fr	8	4	6	8	9	8	4	8	7.5	6.9	1.8	0.92
MM Fo	8.5	5	6	8	8	8	5	8	9	7.3	1.5	0.86
MM Ag	6.5	7	8	5	7	8	6	6	4	6.4	1.3	0.68
CM Fr	8.3	7	9	7	9	8	6	9	8.5	8.0	1.1	0.96
CM Fo	8	4	7	9	9	8	5	8	8	7.3	1.7	0.87
CM Ag	9	8	9	6	8	8.5	8	7	8	7.9	1.0	0.74
CAR Fr	8	7	9	9	8	7	7	9	8.5	8.1	0.9	0.77
CAR Fo	8	7	6	8	9	9	7	8	8.5	7.8	1.0	0.29
CAR Ag	7.5	8	9	7	5	9.5	8	6	7	7.4	1.4	0.61
CF Fr	9	6	9	9	8	8	6	9	7	7.9	1.3	0.63
CF Fo	8.5	6	8	10	8	8	6	9	8.5	8.0	1.3	0.83
CF Ag	7.5	8	9	4	8	9	8	7	7	7.5	1.5	0.93
CFSP Fr	8.5	6	7	9	9	8	6	8	7	7.6	1.2	0.69
CFSP Fo	6	3	4	6	6	8	5	7	6.5	5.7	1.5	0.89
CFSP Ag	8	9	9	7	7	9.5	9	7	7	8.1	1.1	0.93
RB Fr	8.5	6	8	8	9	8	4	9	8	7.6	1.6	0.91
RB Fo	6	6	7	9	8	7	7	8	9	7.4	1.1	0.49
RB Ag	7.5	9	9	7	8	9	8	6	6	7.7	1.2	0.65
SIN Fr	7	4	6	7	8	7	4	8	7	6.4	1.5	0.79
SIN Fo	6	4	5	7	8	7	6	8	6.5	6.4	1.3	0.94
SIN Ag	8	8	9	5	6	9	8	6	4	7.0	1.8	0.96
#301 Fr	7	6	7	8	9	9	7	8	7	7.6	1.0	0.55
#301 Fo	8.5	5	7	9	9	9	6	9	9	7.9	1.6	0.85
#301 Ag	9	8	7	5	9	9	7	6	2	6.9	2.3	0.28
PM Fr	9	8	8	9	9	8	8	9	9	8.6	0.5	0.55
PM Fo	6	6	9	10	8	8	7	9	9	8.0	1.4	0.85
PM Ag	9.5	9	9	6	6	9	8	7	7	7.8	1.4	0.73

CH Fr	8.5	7	5	8	9	8	7	8	8.5	7.7	1.2
CH Fo	7	7	6	8	9	7	5	8	9	7.3	1.3
CH Ag	7.5	7	6	4	5	8	7	5	3	5.8	1.7
CA Fr	8.8	4	6	8	8	7	6	8	9	7.2	1.6
CA Fo	8.5	6	8	9	9	8	6	8	9	7.9	1.2
CA Ag	8	7	7	3	4	8	7	5	4	5.9	1.9
MM Fr	7.5	5	6	8	8	7	5	8	8.5	7.0	1.3
MM Fo	8.8	5	8	8	8	8	5	8	8	7.4	1.4
MM Ag	7.5	7	7	4	4	8	7	5	4	5.9	1.7
CM Fr	8.5	6	9	7	9	8	6	9	8.5	7.9	1.2
CM Fo	8.5	4	7	8	9	8	7	9	9	7.7	1.6
CM Ag	8.8	8	8	6	8	9	8	7	6	7.6	1.1
CAR Fr	8	5	9	9	9	8	7	9	8.5	8.1	1.3
CAR Fo	8	7	9	8	9	8	7	8	9.5	8.2	0.9
CAR Ag	9.2	8	9	6	8	9.5	8	6	7	7.9	1.3

CF Fr	8.5	8	9	9	9	8	8	9	9	8.6	0.5
CF Fo	8.5	6	7	9	9	8	7	9	8	7.9	1.1
CF Ag	8	8	9	4	8	9	9	6	6	7.4	1.7
CFSP Fr	8	7	8	9	9	7	7	9	8.5	8.1	0.9
CFSP Fo	6.5	4	5	7	7	7	5	7	7.5	6.2	1.2
CFSP Ag	8	9	9	6	6	9.5	8	7	7	7.7	1.3
RB Fr	8.5	6	8	9	9	7	5	9	9	7.8	1.5
RB Fo	8.5	8	6	9	9	7	6	9	9	7.9	1.3
RB Ag	8.8	9	9	4	6	9	8	6	7	7.4	1.8
SIN Fr	8	6	8	9	8	7	6	8	8.5	7.6	1.1
SIN Fo	7	3	4	8	8	7	6	8	7	6.4	1.8
SIN Ag	8.5	8	9	3	6	9	8	5	4	6.7	2.3
#301 Fr	8	5	7	9	8	7	7	9	7.5	7.5	1.2
#301 Fo	9	6	8	9	8	8	7	8	8.5	7.9	1.0
#301 Ag	8.8	9	9	4	4	9	8	6	7	7.2	2.1
PM Fr	9	8	9	9	8	8	8	9	9	8.6	0.5
PM Fo	8	7	9	9	9	8	8	9	9	8.4	0.7
PM Ag	8.4	9	9	6	8	9	9	6	6	7.8	1.4
r^2	0.58	0.81	0.70	0.86	0.56	0.59	0.78	0.92	0.72		

Table A.4.8 Observer accuracy in terms of r² and CV for 5 colour appearance attributes

	Obs1	Obs2	Obs3	Obs4	Obs5	Obs6	Obs7	Obs8	Obs9	Mean
Lightness (Lv)										
r^2	0.75	0.85	0.57	0.54	0.76	0.95	0.48	0.78	0.8	**0.724**
CV	0.07	0.2	0.15	0.2	0.19	0.13	0.15	0.21	0.13	**0.163**
Colourfulness (Cv)										
r^2	0.86	0.73	0.72	0.75	0.62	0.87	0.87	0.94	0.66	**0.785**
CV	0.49	0.22	0.27	0.27	0.3	0.23	0.58	0.36	0.33	**0.344**
Hue Angle (hv)										
r^2	0.87	0.82	0.89	0.57	0.96	0.62	0.88	0.7	0.86	**0.8**
CV	0.39	0.27	0.33	0.2	0.46	0.07	0.54	0.1	0.27	**0.295**
Opacity (Opv)										
r^2	0.57	0.86	0.63	0.79	0.59	0.81	0.72	0.77	0.74	**0.723**
CV	0.33	0.38	0.52	0.67	0.49	0.26	0.37	0.41	0.56	**0.447**
Clarity (Clv)										
r^2	0.58	0.81	0.7	0.85	0.55	0.59	0.77	0.92	0.72	**0.725**
CV	0.1	0.24	0.19	0.26	0.19	0.09	0.2	0.17	0.23	**0.189**

Table A.4.9 Observer repeatability in terms of r² and CV for each of the 9 observers

	CH Fr	CH Fo	CH Ag	CA Fr	CA Fo	CA Ag	MM Fr	MM Fo	MM Ag	CM Fr	CM Fo	CM Ag
Lightness												
r²	0.94	0.94	0.77	0.88	0.95	0.79	0.95	0.93	0.84	0.96	0.94	0.85
CV	0.26	0.3	0.32	0.24	0.23	0.26	0.29	0.27	0.26	0.26	0.25	0.18
Colourfulness												
r²	0.83	0.92	0.94	0.92	0.85	0.45	0.95	0.91	0.97	0.93	0.94	0.84
CV	0.29	0.28	0.3	0.33	0.29	0.28	0.25	0.29	0.4	0.38	0.32	0.34
Hue												
r²	0.89	0.93	0.76	0.88	0.83	0.82	0.93	0.83	0.73	0.99	0.73	0.87
CV	0.33	0.32	0.45	0.32	0.32	0.36	0.33	0.32	0.36	0.28	0.29	0.34
Opacity												
r²	0.67	0.58	0.86	0.8	0.56	0.89	0.92	0.61	0.9	0.88	0.87	0.67
CV	0.45	0.38	0.38	0.54	0.39	0.41	0.37	0.42	0.38	0.45	0.4	0.56
Clarity												
r²	0.61	0.75	0.76	0.73	0.83	0.72	0.91	0.85	0.67	0.96	0.87	0.73
CV	0.2	0.2	0.28	0.22	0.15	0.28	0.22	0.19	0.23	0.14	0.21	0.12

	CAR Fr	CAR Fo	CAR Ag	CF Fr	CF Fo	CF Ag	CF SP Fr	CF SP Fo	CF SP Ag	RB Fr	RB Fo	RB Ag
Lightness												
r²	0.92	0.96	0.84	0.95	0.96	0.68	0.99	0.96	0.76	0.98	0.96	0.7
CV	0.24	0.26	0.21	0.23	0.26	0.27	0.26	0.26	0.22	0.23	0.29	0.26
Colourfulness												
r²	0.8	0.69	0.76	0.95	0.95	0.57	0.93	0.69	0.38	0.74	0.78	0.74
CV	0.3	0.37	0.31	0.38	0.36	0.44	0.38	0.29	0.42	0.3	0.3	0.32
Hue												
r²	0.93	0.85	0.93	0.97	0.69	0.89	0.91	0.68	0.92	0.93	0.93	0.66
CV	0.32	0.33	0.4	0.3	0.24	0.37	0.31	0.34	0.34	0.29	0.3	0.37
Opacity												
r²	0.62	0.39	0.79	0.79	0.79	0.9	0.41	0.55	0.91	0.86	0.81	0.83
CV	0.45	0.5	0.6	0.52	0.47	0.8	0.43	0.34	0.71	0.52	0.57	0.56
Clarity												
r²	0.76	0.28	0.61	0.63	0.82	0.93	0.69	0.88	0.92	0.91	0.49	0.64
CV	0.13	0.11	0.17	0.12	0.14	0.21	0.13	0.22	0.14	0.19	0.15	0.19

	SIN Fr	SIN Fo	SIN Ag	#301 Fr	#301 Fo	#301 Ag	PM Fr	PM Fo	PM Ag	Mean
Lightness										
r²	0.92	0.98	0.95	0.96	0.9	0.9	0.91	0.94	0.98	**0.908**
CV	0.25	0.29	0.32	0.23	0.26	0.28	0.24	0.2	0.21	**0.259**
Colourfulness										
r²	0.85	0.97	0.92	0.92	0.94	0.49	0.98	0.81	0.78	**0.826**
CV	0.33	0.28	0.28	0.34	0.36	0.38	0.39	0.32	0.36	**0.337**
Hue										
r²	0.65	0.9	0.84	0.95	0.95	0.98	0.87	0.82	0.99	**0.866**
CV	0.3	0.29	0.42	0.3	0.32	0.38	0.87	0.32	0.33	**0.337**
Opacity										
r²	0.7	0.76	0.89	0.85	0.62	0.82	0.66	0.84	0.98	**0.761**
CV	0.38	0.37	0.64	0.42	0.4	0.79	0.35	0.84	0.68	**0.494**
Clarity										
r²	0.79	0.94	0.95	0.55	0.846	0.27	0.55	0.85	0.73	**0.745**
CV	0.19	0.23	0.29	0.14	0.15	0.3	0.059	0.13	0.17	**0.186**

Table A.4.10 Tristimulus values obtained by Minolta CS-1000 tele-spectroradiometer for each of the locally-brewed beer samples on highball glass at Verivide® Illumination cabinet (duplicate measurement)

		OVER WHITE BACKGROUND							OVER BLACK BACKGROUND					
		1st			2nd				1st			2nd		
		X	Y	Z	X	Y	Z		X	Y	Z	X	Y	Z
CH Fr	1	36.38	31.39	2.97	36.39	31.40	2.98	34	2.33	2.36	1.52	2.33	2.36	1.52
CH Fo	2	33.81	28.98	2.76	33.84	29.01	2.77	35	2.40	2.44	1.63	2.40	2.44	1.63
CH Ag	3	20.35	16.90	1.63	20.35	16.90	1.63	36	1.88	1.74	0.89	1.88	1.74	0.89
CA Fr	4	40.54	36.21	3.68	40.55	36.22	3.67	37	2.41	2.47	1.52	2.41	2.46	1.52
CA Fo	5	38.89	34.10	3.17	38.88	34.09	3.17	38	2.29	2.35	1.57	2.29	2.35	1.57
CA Ag	6	25.60	22.47	2.15	25.60	22.47	2.15	39	2.27	2.14	0.97	2.27	2.14	0.97
MM Fr	7	31.56	26.59	2.53	31.51	26.54	2.52	40	2.05	2.08	1.41	2.05	2.08	1.41
MM Fo	8	37.14	33.12	3.93	37.14	33.12	3.94	41	2.38	2.46	1.64	2.38	2.46	1.64
MM Ag	9	23.10	20.79	2.98	22.98	19.73	1.95	42	1.80	1.77	0.98	1.63	1.60	1.03
CM Fr	10	39.97	37.22	5.82	39.90	37.15	5.81	43	2.62	2.71	1.60	2.62	2.71	1.60
CM Fo	11	38.81	35.70	5.41	38.77	35.67	5.39	44	2.34	2.44	1.62	2.33	2.44	1.62
CM Ag	12	26.53	24.78	3.79	29.03	26.80	3.77	45	1.44	1.45	0.89	2.00	2.03	1.25
CAR Fr	13	44.75	42.71	6.96	44.72	42.69	6.95	46	2.42	2.53	1.51	2.41	2.52	1.50
CAR Fo	14	36.77	33.50	4.78	36.73	33.46	4.78	47	2.09	2.17	1.51	2.09	2.17	1.51
CAR Ag	15	26.11	24.37	3.90	29.70	27.55	3.96	48	1.33	1.34	0.88	1.60	1.63	1.12
CF Fr	16	43.96	41.93	7.05	43.97	41.94	7.05	49	2.43	2.56	1.65	2.43	2.56	1.65
CF Fo	17	38.96	36.07	5.20	38.95	36.07	5.21	50	2.22	2.29	1.34	2.22	2.29	1.34
CF Ag	18	24.54	22.58	3.39	25.85	23.55	3.11	51	1.41	1.41	0.93	1.49	1.51	1.06
CFSP Fr	19	36.01	33.20	5.53	36.01	33.20	5.53	52	2.02	2.12	1.57	2.02	2.12	1.57
CFSP Fo	20	32.32	28.37	3.67	32.29	28.34	3.68	53	3.67	3.57	1.75	3.66	3.57	1.75
CFSP Ag	21	29.03	27.40	4.16	26.44	24.28	3.73	54	1.44	1.46	0.89	1.47	1.50	1.12
RB Fr	22	38.69	36.54	6.57	38.71	36.56	6.56	55	2.09	2.21	1.54	2.09	2.20	1.54
RB Fo	23	35.38	31.51	3.81	35.36	31.50	3.80	56	1.77	1.80	1.22	1.76	1.80	1.22
RB Ag	24	24.16	21.96	3.28	26.95	24.86	3.98	57	1.33	1.33	0.94	1.39	1.41	1.03
SIN Fr	25	36.59	33.51	4.79	36.65	33.57	4.80	58	2.70	2.72	1.46	2.69	2.71	1.46
SIN Fo	26	30.07	25.88	3.11	30.05	25.87	3.10	59	3.82	3.64	1.65	3.84	3.66	1.68
SIN Ag	27	22.93	19.67	1.99	25.49	22.88	3.01	60	1.46	1.42	0.95	1.54	1.57	1.07
#301 Fr	28	36.82	33.44	4.47	36.82	33.44	4.47	61	2.81	2.84	1.59	2.81	2.84	1.59
#301 Fo	29	39.95	37.63	6.29	39.95	37.63	6.29	62	2.17	2.28	1.54	2.18	2.28	1.54
#301 Ag	30	25.92	24.04	3.76	26.93	24.58	3.47	63	1.46	1.47	0.98	1.65	1.67	1.18
PM Fr	31	44.20	42.74	8.03	44.21	42.73	8.04	64	2.38	2.53	1.64	2.38	2.53	1.64
PM Fo	32	44.87	44.19	10.70	44.84	44.15	10.69	65	2.47	2.64	1.68	2.46	2.62	1.68
PM Ag	33	32.83	31.87	6.01	32.83	31.87	6.01	66	1.80	1.84	1.07	1.80	1.84	1.07

Xw	Yw	Zw	X	Y	Z	
94.811	100	107.304	2.13	2.33	2.64	**Black background**
			160.35	177.84	173.80	**White background**

Table A.4.11 CIECAM02 colour appearance predictors obtained by Minolta CS-1000 tele-spectroradiometer for the fresh, forced aged and spontaneously aged locally-brewed beers on high ball glass at Verivide® Illumination cabinet

Sample		Contrast Ratio	J	M	H400	h360	a	b
CH Fr	1	7.5	55.1	66.6	72.4	65.2	0.44	1.37
CH Fo	2	8.4	52.8	65.2	71.2	64.1	0.45	1.33
CH Ag	3	10.3	39.22	52.92	43.62	39.3	0.43	1.06
CA Fr	4	6.8	59.3	66.9	77.3	69.6	0.38	1.43
CA Fo	5	6.9	57.5	67.8	75.2	67.7	0.41	1.42
CA Ag	6	9.5	45.78	60.44	73.67	66.31	0.35	1.19
MM Fr	7	7.8	50.45	64.38	68.50	61.65	0.48	1.28
MM Fo	8	7.4	56.50	62.60	75.28	67.75	0.38	1.32
MM Ag	9	8.5	43.26	55.36	72.15	64.94	0.35	1.08
CM Fr	10	7.3	59.93	58.12	79.61	71.65	0.30	1.27
CM Fo	11	6.8	58.67	58.38	77.74	69.97	0.33	1.26
CM Ag	12	5.8	49.07	54.14	76.66	68.99	0.27	1.12
CAR Fr	13	5.9	64.41	58.98	83.76	75.39	0.25	1.32
CAR Fo	14	6.5	56.73	58.78	76.76	69.09	0.34	1.25
CAR Ag	15	5.5	49.22	53.55	76.61	68.94	0.26	1.11
CF Fr	16	6.1	63.77	58.00	83.26	74.94	0.26	1.30
CF Fo	17	6.3	58.95	59.39	79.55	71.59	0.31	1.29
CF Ag	18	6.2	46.24	53.52	75.33	67.80	0.28	1.08
CFSP Fr	19	6.4	56.39	55.30	76.89	69.20	0.32	1.19
CFSP Fo	20	12.6	52.04	59.01	71.48	64.33	0.41	1.21
CFSP Ag	21	5.3	49.09	53.38	76.62	68.96	0.26	1.10
RB Fr	22	6.0	59.25	54.60	80.46	72.42	0.28	1.20
RB Fo	23	5.7	55.00	61.46	74.83	67.34	0.38	1.29
RB Ag	24	6.1	46.60	52.06	74.55	67.10	0.29	1.05
SIN Fr	25	8.1	56.71	58.62	77.67	69.91	0.33	1.25
SIN Fo	26	14.1	49.61	59.46	69.10	62.19	0.44	1.19
SIN Ag	27	7.2	44.41	56.63	72.24	65.02	0.36	1.11
#301 Fr	28	8.5	56.69	60.07	77.02	69.31	0.34	1.28
#301 Fo	29	6.0	60.22	56.66	80.91	72.82	0.28	1.24
#301 Ag	30	6.1	47.57	53.23	75.46	67.92	0.28	1.09
PM Fr	31	5.9	64.35	55.58	84.58	76.12	0.23	1.25
PM Fo	32	6.0	65.40	49.68	85.10	76.59	0.20	1.13
PM Ag	33	5.8	54.83	51.45	79.99	71.99	0.20	1.11
		X	**Y**		**Z**			
Black background		2.13	2.33		2.64			
White background		160.35	177.84		173.80			

Table A.4.12 Tristimulus values obtained by Minolta CS-1000 tele-spectroradiometer for the fresh, forced aged and spontaneously aged locally-brewed beers on cell at different depths over black/white background

Sample	Depth	Over Black			Over White		
		X	Y	Z	X	Y	Z
CH Fr	50mm	9.29	10.38	11.07	25.71	22.58	11.32
	40mm	9.26	10.37	11.14	29.87	26.83	11.63
	30mm	9.29	10.43	11.24	33.63	31.58	12.58
CH Fo	50mm	9.70	10.90	11.71	28.18	25.72	12.17
	40mm	9.68	10.90	11.76	32.16	30.26	12.96
	30mm	9.69	10.92	11.84	35.41	34.81	14.59
CH Ag	50mm	7.39	7.65	8.49	17.78	14.66	8.58
	40mm	7.42	7.69	8.52	21.10	17.70	8.68
	30mm	7.36	7.67	8.58	25.80	22.48	9.11
CA Fr	50mm	9.43	10.57	11.28	28.19	25.42	11.66
	40mm	9.41	10.58	11.37	32.29	30.00	12.32
	30mm	9.42	10.62	11.44	36.46	35.42	13.99
CA Fo	50mm	9.35	10.50	11.35	28.83	26.37	11.89
	40mm	9.34	10.49	11.37	33.01	31.16	12.75
	30mm	9.34	10.52	11.43	37.67	37.16	14.67
CA Ag	50mm	7.43	7.70	8.31	21.61	18.07	8.47
	40mm	7.44	7.73	8.34	25.20	21.76	8.73
	30mm	7.32	7.65	8.41	30.27	27.35	9.39
MM Fr	50mm	9.47	10.63	11.32	28.74	26.06	11.66
	40mm	9.40	10.57	11.32	32.44	30.39	12.37
	30mm	9.36	10.55	11.31	36.18	35.43	14.21
MM Fo	50mm	9.26	10.41	11.23	26.76	24.53	12.21
	40mm	9.18	10.31	11.01	30.40	28.59	12.32
	30mm	9.32	10.51	11.34	34.24	33.61	14.03
MM Ag	50mm	7.46	7.78	8.41	19.84	17.18	8.76
	40mm	7.39	7.74	8.44	23.65	21.08	9.18
	30mm	7.39	7.76	8.50	28.59	26.60	10.30
CM Fr	50mm	9.66	10.81	11.54	26.03	22.50	11.51
	40mm	9.63	10.80	11.58	29.80	26.37	11.82
	30mm	9.69	10.88	11.65	32.92	30.41	12.39
CM Fo	50mm	9.29	10.42	11.37	26.60	24.02	11.70
	40mm	9.26	10.40	11.34	31.13	28.88	12.30
	30mm	9.33	10.51	11.52	35.75	34.72	14.53
CM Ag	50mm	7.31	7.65	8.44	22.18	19.47	8.90
	40mm	7.29	7.64	8.42	26.02	23.64	9.51
	30mm	7.28	7.65	8.49	30.42	28.90	10.90
CAr Fr	50mm	9.17	10.30	11.24	23.93	21.88	11.57
	40mm	9.22	10.37	11.33	27.61	25.89	12.21
	30mm	9.24	10.41	11.42	31.85	31.07	13.83
CAr Fo	50mm	9.62	10.66	11.31	17.48	16.04	11.35
	40mm	9.51	10.59	11.39	20.74	18.95	11.54
	30mm	9.50	10.63	11.50	25.03	23.33	12.09
CAr Ag	50mm	7.31	7.65	8.52	21.29	18.82	9.00

	40mm	7.34	7.69	8.56	24.92	22.77	9.63
	30mm	7.40	7.77	8.70	30.07	28.64	11.21
CF Fr	**50mm**	9.25	10.41	11.36	24.70	22.69	11.86
	40mm	9.32	10.48	11.43	28.70	27.05	12.57
	30mm	9.33	10.52	11.52	32.64	32.04	14.26
CF Fo	**50mm**	9.35	10.47	11.41	20.17	18.15	11.49
	40mm	9.32	10.47	11.46	23.66	21.47	11.69
	30mm	9.31	10.48	11.54	27.61	25.88	12.52
CF Ag	**50mm**	7.20	7.53	8.41	20.00	17.50	8.75
	40mm	7.19	7.52	8.38	23.52	21.24	9.26
	30mm	7.21	7.56	8.47	28.57	26.88	10.56
CF SP Fr	**50mm**	9.15	10.28	11.16	24.87	22.73	11.68
	40mm	9.19	10.35	11.33	28.85	27.08	12.35
	30mm	9.26	10.45	11.43	32.14	31.48	13.90
CF SP Fo	**50mm**	9.36	10.50	11.35	24.19	21.98	11.60
	40mm	9.38	10.52	11.35	28.48	26.47	12.19
	30mm	9.36	10.54	11.50	32.28	31.27	13.54
CF SP Ag	**50mm**	7.19	7.49	8.41	21.93	19.26	8.86
	40mm	7.19	7.51	8.41	25.62	23.29	9.45
	30mm	7.19	7.53	8.46	30.37	28.88	10.97
RB Fr	**50mm**	9.39	10.50	11.25	24.97	21.51	11.28
	40mm	9.37	10.50	11.33	28.94	25.41	11.52
	30mm	9.40	10.55	11.42	32.87	30.07	12.10
RB Fo	**50mm**	9.40	10.50	11.12	28.39	24.67	11.22
	40mm	9.47	10.61	11.43	31.89	28.61	11.80
	30mm	9.39	10.56	11.27	35.47	33.28	12.62
RB Ag	**50mm**	6.94	7.24	8.26	17.00	14.79	8.53
	40mm	6.98	7.28	8.30	20.43	18.21	8.93
	30mm	7.03	7.35	8.40	25.49	23.60	10.12
SIN Fr	**50mm**	9.17	10.33	11.34	22.23	20.32	11.65
	40mm	9.22	10.39	11.45	26.52	24.68	12.21
	30mm	9.26	10.44	11.52	30.05	29.11	13.63
SIN Fo	**50mm**	9.42	10.54	11.35	21.71	19.51	11.48
	40mm	9.39	10.55	11.48	25.33	23.11	11.80
	30mm	9.39	10.58	11.58	29.86	28.24	12.79
SIN Ag	**50mm**	7.02	7.30	8.30	16.31	13.68	8.39
	40mm	7.02	7.31	8.31	19.68	16.78	8.58
	30mm	7.03	7.33	8.37	24.32	21.50	9.08
#301 Fr	**50mm**	9.26	10.35	11.07	26.73	23.14	11.18
	40mm	9.34	10.48	11.37	30.31	26.97	11.53
	30mm	9.31	10.46	11.25	34.48	32.00	12.26
#301 Fo	**50mm**	9.28	10.39	11.22	24.36	21.13	11.22
	40mm	9.33	10.46	11.33	28.03	24.83	11.52
	30mm	9.34	10.48	11.37	31.01	28.67	12.20
#301 Ag	**50mm**	7.40	7.69	8.68	18.85	16.58	9.15

	40mm	7.31	7.67	8.91	22.55	20.25	9.97
	30mm	7.41	7.60	9.23	27.59	25.86	10.98
PM Fr	**50mm**	9.40	10.57	11.43	30.56	28.89	12.76
	40mm	9.51	10.71	11.55	35.18	34.39	14.36
	30mm	9.42	10.65	11.64	38.12	38.83	17.11
PM Fo	**50mm**	9.36	10.53	11.23	31.70	29.81	12.56
	40mm	9.39	10.58	11.36	35.96	35.01	14.00
	30mm	9.42	10.64	11.55	39.82	40.39	16.72
PM Ag	**50mm**	7.30	7.63	8.34	23.91	21.61	9.16
	40mm	7.28	7.63	8.38	27.34	25.63	10.10
	30mm	7.27	7.64	8.46	32.70	31.90	12.27

Table A.4.13 Mean values of CIECAM02 colour appearance predictors obtained by Minolta CS-1000 tele-spectroradiometer the fresh, forced aged and spontaneously aged locally-brewed beers on different depths over black/white background

		Over Black					Over White				
Sample	**Depth**	**J**	**M**	**h_360**	**a**	**b**	**J**	**M**	**h_360**	**a**	**b**
CH Fr	**50mm**	26.98	3.09	56.80	1.69	2.58	40.98	36.07	56.24	20.04	29.98
	40mm	26.97	3.42	61.91	1.61	3.01	43.71	38.32	62.45	17.72	33.98
	30mm	26.84	3.14	67.11	1.22	2.89	46.52	41.38	69.08	14.78	38.65
CH Fo	**50mm**	26.50	2.94	55.96	1.65	2.44	39.62	33.75	53.36	20.14	27.08
	40mm	26.37	2.63	61.53	1.26	2.32	42.63	37.64	61.07	18.21	32.94
	30mm	26.01	3.11	60.86	1.52	2.72	45.85	41.30	68.27	15.29	38.36
CH Ag	**50mm**	20.33	3.69	28.38	0.05	0.03	28.69	32.68	40.76	0.48	0.41
	40mm	19.98	3.15	28.32	0.04	0.02	31.50	35.78	50.84	0.45	0.55
	30mm	19.84	3.31	23.67	0.05	0.02	35.81	38.70	62.49	0.36	0.70
CA Fr	**50mm**	26.50	2.94	55.96	1.65	2.44	42.94	38.35	60.19	19.06	33.27
	40mm	26.71	2.51	68.82	0.91	2.34	45.63	40.84	65.15	17.16	37.06
	30mm	26.50	3.27	61.39	1.57	2.87	48.26	42.17	70.37	14.17	39.72
CA Fo	**50mm**	26.22	2.73	73.48	0.78	2.61	41.45	37.10	58.42	19.43	31.61
	40mm	26.02	2.79	55.06	1.60	2.29	44.27	39.72	63.81	17.53	35.64
	30mm	26.02	2.79	55.06	1.60	2.29	47.19	41.46	69.84	14.29	38.92
CA Ag	**50mm**	20.16	4.20	25.59	0.06	0.03	31.35	36.19	50.74	0.45	0.55
	40mm	19.68	3.68	27.84	0.05	0.03	34.90	39.44	61.47	0.38	0.70
	30mm	19.30	3.39	28.07	0.05	0.02	39.16	41.40	69.18	0.30	0.80
MM Fr	**50mm**	26.50	2.94	55.96	1.65	2.44	39.90	34.59	54.90	19.89	28.30
	40mm	26.64	3.28	51.57	2.04	2.57	43.11	38.17	62.25	17.77	33.78
	30mm	26.16	3.13	50.55	1.99	2.42	45.21	38.10	67.84	14.37	35.28
MM Fo	**50mm**	26.16	2.87	43.76	2.07	1.98	40.81	34.66	57.43	18.66	29.21
	40mm	25.88	2.16	53.46	1.28	1.73	43.88	38.17	64.44	16.47	34.44
	30mm	26.22	2.73	73.48	0.78	2.61	46.93	38.94	69.60	13.57	36.50
MM Ag	**50mm**	20.33	3.92	27.14	0.05	0.03	30.97	31.94	51.46	0.39	0.49
	40mm	20.01	3.91	30.01	0.05	0.03	34.61	35.43	62.28	0.33	0.63
	30mm	19.70	3.71	27.56	0.05	0.03	38.94	36.28	69.07	0.27	0.70
CM Fr	**50mm**	28.61	2.72	66.14	1.10	2.49	45.28	37.17	64.12	16.22	33.44
	40mm	28.76	2.99	60.09	1.49	2.59	48.25	38.56	68.82	13.93	35.95
	30mm	28.29	2.86	59.55	1.45	2.46	51.29	38.02	71.22	12.24	36.00
CM Fo	**50mm**	26.38	2.31	54.70	1.34	1.89	43.99	36.60	65.58	15.13	33.32
	40mm	26.22	2.73	73.48	0.78	2.61	46.64	38.56	69.40	13.57	36.09
	30mm	25.72	2.55	73.72	0.72	2.45	49.98	37.78	71.59	11.93	35.84
CM Ag	**50mm**	20.78	3.29	26.12	0.05	0.02	33.68	33.97	59.24	0.35	0.59
	40mm	20.48	3.43	30.72	0.05	0.03	37.00	36.36	67.89	0.28	0.69
	30mm	20.22	2.94	30.18	0.04	0.02	41.05	35.89	71.39	0.24	0.71
CAr Fr	**50mm**	26.85	2.78	62.14	1.30	2.46	44.18	37.94	64.23	16.50	34.17
	40mm	26.84	3.14	67.11	1.22	2.89	46.74	38.78	69.07	13.85	36.22
	30mm	26.36	2.98	66.83	1.17	2.74	49.37	38.05	71.97	11.78	36.18
CAr Fo	**50mm**	26.38	2.31	54.70	1.34	1.89	43.50	37.56	64.36	16.25	33.86
	40mm	26.23	2.35	68.63	0.86	2.19	46.26	38.82	68.73	14.09	36.18
	30mm	26.23	2.35	68.63	0.86	2.19	49.28	38.10	71.12	12.33	36.05
CAr Ag	**50mm**	21.02	3.29	27.52	0.04	0.02	33.44	32.64	58.80	0.34	0.56
	40mm	20.80	3.12	29.31	0.04	0.02	36.85	34.84	67.63	0.27	0.66
	30mm	20.61	2.98	30.66	0.04	0.02	41.01	34.59	71.04	0.24	0.69
CF Fr	**50mm**	25.87	2.47	60.90	1.20	2.16	42.70	34.05	63.95	14.95	30.59
	40mm	26.16	3.13	50.55	1.99	2.42	45.32	36.58	69.08	13.06	34.17
	30mm	25.72	2.55	73.72	0.72	2.45	48.53	35.85	70.90	11.73	33.88
CF Fo	**50mm**	26.23	2.35	68.63	0.86	2.19	41.82	34.40	62.37	15.95	30.48
	40mm	25.52	2.35	46.25	1.62	1.70	44.64	37.32	67.24	14.44	34.41
	30mm	25.37	1.99	52.03	1.22	1.56	48.32	36.20	70.70	11.96	34.17
CF Ag	**50mm**	19.81	2.83	21.75	0.04	0.02	31.52	31.93	53.59	0.38	0.51
	40mm	19.72	2.84	40.05	0.03	0.03	34.91	34.88	64.20	0.31	0.64
	30mm	19.31	2.86	26.59	0.04	0.02	39.31	35.24	70.26	0.25	0.69
CF SP Fr	**50mm**	26.37	2.63	61.53	1.26	2.32	40.29	31.28	60.85	15.23	27.31
	40mm	25.88	2.16	53.46	1.28	1.73	43.46	34.70	66.93	13.60	31.93
	30mm	25.87	2.47	60.90	1.20	2.16	46.31	34.36	71.29	11.02	32.55

CF SP Fo	**50mm**	26.64	3.28	51.57	2.04	2.57	34.70	23.45	47.17	15.94	17.19
	40mm	26.50	2.94	55.96	1.65	2.44	37.29	27.54	53.76	16.28	22.22
	30mm	26.50	3.27	61.39	1.57	2.87	40.74	30.70	63.50	13.70	27.47
CF SP Ag	**50mm**	19.79	3.16	22.11	0.04	0.02	32.65	34.02	58.51	0.36	0.58
	40mm	19.52	2.79	24.92	0.04	0.02	35.97	36.15	67.43	0.28	0.68
	30mm	19.29	3.00	25.63	0.04	0.02	40.02	35.75	72.03	0.23	0.71
RB Fr	**50mm**	27.99	2.79	47.41	1.89	2.05	42.78	34.07	62.57	15.70	30.24
	40mm	27.80	2.72	59.09	1.40	2.34	45.91	36.49	68.31	13.48	33.90
	30mm	27.29	2.58	58.71	1.34	2.20	49.00	36.09	70.99	11.76	34.12
RB Fo	**50mm**	28.48	2.91	48.45	1.93	2.18	38.07	28.79	50.38	18.36	22.17
	40mm	28.29	2.86	59.55	1.45	2.46	41.24	33.12	58.76	17.18	28.32
	30mm	27.95	3.03	53.75	1.79	2.44	44.81	35.70	67.00	13.95	32.86
RB Ag	**50mm**	19.94	2.67	15.61	0.04	0.01	29.46	29.57	45.81	0.40	0.42
	40mm	19.70	2.63	23.73	0.04	0.02	32.58	32.09	58.90	0.33	0.55
	30mm	19.51	2.72	23.03	0.04	0.02	36.88	33.55	68.26	0.25	0.64
SIN Fr	**50mm**	26.23	2.35	68.63	0.86	2.19	41.40	32.45	61.03	15.72	28.39
	40mm	26.03	2.51	47.87	1.68	1.86	44.13	34.25	67.66	13.02	31.68
	30mm	25.87	2.47	60.90	1.20	2.16	47.27	34.63	70.86	11.36	32.72
SIN Fo	**50mm**	26.52	2.65	49.28	1.73	2.01	40.26	31.60	59.32	16.12	27.18
	40mm	26.65	3.01	45.20	2.12	2.13	43.64	35.13	66.29	14.12	32.16
	30mm	26.50	2.94	55.96	1.65	2.44	47.04	36.08	71.39	11.52	34.20
SIN Ag	**50mm**	18.86	2.25	19.24	0.03	0.01	27.34	30.35	38.06	0.46	0.36
	40mm	18.60	2.38	23.95	0.03	0.01	30.07	33.54	49.38	0.43	0.50
	30mm	18.44	2.49	18.38	0.03	0.01	34.14	36.40	62.03	0.34	0.65
#301 Fr	**50mm**	27.99	2.79	47.41	1.89	2.05	40.36	29.86	56.10	16.66	24.79
	40mm	27.95	3.03	53.75	1.79	2.44	43.54	33.88	65.56	14.02	30.84
	30mm	27.80	2.72	59.09	1.40	2.34	47.26	35.53	70.21	12.03	33.43
#301 Fo	**50mm**	28.29	2.86	59.55	1.45	2.46	39.29	30.02	53.97	17.66	24.28
	40mm	28.13	2.59	65.92	1.06	2.37	42.67	34.18	61.44	16.34	30.02
	30mm	27.63	2.45	65.83	1.00	2.24	46.31	36.84	69.58	12.85	34.52
#301 Ag	**50mm**	20.07	2.85	23.02	0.04	0.02	30.91	29.83	50.76	0.37	0.46
	40mm	19.75	1.97	25.84	0.03	0.01	34.23	31.99	60.77	0.32	0.57
	30mm	19.65	2.61	6.29	0.04	0.00	38.47	33.48	68.82	0.25	0.65
PM Fr	**50mm**	26.38	2.31	54.70	1.34	1.89	46.20	36.00	68.55	13.16	33.50
	40mm	26.23	2.35	68.63	0.86	2.19	48.93	35.95	70.35	12.09	33.85
	30mm	25.87	2.47	60.90	1.20	2.16	51.70	33.57	72.36	10.17	31.99
PM Fo	**50mm**	26.37	2.63	61.53	1.26	2.32	46.56	38.61	68.52	14.14	35.93
	40mm	25.87	2.47	60.90	1.20	2.16	49.28	38.10	71.12	12.33	36.05
	30mm	25.73	2.18	68.51	0.80	2.03	51.35	34.48	73.03	10.06	32.98
PM Ag	**50mm**	20.41	3.50	26.96	0.05	0.02	35.37	34.88	65.30	0.30	0.64
	40mm	20.09	3.41	28.79	0.05	0.03	38.65	35.52	70.46	0.25	0.69
	30mm	19.75	3.16	30.38	0.04	0.02	42.54	33.87	72.41	0.22	0.68

Table A.4.14 Device coordinates (RGB)obtained by DigiEye System-VeriVide® (Digital Imaging) for the fresh, forced aged and spontaneously aged locally-brewed beers on cell at different depths over black/white background

		Over Black			Over White		
Sample	**Depth**	**R**	**G**	**B**	**R**	**G**	**B**
CH Fr	**50mm**	35	37	41	139	60	32
	40mm	35	37	40	145	71	33
	30mm	34	37	40	149	84	33
CH Fo	**50mm**	34	36	40	133	56	33
	40mm	33	36	40	142	67	32
	30mm	33	35	38	148	81	32
CH Ag	**50mm**	30	30	32	109	41	28
	40mm	29	30	32	124	51	27
	30mm	28	29	32	139	67	27
CA Fr	**50mm**	34	36	40	145	67	32
	40mm	33	37	41	151	78	33
	30mm	34	36	39	153	91	35
CA Fo	**50mm**	32	36	39	140	62	31
	40mm	33	35	39	147	73	32
	30mm	33	35	39	150	87	34
CA Ag	**50mm**	30	30	32	124	50	26
	40mm	29	29	31	137	64	26
	30mm	28	28	30	148	80	28
MM Fr	**50mm**	34	36	40	134	57	32
	40mm	35	36	40	143	69	32
	30mm	34	35	39	143	80	35
MM Fo	**50mm**	34	35	40	135	61	33
	40mm	32	35	40	143	73	33
	30mm	32	36	39	147	87	37
MM Ag	**50mm**	30	30	32	113	51	29
	40mm	29	30	31	129	65	29
	30mm	29	29	31	141	82	34
CM Fr	**50mm**	33	37	41	138	73	36
	40mm	34	37	41	143	85	39
	30mm	33	36	40	148	97	46
CM Fo	**50mm**	33	36	41	140	75	35
	40mm	32	36	39	146	86	37
	30mm	31	35	38	152	100	45
CM Ag	**50mm**	30	31	34	125	61	30
	40mm	30	31	33	134	75	31
	30mm	29	30	33	144	90	37
CAr Fr	**50mm**	34	37	41	144	74	34
	40mm	34	37	40	147	86	37
	30mm	33	36	39	150	98	43
CAr Fo	**50mm**	33	36	41	141	72	33
	40mm	32	36	40	146	84	36
	30mm	32	36	40	151	97	43
CAr Ag	**50mm**	31	32	35	121	61	31

	40mm	30	32	34	132	75	32
	30mm	30	31	34	143	91	39
CF Fr	**50mm**	32	35	39	134	71	36
	40mm	34	35	39	140	82	37
	30mm	31	35	38	147	95	45
CF Fo	**50mm**	32	36	40	133	67	34
	40mm	32	34	39	141	78	35
	30mm	31	34	39	147	94	44
CF Ag	**50mm**	28	29	32	115	53	29
	40mm	28	30	31	127	67	30
	30mm	27	28	31	139	84	36
CF SP Fr	**50mm**	33	36	40	124	63	35
	40mm	32	35	40	134	75	36
	30mm	32	35	39	138	88	42
CF SP Fo	**50mm**	35	36	40	98	46	36
	40mm	34	36	40	112	53	35
	30mm	34	36	39	122	66	36
CF SP Ag	**50mm**	28	29	32	120	58	28
	40mm	27	29	32	130	71	29
	30mm	27	28	31	140	87	36
RB Fr	**50mm**	33	35	40	127	66	35
	40mm	32	35	39	134	78	37
	30mm	31	34	38	140	90	44
RB Fo	**50mm**	34	36	41	112	50	35
	40mm	33	36	40	124	60	34
	30mm	33	35	39	131	74	36
RB Ag	**50mm**	28	29	33	104	46	29
	40mm	27	29	32	116	58	29
	30mm	27	29	32	129	76	34
SIN Fr	**50mm**	32	36	40	130	66	36
	40mm	33	35	40	135	78	38
	30mm	32	35	39	142	91	44
SIN Fo	**50mm**	34	36	41	126	62	35
	40mm	35	36	41	136	75	36
	30mm	34	36	40	142	90	41
SIN Ag	**50mm**	26	27	31	98	38	27
	40mm	25	27	30	113	47	26
	30mm	25	26	29	128	63	27
#301 Fr	**50mm**	33	35	40	118	58	37
	40mm	33	35	39	126	70	36
	30mm	32	35	39	135	84	41
#301 Fo	**50mm**	33	36	40	116	54	35
	40mm	32	36	40	128	65	35
	30mm	31	35	39	134	80	37
#301 Ag	**50mm**	28	30	33	109	51	31

	40mm	27	29	33	122	64	33
	30mm	27	28	33	135	81	37
PM Fr	**50mm**	33	36	41	143	85	40
	40mm	32	36	40	149	96	46
	30mm	32	35	39	152	108	57
PM Fo	**50mm**	33	36	40	147	85	37
	40mm	32	35	39	151	97	43
	30mm	31	35	39	151	107	54
PM Ag	**50mm**	30	31	33	128	69	30
	40mm	29	30	32	136	82	34
	30mm	28	29	31	145	97	43

Table A.4.15 Tristimulus values obtained by DigiEye System-VeriVide® (Digital Imaging) for the fresh, forced aged and spontaneously aged locally-brewed beers on cell at different depths over black/white background

		Over Black			Over White		
Sample	**Depth**	**X**	**Y**	**Z**	**X**	**Y**	**Z**
CH Fr	**50mm**	4.96	5.09	4.91	14.22	11.85	4.27
	40mm	4.95	5.08	4.82	15.79	13.64	4.40
	30mm	4.87	5.04	4.79	17.42	15.66	4.43
CH Fo	**50mm**	4.79	4.92	4.77	13.31	11.02	4.37
	40mm	4.72	4.87	4.75	15.09	12.91	4.25
	30mm	4.62	4.75	4.54	16.99	15.16	4.27
CH Ag	**50mm**	5.28	5.36	5.42	11.76	9.40	4.19
	40mm	5.10	5.20	5.31	13.59	11.20	3.77
	30mm	5.05	5.13	5.27	16.38	14.32	3.77
CA Fr	**50mm**	4.79	4.92	4.77	15.45	13.12	4.28
	40mm	4.80	4.99	4.86	17.16	15.00	4.44
	30mm	4.78	4.92	4.68	18.72	17.00	4.82
CA Fo	**50mm**	4.63	4.82	4.63	14.45	12.15	4.12
	40mm	4.63	4.75	4.63	16.17	14.02	4.27
	30mm	4.63	4.75	4.63	17.87	16.17	4.61
CA Ag	**50mm**	5.23	5.27	5.32	13.51	11.10	3.66
	40mm	4.98	5.05	5.10	15.80	13.63	3.44
	30mm	4.80	4.88	4.95	18.73	16.99	3.89
MM Fr	**50mm**	4.79	4.92	4.77	13.46	11.19	4.23
	40mm	4.87	4.97	4.79	15.36	13.23	4.24
	30mm	4.70	4.80	4.65	16.33	14.69	4.65
MM Fo	**50mm**	4.71	4.80	4.74	13.89	11.75	4.36
	40mm	4.56	4.71	4.70	15.70	13.75	4.37
	30mm	4.63	4.82	4.63	17.52	15.96	5.00
MM Ag	**50mm**	5.29	5.35	5.40	12.89	10.94	4.19
	40mm	5.14	5.20	5.21	15.23	13.50	4.03
	30mm	5.00	5.06	5.12	18.20	16.89	4.91
CM Fr	**50mm**	5.49	5.69	5.53	16.72	14.75	5.05
	40mm	5.57	5.75	5.57	18.67	17.00	5.62
	30mm	5.40	5.56	5.41	20.95	19.52	6.87
CM Fo	**50mm**	4.73	4.88	4.84	15.55	13.83	4.62
	40mm	4.63	4.82	4.63	17.30	15.75	4.99
	30mm	4.46	4.65	4.50	19.74	18.41	6.35
CM Ag	**50mm**	5.48	5.58	5.71	14.61	12.82	4.19
	40mm	5.34	5.44	5.49	16.74	15.35	4.31
	30mm	5.19	5.32	5.43	19.74	18.68	5.65
CAr Fr	**50mm**	4.88	5.04	4.89	15.93	13.96	4.52
	40mm	4.87	5.04	4.79	17.43	15.82	5.00
	30mm	4.71	4.87	4.66	19.18	17.89	6.01
CAr Fo	**50mm**	4.73	4.88	4.84	15.38	13.49	4.35
	40mm	4.64	4.82	4.72	17.09	15.46	4.83
	30mm	4.64	4.82	4.72	19.22	17.83	6.01
CAr Ag	**50mm**	5.59	5.70	5.81	14.37	12.67	4.39

	40mm	5.48	5.60	5.71	16.55	15.26	4.60
	30mm	5.37	5.50	5.61	19.65	18.65	5.99
CF Fr	50mm	4.55	4.70	4.61	14.60	12.96	4.72
	40mm	4.70	4.80	4.65	16.19	14.77	4.91
	30mm	4.46	4.65	4.50	18.47	17.21	6.21
CF Fo	50mm	4.64	4.82	4.72	14.14	12.38	4.45
	40mm	4.47	4.59	4.58	15.92	14.29	4.63
	30mm	4.39	4.54	4.55	18.35	17.05	6.06
CF Ag	50mm	5.01	5.12	5.31	13.18	11.32	4.23
	40mm	4.94	5.08	5.11	15.29	13.76	4.13
	30mm	4.78	4.89	5.03	18.34	17.23	5.24
CF SP Fr	50mm	4.72	4.87	4.75	13.01	11.43	4.55
	40mm	4.56	4.71	4.70	14.91	13.47	4.72
	30mm	4.55	4.70	4.61	16.58	15.50	5.63
CF SP Fo	50mm	4.87	4.97	4.79	9.78	8.35	4.64
	40mm	4.79	4.92	4.77	11.29	9.69	4.53
	30mm	4.78	4.92	4.68	13.07	11.70	4.67
CF SP Ag	50mm	5.02	5.11	5.28	13.89	12.10	3.90
	40mm	4.88	4.99	5.15	15.95	14.57	4.06
	30mm	4.78	4.88	5.01	18.80	17.83	5.29
RB Fr	50mm	5.33	5.46	5.39	14.78	13.01	4.82
	40mm	5.22	5.38	5.26	16.71	15.20	5.18
	30mm	5.03	5.20	5.10	18.87	17.59	6.35
RB Fo	50mm	5.51	5.64	5.55	12.05	10.13	4.81
	40mm	5.40	5.56	5.41	13.94	12.01	4.67
	30mm	5.31	5.44	5.29	15.95	14.40	5.00
RB Ag	50mm	5.07	5.19	5.45	11.89	9.97	4.51
	40mm	4.95	5.08	5.26	13.69	12.09	4.21
	30mm	4.87	4.98	5.17	16.44	15.31	4.87
SIN Fr	50mm	4.64	4.82	4.72	13.82	12.11	4.71
	40mm	4.63	4.75	4.72	15.30	13.93	5.01
	30mm	4.55	4.70	4.61	17.39	16.23	5.98
SIN Fo	50mm	4.80	4.92	4.86	13.12	11.41	4.56
	40mm	4.88	4.97	4.88	15.13	13.59	4.73
	30mm	4.79	4.92	4.77	17.24	16.05	5.55
SIN Ag	50mm	4.57	4.70	4.92	10.74	8.63	4.29
	40mm	4.46	4.58	4.76	12.45	10.31	3.79
	30mm	4.39	4.50	4.71	14.95	13.14	3.72
#301 Fr	50mm	5.33	5.46	5.39	13.27	11.47	5.09
	40mm	5.31	5.44	5.29	15.04	13.52	4.97
	30mm	5.22	5.38	5.26	17.50	16.22	5.80
#301 Fo	50mm	5.40	5.56	5.41	12.72	10.83	4.81
	40mm	5.31	5.51	5.37	14.80	12.94	4.83
	30mm	5.13	5.32	5.22	16.91	15.50	5.20
#301 Ag	50mm	5.13	5.25	5.43	12.73	10.93	4.60

	40mm	4.95	5.11	5.34	14.80	13.27	4.68
	30mm	4.94	5.05	5.39	17.67	16.57	5.43
PM Fr	**50mm**	4.73	4.88	4.84	16.88	15.42	5.38
	40mm	4.64	4.82	4.72	18.88	17.54	6.39
	30mm	4.55	4.70	4.61	20.89	19.88	8.16
PM Fo	**50mm**	4.72	4.87	4.75	17.34	15.68	4.99
	40mm	4.55	4.70	4.61	19.22	17.83	6.01
	30mm	4.47	4.65	4.58	20.56	19.57	7.71
PM Ag	**50mm**	5.31	5.40	5.49	15.57	14.11	4.22
	40mm	5.16	5.25	5.33	17.80	16.70	4.93
	30mm	4.99	5.09	5.17	20.79	20.00	6.74

Table A.4.16 Mean values of CIECAM02 colour appearance predictors obtained by DigiEye System-VeriVide® (Digital Imaging) for the fresh, forced aged and spontaneously aged locally-brewed beers on different depths over black/white background

		Over Black					Over White				
Sample	Depth	J	M	h_360	A	B	J	M	h_360	a	b
CH Fr	50mm	26.98	3.09	56.80	1.69	2.58	40.98	36.07	56.24	20.04	29.98
	40mm	26.97	3.42	61.91	1.61	3.01	43.71	38.32	62.45	17.72	33.98
	30mm	26.84	3.14	67.11	1.22	2.89	46.52	41.38	69.08	14.78	38.65
CH Fo	50mm	26.50	2.94	55.96	1.65	2.44	39.62	33.75	53.36	20.14	27.08
	40mm	26.37	2.63	61.53	1.26	2.32	42.63	37.64	61.07	18.21	32.94
	30mm	26.01	3.11	60.86	1.52	2.72	45.85	41.30	68.27	15.29	38.36
CH Ag	50mm	20.33	3.69	28.38	0.05	0.03	28.69	32.68	40.76	0.48	0.41
	40mm	19.98	3.15	28.32	0.04	0.02	31.50	35.78	50.84	0.45	0.55
	30mm	19.84	3.31	23.67	0.05	0.02	35.81	38.70	62.49	0.36	0.70
CA Fr	50mm	26.50	2.94	55.96	1.65	2.44	42.94	38.35	60.19	19.06	33.27
	40mm	26.71	2.51	68.82	0.91	2.34	45.63	40.84	65.15	17.16	37.06
	30mm	26.50	3.27	61.39	1.57	2.87	48.26	42.17	70.37	14.17	39.72
CA Fo	50mm	26.22	2.73	73.48	0.78	2.61	41.45	37.10	58.42	19.43	31.61
	40mm	26.02	2.79	55.06	1.60	2.29	44.27	39.72	63.81	17.53	35.64
	30mm	26.02	2.79	55.06	1.60	2.29	47.19	41.46	69.84	14.29	38.92
CA Ag	50mm	20.16	4.20	25.59	0.06	0.03	31.35	36.19	50.74	0.45	0.55
	40mm	19.68	3.68	27.84	0.05	0.03	34.90	39.44	61.47	0.38	0.70
	30mm	19.30	3.39	28.07	0.05	0.02	39.16	41.40	69.18	0.30	0.80
MM Fr	50mm	26.50	2.94	55.96	1.65	2.44	39.90	34.59	54.90	19.89	28.30
	40mm	26.64	3.28	51.57	2.04	2.57	43.11	38.17	62.25	17.77	33.78
	30mm	26.16	3.13	50.55	1.99	2.42	45.21	38.10	67.84	14.37	35.28
MM Fo	50mm	26.16	2.87	43.76	2.07	1.98	40.81	34.66	57.43	18.66	29.21
	40mm	25.88	2.16	53.46	1.28	1.73	43.88	38.17	64.44	16.47	34.44
	30mm	26.22	2.73	73.48	0.78	2.61	46.93	38.94	69.60	13.57	36.50
MM Ag	50mm	20.33	3.92	27.14	0.05	0.03	30.97	31.94	51.46	0.39	0.49
	40mm	20.01	3.91	30.01	0.05	0.03	34.61	35.43	62.28	0.33	0.63
	30mm	19.70	3.71	27.56	0.05	0.03	38.94	36.28	69.07	0.27	0.70
CM Fr	50mm	28.61	2.72	66.14	1.10	2.49	45.28	37.17	64.12	16.22	33.44
	40mm	28.76	2.99	60.09	1.49	2.59	48.25	38.56	68.82	13.93	35.95
	30mm	28.29	2.86	59.55	1.45	2.46	51.29	38.02	71.22	12.24	36.00
CM Fo	50mm	26.38	2.31	54.70	1.34	1.89	43.99	36.60	65.58	15.13	33.32
	40mm	26.22	2.73	73.48	0.78	2.61	46.64	38.56	69.40	13.57	36.09
	30mm	25.72	2.55	73.72	0.72	2.45	49.98	37.78	71.59	11.93	35.84
CM Ag	50mm	20.78	3.29	26.12	0.05	0.02	33.68	33.97	59.24	0.35	0.59
	40mm	20.48	3.43	30.72	0.05	0.03	37.00	36.36	67.89	0.28	0.69
	30mm	20.22	2.94	30.18	0.04	0.02	41.05	35.89	71.39	0.24	0.71
CAr Fr	50mm	26.85	2.78	62.14	1.30	2.46	44.18	37.94	64.23	16.50	34.17
	40mm	26.84	3.14	67.11	1.22	2.89	46.74	38.78	69.07	13.85	36.22
	30mm	26.36	2.98	66.83	1.17	2.74	49.37	38.05	71.97	11.78	36.18
CAr Fo	50mm	26.38	2.31	54.70	1.34	1.89	43.50	37.56	64.36	16.25	33.86
	40mm	26.23	2.35	68.63	0.86	2.19	46.26	38.82	68.73	14.09	36.18
	30mm	26.23	2.35	68.63	0.86	2.19	49.28	38.10	71.12	12.33	36.05
CAr Ag	50mm	21.02	3.29	27.52	0.04	0.02	33.44	32.64	58.80	0.34	0.56
	40mm	20.80	3.12	29.31	0.04	0.02	36.85	34.84	67.63	0.27	0.66
	30mm	20.61	2.98	30.66	0.04	0.02	41.01	34.59	71.04	0.24	0.69
CF Fr	50mm	25.87	2.47	60.90	1.20	2.16	42.70	34.05	63.95	14.95	30.59
	40mm	26.16	3.13	50.55	1.99	2.42	45.32	36.58	69.08	13.06	34.17
	30mm	25.72	2.55	73.72	0.72	2.45	48.53	35.85	70.90	11.73	33.88
CF Fo	50mm	26.23	2.35	68.63	0.86	2.19	41.82	34.40	62.37	15.95	30.48
	40mm	25.52	2.35	46.25	1.62	1.70	44.64	37.32	67.24	14.44	34.41
	30mm	25.37	1.99	52.03	1.22	1.56	48.32	36.20	70.70	11.96	34.17
CF Ag	50mm	19.81	2.83	21.75	0.04	0.02	31.52	31.93	53.59	0.38	0.51
	40mm	19.72	2.84	40.05	0.03	0.03	34.91	34.88	64.20	0.31	0.64
	30mm	19.31	2.86	26.59	0.04	0.02	39.31	35.24	70.26	0.25	0.69
CF SP Fr	50mm	26.37	2.63	61.53	1.26	2.32	40.29	31.28	60.85	15.23	27.31

	40mm	25.88	2.16	53.46	1.28	1.73	43.46	34.70	66.93	13.60	31.93
	30mm	25.87	2.47	60.90	1.20	2.16	46.31	34.36	71.29	11.02	32.55
CF SP Fo	**50mm**	26.64	3.28	51.57	2.04	2.57	34.70	23.45	47.17	15.94	17.19
	40mm	26.50	2.94	55.96	1.65	2.44	37.29	27.54	53.76	16.28	22.22
	30mm	26.50	3.27	61.39	1.57	2.87	40.74	30.70	63.50	13.70	27.47
CF SP Ag	**50mm**	19.79	3.16	22.11	0.04	0.02	32.65	34.02	58.51	0.36	0.58
	40mm	19.52	2.79	24.92	0.04	0.02	35.97	36.15	67.43	0.28	0.68
	30mm	19.29	3.00	25.63	0.04	0.02	40.02	35.75	72.03	0.23	0.71
RB Fr	**50mm**	27.99	2.79	47.41	1.89	2.05	42.78	34.07	62.57	15.70	30.24
	40mm	27.80	2.72	59.09	1.40	2.34	45.91	36.49	68.31	13.48	33.90
	30mm	27.29	2.58	58.71	1.34	2.20	49.00	36.09	70.99	11.76	34.12
RB Fo	**50mm**	28.48	2.91	48.45	1.93	2.18	38.07	28.79	50.38	18.36	22.17
	40mm	28.29	2.86	59.55	1.45	2.46	41.24	33.12	58.76	17.18	28.32
	30mm	27.95	3.03	53.75	1.79	2.44	44.81	35.70	67.00	13.95	32.86
RB Ag	**50mm**	19.94	2.67	15.61	0.04	0.01	29.46	29.57	45.81	0.40	0.42
	40mm	19.70	2.63	23.73	0.04	0.02	32.58	32.09	58.90	0.33	0.55
	30mm	19.51	2.72	23.03	0.04	0.02	36.88	33.55	68.26	0.25	0.64
SIN Fr	**50mm**	26.23	2.35	68.63	0.86	2.19	41.40	32.45	61.03	15.72	28.39
	40mm	26.03	2.51	47.87	1.68	1.86	44.13	34.25	67.66	13.02	31.68
	30mm	25.87	2.47	60.90	1.20	2.16	47.27	34.63	70.86	11.36	32.72
SIN Fo	**50mm**	26.52	2.65	49.28	1.73	2.01	40.26	31.60	59.32	16.12	27.18
	40mm	26.65	3.01	45.20	2.12	2.13	43.64	35.13	66.29	14.12	32.16
	30mm	26.50	2.94	55.96	1.65	2.44	47.04	36.08	71.39	11.52	34.20
SIN Ag	**50mm**	18.86	2.25	19.24	0.03	0.01	27.34	30.35	38.06	0.46	0.36
	40mm	18.60	2.38	23.95	0.03	0.01	30.07	33.54	49.38	0.43	0.50
	30mm	18.44	2.49	18.38	0.03	0.01	34.14	36.40	62.03	0.34	0.65
#301 Fr	**50mm**	27.99	2.79	47.41	1.89	2.05	40.36	29.86	56.10	16.66	24.79
	40mm	27.95	3.03	53.75	1.79	2.44	43.54	33.88	65.56	14.02	30.84
	30mm	27.80	2.72	59.09	1.40	2.34	47.26	35.53	70.21	12.03	33.43
#301 Fo	**50mm**	28.29	2.86	59.55	1.45	2.46	39.29	30.02	53.97	17.66	24.28
	40mm	28.13	2.59	65.92	1.06	2.37	42.67	34.18	61.44	16.34	30.02
	30mm	27.63	2.45	65.83	1.00	2.24	46.31	36.84	69.58	12.85	34.52
#301 Ag	**50mm**	20.07	2.85	23.02	0.04	0.02	30.91	29.83	50.76	0.37	0.46
	40mm	19.75	1.97	25.84	0.03	0.01	34.23	31.99	60.77	0.32	0.57
	30mm	19.65	2.61	6.29	0.04	0.00	38.47	33.48	68.82	0.25	0.65
PM Fr	**50mm**	26.38	2.31	54.70	1.34	1.89	46.20	36.00	68.55	13.16	33.50
	40mm	26.23	2.35	68.63	0.86	2.19	48.93	35.95	70.35	12.09	33.85
	30mm	25.87	2.47	60.90	1.20	2.16	51.70	33.57	72.36	10.17	31.99
PM Fo	**50mm**	26.37	2.63	61.53	1.26	2.32	46.56	38.61	68.52	14.14	35.93
	40mm	25.87	2.47	60.90	1.20	2.16	49.28	38.10	71.12	12.33	36.05
	30mm	25.73	2.18	68.51	0.80	2.03	51.35	34.48	73.03	10.06	32.98
PM Ag	**50mm**	20.41	3.50	26.96	0.05	0.02	35.37	34.88	65.30	0.30	0.64
	40mm	20.09	3.41	28.79	0.05	0.03	38.65	35.52	70.46	0.25	0.69
	30mm	19.75	3.16	30.38	0.04	0.02	42.54	33.87	72.41	0.22	0.68

Table A.4.17 Comparative mean values of CIECAM02 colour appearance predictors obtained by Minolta CS-1000 tele-spectroradiometer and DigiEye System-VeriVide® (Digital Imaging) the fresh, forced aged and spontaneously aged locally-brewed beers on different depths over white background

		TSR CS-1000 Over White			DigiEye® System Over White		
Sample	**Depth**	**J**	**M**	**h_360**	**J**	**M**	**h_360**
CH Fr	**50mm**	45.86	31.52	48.88	32.54	34.12	41.13
	40mm	50.29	34.36	56.48	34.99	35.02	50.92
	30mm	54.71	35.27	65.62	37.57	36.72	62.21
CH Fo	**50mm**	49.04	31.09	56.72	31.30	32.53	36.81
	40mm	53.43	33.06	64.36	34.00	34.69	48.69
	30mm	57.40	33.14	72.70	28.7	32.68	40.76
CH Ag	**50mm**	36.44	30.67	35.43	31.5	35.78	50.84
	40mm	40.36	33.38	43.45	35.8	38.7	62.49
	30mm	45.83	36.01	53.74	36.94	36.78	60.86
CA Fr	**50mm**	48.80	32.41	55.58	34.33	35.42	47.34
	40mm	53.26	34.58	63.24	36.81	36.74	55.52
	30mm	58.03	35.21	71.61	39.25	37.15	64.40
CA Fo	**50mm**	49.71	32.21	58.37	32.95	34.69	44.52
	40mm	54.28	34.27	65.96	35.52	36.04	53.26
	30mm	59.46	35.23	74.27	31.35	36.19	50.74
CA Ag	**50mm**	40.84	34.53	44.41	34.90	39.44	61.47
	40mm	45.07	36.50	52.74	39.16	41.40	69.18
	30mm	50.82	39.07	62.52	38.20	36.67	63.47
MM Fr	**50mm**	49.44	32.80	57.19	31.54	33.05	39.09
	40mm	53.59	34.52	64.74	34.43	34.96	50.62
	30mm	57.99	34.57	72.77	36.28	34.11	59.71
MM Fo	**50mm**	47.75	29.36	55.96	32.33	32.67	42.87
	40mm	51.80	32.43	64.22	35.10	34.63	54.14
	30mm	56.32	32.95	72.49	30.97	31.94	51.46
MM Ag	**50mm**	39.55	29.99	46.33	34.61	35.43	62.28
	40mm	44.12	32.55	55.19	38.94	36.28	69.07
	30mm	49.88	34.74	64.64	37.91	34.56	62.68
CM Fr	**50mm**	45.85	32.34	46.05	36.43	33.68	53.42
	40mm	49.90	34.50	53.39	39.23	34.19	61.17
	30mm	53.69	35.21	62.43	42.19	33.35	64.88
CM Fo	**50mm**	47.29	30.60	54.10	35.15	33.12	55.83
	40mm	52.17	33.50	62.10	37.63	34.26	62.29
	30mm	57.39	33.53	70.51	33.68	33.97	59.24
CM Ag	**50mm**	42.31	31.97	51.61	37.00	36.36	67.89
	40mm	46.88	34.04	60.06	41.05	35.89	71.39
	30mm	52.07	35.23	68.56	40.86	33.20	65.58
CAr Fr	**50mm**	44.86	27.35	53.67	35.39	34.43	53.75
	40mm	49.07	29.66	61.51	37.74	34.47	61.76
	30mm	53.98	30.81	70.20	40.23	33.45	66.34
CAr Fo	**50mm**	37.76	19.55	41.68	34.73	34.13	53.97
	40mm	41.44	23.58	48.25	37.28	34.58	61.23
	30mm	46.36	27.08	57.71	33.44	32.64	58.80
CAr Ag	**50mm**	41.49	30.39	51.34	36.85	34.84	67.63
	40mm	45.90	32.34	59.77	41.01	34.59	71.04
	30mm	51.79	34.17	68.31	40.18	33.56	64.91
CF Fr	**50mm**	45.74	27.57	54.87	33.93	31.15	52.94
	40mm	50.24	30.09	62.81	36.33	32.68	61.56

	30mm	54.86	30.87	71.34	39.39	31.71	64.21
CF Fo	**50mm**	40.53	23.76	43.85	33.15	31.70	50.50
	40mm	44.43	27.12	51.39	35.74	33.53	58.63
	30mm	49.06	29.10	60.78	31.52	31.93	53.59
CF Ag	**50mm**	39.91	29.70	48.44	34.91	34.88	64.20
	40mm	44.24	31.80	57.16	39.31	35.24	70.26
	30mm	50.10	34.01	66.18	39.20	32.03	63.96
CF SP Fr	**50mm**	45.82	28.26	54.49	31.70	29.19	47.89
	40mm	50.29	30.75	62.57	34.58	31.37	57.84
	30mm	54.35	31.01	71.09	37.19	30.55	64.81
CF SP Fo	**50mm**	45.00	27.84	52.61	26.76	23.77	28.28
	40mm	49.72	30.87	60.47	29.04	26.80	37.25
	30mm	54.21	31.84	69.37	32.65	34.02	58.51
CF SP Ag	**50mm**	42.06	31.72	51.49	35.97	36.15	67.43
	40mm	46.50	33.70	59.95	40.02	35.75	72.03
	30mm	52.04	35.02	68.59	32.05	28.37	51.94
RB Fr	**50mm**	44.75	31.83	44.67	34.03	31.32	50.73
	40mm	48.94	34.49	51.86	36.92	32.63	60.20
	30mm	53.43	35.92	61.16	39.86	31.87	64.36
RB Fo	**50mm**	48.21	34.91	50.35	29.82	28.36	32.55
	40mm	52.10	36.08	57.55	32.65	31.05	44.78
	30mm	56.31	36.99	66.46	29.46	29.57	45.81
RB Ag	**50mm**	36.39	26.49	42.60	32.58	32.09	58.90
	40mm	40.70	29.09	51.83	36.88	33.55	68.26
	30mm	46.73	31.67	61.61	35.87	32.14	57.98
SIN Fr	**50mm**	43.07	25.23	50.71	32.74	30.15	48.22
	40mm	47.83	28.62	58.80	35.19	30.87	58.91
	30mm	52.13	29.27	67.83	38.14	30.75	64.04
SIN Fo	**50mm**	42.19	25.67	46.78	31.71	29.67	45.57
	40mm	46.25	28.64	54.42	34.77	31.79	56.83
	30mm	51.41	30.89	64.01	27.34	30.35	38.06
SIN Ag	**50mm**	35.00	28.00	35.48	30.07	33.54	49.38
	40mm	39.11	30.95	44.18	34.14	36.40	62.03
	30mm	44.64	33.85	54.77	37.93	31.97	65.22
#301 Fr	**50mm**	46.56	33.52	47.99	31.81	28.48	40.65
	40mm	50.49	35.29	55.39	34.67	30.78	55.46
	30mm	55.19	36.90	64.47	38.16	31.57	63.11
#301 Fo	**50mm**	44.28	30.88	45.21	30.88	28.97	37.59
	40mm	48.28	33.19	52.57	33.95	31.56	48.96
	30mm	51.98	33.62	61.60	30.91	29.83	50.76
#301Ag	**50mm**	38.70	27.23	45.87	34.23	31.99	60.77
	40mm	43.10	29.36	52.88	38.47	33.48	68.82
	30mm	49.06	32.07	63.92	37.28	32.80	62.36
PM Fr	**50mm**	52.06	31.71	64.52	37.18	32.17	60.50
	40mm	57.05	33.30	71.73	39.81	31.80	63.26
	30mm	60.67	31.87	78.77	42.50	29.49	65.99
PM Fo	**50mm**	53.00	33.35	64.69	37.57	34.39	60.82
	40mm	57.64	34.72	71.72	40.18	33.56	64.91
	30mm	62.03	34.08	78.77	42.14	30.24	67.31
PM Ag	**50mm**	44.66	32.46	58.00	35.37	34.88	65.30
	40mm	48.83	33.66	65.51	38.65	35.52	70.46
	30mm	54.79	34.78	72.72	42.5	33.87	72.41

Table A.5.1 Concentration levels of beer ageing compounds of the locally-brewed beers at fresh conditions

CARAHELL®

	FRESH		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	3.84	3.78	3.81	0.04	1.11	0.06
2-Methylbutanal	2.62	2.74	2.68	0.08	3.17	0.12
3-Methylbutanal	6.27	6.38	6.33	0.08	1.23	0.11
Pentanal	0.71	0.68	0.70	0.02	3.05	0.03
Hexanal	0.74	0.81	0.78	0.05	6.39	0.07
2-Furfural	13.64	14.06	13.85	0.30	2.14	0.41
Methional	3.04	3.11	3.08	0.05	1.61	0.07
2-Phenylethanal	17.46	17.11	17.29	0.25	1.43	0.34
(*E*)-2-nonenal	0.00	0.00	0.00	0.00	8.66	0.00
Benzaldehyde	1.38	1.29	1.34	0.06	4.77	0.09
Sum of aldehydes			**49.83**			

CARAAMBER®

	FRESH		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	4.07	4.11	4.09	0.03	0.69	0.04
2-Methylbutanal	2.88	2.91	2.90	0.02	0.73	0.03
3-Methylbutanal	6.64	6.79	6.72	0.11	1.58	0.15
Pentanal	1.00	0.94	0.97	0.04	4.37	0.06
Hexanal	1.75	1.68	1.72	0.05	2.89	0.07
2-Furfural	12.50	12.17	12.34	0.23	1.89	0.32
Methional	3.55	3.39	3.47	0.11	3.26	0.16
2-Phenylethanal	17.16	16.81	16.99	0.25	1.46	0.34
(*E*)-2-nonenal	0.00	0.00	0.00	0.00	9.43	0.00
Benzaldehyde	1.11	1.08	1.10	0.02	1.94	0.03
Sum of aldehydes			**50.27**			

MELANOIDIN MALT

	FRESH		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	4.99	4.75	4.87	0.17	3.48	0.24
2-Methylbutanal	2.50	2.61	2.56	0.08	3.04	0.11
3-Methylbutanal	6.28	6.22	6.25	0.04	0.68	0.06
Pentanal	0.71	0.64	0.68	0.05	7.33	0.07
Hexanal	1.17	1.30	1.24	0.09	7.44	0.13
2-Furfural	10.31	10.55	10.43	0.17	1.63	0.24
Methional	1.85	1.97	1.91	0.08	4.44	0.12
2-Phenylethanal	14.27	14.06	14.17	0.15	1.05	0.21
(*E*)-2-nonenal	0.01	0.01	0.01	0.00	5.05	0.00
Benzaldehyde	1.16	1.33	1.25	0.12	9.66	0.17
Sum of aldehydes			**43.34**			

CARAMUNICH® TYPE III

	FRESH		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	3.33	3.36	3.35	0.02	0.63	0.03
2-Methylbutanal	1.52	1.66	1.59	0.10	6.23	0.14
3-Methylbutanal	4.20	4.22	4.21	0.01	0.34	0.02
Pentanal	0.83	0.74	0.79	0.06	8.11	0.09
Hexanal	1.00	1.12	1.06	0.08	8.00	0.12
2-Furfural	10.30	10.88	10.59	0.41	3.87	0.57
Methional	3.91	3.72	3.82	0.13	3.52	0.19
2-Phenylethanal	10.20	10.48	10.34	0.20	1.91	0.27
(*E*)-2-nonenal	0.00	0.00	0.00	0.00	10.48	0.00
Benzaldehyde	1.50	1.28	1.39	0.16	11.19	0.22
Sum of aldehydes			**37.13**			

CARAAROMA®

	FRESH		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	3.09	3.12	3.11	0.02	0.68	0.03
2-Methylbutanal	1.87	1.95	1.91	0.06	2.96	0.08
3-Methylbutanal	4.69	4.76	4.73	0.05	1.05	0.07
Pentanal	1.02	0.81	0.92	0.15	16.23	0.21
Hexanal	1.02	1.22	1.12	0.14	12.63	0.20
2-Furfural	10.68	12.58	11.63	1.34	11.55	1.86
Methional	2.65	2.56	2.61	0.06	2.44	0.09
2-Phenylethanal	7.95	8.16	8.06	0.15	1.84	0.21
(*E*)-2-nonenal	0.00	0.00	0.00	0.00	9.43	0.00
Benzaldehyde	1.49	1.28	1.39	0.15	10.72	0.21
Sum of aldehydes			**35.45**			

CARAFA® TYPE III

	FRESH		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	2.14	2.13	2.14	0.01	0.33	0.01
2-Methylbutanal	1.21	1.46	1.34	0.18	13.24	0.24
3-Methylbutanal	2.98	3.01	3.00	0.02	0.71	0.03
Pentanal	0.73	0.81	0.77	0.06	7.35	0.08
Hexanal	1.12	1.08	1.10	0.03	2.57	0.04
2-Furfural	9.77	9.43	9.60	0.24	2.50	0.33
Methional	3.00	3.09	3.05	0.06	2.09	0.09
2-Phenylethanal	8.50	8.31	8.41	0.13	1.60	0.19
(*E*)-2-nonenal	0.00	0.00	0.00	0.00	8.32	0.00
Benzaldehyde	1.33	1.44	1.39	0.08	5.62	0.11
Sum of aldehydes			**30.77**			

CARAFA® SPECIAL TYPE III

	FRESH		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	2.33	2.40	2.37	0.05	2.09	0.07
2-Methylbutanal	1.13	1.31	1.22	0.13	10.43	0.18
3-Methylbutanal	3.26	3.15	3.21	0.08	2.43	0.11
Pentanal	1.21	0.76	0.99	0.32	32.30	0.44
Hexanal	1.65	1.70	1.68	0.04	2.11	0.05
2-Furfural	11.32	11.95	11.64	0.45	3.83	0.62
Methional	2.49	2.43	2.46	0.04	1.72	0.06
2-Phenylethanal	14.41	14.72	14.57	0.22	1.50	0.30
(*E*)-2-nonenal	0.01	0.01	0.01	0.00	6.37	0.00
Benzaldehyde	1.10	0.99	1.05	0.08	7.44	0.11
Sum of aldehydes			**39.16**			

ROASTED BARLEY

	FRESH		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	3.34	3.37	3.36	0.02	0.63	0.03
2-Methylbutanal	2.06	2.14	2.10	0.06	2.69	0.08
3-Methylbutanal	5.34	5.38	5.36	0.03	0.53	0.04
Pentanal	0.93	0.95	0.94	0.01	1.50	0.02
Hexanal	1.06	1.12	1.09	0.04	3.89	0.06
2-Furfural	9.63	10.36	10.00	0.52	5.16	0.72
Methional	2.19	2.28	2.24	0.06	2.85	0.09
2-Phenylethanal	12.10	11.91	12.01	0.13	1.12	0.19
(*E*)-2-nonenal	0.00	0.00	0.00	0.00	5.24	0.00
Benzaldehyde	1.84	1.73	1.79	0.08	4.36	0.11
Sum of aldehydes			**38.87**			

SINAMAR®

	FRESH		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	3.50	3.51	3.51	0.01	0.20	0.01
2-Methylbutanal	2.01	2.11	2.06	0.07	3.43	0.10
3-Methylbutanal	4.07	4.11	4.09	0.03	0.71	0.04
Pentanal	0.85	0.74	0.80	0.08	9.78	0.11
Hexanal	1.14	1.25	1.20	0.08	6.51	0.11
2-Furfural	7.50	7.54	7.52	0.03	0.38	0.04
Methional	2.00	2.11	2.06	0.08	3.78	0.11
2-Phenylethanal	8.58	8.86	8.72	0.20	2.27	0.27
(*E*)-2-nonenal	0.00	0.00	0.00	0.00	9.69	0.00
Benzaldehyde	1.70	1.64	1.67	0.04	2.54	0.06
Sum of aldehydes			**31.61**			

CARAMEL #301

	FRESH		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	3.74	3.88	3.81	0.10	2.60	0.14
2-Methylbutanal	2.54	2.61	2.58	0.05	1.92	0.07
3-Methylbutanal	5.96	6.16	6.06	0.14	2.33	0.20
Pentanal	0.86	0.81	0.84	0.04	4.23	0.05
Hexanal	1.21	1.18	1.20	0.02	1.78	0.03
2-Furfural	10.05	9.86	9.96	0.13	1.35	0.19
Methional	2.10	2.13	2.12	0.02	1.00	0.03
2-Phenylethanal	11.95	11.87	11.91	0.06	0.47	0.08
(*E*)-2-nonenal	0.00	0.00	0.00	0.00	18.45	0.00
Benzaldehyde	1.22	1.00	1.11	0.16	14.01	0.22
Sum of aldehydes			**39.57**			

PILSNER MALT

	FRESH		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	3.38	3.42	3.40	0.03	0.83	0.04
2-Methylbutanal	2.35	2.20	2.28	0.11	4.66	0.15
3-Methylbutanal	5.13	5.11	5.12	0.01	0.28	0.02
Pentanal	0.57	0.69	0.63	0.08	13.47	0.12
Hexanal	0.96	0.99	0.98	0.02	2.18	0.03
2-Furfural	8.91	9.42	9.17	0.36	3.93	0.50
Methional	1.67	1.51	1.59	0.11	7.12	0.16
2-Phenylethanal	11.72	11.51	11.62	0.15	1.28	0.21
(*E*)-2-nonenal	0.01	0.01	0.01	0.00	5.40	0.00
Benzaldehyde	1.76	1.54	1.65	0.16	9.43	0.22
Sum of aldehydes			**36.43**			

Table A.5.2 Concentration levels of beer ageing compounds of the locally-brewed beers at forced aged conditions

CARAHELL®

	FORCED		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	26.50	27.84	27.17	0.95	3.49	1.31
2-Methylbutanal	19.40	19.86	19.63	0.33	1.66	0.45
3-Methylbutanal	30.90	31.25	31.08	0.25	0.80	0.34
Pentanal	1.54	1.62	1.58	0.06	3.58	0.08
Hexanal	2.75	2.58	2.67	0.12	4.51	0.17
2-Furfural	229.60	230.58	230.09	0.69	0.30	0.96
Methional	9.00	9.56	9.28	0.40	4.27	0.55
2-Phenylethanal	37.80	41.25	39.53	2.44	6.17	3.38
(*E*)-2-nonenal	0.01	0.01	0.01	0.00	4.95	0.00
Benzaldehyde	3.14	3.56	3.35	0.30	8.87	0.41
Sum of aldehydes			**364.38**			

CARAAMBER®

	FORCED		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	34.90	35.19	35.05	0.21	0.59	0.28
2-Methylbutanal	6.03	6.11	6.07	0.06	1.04	0.09
3-Methylbutanal	10.58	10.36	10.47	0.16	1.49	0.22
Pentanal	1.75	1.68	1.72	0.05	2.89	0.07
Hexanal	2.08	2.18	2.13	0.07	3.32	0.10
2-Furfural	70.78	68.58	69.68	1.56	2.23	2.16
Methional	5.32	5.74	5.53	0.29	5.33	0.41
2-Phenylethanal	26.29	27.08	26.69	0.56	2.09	0.77
(*E*)-2-nonenal	0.01	0.01	0.01	0.00	3.26	0.00
Benzaldehyde	2.85	2.69	2.77	0.11	4.08	0.16
Sum of aldehydes			**160.11**			

MELANOIDIN MALT

	FORCED		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	13.50	13.11	13.31	0.28	2.07	0.38
2-Methylbutanal	5.40	5.07	5.24	0.23	4.46	0.32
3-Methylbutanal	8.60	8.99	8.80	0.28	3.14	0.38
Pentanal	1.52	1.49	1.51	0.02	1.41	0.03
Hexanal	1.87	1.95	1.91	0.06	2.96	0.08
2-Furfural	52.66	55.89	54.28	2.28	4.21	3.17
Methional	2.73	2.55	2.64	0.13	4.82	0.18
2-Phenylethanal	18.01	18.55	18.28	0.38	2.09	0.53
(*E*)-2-nonenal	0.01	0.01	0.01	0.00	6.64	0.00
Benzaldehyde	3.15	2.98	3.07	0.12	3.92	0.17
Sum of aldehydes			**109.02**			

CARAMUNICH® TYPE III

	FORCED		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	20.69	20.88	20.79	0.13	0.65	0.19
2-Methylbutanal	7.50	7.96	7.73	0.33	4.21	0.45
3-Methylbutanal	12.30	13.12	12.71	0.58	4.56	0.80
Pentanal	3.50	3.12	3.31	0.27	8.12	0.37
Hexanal	4.25	4.69	4.47	0.31	6.96	0.43
2-Furfural	70.94	71.25	71.10	0.22	0.31	0.30
Methional	4.51	4.45	4.48	0.04	0.95	0.06
2-Phenylethanal	18.93	18.11	18.52	0.58	3.13	0.80
(*E*)-2-nonenal	0.01	0.02	0.01	0.00	4.81	0.00
Benzaldehyde	3.85	3.91	3.88	0.04	1.09	0.06
Sum of aldehydes			**146.99**			

CARAAROMA®

	FORCED		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	10.35	10.11	10.23	0.17	1.66	0.24
2-Methylbutanal	3.19	3.08	3.14	0.08	2.48	0.11
3-Methylbutanal	8.08	7.95	8.02	0.09	1.15	0.13
Pentanal	1.20	1.31	1.26	0.08	6.20	0.11
Hexanal	2.89	2.78	2.84	0.08	2.74	0.11
2-Furfural	51.52	52.36	51.94	0.59	1.14	0.82
Methional	3.58	3.41	3.50	0.12	3.44	0.17
2-Phenylethanal	12.30	11.99	12.15	0.22	1.80	0.30
(*E*)-2-nonenal	0.02	0.02	0.02	0.00	1.75	0.00
Benzaldehyde	1.90	1.99	1.95	0.06	3.27	0.09
Sum of aldehydes			**95.01**			

CARAFA® TYPE III

	FORCED		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	20.04	19.97	20.01	0.05	0.25	0.07
2-Methylbutanal	5.23	5.46	5.35	0.16	3.04	0.23
3-Methylbutanal	8.52	8.78	8.65	0.18	2.13	0.25
Pentanal	1.24	1.31	1.28	0.05	3.88	0.07
Hexanal	3.01	3.15	3.08	0.10	3.21	0.14
2-Furfural	50.91	51.51	51.21	0.42	0.83	0.59
Methional	3.62	3.54	3.58	0.06	1.58	0.08
2-Phenylethanal	10.68	10.24	10.46	0.31	2.97	0.43
(*E*)-2-nonenal	0.01	0.01	0.01	0.00	3.90	0.00
Benzaldehyde	3.41	3.38	3.40	0.02	0.62	0.03
Sum of aldehydes			**107.01**			

CARAFA® SPECIAL TYPE III

	FORCED		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	18.21	18.54	18.38	0.23	1.27	0.32
2-Methylbutanal	8.33	8.54	8.44	0.15	1.76	0.21
3-Methylbutanal	6.63	6.11	6.37	0.37	5.77	0.51
Pentanal	2.39	2.56	2.48	0.12	4.86	0.17
Hexanal	3.48	3.65	3.57	0.12	3.37	0.17
2-Furfural	90.63	93.56	92.10	2.07	2.25	2.87
Methional	7.26	7.78	7.52	0.37	4.89	0.51
2-Phenylethanal	17.98	18.23	18.11	0.18	0.98	0.24
(*E*)-2-nonenal	0.01	0.01	0.01	0.00	3.60	0.00
Benzaldehyde	4.59	4.89	4.74	0.22	4.55	0.30
Sum of aldehydes			**161.69**			

ROASTED BARLEY

	FORCED		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	12.40	12.36	12.38	0.03	0.23	0.04
2-Methylbutanal	8.00	7.85	7.93	0.11	1.34	0.15
3-Methylbutanal	9.89	10.33	10.11	0.31	3.08	0.43
Pentanal	1.64	1.87	1.76	0.16	9.27	0.23
Hexanal	2.19	2.00	2.10	0.13	6.41	0.19
2-Furfural	71.36	71.52	71.44	0.11	0.16	0.16
Methional	11.00	11.26	11.13	0.18	1.65	0.25
2-Phenylethanal	20.30	20.61	20.46	0.22	1.07	0.30
(*E*)-2-nonenal	0.02	0.02	0.02	0.00	3.14	0.00
Benzaldehyde	5.01	4.89	4.95	0.08	1.71	0.12
Sum of aldehydes			**142.26**			

SINAMAR®

	FORCED		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	18.55	19.14	18.85	0.42	2.21	0.58
2-Methylbutanal	11.44	11.75	11.60	0.22	1.89	0.30
3-Methylbutanal	19.28	19.88	19.58	0.42	2.17	0.59
Pentanal	1.60	1.54	1.57	0.04	2.70	0.06
Hexanal	2.62	2.88	2.75	0.18	6.69	0.25
2-Furfural	57.80	58.20	58.00	0.28	0.49	0.39
Methional	3.21	3.85	3.53	0.45	12.82	0.63
2-Phenylethanal	17.70	18.18	17.94	0.34	1.89	0.47
(*E*)-2-nonenal	0.01	0.01	0.01	0.00	8.00	0.00
Benzaldehyde	2.99	3.08	3.04	0.06	2.10	0.09
Sum of aldehydes			**136.86**			

CARAMEL #301

	FORCED		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	10.58	11.22	10.90	0.45	4.15	0.63
2-Methylbutanal	7.78	8.05	7.92	0.19	2.41	0.26
3-Methylbutanal	12.36	12.66	12.51	0.21	1.70	0.29
Pentanal	1.56	1.77	1.67	0.15	8.92	0.21
Hexanal	3.00	3.41	3.21	0.29	9.05	0.40
2-Furfural	87.63	88.97	88.30	0.95	1.07	1.31
Methional	4.85	4.71	4.78	0.10	2.07	0.14
2-Phenylethanal	18.32	18.08	18.20	0.17	0.93	0.24
(*E*)-2-nonenal	0.02	0.02	0.02	0.00	2.85	0.00
Benzaldehyde	3.85	4.08	3.97	0.16	4.10	0.23
Sum of aldehydes			**151.46**			

PILSNER MALT

	FORCED		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	17.99	17.41	17.70	0.41	2.32	0.57
2-Methylbutanal	6.50	6.89	6.70	0.28	4.12	0.38
3-Methylbutanal	13.20	13.56	13.38	0.25	1.90	0.35
Pentanal	1.24	1.18	1.21	0.04	3.51	0.06
Hexanal	2.88	2.54	2.71	0.24	8.87	0.33
2-Furfural	58.94	60.32	59.63	0.98	1.64	1.35
Methional	3.50	3.41	3.46	0.06	1.84	0.09
2-Phenylethanal	18.20	20.32	19.26	1.50	7.78	2.08
(*E*)-2-nonenal	0.01	0.02	0.01	0.00	4.31	0.00
Benzaldehyde	3.25	3.14	3.20	0.08	2.43	0.11
Sum of aldehydes			**127.25**			

Table A.5.3 Concentration levels of beer ageing compounds of the locally-brewed beers at spontaneously aged conditions

CARAHELL®

	AGED		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	43.38	43.12	43.25	0.18	0.43	0.25
2-Methylbutanal	25.41	25.31	25.36	0.07	0.28	0.10
3-Methylbutanal	41.14	41.63	41.39	0.35	0.84	0.48
Pentanal	2.35	2.14	2.25	0.15	6.61	0.21
Hexanal	4.93	4.75	4.84	0.13	2.63	0.18
2-Furfural	373.25	370.14	371.70	2.20	0.59	3.05
Methional	13.95	13.68	13.82	0.19	1.38	0.26
2-Phenylethanal	72.56	72.33	72.45	0.16	0.22	0.23
(*E*)-2-nonenal	0.04	0.04	0.04	0.00	3.82	0.00
Benzaldehyde	5.86	5.94	5.90	0.06	0.96	0.08
Sum of aldehydes			**580.97**			

CARAAMBER®

	AGED		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	49.24	48.87	49.06	0.26	0.53	0.36
2-Methylbutanal	9.51	9.78	9.65	0.19	1.98	0.26
3-Methylbutanal	13.04	13.56	13.30	0.37	2.76	0.51
Pentanal	2.09	2.35	2.22	0.18	8.28	0.25
Hexanal	3.18	3.34	3.26	0.11	3.47	0.16
2-Furfural	105.21	106.08	105.65	0.62	0.58	0.85
Methional	8.74	8.54	8.64	0.14	1.64	0.20
2-Phenylethanal	41.80	40.85	41.33	0.67	1.63	0.93
(*E*)-2-nonenal	0.04	0.05	0.04	0.00	8.32	0.00
Benzaldehyde	4.44	4.21	4.33	0.16	3.76	0.23
Sum of aldehydes			**237.46**			

MELANOIDIN MALT

	AGED		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	23.96	23.47	23.72	0.35	1.46	0.48
2-Methylbutanal	7.80	7.59	7.70	0.15	1.93	0.21
3-Methylbutanal	15.84	15.69	15.77	0.11	0.67	0.15
Pentanal	2.60	2.75	2.68	0.11	3.97	0.15
Hexanal	3.88	3.74	3.81	0.10	2.60	0.14
2-Furfural	66.83	67.14	66.99	0.22	0.33	0.30
Methional	3.80	3.41	3.61	0.28	7.65	0.38
2-Phenylethanal	21.48	21.36	21.42	0.08	0.40	0.12
(*E*)-2-nonenal	0.03	0.03	0.03	0.00	6.73	0.00
Benzaldehyde	4.10	4.26	4.18	0.11	2.71	0.16
Sum of aldehydes			**149.88**			

CARAMUNICH® TYPE III

	AGED		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	33.80	33.25	33.53	0.39	1.16	0.54
2-Methylbutanal	15.72	16.11	15.92	0.28	1.73	0.38
3-Methylbutanal	26.58	26.13	26.36	0.32	1.21	0.44
Pentanal	4.80	4.15	4.48	0.46	10.27	0.64
Hexanal	8.07	8.01	8.04	0.04	0.53	0.06
2-Furfural	152.00	148.56	150.28	2.43	1.62	3.37
Methional	5.17	5.26	5.22	0.06	1.22	0.09
2-Phenylethanal	26.29	26.85	26.57	0.40	1.49	0.55
(*E*)-2-nonenal	0.03	0.04	0.03	0.00	8.57	0.00
Benzaldehyde	6.68	6.48	6.58	0.14	2.15	0.20
Sum of aldehydes			**276.99**			

CARAAROMA®

	AGED		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	14.27	14.89	14.58	0.44	3.01	0.61
2-Methylbutanal	5.51	5.66	5.59	0.11	1.90	0.15
3-Methylbutanal	13.45	13.99	13.72	0.38	2.78	0.53
Pentanal	3.39	3.55	3.47	0.11	3.26	0.16
Hexanal	5.18	5.28	5.23	0.07	1.35	0.10
2-Furfural	123.61	122.89	123.25	0.51	0.41	0.71
Methional	4.99	5.14	5.07	0.11	2.09	0.15
2-Phenylethanal	14.82	15.23	15.03	0.29	1.93	0.40
(*E*)-2-nonenal	0.03	0.04	0.03	0.00	14.35	0.01
Benzaldehyde	3.34	3.56	3.45	0.16	4.51	0.22
Sum of aldehydes			**189.41**			

CARAFA® TYPE III

	AGED		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	23.25	23.69	23.47	0.31	1.33	0.43
2-Methylbutanal	11.56	11.23	11.40	0.23	2.05	0.32
3-Methylbutanal	16.47	16.69	16.58	0.16	0.94	0.22
Pentanal	2.08	2.15	2.12	0.05	2.34	0.07
Hexanal	5.14	5.45	5.30	0.22	4.14	0.30
2-Furfural	100.50	101.65	101.08	0.81	0.80	1.13
Methional	4.16	4.25	4.21	0.06	1.51	0.09
2-Phenylethanal	25.60	25.14	25.37	0.33	1.28	0.45
(*E*)-2-nonenal	0.04	0.04	0.04	0.00	0.92	0.00
Benzaldehyde	7.77	7.54	7.66	0.16	2.12	0.23
Sum of aldehydes			**197.20**			

CARAFA® SPECIAL TYPE III

	AGED		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	19.39	19.02	19.21	0.26	1.36	0.36
2-Methylbutanal	12.60	12.32	12.46	0.20	1.59	0.27
3-Methylbutanal	12.26	12.31	12.29	0.04	0.29	0.05
Pentanal	4.64	4.57	4.61	0.05	1.07	0.07
Hexanal	6.18	6.23	6.21	0.04	0.57	0.05
2-Furfural	124.96	125.47	125.22	0.36	0.29	0.50
Methional	16.71	16.21	16.46	0.35	2.15	0.49
2-Phenylethanal	21.31	21.11	21.21	0.14	0.67	0.20
(*E*)-2-nonenal	0.03	0.03	0.03	0.00	8.84	0.00
Benzaldehyde	11.41	11.25	11.33	0.11	1.00	0.16
Sum of aldehydes			**229.01**			

ROASTED BARLEY

	AGED		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	19.16	19.11	19.14	0.04	0.18	0.05
2-Methylbutanal	9.67	9.85	9.76	0.13	1.30	0.18
3-Methylbutanal	15.36	15.47	15.42	0.08	0.50	0.11
Pentanal	3.41	3.24	3.33	0.12	3.62	0.17
Hexanal	4.67	4.57	4.62	0.07	1.53	0.10
2-Furfural	93.82	94.14	93.98	0.23	0.24	0.31
Methional	14.39	14.21	14.30	0.13	0.89	0.18
2-Phenylethanal	37.54	37.87	37.71	0.23	0.62	0.32
(*E*)-2-nonenal	0.19	0.18	0.18	0.00	2.32	0.01
Benzaldehyde	9.39	9.31	9.35	0.06	0.61	0.08
Sum of aldehydes			**207.77**			

SINAMAR®

	AGED		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	22.07	22.36	22.22	0.21	0.92	0.28
2-Methylbutanal	16.60	16.14	16.37	0.33	1.99	0.45
3-Methylbutanal	23.70	22.85	23.28	0.60	2.58	0.83
Pentanal	2.23	2.20	2.22	0.02	0.96	0.03
Hexanal	4.14	4.28	4.21	0.10	2.35	0.14
2-Furfural	62.85	63.41	63.13	0.40	0.63	0.55
Methional	5.56	5.38	5.47	0.13	2.33	0.18
2-Phenylethanal	27.11	27.45	27.28	0.24	0.88	0.33
(*E*)-2-nonenal	0.04	0.03	0.04	0.00	9.96	0.00
Benzaldehyde	5.09	5.01	5.05	0.06	1.12	0.08
Sum of aldehydes			**169.25**			

CARAMEL #301

	AGED		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	26.18	26.07	26.13	0.08	0.30	0.11
2-Methylbutanal	17.36	17.15	17.26	0.15	0.86	0.21
3-Methylbutanal	30.62	30.14	30.38	0.34	1.12	0.47
Pentanal	3.77	3.68	3.73	0.06	1.71	0.09
Hexanal	6.58	6.47	6.53	0.08	1.19	0.11
2-Furfural	125.19	125.99	125.59	0.57	0.45	0.78
Methional	10.31	10.41	10.36	0.07	0.68	0.10
2-Phenylethanal	20.80	21.35	21.08	0.39	1.85	0.54
(*E*)-2-nonenal	0.12	0.12	0.12	0.00	1.78	0.00
Benzaldehyde	9.65	9.54	9.60	0.08	0.81	0.11
Sum of aldehydes			**250.75**			

PILSNER MALT

	AGED		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	30.12	30.52	30.32	0.28	0.93	0.39
2-Methylbutanal	11.98	11.84	11.91	0.10	0.83	0.14
3-Methylbutanal	22.91	23.08	23.00	0.12	0.52	0.17
Pentanal	2.33	2.45	2.39	0.08	3.55	0.12
Hexanal	5.48	5.44	5.46	0.03	0.52	0.04
2-Furfural	76.65	76.14	76.40	0.36	0.47	0.50
Methional	5.15	5.21	5.18	0.04	0.82	0.06
2-Phenylethanal	34.50	34.08	34.29	0.30	0.87	0.41
(*E*)-2-nonenal	0.05	0.05	0.05	0.00	4.29	0.00
Benzaldehyde	5.35	5.21	5.28	0.10	1.87	0.14
Sum of aldehydes			**194.27**			

Table A.6.1 Correlation values between colour appearance predictors and beer ageing compounds of the fresh, forced aged and spontaneously aged locally-brewed beers

Variables	**Fresh**	**Forced**	**Aged**
Lv vs 2-Methylpropanal	0.29	0.25	0.04
Cv vs 2-Methylpropanal	0.44	0.07	0.22
hv vs 2-Methylpropanal	0.54	0.06	0.13
Opv vs 2-Methylpropanal	0.22	0.02	0.28
Clv vs 2-Methylpropanal	0.46	0.01	0.40
J_TSR (highball) vs 2-Methylpropanal	0.38	0.03	0.09
M_TSR (highball) vs 2-Methylpropanal	0.44	0.07	0.23
h_TSR (highball) vs 2-Methylpropanal	0.45	0.06	0.23
J_TSR (cell) vs 2-Methylpropanal	0.00	0.26	0.05
M_TSR (cell) vs 2-Methylpropanal	0.04	0.36	0.00
h_TSR (cell) vs 2-Methylpropanal	0.02	0.16	0.10
J_DIG (cell) vs 2-Methylpropanal	**0.66**	0.00	0.00
M_DIG (cell) vs 2-Methylpropanal	0.08	0.01	0.10
h_DIG (cell) vs 2-Methylpropanal	0.03	0.00	0.00
Lv vs 2-Methylbutanal	0.11	0.12	0.09
Cv vs 2-Methylbutanal	0.28	0.23	0.26
hv vs 2-Methylbutanal	0.36	0.29	0.16
Opv vs 2-Methylbutanal	0.11	0.19	0.09
Clv vs 2-Methylbutanal	0.27	0.17	0.11
J_TSR (highball) vs 2-Methylbutanal	0.14	0.12	0.19
M_TSR (highball) vs 2-Methylbutanal	0.52	0.23	0.03
h_TSR (highball) vs 2-Methylbutanal	0.21	0.29	0.52
J_TSR (cell) vs 2-Methylbutanal	0.00	0.00	0.00
M_TSR (cell) vs 2-Methylbutanal	0.05	0.01	0.16
h_TSR (cell) vs 2-Methylbutanal	0.02	0.01	0.00
J_DIG (cell) vs 2-Methylbutanal	0.03	0.00	0.00
M_DIG (cell) vs 2-Methylbutanal	**0.67**	0.18	0.24
h_DIG (cell) vs 2-Methylbutanal	0.08	0.00	0.00
Lv vs 3-Methylbutanal	0.11	0.01	0.03
Cv vs 3-Methylbutanal	0.28	0.09	0.17
hv vs 3-Methylbutanal	0.35	0.13	0.12
Opv vs 3-Methylbutanal	0.07	0.03	0.11
Clv vs 3-Methylbutanal	0.23	0.02	0.12
J_TSR (highball) vs 3-Methylbutanal	0.16	0.01	0.14
M_TSR (highball) vs 3-Methylbutanal	0.49	0.09	0.08
h_TSR (highball) vs 3-Methylbutanal	0.25	0.13	0.50
J_TSR (cell) vs 3-Methylbutanal	0.00	0.01	0.00
M_TSR (cell) vs 3-Methylbutanal	0.04	0.04	0.13
h_TSR (cell) vs 3-Methylbutanal	0.02	0.00	0.02
J_DIG (cell) vs 3-Methylbutanal	0.02	0.00	0.02
M_DIG (cell) vs 3-Methylbutanal	**0.65**	0.13	0.09
h_DIG (cell) vs 3-Methylbutanal	0.08	0.00	0.03
Lv vs Benzaldehyde	0.13	0.06	0.01
Cv vs Benzaldehyde	0.10	0.02	0.06
hv vs Benzaldehyde	0.08	0.04	0.06
Opv vs Benzaldehyde	0.16	0.16	0.06
Clv vs Benzaldehyde	0.05	0.12	0.18
J_TSR (highball) vs Benzaldehyde	0.12	0.06	0.02
M_TSR (highball) vs Benzaldehyde	0.23	0.02	0.19
h_TSR (highball) vs Benzaldehyde	0.18	0.04	0.02
J_TSR (cell) vs Benzaldehyde	0.00	0.00	0.00

M_TSR (cell) vs Benzaldehyde	**0.67**	0.00	0.16
h_TSR (cell) vs Benzaldehyde	0.09	0.01	0.03
J_DIG (cell) vs Benzaldehyde	0.03	0.00	0.01
M_DIG (cell) vs Benzaldehyde	**0.67**	0.17	0.23
h_DIG (cell) vs Benzaldehyde	0.09	0.00	0.01
Lv vs 2-Phenylethanal	0.33	0.08	0.06
Cv vs 2-Phenylethanal	0.43	0.02	0.35
hv vs 2-Phenylethanal	0.40	0.19	0.36
Opv vs 2-Phenylethanal	0.18	0.02	0.31
Clv vs 2-Phenylethanal	0.16	0.02	0.33
J_TSR (highball) vs 2-Phenylethanal	0.31	0.08	0.28
M_TSR (highball) vs 2-Phenylethanal	0.38	0.21	0.00
h_TSR (highball) vs 2-Phenylethanal	0.42	0.19	**0.72**
J_TSR (cell) vs 2-Phenylethanal	0.00	0.03	0.01
M_TSR (cell) vs 2-Phenylethanal	0.01	0.10	0.01
h_TSR (cell) vs 2-Phenylethanal	0.01	0.01	0.11
J_DIG (cell) vs 2-Phenylethanal	0.00	0.01	0.07
M_DIG (cell) vs 2-Phenylethanal	0.58	0.06	0.01
h_DIG (cell) vs 2-Phenylethanal	0.02	0.02	0.12
Lv vs Pentanal	0.00	0.07	0.01
Cv vs Pentanal	0.02	0.05	0.27
hv vs Pentanal	0.03	0.05	0.20
Opv vs Pentanal	0.00	0.14	0.27
Clv vs Pentanal	0.01	0.15	0.34
J_TSR (highball) vs Pentanal	0.01	0.07	0.14
M_TSR (highball) vs Pentanal	0.03	0.05	0.09
h_TSR (highball) vs Pentanal	0.03	0.05	0.12
J_TSR (cell) vs Pentanal	0.00	0.00	0.01
M_TSR (cell) vs Pentanal	0.05	0.00	0.15
h_TSR (cell) vs Pentanal	0.02	0.01	0.04
J_DIG (cell) vs Pentanal	0.03	0.00	0.01
M_DIG (cell) vs Pentanal	**0.67**	0.17	0.22
h_DIG (cell) vs Pentanal	0.09	0.00	0.01
Lv vs Hexanal	0.05	0.02	0.14
Cv vs Hexanal	0.02	0.04	0.30
hv vs Hexanal	0.01	0.03	0.37
Opv vs Hexanal	0.10	0.03	0.39
Clv vs Hexanal	0.07	0.03	0.42
J_TSR (highball) vs Hexanal	0.03	0.02	0.20
M_TSR (highball) vs Hexanal	0.00	0.04	0.27
h_TSR (highball) vs Hexanal	0.02	0.03	0.05
J_TSR (cell) vs Hexanal	0.00	0.00	0.00
M_TSR (cell) vs Hexanal	0.05	0.00	0.14
h_TSR (cell) vs Hexanal	0.02	0.01	0.03
J_DIG (cell) vs Hexanal	0.03	0.00	0.01
M_DIG (cell) vs Hexanal	**0.67**	0.17	0.21
h_DIG (cell) vs Hexanal	0.09	0.00	0.01
Lv vs Methional	0.01	0.23	0.05
Cv vs Methional	0.00	0.23	0.02
hv vs Methional	0.00	0.00	0.00
Opv vs Methional	**0.67**	0.00	0.16
Clv vs Methional	0.09	0.01	0.03
J_TSR (highball) vs Methional	0.03	0.00	0.01
M_TSR (highball) vs Methional	**0.67**	0.17	0.23
h_TSR (highball) vs Methional	0.09	0.00	0.01
J_TSR (cell) vs Methional	0.33	0.08	0.06
M_TSR (cell) vs Methional	0.43	0.02	0.35

h_TSR (cell) vs Methional	0.40	0.19	0.36
J_DIG (cell) vs Methional	0.18	0.02	0.31
M_DIG (cell) vs Methional	0.16	0.02	0.33
h_DIG (cell) vs Methional	0.31	0.08	0.28
Lv vs (*E*)-2-Nonenal	0.38	0.21	0.00
Cv vs (*E*)-2-Nonenal	0.42	0.19	**0.72**
hv vs (*E*)-2-Nonenal	0.00	0.03	0.01
Opv vs (*E*)-2-Nonenal	0.01	0.10	0.01
Clv vs (*E*)-2-Nonenal	0.01	0.01	0.11
J_TSR (highball) vs (*E*)-2-Nonenal	0.00	0.01	0.07
M_TSR (highball) vs (*E*)-2-Nonenal	0.58	0.06	0.01
h_TSR (highball) vs (*E*)-2-Nonenal	0.02	0.02	0.12
J_TSR (cell) vs (*E*)-2-Nonenal	0.00	0.07	0.01
M_TSR (cell) vs (*E*)-2-Nonenal	0.02	0.05	0.27
h_TSR (cell) vs (*E*)-2-Nonenal	0.03	0.05	0.20
J_DIG (cell) vs (*E*)-2-Nonenal	0.00	0.14	0.27
M_DIG (cell) vs (*E*)-2-Nonenal	0.01	0.15	0.34
h_DIG (cell) vs (*E*)-2-Nonenal	0.01	0.07	0.14
Lv vs 2-Furfural	0.03	0.05	0.09
Cv vs 2-Furfural	0.03	0.05	0.12
hv vs 2-Furfural	0.00	0.00	0.01
Opv vs 2-Furfural	0.05	0.00	0.15
Clv vs 2-Furfural	0.02	0.01	0.04
J_TSR (highball) vs 2-Furfural	0.03	0.00	0.01
M_TSR (highball) vs 2-Furfural	**0.67**	0.17	0.22
h_TSR (highball) vs 2-Furfural	0.09	0.00	0.01
J_TSR (cell) vs 2-Furfural	0.05	0.02	0.14
M_TSR (cell) vs 2-Furfural	0.02	0.04	0.30
h_TSR (cell) vs 2-Furfural	0.01	0.03	0.37
J_DIG (cell) vs 2-Furfural	0.10	0.03	0.39
M_DIG (cell) vs 2-Furfural	0.07	0.03	0.42
h_DIG (cell) vs 2-Furfural	0.03	0.02	0.20
Lv vs Sum of aldehydes	-0.55	-0.33	-0.39
Mv vs Sum of aldehydes	**0.65**	0.45	0.47
hv vs Sum of aldehydes	**-0.73**	-0.56	-0.46
Opv vs Sum of aldehydes	0.35	0.26	0.48
Clv vs Sum of aldehydes	-0.44	-0.23	-0.45
J_TSR (highball) vs Sum of aldehydes	-0.49	-0.34	-0.53
M_TSR (highball) vs Sum of aldehydes	**0.77**	0.41	-0.16
h_TSR (highball) vs Sum of aldehydes	**-0.62**	-0.40	**-0.90**
J_TSR (cell) vs Sum of aldehydes	0.34	0.35	0.16
M_TSR (cell) vs Sum of aldehydes	**0.66**	0.31	0.20
h_TSR (cell) vs Sum of aldehydes	-0.05	0.32	-0.47
J_DIG (cell) vs Sum of aldehydes	-0.31	-0.28	-0.05
M_DIG (cell) vs Sum of aldehydes	**0.60**	0.06	0.25
h_DIG (cell) vs Sum of aldehydes	**-0.65**	-0.36	-0.41

Marked correlations are significant at p<0.05

Table A.7.1 Concentration levels of organic radical in whole grain of CARAHELL® (whole grain measurement)

Marker **1.89E-07 Mmol**

Name	Weight (g)	Intensity Food	Intensity Marker	Food/marker/Weight	Mean	Stdev. (Sx)
carahell_grain1_1	0.0944	105273.00	306878.00	3.633952531	3.66	0.133
carahell_grain1_2	0.0944	104852.00	306878.00	3.619419896		
carahell_grain1_3	0.0944	99404.00	297142.00	3.543788743		
carahell_grain1_4	0.0944	105980.00	291352.00	3.853309713		
carahell_grain2_1	0.0822	96215.00	384340.00	3.045477399	3.09	0.038
carahell_grain2_2	0.0822	96526.00	378839.00	3.099686776		
carahell_grain2_3	0.0822	96192.00	375283.00	3.118230717		
carahell_grain3_1	0.0699	102314.00	313681.00	4.666267958	4.62	0.041
carahell_grain3_2	0.0699	100133.00	312399.00	4.585539271		
carahell_grain3_3	0.0699	101073.00	313235.00	4.616232749		

%Stdev.	Grand Mean	Stdev. (Sx)	%Stdev.	mmol/g org radicals
3.63	3.79	0.775	20.45	**7.17E-07**
1.22				
0.88				

Table A.7.2 Concentration levels of organic radical in whole grain of CARAAMBER® (whole grain measurement)

Marker **1.89E-07 mmol**

Name	Weight (g)	Intensity Food	Intensity Marker	Food/marker/Weight	Mean	Stdev. (Sx)
caraamber_grain_1_1	0.0802	148216.7	447779.0	4.1272	4.14	0.047
caraamber_grain_1_2	0.0802	150571.3	447231.7	4.1979		
caraamber_grain_1_3	0.0802	147389.3	447402.3	4.1076		
caraamber_grain_2_1	0.0674	114547.0	472334.0	3.5981	3.57	0.068
caraamber_grain_2_2	0.0674	111016.7	471045.7	3.4968		
caraamber_grain_2_3	0.0674	113869.3	465861.3	3.6265		
caraamber_grain_3_1	0.0754	132559.3	465353.0	3.778	3.79	0.018
caraamber_grain_3_2	0.0754	134264.7	466980.7	3.8132		
caraamber_grain_3_3	0.0754	133631.0	467301.0	3.7926		
caraamber_grain_4_1	0.0775	118789.3	617208.0	2.4834	2.68	0.220
caraamber_grain_4_2	0.0775	138618.3	614680.0	2.9098		
caraamber_grain_4_3	0.0775	124941.3	617753.7	2.6097		

%Stdev.	Grand Mean	Stdev. (Sx)	%Stdev.	mmol/g org radicals
1.15	3.54	0.630	17.78	**6.71E-07**
1.91				
0.47				
8.21				

Table A.7.3 Concentration levels of organic radical in whole grain of melanoidin malt (whole grain measurement)

Marker **1.89E-07 mmol**

Name	Weight (g)	Intensity Food	Intensity Marker	Food/marker/Weight	Mean	Stdev. (Sx)
melanoidin_grain_1_1	0.0886	63242.0	530407.0	1.3457	1.51	0.113
melanoidin_grain_1_2	0.0886	67458.3	526361.7	1.4465		
melanoidin_grain_1_3	0.0886	77597.0	524760.7	1.669		
melanoidin_grain_1_4	0.0886	71803.3	520579.7	1.5568		
melanoidin_grain_1_5	0.0886	65055.7	501610.0	1.4638		
melanoidin_grain_1_6	0.0886	70676.3	507876.0	1.5707		
melanoidin_grain_2_1	0.0732	40967.0	461056.0	1.2139	1.11	0.127
melanoidin_grain_2_2	0.0732	32704.0	456053.7	0.9797		
melanoidin_grain_2_3	0.0732	34177.3	454135.3	1.0281		
melanoidin_grain_2_3	0.0732	40518.0	450216.0	1.2295		
melanoidin_grain_3_1	0.0944	58415.0	420540.3	1.4714	1.55	0.063
melanoidin_grain_3_2	0.0944	62073.7	416344.3	1.5794		
melanoidin_grain_3_4	0.0944	63815.7	417000.3	1.6211		
melanoidin_grain_3_4	0.0944	60478.3	414417.3	1.5459		

%Stdev.	Grand Mean	Stdev. (Sx)	%Stdev.	mmol/g org radicals
7.52	1.39	0.242	17.4	**2.63E-07**
11.45				
4.07				

Table A.7.4 Concentration levels of organic radical in whole grain of CARAMUNICH® Type III (whole grain measurement)

Marker **1.89E-07 mmol**

Name	Weight (g)	Intensity Food	Intensity Marker	Food/marker/Weight	Mean	Stdev. (Sx)
caramunichIII_grain_1_1	0.0855	228667.7	456740.3	5.8556	5.24	0.436
caramunichIII_grain_1_2	0.0855	178170.0	448573.7	4.6455		
caramunichIII_grain_1_3	0.0855	206257.7	448464.3	5.3792		
caramunichIII_grain_1_4	0.0855	194398.0	438903.3	5.1803		
caramunichIII_grain_1_5	0.0855	195953.7	444530.3	5.1557		
caramunichIII_grain_2_1	0.0843	223971.7	468417.7	5.6719	5.51	0.111
caramunichIII_grain_2_2	0.0843	217019.7	468509.3	5.4948		
caramunichIII_grain_2_3	0.0843	216474.3	467167.7	5.4968		
caramunichIII_grain_2_4	0.0843	211546.0	464291.0	5.4049		
caramunichIII_grain_3_1	0.0818	226962.0	610900.7	4.5418	4.42	0.078
caramunichIII_grain_3_2	0.0843	225262.0	612446.3	4.3631		
caramunichIII_grain_3_3	0.0843	226544.3	608432.7	4.4169		
caramunichIII_grain_3_4	0.0843	224720.7	606838.0	4.3928		
caramunichIII_grain_4_1	0.0894	233915.0	470443.3	5.5618	5.60	0.141
caramunichIII_grain_4_2	0.0894	225097.0	464172.3	5.4244		
caramunichIII_grain_4_3	0.0894	238738.0	464580.7	5.7481		
caramunichIII_grain_4_4	0.0894	236523.3	466048.0	5.6768		

%Stdev.	Grand Mean	Stdev. (Sx)	%Stdev.	mmol/g org radicals
8.326	5.18	0.535	10.3	**9.83E-07**
2.025				
1.774				
2.526				

Table A.7.5 Concentration levels of organic radical in whole grain of CARAAROMA® (whole grain measurement)

Marker **1.89E-07 mmol**

Name	Weight (g)	Intensity Food	Intensity Marker	Food/marker/Weight	Mean	Stdev. (Sx)
caraaroma_grain_1_1	0.0815	322637.0	484326.0	8.1737	7.87	0.201
caraaroma_grain_1_2	0.0815	302113.0	477845.3	7.7575		
caraaroma_grain_1_3	0.0815	301029.3	474698.0	7.781		
caraaroma_grain_1_4	0.0815	299661.7	472840.3	7.776		
caraaroma_grain_2_1	0.0972	519958.0	600900.7	8.9022	9.39	0.321
caraaroma_grain_2_2	0.0972	559868.0	593719.7	9.7015		
caraaroma_grain_2_3	0.0972	527760.0	587219.3	9.2463		
caraaroma_grain_2_4	0.0972	548491.0	587868.0	9.5989		
caraaroma_grain_2_5	0.0972	544353.0	588874.7	9.5102		
caraaroma_grain_3_1	0.0831	354688.3	503384.7	8.479	8.41	0.062
caraaroma_grain_3_2	0.0831	354045.7	506107.3	8.4181		
caraaroma_grain_3_3	0.0831	349285.3	503110.0	8.3544		
caraaroma_grain_4_1	0.0673	417833.3	656258.3	9.4605	9.61	0.187
caraaroma_grain_4_2	0.0673	418628.7	655282.0	9.4926		
caraaroma_grain_4_3	0.0673	431473.0	653272.7	9.814		
caraaroma_grain_4_4	0.0673	433883.0	656122.0	9.8259		
caraaroma_grain_4_5	0.0673	415945.7	651534.7	9.486		

%Stdev.	Grand Mean	Stdev. (Sx)	%Stdev.	mmol/g org radicals
2.5	8.82	0.821	9.3	**1.67E-06**
3.4				
0.7				
1.9				

Table A.7.6 Concentration levels of organic radical in whole grain of CARAFA® Type III (whole grain measurement)

Marker **1.89E-07 mmol**

Name	Weight (g)	Intensity Food	Intensity Marker	Food/marker/Weight	Mean	Stdev
carafa_grain_1_1	0.0785	4240334.5	427848.7	126.2526	127.07	1.886
carafa_grain_1_2	0.0785	4206761.0	426177.0	125.7443		
carafa_grain_1_3	0.0785	4211170.5	415096.0	129.2363		
carafa_grain_2_1	0.067	5417097.5	551037.3	146.7273	147.93	0.856
carafa_grain_2_1	0.067	5400435.5	546985.0	147.3596		
carafa_grain_2_2	0.067	5400008.0	542751.7	148.4973		
carafa_grain_2_3	0.067	5391590.0	540995.0	148.7472		
carafa_grain_2_4	0.067	5391103.0	542411.7	148.3453		
carafa_grain_3_1	0.0833	4759085.5	426157.7	134.0628	134.82	0.857
carafa_grain_3_2	0.0833	4806349.5	425033.3	135.7523		
carafa_grain_3_3	0.0833	4738509.5	422460.7	134.6513		
carafa_grain_4_1	0.074	3309807.0	474713.3	94.2192	94.45	0.200
carafa_grain_4_2	0.074	3308155.3	472736.7	94.566		
carafa_grain_4_3	0.074	3299713.0	471529.7	94.5661		
carafa_grain_5_1	0.0786	4228846.5	463557.3	116.0636	116.23	0.512
carafa_grain_5_2	0.0786	4241176.5	465698.0	115.8669		
carafa_grain_5_3	0.0786	4239361.5	461021.7	116.9921		
carafa_grain_5_4	0.0786	4233857.5	464305.7	116.0138		

%Stdev.	Grand Mean	Stdev.	%Stdev.	mmol/g org radicals
1.484580226	124.10	20.204	16.3	**2.34E-05**
0.578915009				
0.636102882				
0.212020146				
0.440650009				

Table A.7.7 Concentration levels of organic radical in whole grain of CARAFA® SPECIAL Type III (whole grain measurement)

Marker **1.8916E-07 mmol**

Name	Weight (g)	Intensity Food	Intensity Marker	Food/marker/Weight	Mean
Carafaspecial_grain_1_1	0.0963	5099431.5	401336.3	131.9432	133.99
Carafaspecial_grain_1_2	0.0963	5055050.0	392042.0	133.8957	
Carafaspecial_grain_1_3	0.0963	5091371.5	392971.7	134.5387	
Carafaspecial_grain_1_4	0.0963	5088235.5	389600.7	135.6192	
Carafaspecial_grain_2_1	0.0723	3437076.3	422206.0	112.5969	113.57
Carafaspecial_grain_2_2	0.0723	3490173.0	424361.3	113.7556	
Carafaspecial_grain_2_3	0.0723	3488905.3	423169.7	114.0345	
Carafaspecial_grain_2_4	0.0723	3484210.8	423049.7	113.9134	
Carafaspecial_grain_3_1	0.0715	5562626.5	566623.7	137.3027	138.81
Carafaspecial_grain_3_2	0.0715	5651421.5	568545.3	139.023	
Carafaspecial_grain_3_3	0.0715	5644936.0	567409.0	139.1415	
Carafaspecial_grain_3_4	0.0715	5642541.5	564531.3	139.7915	
Carafaspecial_grain_4_1	0.0711	3094932.8	410956.0	105.922	106.41
Carafaspecial_grain_4_2	0.0711	3122187.0	409282.3	107.2917	
Carafaspecial_grain_4_3	0.0711	3078881.8	408447.0	106.02	
Carafaspecial_grain_6_1	0.0699	3978654.3	423215.0	134.4925	134.83
Carafaspecial_grain_6_2	0.0699	3977531.3	419561.3	135.6254	
Carafaspecial_grain_6_3	0.0699	3967535.3	422369.0	134.3852	

Stdev. (Sx)	%Stdev.	Grand Mean	Stdev. (Sx)	%Stdev.	mmol/g org radicals
1.544	1.15	125.53	14.519	11.6	**2.37E-05**
0.662	0.58				
1.063	0.76				
0.764	0.71				
0.687	0.51				

Table A.7.8 Concentration levels of organic radical in whole grain of roasted barley (whole grain measurement)

Marker **1.8916 E-07 mmol**

Name	Weight (g)	Intensity Food	Intensity Marker	Food/marker/Weight	Mean	Stdev. (Sx)
roasted barley_grain_1_1	0.0735	2408425.3	451762.3	72.533	75.49	2.221
roasted barley_grain_1_2	0.0735	2411445.0	437183.0	75.0459		
roasted barley_grain_1_3	0.0735	2399187.8	424123.0	76.9635		
roasted barley_grain_1_4	0.0735	2408377.8	423292.0	77.41		
roasted barley_grain_2_1	0.0696	2615528.3	431700.0	87.0499	88.03	0.864
roasted barley_grain_2_2	0.0696	2595028.0	421873.7	88.3793		
roasted barley_grain_2_3	0.0696	2593693.0	420269.7	88.6709		
roasted barley_grain_3_1	0.0915	3299433.3	529923.7	68.0464	68.46	0.397
roasted barley_grain_3_2	0.0915	3291111.3	525102.0	68.498		
roasted barley_grain_3_3	0.0915	3285922.8	521688.7	68.8375		
roasted barley_grain_4_1	0.0786	2571468.8	390732.7	83.7296	83.38	0.307
roasted barley_grain_4_2	0.0786	2547396.3	389828.3	83.1382		
roasted barley_grain_4_3	0.0786	2566785.8	392095.7	83.2866		

%Stdev.	Grand Mean	Stdev. (Sx)	%Stdev.	mmol/g org radicals
2.94	78.84	8.643	10.9	**1.49E-05**
0.98				
0.58				
0.36				

Table A.7.9 Concentration levels of organic radical in whole grain of pilsner malt (whole grain measurement)

Marker **1.89E-07 mmol**

Name	Weight (g)	Intensity Food	Intensity Marker	Food/marker/Weight	Mean	Stdev. (Sx)
pils_grain_1_1	0.0711	165618.3	490570.0	4.7483	4.65	0.101
pils_grain_1_2	0.0711	157318.7	486568.7	4.5474		
pils_grain_1_3	0.0711	161038.0	485659.7	4.6637		
pils_grain_2_1	0.0747	137851.3	486774.3	3.7911	4.03	0.165
pils_grain_2_2	0.0747	143529.7	481524.3	3.9903		
pils_grain_2_3	0.0747	143998.3	478704.7	4.0269		
pils_grain_2_4	0.0747	150523.7	475846.7	4.2346		
pils_grain_2_5	0.0747	146805.3	476640.0	4.1232		
pils_grain_3_1	0.0698	191359.0	623142.3	4.3995	4.38	0.020
pils_grain_3_2	0.0698	187955.0	617610.7	4.36		
pils_grain_3_3	0.0698	184576.3	605010.7	4.3708		
pils_grain_4_1	0.0601	132654.7	481148.3	4.5874	4.70	0.211
pils_grain_4_2	0.0601	140685.7	481398.7	4.8626		
pils_grain_4_3	0.0601	126590.7	481057.0	4.3786		
pils_grain_4_4	0.0601	139679.7	481044.0	4.8314		
pils_grain_4_5	0.0601	139051.3	478501.0	4.8352		

%Stdev.	Grand Mean	Stdev. (Sx)	%Stdev.	mmol/g org radicals
2.16	4.44	0.306	6.9	**8.40E-07**
4.09				
0.46				
4.49				

Table A.7.10 Concentration levels of organic radical in whole grain of artificial caramel colorant (CARAMEL #301) and colouring beer (SINAMAR®)

Marker	**1.89E-07**	Mmol

Name	Weight (g)	Intensity Food	Intensity Marker	Food/marker/Weight	Average	Stdev
Caramel_1_1	0.0045	37629.3	550838.3	15.1806	15.98845	0.8183738
Caramel_1_2	0.0045	38075.3	549913.7	15.3864		
Caramel_1_3	0.0045	41146.0	547396.3	16.7037		
Caramel_1_4	0.0045	41124.0	547780.0	16.6831		
Caramel_2_1	0.0041	30977.0	554682.3	13.6211	14.26687	0.61935189
Caramel_2_2	0.0041	32649.0	555946.3	14.3236		
Caramel_2_3	0.0041	33624.3	552040.3	14.8559		
Caramel_3_1	0.0047	37802.7	549151.7	14.6464	14.71057	1.06550008
Caramel_3_2	0.0047	40477.0	544839.0	15.8067		
Caramel_3_3	0.0047	35531.7	552682.7	13.6786		
Sinamar_1_1	0.0076	99425.3	456221.3	28.6753	28.31640	0.32302029
Sinamar_1_2	0.0076	98954.3	461305.0	28.2249		
Sinamar_1_3	0.0076	97951.7	459494.3	28.049		
Sinamar_2_1	0.006	84065.7	483896.0	28.9545	28.05567	0.87730704
Sinamar_2_2	0.006	81368.3	484147.3	28.0109		
Sinamar_2_3	0.006	78744.0	482471.7	27.2016		
Sinamar_3_1	0.0091	109609.3	403338.7	29.8632	29.88913	0.27970313
Sinamar_3_2	0.0091	110340.3	401754.0	30.1809		
Sinamar_3_3	0.0091	107683.7	399461.7	29.6233		

Coloring agent	Organic radicals (mmol/g)	Standard deviation
Caramel #301	2.83534E-06	5.93496E-08
Sinamar®	5.43923E-06	1.87632E-07

Table A.8.1 Concentration of beer ageing compounds of the second round of locally-brewed beers at fresh conditions

CARAHELL®

	FRESH		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	6.41	6.36	6.39	0.04	0.55	0.05
2-Methylbutanal	2.86	3.98	3.42	0.79	23.16	1.10
3-Methylbutanal	8.28	7.87	8.08	0.29	3.59	0.40
Pentanal	0.64	0.59	0.62	0.04	5.75	0.05
Hexanal	1	0.94	0.97	0.04	4.37	0.06
Methional	1.84	1.98	1.91	0.10	5.18	0.14
(*E*)-2-nonenal	0.0079	0.0084	0.01	0.00	4.34	0.00
Benzaldehyde	1.28	1.35	1.32	0.05	3.76	0.07
2-Furfural	12.48	13	12.74	0.37	2.89	0.51
5-Hydroxymethylfurfural	0.49	0.45	0.47	0.03	6.02	0.04
2-Phenylethanal	8.62	8.48	8.55	0.10	1.16	0.14
Ethyl furfuryl ether	3.9	3.99	3.95	0.06	1.61	0.09
Ethyl nicotinate	19.33	19.18	19.26	0.11	0.55	0.15
Ethyl phenyl acetate	1.8	1.74	1.77	0.04	2.40	0.06
Acetyl furan	12.26	12.53	12.40	0.19	1.54	0.26
γ-Nonalactone	25.04	25.36	25.20	0.23	0.90	0.31
Sum of warm indicators	56.85	57.54	57.20	57.37	57.28	57.32
Sum of oxygen indicators	27.45	28.04	27.75	27.89	27.82	27.86
Sum of ageing compounds	106.24	107.81	107.02	107.42	107.22	107.32
Forcing Index	61.03	60.97	61.00	60.99	60.99	60.99
Ageing Index	82.33	82.66	82.50	82.58	82.54	82.56

MELANOIDIN MALT

	FRESH		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	6.41	6.36	6.39	0.04	0.55	0.05
2-Methylbutanal	2.86	3.98	3.42	0.79	23.16	1.10
3-Methylbutanal	8.28	7.87	8.08	0.29	3.59	0.40
Pentanal	0.64	0.59	0.62	0.04	5.75	0.05
Hexanal	1	0.94	0.97	0.04	4.37	0.06
Methional	1.84	1.98	1.91	0.10	5.18	0.14
(*E*)-2-nonenal	0.0079	0.0084	0.01	0.00	4.34	0.00
Benzaldehyde	1.28	1.35	1.32	0.05	3.76	0.07
2-Furfural	12.48	13	12.74	0.37	2.89	0.51
5-Hydroxymethylfurfural	0.44	0.48	0.46	0.03	6.15	0.04
2-Phenylethanal	9.61	9.36	9.49	0.18	1.86	0.24
Ethyl furfuryl ether	2.73	2.59	2.66	0.10	3.72	0.14
Ethyl nicotinate	17.2	17.11	17.16	0.06	0.37	0.09
Ethyl phenyl acetate	0.8	0.78	0.79	0.01	1.79	0.02
Acetyl furan	12.95	13.21	13.08	0.18	1.41	0.25
γ-Nonalactone	22.35	22.98	22.67	0.45	1.97	0.62
Sum of warm indicators	52.03	53.09	52.56	52.83	52.69	52.76
Sum of oxygen indicators	28.44	28.92	28.68	28.80	28.74	28.77
Sum of ageing compounds	100.88	102.59	101.73	102.16	101.95	102.05
Forcing Index	61.56	61.58	61.57	61.58	61.57	61.57
Ageing Index	76.01	75.31	75.66	75.49	75.57	75.53

CARAFA® SPECIAL TYPE III

	FRESH		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	2.34	2.11	2.23	0.16	7.31	0.23
2-Methylbutanal	1.29	1.4	1.35	0.08	5.78	0.11
3-Methylbutanal	3.34	3.86	3.60	0.37	10.21	0.51
Pentanal	1.65	1.37	1.51	0.20	13.11	0.27
Hexanal	1.74	1.76	1.75	0.01	0.81	0.02
Methional	2.58	2.51	2.55	0.05	1.94	0.07
(*E*)-2-nonenal	0.00586	0.00608	0.01	0.00	2.61	0.00
Benzaldehyde	1.05	1.03	1.04	0.01	1.36	0.02
2-Furfural	7.3	7.47	7.39	0.12	1.63	0.17
5-Hydroxymethylfurfural	0.4	0.38	0.39	0.01	3.63	0.02
2-Phenylethanal	7.21	7.35	7.28	0.10	1.36	0.14
Ethyl furfuryl ether	3.17	3.08	3.13	0.06	2.04	0.09
Ethyl nicotinate	16.86	17.32	17.09	0.33	1.90	0.45
Ethyl phenyl acetate	0.78	0.71	0.75	0.05	6.64	0.07
Acetyl furan	11.8	11.65	11.73	0.11	0.90	0.15
γ-Nonalactone	20.37	20.24	20.31	0.09	0.45	0.13
Sum of warm indicators	44.53	45.03	44.78	44.91	44.84	44.87
Sum of oxygen indicators	15.23	15.75	15.49	15.62	15.56	15.59
Sum of ageing compounds	81.89	82.25	82.07	82.16	82.11	82.13
Forcing Index	45.90	46.68	46.29	46.49	46.39	46.44
Ageing Index	62.53	62.79	62.66	62.73	62.69	62.71

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	FRESH		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	3.25	3.08	3.17	0.12	3.80	0.17
2-Methylbutanal	1.9	1.97	1.94	0.05	2.56	0.07
3-Methylbutanal	5.15	4.98	5.07	0.12	2.37	0.17
Pentanal	0.82	0.78	0.80	0.03	3.54	0.04
Hexanal	1.22	1.24	1.23	0.01	1.15	0.02
Methional	2.37	2.46	2.42	0.06	2.64	0.09
(*E*)-2-nonenal	0.0095	0.0098	0.01	0.00	2.20	0.00
Benzaldehyde	0.92	1.07	1.00	0.11	10.66	0.15
2-Furfural	8.15	8.47	8.31	0.23	2.72	0.31
5-Hydroxymethylfurfural	0.46	0.44	0.45	0.01	3.14	0.02
2-Phenylethanal	9.1	9.17	9.14	0.05	0.54	0.07
Ethyl furfuryl ether	3.47	3.39	3.43	0.06	1.65	0.08
Ethyl nicotinate	14.66	14.87	14.77	0.15	1.01	0.21
Ethyl phenyl acetate	0.82	0.89	0.86	0.05	5.79	0.07
Acetyl furan	11.51	11.63	11.57	0.08	0.73	0.12
γ-Nonalactone	21.14	21.58	21.36	0.31	1.46	0.43
Sum of warm indicators	43.95	44.92	44.44	44.68	44.56	44.62
Sum of oxygen indicators	20.32	20.27	20.30	20.28	20.29	20.29
Sum of ageing compounds	84.95	86.03	85.49	85.76	85.62	85.69
Forcing Index	50.48	50.71	50.60	50.65	50.62	50.64
Ageing Index	68.65	68.55	68.60	68.58	68.59	68.58

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	FRESH		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	3.76	3.58	3.67	0.13	3.47	0.18
2-Methylbutanal	3.66	3.6	3.63	0.04	1.17	0.06
3-Methylbutanal	8.64	8.33	8.49	0.22	2.58	0.30
Pentanal	0.64	0.605	0.62	0.02	3.98	0.03
Hexanal	1.47	1.71	1.59	0.17	10.67	0.24
Methional	2.12	2.18	2.15	0.04	1.97	0.06
(*E*)-2-nonenal	0.011	0.01	0.01	0.00	6.73	0.00
Benzaldehyde	1.11	1.01	1.06	0.07	6.67	0.10
2-Furfural	6.61	6.38	6.50	0.16	2.50	0.23
5-Hydroxymethylfurfural	0.29	0.34	0.32	0.04	11.22	0.05
2-Phenylethanal	10.19	9.75	9.97	0.31	3.12	0.43
Ethyl furfuryl ether	2.02	1.91	1.97	0.08	3.96	0.11
Ethyl nicotinate	13.07	13.66	13.37	0.42	3.12	0.58
Ethyl phenyl acetate	0.56	0.62	0.59	0.04	7.19	0.06
Acetyl furan	10.47	10.98	10.73	0.36	3.36	0.50
γ-Nonalactone	19.94	19.32	19.63	0.44	2.23	0.61
Sum of warm indicators	39.62	39.36	39.49	39.43	39.46	39.44
Sum of oxygen indicators	27.36	26.27	26.82	26.54	26.68	26.61
Sum of ageing compounds	84.56	83.99	84.27	84.13	84.20	84.17
Forcing Index	54.94	54.75	54.84	54.80	54.82	54.81
Ageing Index	65.60	64.92	65.26	65.09	65.17	65.13

Table A.8.2 Concentration of beer ageing compounds of the second round of locally-brewed beers at forced aged conditions

CARAHELL®

	FORCED		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	20.71	21.25	20.98	0.38	1.82	0.53
2-Methylbutanal	17.01	18.18	17.60	0.83	4.70	1.15
3-Methylbutanal	35.5	36.43	35.97	0.66	1.83	0.91
Pentanal	1.9	2.05	1.98	0.11	5.37	0.15
Hexanal	2.23	2.35	2.29	0.08	3.71	0.12
Methional	8.8	8.36	8.58	0.31	3.63	0.43
(*E*)-2-nonenal	0.0119	0.0113	0.01	0.00	3.66	0.00
Benzaldehyde	3.52	3.64	3.58	0.08	2.37	0.12
2-Furfural	189.6	193.45	191.53	2.72	1.42	3.77
5-Hydroxymethylfurfural	0.88	0.93	0.91	0.04	3.91	0.05
2-Phenylethanal	30.42	29.95	30.19	0.33	1.10	0.46
Ethyl furfuryl ether	6.74	6.64	6.69	0.07	1.06	0.10
Ethyl nicotinate	30.69	30.45	30.57	0.17	0.56	0.24
Ethyl phenyl acetate	2.59	2.68	2.64	0.06	2.42	0.09
Acetyl furan	14.59	14.95	14.77	0.25	1.72	0.35
γ-Nonalactone	33.77	34.11	33.94	0.24	0.71	0.33
Sum of warm indicators	254.06	258.01	256.04	257.02	256.53	256.78
Sum of oxygen indicators	107.16	109.45	108.31	108.88	108.59	108.73
Sum of ageing compounds	398.96	405.43	402.20	403.81	403.01	403.41
Forcing Index	179.68	183.15	181.41	182.28	181.85	182.07
Ageing Index	215.97	219.03	217.50	218.27	217.88	218.07

MELANOIDIN MALT

	FORCED		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	13.3	13.11	13.21	0.13	1.02	0.19
2-Methylbutanal	6.98	6.73	6.86	0.18	2.58	0.24
3-Methylbutanal	10.8	10.53	10.67	0.19	1.79	0.26
Pentanal	0.98	1.09	1.04	0.08	7.52	0.11
Hexanal	2.5	2.18	2.34	0.23	9.67	0.31
Methional	2.43	2.68	2.56	0.18	6.92	0.24
(*E*)-2-nonenal	0.0125	0.0128	0.01	0.00	1.68	0.00
Benzaldehyde	2.56	2.47	2.52	0.06	2.53	0.09
2-Furfural	63.16	63.78	63.47	0.44	0.69	0.61
5-Hydroxymethylfurfural	0.58	0.63	0.61	0.04	5.84	0.05
2-Phenylethanal	22.75	22.31	22.53	0.31	1.38	0.43
Ethyl furfuryl ether	5.01	5.23	5.12	0.16	3.04	0.22
Ethyl nicotinate	26.8	26.35	26.58	0.32	1.20	0.44
Ethyl phenyl acetate	1.99	2.12	2.06	0.09	4.47	0.13
Acetyl furan	15.83	15.96	15.90	0.09	0.58	0.13
γ-Nonalactone	25.96	26.32	26.14	0.25	0.97	0.35
Sum of warm indicators	115.92	116.45	116.19	116.32	116.25	116.28
Sum of oxygen indicators	56.39	55.15	55.77	55.46	55.62	55.54
Sum of ageing compounds	201.64	201.50	201.57	201.54	201.56	201.55
Forcing Index	93.41	93.24	93.32	93.28	93.30	93.29
Ageing Index	120.45	121.51	120.98	121.24	121.11	121.18

CARAFA® SPECIAL TYPE III

	FORCED		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	14.88	14.94	14.91	0.04	0.28	0.06
2-Methylbutanal	6.59	6.89	6.74	0.21	3.15	0.29
3-Methylbutanal	10.25	9.93	10.09	0.23	2.24	0.31
Pentanal	2.59	2.63	2.61	0.03	1.08	0.04
Hexanal	3.41	3.84	3.63	0.30	8.39	0.42
Methional	8.1	7.94	8.02	0.11	1.41	0.16
(*E*)-2-nonenal	0.0107	0.0109	0.01	0.00	1.31	0.00
Benzaldehyde	3.38	3.47	3.43	0.06	1.86	0.09
2-Furfural	91.8	91.08	91.44	0.51	0.56	0.71
5-Hydroxymethylfurfural	0.66	0.65	0.66	0.01	1.08	0.01
2-Phenylethanal	16.85	17.08	16.97	0.16	0.96	0.23
Ethyl furfuryl ether	4.78	4.61	4.70	0.12	2.56	0.17
Ethyl nicotinate	22.7	22.88	22.79	0.13	0.56	0.18
Ethyl phenyl acetate	2.23	2.14	2.19	0.06	2.91	0.09
Acetyl furan	14.17	14.56	14.37	0.28	1.92	0.38
γ-Nonalactone	27.81	28.08	27.95	0.19	0.68	0.26
Sum of warm indicators	142.31	142.04	142.18	142.11	142.14	142.12
Sum of oxygen indicators	51.95	52.31	52.13	52.22	52.18	52.20
Sum of ageing compounds	230.21	230.73	230.47	230.60	230.54	230.57
Forcing Index	94.12	94.33	94.23	94.28	94.25	94.26
Ageing Index	120.25	119.52	119.89	119.70	119.79	119.75

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	FORCED		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	15.26	15.38	15.32	0.08	0.55	0.12
2-Methylbutanal	12.47	12.72	12.60	0.18	1.40	0.24
3-Methylbutanal	15.07	15.22	15.15	0.11	0.70	0.15
Pentanal	1.48	1.54	1.51	0.04	2.81	0.06
Hexanal	5.04	5.17	5.11	0.09	1.80	0.13
Methional	5.4	5.14	5.27	0.18	3.49	0.25
(*E*)-2-nonenal	0.0201	0.0191	0.02	0.00	3.61	0.00
Benzaldehyde	3.5	3.38	3.44	0.08	2.47	0.12
2-Furfural	73.84	75.24	74.54	0.99	1.33	1.37
5-Hydroxymethylfurfural	0.67	0.74	0.71	0.05	7.02	0.07
2-Phenylethanal	18.56	19.14	18.85	0.41	2.18	0.57
Ethyl furfuryl ether	4.36	4.58	4.47	0.16	3.48	0.22
Ethyl nicotinate	24.93	24.54	24.74	0.28	1.11	0.38
Ethyl phenyl acetate	1.89	1.82	1.86	0.05	2.67	0.07
Acetyl furan	13.18	13.32	13.25	0.10	0.75	0.14
γ-Nonalactone	25.79	26.03	25.91	0.17	0.65	0.24
Sum of warm indicators	124.56	125.81	125.19	125.50	125.34	125.42
Sum of oxygen indicators	64.86	65.84	65.35	65.60	65.47	65.53
Sum of ageing compounds	221.46	223.98	222.72	223.35	223.03	223.19
Forcing Index	97.14	98.48	97.81	98.14	97.97	98.06
Ageing Index	120.83	123.20	122.01	122.60	122.31	122.45

PILSNER MALT

	FORCED		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	16.5	16.69	16.60	0.13	0.81	0.19
2-Methylbutanal	6.46	6.43	6.45	0.02	0.33	0.03
3-Methylbutanal	16.06	15.77	15.92	0.21	1.29	0.28
Pentanal	1.29	1.18	1.24	0.08	6.30	0.11
Hexanal	2.45	2.51	2.48	0.04	1.71	0.06
Methional	3	3.14	3.07	0.10	3.22	0.14
(*E*)-2-nonenal	0.0225	0.024	0.02	0.00	4.56	0.00
Benzaldehyde	3.74	3.88	3.81	0.10	2.60	0.14
2-Furfural	54.03	55.08	54.56	0.74	1.36	1.03
5-Hydroxymethylfurfural	0.49	0.44	0.47	0.04	7.60	0.05
2-Phenylethanal	17.42	17.11	2.84	0.08	2.74	0.11
Ethyl furfuryl ether	2.78	2.89	19.67	0.46	2.34	0.64
Ethyl nicotinate	19.34	19.99	1.59	0.14	8.89	0.20
Ethyl phenyl acetate	1.69	1.49	12.14	0.30	2.45	0.41
Acetyl furan	11.93	12.35	21.83	0.22	1.00	0.30
γ-Nonalactone	21.67	21.98	21.83	0.22	1.00	0.30
Sum of warm indicators	95.04	97.05	96.05	96.55	96.30	96.42
Sum of oxygen indicators	60.18	59.88	60.03	59.96	59.99	59.97
Sum of ageing compounds	178.87	180.95	179.91	180.43	180.17	180.30
Forcing Index	89.03	89.56	89.29	89.42	89.36	89.39
Ageing Index	104.62	105.50	105.06	105.28	105.17	105.22

Table A.8.3 Concentration of beer ageing compounds of the second round of locally-brewed beers at spontaneously aged conditions

CARAHELL®

	AGED		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	58.6	57.1	57.85	1.06	1.83	1.47
2-Methylbutanal	36	37.8	36.90	1.27	3.45	1.76
3-Methylbutanal	53.8	55.6	54.70	1.27	2.33	1.76
Pentanal	3.18	3.36	3.27	0.13	3.89	0.18
Hexanal	8.93	8.85	8.89	0.06	0.64	0.08
Methional	17.26	16.88	17.07	0.27	1.57	0.37
(*E*)-2-nonenal	575.8	588.2	582.00	8.77	1.51	12.15
Benzaldehyde	0.0658	0.0663	0.07	0.00	0.54	0.00
2-Furfural	7.49	7.32	7.41	0.12	1.62	0.17
5-Hydroxymethylfurfural	1.89	1.96	1.93	0.05	2.57	0.07
2-Phenylethanal	90.6	88.7	89.65	1.34	1.50	1.86
Ethyl furfuryl ether	20.61	21.09	20.85	0.34	1.63	0.47
Ethyl nicotinate	62.72	63.44	63.08	0.51	0.81	0.71
Ethyl phenyl acetate	7.38	7.24	7.31	0.10	1.35	0.14
Acetyl furan	31.25	31.85	31.55	0.42	1.34	0.59
γ-Nonalactone	142.9	143.52	143.21	0.44	0.31	0.61
Sum of warm indicators	213.11	214.28	213.70	213.99	213.84	213.91
Sum of oxygen indicators	239.07	239.27	239.17	239.22	239.19	239.20
Sum of ageing compounds	1118.48	1132.98	1125.73	1129.35	1127.54	1128.44
Forcing Index	288.72	292.84	290.78	291.81	291.30	291.55
Ageing Index	399.15	405.53	402.34	403.94	403.14	403.54

MELANOIDIN MALT

	AGED		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	35.7	36.9	36.30	0.85	2.34	1.18
2-Methylbutanal	12.38	13.25	12.82	0.62	4.80	0.85
3-Methylbutanal	20.1	21.5	20.80	0.99	4.76	1.37
Pentanal	4.23	4.54	4.39	0.22	5.00	0.30
Hexanal	7.26	7.51	7.39	0.18	2.39	0.24
Methional	6.29	7.47	6.88	0.83	12.13	1.16
(*E*)-2-nonenal	152.7	154.8	153.75	1.48	0.97	2.06
Benzaldehyde	0.075	0.0725	0.07	0.00	2.40	0.00
2-Furfural	5.83	5.69	5.76	0.10	1.72	0.14
5-Hydroxymethylfurfural	1.54	1.62	1.58	0.06	3.58	0.08
2-Phenylethanal	29.4	29.78	29.59	0.27	0.91	0.37
Ethyl furfuryl ether	14.9	14.98	14.94	0.06	0.38	0.08
Ethyl nicotinate	48.18	48.74	48.46	0.40	0.82	0.55
Ethyl phenyl acetate	5.05	5.23	5.14	0.13	2.48	0.18
Acetyl furan	28.36	28.78	28.57	0.30	1.04	0.41
γ-Nonalactone	126.1	127.32	126.71	0.86	0.68	1.20
Sum of warm indicators	180.11	181.75	180.93	181.34	181.14	181.24
Sum of oxygen indicators	97.66	101.50	99.58	100.54	100.06	100.30
Sum of ageing compounds	498.10	508.18	503.14	505.66	504.40	505.03
Forcing Index	176.13	180.53	178.33	179.43	178.88	179.16
Ageing Index	255.68	260.66	258.17	259.42	258.79	259.10

CARAFA® SPECIAL TYPE III

	AGED		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	28.3	27.1	27.70	0.85	3.06	1.18
2-Methylbutanal	20.9	21.5	21.20	0.42	2.00	0.59
3-Methylbutanal	19.2	19.8	19.50	0.42	2.18	0.59
Pentanal	7	7.11	7.06	0.08	1.10	0.11
Hexanal	11.8	12.15	11.98	0.25	2.07	0.34
Methional	22.38	21.74	22.06	0.45	2.05	0.63
(*E*)-2-nonenal	220	226.5	223.25	4.60	2.06	6.37
Benzaldehyde	0.0685	0.0694	0.07	0.00	0.92	0.00
2-Furfural	14.87	15.32	15.10	0.32	2.11	0.44
5-Hydroxymethylfurfural	1.28	1.26	1.27	0.01	1.11	0.02
2-Phenylethanal	28.3	29.65	28.98	0.95	3.29	1.32
Ethyl furfuryl ether	11.86	12.08	11.97	0.16	1.30	0.22
Ethyl nicotinate	47.51	47.89	47.70	0.27	0.56	0.37
Ethyl phenyl acetate	6.64	6.25	6.45	0.28	4.28	0.38
Acetyl furan	28.7	28.44	28.57	0.18	0.64	0.25
γ-Nonalactone	124.4	122.9	123.65	1.06	0.86	1.47
Sum of warm indicators	186.78	186.11	186.45	186.28	186.36	186.32
Sum of oxygen indicators	96.77	98.12	97.44	97.78	97.61	97.70
Sum of ageing compounds	593.21	599.76	596.48	598.12	597.30	597.71
Forcing Index	175.87	176.59	176.23	176.41	176.32	176.36
Ageing Index	241.81	243.24	242.52	242.88	242.70	242.79

CARAMEL #301

	AGED		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	35.2	34.4	34.80	0.57	1.63	0.78
2-Methylbutanal	23.2	25.4	24.30	1.56	6.40	2.16
3-Methylbutanal	40.8	42.3	41.55	1.06	2.55	1.47
Pentanal	5.74	5.88	5.81	0.10	1.70	0.14
Hexanal	11.35	11.08	11.22	0.19	1.70	0.26
Methional	13.17	13.55	13.36	0.27	2.01	0.37
(*E*)-2-nonenal	224.3	229.5	226.90	3.68	1.62	5.10
Benzaldehyde	0.148	0.149	0.15	0.00	0.48	0.00
2-Furfural	11.86	11.08	11.47	0.55	4.81	0.76
5-Hydroxymethylfurfural	1.25	1.29	1.27	0.03	2.23	0.04
2-Phenylethanal	30.36	32.51	31.44	1.52	4.84	2.11
Ethyl furfuryl ether	13.4	13.75	13.58	0.25	1.82	0.34
Ethyl nicotinate	46.33	46.17	46.25	0.11	0.24	0.16
Ethyl phenyl acetate	5.32	5.47	5.40	0.11	1.97	0.15
Acetyl furan	26.17	26.58	26.38	0.29	1.10	0.40
γ-Nonalactone	135.7	133.89	134.80	1.28	0.95	1.77
Sum of warm indicators	193.89	191.14	192.52	191.83	192.17	192.00
Sum of oxygen indicators	129.71	134.76	132.23	133.50	132.86	133.18
Sum of ageing compounds	624.30	633.00	628.65	630.82	629.74	630.28
Forcing Index	219.94	223.73	221.83	222.78	222.31	222.54
Ageing Index	292.26	297.95	295.10	296.53	295.81	296.17

PILSNER MALT

	AGED		Mean	Sx	CV (%)	CI (abs)
2-Methylpropanal	40.2	39.5	39.85	0.49	1.24	0.69
2-Methylbutanal	18.2	19.5	18.85	0.92	4.88	1.27
3-Methylbutanal	34.1	33.2	33.65	0.64	1.89	0.88
Pentanal	4.08	3.94	4.01	0.10	2.47	0.14
Hexanal	10.6	10.25	10.43	0.25	2.37	0.34
Methional	8.3	8.08	8.19	0.16	1.90	0.22
(*E*)-2-nonenal	130	133.8	131.90	2.69	2.04	3.72
Benzaldehyde	0.0911	0.0925	0.09	0.00	1.08	0.00
2-Furfural	6.8	6.95	6.88	0.11	1.54	0.15
5-Hydroxymethylfurfural	1.18	1.28	1.23	0.07	5.75	0.10
2-Phenylethanal	41.5	40.85	41.18	0.46	1.12	0.64
Ethyl furfuryl ether	8.98	8.95	8.97	0.02	0.24	0.03
Ethyl nicotinate	45.7	45.98	45.84	0.20	0.43	0.27
Ethyl phenyl acetate	3.96	3.85	3.91	0.08	1.99	0.11
Acetyl furan	20.33	20.98	20.66	0.46	2.23	0.64
γ-Nonalactone	116.2	115.5	115.85	0.49	0.43	0.69
Sum of warm indicators	168.70	168.43	168.57	168.50	168.53	168.51
Sum of oxygen indicators	134.09	133.14	133.62	133.38	133.50	133.44
Sum of ageing compounds	490.22	492.70	491.46	492.08	491.77	491.93
Forcing Index	189.41	188.27	188.84	188.56	188.70	188.63
Ageing Index	238.27	236.87	237.57	237.22	237.40	237.31

Table A.9.1 Sensory evaluation results of the second round of fresh locally-brewed beer colour adjusted with CARAHELL®

Sensory Evaluation

CARAHELL® (Fresh)

Beer Aroma (0-5)

	Taster 1		**Mean**	Taster 2		**Mean**	Taster 3		**Mean**	Taster 4		**Mean**
Fruity	0	5	2.5	2	3	2.5	3	5	4	2	2	2
Floral	0	3	1.5	0	1	0.5	3	4	3.5	0	1	0.5
Hoppy	2	2	2	1	1	1	3	1	2	1	0	0.5
Grainy	3	0	1.5	2	0	1	3	0	1.5	1	1	1
Malty	2	0	1	2	0	1	3	0	1.5	1	1	1
Sweet	2	2	2	2	3	2.5	4	5	4.5	3	0	1.5
Acetaldehyde	2	1	1.5	2	2	2	1	3	2	2	0	1
Oxidised	2	0	1	1	0	0.5	2	1	1.5	1	4	2.5
Acidic	0	0	0	0	1	0.5	1	3	2	3	2	2.5
Overall quality	2	4	3	2	4	3	4	0	2	2	5	3.5

Beer Taste (0-5)

	Taster 1		**Mean**	Taster 2		**Mean**	Taster 3		**Mean**	Taster 4		**Mean**
Fruity	2	4	3	2	3	2.5	3	4	3.5	2	2	2
Spicy	3	2	2.5	2	1	1.5	3	3	3	2	3	2.5
Grainy	2	1	1.5	2	0	1	3	1	2	1	1	1
Malty	2	1	1.5	2	0	1	3	1	2	1	1	1
Sulphury	2	3	2.5	1	2	1.5	2	3	2.5	0	4	2
Acetaldehyde	0	2	1	2	2	2	2	3	2.5	2	2	2
Phenolic	0	2	1	0	0	0	4	1	2.5	2	4	3
Oxidised	2	3	2.5	1	1	1	3	0	1.5	1	3	2
Acidic	0	1	0.5	1	1	1	3	3	3	1	3	2
Astrigent	1	2	1.5	2	1	1.5	4	2	3	2	3	2.5
Overall quality	2	3	2.5	2	4	3	2	2	2	3	1	2

Sensory Evaluation

CARAHELL® (Fresh)

Beer Aroma (0-5)

	Taster 5		**Mean**	Taster 6		**Mean**	Taster 7		**Mean**	Taster 8		**Mean**
Fruity	0	4	2	2	3	2.5	0	1	0.5	2	3	2.5
Floral	0	1	0.5	0	2	1	0	0	0	0	0	0
Hoppy	1	1	1	1	3	2	3	0	1.5	1	1	1
Grainy	1	1	1	0	2	1	3	0	1.5	2	0	1
Malty	0	1	0.5	0	1	0.5	3	0	1.5	2	1	1.5
Sweet	0	3	1.5	2	2	2	1	3	2	3	4	3.5
Acetaldehyde	2	0	0	0	2	2	2	2	1	1.5	0	2
Oxidised	1	0	0.5	1	2	1.5	2	2	2	1	0	0.5
Acidic	0	0	0	0	3	1.5	1	3	2	2	0	1
Overall quality	2	1	3	2	2	3	2.5	3	0	1.5	1	1

Beer Taste (0-5)

	Taster 5		**Mean**	Taster 6		**Mean**	Taster 7		**Mean**	Taster 8		**Mean**
Fruity	0	4	2	2	2	2	0	0	0	1	2	1.5
Spicy	0	3	1.5	2	1	1.5	1	2	1.5	2	0	1
Grainy	2	1	1.5	1	3	2	1	0	0.5	3	0	1.5
Malty	0	1	0.5	1	3	2	2	1	1.5	3	2	2.5
Sulphury	1	3	2	0	1	0.5	0	3	1.5	2	1	1.5
Acetaldehyde	0	0	3	1.5	2	4	3	0	0	0	0	3
Phenolic	0	2	1	0	3	1.5	1	2	1.5	0	0	0
Oxidised	1	1	1	1	3	2	3	4	3.5	1	0	0.5
Acidic	2	0	1	1	2	1.5	2	4	3	1	0	0.5
Astrigent	3	1	2	2	3	2.5	4	4	4	4	1	2.5
Overall quality	2	2	4	3	2	1	1.5	2	0	1	3	3

Sensory Evaluation

CARAHELL® (Fresh)

Beer Aroma (0-5)

	Taster 9		**Mean**	Taster 10		**Mean**
Fruity	3	4	3.5	2	4	3
Floral	2	3	2.5	0	3	1.5
Hoppy	3	3	3	1	1	1
Grainy	2	2	2	2	1	1.5
Malty	2	1	1.5	2	1	1.5
Sweet	2	2	2	2	2	2
Acetaldehyde	2	1	3	2	2	2
Oxidised	1	1	1	1	0	0.5
Acidic	1	1	1	0	0	0
Overall quality	2	3	2	2.5	2	4

Beer Taste (0-5)

	Taster 9		**Mean**	Taster 10		**Mean**
Fruity	2	4	3	2	4	3
Spicy	2	1	1.5	2	3	2.5
Grainy	1	0	0.5	1	1	1
Malty	1	2	1.5	2	1	1.5
Sulphury	2	1	1.5	1	3	2
Acetaldehyde	0	2	4	3	0	2
Phenolic	0	1	0.5	0	2	1
Oxidised	1	1	1	1	3	2
Acidic	2	1	1.5	1	2	1.5
Astrigent	1	3	2	3	2	2.5
Overall quality	2	3	3	3	2	4

Table A.9.2 Sensory evaluation results of the second round of forced aged locally-brewed beer colour adjusted with CARAHELL®

Sensory Evaluation

CARAHELL® (Forced aged)

Beer Aroma (0-5)

	Taster 1		**Mean**	Taster 2		**Mean**	Taster 3		**Mean**	Taster 4		**Mean**
Fruity	2	4	3	1	5	3	5	4	4.5	4	2	3
Floral	3	2	2.5	2	2	2	4	4	4	4	3	3.5
Hoppy	3	2	2.5	4	1	2.5	2	2	2	2	1	1.5
Grainy	3	1	2	3	2	2.5	1	2	1.5	0	2	1
Malty	2	3	2.5	4	2	3	1	2	1.5	0	3	1.5
Sweet	1	5	3	2	4	3	5	5	5	4	3	3.5
Acetaldehyde	2	1	2	1.5	2	2	2	2	2	2	4	4
Oxidised	0	1	0.5	3	3	3	0	1	0.5	2	2	2
Acidic	0	2	1	1	3	2	3	4	3.5	3	2	2.5
Overall quality	2	3	2	2.5	3	3	3	4	3	3.5	4	3

Beer Taste (0-5)

	Taster 1		**Mean**	Taster 2		**Mean**	Taster 3		**Mean**	Taster 4		**Mean**
Fruity	3	4	3.5	3	2	2.5	4	5	4.5	4	2	3
Spicy	2	1	1.5	2	0	1	4	2	3	2	3	2.5
Grainy	1	2	1.5	2	3	2.5	1	2	1.5	0	4	2
Malty	1	2	1.5	3	4	3.5	1	2	1.5	0	4	2
Sulphury	2	4	3	3	2	2.5	2	4	3	2	2	2
Acetaldehyde	0	1	2	1.5	2	2	2	3	2	2.5	4	1
Phenolic	1	1	1	4	2	3	1	1	1	4	3	3.5
Oxidised	1	1	1	2	1	1.5	1	1	1	1	1	1
Acidic	0	0	0	1	2	1.5	3	3	3	3	1	2
Astrigent	1	3	2	4	2	3	2	3	2.5	2	1	1.5
Overall quality	2	3	4	3.5	4	2	3	2	2	2	3	3

Sensory Evaluation

CARAHELL® (Forced aged)

Beer Aroma (0-5)

	Taster 5		**Mean**	Taster 6		**Mean**	Taster 7		**Mean**	Taster 8		**Mean**
Fruity	0	4	2	3	3	3	0	1	0.5	4	3	3.5
Floral	0	3	1.5	3	2	2.5	0	1	0.5	2	1	1.5
Hoppy	0	1	0.5	1	1	1	3	3	3	2	1	1.5
Grainy	0	1	0.5	0	3	1.5	1	2	1.5	2	0	1
Malty	0	3	1.5	1	3	2	1	3	2	3	2	2.5
Sweet	0	4	2	3	4	3.5	0	3	1.5	4	4	4
Acetaldehyde	2	0	1	0.5	2	3	2.5	1	0	0.5	1	3
Oxidised	3	2	2.5	0	3	1.5	3	3	3	0	0	0
Acidic	0	3	1.5	1	1	1	1	3	2	0	0	0
Overall quality	2	1	2	1.5	4	2	3	2	3	2.5	4	1

Beer Taste (0-5)

	Taster 5		**Mean**	Taster 6		**Mean**	Taster 7		**Mean**	Taster 8		**Mean**
Fruity	0	4	2	4	3	3.5	0	0	0	2	1	1.5
Spicy	0	2	1	3	1	2	0	3	1.5	1	1	1
Grainy	0	2	1	1	3	2	1	1	1	2	3	2.5
Malty	0	3	1.5	1	3	2	2	1	1.5	2	3	2.5
Sulphury	2	2	2	0	1	0.5	0	2	1	4	4	4
Acetaldehyde	0	0	2	1	0	4	2	0	0	0	1	2
Phenolic	0	2	1	0	4	2	1	3	2	0	0	0
Oxidised	3	2	2.5	0	3	1.5	3	4	3.5	2	1	1.5
Acidic	2	0	1	0	1	0.5	1	2	1.5	2	0	1
Astrigent	0	2	1	1	4	2.5	3	4	3.5	4	1	2.5
Overall quality	2	1	3	2	4	2	3	2	1	1.5	3	2

Sensory Evaluation

CARAHELL® (Forced aged)

Beer Aroma (0-5)

	Taster 9		**Mean**	Taster 10		**Mean**
Fruity	3	5	4	3	3	3
Floral	2	2	2	3	2	2.5
Hoppy	3	2	2.5	3	2	2.5
Grainy	2	0	1	0	2	1
Malty	2	1	1.5	1	3	2
Sweet	2	2	2	4	2	3
Acetaldehyde	2	4	3	3.5	2	2
Oxidised	1	0	0.5	0	3	1.5
Acidic	2	2	2	1	1	1
Overall quality	2	3	2	2.5	4	3

Beer Taste (0-5)

	Taster 9		**Mean**	Taster 10		**Mean**
Fruity	3	2	2.5	4	4	4
Spicy	1	1	1	2	1	1.5
Grainy	1	1	1	1	3	2
Malty	1	0	0.5	0	2	1
Sulphury	1	0	0.5	2	2	2
Acetaldehyde	0	3	3	3	2	2
Phenolic	1	2	1.5	1	3	2
Oxidised	1	1	1	1	1	1
Acidic	2	2	2	3	1	2
Astrigent	2	1	1.5	2	2	2
Overall quality	2	3	3	3	3	3

Table A.9.3 Sensory evaluation results of the second round of spontaneously aged locally-brewed beer colour adjusted with CARAHELL®

Sensory Evaluation

CARAHELL® (Spontaneously aged)

Beer Aroma (0-5)

	Taster 1		**Mean**	Taster 2		**Mean**	Taster 3		**Mean**	Taster 4		**Mean**
Fruity	1	2	1.5	3	3.5	3.25	3	4	3.5	3	2	2.5
Floral	2	3	2.5	3	3	3	2	4	3	3	1	2
Hoppy	1	1	1	2	2	2	2	2	2	0	0	0
Grainy	2	3	2.5	2	2	2	1	3	2	2	1	1.5
Malty	3	3	3	2	3	2.5	1	3	2	2	2	2
Sweet	2	3	2.5	4	4	4	4	3	3.5	3	1	2
Acetaldehyde	2	3	3	3	3.5	3	3.25	2	4	3	3	2
Oxidised	2	1	1.5	4	1	2.5	2	2	2	2	1	1.5
Acidic	2	1	1.5	3	2	2.5	1	3	2	3	1	2
Overall quality	2	2	2	2	2	4	3	3	4	3.5	2	1

Beer Taste (0-5)

	Taster 1		**Mean**	Taster 2		**Mean**	Taster 3		**Mean**	Taster 4		**Mean**
Fruity	1	1	1	1	2	1.5	3	4	3.5	1	2	1.5
Spicy	1	3	2	3	3	3	4	3	3.5	2	3	2.5
Grainy	3	1	2	3	2	2.5	2	3	2.5	1	2	1.5
Malty	3	1	2	4	3	3.5	2	3	2.5	2	2	2
Sulphury	1	1	1	3	1	2	4	3	3.5	1	3	2
Acetaldehyde	0	4	4	4	2	3	2.5	3	4	3.5	2	4
Phenolic	2	4	3	4	4	4	4	3	3.5	3	3	3
Oxidised	3	4	3.5	2	2	2	1	4	2.5	2	2	2
Acidic	1	3	2	1	1	1	3	3	3	4	4	4
Astrigent	3	3	3	4	4	4	5	3	4	3	1	2

Overall quality	2	1	1	1	2	3	2.5	1	2	1.5	2	3

Sensory Evaluation

CARAHELL® (Spontaneously aged)

Beer Aroma (0-5)

	Taster 5		**Mean**	Taster 6		**Mean**	Taster 7		**Mean**	Taster 8		**Mean**
Fruity	0	2	1	3	1	2	1	2	1.5	3	2	2.5
Floral	0	0	0	1	1	1	0	2	1	1	1	1
Hoppy	0	0	0	0	1	0.5	1	1	1	1	0	0.5
Grainy	1	0	0.5	3	0	1.5	1	0	0.5	2	1	1.5
Malty	0	0	0	3	2	2.5	1	1	1	2	2	2
Sweet	0	1	0.5	1	1	1	0	2	1	4	2	3
Acetaldehyde	2	0	2	1	3	0	1.5	0	0	0	1	2
Oxidised	3	0	1.5	4	0	2	3	2	2.5	2	2	2
Acidic	2	0	1	0	0	0	3	0	1.5	2	1	1.5
Overall quality	2	2	4	3	2	2	2	2	2	2	3	2

Beer Taste (0-5)

	Taster 5		**Mean**	Taster 6		**Mean**	Taster 7		**Mean**	Taster 8		**Mean**
Fruity	0	2	1	3	1	2	0	1	0.5	1	0	0.5
Spicy	2	0	1	2	1	1.5	1	0	0.5	1	0	0.5
Grainy	2	0	1	0	1	0.5	2	1	1.5	2	2	2
Malty	0	0	0	0	2	1	1	2	1.5	2	2	2
Sulphury	0	0	0	0	0	0	0	0	0	3	3	3
Acetaldehyde	0	0	1	0.5	3	0	1.5	0	0	0	0	0
Phenolic	0	0	0	4	0	2	0	0	0	0	0	0
Oxidised	3	0	1.5	3	0	1.5	3	1	2	2	4	3
Acidic	2	0	1	1	0	0.5	1	0	0.5	2	0	1
Astrigent	2	2	2	4	2	3	3	3	3	4	0	2
Overall quality	2	2	4	3	1	2	1.5	2	3	2.5	2	1

Sensory Evaluation
CARAHELL® (Spontaneously aged)
Beer Aroma (0-5)

	Taster 9		**Mean**	Taster 10		**Mean**
Fruity	3	4	3.5	1	3	2
Floral	2	3	2.5	0	3	1.5
Hoppy	2	3	2.5	1	2	1.5
Grainy	1	2	1.5	3	1	2
Malty	1	2	1.5	3	1	2
Sweet	1	2	1.5	0	3	1.5
Acetaldehyde	2	2	3	2.5	0	1
Oxidised	1	0	0.5	2	1	1.5
Acidic	2	1	1.5	0	1	0.5
Overall quality	2	3	2	2.5	1	3

Beer Taste (0-5)

	Taster 9		**Mean**	Taster 10		**Mean**
Fruity	4	2	3	0	2	1
Spicy	2	1	1.5	0	1	0.5
Grainy	1	0	0.5	2	2	2
Malty	1	0	0.5	0	2	1
Sulphury	1	0	0.5	1	1	1
Acetaldehyde	0	4	4	4	1	1
Phenolic	0	2	1	0	1	0.5
Oxidised	1	1	1	3	1	2
Acidic	2	2	2	0	1	0.5
Astrigent	3	3	3	2	2	2
Overall quality	2	3	3	3	1	3

Table A.9.4 Sensory evaluation results of the second round of fresh locally-brewed beer colour adjusted with melanoidin malt

Sensory Evaluation

MELANOIDIN MALT (Fresh)

Beer Aroma (0-5)

	Taster 1		**Mean**	Taster 2		**Mean**	Taster 3		**Mean**	Taster 4		**Mean**
Fruity	0	2	1	3	4.5	3.75	4	5	4.5	3	4	3.5
Floral	0	1	0.5	3	4	3.5	3	4	3.5	3	3	3
Hoppy	0	1	0.5	2	2	2	1	2	1.5	1	0	0.5
Grainy	2	3	2.5	2	1	1.5	1	1	1	2	2	2
Malty	1	3	2	2	1	1.5	1	1	1	1	1	1
Sweet	0	1	0.5	3.5	4	3.75	3	4	3.5	3	4	3.5
Acetaldehyde	2	0	0	0	3	4	3.5	3	2	2.5	2	3
Oxidised	2	0	1	1	0	0.5	1	0	0.5	1	1	1
Acidic	0	0	0	2	3	2.5	1	2	1.5	2	1	1.5
Overall quality	2	3	4	3.5	4	5	4.5	3	4	3.5	3	2

Beer Taste (0-5)

	Taster 1		**Mean**	Taster 2		**Mean**	Taster 3		**Mean**	Taster 4		**Mean**
Fruity	3	1	2	4	3	3.5	3	4	3.5	1	3	2
Spicy	2	3	2.5	3	2	2.5	4	2	3	1	2	1.5
Grainy	1	2	1.5	3	1	2	2	2	2	3	3	3
Malty	2	3	2.5	2	1	1.5	2	2	2	3	2	2.5
Sulphury	2	0	1	1	1	1	3	2	2.5	1	1	1
Acetaldehyde	0	3	0	1.5	4	4	4	3	4	3.5	2	1
Phenolic	3	0	1.5	3	3	3	3	2	2.5	3	1	2
Oxidised	2	0	1	1	1	1	3	1	2	1	1	1
Acidic	1	0	0.5	2	3.5	2.75	4	3	3.5	3	2	2.5
Astrigent	0	2	1	1	1	1	1	2	1.5	2	1	1.5
Overall quality	2	2	4	3	4	4	4	4	4	4	4	4

Sensory Evaluation

MELANOIDIN MALT (Fresh)

Beer Aroma (0-5)

	Taster 5		**Mean**	Taster 6		**Mean**	Taster 7		**Mean**	Taster 8		**Mean**
Fruity	2	0	1	3	4	3.5	1	0	0.5	2	2	2
Floral	0	0	0	3	4	3.5	1	1	1	2	2	2
Hoppy	1	1	1	2	1	1.5	1	3	2	1	1	1
Grainy	0	0	0	2	1	1.5	2	0	1	0	1	0.5
Malty	0	1	0.5	1	1	1	3	2	2.5	0	1	0.5
Sweet	2	1	1.5	3	3	3	3	1	2	2	2	2
Acetaldehyde	2	2	0	1	2	2	2	1	0	0.5	2	3
Oxidised	0	0	0	0	1	0.5	0	0	0	0	1	0.5
Acidic	0	0	0	0	1	0.5	0	0	0	0	1	0.5
Overall quality	2	4	4	4	4	4	4	4	2	3	4	4

Beer Taste (0-5)

	Taster 5		**Mean**	Taster 6		**Mean**	Taster 7		**Mean**	Taster 8		**Mean**
Fruity	0	0	0	3	4	3.5	0	0	0	0	1	0.5
Spicy	0	0	0	3	2	2.5	1	2	1.5	0	1	0.5
Grainy	0	0	0	1	2	1.5	0	3	1.5	2	2	2
Malty	1	2	1.5	2	1	1.5	2	1	1.5	2	2	2
Sulphury	0	0	0	0	1	0.5	1	1	1	4	3	3.5
Acetaldehyde	0	1	0	0.5	3	3	3	0	0	0	1	2
Phenolic	0	0	0	0	2	1	1	1	1	0	1	0.5
Oxidised	0	0	0	0	1	0.5	1	3	2	4	3	3.5
Acidic	0	0	0	1	0	0.5	0	1	0.5	2	1	1.5
Astrigent	1	0	0.5	2	1	1.5	2	2	2	3	3	3
Overall quality	2	4	3	3.5	4	3	3.5	4	1	2.5	2	1

Sensory Evaluation

MELANOIDIN MALT (Fresh)

Beer Aroma (0-5)

	Taster 9		**Mean**	Taster 10		**Mean**
Fruity	2	3	2.5	4	2	3
Floral	2	2	2	2	1	1.5
Hoppy	0	2	1	1	1	1
Grainy	0	0	0	1	2	1.5
Malty	0	0	0	1	2	1.5
Sweet	1	1	1	3	3	3
Acetaldehyde	2	1	2	1.5	1	3
Oxidised	1	0	0.5	0	0	0
Acidic	1	1	1	0	2	1
Overall quality	2	3.5	3	3.25	5	1

Beer Taste (0-5)

	Taster 9		**Mean**	Taster 10		**Mean**
Fruity	3	4	3.5	4	3	3.5
Spicy	1	1	1	3	2	2.5
Grainy	1	2	1.5	1	3	2
Malty	1	2	1.5	3	1	2
Sulphury	1	2	1.5	0	0	0
Acetaldehyde	0	2	3	2.5	1	1
Phenolic	0	0	0	1	3	2
Oxidised	1	1	1	0	1	0.5
Acidic	1	2	1.5	0	2	1
Astrigent	4	2	3	2	1	1.5
Overall quality	2	3.5	3	3.25	5	3

Table A.9.5 Sensory evaluation results of the second round of forced aged locally-brewed beer colour adjusted with melanoidin malt

Sensory Evaluation

MELANOIDIN MALT (Forced aged)

Beer Aroma (0-5)

	Taster 1		**Mean**	Taster 2		**Mean**	Taster 3		**Mean**	Taster 4		**Mean**
Fruity	3	1	2	1	0	0.5	5	5	5	4	3	3.5
Floral	2	0	1	1	1	1	4	3	3.5	3	2	2.5
Hoppy	2	0	1	3	4	3.5	3	3	3	1	0	0.5
Grainy	4	3	3.5	4	5	4.5	2	2	2	2	1	1.5
Malty	3	0	1.5	5	5	5	2	2	2	2	1	1.5
Sweet	1	0	0.5	2	2.5	2.25	5	4	4.5	4	3	3.5
Acetaldehyde	2	0	1	0.5	1	1	1	3	2	2.5	3	2
Oxidised	0	3	1.5	3	4	3.5	1	2	1.5	1	4	2.5
Acidic	0	1	0.5	1	3	2	3	1	2	2	2	2
Overall quality	2	4	1	2.5	2	2	2	3	4	3.5	3	4

Beer Taste (0-5)

	Taster 1		**Mean**	Taster 2		**Mean**	Taster 3		**Mean**	Taster 4		**Mean**
Fruity	4	3	3.5	1	2	1.5	3	3	3	1	4	2.5
Spicy	4	2	3	4	4	4	3	4	3.5	1	3	2
Grainy	2	1	1.5	4	5	4.5	3	2	2.5	1	1	1
Malty	2	0	1	5	5	5	3	2	2.5	1	0	0.5
Sulphury	1	0	0.5	4	4	4	3	2	2.5	3	3	3
Acetaldehyde	0	3	2	2.5	1	2	1.5	3	3	3	2	3
Phenolic	2	2	2	3	4.5	3.75	3	3	3	5	4	4.5
Oxidised	1	2	1.5	3	3	3	2	2	2	2	2	2
Acidic	0	1	0.5	1	1	1	3	3	3	2	2	2
Astrigent	0	1	0.5	3	1	2	2	2	2	1	2	1.5
Overall quality	2	4	3	3.5	2	4	3	3	2	2.5	1	2

Sensory Evaluation

MELANOIDIN MALT (Forced aged)

Beer Aroma (0-5)

	Taster 5		**Mean**	Taster 6		**Mean**	Taster 7		**Mean**	Taster 8		**Mean**
Fruity	1	2	1.5	4	2	3	1	1	1	4	1	2.5
Floral	0	0	0	3	2	2.5	0	1	0.5	3	4	3.5
Hoppy	1	0	0.5	1	1	1	0	2	1	2	2	2
Grainy	0	0	0	4	3	3.5	2	0	1	0	1	0.5
Malty	0	0	0	2	3	2.5	1	0	0.5	1	2	1.5
Sweet	1	0	0.5	1	4	2.5	1	2	1.5	3	5	4
Acetaldehyde	2	1	2	1.5	2	2	2	0	2	1	4	2
Oxidised	0	0	0	1	3	2	4	3	3.5	0	1	0.5
Acidic	0	2	1	0	1	0.5	2	1	1.5	1	1	1
Overall quality	2	2	2	2	3	3	3	0	1	0.5	1	3

Beer Taste (0-5)

	Taster 5		**Mean**	Taster 6		**Mean**	Taster 7		**Mean**	Taster 8		**Mean**
Fruity	1	0	0.5	3	3	3	0	0	0	3	0	1.5
Spicy	0	3	1.5	2	2	2	1	1	1	2	2	2
Grainy	0	1	0.5	3	2	2.5	0	2	1	1	0	0.5
Malty	0	0	0	2	3	2.5	1	1	1	2	0	1
Sulphury	0	0	0	4	0	2	4	3	3.5	3	2	2.5
Acetaldehyde	0	0	0	0	2	2	2	0	1	0.5	4	0
Phenolic	0	0	0	2	3	2.5	3	4	3.5	0	0	0
Oxidised	0	0	0	3	2	2.5	3	3	3	2	5	3.5
Acidic	0	2	1	1	1	1	1	1	1	2	4	3
Astrigent	0	3	1.5	1	3	2	2	2	2	3	0	1.5
Overall quality	2	2	2	2	2	2	2	0	1	0.5	3	0

Sensory Evaluation

MELANOIDIN MALT (Forced aged)

Beer Aroma (0-5)

	Taster 9		**Mean**	Taster 10		**Mean**
Fruity	2	2	2	2	2	2
Floral	1	1	1	1	3	2
Hoppy	1	3	2	1	0	0.5
Grainy	1	2	1.5	2	3	2.5
Malty	0	1	0.5	2	2	2
Sweet	1	1	1	3	2	2.5
Acetaldehyde	2	0	1	0.5	4	4
Oxidised	0	0	0	1	2	1.5
Acidic	0	0	0	2	2	2
Overall quality	2	1	3	2	1	2

Beer Taste (0-5)

	Taster 9		**Mean**	Taster 10		**Mean**
Fruity	2	4	3	3	2	2.5
Spicy	1	2	1.5	3	0	1.5
Grainy	2	2	2	1	3	2
Malty	1	3	2	2	4	3
Sulphury	2	2	2	4	1	2.5
Acetaldehyde	0	1	4	2.5	1	2
Phenolic	2	1	1.5	3	2	2.5
Oxidised	2	1	1.5	3	2	2.5
Acidic	0	2	1	0	2	1
Astrigent	3	3	3	1	3	2
Overall quality	2	1	2	1.5	2	2

Table A.9.6 Sensory evaluation results of the second round of spontaneously aged locally-brewed beer colour adjusted with melanoidin malt

Sensory Evaluation

MELANOIDIN MALT (Spontaneously aged)

Beer Aroma (0-5)

	Taster 1		**Mean**	Taster 2		**Mean**	Taster 3		**Mean**	Taster 4		**Mean**
Fruity	0	3	1.5	1	3	2	3	3	3	2	2	2
Floral	0	2	1	1	3	2	2	3	2.5	4	3	3.5
Hoppy	0	2	1	2	3	2.5	2	3	2.5	1	2	1.5
Grainy	3	1	2	2	2	2	1	2	1.5	2	2	2
Malty	1	1	1	3	2	2.5	2	2	2	2	2	2
Sweet	0	0	0	1	3	2	3	4	3.5	3	3	3
Acetaldehyde	2	1	0	0.5	1	3	2	3	3	3	1	2
Oxidised	2	0	1	3	1	2	2	1	1.5	1	1	1
Acidic	0	0	0	1	2	1.5	0	2	1	2	1	1.5
Overall quality	2	2	2	2	3	4	3.5	3	4	3.5	4	4

Beer Taste (0-5)

	Taster 1		**Mean**	Taster 2		**Mean**	Taster 3		**Mean**	Taster 4		**Mean**
Fruity	3	1	2	1	2	1.5	2	2	2	3	3	3
Spicy	2	2	2	2	2	2	2	4	3	2	2	2
Grainy	1	2	1.5	3	3	3	1	1	1	1	2	1.5
Malty	1	3	2	3	3	3	2	1	1.5	1	1	1
Sulphury	0	0	0	5	2	3.5	1	2	1.5	1	2	1.5
Acetaldehyde	0	1	0	0.5	1	3	2	3	2	2.5	3	2
Phenolic	0	0	0	2	3	2.5	1	3	2	2	3	2.5
Oxidised	1	0	0.5	2	2	2	2	2	2	1	2	1.5
Acidic	0	0	0	1	1	1	0	2	1	2	3	2.5
Astrigent	3	2	2.5	1	2	1.5	2	2	2	2	2	2
Overall quality	2	4	4	4	2	4	3	3	4	3.5	3	2

Sensory Evaluation

MELANOIDIN MALT (Spontaneously aged)

Beer Aroma (0-5)

	Taster 5		**Mean**	Taster 6		**Mean**	Taster 7		**Mean**	Taster 8		**Mean**
Fruity	1	3	2	3	3	3	2	0	1	3	3	3
Floral	1	2	1.5	2	3	2.5	1	0	0.5	2	2	2
Hoppy	0	2	1	2	3	2.5	2	1	1.5	2	1	1.5
Grainy	0	1	0.5	1	1	1	1	0	0.5	1	0	0.5
Malty	0	1	0.5	1	1	1	2	1	1.5	2	1	1.5
Sweet	3	3	3	1	2	1.5	1	1	1	3	2	2.5
Acetaldehyde	2	0	1	0.5	3	2	2.5	0	0	0	3	2
Oxidised	0	0	0	0	1	0.5	0	2	1	1	1	1
Acidic	0	0	0	0	0	0	1	2	1.5	1	1	1
Overall quality	2	4	4	4	4	3	3.5	2	1	1.5	4	2

Beer Taste (0-5)

	Taster 5		**Mean**	Taster 6		**Mean**	Taster 7		**Mean**	Taster 8		**Mean**
Fruity	1	2	1.5	3	4	3.5	1	0	0.5	2	1	1.5
Spicy	1	2	1.5	1	2	1.5	0	0	0	1	2	1.5
Grainy	0	0	0	1	1	1	1	1	1	1	3	2
Malty	1	0	0.5	2	1	1.5	2	2	2	2	3	2.5
Sulphury	0	0	0	0	0	0	0	2	1	1	4	2.5
Acetaldehyde	0	0	1	0.5	3	2	2.5	0	1	0.5	3	1
Phenolic	0	1	0.5	0	1	0.5	0	1	0.5	0	0	0
Oxidised	0	0	0	0	1	0.5	0	2	1	2	3	2.5
Acidic	0	0	0	2	2	2	0	1	0.5	0	0	0
Astrigent	2	2	2	2	1	1.5	2	2	2	2	1	1.5
Overall quality	2	4	4	4	4	3	3.5	2	4	3	3	2

Sensory Evaluation
MELANOIDIN MALT (Spontaneously aged)

Beer Aroma (0-5)

	Taster 9		**Mean**	Taster 10		**Mean**
Fruity	1	3	2	2	3	2.5
Floral	2	3	2.5	0	2	1
Hoppy	3	1	2	1	2	1.5
Grainy	1	2	1.5	0	1	0.5
Malty	1	2	1.5	0	2	1
Sweet	2	3	2.5	2	3	2.5
Acetaldehyde	2	2	0	1	0	2
Oxidised	1	2	1.5	0	2	1
Acidic	1	0	0.5	0	1	0.5
Overall quality	2	1	2	1.5	3	4

Beer Taste (0-5)

	Taster 9		**Mean**	Taster 10		**Mean**
Fruity	3	2	2.5	0	2	1
Spicy	1	1	1	1	2	1.5
Grainy	1	2	1.5	0	3	1.5
Malty	1	2	1.5	2	1	1.5
Sulphury	1	0	0.5	0	2	1
Acetaldehyde	0	2	1	1.5	0	1
Phenolic	0	2	1	0	0	0
Oxidised	1	1	1	0	2	1
Acidic	1	0	0.5	0	1	0.5
Astrigent	1	2	1.5	1	2	1.5
Overall quality	2	4	4	4	3	4

Table A.9.7 Sensory evaluation results of the second round of fresh locally-brewed beer colour adjusted with CARAFA® SPECIAL Type III

Sensory Evaluation

CARAFA® SPECIAL TYPE III (Fresh)

Beer Aroma (0-5)

	Taster 1		**Mean**	Taster 2		**Mean**	Taster 3		**Mean**	Taster 4		**Mean**
Fruity	2	3	2.5	3	3	3	0	3	1.5	3	2	2.5
Floral	2	3	2.5	3	3	3	1	2	1.5	2	2	2
Hoppy	0	1	0.5	2	3	2.5	1	1	1	0	0	0
Grainy	2	1	1.5	2	2	2	0	2	1	2	1	1.5
Malty	3	2	2.5	2	3.5	2.75	1	2	1.5	2	1	1.5
Sweet	3	2	2.5	3	2	2.5	0	2	1	3	0	1.5
Acetaldehyde	2	2	2	2	3	3	3	0	1	0.5	3	3
Oxidised	0	2	1	1	3.5	2.25	1	2	1.5	1	2	1.5
Acidic	1	0	0.5	1	1	1	0	1	0.5	1	1	1
Overall quality	2	4	2	3	3	2	2.5	2	3	2.5	4	1

Beer Taste (0-5)

	Taster 1		**Mean**	Taster 2		**Mean**	Taster 3		**Mean**	Taster 4		**Mean**
Fruity	3	2	2.5	2	2.5	2.25	1	2	1.5	3	4	3.5
Spicy	2	1	1.5	3	2	2.5	1	5	3	3	2	2.5
Grainy	1	3	2	3	3	3	2	3	2.5	1	3	2
Malty	2	2	2	2	2	2	2	3	2.5	1	2	1.5
Sulphury	0	1	0.5	3	1	2	0	4	2	2	1	1.5
Acetaldehyde	0	2	0	1	1	3	2	0	2	1	3	3
Phenolic	1	2	1.5	4	3	3.5	0	4	2	3	2	2.5
Oxidised	0	3	1.5	1	3	2	0	3	1.5	2	1	1.5
Acidic	0	2	1	1	2	1.5	0	3	1.5	2	1	1.5
Astrigent	3	4	3.5	4	3	3.5	1	5	3	2	1	1.5
Overall quality	2	4	2	3	2	2	2	2	1	1.5	3	3

Sensory Evaluation

CARAFA® SPECIAL TYPE III (Fresh)

Beer Aroma (0-5)

	Taster 5		**Mean**	Taster 6		**Mean**	Taster 7		**Mean**	Taster 8		**Mean**
Fruity	2	0	1	3	3	3	3	2	2.5	2	1	1.5
Floral	2	0	1	3	2	2.5	1	0	0.5	2	1	1.5
Hoppy	0	2	1	1	1	1	0	0	0	1	2	1.5
Grainy	0	1	0.5	0	1	0.5	0	1	0.5	1	1	1
Malty	0	0	0	2	1	1.5	1	1	1	2	1	1.5
Sweet	3	0	1.5	3	0	1.5	3	2	2.5	3	3	3
Acetaldehyde	2	0	0	0	3	3	3	0	0	0	1	2
Oxidised	0	0	0	0	2	1	1	2	1.5	1	1	1
Acidic	0	0	0	0	0	0	0	0	0	1	0	0.5
Overall quality	2	4	3	3.5	4	3	3.5	1	2	1.5	3	3

Beer Taste (0-5)

	Taster 5		**Mean**	Taster 6		**Mean**	Taster 7		**Mean**	Taster 8		**Mean**
Fruity	3	0	1.5	3	2	2.5	0	1	0.5	0	2	1
Spicy	0	2	1	2	1	1.5	1	1	1	0	1	0.5
Grainy	0	0	0	2	1	1.5	2	1	1.5	1	2	1.5
Malty	0	0	0	3	2	2.5	1	1	1	3	2	2.5
Sulphury	1	0	0.5	1	1	1	1	0	0.5	3	2	2.5
Acetaldehyde	0	0	0	0	2	2	2	0	0	0	2	0
Phenolic	0	0	0	0	1	0.5	2	1	1.5	1	0	0.5
Oxidised	0	0	0	0	4	2	1	3	2	4	2	3
Acidic	0	0	0	0	2	1	1	1	1	1	0	0.5
Astrigent	0	2	1	2	1	1.5	4	2	3	3	2	2.5
Overall quality	2	5	4	4.5	2	3	2.5	2	1	1.5	2	3

Sensory Evaluation

CARAFA® SPECIAL TYPE III (Fresh)

Beer Aroma (0-5)

	Taster 9		**Mean**	Taster 10		**Mean**
Fruity	2	4	3	3	4	3.5
Floral	3	2	2.5	2	2	2
Hoppy	2	1	1.5	0	0	0
Grainy	1	1	1	0	2	1
Malty	0	1	0.5	2	1	1.5
Sweet	1	2	1.5	3	0	1.5
Acetaldehyde	2	2	1	1.5	2	3
Oxidised	1	1	1	1	2	1.5
Acidic	0	1	0.5	0	0	0
Overall quality	2	4	4	4	4	2

Beer Taste (0-5)

	Taster 9		**Mean**	Taster 10		**Mean**
Fruity	3	3	3	3	4	3.5
Spicy	1	2	1.5	0	1	0.5
Grainy	1	1	1	1	3	2
Malty	3	2	2.5	0	3	1.5
Sulphury	0	0	0	1	0	0.5
Acetaldehyde	0	3	0	1.5	1	0
Phenolic	1	0	0.5	0	0	0
Oxidised	1	1	1	0	2	1
Acidic	2	2	2	1	2	1.5
Astrigent	3	3	3	2	1	1.5
Overall quality	2	4	4	4	4	4

Table A.9.8 Sensory evaluation results of the second round of forced aged locally-brewed beer colour adjusted with CARAFA® SPECIAL Type III

Sensory Evaluation

CARAFA® SPECIAL TYPE III (Forced aged)

Beer Aroma (0-5)

	Taster 1		**Mean**	Taster 2		**Mean**	Taster 3		**Mean**	Taster 4		**Mean**
Fruity	2	3	2.5	3.5	2	2.75	3	5	4	3	4	3.5
Floral	2	2	2	3	2	2.5	3	3	3	2	3	2.5
Hoppy	1	1	1	2	1	1.5	1	1	1	1	0	0.5
Grainy	0	1	0.5	2	4	3	2	3	2.5	2	2	2
Malty	0	1	0.5	2	4	3	2	3	2.5	2	2	2
Sweet	1	2	1.5	3.5	2	2.75	3	2	2.5	3	3	3
Acetaldehyde	2	0	3	1.5	3	2	2.5	4	4	4	3	4
Oxidised	0	3	1.5	4	4	4	2	4	3	2	2	2
Acidic	0	0	0	2	1	1.5	1	5	3	1	2	1.5
Overall quality	2	3	1	2	2	1	1.5	3	1	2	2	4

Beer Taste (0-5)

	Taster 1		**Mean**	Taster 2		**Mean**	Taster 3		**Mean**	Taster 4		**Mean**
Fruity	3	2	2.5	2	2	2	4	3	3.5	2	1	1.5
Spicy	3	0	1.5	2	4	3	3	5	4	2	2	2
Grainy	2	3	2.5	3	3	3	1	2	1.5	2	2	2
Malty	2	2	2	3	3	3	1	2	1.5	1	2	1.5
Sulphury	0	2	1	0	2	1	0	4	2	2	2	2
Acetaldehyde	0	1	2	1.5	3	2	2.5	3	2	2.5	2	1
Phenolic	1	0	0.5	2	4	3	2	3	2.5	3	3	3
Oxidised	0	4	2	4	4	4	3	4	3.5	2	1	1.5
Acidic	0	2	1	1	4	2.5	1	2	1.5	1	1	1
Astrigent	3	4	3.5	2	4	3	3	3	3	3	1	2
Overall quality	2	3	1	2	2	1	1.5	2	2	2	2	2

Sensory Evaluation

CARAFA® SPECIAL TYPE III (Forced aged)

Beer Aroma (0-5)

	Taster 5		**Mean**	Taster 6		**Mean**	Taster 7		**Mean**	Taster 8		**Mean**
Fruity	3	0	1.5	4	4	4	1	3	2	0	1	0.5
Floral	0	0	0	2	2	2	0	2	1	1	2	1.5
Hoppy	0	0	0	1	0	0.5	1	1	1	1	1	1
Grainy	0	0	0	2	2	2	2	3	2.5	3	3	3
Malty	0	0	0	2	2	2	1	0	0.5	3	3	3
Sweet	0	0	0	3	2	2.5	0	2	1	3	4	3.5
Acetaldehyde	2	4	0	2	3	3	3	0	2	1	0	0
Oxidised	0	0	0	2	4	3	3	1	2	1	1	1
Acidic	0	0	0	0	4	2	1	0	0.5	0	0	0
Overall quality	2	3	2	2.5	2	2	2	2	2	2	2	3

Beer Taste (0-5)

	Taster 5		**Mean**	Taster 6		**Mean**	Taster 7		**Mean**	Taster 8		**Mean**
Fruity	3	0	1.5	3	2	2.5	0	1	0.5	0	1	0.5
Spicy	0	0	0	1	3	2	0	0	0	0	1	0.5
Grainy	0	0	0	2	1	1.5	2	2	2	3	3	3
Malty	0	3	1.5	1	1	1	1	1	1	3	3	3
Sulphury	0	0	0	0	2	1	1	0	0.5	2	4	3
Acetaldehyde	0	3	0	1.5	4	2	3	0	1	0.5	0	0
Phenolic	0	0	0	1	2	1.5	2	0	1	0	1	0.5
Oxidised	0	0	0	3	4	3.5	3	0	1.5	1	2	1.5
Acidic	0	0	0	1	3	2	1	0	0.5	0	0	0
Astrigent	2	1	1.5	1	4	2.5	3	3	3	1	1	1
Overall quality	2	4	3	3.5	3	2	2.5	1	2	1.5	3	2

Sensory Evaluation

CARAFA® SPECIAL TYPE III (Forced aged)

Beer Aroma (0-5)

	Taster 9		**Mean**	Taster 10		**Mean**
Fruity	2	2	2	2	3	2.5
Floral	3	1	2	1	1	1
Hoppy	1	2	1.5	0	1	0.5
Grainy	1	1	1	1	3	2
Malty	1	1	1	1	2	1.5
Sweet	1	1	1	4	2	3
Acetaldehyde	2	3	2	2.5	3	4
Oxidised	0	1	0.5	1	4	2.5
Acidic	1	1	1	0	1	0.5
Overall quality	2	4	4	4	2	1

Beer Taste (0-5)

	Taster 9		**Mean**	Taster 10		**Mean**
Fruity	3	2	2.5	4	0	2
Spicy	2	2	2	0	0	0
Grainy	3	1	2	2	3	2.5
Malty	1	3	2	2	1	1.5
Sulphury	1	1	1	2	2	2
Acetaldehyde	0	3	3	3	2	0
Phenolic	1	0	0.5	0	0	0
Oxidised	1	0	0.5	2	3	2.5
Acidic	2	2	2	1	1	1
Astrigent	3	3	3	3	2	2.5
Overall quality	2	4	3	3.5	2	3

Table A.9.9 Sensory evaluation results of the second round of spontaneously aged locally-brewed beer colour adjusted with CARAFA® SPECIAL Type III

Sensory Evaluation

CARAFA® SPECIAL TYPE III (Spontaneously aged)

Beer Aroma (0-5)

	Taster 1		**Mean**	Taster 2		**Mean**	Taster 3		**Mean**	Taster 4		**Mean**
Fruity	2	4	3	3	4	3.5	4	2.5	3.25	2	1	1.5
Floral	2	3	2.5	3	4	3.5	3	3	3	2	2	2
Hoppy	2	3	2.5	1	1	1	2.5	1	1.75	0	3	1.5
Grainy	1	2	1.5	2	2	2	2	1.5	1.75	3	1	2
Malty	1	1	1	3.5	1	2.25	2	1.5	1.75	2	1	1.5
Sweet	2	3	2.5	3	4	3.5	3	3	3	2	1	1.5
Acetaldehyde	2	1	2	1.5	3	4	3.5	2	3	2.5	2	2
Oxidised	0	0	0	1	1	1	1	0	0.5	1	3	2
Acidic	0	0	0	1	1	1	1	0	0.5	1	2	1.5
Overall quality	2	2	3	2.5	3	4	3.5	4	2	3	2	1

Beer Taste (0-5)

	Taster 1		**Mean**	Taster 2		**Mean**	Taster 3		**Mean**	Taster 4		**Mean**
Fruity	2	3	2.5	2	4	3	4	2	3	2	3	2.5
Spicy	2	3	2.5	3.5	4	3.75	3	3	3	1	2	1.5
Grainy	1	2	1.5	3	1	2	3	2	2.5	2	2	2
Malty	3	3	3	3	2	2.5	3	3	3	2	1	1.5
Sulphury	0	3	1.5	2	1	1.5	3	4	3.5	2	4	3
Acetaldehyde	0	0	3	1.5	2	4	3	3	2	2.5	1	3
Phenolic	0	2	1	5	4	4.5	2	3	2.5	3	3	3
Oxidised	1	3	2	2	1	1.5	3	1	2	1	2	1.5
Acidic	0	1	0.5	1	1	1	2	2	2	2	1	1.5
Astrigent	3	3	3	5	4	4.5	2	2	2	2	2	2
Overall quality	2	2	2	2	2	3	2.5	3	2	2.5	2	2

Sensory Evaluation

CARAFA® SPECIAL TYPE III (Spontaneously Aged)

Beer Aroma (0-5)

	Taster 5		**Mean**	Taster 6		**Mean**	Taster 7		**Mean**	Taster 8		**Mean**
Fruity	0	0	0	3	3	3	1	3	2	4	1	2.5
Floral	0	0	0	1	2	1.5	0	1	0.5	2	1	1.5
Hoppy	0	2	1	2	2	2	1	1	1	1	1	1
Grainy	0	0	0	1	2	1.5	1	2	1.5	1	2	1.5
Malty	0	0	0	0	2	1	0	2	1	2	3	2.5
Sweet	0	0	0	3	4	3.5	2	3	2.5	2	4	3
Acetaldehyde	2	1	0	0.5	1	1	1	0	1	0.5	4	0
Oxidised	1	0	0.5	1	2	1.5	2	0	1	1	0	0.5
Acidic	1	0	0.5	0	2	1	0	0	0	1	0	0.5
Overall quality	2	2	3	2.5	2	3	2.5	2	4	3	3	3

Beer Taste (0-5)

	Taster 5		**Mean**	Taster 6		**Mean**	Taster 7		**Mean**	Taster 8		**Mean**
Fruity	0	0	0	2	3	2.5	0	0	0	2	2	2
Spicy	0	1	0.5	3	2	2.5	0	0	0	0	1	0.5
Grainy	0	0	0	3	2	2.5	2	1	1.5	2	2	2
Malty	0	1	0.5	3	3	3	2	2	2	2	3	2.5
Sulphury	0	0	0	2	4	3	0	0	0	2	3	2.5
Acetaldehyde	0	0	0	0	2	2	2	0	0	0	1	2
Phenolic	0	0	0	4	2	3	1	1	1	0	0	0
Oxidised	3	0	1.5	2	3	2.5	2	4	3	2	3	2.5
Acidic	3	0	1.5	2	1	1.5	0	1	0.5	0	0	0
Astrigent	2	1	1.5	2	2	2	3	2	2.5	1	3	2
Overall quality	2	0	4	2	3	2	2.5	2	1	1.5	3	2

Sensory Evaluation

CARAFA® SPECIAL TYPE III (Spontaneously aged)

Beer Aroma (0-5)

	Taster 9		**Mean**	Taster 10		**Mean**
Fruity	2	3	2.5	2	2	2
Floral	2	1	1.5	4	2	3
Hoppy	2	2	2	2	3	2.5
Grainy	1	1	1	0	2	1
Malty	0	1	0.5	2	1	1.5
Sweet	2	3	2.5	3	3	3
Acetaldehyde	2	2	2	2	0	2
Oxidised	0	0	0	1	0	0.5
Acidic	2	1	1.5	2	1	1.5
Overall quality	2	3	2	2.5	2	2

Beer Taste (0-5)

	Taster 9		**Mean**	Taster 10		**Mean**
Fruity	1	3	2	2	3	2.5
Spicy	2	2	2	0	2	1
Grainy	1	2	1.5	1	2	1.5
Malty	1	3	2	3	3	3
Sulphury	0	1	0.5	1	3	2
Acetaldehyde	0	4	3	3.5	3	3
Phenolic	0	1	0.5	4	2	3
Oxidised	0	1	0.5	1	1	1
Acidic	2	2	2	2	1	1.5
Astrigent	2	3	2.5	2	1	1.5
Overall quality	2	3	3	3	2	3

Table A.9.10 Sensory evaluation results of the second round of fresh locally-brewed beer colour adjusted with caramel #301

Sensory Evaluation

CARAMEL #301 (Fresh)

Beer Aroma (0-5)

	Taster 1		**Mean**	Taster 2		**Mean**	Taster 3		**Mean**	Taster 4		**Mean**
Fruity	3	2	2.5	4	3	3.5	5	4	4.5	4	4	4
Floral	2	1	1.5	3	3	3	3	3	3	4	4	4
Hoppy	0	1	0.5	1	2	1.5	2	1	1.5	1	0	0.5
Grainy	2	2	2	2	2	2	4	2	3	1	2	1.5
Malty	2	2	2	2	2	2	4	2	3	1	3	2
Sweet	3	1	2	4	3	3.5	3	2	2.5	2	4	3
Acetaldehyde	2	4	1	2.5	4	3	3.5	3	3	3	2	3
Oxidised	2	2	2	1	1	1	1	1	1	1	2	1.5
Acidic	0	1	0.5	2	4	3	3	1	2	2	3	2.5
Overall quality	2	3	2	2.5	4	2	3	2	3	2.5	3	3

Beer Taste (0-5)

	Taster 1		**Mean**	Taster 2		**Mean**	Taster 3		**Mean**	Taster 4		**Mean**
Fruity	2	2	2	3	3	3	2	3	2.5	2	2	2
Spicy	3	2	2.5	1	1	1	4	4	4	2	3	2.5
Grainy	2	2	2	3	2	2.5	2	1	1.5	1	1	1
Malty	2	2	2	3.5	2	2.75	2	1	1.5	1	1	1
Sulphury	1	1	1	1	1	1	4	3	3.5	1	3	2
Acetaldehyde	0	3	0	1.5	4	3	3.5	3	2	2.5	3	3
Phenolic	0	0	0	2	2	2	4	4	4	3	3	3
Oxidised	3	1	2	1	3	2	2	2	2	1	2	1.5
Acidic	0	0	0	2	4	3	4	3	3.5	3	3	3
Astrigent	2	2	2	2	3	2.5	4	4	4	2	1	1.5
Overall quality	2	2	3	2.5	4	2	3	2	2	2	3	2

Sensory Evaluation

CARAMEL #301 (Fresh)

Beer Aroma (0-5)

	Taster 5		**Mean**	Taster 6		**Mean**	Taster 7		**Mean**	Taster 8		**Mean**
Fruity	0	0	0	4	4	4	1	4	2.5	1	3	2
Floral	0	0	0	3	3	3	2	1	1.5	1	2	1.5
Hoppy	0	0	0	2	2	2	2	1	1.5	3	2	2.5
Grainy	0	0	0	4	2	3	2	0	1	1	0	0.5
Malty	0	2.5	1.25	2	2	2	2	1	1.5	1	2	1.5
Sweet	0	3	1.5	3	2	2.5	3	2	2.5	1	2	1.5
Acetaldehyde	2	0	0	0	4	3	3.5	0	1	0.5	2	2
Oxidised	0	0	0	0	1	0.5	1	1	1	0	0	0
Acidic	0	0	0	0	1	0.5	2	1	1.5	2	0	1
Overall quality	2	2	5	3.5	2	3	2.5	3	3	3	3	4

Beer Taste (0-5)

	Taster 5		**Mean**	Taster 6		**Mean**	Taster 7		**Mean**	Taster 8		**Mean**
Fruity	0	0	0	2	2	2	1	1	1	1	2	1.5
Spicy	1	0	0.5	2	3	2.5	1	0	0.5	1	1	1
Grainy	0	0	0	2	1	1.5	1	2	1.5	2	0	1
Malty	0	2	1	2	2	2	2	2	2	3	2	2.5
Sulphury	0	0	0	1	1	1	0	0	0	1	2	1.5
Acetaldehyde	0	0	0	0	3	2	2.5	0	2	1	1	0
Phenolic	1	0	0.5	1	4	2.5	0	0	0	0	0	0
Oxidised	0	0	0	2	2	2	0	2	1	2	2	2
Acidic	2	0	1	2	0	1	1	1	1	0	0	0
Astrigent	2	0	1	2	3	2.5	3	2	2.5	4	3	3.5
Overall quality	2	2	5	3.5	3	3	3	4	2	3	3.5	3

Sensory Evaluation

CARAMEL #301 (Fresh)

Beer Aroma (0-5)

	Taster 9		**Mean**	Taster 10		**Mean**
Fruity	3	3	3	4	3	3.5
Floral	2	1	1.5	3	3	3
Hoppy	2	1	1.5	2	2	2
Grainy	1	2	1.5	2	1	1.5
Malty	1	3	2	1	3	2
Sweet	1	4	2.5	2	2	2
Acetaldehyde	2	2	2	2	2	2
Oxidised	0	1	0.5	2	0	1
Acidic	1	0	0.5	1	0	0.5
Overall quality	2	4	3	3.5	3	3

Beer Taste (0-5)

	Taster 9		**Mean**	Taster 10		**Mean**
Fruity	2	3	2.5	2	2	2
Spicy	1	3	2	1	4	2.5
Grainy	1	1	1	0	0	0
Malty	2	3	2.5	2	2	2
Sulphury	1	2	1.5	0	2	1
Acetaldehyde	0	2	1	1.5	2	2
Phenolic	1	1	1	0	3	1.5
Oxidised	1	0	0.5	1	2	1.5
Acidic	1	0	0.5	1	1	1
Astrigent	1	3	2	1	3	2
Overall quality	2	4	4	4	3	4

Table A.9.11 Sensory evaluation results of the second round of forced aged locally-brewed beer colour adjusted with caramel #301

Sensory Evaluation

CARAMEL #301 (Forced aged)

Beer Aroma (0-5)

	Taster 1		**Mean**	Taster 2		**Mean**	Taster 3		**Mean**	Taster 4		**Mean**
Fruity	1	1	1	3	3	3	5	5	5	4	3	3.5
Floral	0	1	0.5	2	3	2.5	4	5	4.5	4	3	3.5
Hoppy	1	3	2	3	2	2.5	4	3	3.5	0	1	0.5
Grainy	3	1	2	4	4	4	4	3	3.5	1	2	1.5
Malty	3	1	2	4	4	4	4	3	3.5	1	2	1.5
Sweet	3	2	2.5	2	3	2.5	3	5	4	3	2	2.5
Acetaldehyde	2	2	4	3	2	3	2.5	4	4	4	3	3
Oxidised	4	3	3.5	4	3	3.5	1	2	1.5	1	1	1
Acidic	0	1	0.5	1	1	1	4	3	3.5	1	2	1.5
Overall quality	2	1	2	1.5	2	2	2	4	4	4	3	4

Beer Taste (0-5)

	Taster 1		**Mean**	Taster 2		**Mean**	Taster 3		**Mean**	Taster 4		**Mean**
Fruity	0	3	1.5	2	2	2	4	5	4.5	3	2	2.5
Spicy	2	3	2.5	1	2	1.5	5	3	4	3	1	2
Grainy	1	1	1	4	2	3	2	3	2.5	1	2	1.5
Malty	1	2	1.5	4	2	3	2	3	2.5	1	2	1.5
Sulphury	0	2	1	3	1	2	3	4	3.5	2	3	2.5
Acetaldehyde	0	3	3	3	2	3	2.5	4	4	4	2	2
Phenolic	0	3	1.5	4	3	3.5	3.5	3	3.25	1	4	2.5
Oxidised	3	2	2.5	3	1	2	3	2	2.5	0	3	1.5
Acidic	0	1	0.5	1	1	1	4	3	3.5	3	1	2
Astrigent	2	3	2.5	2	3	2.5	2	4	3	4	1	2.5
Overall quality	2	2	2	2	2	3	2.5	3	4	3.5	3	1

Sensory Evaluation

CARAMEL #301 (Forced aged)

Beer Aroma (0-5)

	Taster 5		**Mean**	Taster 6		**Mean**	Taster 7		**Mean**	Taster 8		**Mean**
Fruity	0	0	0	1	4	2.5	2	0	1	1	3	2
Floral	0	0	0	2	3	2.5	1	0	0.5	0	0	0
Hoppy	0	0	0	0	1	0.5	1	0	0.5	0	1	0.5
Grainy	0	0	0	3	1	2	1	1	1	0	2	1
Malty	0	0	0	1	2	1.5	2	1	1.5	2	2	2
Sweet	0	0	0	3	1	2	1	1	1	5	3	4
Acetaldehyde	2	0	0	0	2	1	1.5	0	0	0	0	1
Oxidised	3	2	2.5	2	0	1	2	3	2.5	0	1	0.5
Acidic	0	2	1	0	0	0	1	4	2.5	0	0	0
Overall quality	2	1	1	1	2	3	2.5	2	0	1	2	2

Beer Taste (0-5)

	Taster 5		**Mean**	Taster 6		**Mean**	Taster 7		**Mean**	Taster 8		**Mean**
Fruity	0	0	0	0	1	0.5	0	1	0.5	0	1	0.5
Spicy	0	0	0	3	2	2.5	0	1	0.5	1	0	0.5
Grainy	0	0	0	1	2	1.5	1	1	1	2	2	2
Malty	0	0	0	2	2	2	1	1	1	3	2	2.5
Sulphury	0	0	0	1	0	0.5	1	0	0.5	4	3	3.5
Acetaldehyde	0	0	0	0	2	0	1	0	0	0	0	0
Phenolic	0	0	0	0	1	0.5	3	0	1.5	1	0	0.5
Oxidised	2	2	2	3	0	1.5	3	3	3	4	3	3.5
Acidic	0	2	1	0	0	0	2	3	2.5	3	0	1.5
Astrigent	2	1	1.5	2	2	2	2	3	2.5	3	2	2.5
Overall quality	2	1	1	1	2	3	2.5	1	1	1	1	2

Sensory Evaluation

CARAMEL #301 (Forced aged)

Beer Aroma (0-5)

	Taster 9		**Mean**	Taster 10		**Mean**
Fruity	1	2	1.5	1	2	1.5
Floral	1	1	1	0	0	0
Hoppy	0	1	0.5	0	1	0.5
Grainy	1	0	0.5	3	2	2.5
Malty	1	1	1	1	1	1
Sweet	1	2	1.5	2	0	1
Acetaldehyde	2	1	3	2	1	2
Oxidised	0	2	1	2	2	2
Acidic	1	2	1.5	1	1	1
Overall quality	2	4	3	3.5	2	2

Beer Taste (0-5)

	Taster 9		**Mean**	Taster 10		**Mean**
Fruity	2	2	2	0	2	1
Spicy	3	2	2.5	2	3	2.5
Grainy	2	1	1.5	3	2	2.5
Malty	2	2	2	3	2	2.5
Sulphury	1	1	1	0	0	0
Acetaldehyde	0	3	3	3	0	3
Phenolic	1	2	1.5	3	3	3
Oxidised	1	2	1.5	3	1	2
Acidic	1	1	1	3	1	2
Astrigent	1	3	2	2	2	2
Overall quality	2	4	4	4	2	2

Table A.9.12 Sensory evaluation results of the second round of spontaneously aged locally-brewed beer colour adjusted with caramel #301

Sensory Evaluation

CARAMEL #301 (Spontaneously aged)

Beer Aroma (0-5)

	Taster 1		**Mean**	Taster 2		**Mean**	Taster 3		**Mean**	Taster 4		**Mean**
Fruity	1	4	2.5	3	4	3.5	4	5	4.5	3	2	2.5
Floral	1	3	2	3	3	3	4	4	4	3	2	2.5
Hoppy	3	3	3	1	2	1.5	3	2	2.5	0	1	0.5
Grainy	3	2	2.5	3	2	2.5	3	3	3	1	4	2.5
Malty	3	3	3	4	2	3	3	3	3	1	3	2
Sweet	2	4	3	3	3.5	3.25	4	4	4	3	3	3
Acetaldehyde	2	1	0	0.5	3	4	3.5	2	2	2	2	2
Oxidised	1	1	1	2	1	1.5	1	1	1	1	2	1.5
Acidic	1	0	0.5	1	3	2	2	3	2.5	2	2	2
Overall quality	2	4	4	4	2	4	3	3	4	3.5	3	3

Beer Taste (0-5)

	Taster 1		**Mean**	Taster 2		**Mean**	Taster 3		**Mean**	Taster 4		**Mean**
Fruity	1	4	2.5	2	4	3	4	4	4	4	2	3
Spicy	2	4	3	1	2	1.5	3	3	3	3	4	3.5
Grainy	3	2	2.5	3	2	2.5	2	1	1.5	2	3	2.5
Malty	4	3	3.5	3	2	2.5	2	1	1.5	1	2	1.5
Sulphury	2	0	1	1	1	1	2	3	2.5	1	2	1.5
Acetaldehyde	0	1	3	2	2	4	3	4	2	3	3	2
Phenolic	0	0	0	4	4	4	2	3	2.5	3	3	3
Oxidised	0	2	1	3	1	2	1	1	1	1	1	1
Acidic	0	0	0	1	3	2	2	3	2.5	3	2	2.5
Astrigent	0	1	0.5	4	3	3.5	4	4	4	1	2	1.5
Overall quality	2	4	3	3.5	2	4	3	2	3	2.5	4	4

Sensory Evaluation

CARAMEL #301 (Spontaneously aged)

Beer Aroma (0-5)

	Taster 5		**Mean**	Taster 6		**Mean**	Taster 7		**Mean**	Taster 8		**Mean**
Fruity	2	0	1	3	4	3.5	1	1	1	1	2	1.5
Floral	0	0	0	3	3	3	2	0	1	1	2	1.5
Hoppy	0	0	0	1	2	1.5	2	2	2	1	2	1.5
Grainy	0	2	1	3	2	2.5	1	1	1	1	2	1.5
Malty	0	0	0	1	3	2	2	1	1.5	1	2	1.5
Sweet	3	0	1.5	3	4	3.5	2	1	1.5	2	3	2.5
Acetaldehyde	2	0	0	0	2	2	2	1	1	1	0	2
Oxidised	0	2	1	1	1	1	0	3	1.5	0	2	1
Acidic	0	0	0	1	1	1	0	2	1	0	0	0
Overall quality	2	5	2.5	3.75	3	4	3.5	3	1	2	3	2

Beer Taste (0-5)

	Taster 5		**Mean**	Taster 6		**Mean**	Taster 7		**Mean**	Taster 8		**Mean**
Fruity	0	0	0	2	2	2	1	1	1	0	0	0
Spicy	3	0	1.5	3	3	3	0	0	0	1	1	1
Grainy	0	0	0	3	2	2.5	1	1	1	0	2	1
Malty	0	2	1	2	1	1.5	2	1	1.5	1	2	1.5
Sulphury	0	0	0	2	1	1.5	0	0	0	0	4	2
Acetaldehyde	0	0	0	0	4	2	3	0	1	0.5	0	0
Phenolic	0	0	0	0	3	1.5	1	2	1.5	0	0	0
Oxidised	0	0	0	1	1	1	1	3	2	0	4	2
Acidic	0	0	0	1	3	2	0	1	0.5	0	0	0
Astrigent	4	1	2.5	4	1	2.5	2	1	1.5	4	3	3.5
Overall quality	2	2.5	3	2.75	3	3	3	3	1	2	2	1

Sensory Evaluation

CARAMEL #301 (Spontaneously aged)

Beer Aroma (0-5)

	Taster 9		**Mean**	Taster 10		**Mean**
Fruity	3	3	3	3	4	3.5
Floral	3	2	2.5	4	4	4
Hoppy	2	0	1	2	2	2
Grainy	1	0	0.5	3	3	3
Malty	1	2	1.5	0	3	1.5
Sweet	1	1	1	2	3	2.5
Acetaldehyde	2	2	1	1.5	2	2
Oxidised	0	0	0	0	2	1
Acidic	1	0	0.5	1	0	0.5
Overall quality	2	5	3	4	3	4

Beer Taste (0-5)

	Taster 9		**Mean**	Taster 10		**Mean**
Fruity	2	1	1.5	4	2	3
Spicy	1	2	1.5	2	3	2.5
Grainy	1	2	1.5	3	2	2.5
Malty	2	2	2	3	3	3
Sulphury	0	1	0.5	0	3	1.5
Acetaldehyde	0	3	0	1.5	3	2
Phenolic	1	0	0.5	2	0	1
Oxidised	1	2	1.5	1	1	1
Acidic	2	0	1	1	3	2
Astrigent	1	3	2	3	3	3
Overall quality	2	4	2	3	3	2

Table A.9.13 Sensory evaluation results of the second round of fresh locally-brewed beer (blank sample)

Sensory Evaluation

PILSNER MALT (Fresh)

Beer Aroma (0-5)

	Taster 1		**Mean**	Taster 2		**Mean**	Taster 3		**Mean**	Taster 4		**Mean**
Fruity	1	4	2.5	4	4	4	3	4	3.5	1	1	1
Floral	1	1	1	4	3	3.5	4	1	2.5	2	1	1.5
Hoppy	0	2	1	2	1	1.5	1	2	1.5	0	0	0
Grainy	0	1	0.5	2	2	2	1	1	1	1	1	1
Malty	2	1	1.5	2	2	2	2	1	1.5	1	1	1
Sweet	1	3	2	4	3	3.5	2	3	2.5	0	0	0
Acetaldehyde	2	0	2	1	4	4	4	3	3	3	3	0
Oxidised	0	0	0	1	1	1	2	2	2	2	3	2.5
Acidic	0	1	0.5	3	1	2	1	4	2.5	1	1	1
Overall quality	2	2	4	3	4	4	4	3	3	3	1	1

Beer Taste (0-5)

	Taster 1		**Mean**	Taster 2		**Mean**	Taster 3		**Mean**	Taster 4		**Mean**
Fruity	0	3	1.5	4	4	4	1	4	2.5	1	3	2
Spicy	1	2	1.5	3	1	2	3	4	3.5	3	2	2.5
Grainy	1	2	1.5	3	2	2.5	1	2	1.5	1	1	1
Malty	3	2	2.5	1	2	1.5	1	2	1.5	1	1	1
Sulphury	0	1	0.5	0	1	0.5	1	2	1.5	2	2	2
Acetaldehyde	0	0	3	1.5	4	4	4	3	3	3	2	1
Phenolic	0	4	2	2	3	2.5	2	4	3	3	4	3.5
Oxidised	0	2	1	1	1	1	2	2	2	2	2	2
Acidic	0	1	0.5	3	1	2	2	3	2.5	2	3	2.5
Astrigent	2	3	2.5	2	3.5	2.75	2	3	2.5	2	2	2
Overall quality	2	2	3	2.5	4	4	4	3	3	3	1	2

Sensory Evaluation

PILSNER MALT (Fresh)

Beer Aroma (0-5)

	Taster 5		**Mean**	Taster 6		**Mean**	Taster 7		**Mean**	Taster 8		**Mean**
Fruity	2	2	2	4	3	3.5	2	0	1	3	3	3
Floral	0	0	0	4	1	2.5	1	0	0.5	2	2	2
Hoppy	0	0	0	0	0	0	2	1	1.5	1	2	1.5
Grainy	0	0	0	2	2	2	1	2	1.5	1	0	0.5
Malty	0	0	0	2	2	2	2	1	1.5	2	1	1.5
Sweet	0	2	1	1	3	2	3	1	2	3	3	3
Acetaldehyde	2	0	3	1.5	3	4	3.5	1	0	0.5	2	3
Oxidised	0	0	0	2	3	2.5	0	4	2	0	0	0
Acidic	1	0	0.5	2	0	1	0	2	1	1	0	0.5
Overall quality	2	1	4	2.5	2	3	2.5	4	0	2	4	4

Beer Taste (0-5)

	Taster 5		**Mean**	Taster 6		**Mean**	Taster 7		**Mean**	Taster 8		**Mean**
Fruity	0	2	1	0	2	1	1	0	0.5	2	1	1.5
Spicy	0	0	0	0	2	1	0	2	1	0	1	0.5
Grainy	0	0	0	1	1	1	2	2	2	0	2	1
Malty	0	0	0	1	1	1	2	1	1.5	1	2	1.5
Sulphury	1	0	0.5	1	0	0.5	0	0	0	0	2	1
Acetaldehyde	0	0	2	1	4	3	3.5	1	0	0.5	3	3
Phenolic	0	0	0	2	4	3	0	1	0.5	1	0	0.5
Oxidised	0	0	0	2	2	2	0	2	1	1	2	1.5
Acidic	2	0	1	2	1	1.5	1	1	1	0	1	0.5
Astrigent	0	1	0.5	2	2	2	3	3	3	2	3	2.5
Overall quality	2	0	3	1.5	3	3	3	4	2	3	3	2

Sensory Evaluation

PILSNER MALT (Fresh)

Beer Aroma (0-5)

	Taster 9		**Mean**	Taster 10		**Mean**
Fruity	3	4	3.5	2	3	2.5
Floral	2	3	2.5	3	1	2
Hoppy	2	2	2	1	1	1
Grainy	1	1	1	1	1	1
Malty	1	1	1	2	1	1.5
Sweet	2	1	1.5	3	3	3
Acetaldehyde	2	3	2	2.5	3	3
Oxidised	0	1	0.5	0	0	0
Acidic	1	1	1	1	0	0.5
Overall quality	2	2	5	3.5	3	4

Beer Taste (0-5)

	Taster 9		**Mean**	Taster 10		**Mean**
Fruity	4	3	3.5	1	2	1.5
Spicy	2	1	1.5	1	2	1.5
Grainy	1	2	1.5	1	1	1
Malty	1	2	1.5	1	1	1
Sulphury	0	2	1	0	0	0
Acetaldehyde	0	3	3	3	3	2
Phenolic	1	0	0.5	2	0	1
Oxidised	1	1	1	1	0	0.5
Acidic	2	1	1.5	2	0	1
Astrigent	2	3	2.5	2	1	1.5
Overall quality	2	4	4	4	3	2

Table A.9.14 Sensory evaluation results of the second round of forced aged locally-brewed beer (blank sample)

Sensory Evaluation

PILSNER MALT (Forced aged)

Beer Aroma (0-5)

	Taster 1		**Mean**	Taster 2		**Mean**	Taster 3		**Mean**	Taster 4		**Mean**
Fruity	2	1	1.5	2	3	2.5	5	5	5	2	4	3
Floral	1	0	0.5	2	2	2	3	3	3	2	3	2.5
Hoppy	2	0	1	4	4	4	1	2	1.5	0	0	0
Grainy	3	2	2.5	3	2	2.5	2	1	1.5	3	1	2
Malty	2	2	2	4	2	3	2	1	1.5	3	1	2
Sweet	0	0	0	2	3	2.5	4	3	3.5	2	4	3
Acetaldehyde	2	3	1	2	2	4	3	3	4	3.5	2	2
Oxidised	4	3	3.5	2	1	1.5	2	1	1.5	3	1	2
Acidic	0	0	0	1	1	1	3	1	2	1	1	1
Overall quality	2	2.5	1	1.75	3	4	3.5	3	4	3.5	2	4

Beer Taste (0-5)

	Taster 1		**Mean**	Taster 2		**Mean**	Taster 3		**Mean**	Taster 4		**Mean**
Fruity	4	3	3.5	1	2	1.5	2	3	2.5	1	2	1.5
Spicy	3	2	2.5	3	1	2	3	2	2.5	1	2	1.5
Grainy	1	1	1	4	4	4	4	1	2.5	0	1	0.5
Malty	1	1	1	4	3.5	3.75	4	1	2.5	2	1	1.5
Sulphury	2	0	1	4	4	4	4	0	2	4	1	2.5
Acetaldehyde	0	3	2	2.5	2	2	2	2	2	2	0	2
Phenolic	2	2	2	3.5	3	3.25	3	2	2.5	5	2	3.5
Oxidised	2	3	2.5	3	1	2	3	3	3	1	2	1.5
Acidic	0	0	0	2	2	2	3	0	1.5	2	2	2
Astrigent	0	2	1	4	4	4	3	2	2.5	2	3	2.5
Overall quality	2	2.5	1	1.75	3	3	3	1	1	1	1	3

Sensory Evaluation

PILSNER MALT (Forced aged)

Beer Aroma (0-5)

	Taster 5		**Mean**	Taster 6		**Mean**	Taster 7		**Mean**	Taster 8		**Mean**
Fruity	0	0	0	2	4	3	3	2	2.5	4	1	2.5
Floral	0	0	0	2	3	2.5	2	2	2	2	1	1.5
Hoppy	0	0	0	1	0	0.5	1	1	1	1	2	1.5
Grainy	2	0	1	3	4	3.5	0	0	0	2	2	2
Malty	2	0	1	4	4	4	0	1	0.5	3	3	3
Sweet	0	0	0	1	5	3	1	3	2	4	3	3.5
Acetaldehyde	2	0	0	0	2	2	2	1	0	0.5	1	3
Oxidised	2	2	2	3	1	2	1	2	1.5	1	2	1.5
Acidic	2	2	2	1	3	2	2	2	2	0	2	1
Overall quality	2	1	4	2.5	1	3	2	1	2	1.5	3	3

Beer Taste (0-5)

	Taster 5		**Mean**	Taster 6		**Mean**	Taster 7		**Mean**	Taster 8		**Mean**
Fruity	0	0	0	1	3	2	1	0	0.5	1	2	1.5
Spicy	0	0	0	3	4	3.5	2	1	1.5	2	1	1.5
Grainy	3	0	1.5	1	4	2.5	0	1	0.5	0	1	0.5
Malty	0	0	0	3	4	3.5	0	1	0.5	0	2	1
Sulphury	0	1	0.5	2	2	2	0	1	0.5	0	4	2
Acetaldehyde	0	0	0	0	2	4	3	1	0	0.5	1	2
Phenolic	0	0	0	0	2	1	0	4	2	0	0	0
Oxidised	3	3	3	3	1	2	2	3	2.5	2	4	3
Acidic	2	0	1	2	4	3	2	2	2	2	2	2
Astrigent	2	2	2	3	2	2.5	3	3	3	3	1	2
Overall quality	2	1	1	1	1	1	1	2	1	1.5	2	1

Sensory Evaluation

PILSNER MALT (Forced aged)

Beer Aroma (0-5)

	Taster 9		**Mean**	Taster 10		**Mean**
Fruity	4	2	3	2	3	2.5
Floral	3	3	3	2	3	2.5
Hoppy	1	4	2.5	1	2	1.5
Grainy	1	2	1.5	2	2	2
Malty	1	1	1	2	1	1.5
Sweet	1	2	1.5	1	3	2
Acetaldehyde	2	2	1	1.5	1	4
Oxidised	0	1	0.5	2	1	1.5
Acidic	1	0	0.5	1	1	1
Overall quality	2	3	2	2.5	2	4

Beer Taste (0-5)

	Taster 9		**Mean**	Taster 10		**Mean**
Fruity	4	3	3.5	0	3	1.5
Spicy	0	2	1	2	2	2
Grainy	1	1	1	0	4	2
Malty	2	2	2	4	3	3.5
Sulphury	2	2	2	2	3	2.5
Acetaldehyde	0	3	3	3	2	2
Phenolic	0	1	0.5	1	2	1.5
Oxidised	0	1	0.5	3	3	3
Acidic	1	0	0.5	2	2	2
Astrigent	1	3	2	1	3	2
Overall quality	2	3	2	2.5	0	2

Table A.9.15 Sensory evaluation results of the second round of spontaneously aged locally-brewed beer (blank sample)

Sensory Evaluation

PILSNER MALT (Spontaneously aged)

Beer Aroma (0-5)

	Taster 1		**Mean**	Taster 2		**Mean**	Taster 3		**Mean**	Taster 4		**Mean**
Fruity	1	3	2	4	3	3.5	5	5	5	2	2	2
Floral	1	1	1	4	3	3.5	4	3	3.5	1	4	2.5
Hoppy	1	0	0.5	2	1	1.5	1	2	1.5	0	1	0.5
Grainy	4	0	2	2	2	2	1	1	1	0	0	0
Malty	4	0	2	3	3	3	1	1	1	1	1	1
Sweet	1	3	2	3	3	3	5	5	5	1	4	2.5
Acetaldehyde	2	4	3	3.5	1	3	2	1	0	0.5	2	4
Oxidised	4	3	3.5	2	1	1.5	1	0	0.5	4	1	2.5
Acidic	3	2	2.5	0	1	0.5	0	1	0.5	2	2	2
Overall quality	2	4	1	2.5	3	4	3.5	5	4	4.5	4	1

Beer Taste (0-5)

	Taster 1		**Mean**	Taster 2		**Mean**	Taster 3		**Mean**	Taster 4		**Mean**
Fruity	1	2	1.5	3	2	2.5	3	4	3.5	2	4	3
Spicy	1	1	1	2	3	2.5	1	4	2.5	0	3	1.5
Grainy	3	3	3	3	2	2.5	2	1	1.5	1	1	1
Malty	4	2	3	2	3	2.5	2	1	1.5	1	0	0.5
Sulphury	1	1	1	1	2	1.5	1	3	2	2	2	2
Acetaldehyde	0	4	4	4	4	4	4	3	2	2.5	2	2
Phenolic	4	3	3.5	3	3	3	2	3	2.5	4	3	3.5
Oxidised	4	3	3.5	3	1	2	3	2	2.5	3	1	2
Acidic	2	1	1.5	3	4	3.5	2	4	3	1	4	2.5
Astrigent	4	4	4	1	3	2	3	2	2.5	4	2	3
Overall quality	2	1	1	1	3	3	3	3	2	2.5	1	2

Sensory Evaluation

PILSNER MALT (Spontaneously aged)

Beer Aroma (0-5)

	Taster 5		**Mean**	Taster 6		**Mean**	Taster 7		**Mean**	Taster 8		**Mean**
Fruity	0	0	0	2	1	1.5	0	1	0.5	2	4	3
Floral	0	0	0	1	1	1	1	1	1	2	1	1.5
Hoppy	1	2	1.5	2	2	2	0	2	1	1	1	1
Grainy	0	0	0	0	1	0.5	2	1	1.5	3	1	2
Malty	1	1	1	1	1	1	1	2	1.5	3	1	2
Sweet	2	0	1	3	2	2.5	1	1	1	4	2	3
Acetaldehyde	2	2	0	1	1	2	1.5	0	0	0	3	2
Oxidised	0	0	0	3	2	2.5	3	4	3.5	0	1	0.5
Acidic	0	0	0	1	2	1.5	2	1	1.5	0	2	1
Overall quality	2	2	2	2	2	1	1.5	4	1	2.5	3	3

Beer Taste (0-5)

	Taster 5		**Mean**	Taster 6		**Mean**	Taster 7		**Mean**	Taster 8		**Mean**
Fruity	1	0	0.5	3	2	2.5	0	0	0	0	2	1
Spicy	0	1	0.5	3	3	3	0	0	0	0	0	0
Grainy	1	0	0.5	1	1	1	2	3	2.5	1	1	1
Malty	4	3	3.5	2	3	2.5	2	1	1.5	2	1	1.5
Sulphury	1	0	0.5	3	1	2	1	1	1	0	0	0
Acetaldehyde	0	0	0	0	1	0	0.5	2	0	1	0	2
Phenolic	0	0	0	0	1	0.5	2	1	1.5	0	0	0
Oxidised	2	0	1	4	2	3	3	2	2.5	1	3	2
Acidic	0	0	0	2	1	1.5	1	0	0.5	0	5	2.5
Astrigent	2	2	2	4	1	2.5	2	2	2	3	1	2
Overall quality	2	3	3	3	3	3	3	2	1	1.5	1	1

Sensory Evaluation

PILSNER MALT (Spontaneously aged)

Beer Aroma (0-5)

	Taster 9		**Mean**	Taster 10		**Mean**
Fruity	0	4	2	4	3	3.5
Floral	3	3	3	4	3	3.5
Hoppy	3	3	3	2	2	2
Grainy	3	2	2.5	3	2	2.5
Malty	1	1	1	1	1	1
Sweet	1	1	1	3	3	3
Acetaldehyde	2	4	3	3.5	2	2
Oxidised	1	1	1	1	2	1.5
Acidic	3	1	2	1	1	1
Overall quality	2	2	3	2.5	3	3

Beer Taste (0-5)

	Taster 9		**Mean**	Taster 10		**Mean**
Fruity	3	4	3.5	3	2	2.5
Spicy	2	1	1.5	1	3	2
Grainy	2	2	2	2	1	1.5
Malty	0	1	0.5	2	3	2.5
Sulphury	2	1	1.5	2	1	1.5
Acetaldehyde	0	3	3	3	3	2
Phenolic	2	2	2	0	3	1.5
Oxidised	2	1	1.5	3	0	1.5
Acidic	1	2	1.5	2	4	3
Astrigent	3	2	2.5	1	2	1.5
Overall quality	2	2	3	2.5	2	3

APPENDIX B. Charts

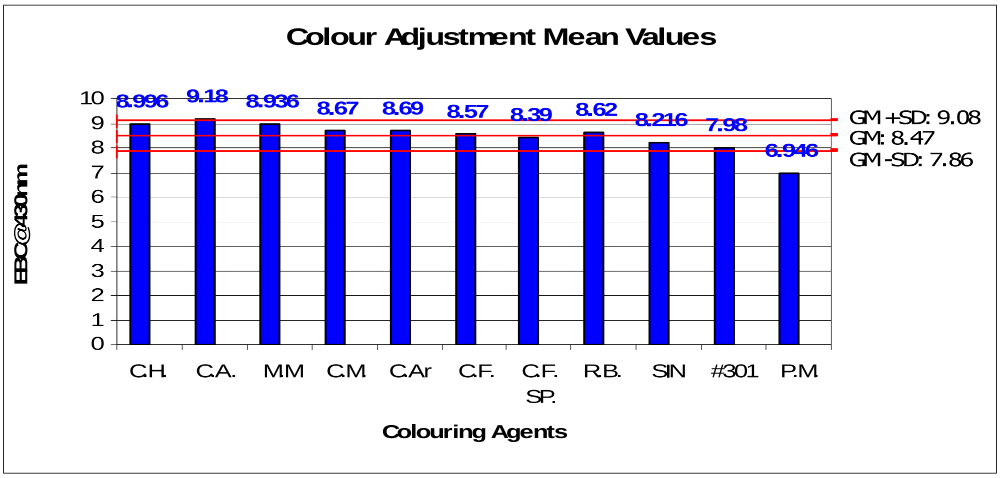

Chart B.1.1 EBC colour units of beers trials brewed with distinct colouring agents

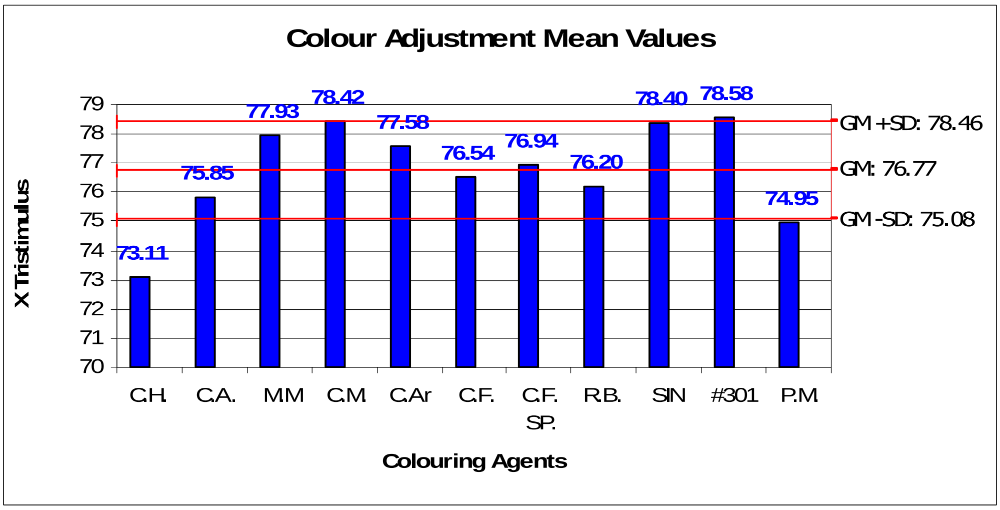

Chart B.1.2 Tristimulus value X (Red) of beers trials brewed with distinct colouring agents

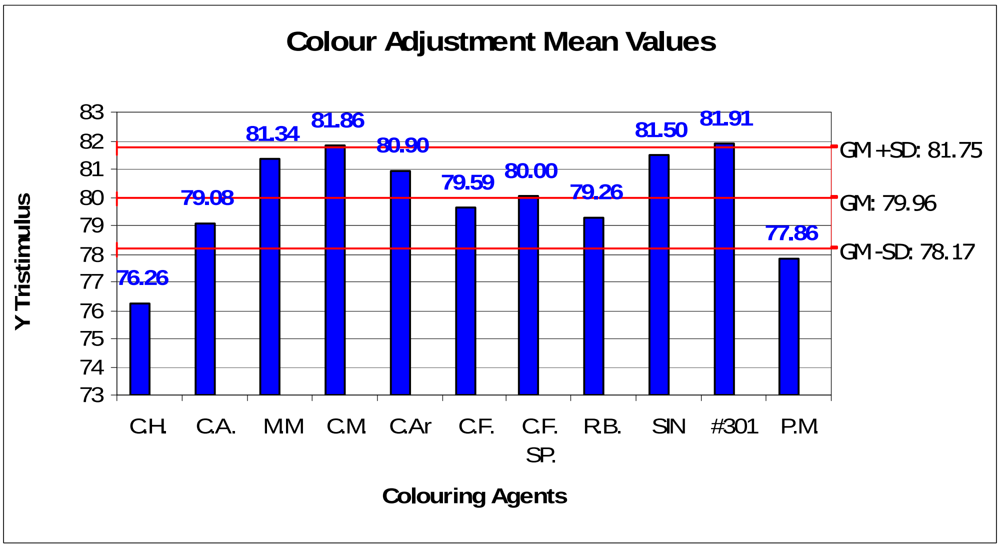

Chart B.1.3 Tristimulus value Y (Green) of beers trials brewed with distinct colouring agents

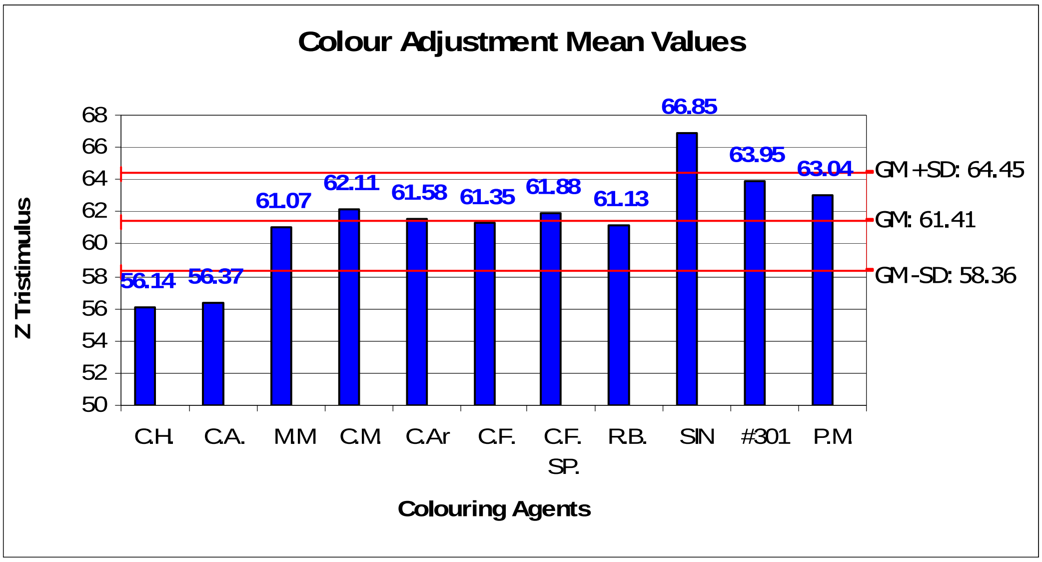

Chart B.1.4 Tristimulus value Z (Blue) of beers trials brewed with distinct colouring agents

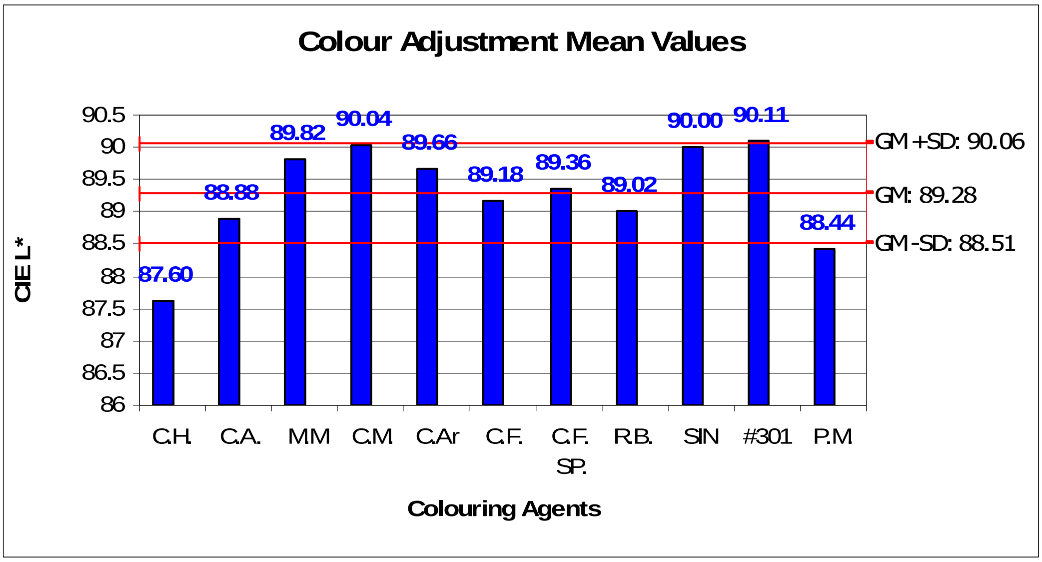

Chart B.1.5 CIE Colour Space L* of beers trials brewed with distinct colouring agents

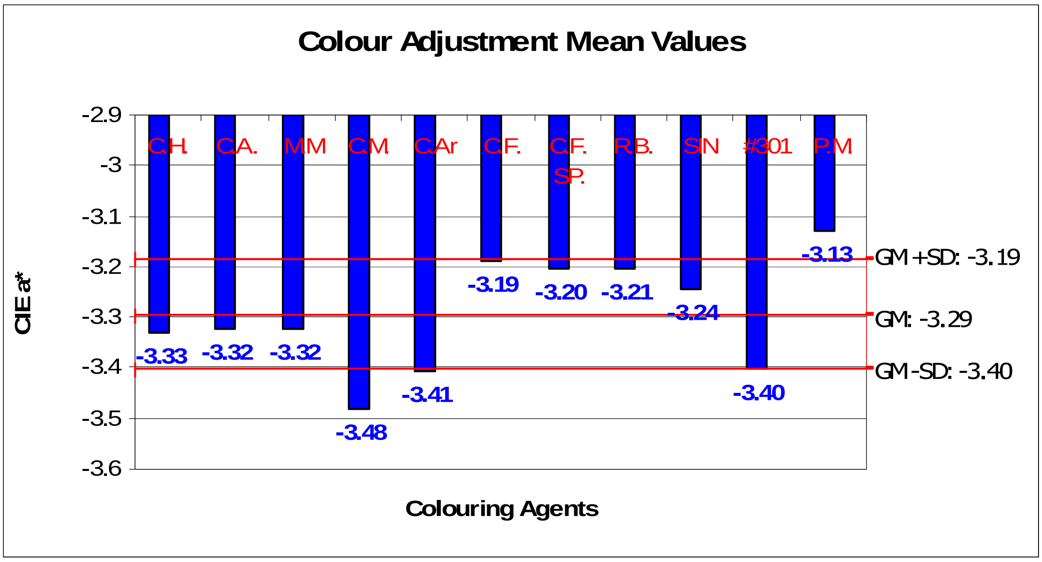

Chart B.1.6 CIE Colour Space a* of beers trials brewed with distinct colouring agents

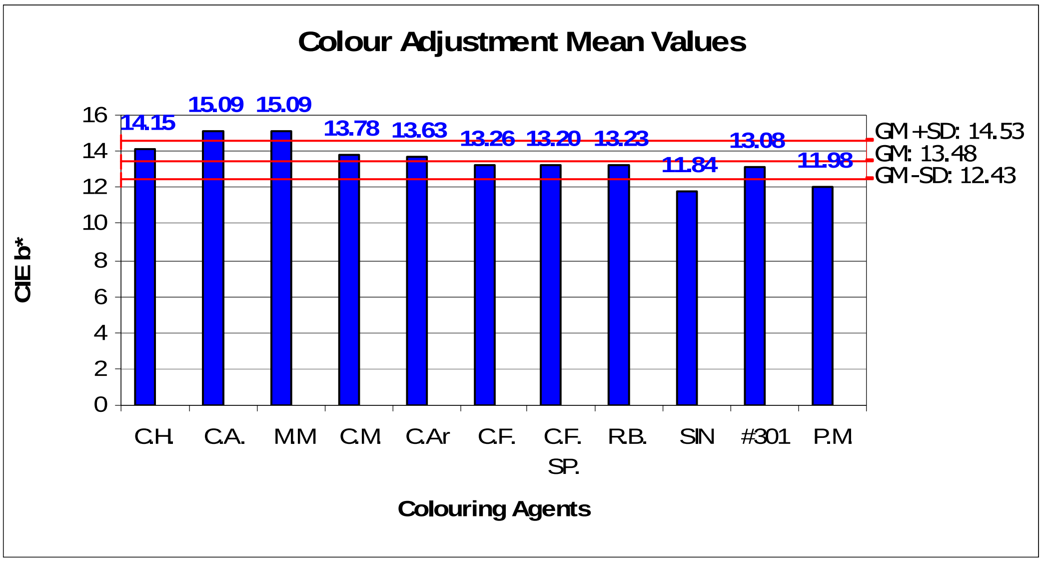

Chart B.1.7 CIE Colour Space b* of beers trials brewed with distinct colouring agents

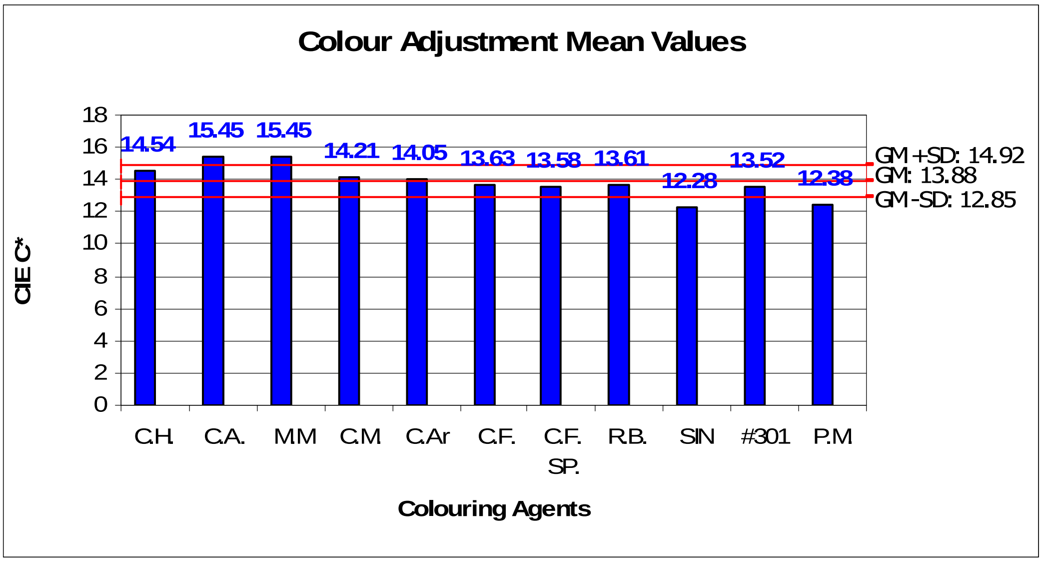

Chart B.1.8 CIE Metric Chroma of beers trials brewed with distinct colouring agents

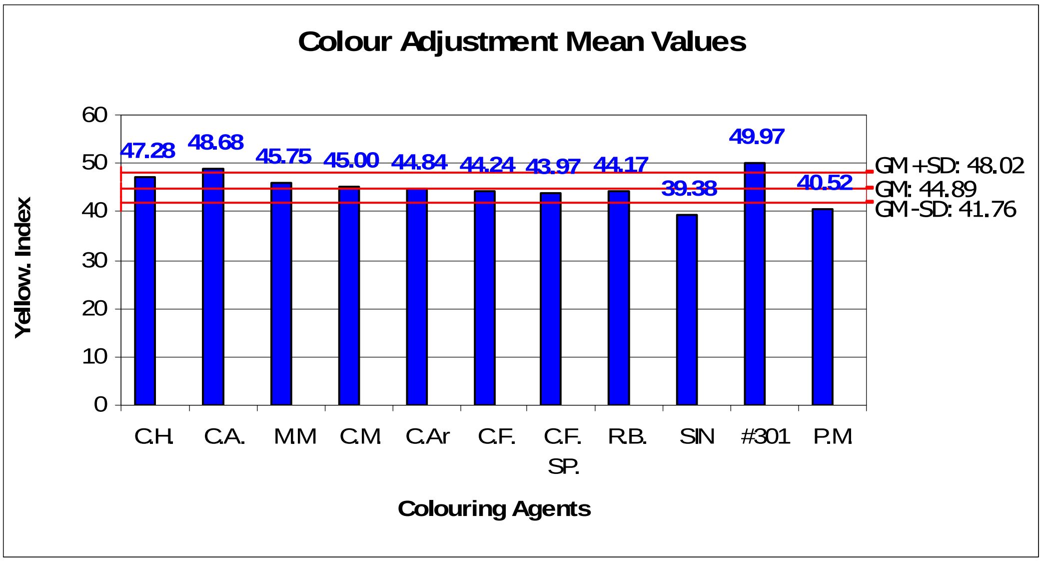

Chart B.1.9 Yellowness Index of beers trials brewed with distinct colouring agents

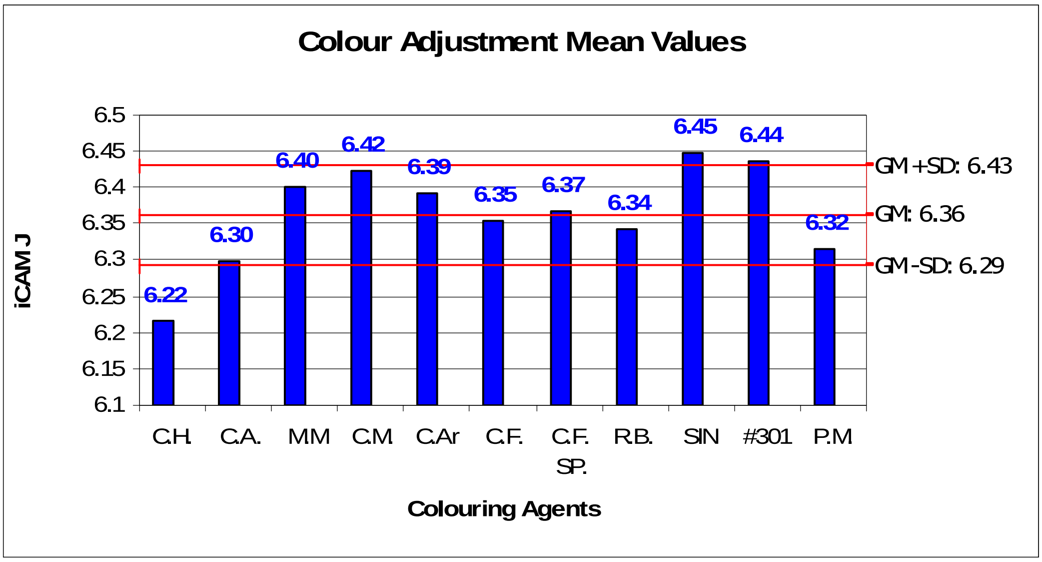

Chart B.1.10 iCAM Lightness of beers trials brewed with distinct colouring agents

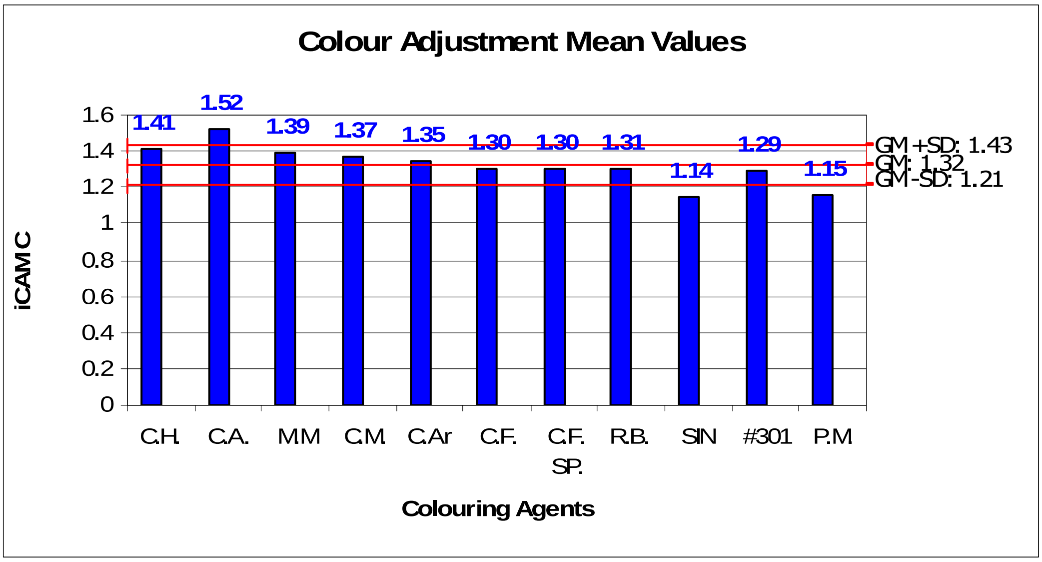

Chart B.1.11 iCAM Chroma of beers trials brewed with distinct colouring agents

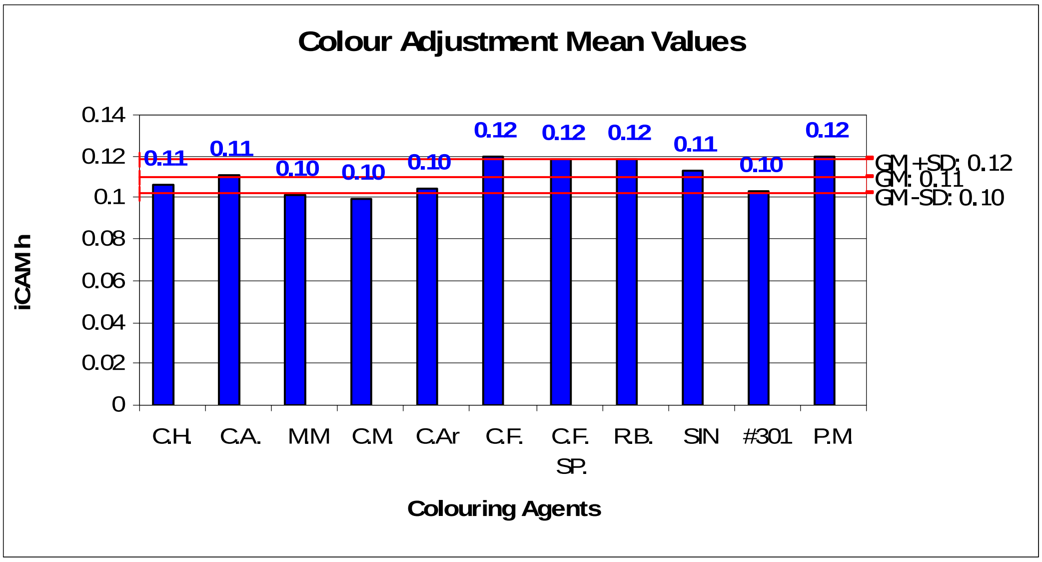

Chart B.1.12 iCAM Hue angle of beers trials brewed with distinct colouring agents

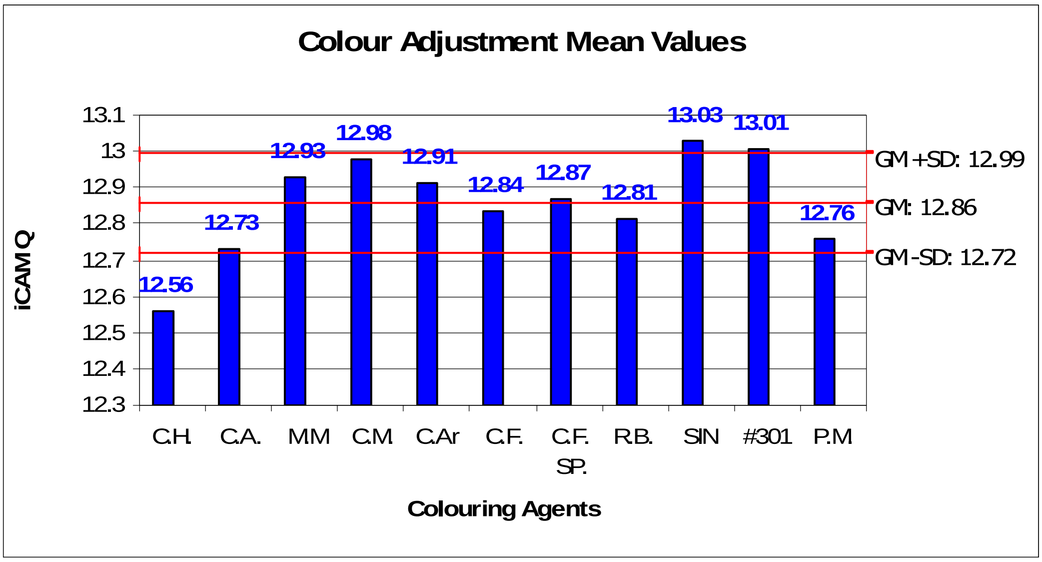

Chart B.1.13 iCAM Brightness of beers trials brewed with distinct colouring agents

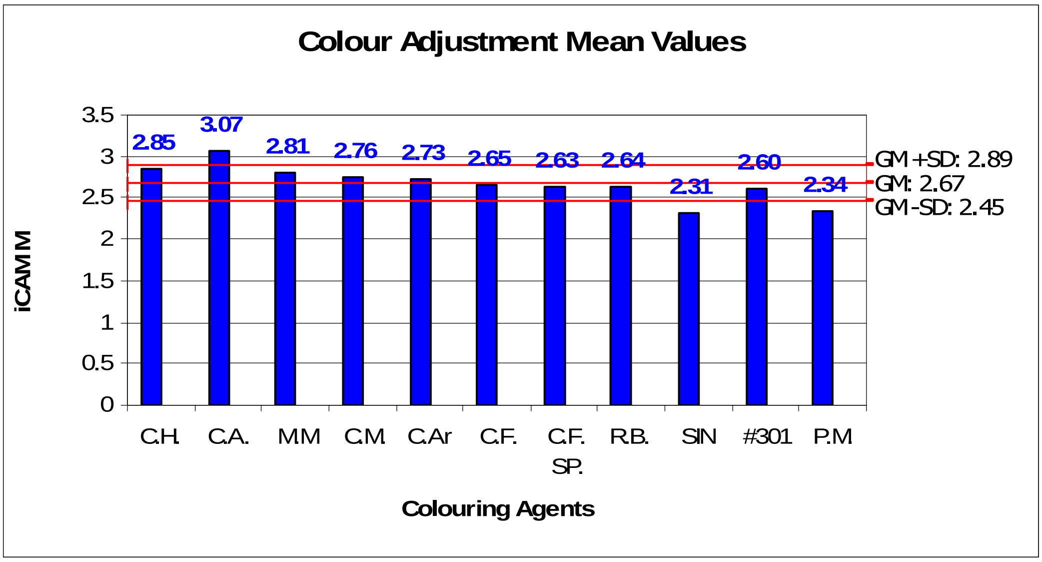

Chart B.1.14 iCAM Colourfulness of beers trials brewed with distinct colouring agents

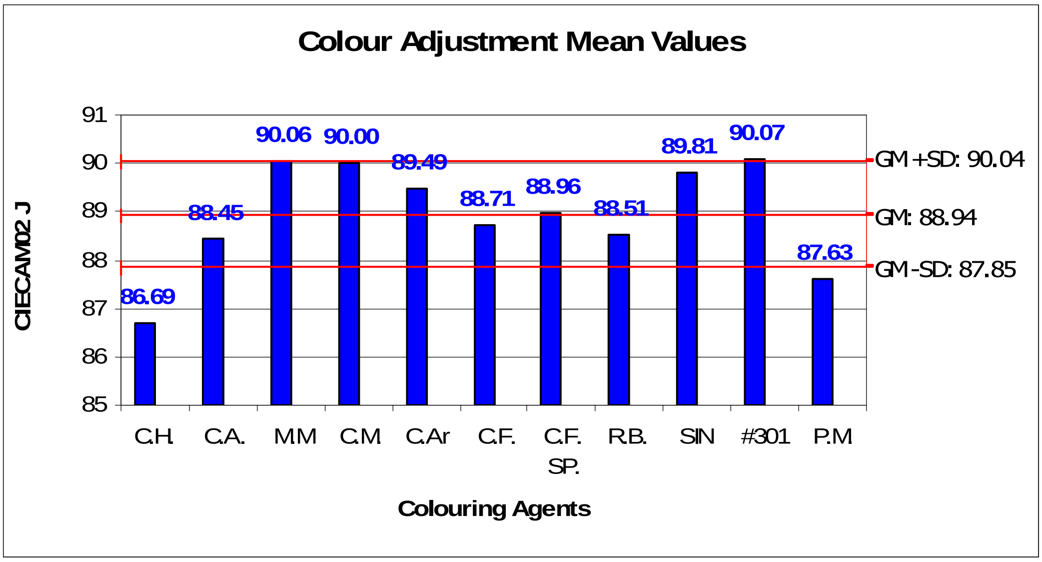

Chart B.1.15 CIECAM02 Lightness of beers trials brewed with distinct colouring agents

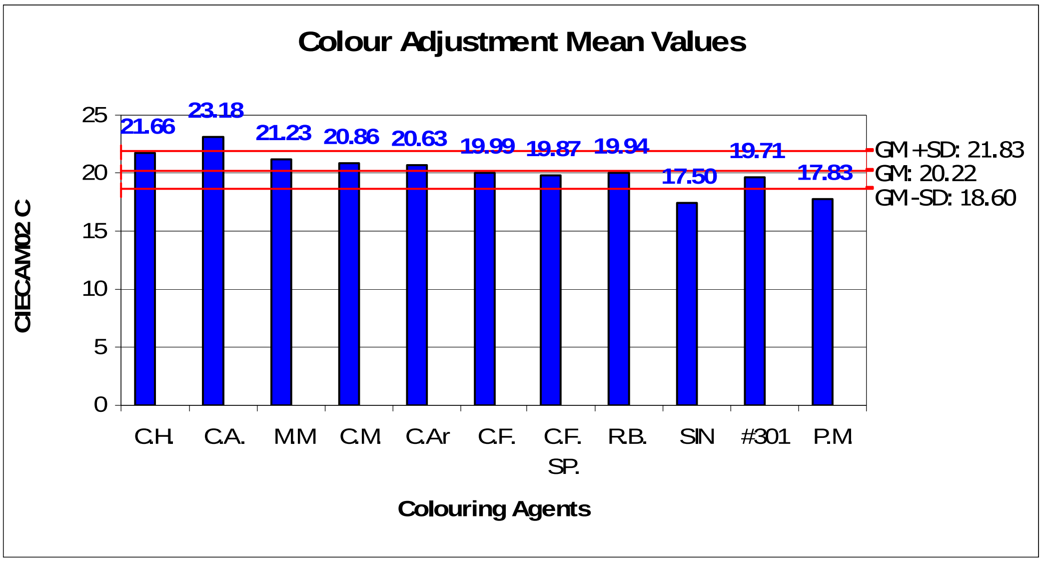

Chart B.1.16 CIECAM02 Chroma of beers trials brewed with distinct colouring agents

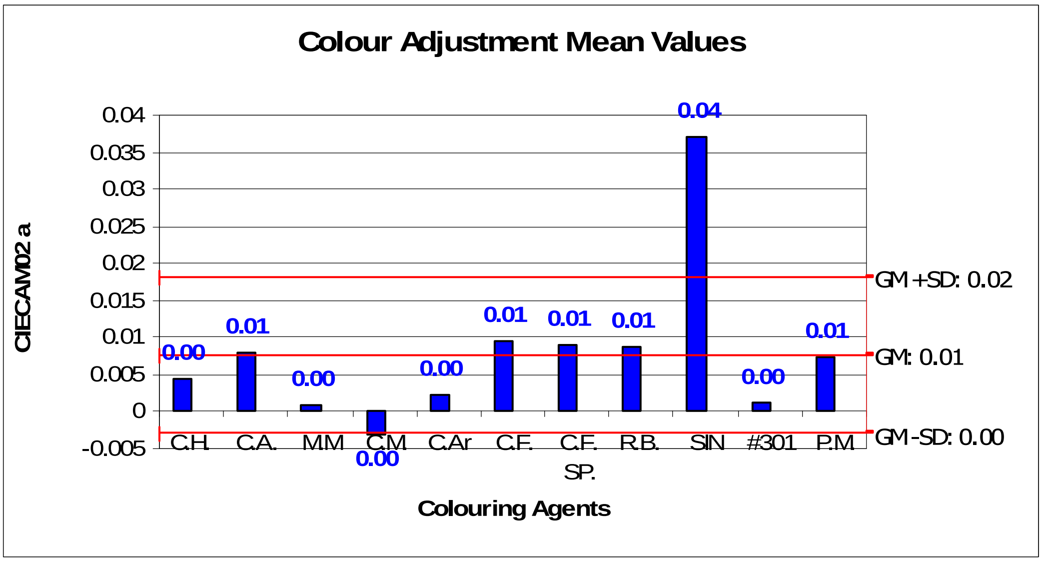

Chart B.1.17 CIECAM02 Redness- Greenness of beers trials brewed with distinct colouring agents

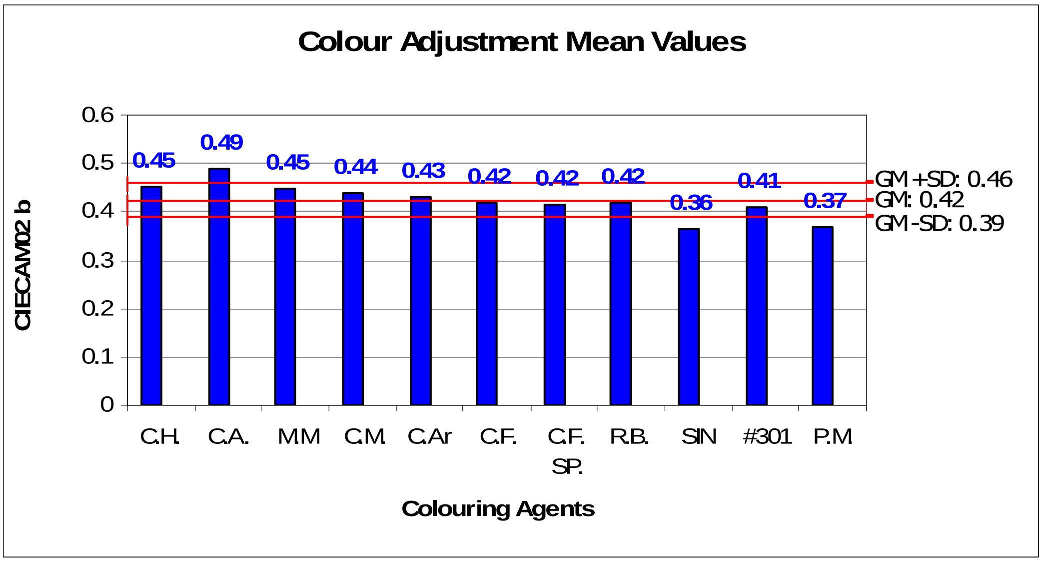

Chart B.1.18 CIECAM02 Yellowness-Blueness of beers trials brewed with distinct colouring agents

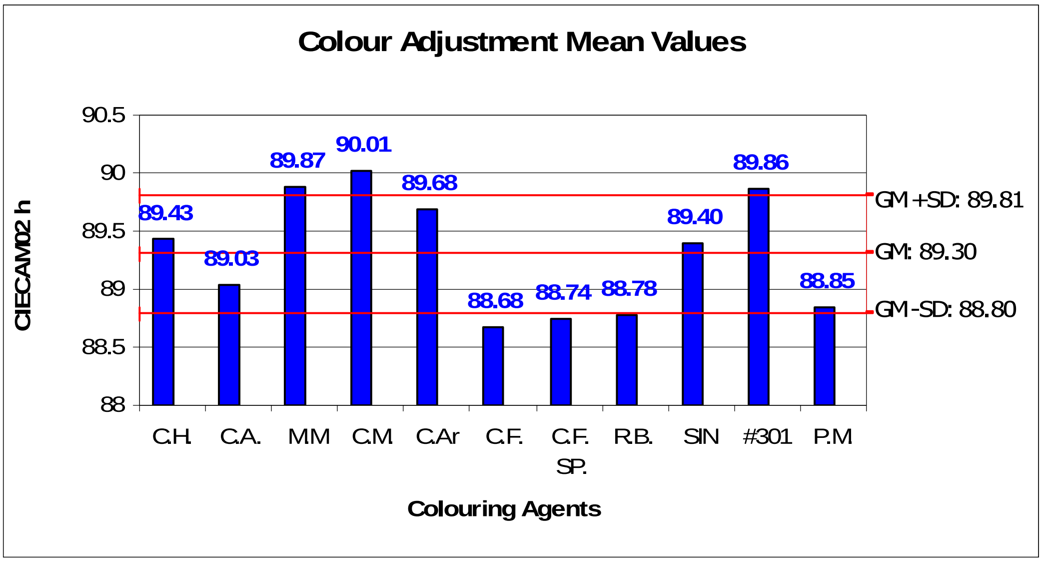

Chart B.1.19 CIECAM02 Hue angle of beers trials brewed with distinct colouring agents

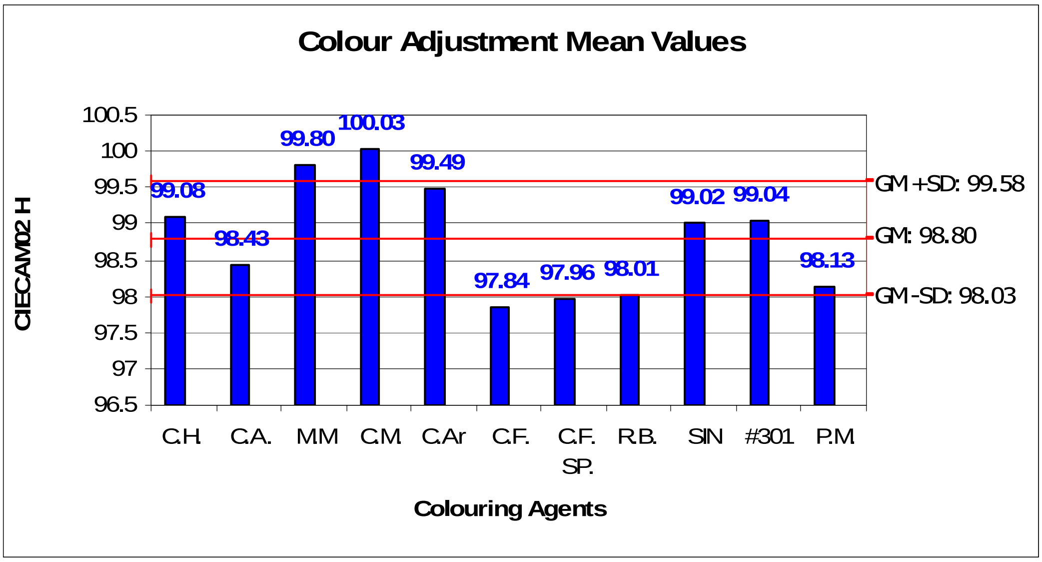

Chart B.1.20 CIECAM02 Hue quadrature of beers trials brewed with distinct colouring agents

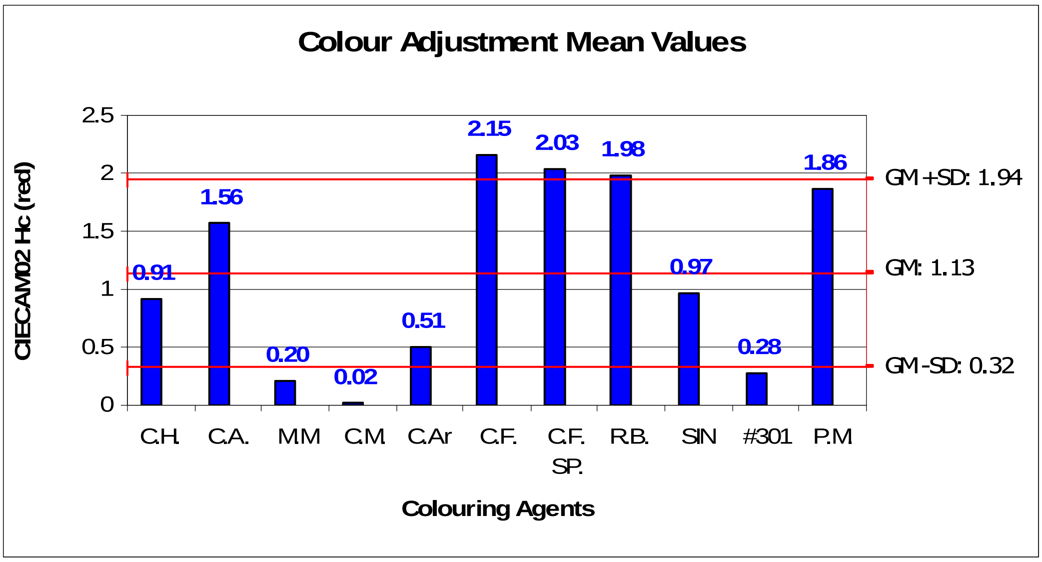

Chart B.1.21 CIECAM02 redness hue component of beers trials brewed with distinct colouring agents

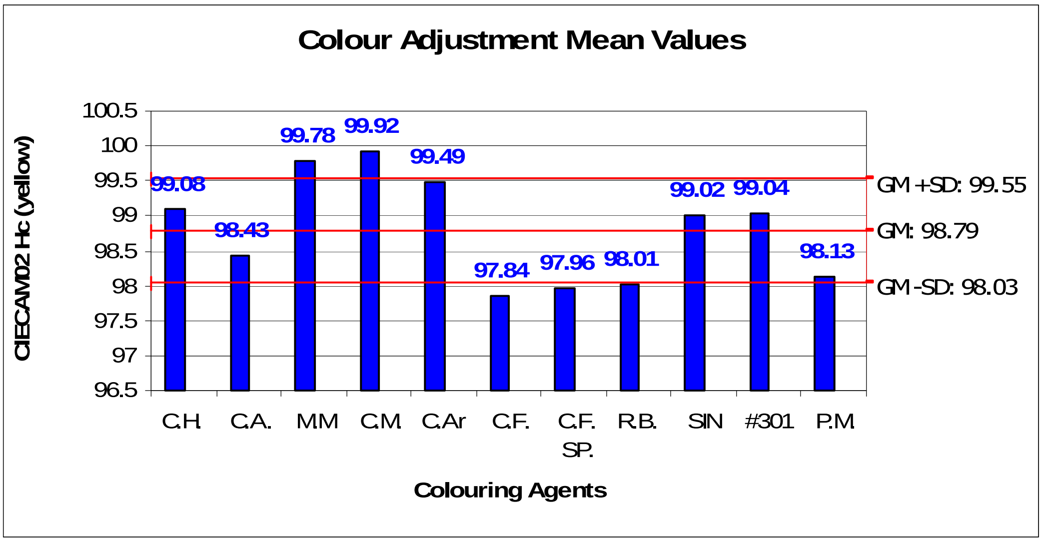

Chart B.1.22 CIECAM02 yellowness hue component of beers trials brewed with distinct colouring agents

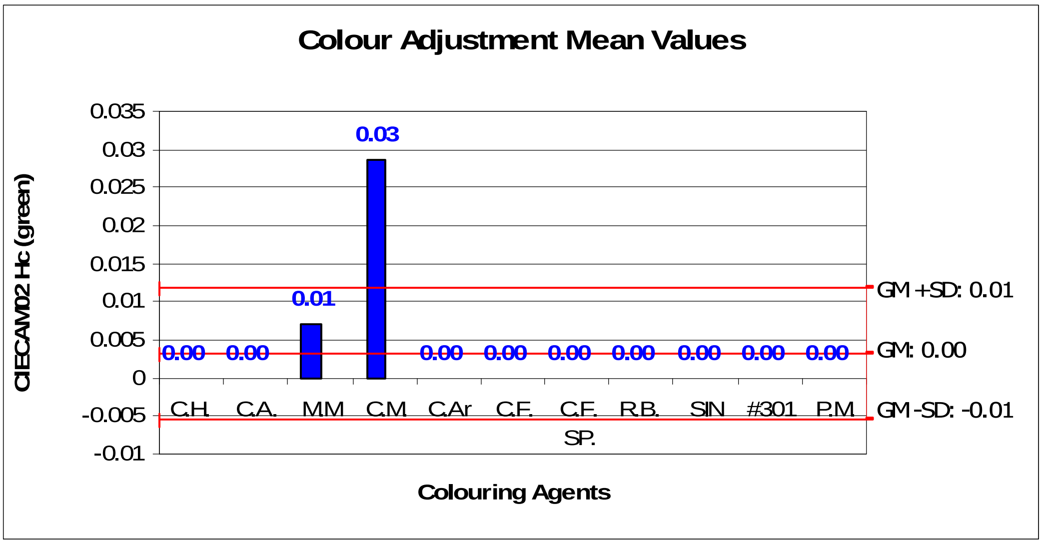

Chart B.1.23 CIECAM02 greenness hue component of beers trials brewed with distinct colouring agents

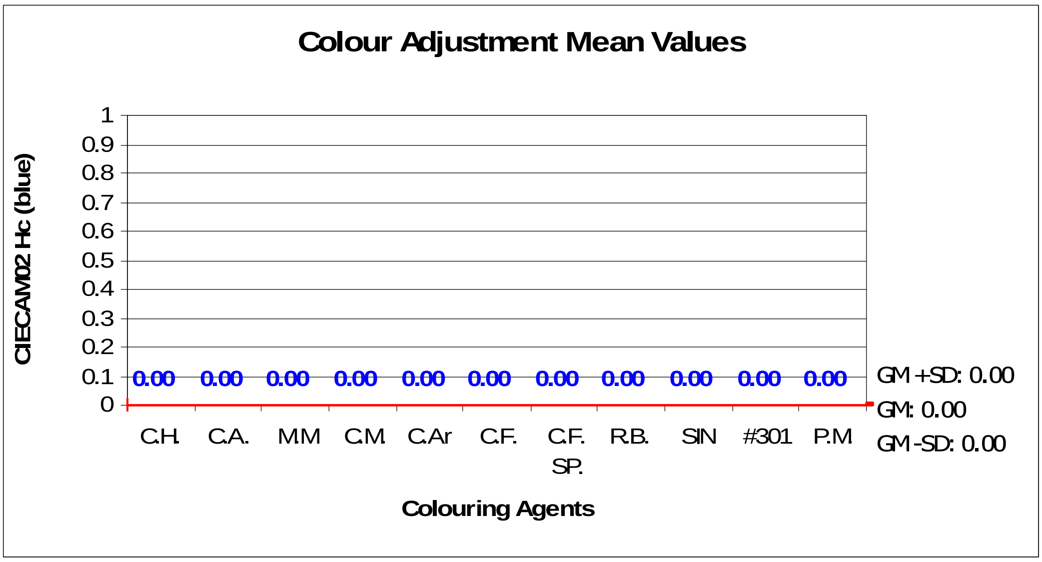

Chart B.1.24 CIECAM02 blueness hue component of beers trials brewed with distinct colouring agents

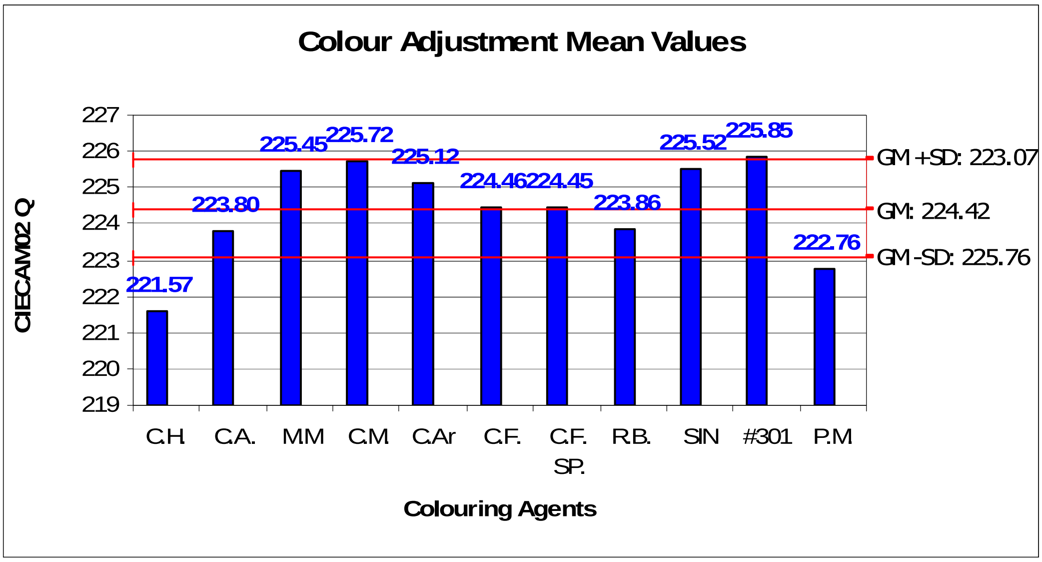

Chart B.1.25 CIECAM02 Brightness of beers trials brewed with distinct colouring agents

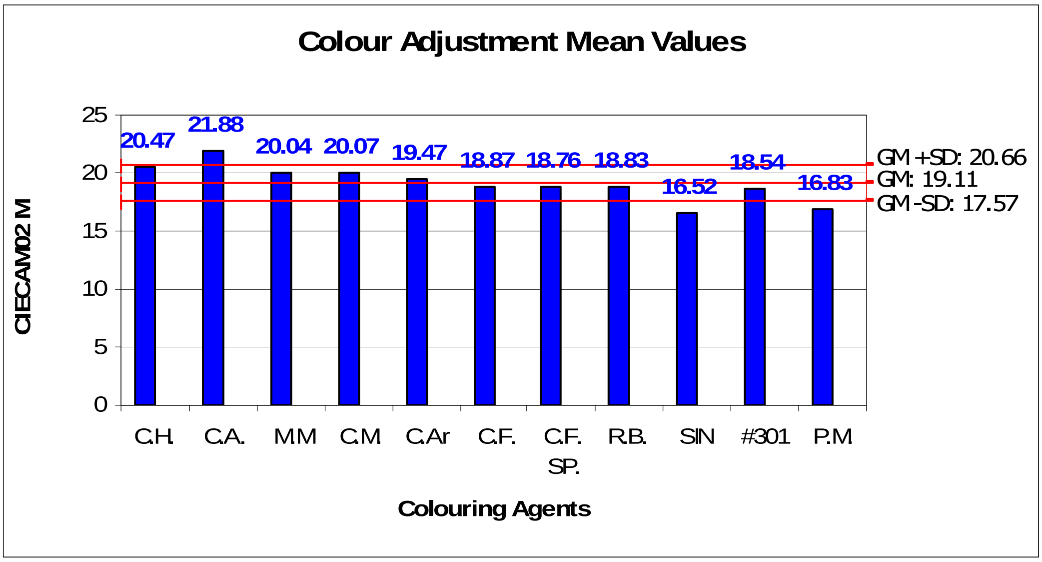

Chart B.1.26 CIECAM02 Colourfulness of beers trials brewed with distinct colouring agents

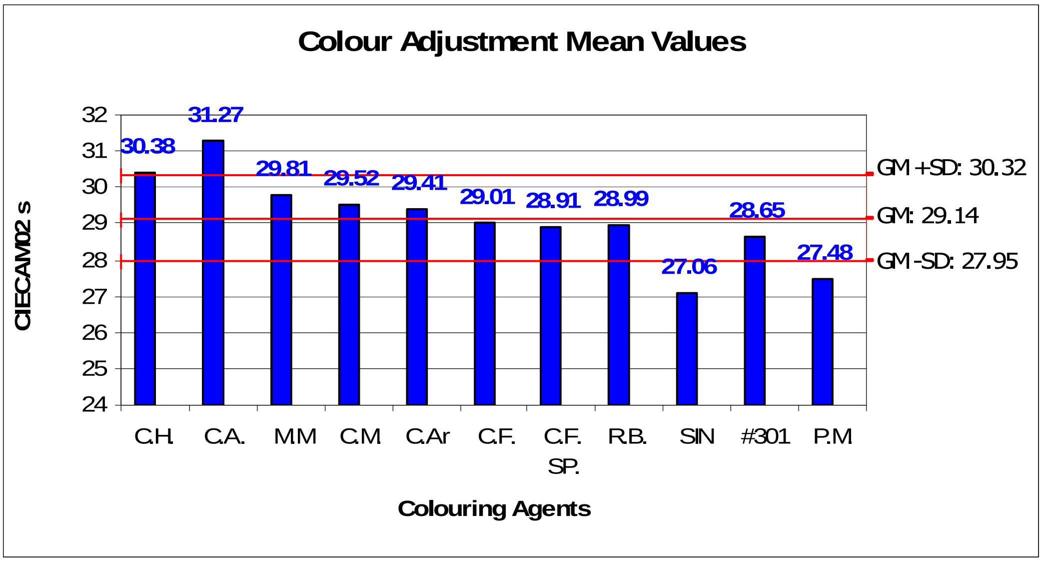

Chart B.1.27 CIECAM02 Saturation of beers trials brewed with distinct colouring agents

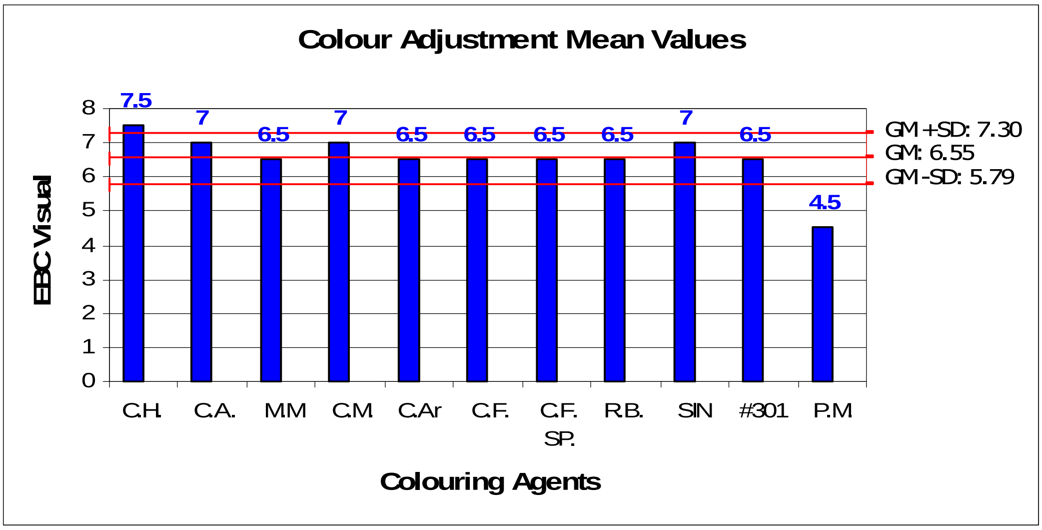

Chart B.2.1 EBC colour units (visual method) of fresh locally-brewed beers

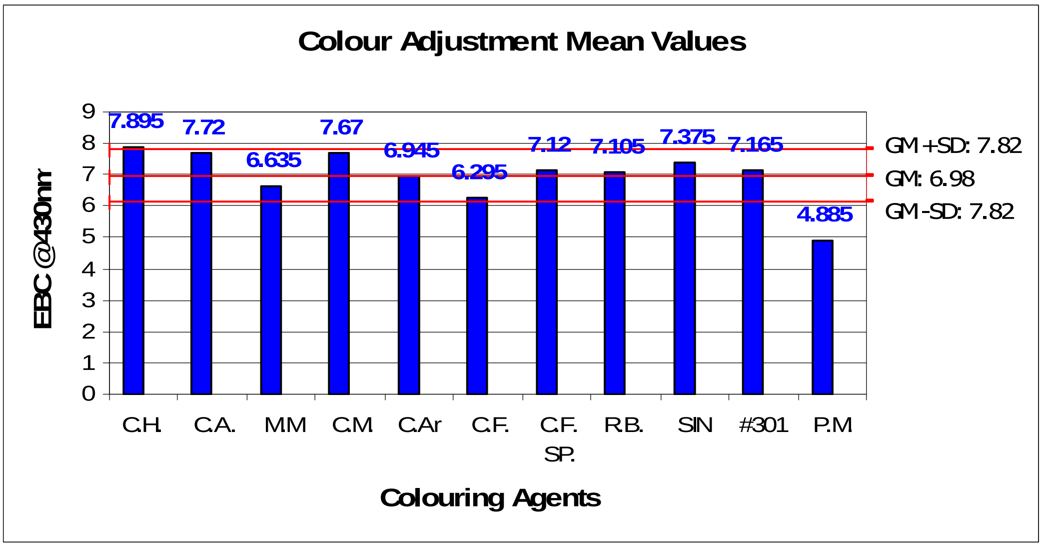

Chart B.2.2 EBC colour units (spectrophotometric method) of fresh locally-brewed beers

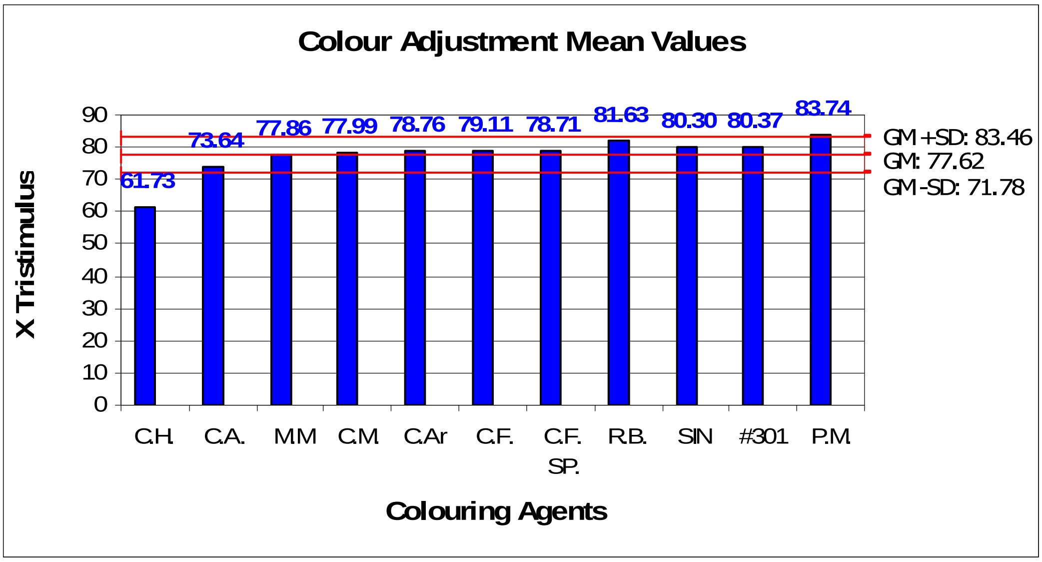

Chart B.2.3 Tristimulus value X (Red) of fresh locally-brewed beers

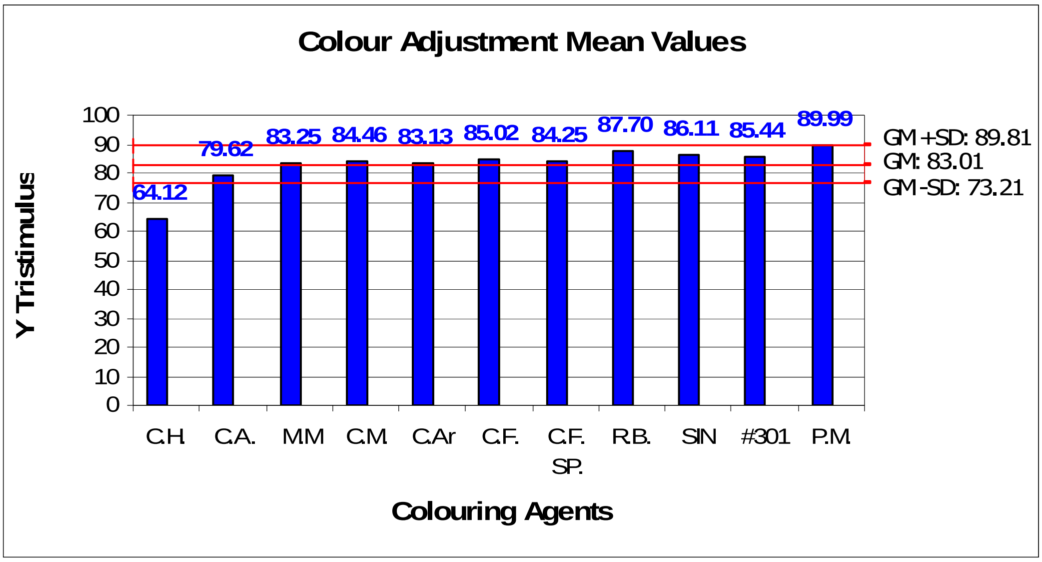

Chart B.2.4 Tristimulus value Y (Green) of fresh locally-brewed beers

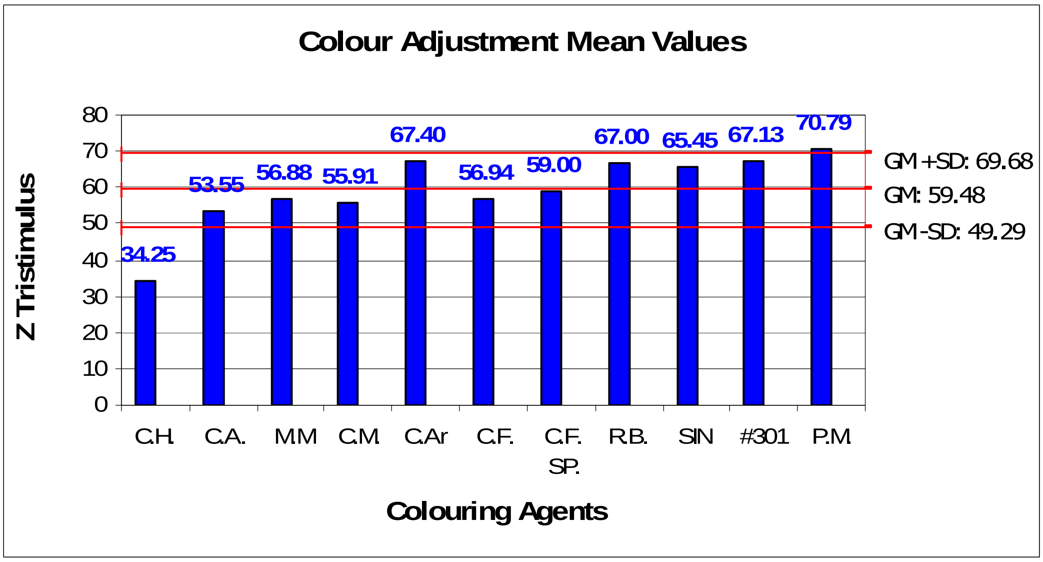

Chart B.2.5 Tristimulus value Z (Blue) of fresh locally-brewed beers

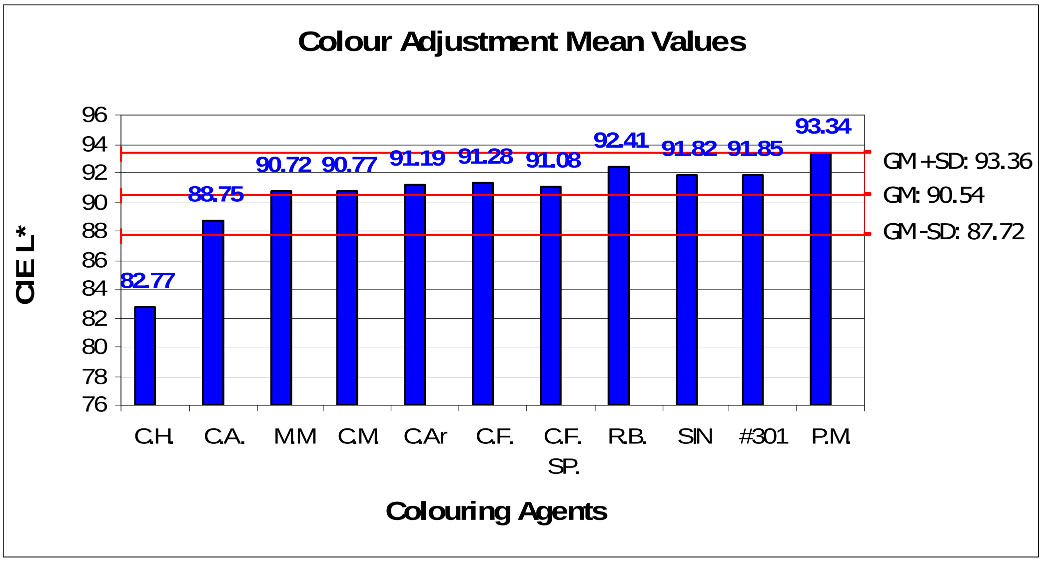

Chart B.2.6 CIE Colour Space L* of fresh locally-brewed beers

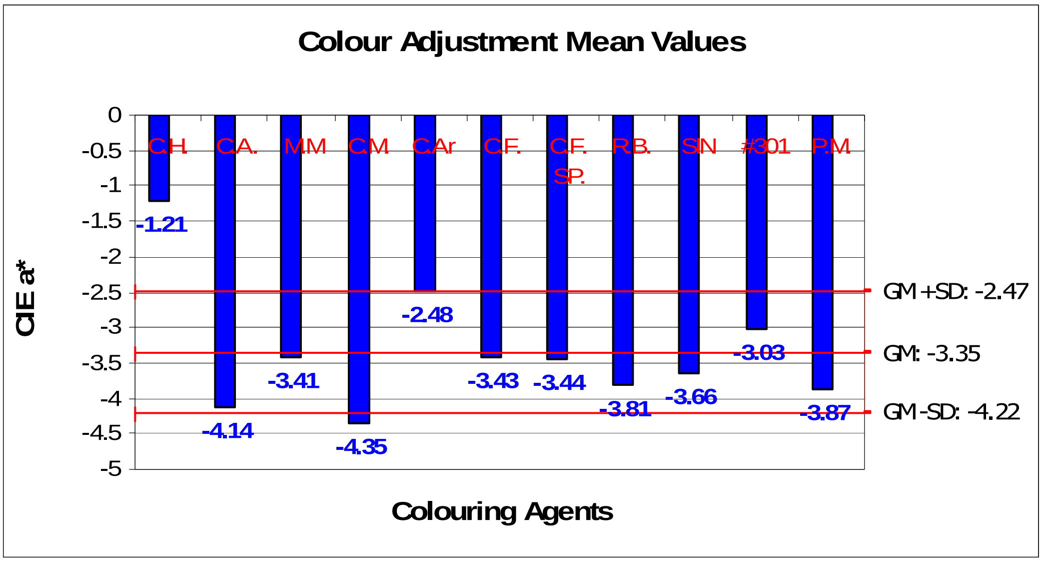

Chart B.2.7 CIE Colour Space a* of fresh locally-brewed beers

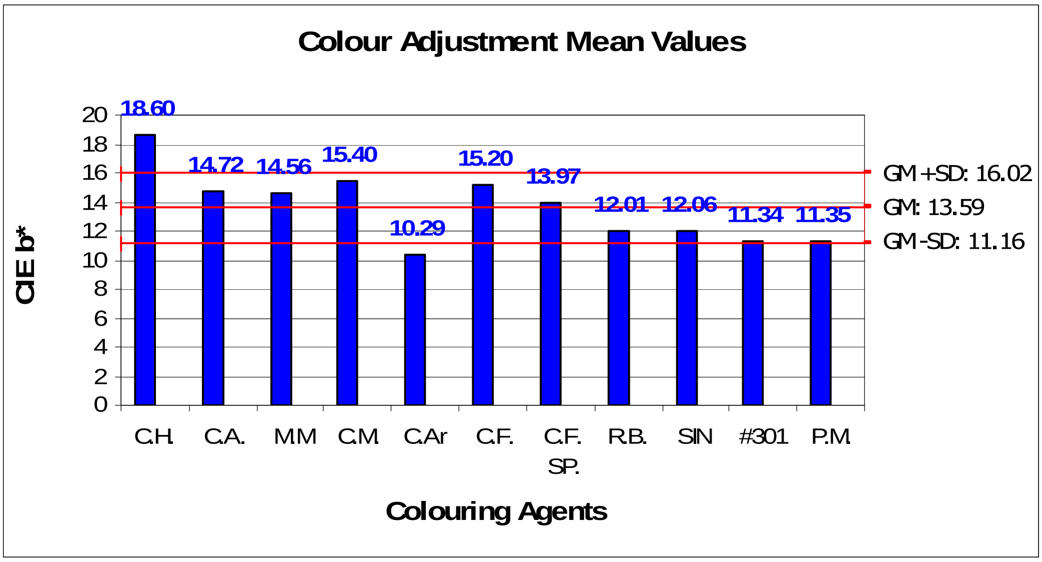

Chart B.2.8 CIE Colour Space b* of fresh locally-brewed beers

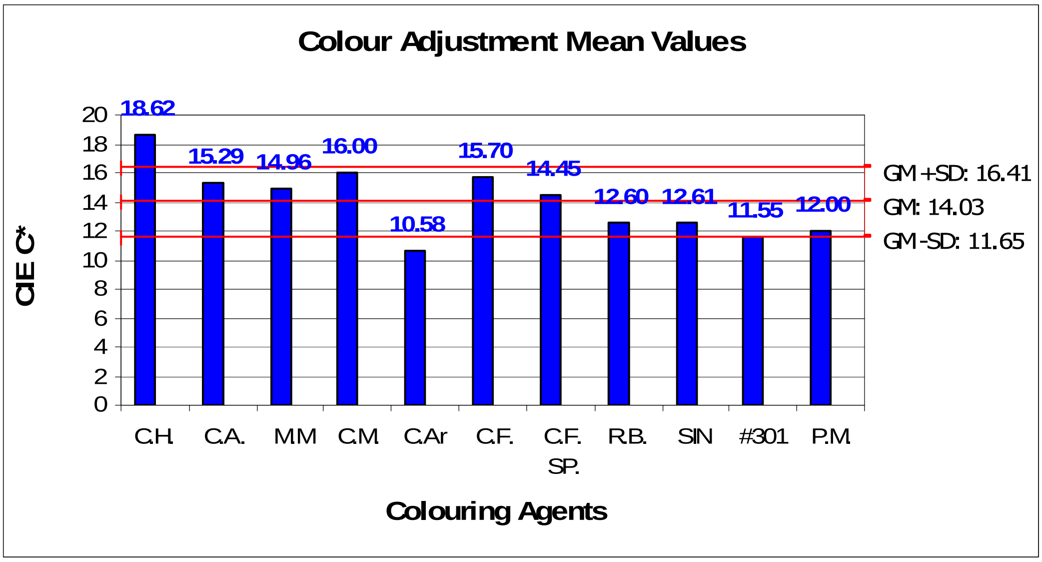

Chart B.2.9 CIE Metric Chroma of fresh locally-brewed beers

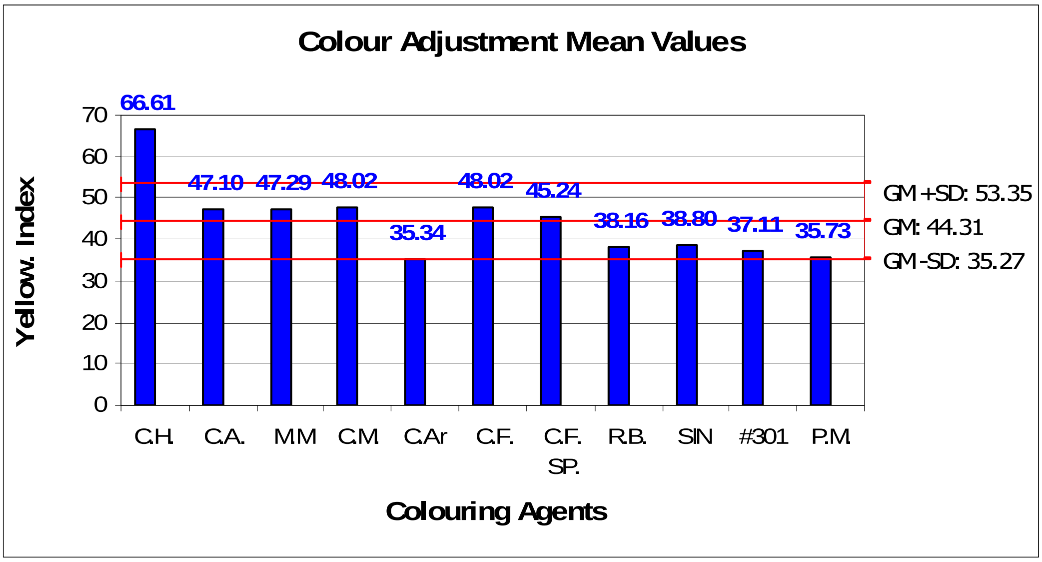

Chart B.2.10 Yellowness Index of fresh locally-brewed beers

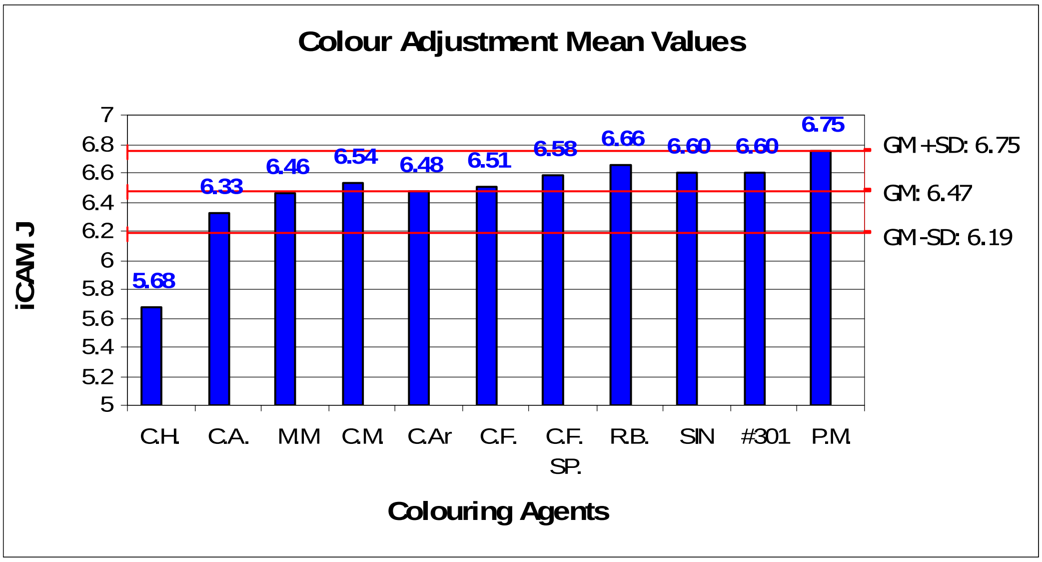

Chart B.2.11 iCAM Lightness of fresh locally-brewed beers

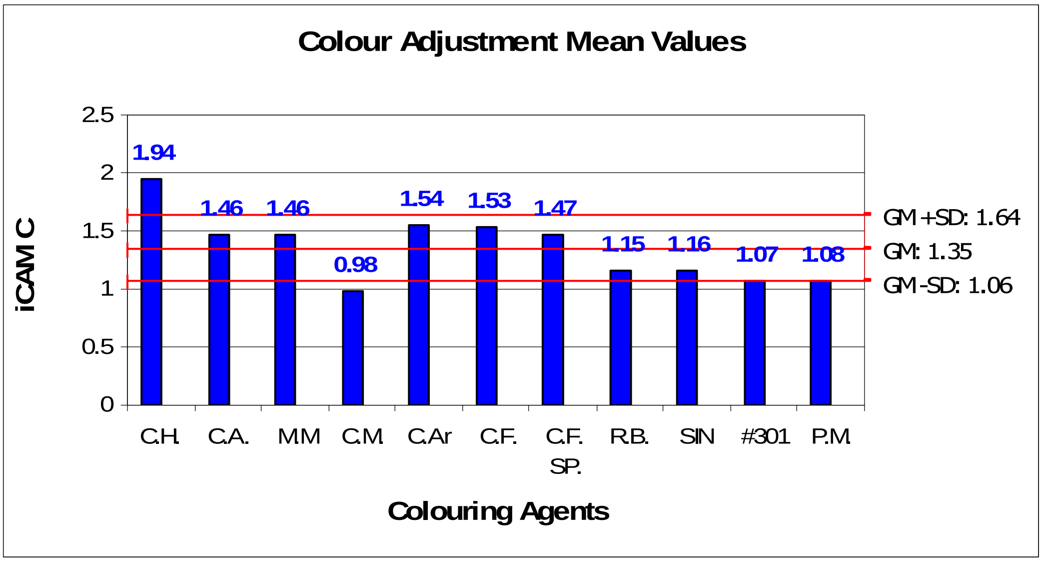

Chart B.2.12 iCAM Chroma of fresh locally-brewed beers

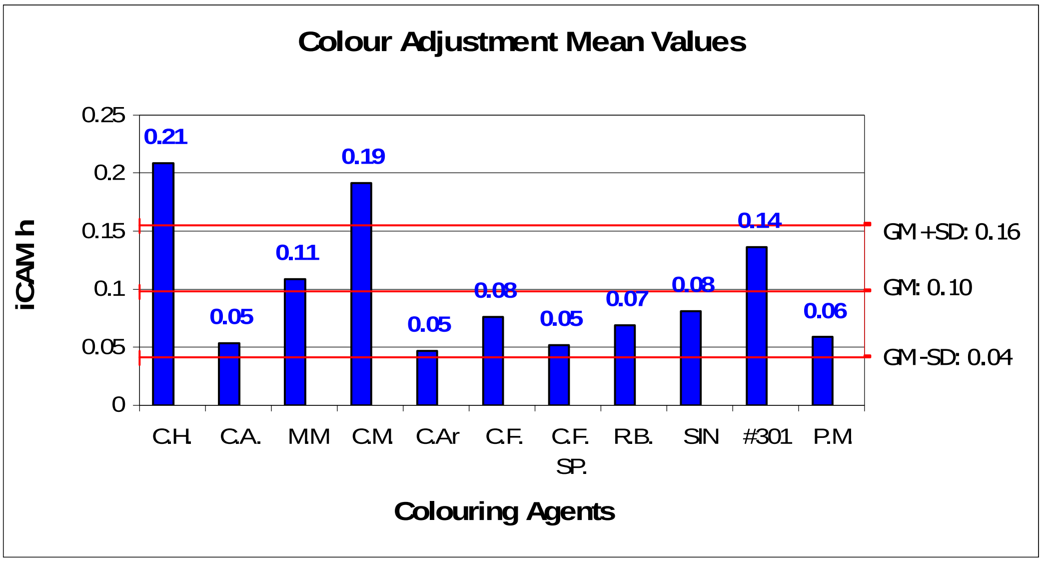

Chart B.2.13 iCAM Hue angle of fresh locally-brewed beers

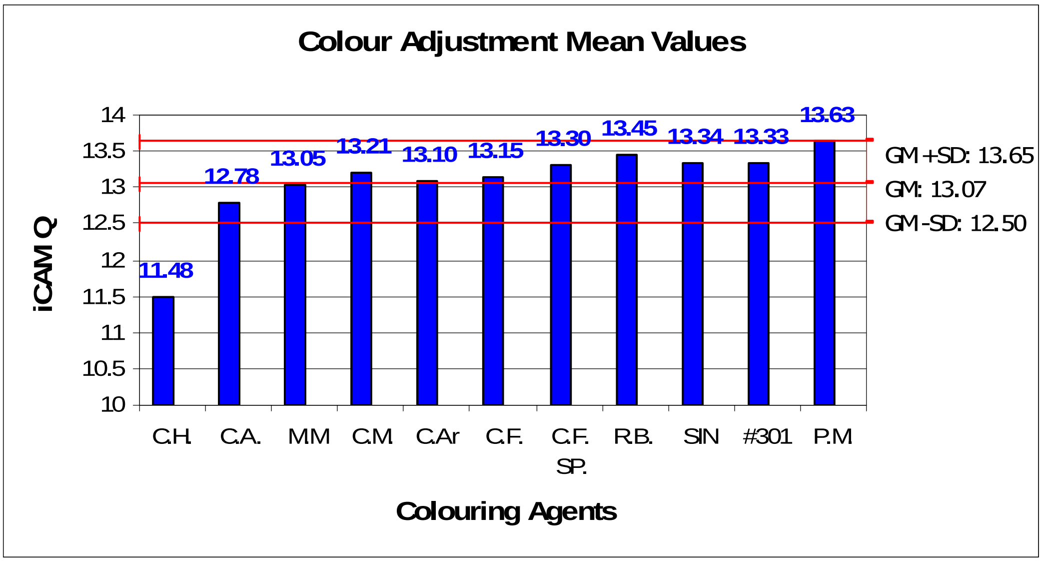

Chart B.2.14 iCAM Brightness of fresh locally-brewed beers

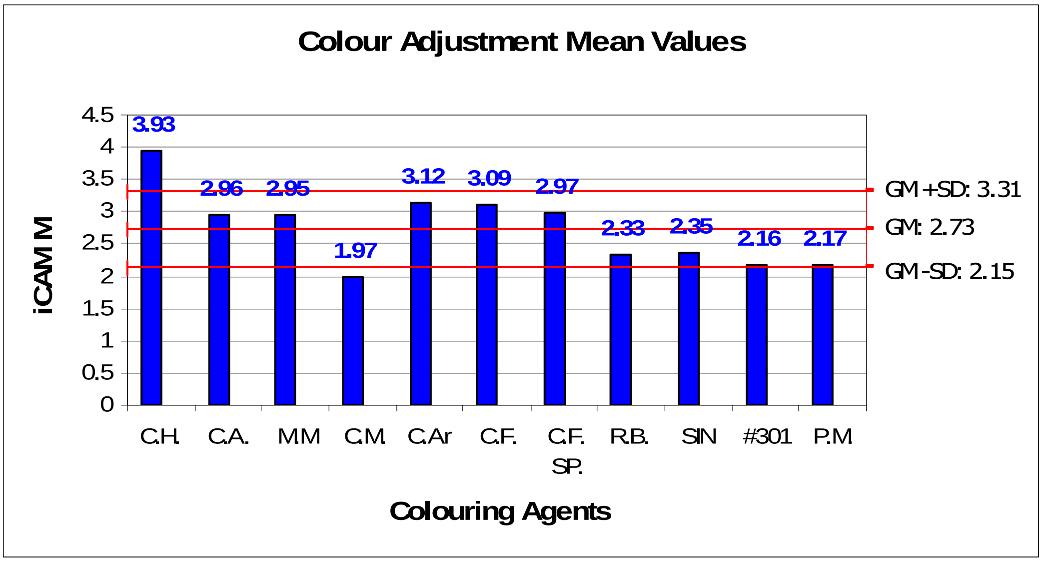

Chart B.2.15 iCAM Colourfulness of fresh locally-brewed beers

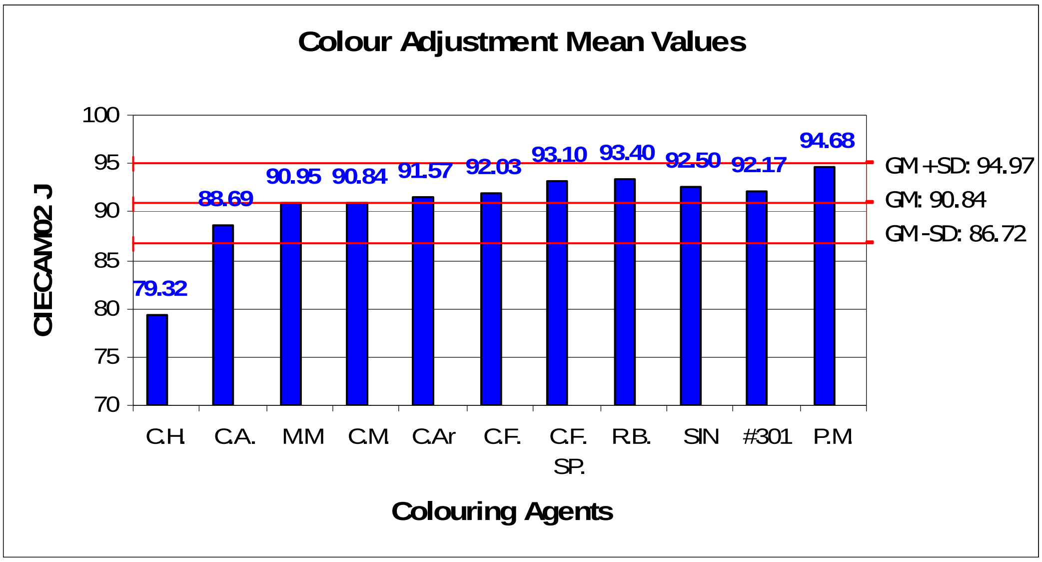

Chart B.2.16 CIECAM02 Lightness of fresh locally-brewed beers

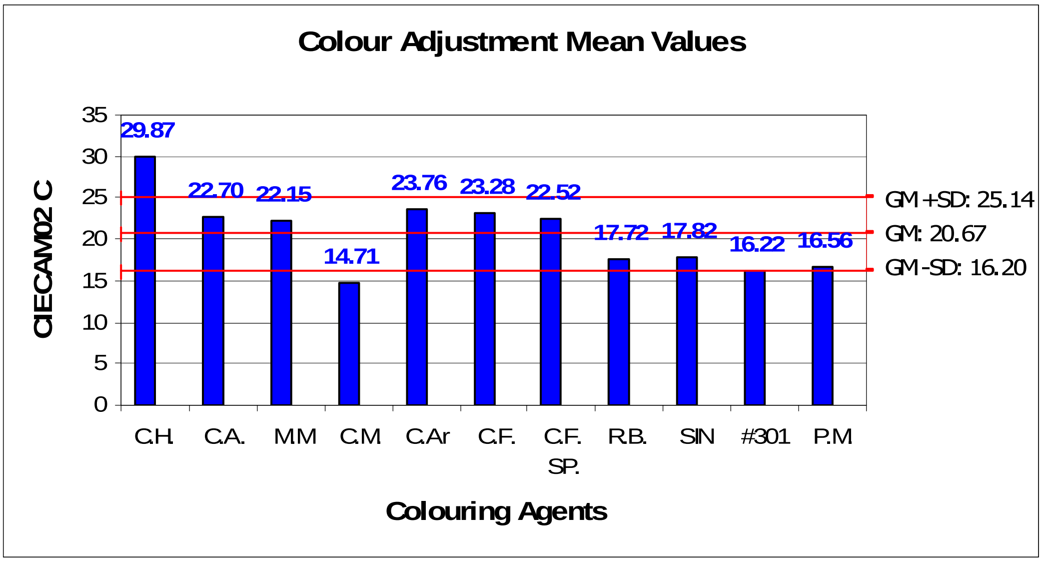

Chart B.2.17 CIECAM02 Chroma of fresh locally-brewed beers

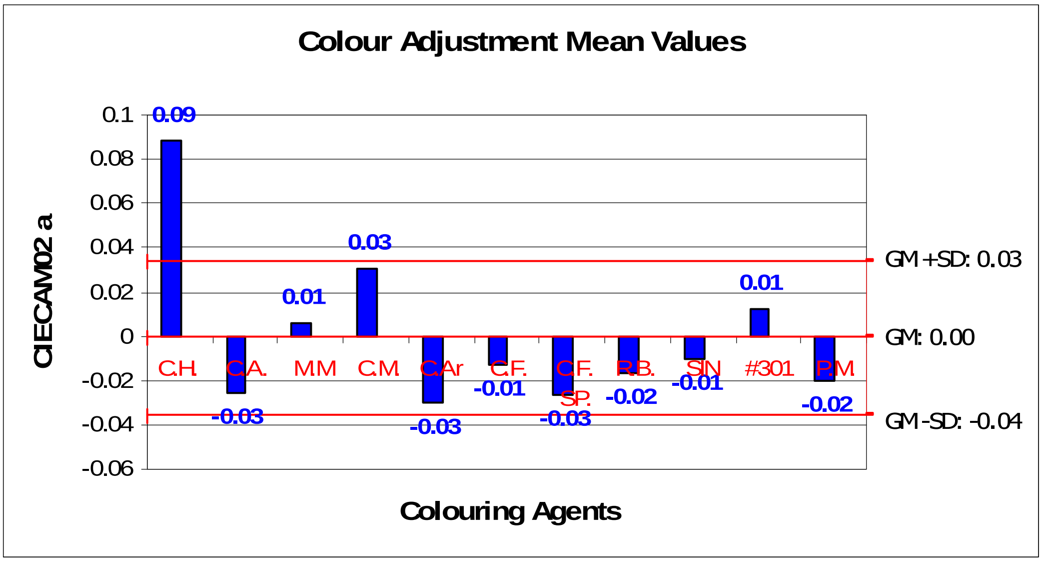

Chart B.2.18 CIECAM02 Redness- Greenness of fresh locally-brewed beers

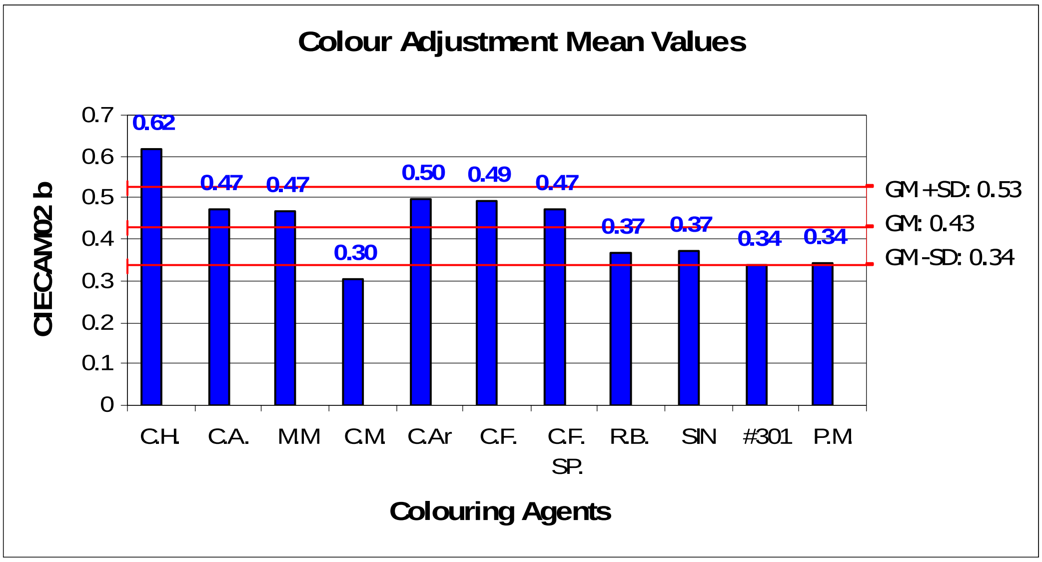

Chart B.2.19 CIECAM02 Yellowness-Blueness of fresh locally-brewed beers

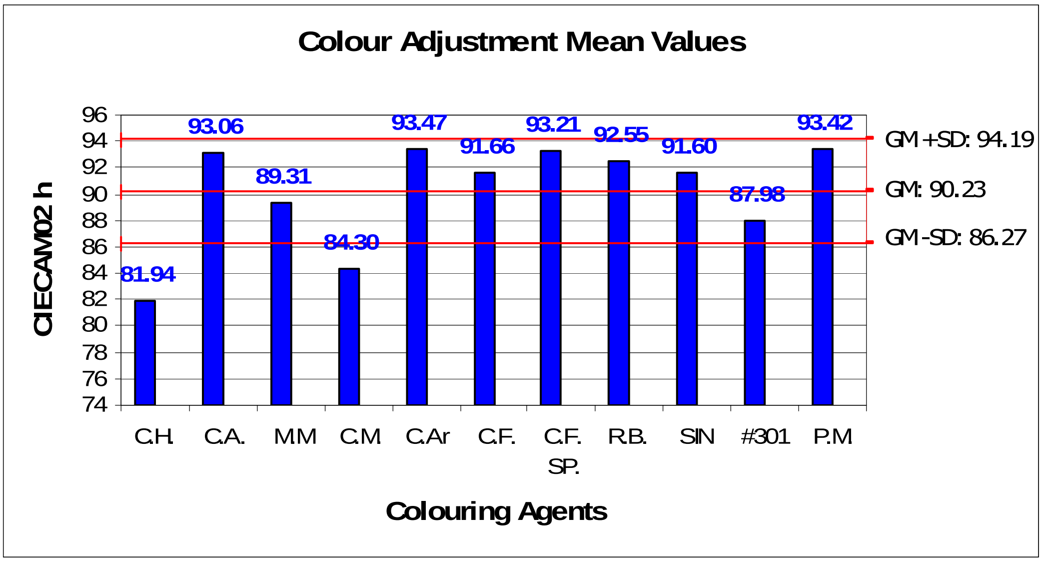

Chart B.2.20 CIECAM02 Hue angle of fresh locally-brewed beers

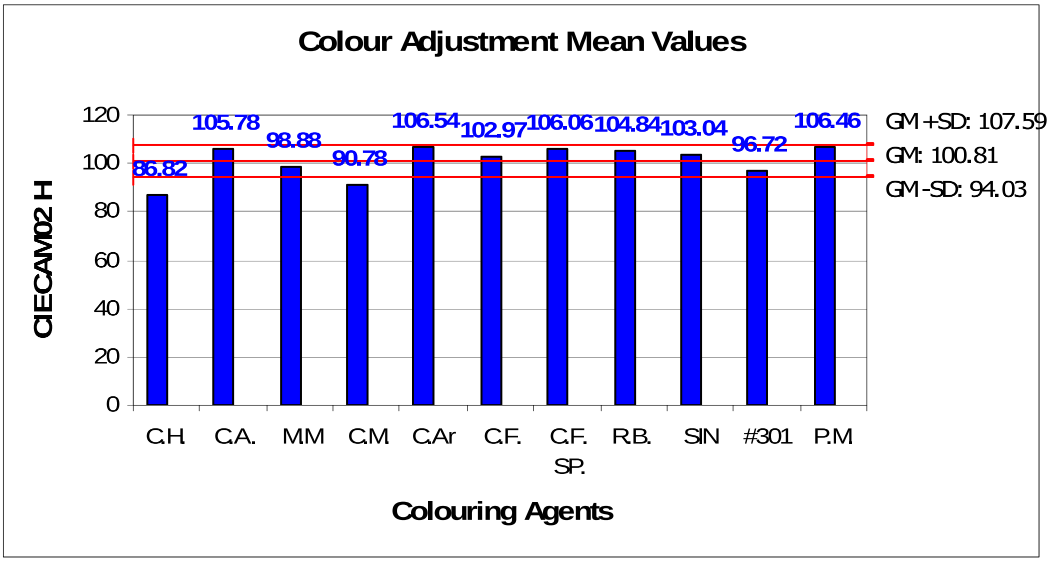

Chart B.2.21 CIECAM02 Hue quadrature of fresh locally-brewed beers

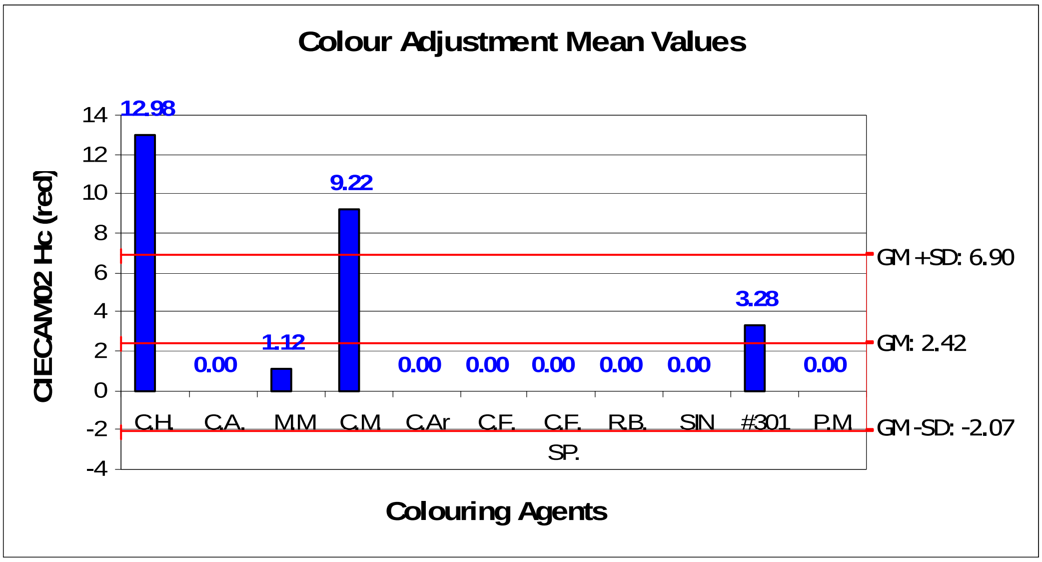

Chart B.2.22 CIECAM02 redness hue component of fresh locally-brewed beers

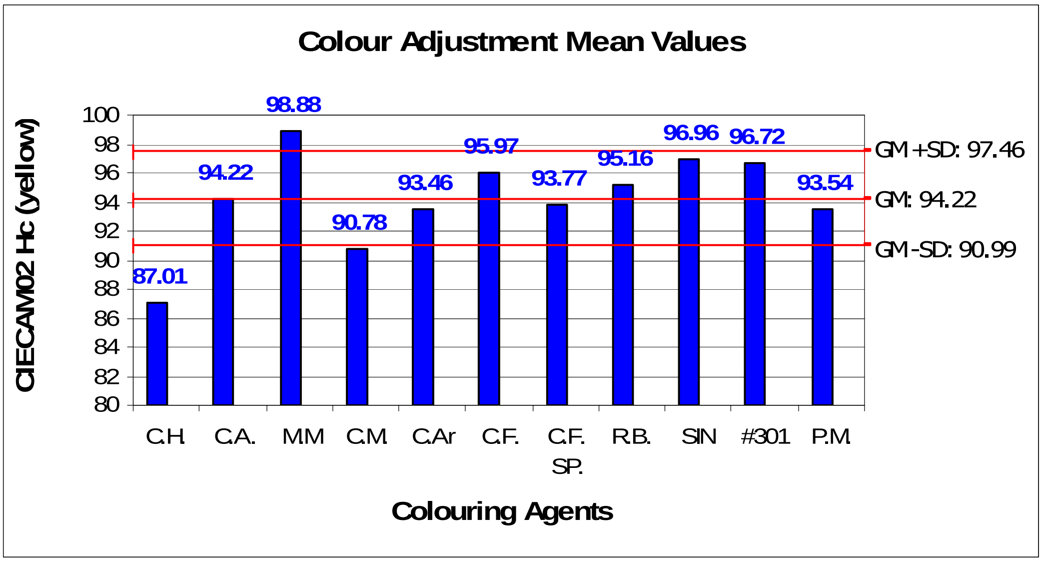

Chart B.2.23 CIECAM02 yellowness hue component of fresh locally-brewed beers

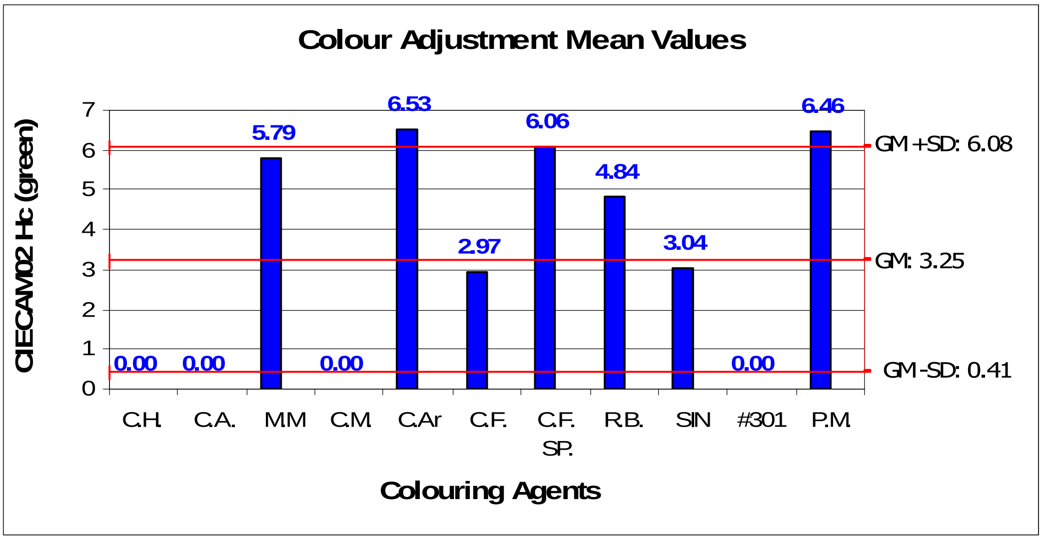

Chart B.2.24 CIECAM02 greenness hue component of fresh locally-brewed beers

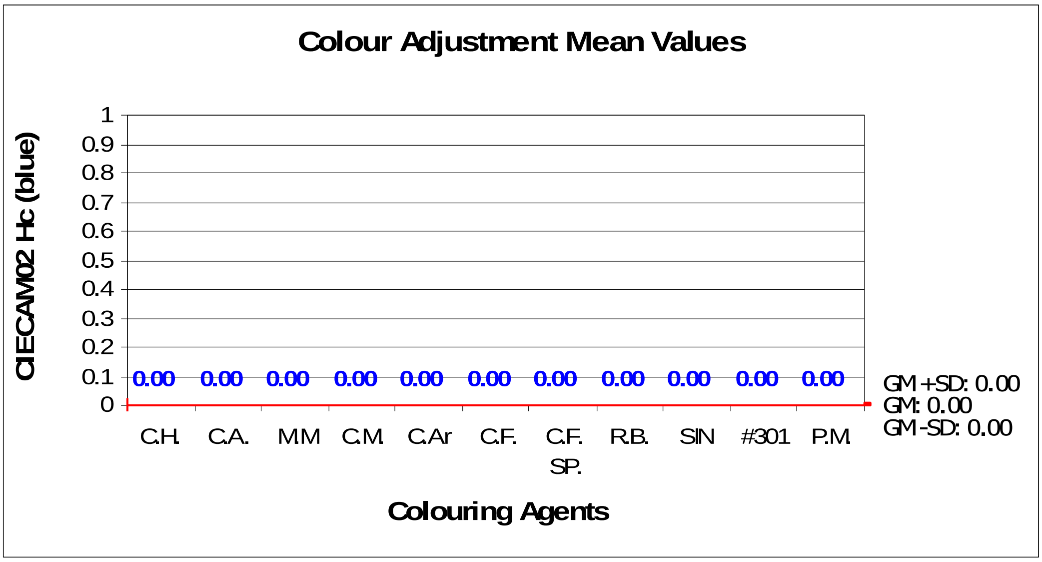

Chart B.2.25 CIECAM02 blueness hue component of fresh locally-brewed beers

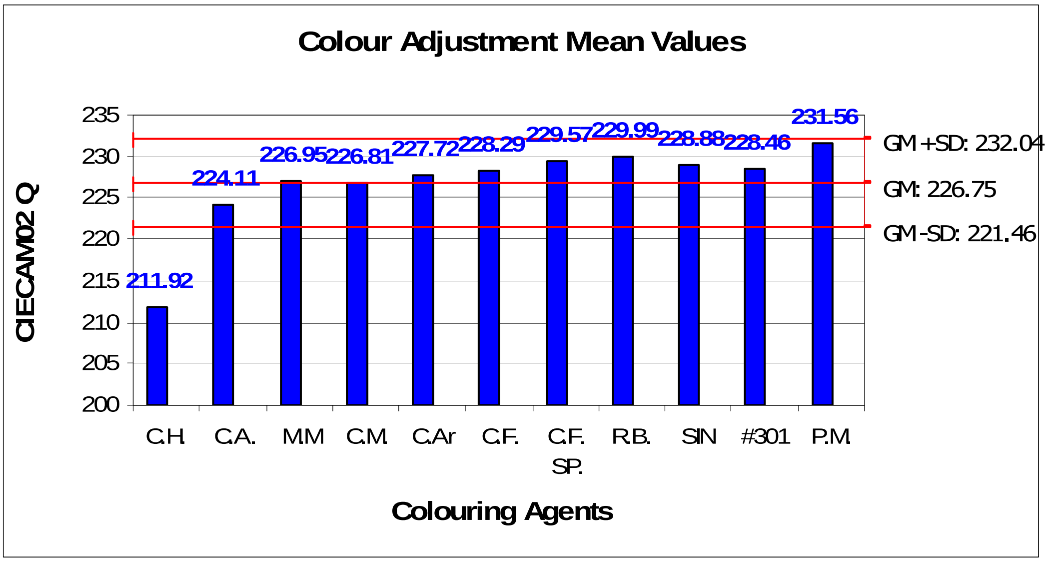

Chart B.2.26 CIECAM02 Brightness of fresh locally-brewed beers

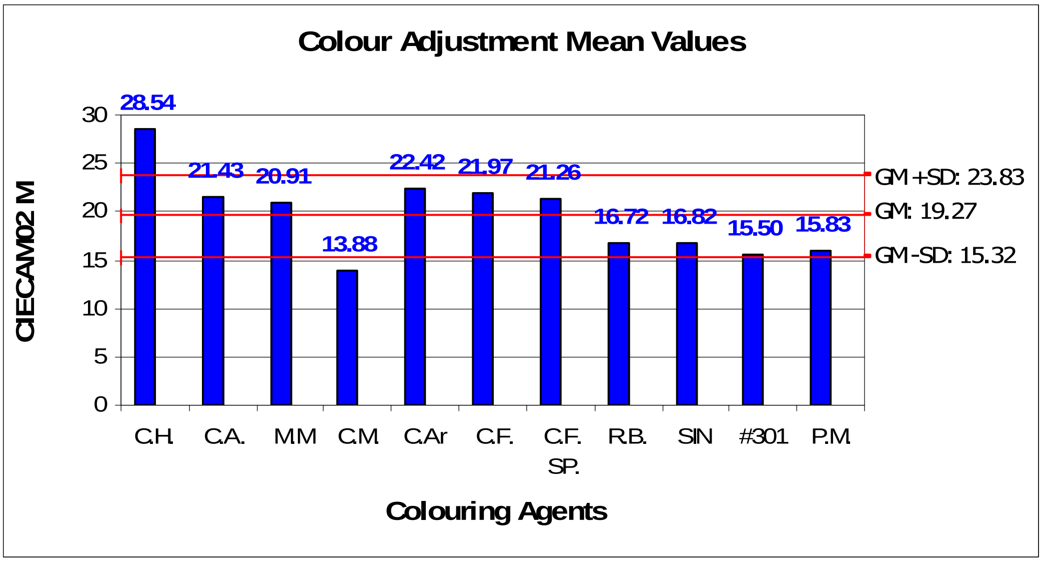

Chart B.2.27 CIECAM02 Colourfulness of fresh locally-brewed beers

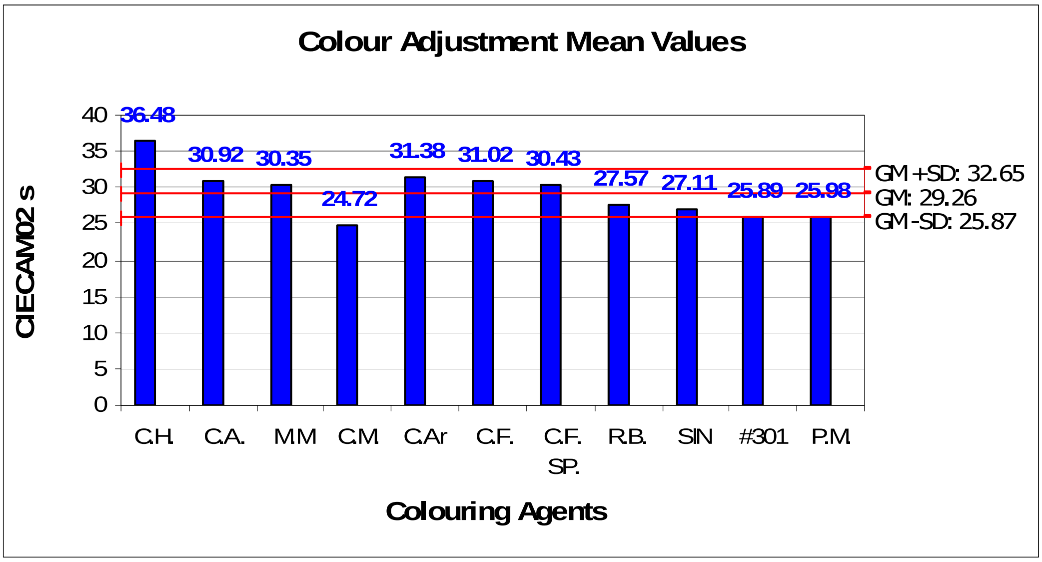

Chart B.2.28 CIECAM02 Saturation of fresh locally-brewed beers

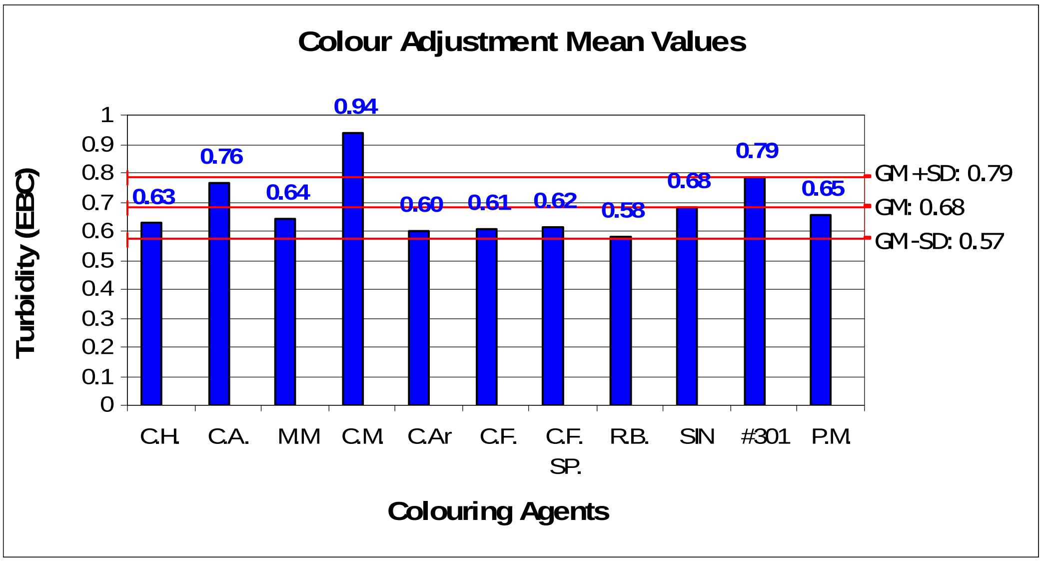

Chart B.2.29 Turbidity (EBC) of fresh locally-brewed beers

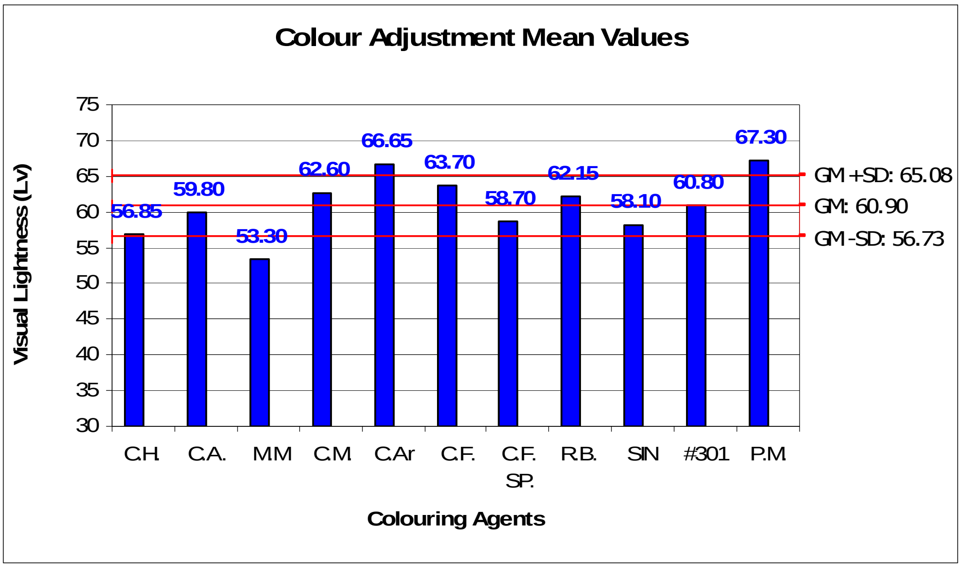

Chart B.3.1 Visual lightness (Lv) of fresh locally-brewed beers

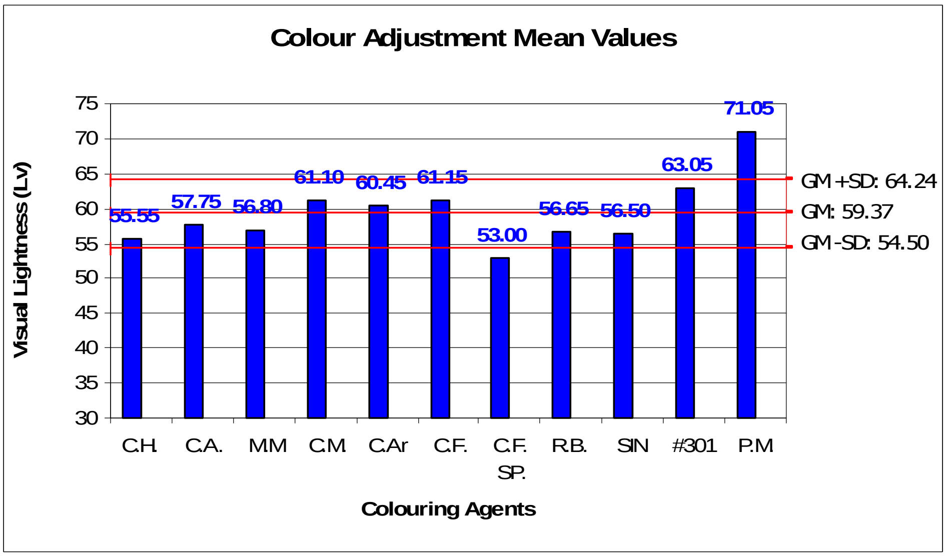

Chart B.3.2 Visual lightness (Lv) of forced aged locally-brewed beers

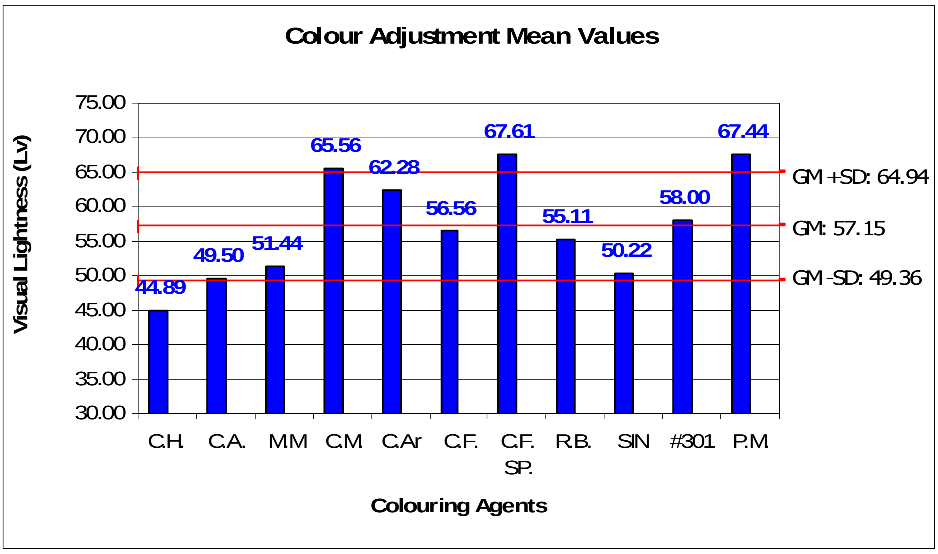

Chart B.3.3 Visual lightness (Lv) of spontaneously aged locally-brewed beers

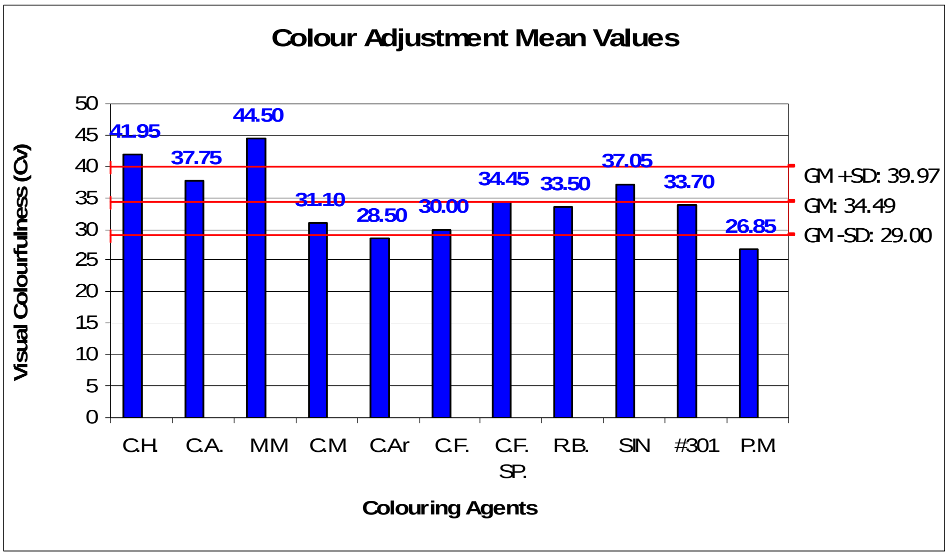

Chart B.3.4 Visual colourfulness (Cv) of fresh locally-brewed beers

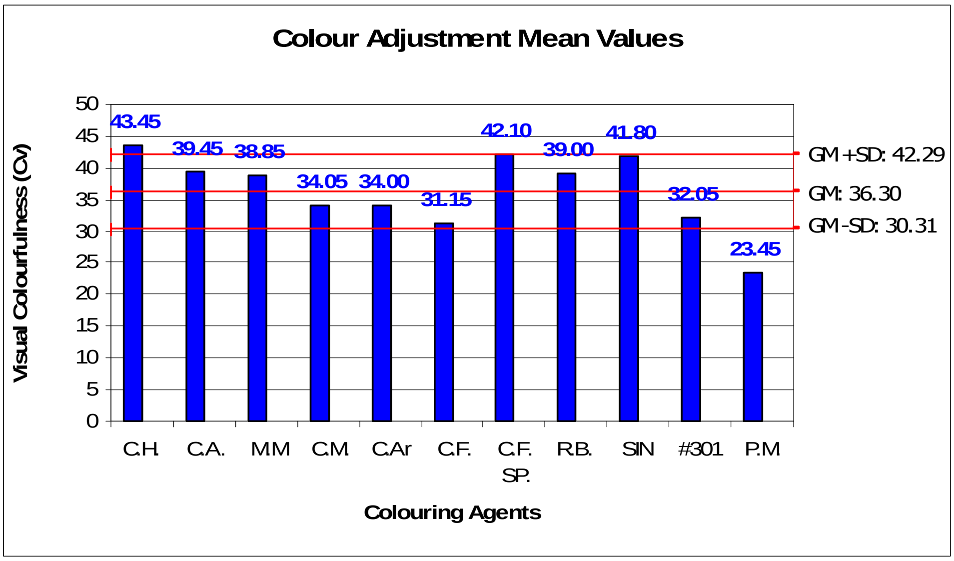

Chart B.3.5 Visual colourfulness (Cv) of forced aged locally-brewed beers

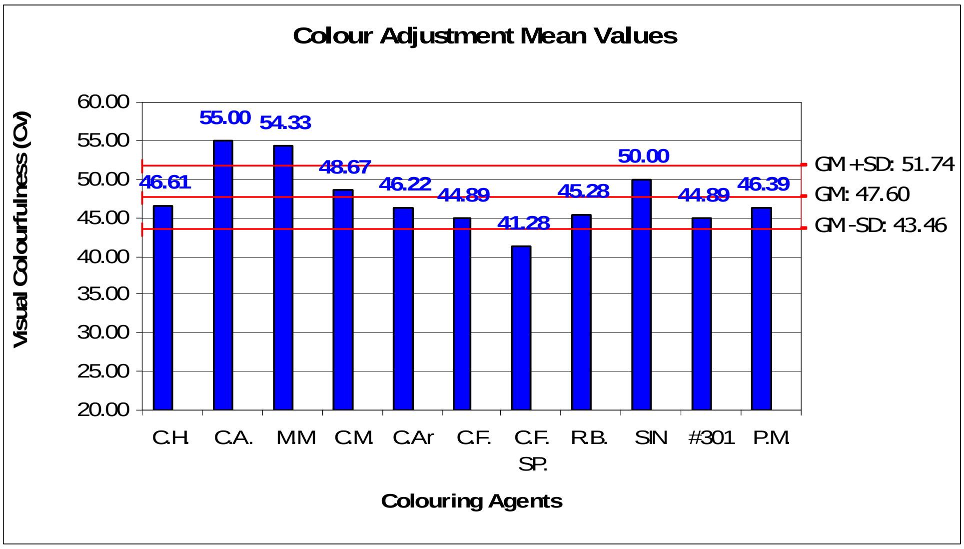

Chart B.3.6 Visual colourfulness (Cv) of spontaneously aged locally-brewed beers

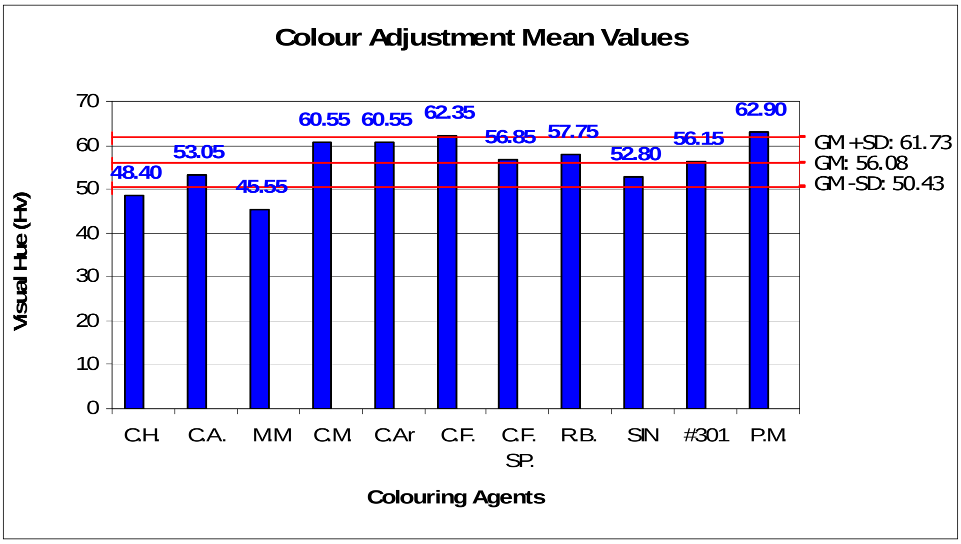

Chart B.3.7 Visual hue (hv) of fresh locally-brewed beers

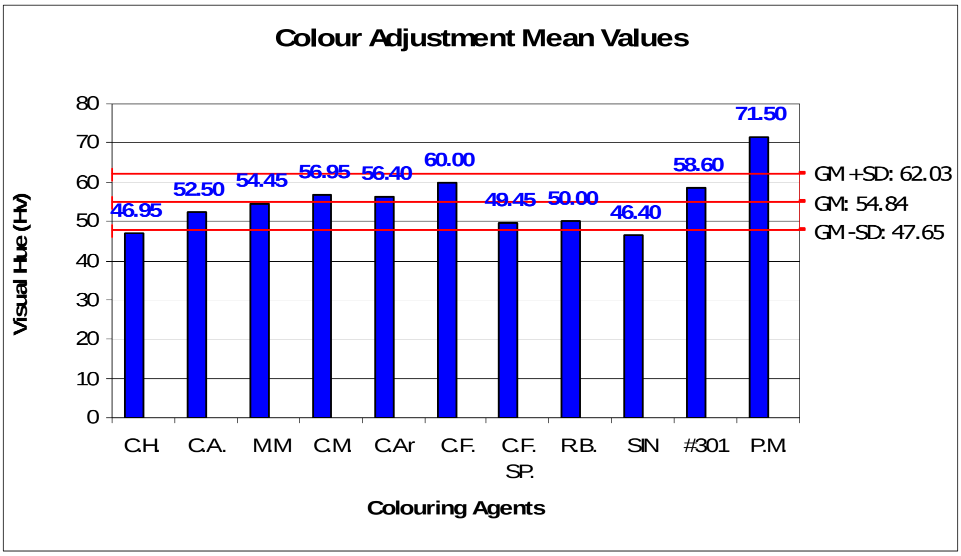

Chart B.3.8 Visual hue (hv) of forced aged locally-brewed beers

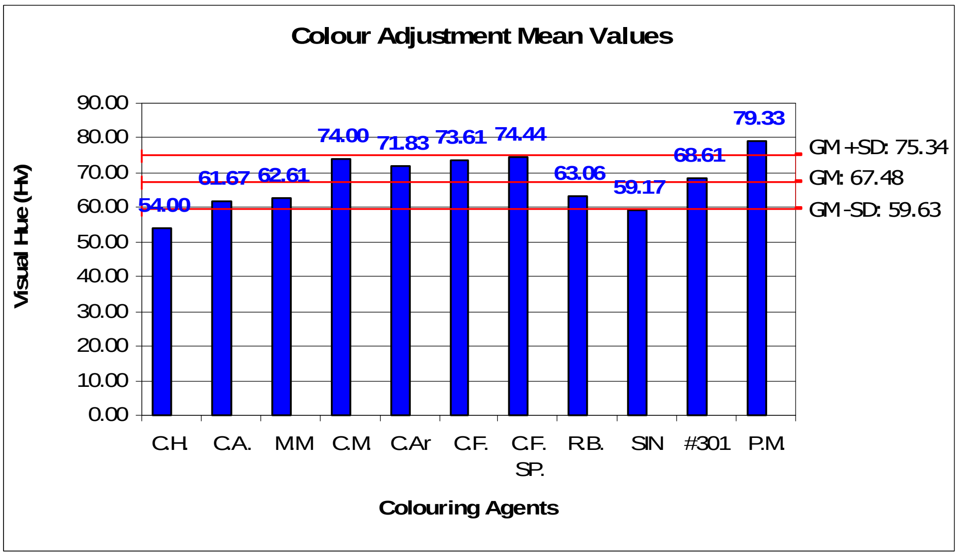

Chart B.3.9 Visual hue (hv) of spontaneously aged locally-brewed beers

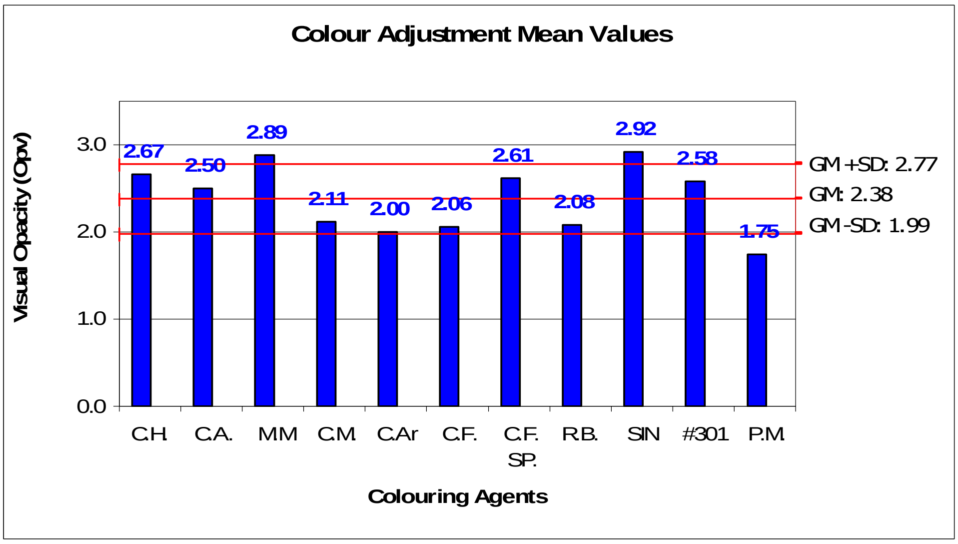

Chart B.3.10 Visual opacity (Opv) of fresh locally-brewed beers

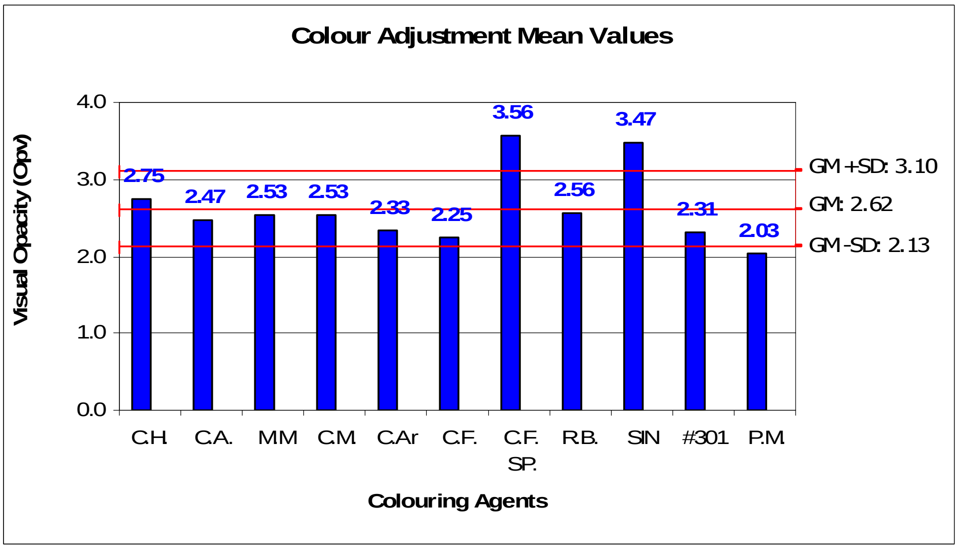

Chart B.3.11 Visual opacity (Opv) of forced aged locally-brewed beers

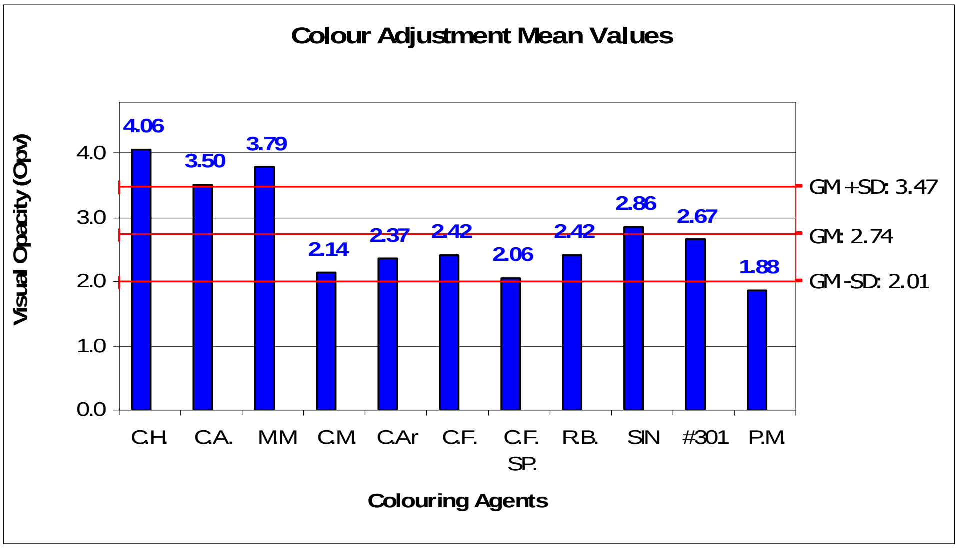

Chart B.3.12 Visual opacity (Opv) of spontaneously aged locally-brewed beers

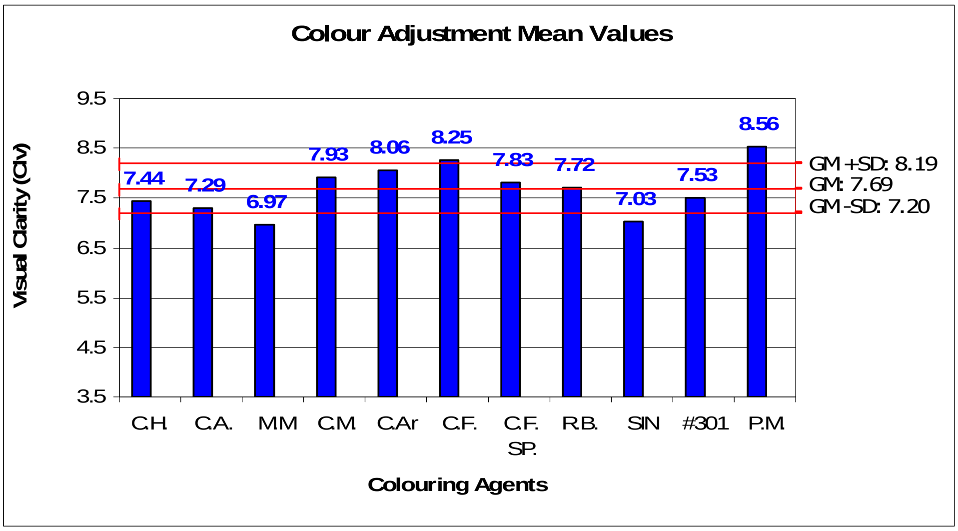

Chart B.3.13 Visual clarity (Clv) of fresh locally-brewed beers

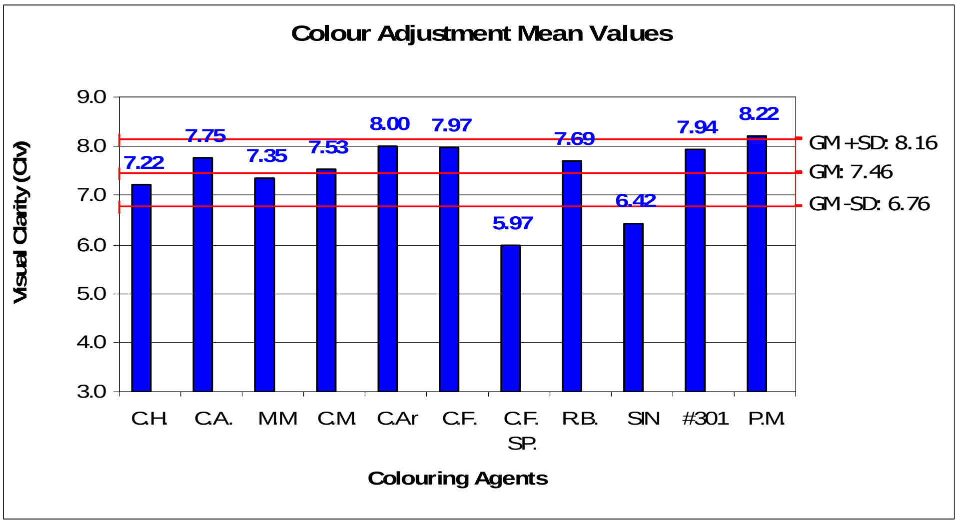

Chart B.3.14 Visual clarity (Clv) of forced aged locally-brewed beers

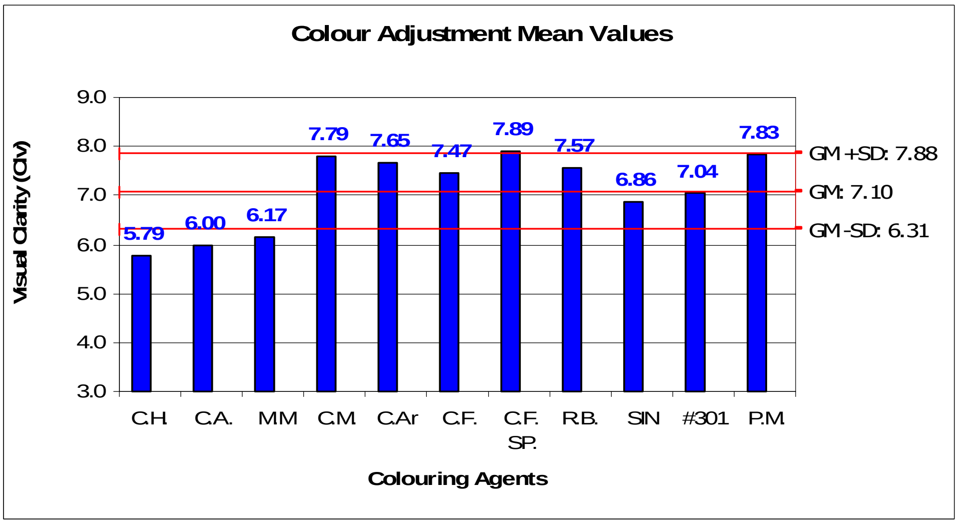

Chart B.3.15 Visual clarity (Clv) of spontaneously aged locally-brewed beers

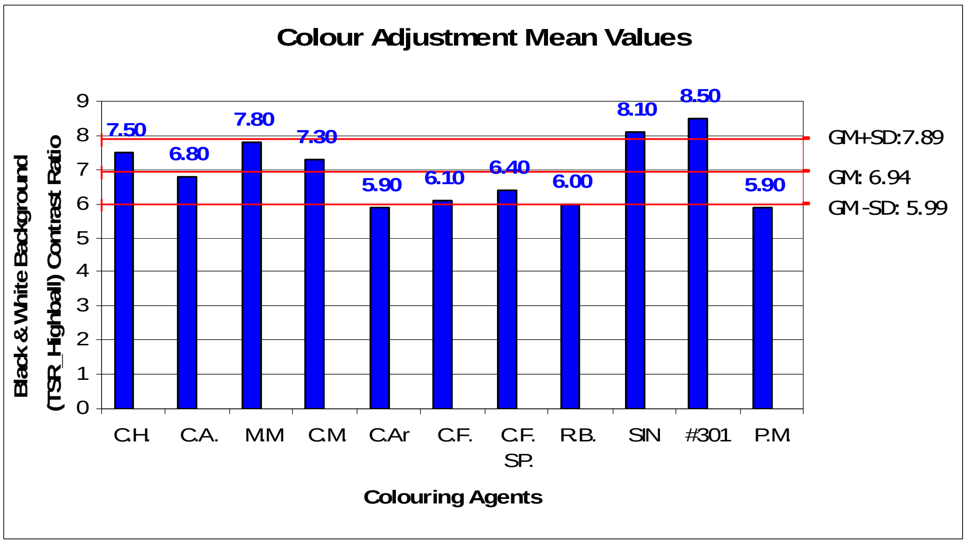

Chart B.316 Contrast Ratio for Tele-spectroradiometrical measurements in highball glass over black & white backgrounds of fresh locally-brewed beers

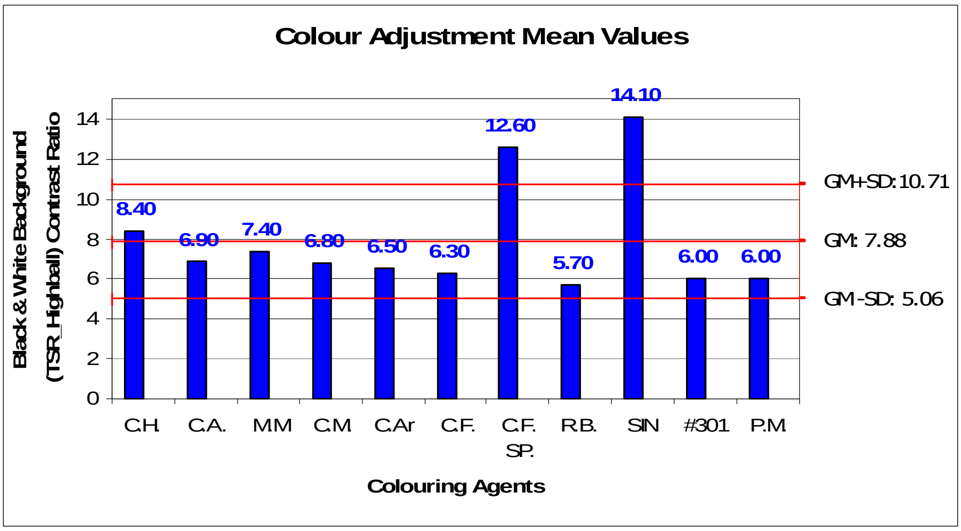

Chart B.3.17 Contrast Ratio for Tele-spectroradiometrical measurements in highball glass over black & white backgrounds of forced aged locally-brewed beers

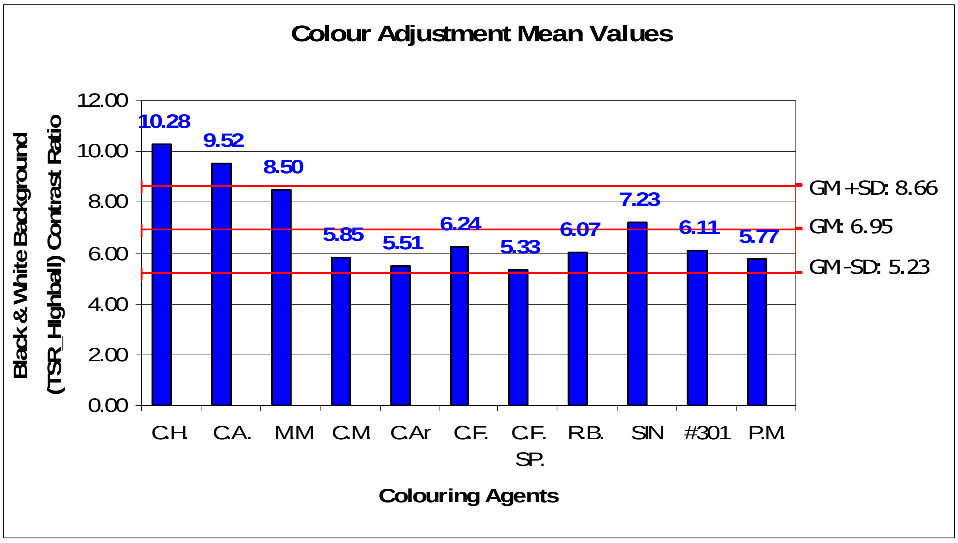

Chart B.3.18 Contrast Ratio for Tele-spectroradiometrical measurements in highball glass over black & white backgrounds of spontaneously aged locally-brewed beers

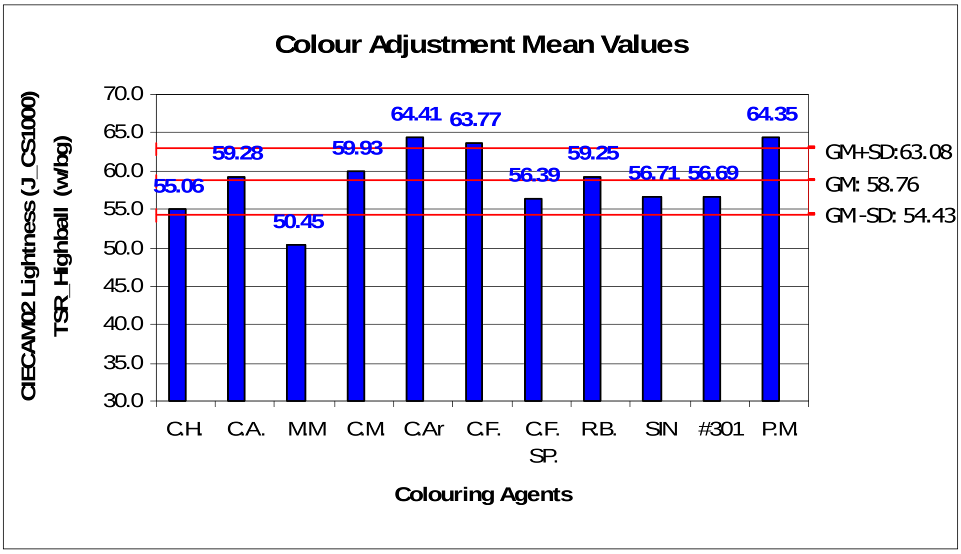

Chart B.3.19 CIECAM02 Lightness (J_TSR) by Telespectroradiometry in highball glass of fresh locally-brewed beers

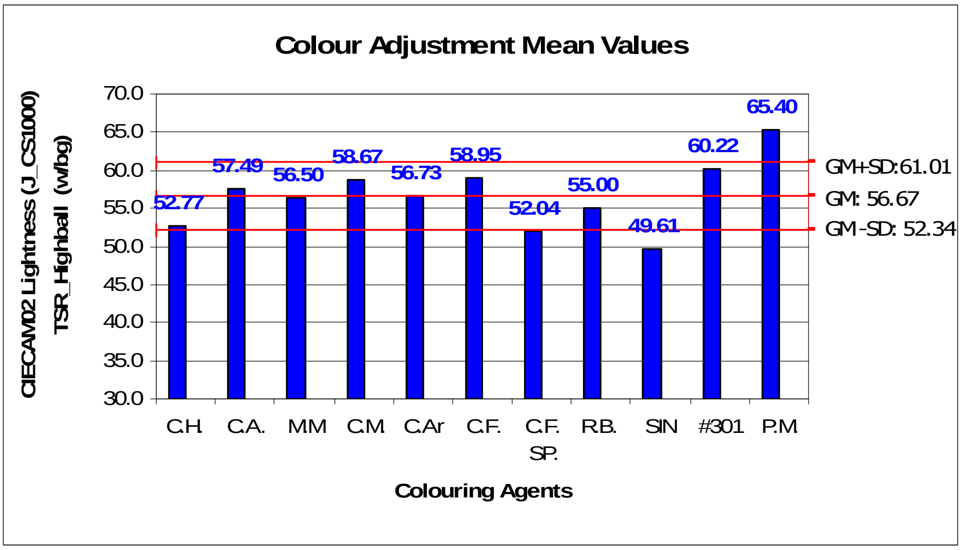

Chart B.3.20 CIECAM02 Lightness (J_TSR) by Telespectroradiometry in highball glass of forced aged locally-brewed beers

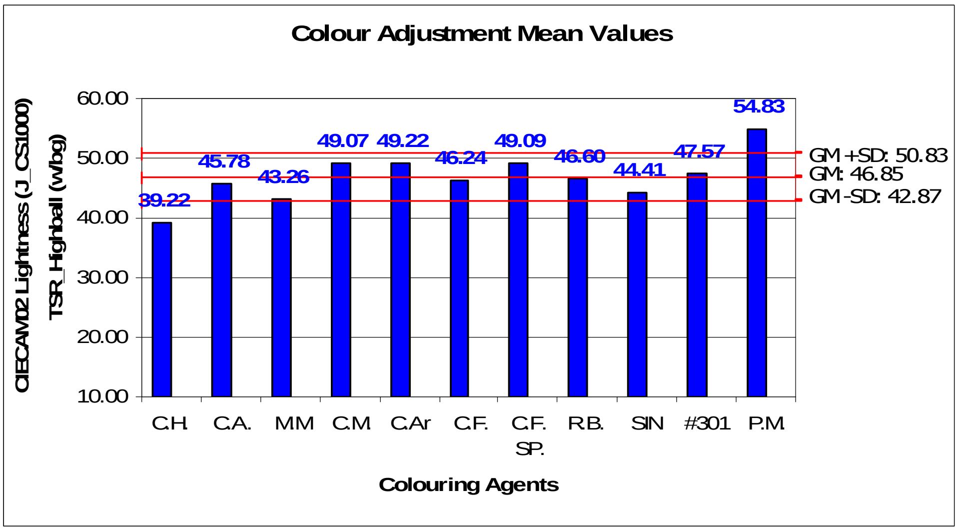

Chart B.3.21 CIECAM02 Lightness (J_TSR) by Telespectroradiometry in highball glass of spontaneously aged locally-brewed beers

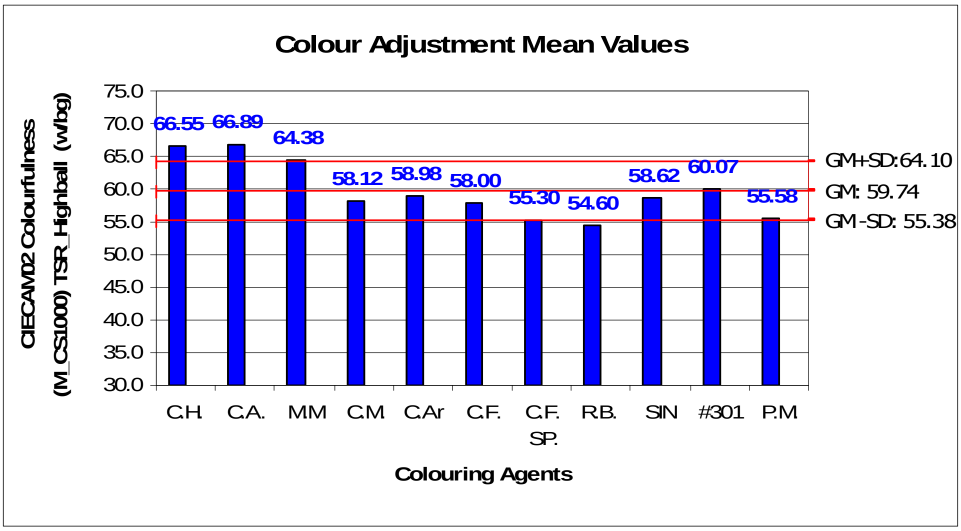

Chart B.3.22 CIECAM02 Colourfulness (M_TSR) by Telespectroradiometry in highball glass of fresh locally-brewed beers

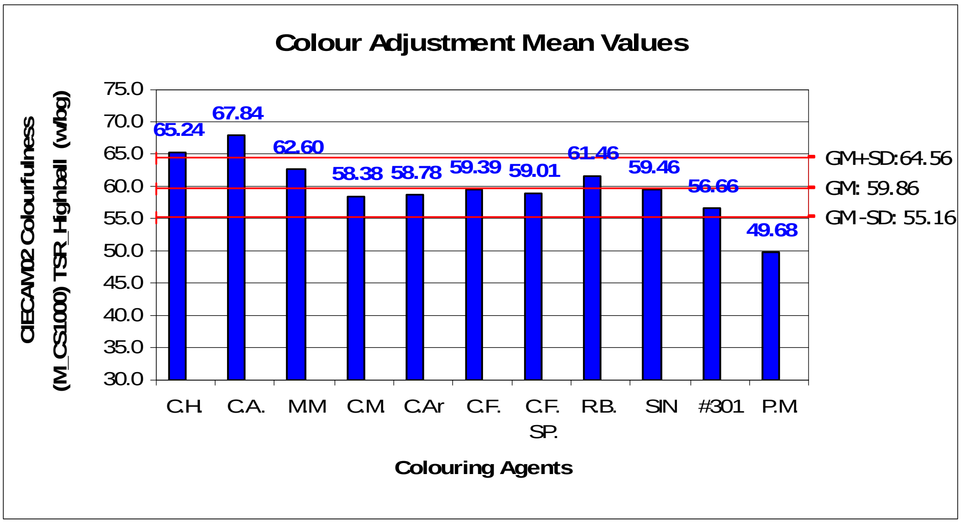

Chart B.3.23 CIECAM02 Colourfulness (M_TSR) by Telespectroradiometry in highball glass of forced aged locally-brewed beers

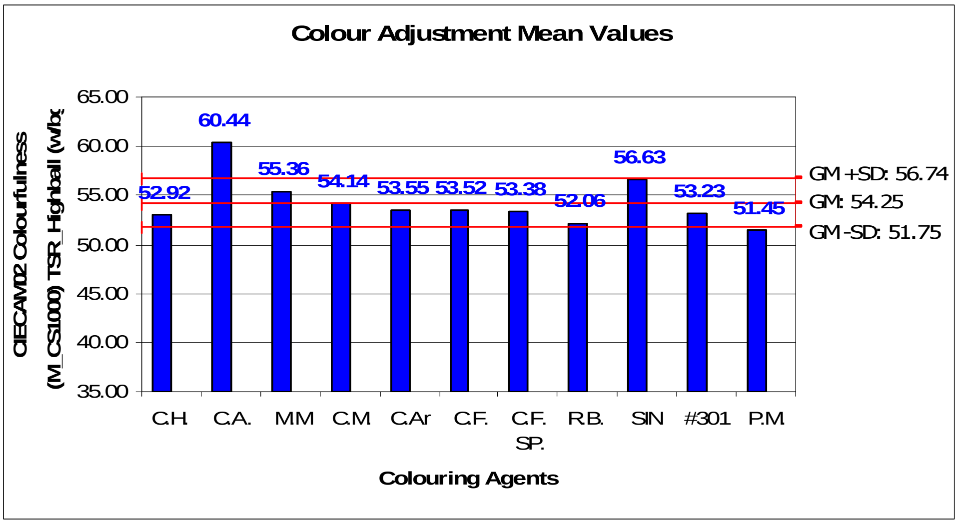

Chart B.3.24 CIECAM02 Colourfulness (M_TSR) by Telespectroradiometry in highball glass of spontaneously aged locally-brewed beers

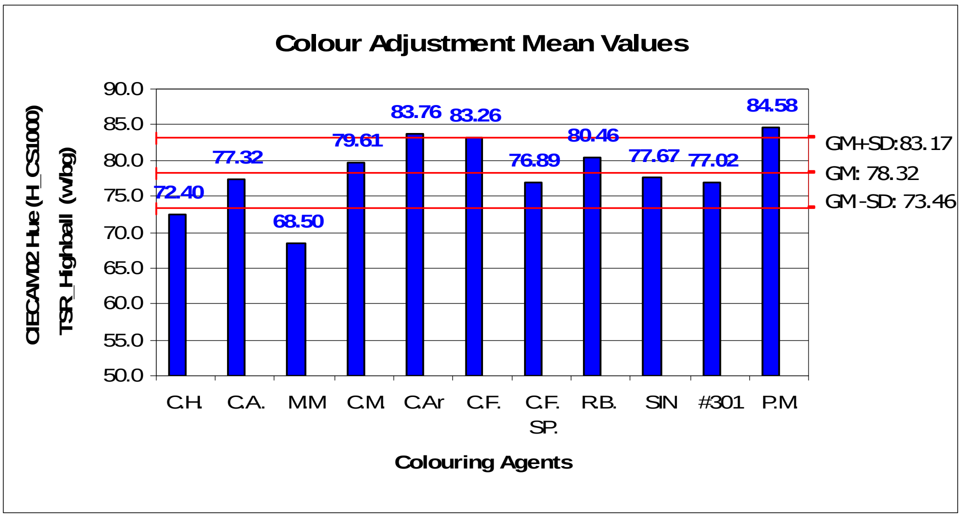

Chart B.3.25 CIECAM02 Hue Quadrature (H_TSR) by Telespectroradiometry in highball glass with of fresh locally-brewed beers

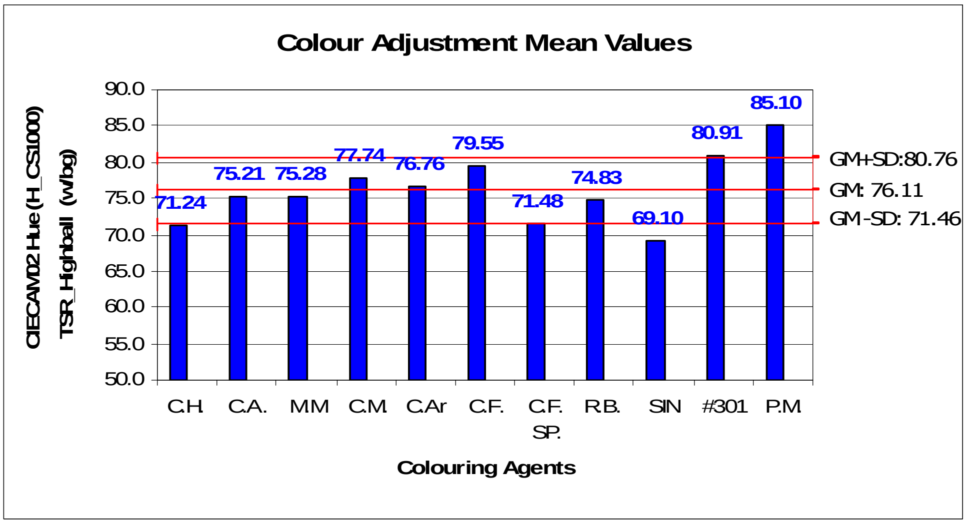

Chart B.3.26 CIECAM02 Hue Quadrature(H_TSR) by Telespectroradiometry in highball glass of forced aged locally-brewed beers

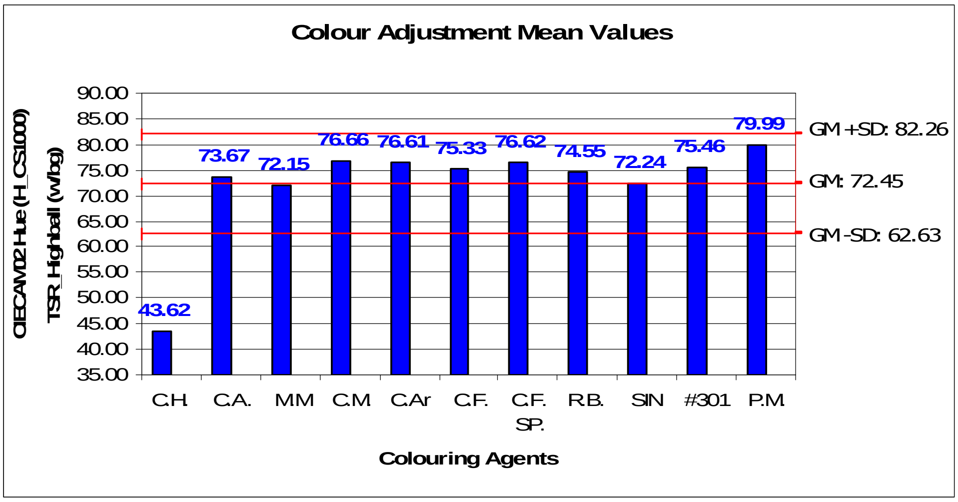

Chart B.3.27 CIECAM02 Hue Quadrature (H_TSR) by Telespectroradiometry in highball glass of spontaneously aged locally-brewed beers

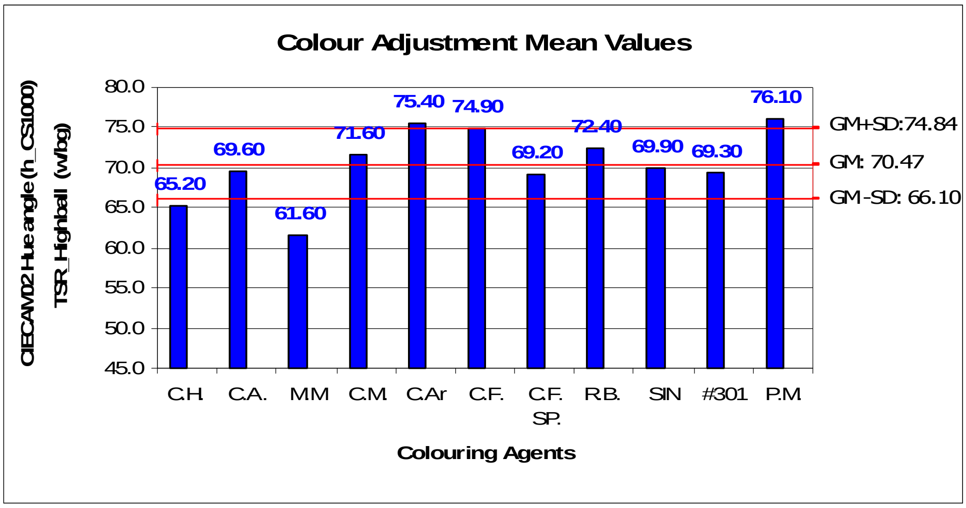

Chart B.3.28 CIECAM02 Hue angle (h_TSR) by Telespectroradiometry in highball glass of fresh locally-brewed beers

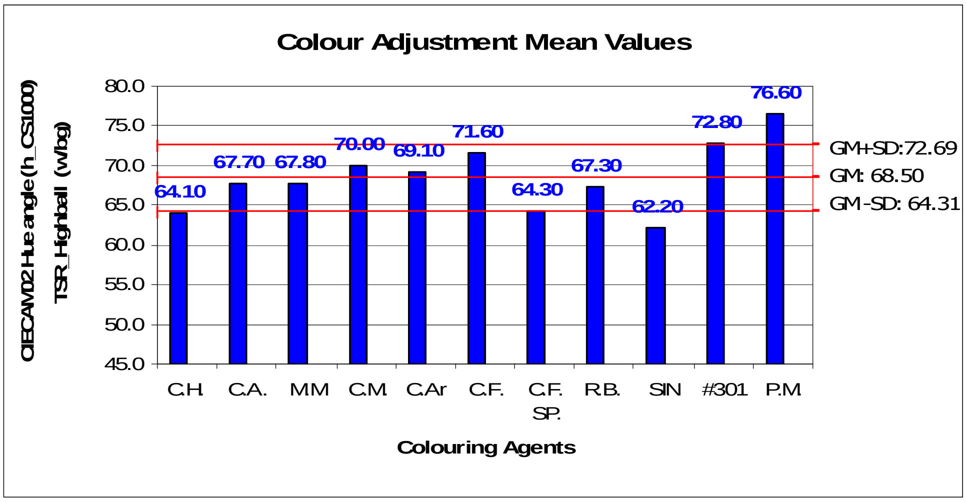

Chart B.3.29 CIECAM02 Hue angle (h_TSR) by Telespectroradiometry in highball glass of forced aged locally-brewed beers

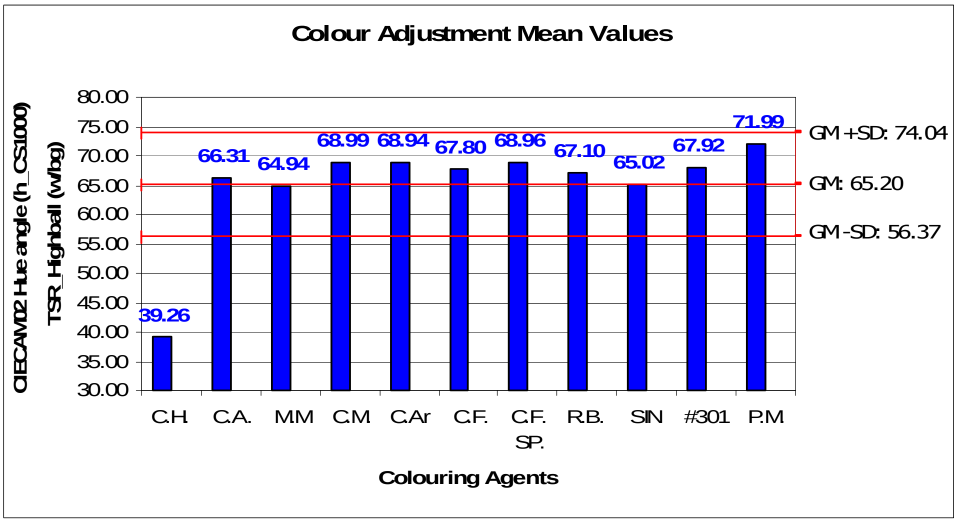

Chart B.3.30 CIECAM02 Hue angle (h_TSR) by Telespectroradiometry in highball glass of spontaneously aged locally-brewed beers

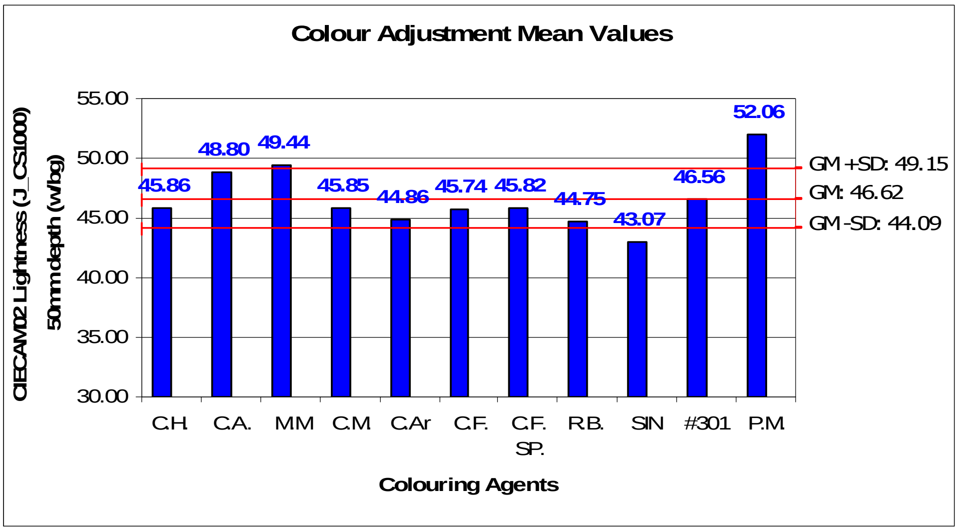

Chart B.3.31 CIECAM02 Lightness (J_TSR) by Telespectroradiometry at 50.0 mm depth over white background of fresh locally-brewed beers

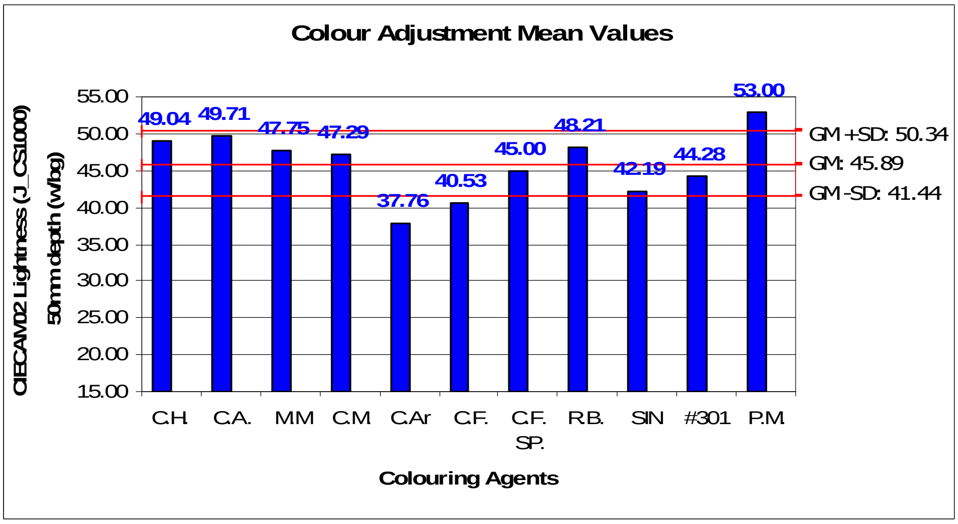

Chart B.3.32 CIECAM02 Lightness (J_TSR) by Telespectroradiometry at 50.0 mm depth over white background of forced aged locally-brewed beers

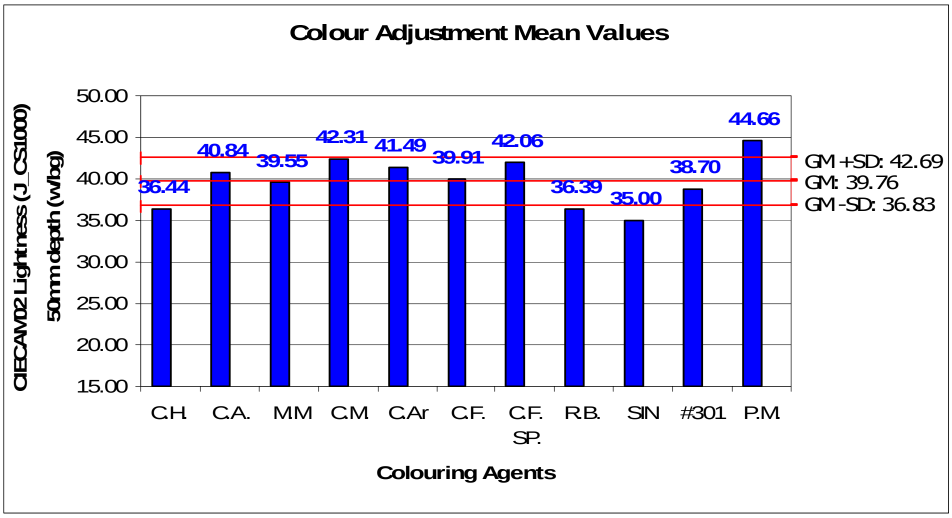

Chart B.3.33 CIECAM02 Lightness (J_TSR) by Telespectroradiometry at 50.0 mm depth over white background of spontaneously aged locally-brewed beers

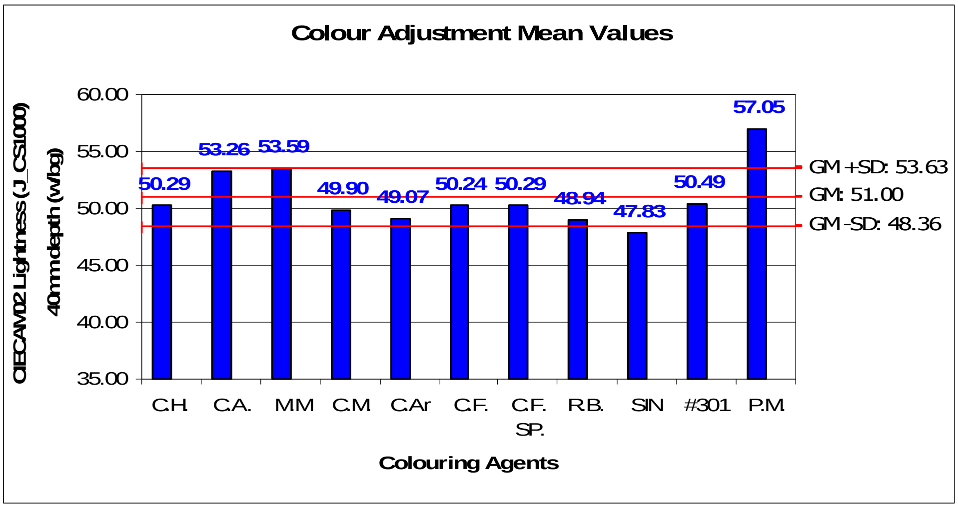

Chart B.3.34 CIECAM02 Lightness (J_TSR) by Telespectroradiometry at 40.0 mm depth over white background of fresh locally-brewed beers

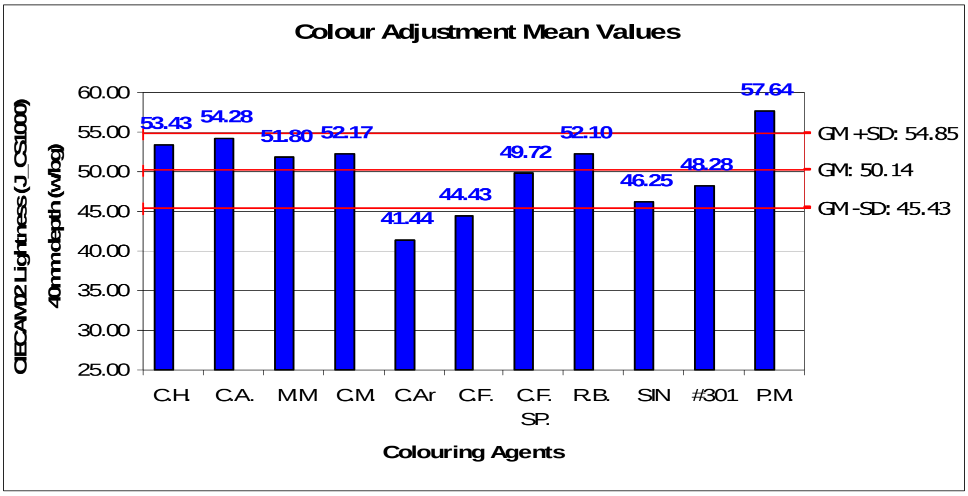

Chart B.3.35 CIECAM02 Lightness (J_TSR) by Telespectroradiometry at 40.0 mm depth over white background of forced aged locally-brewed beers

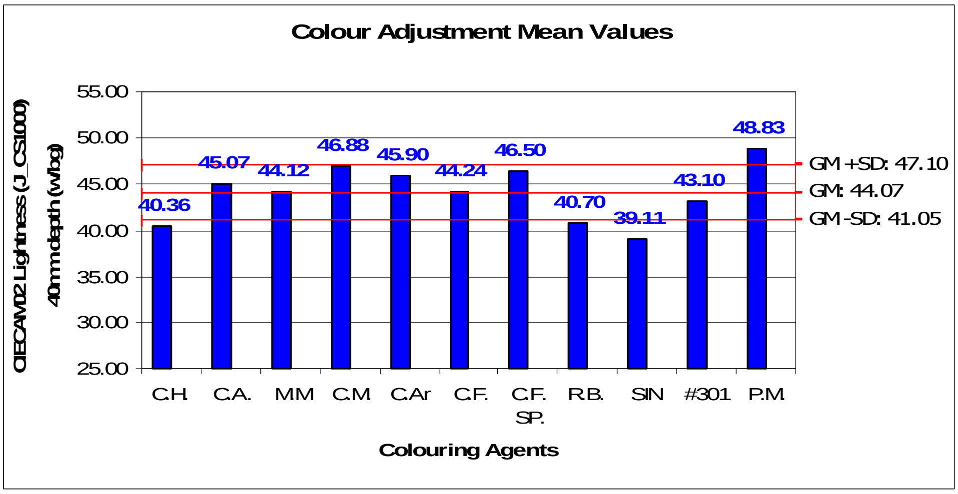

Chart B.3.36 CIECAM02 Lightness (J_TSR) by Telespectroradiometry at 40.0 mm depth over white background of spontaneously aged locally-brewed beers

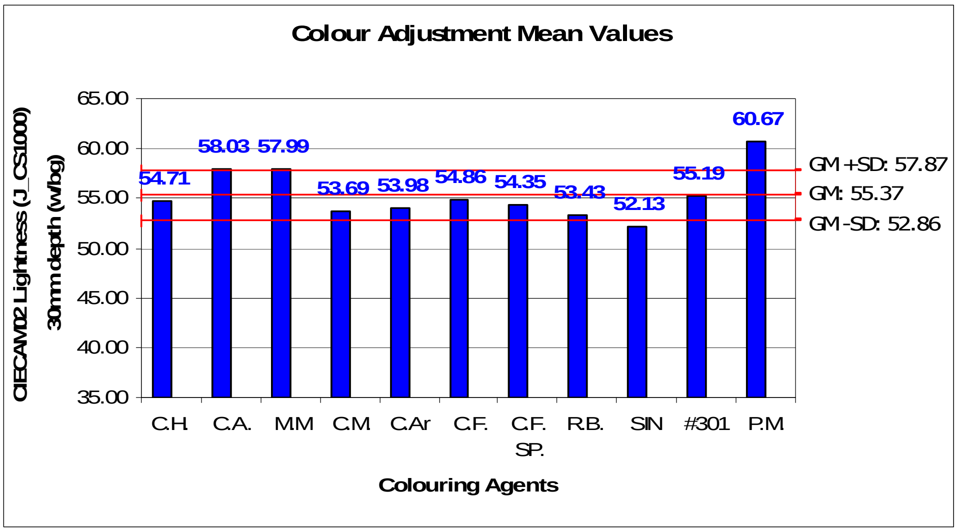

Chart B.3.37 CIECAM02 Lightness (J_TSR) by Telespectroradiometry at 30.0 mm depth over white background of fresh locally-brewed beers

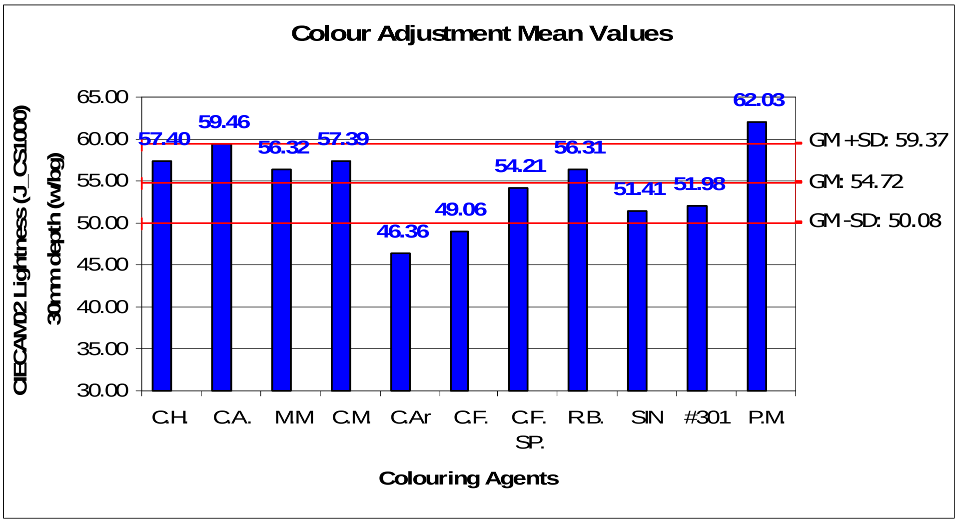

Chart B.3.38 CIECAM02 Lightness (J_TSR) by Telespectroradiometry at 30.0 mm depth over white background of forced aged locally-brewed beers

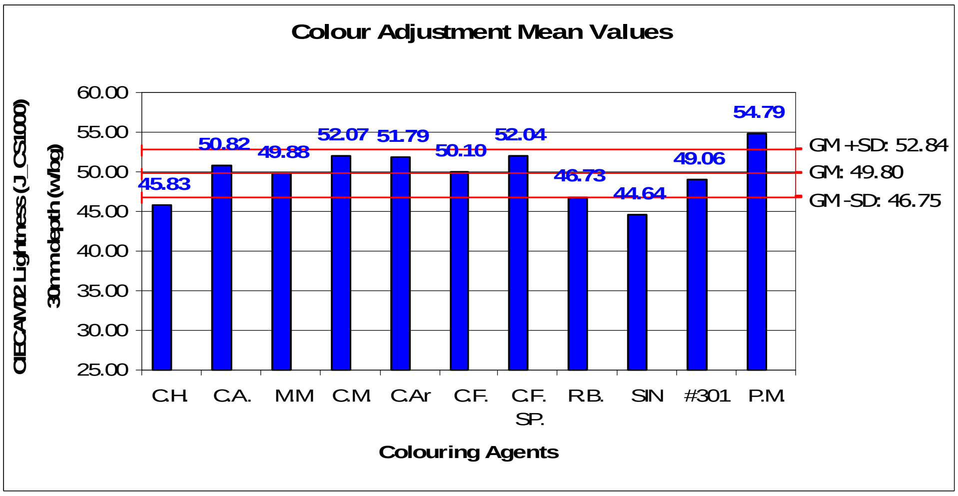

Chart B.3.39 CIECAM02 Lightness (J_TSR) by Telespectroradiometry at 30.0 mm depth over white background of spontaneously aged locally-brewed beers

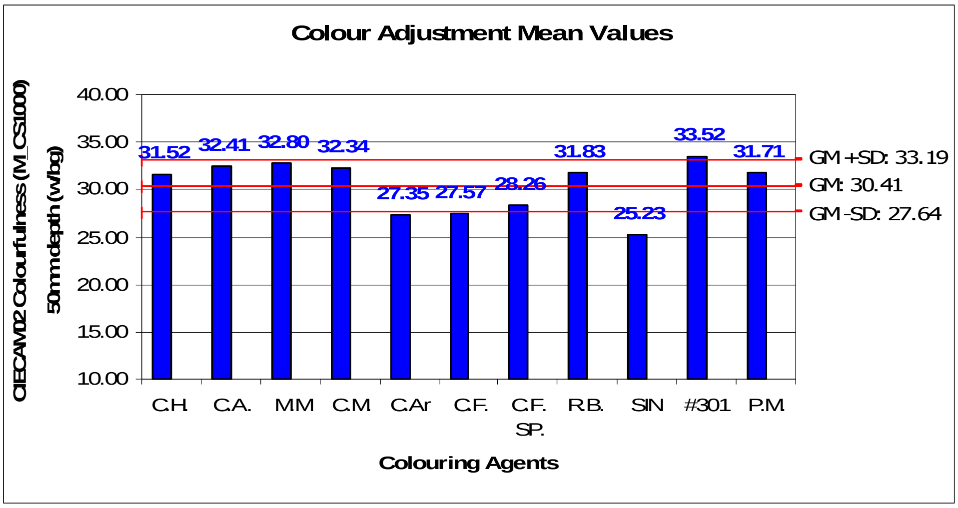

Chart B.3.40 CIECAM02 Colourfulness (M_TSR) by Telespectroradiometry at 50.0 mm depth over white background of fresh locally-brewed beers

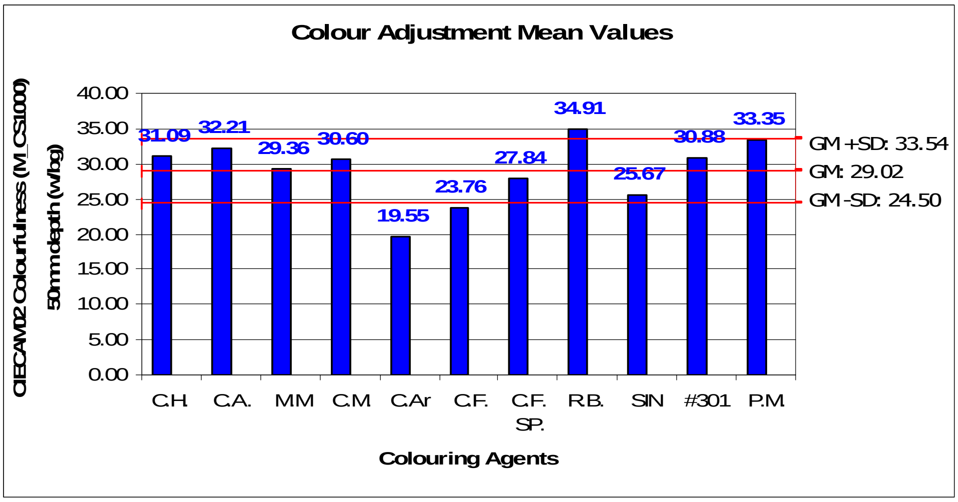

Chart B.3.41 CIECAM02 Colourfulness (M_TSR) by Telespectroradiometry at 50.0 mm depth over white background of forced aged locally-brewed beers

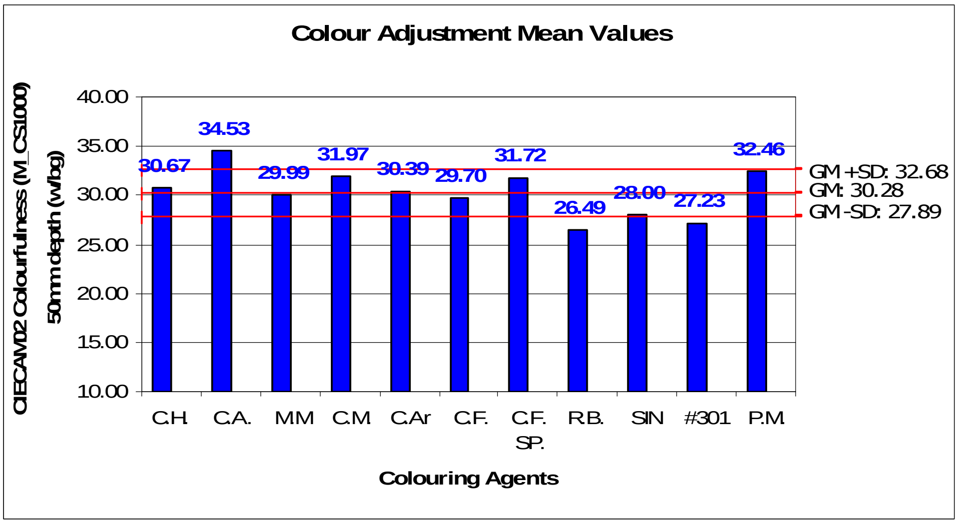

Chart B.3.42 CIECAM02 Colourfulness (M_TSR) by Telespectroradiometry at 50.0 mm depth over white background of spontaneously aged locally-brewed beers

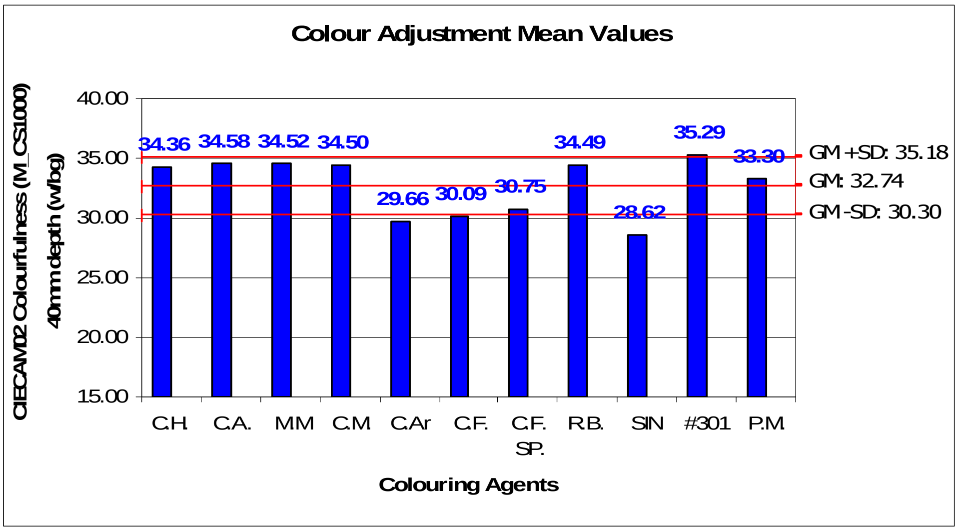

Chart B.3.43 CIECAM02 Colourfulness (M_TSR) by Telespectroradiometry at 40.0 mm depth over white background of fresh locally-brewed beers

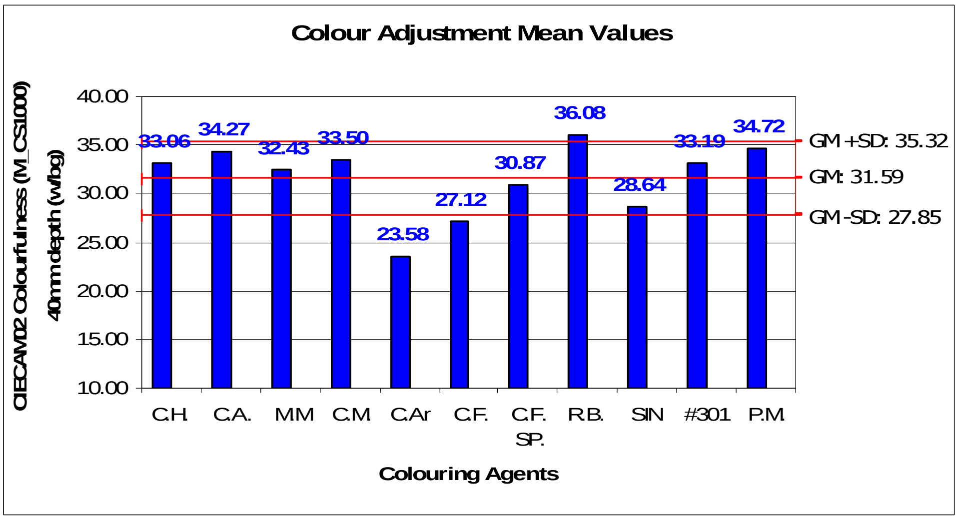

Chart B.3.44 CIECAM02 Colourfulness (M_TSR) by Telespectroradiometry at 40.0 mm depth over white background of forced aged locally-brewed beers

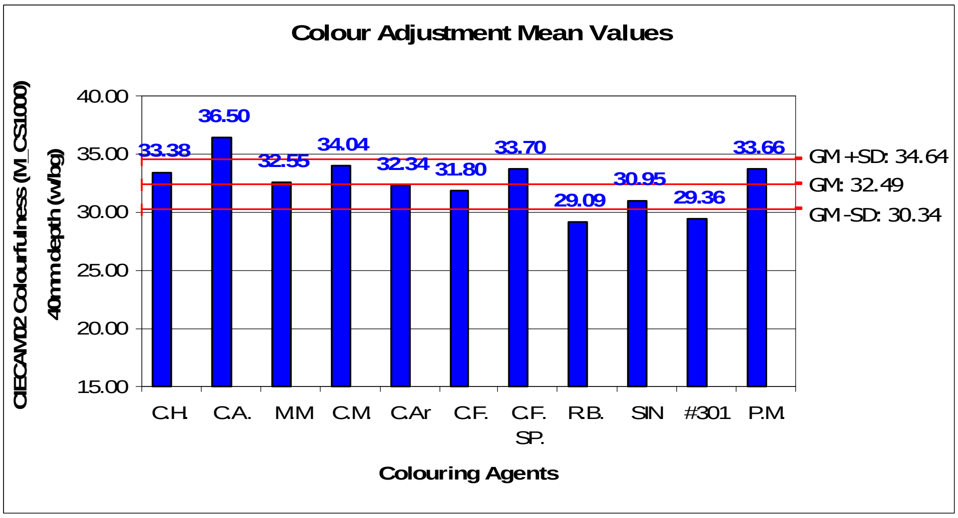

Chart B.3.45 CIECAM02 Colourfulness (M_TSR) by Telespectroradiometry at 40.0 mm depth over white background of spontaneously aged locally-brewed beers

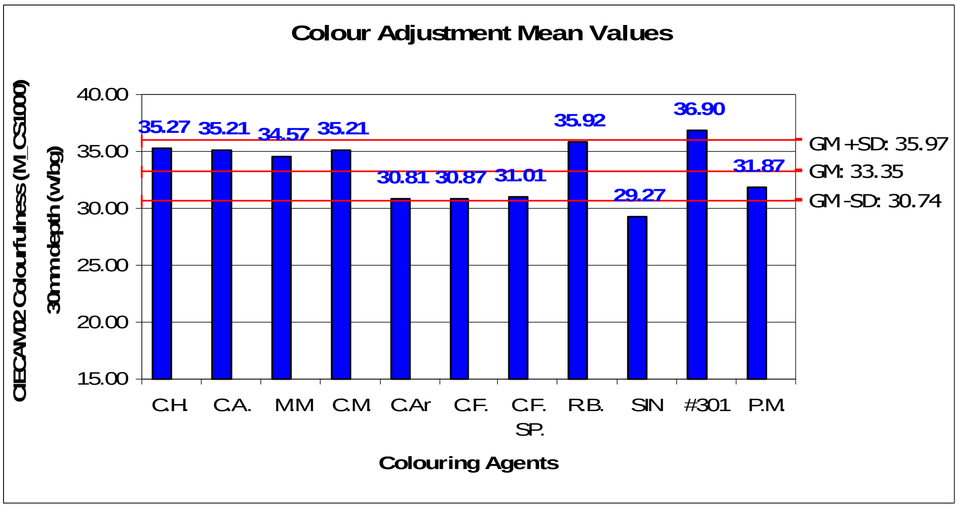

Chart B.3.46 CIECAM02 Colourfulness (M_TSR) by Telespectroradiometry at 30.0 mm depth over white background of fresh locally-brewed beers

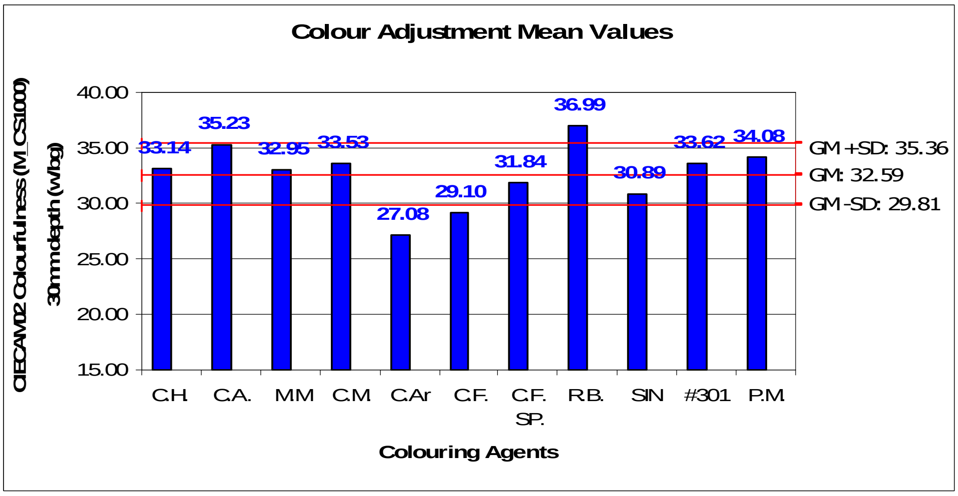

Chart B.3.47 CIECAM02 Colourfulness (M_TSR) by Telespectroradiometry at 30.0 mm depth over white background of forced aged locally-brewed beers

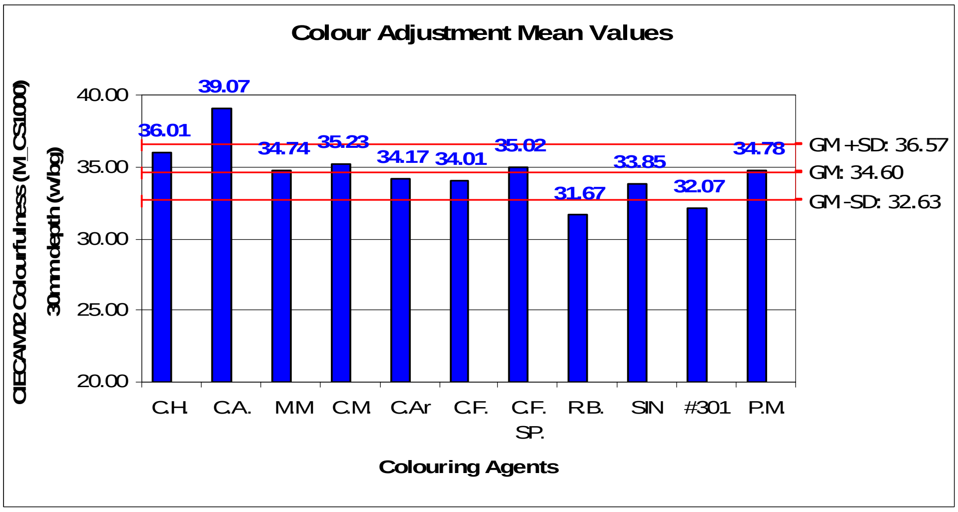

Chart B.3.48 CIECAM02 Colourfulness (M_TSR) by Telespectroradiometry at 30.0 mm depth over white background of spontaneously aged locally-brewed beers

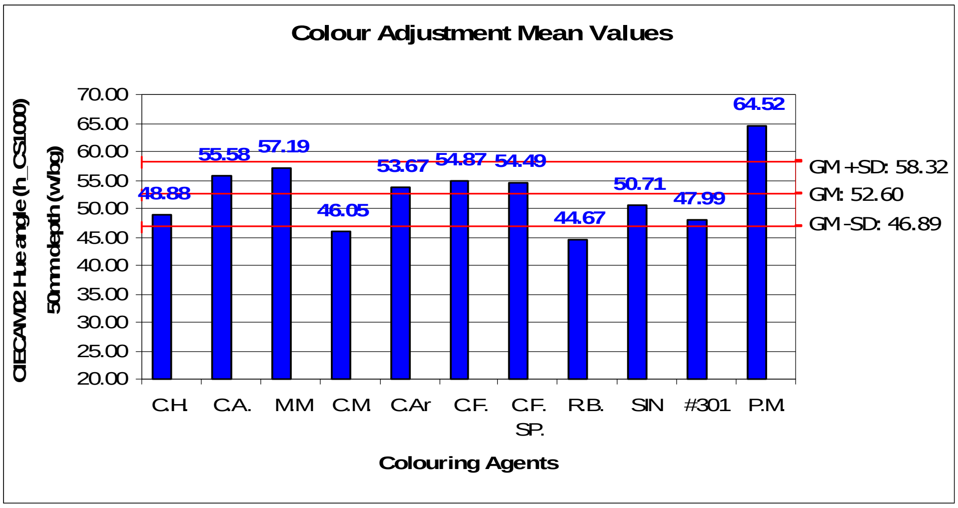

Chart B.3.49 CIECAM02 Hue angle (h_TSR) by Telespectroradiometry at 50.0 mm depth over white background of fresh locally-brewed beers

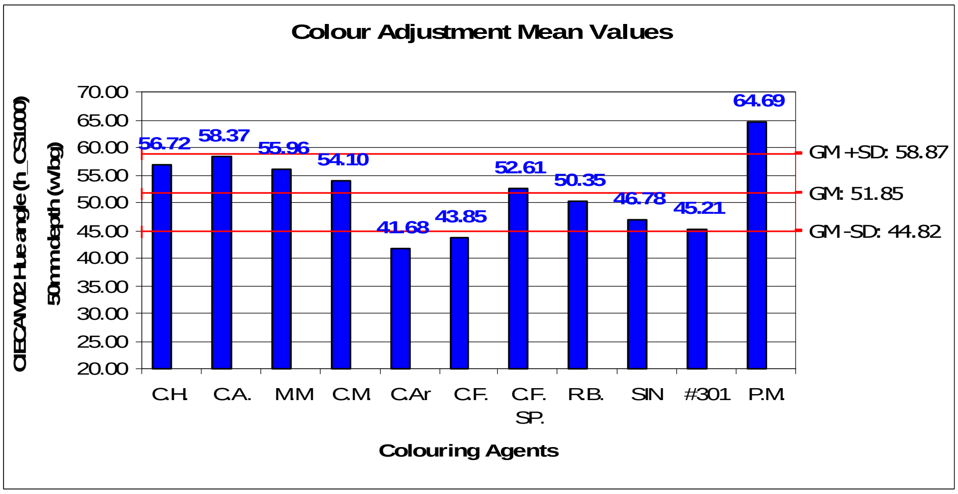

Chart B.3.50 CIECAM02 Hue angle (h_TSR) by Telespectroradiometry at 50.0 mm depth over white background of forced aged locally-brewed beers

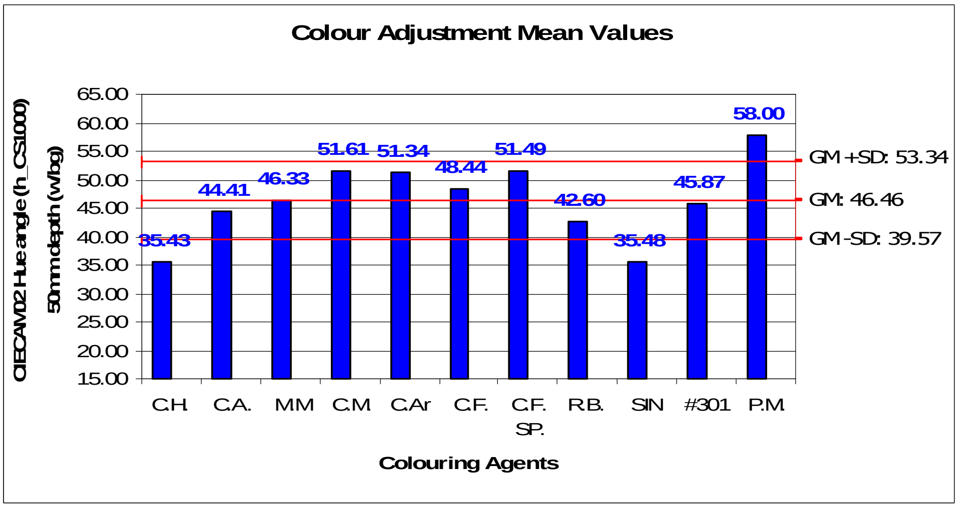

Chart B.3.51 CIECAM02 Hue angle (h_TSR) by Telespectroradiometry at 50.0 mm depth over white background of spontaneously aged locally-brewed beers

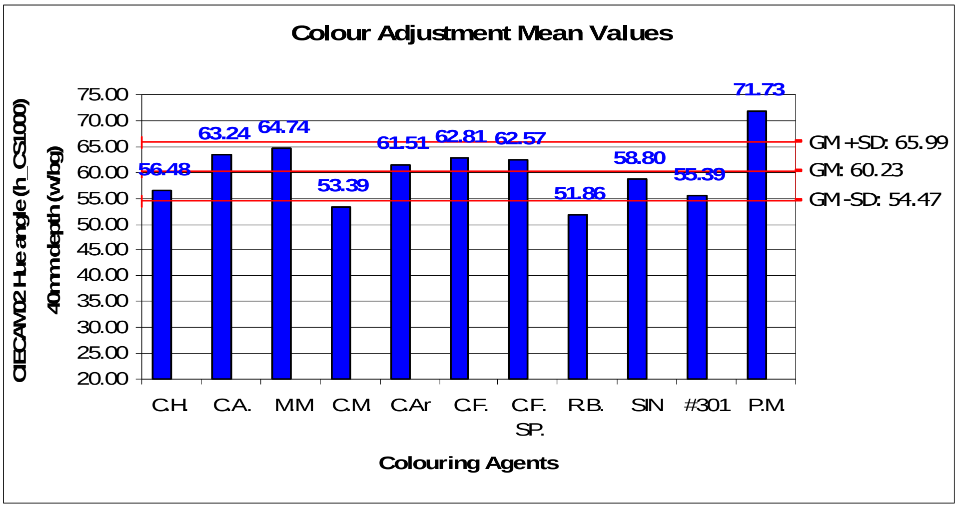

Chart B.3.52 CIECAM02 Hue angle (h_TSR) by Telespectroradiometry at 40.0 mm depth over white background of fresh locally-brewed beers

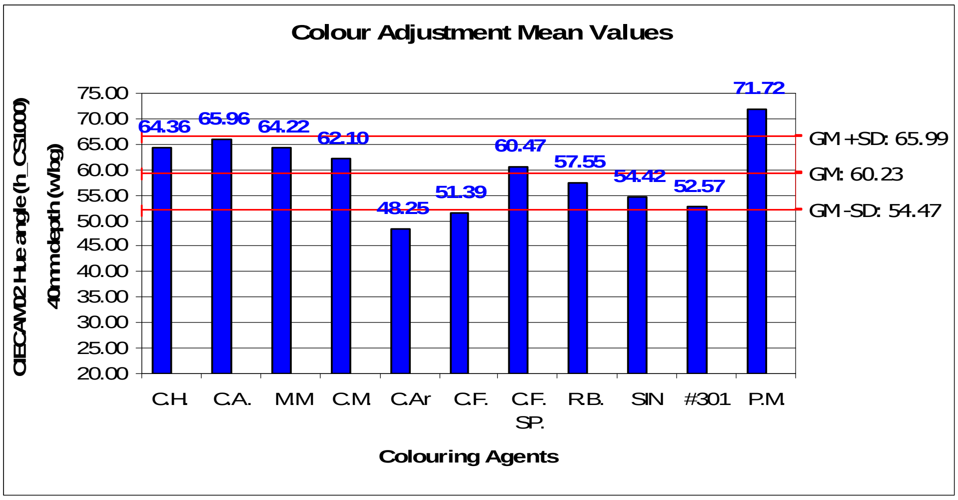

Chart B.3.53 CIECAM02 Hue angle (h_TSR) by Telespectroradiometry at 40.0 mm depth over white background of forced aged locally-brewed beers

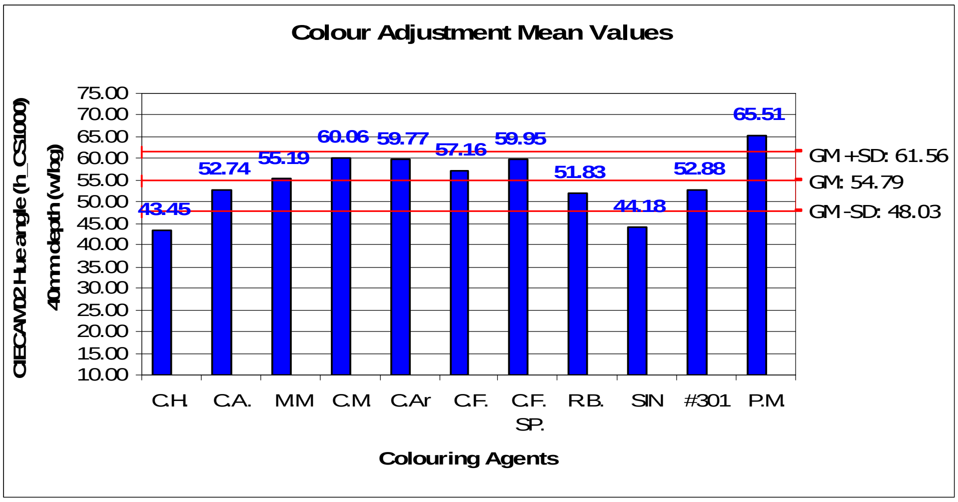

Chart B.3.54 CIECAM02 Hue angle (h_TSR) by Telespectroradiometry at 40.0 mm depth over white background of spontaneously aged locally-brewed beers

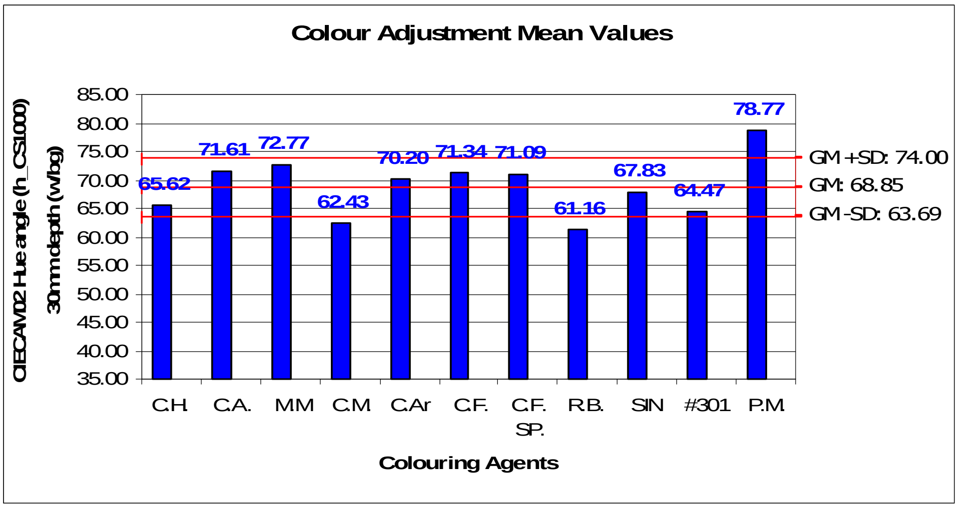

Chart B.3.55 CIECAM02 Hue angle (h_TSR) by Telespectroradiometry at 30.0 mm depth with white background of fresh locally-brewed beers

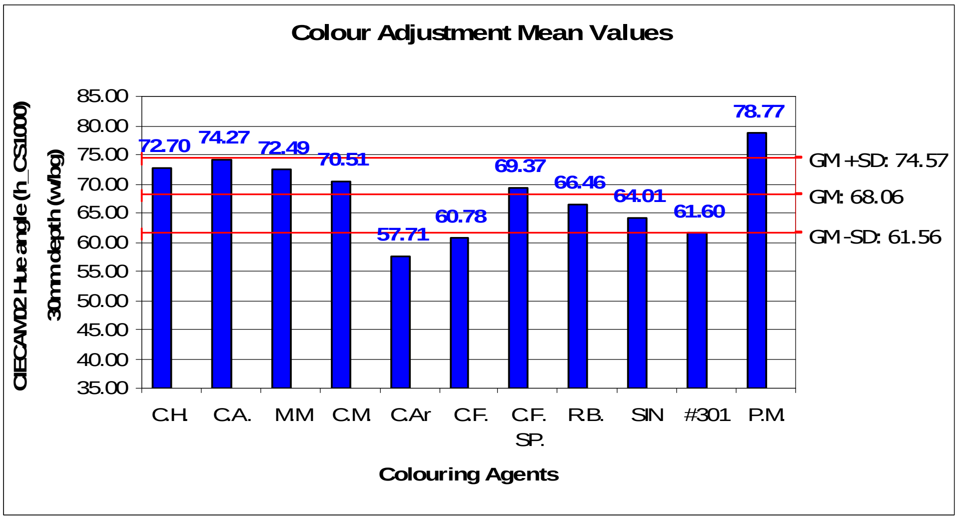

Chart B.3.56 CIECAM02 Hue angle (h_TSR) by Telespectroradiometry at 30.0 mm depth with white background of forced aged locally-brewed beers

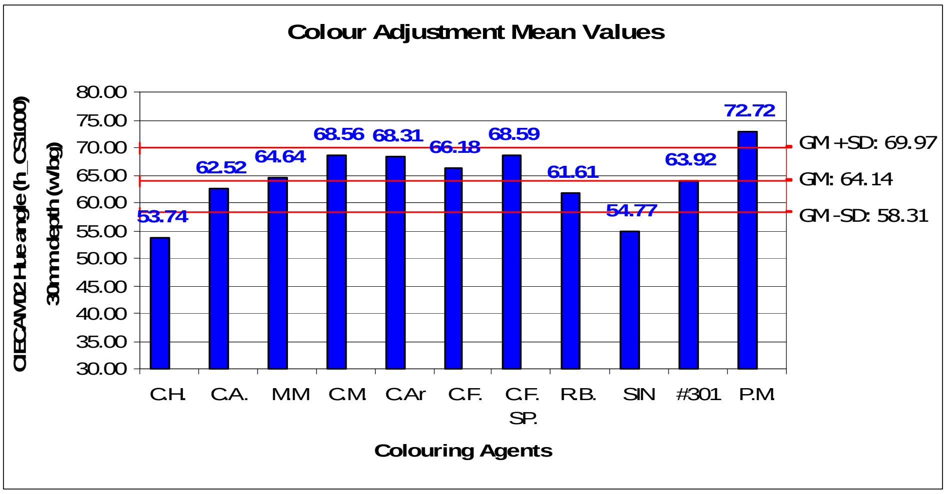

Chart B.3.57 CIECAM02 Hue angle (h_TSR) by Telespectroradiometry at 30.0 mm depth with white background of spontaneously aged locally-brewed beers

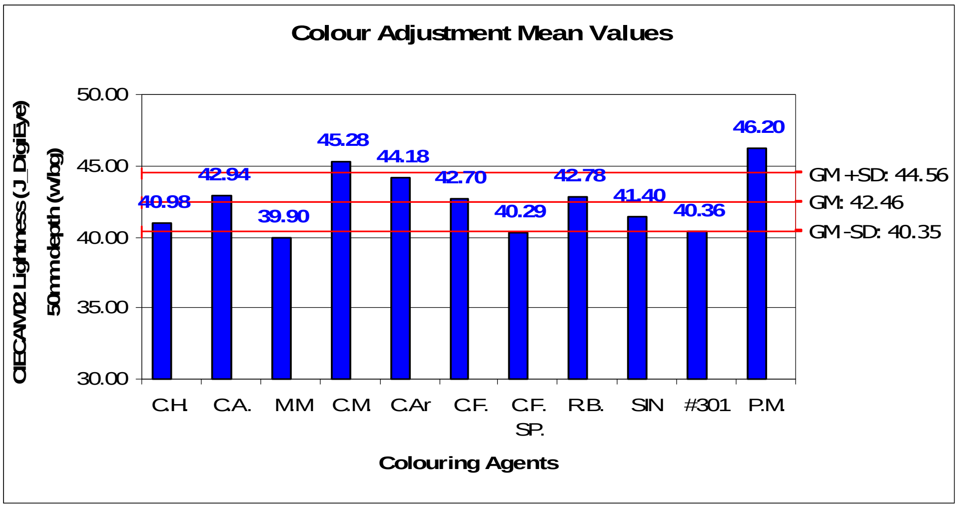

Chart B.3.58 CIECAM02 Lightness (J_DIG) by Digital Imaging at 50.0 mm depth over white background of fresh locally-brewed beers

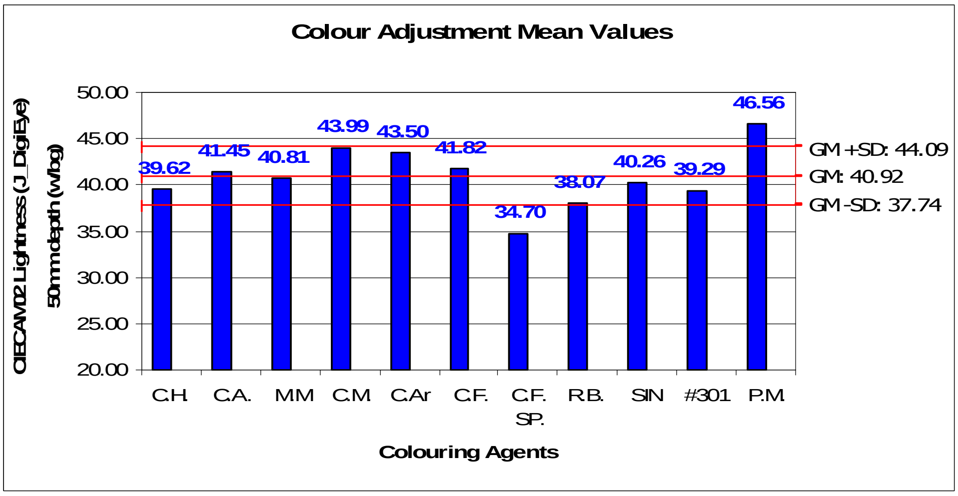

Chart B.3.59 CIECAM02 Lightness (J_DIG) by Digital Imaging at 50.0 mm depth over white background of forced aged locally-brewed beers

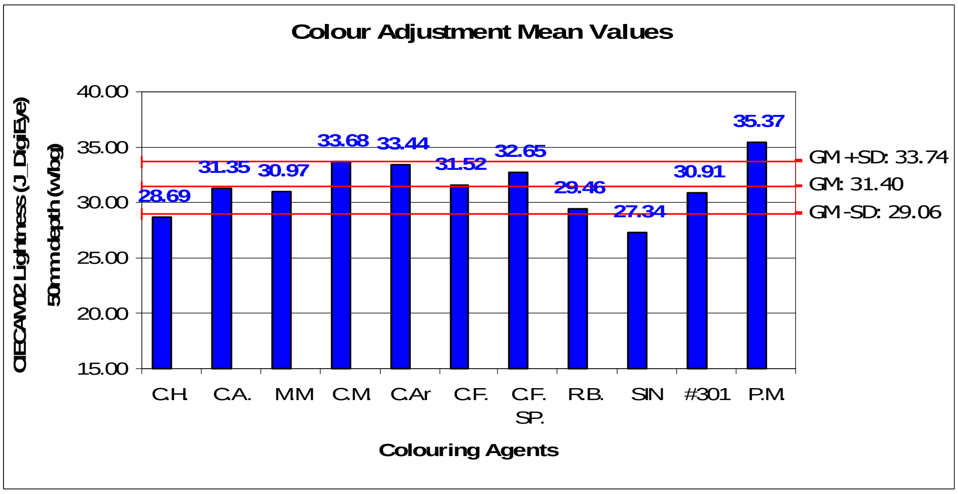

Chart B.3.60 CIECAM02 Lightness (J_DIG) by Digital Imaging at 50.0 mm depth over white background of spontaneously aged locally-brewed beers

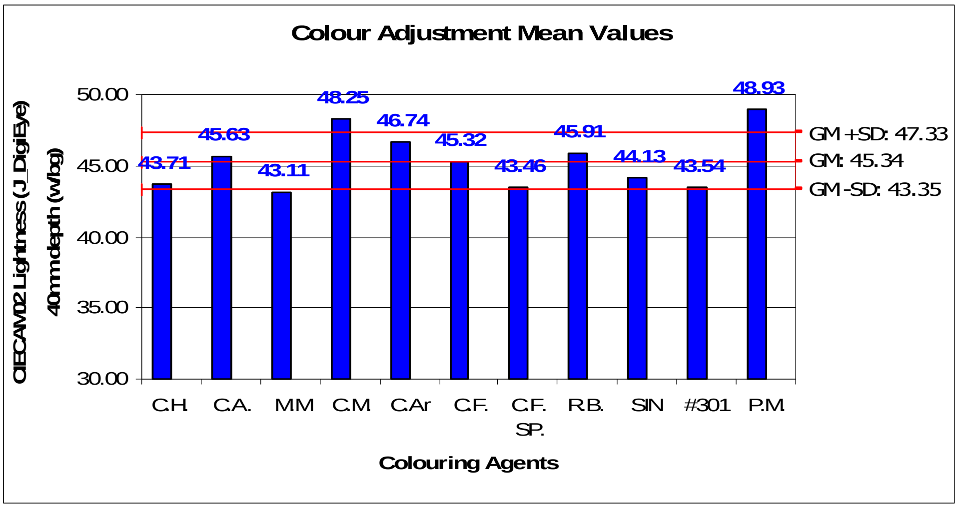

Chart B.3.61 CIECAM02 Lightness (J_DIG) by Digital Imaging at 40.0 mm depth over white background of fresh locally-brewed beers

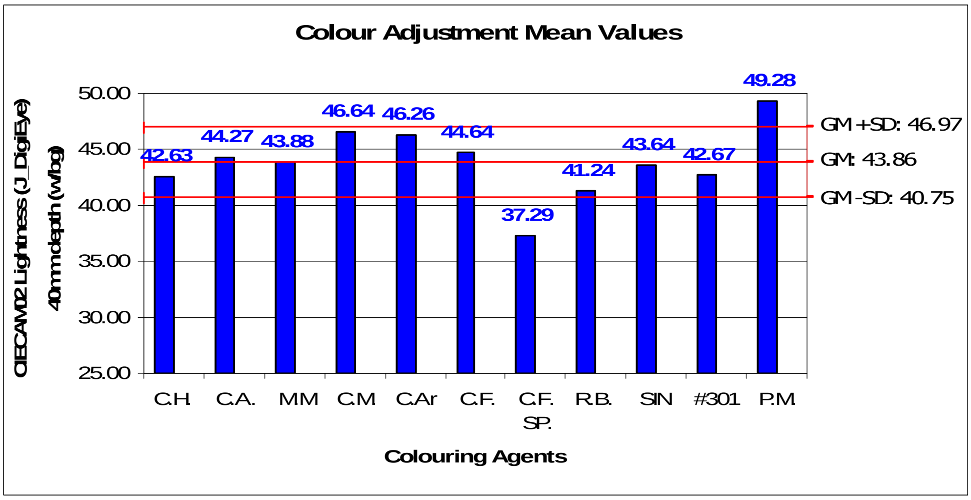

Chart B.3.62 CIECAM02 Lightness (J_DIG) by Digital Imaging at 40.0 mm depth over white background of forced aged locally-brewed beers

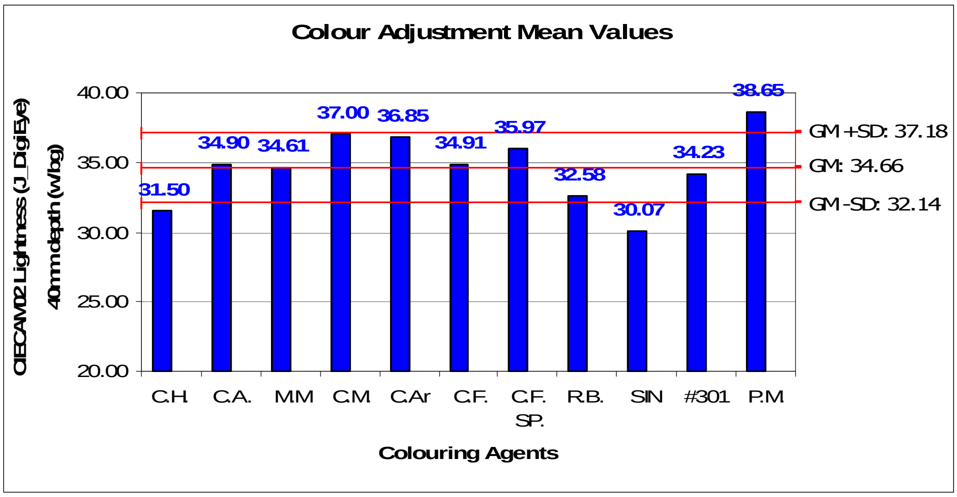

Chart B.3.63 CIECAM02 Lightness (J_DIG) by Digital Imaging at 40.0 mm depth over white background of spontaneously aged locally-brewed beers

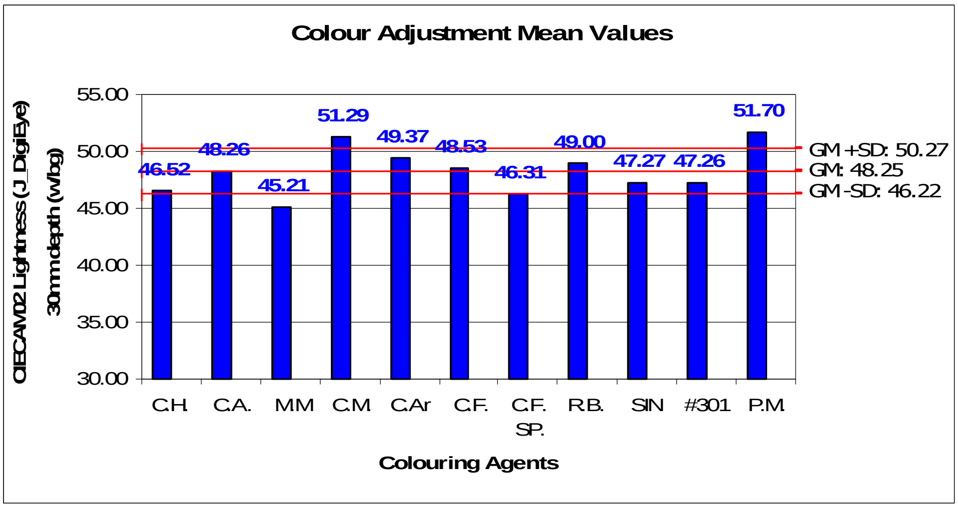

Chart B.3.64 CIECAM02 Lightness (J_DIG) by Digital Imaging at 30.0 mm depth over white background of fresh locally-brewed beers

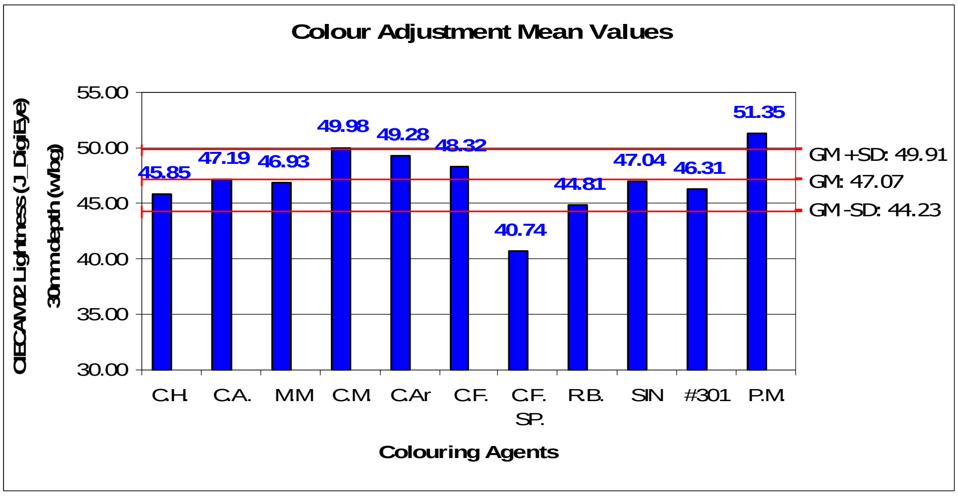

Chart B.3.65 CIECAM02 Lightness (J_DIG) by Digital Imaging at 30.0 mm depth over white background of forced aged locally-brewed beers

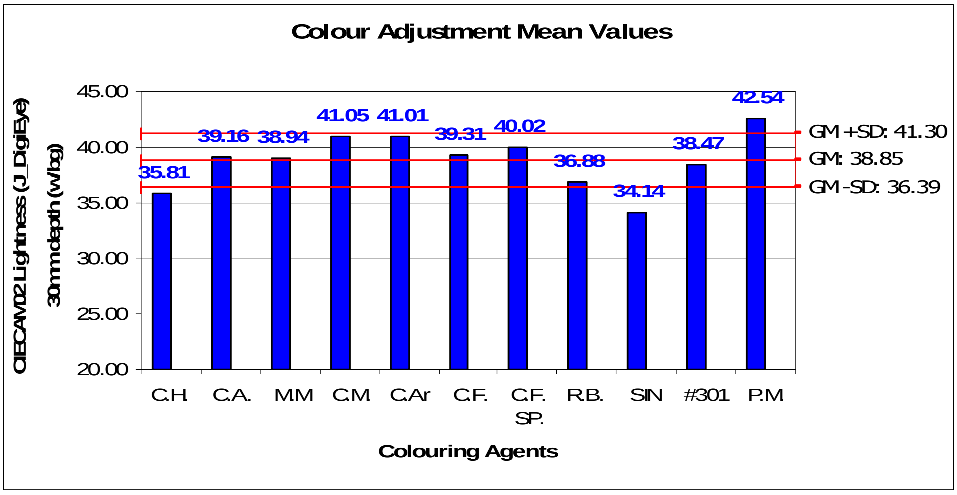

Chart B.3.66 CIECAM02 Lightness (J_DIG) by Digital Imaging at 30.0 mm depth over white background of spontaneously aged locally-brewed beers

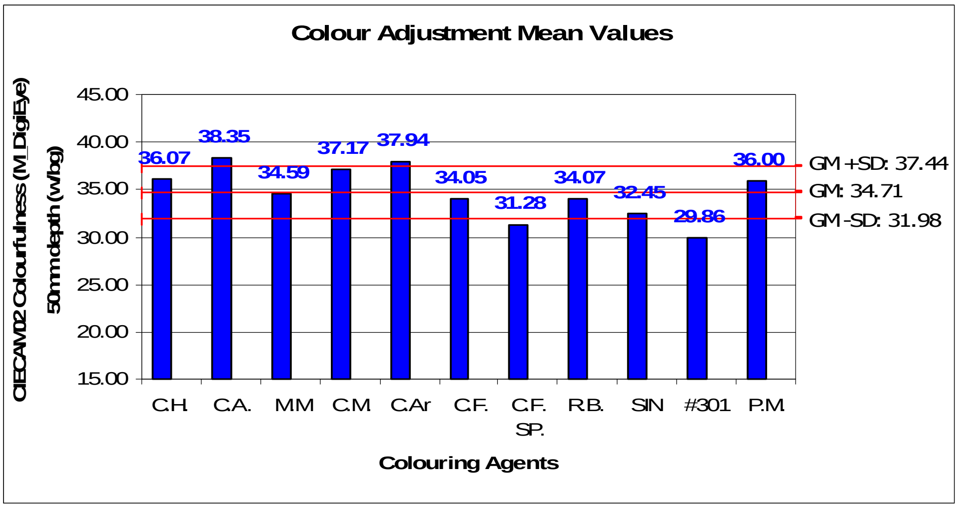

Chart B.3.67 CIECAM02 Colourfulness (M_DIG) by Digital Imaging at 50.0 mm depth over white background of fresh locally-brewed beers

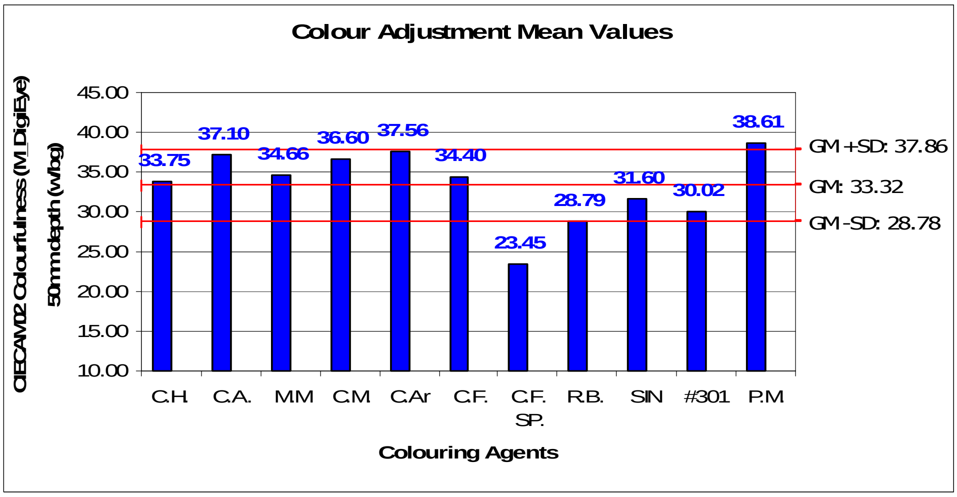

Chart B.3.68 CIECAM02 Colourfulness (M_DIG) by Digital Imaging at 50.0 mm depth over white background of forced aged locally-brewed beers

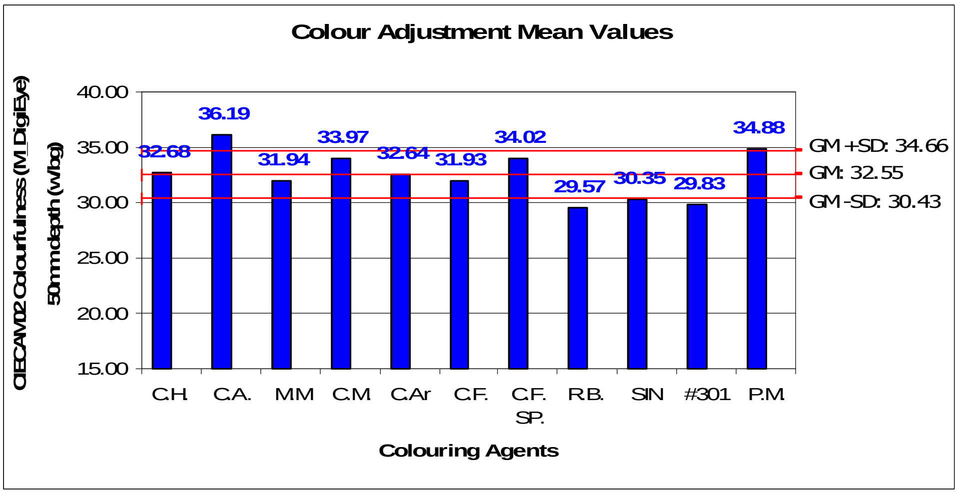

Chart B.3.69 CIECAM02 Colourfulness (M_DIG) by Digital Imaging at 50.0 mm depth over white background of spontaneously aged locally-brewed beers

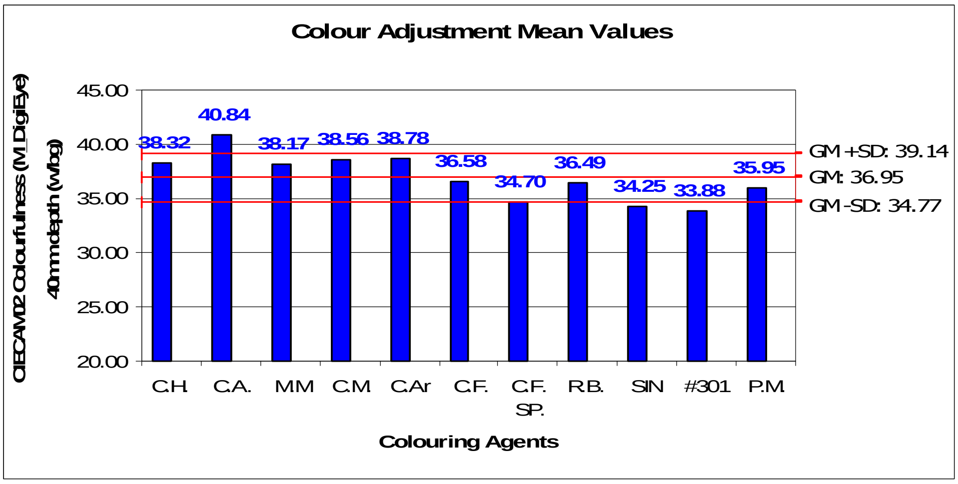

Chart B.3.70 CIECAM02 Colourfulness (M_DIG) by Digital Imaging at 40.0 mm depth over white background of fresh locally-brewed beers

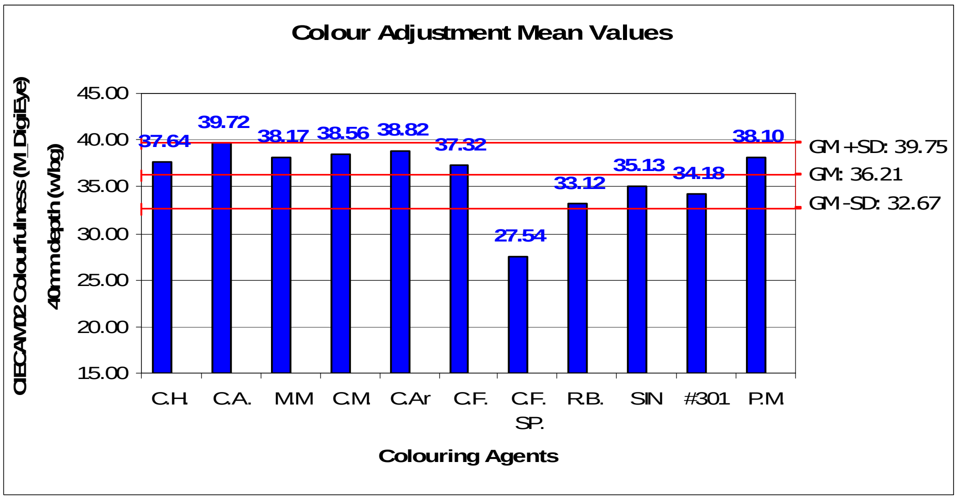

Chart B.3.71 CIECAM02 Colourfulness (M_DIG) by Digital Imaging at 40.0 mm depth over white background of forced aged locally-brewed beers

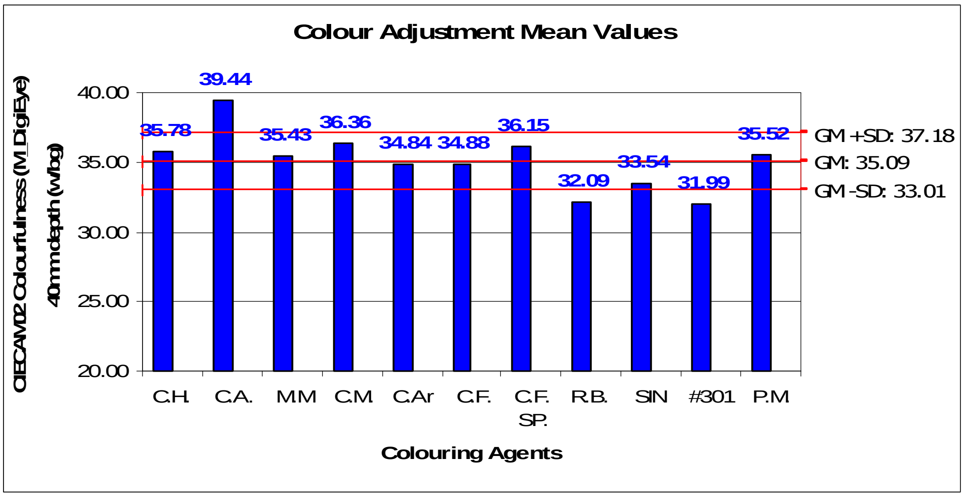

Chart B.3.72 CIECAM02 Colourfulness (M_DIG) by Digital Imaging at 40.0 mm depth over white background of spontaneously aged locally-brewed beers

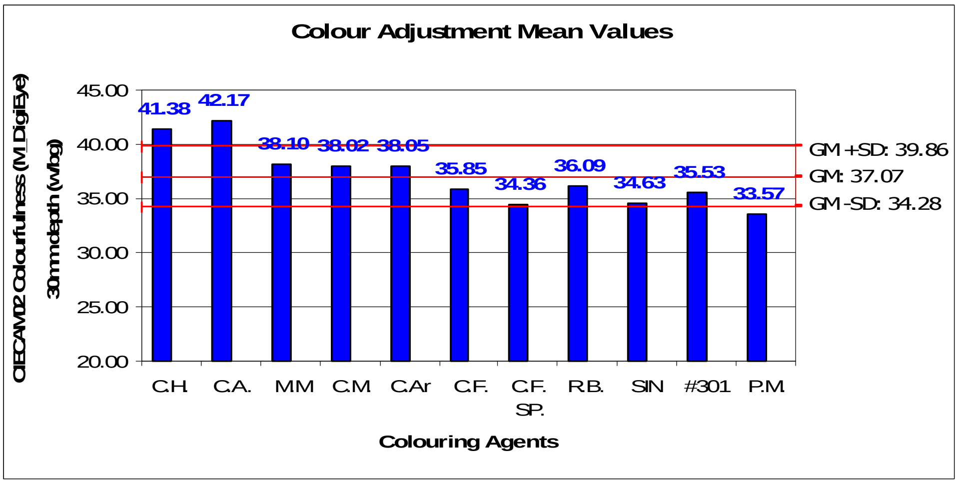

Chart B.3.73 CIECAM02 Colourfulness (M_DIG) by Digital Imaging at 30.0 mm depth over white background of fresh locally-brewed beers

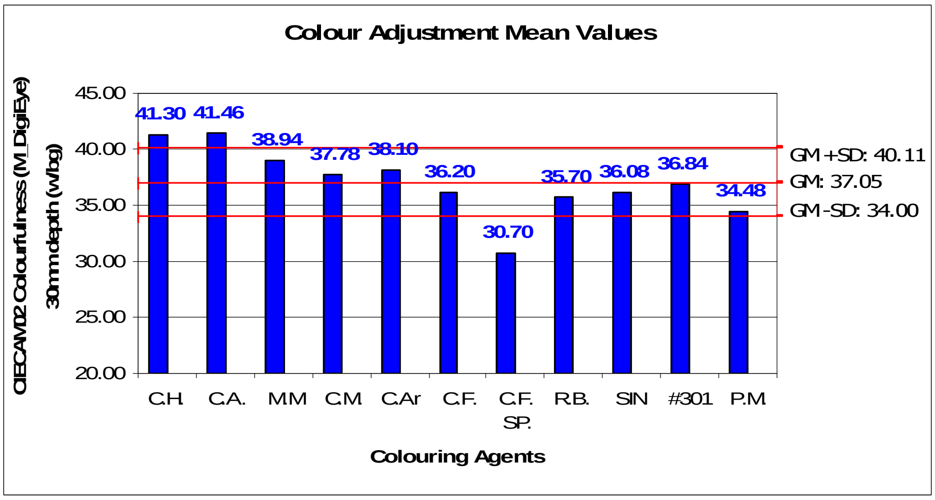

Chart B.3.74 CIECAM02 Colourfulness (M_DIG) by Digital Imaging at 30.0 mm depth over white background of forced aged locally-brewed beers

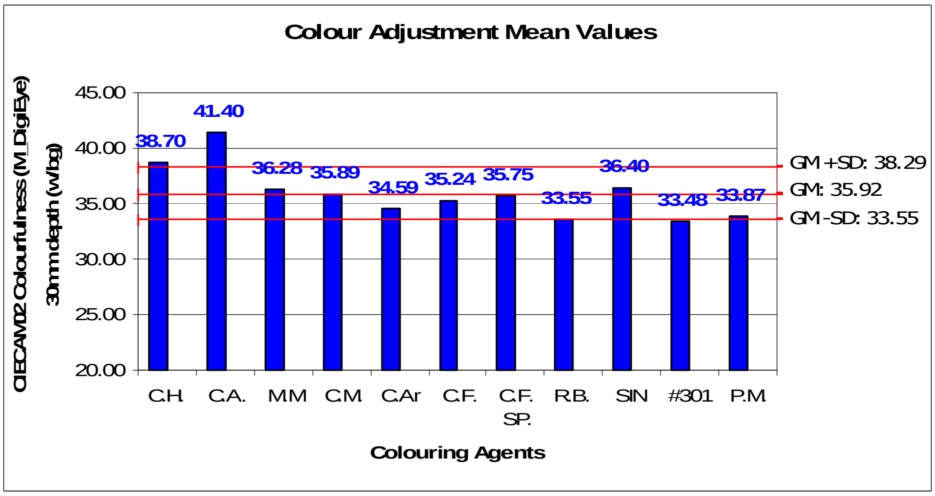

Chart B.3.75 CIECAM02 Colourfulness (M_DIG) by Digital Imaging at 30.0 mm depth over white background of spontaneously aged locally-brewed beers

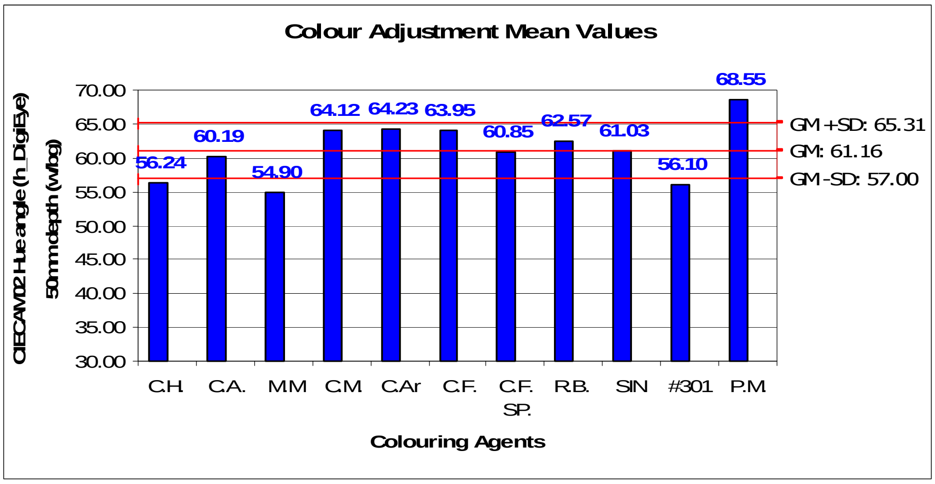

Chart B.3.76 CIECAM02 Hue angle (h_DIG) by Digital Imaging at 50.0 mm depth over white background of fresh locally-brewed beers

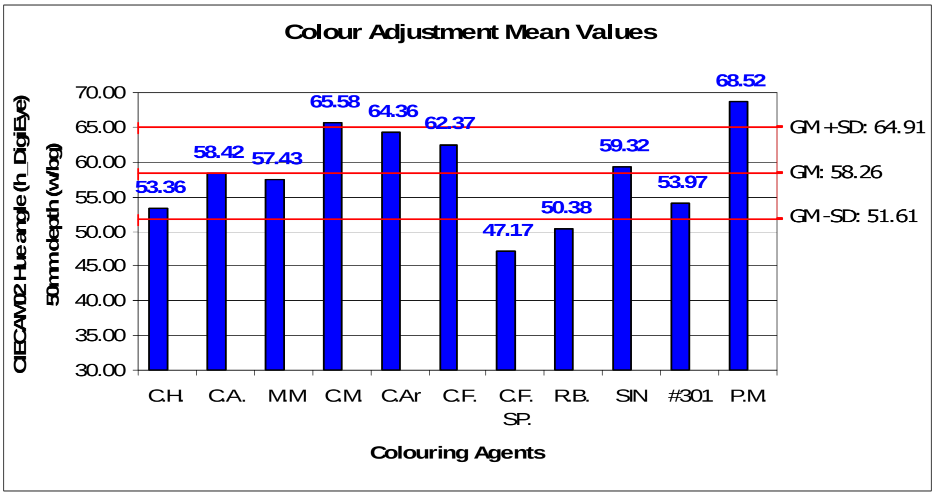

Chart B.3.77 CIECAM02 Hue angle (h_DIG) by Digital Imaging at 50.0 mm depth over white background of forced aged locally-brewed beers

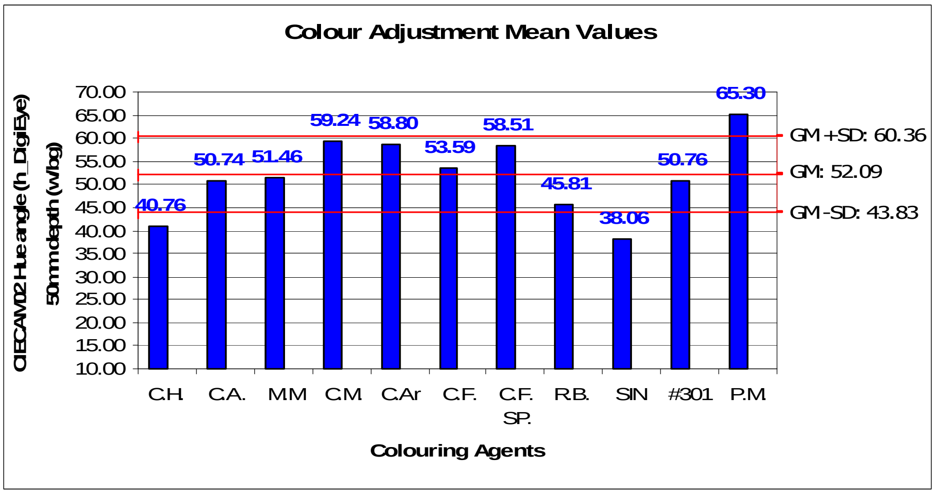

Chart B.3.78 CIECAM02 Hue angle (h_DIG) by Digital Imaging at 50.0 mm depth over white background of spontaneously aged locally-brewed beers

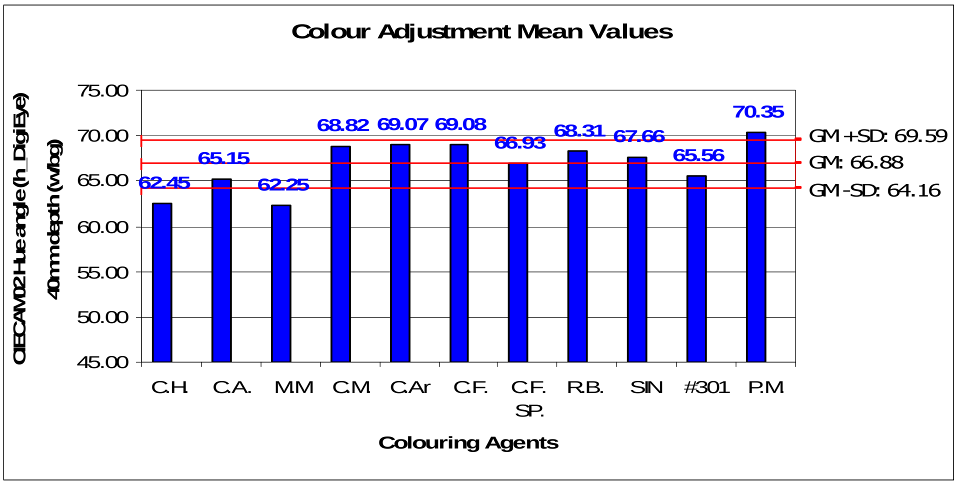

Chart B.3.79 CIECAM02 Hue angle (h_DIG) by Digital Imaging at 40.0 mm depth over white background of fresh locally-brewed beers

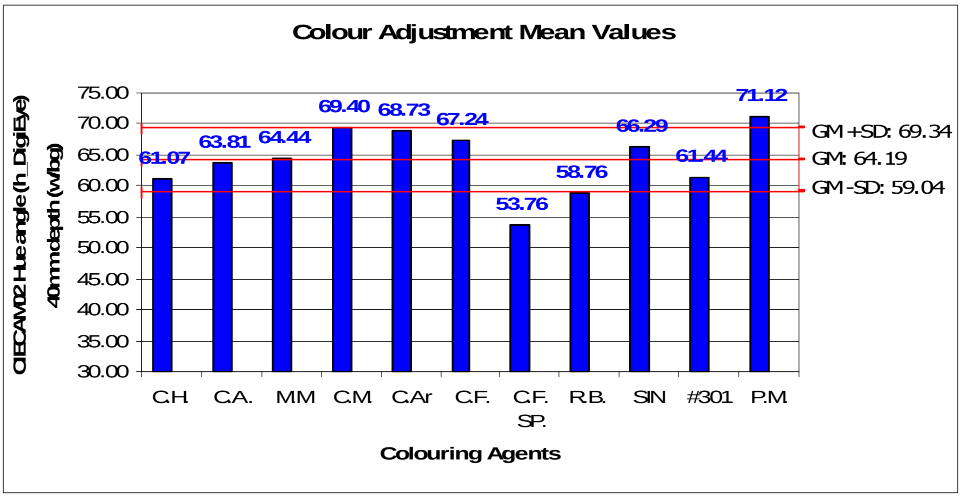

Chart B.3.80 CIECAM02 Hue angle (h_DIG) by Digital Imaging at 40.0 mm depth over white background of forced aged locally-brewed beers

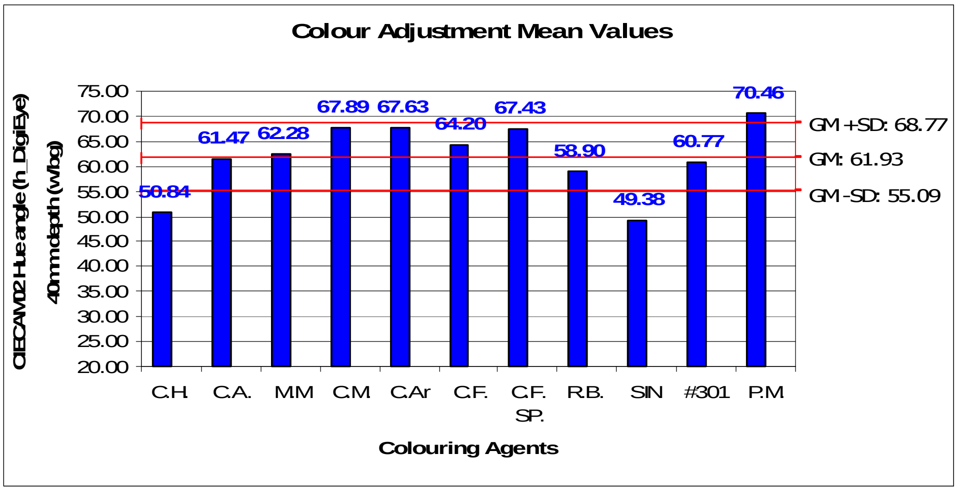

Chart B.3.81 CIECAM02 Hue angle (h_DIG) by Digital Imaging at 40.0 mm depth over white background of spontaneously aged locally-brewed beers

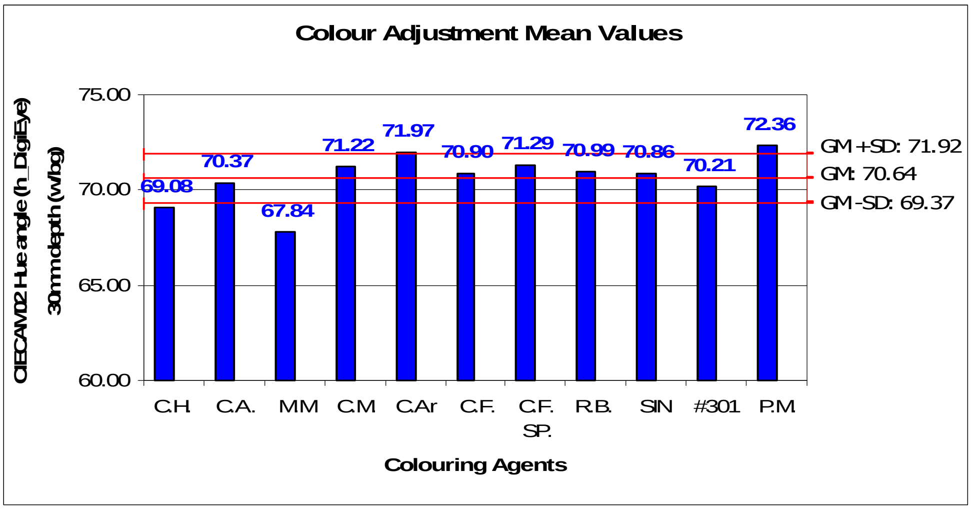

Chart B.3.82 CIECAM02 Hue angle (h_DIG) by Digital Imaging at 30.0 mm depth over white background of fresh locally-brewed beers

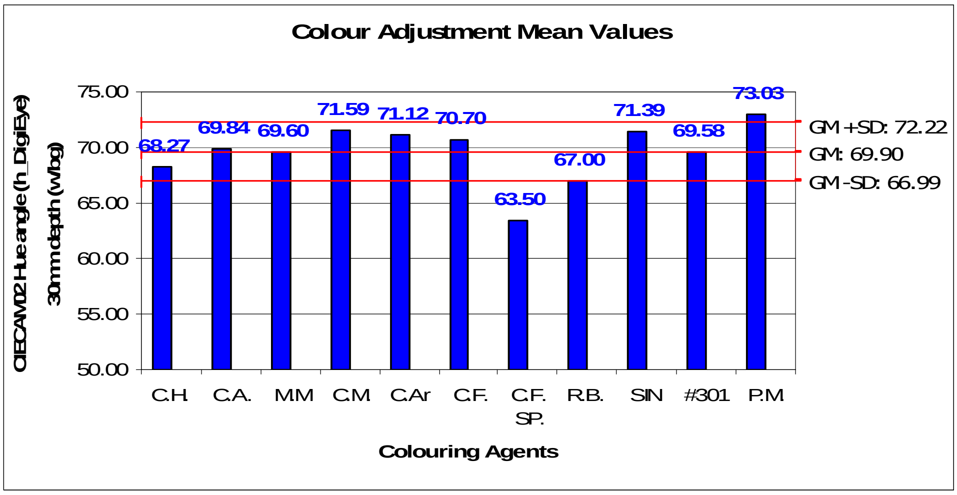

Chart B.3.83 CIECAM02 Hue angle (h_DIG) by Digital Imaging at 30.0 mm depth over white background of forced aged locally-brewed beers

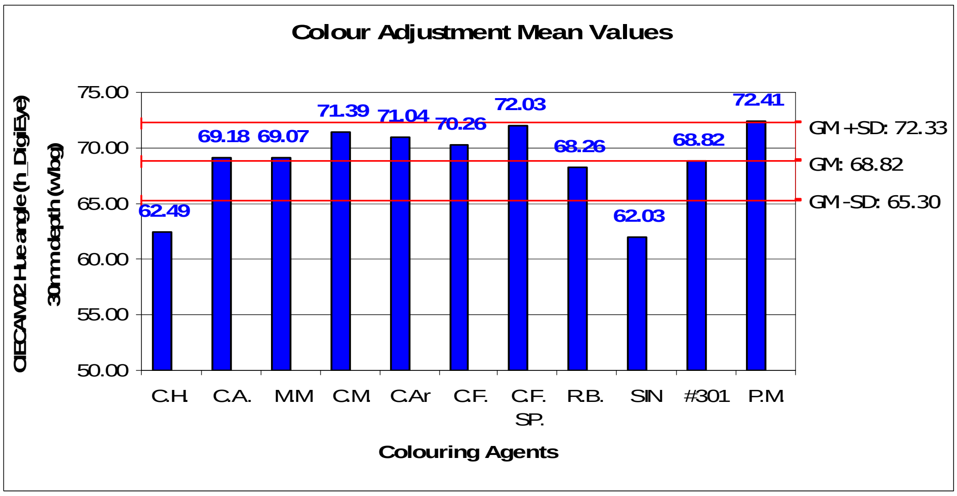

Chart B.3.84 CIECAM02 Hue angle (h_DIG) by Digital Imaging at 30.0 mm depth with over white background of spontaneously aged locally-brewed beers

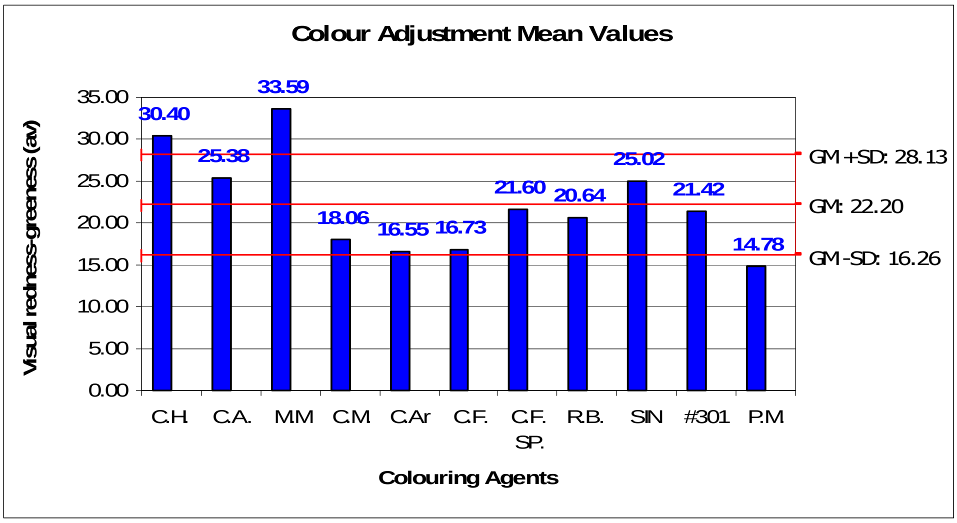

Chart B.3.85 Visual redness- greenness (av) by sensory viewing of fresh locally-brewed beers

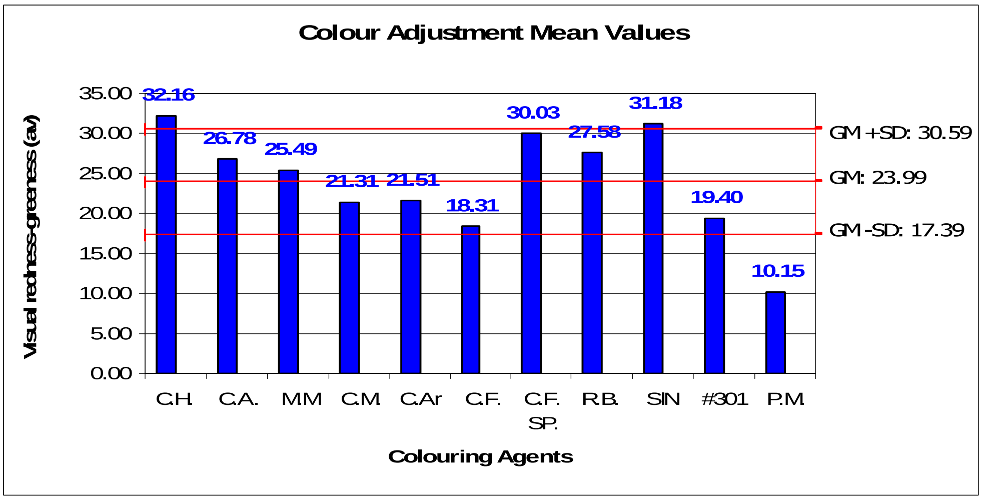

Chart B.3.86 Visual redness- greenness (av) by sensory viewing of forced aged locally-brewed beers

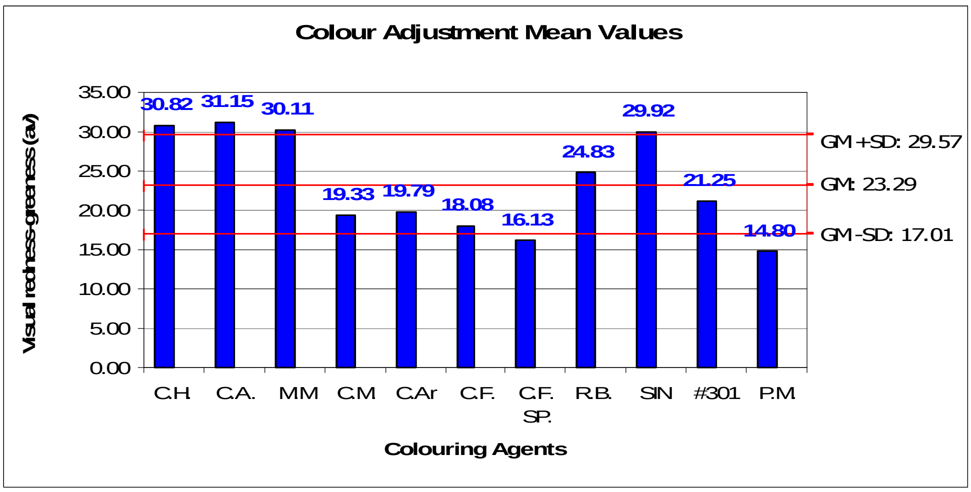

Chart B.3.87 Visual redness- greenness (av) by sensory viewing of spontaneously aged locally-brewed beers

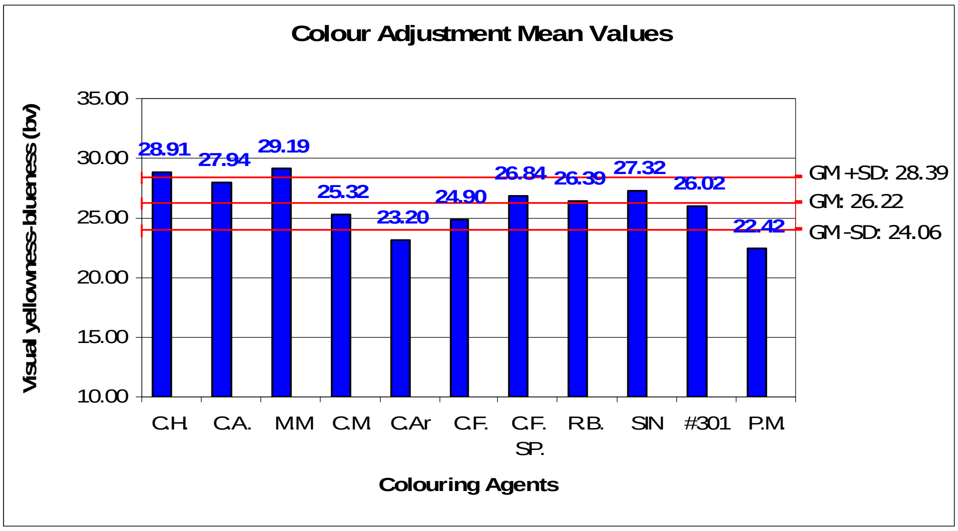

Chart B.3.88 Visual yellowness- blueness (bv) by sensory viewing of fresh locally-brewed beers

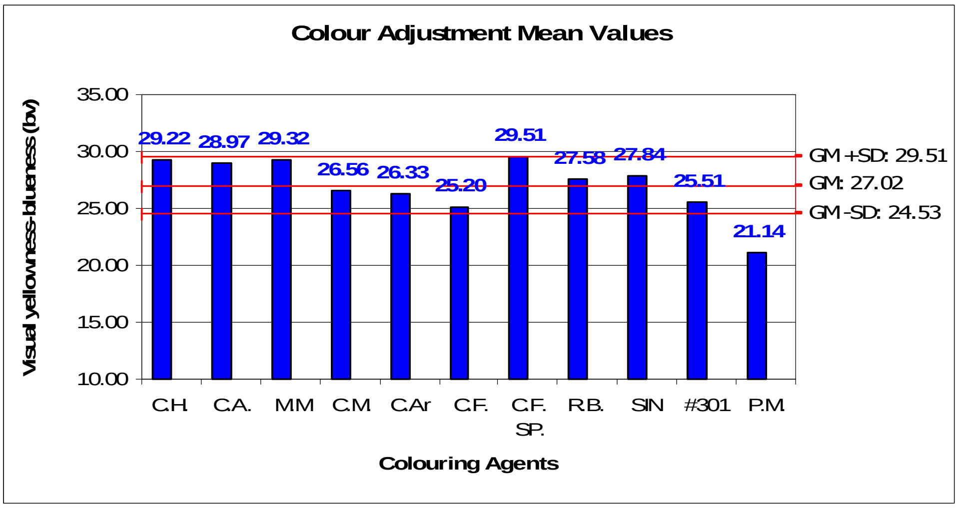

Chart B.3.89 Visual yellowness- blueness (bv) by sensory viewing of forced aged locally-brewed beers

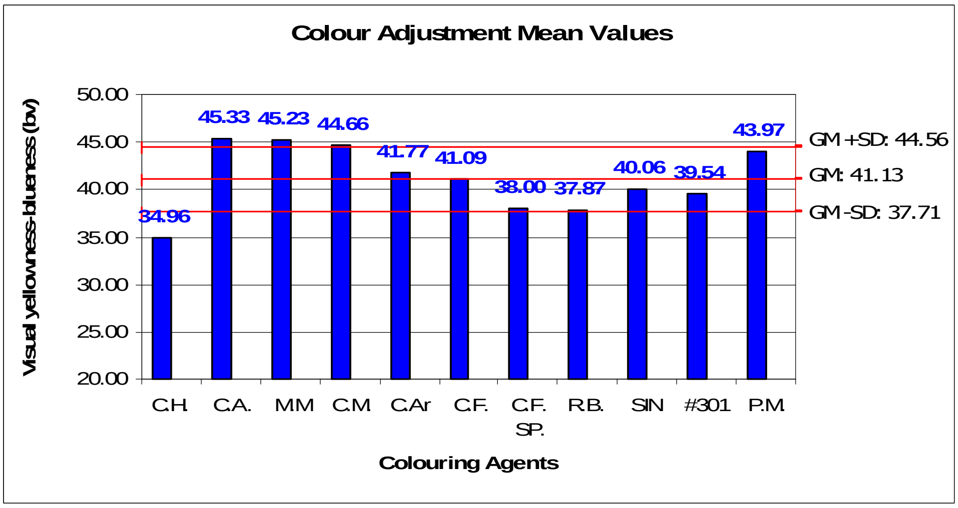

Chart B.3.90 Visual yellowness- blueness (bv) by sensory viewing of spontaneously aged locally-brewed beers

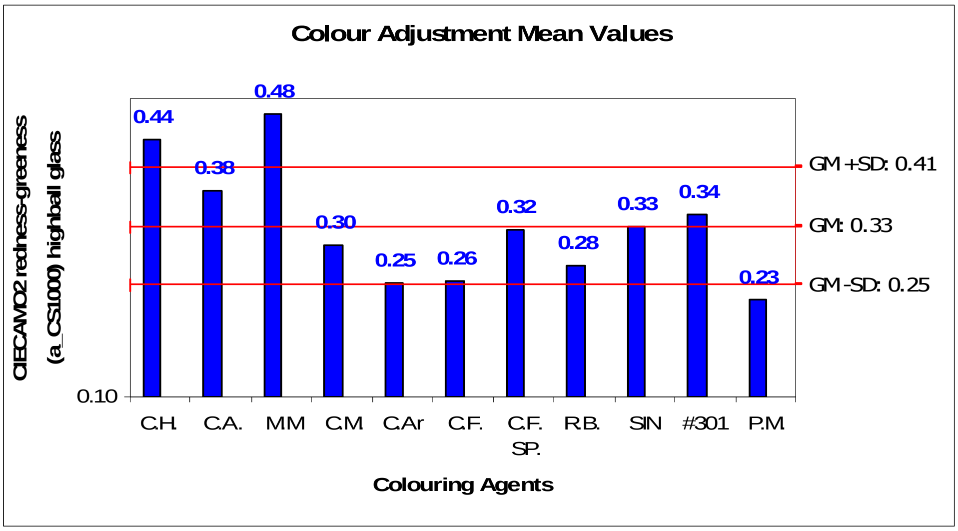

Chart B.3.91 CIECAM02 redness- greenness (a_TSR) by tele-spectroradiometry in highball glass of fresh locally-brewed beers

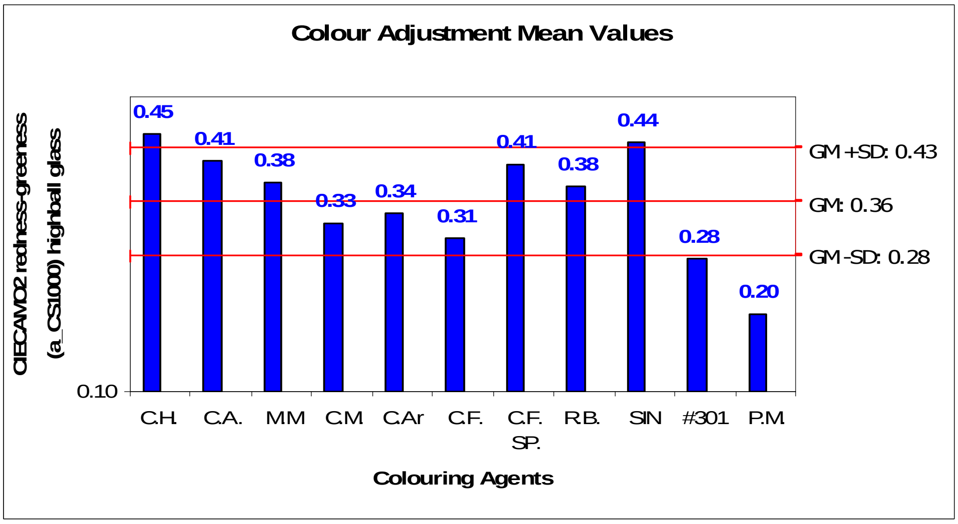

Chart B.3.92 CIECAM02 redness- greenness (a_TSR) by tele-spectroradiometry in highball glass of forced aged locally-brewed beers

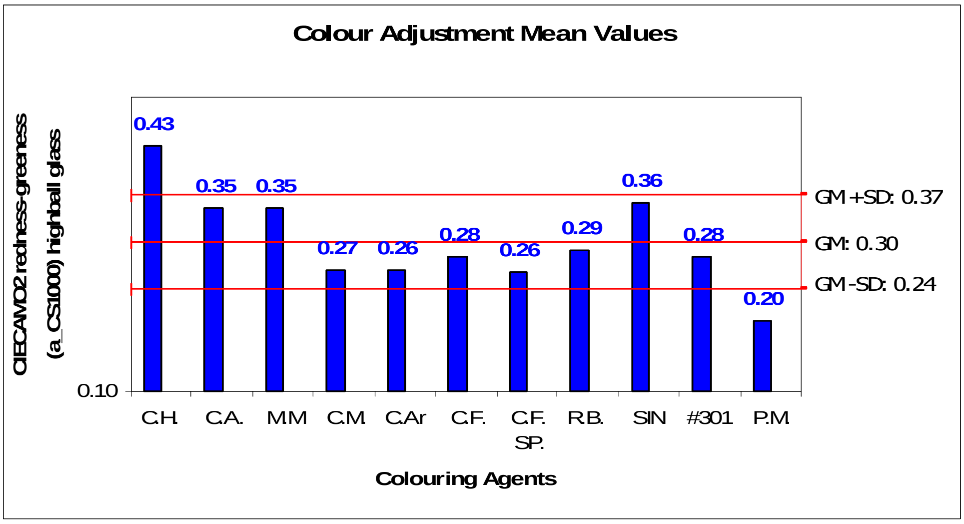

Chart B.3.93 CIECAM02 redness- greenness (a_TSR) by tele-spectroradiometry in highball glass of spontaneously aged locally-brewed beers

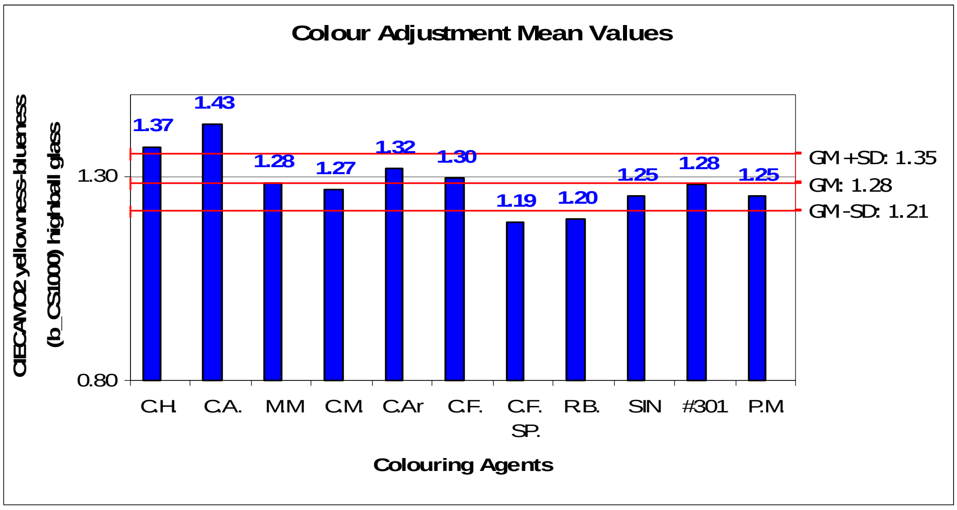

Chart B.3.94 CIECAM02 yellowness-blueness (b_TSR) by tele-spectroradiometry in highball glass of fresh locally-brewed beers

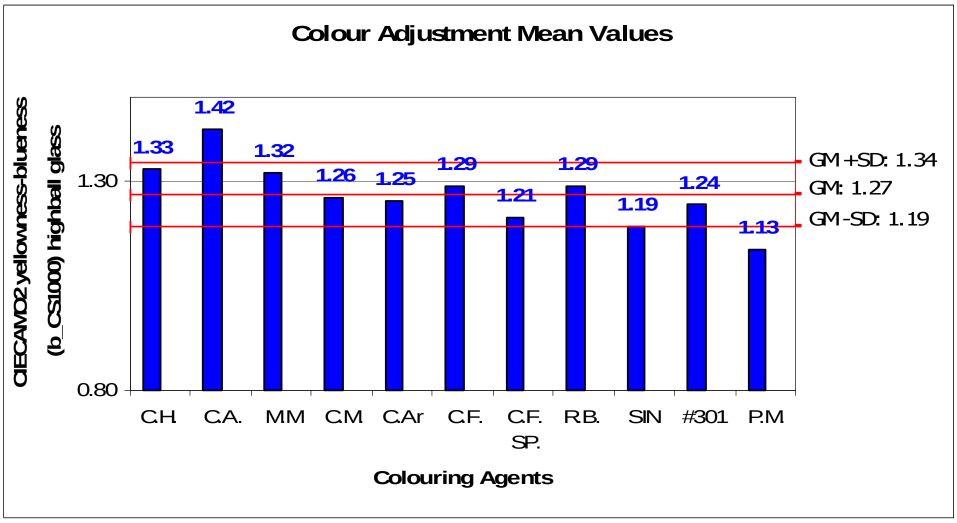

Chart B.3.95 CIECAM02 yellowness-blueness (b_TSR) by tele-spectroradiometry in highball glass of forced aged locally-brewed beers

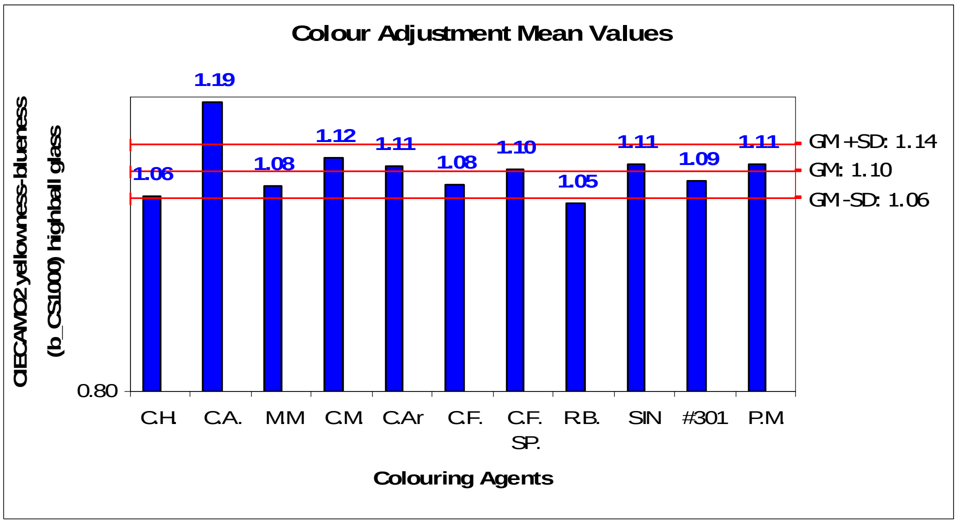

Chart B.3.96 CIECAM02 yellowness-blueness (b_TSR) by tele-spectroradiometry in highball glass of spontaneously aged locally-brewed beers

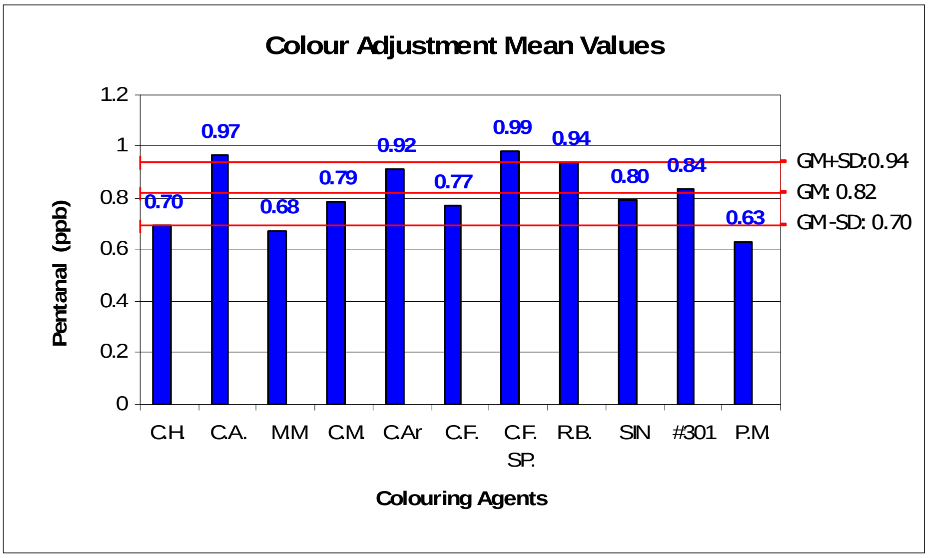

Chart B.4.1 Concentration of pentanal on fresh locally-brewed beers

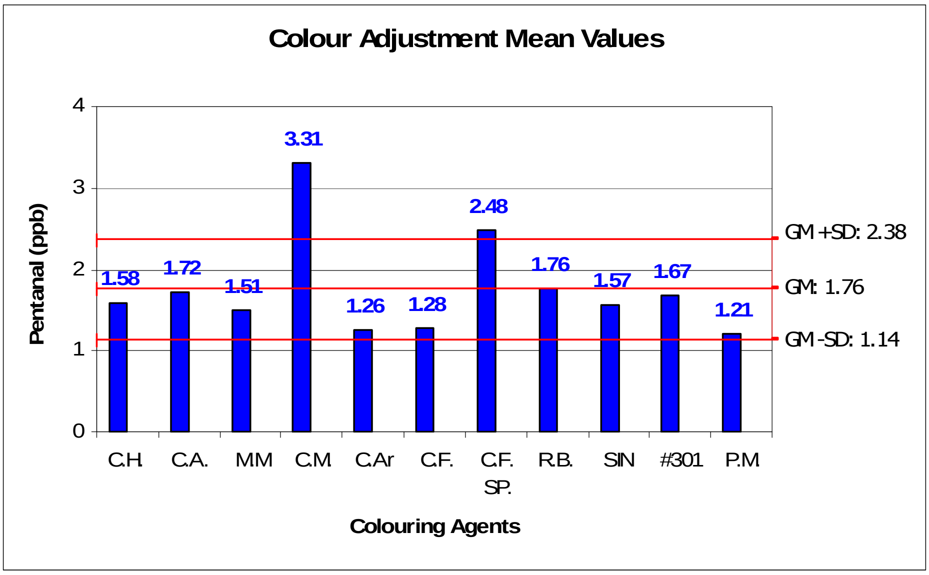

Chart B.4.2 Concentration of pentanal on forced aged locally-brewed beers

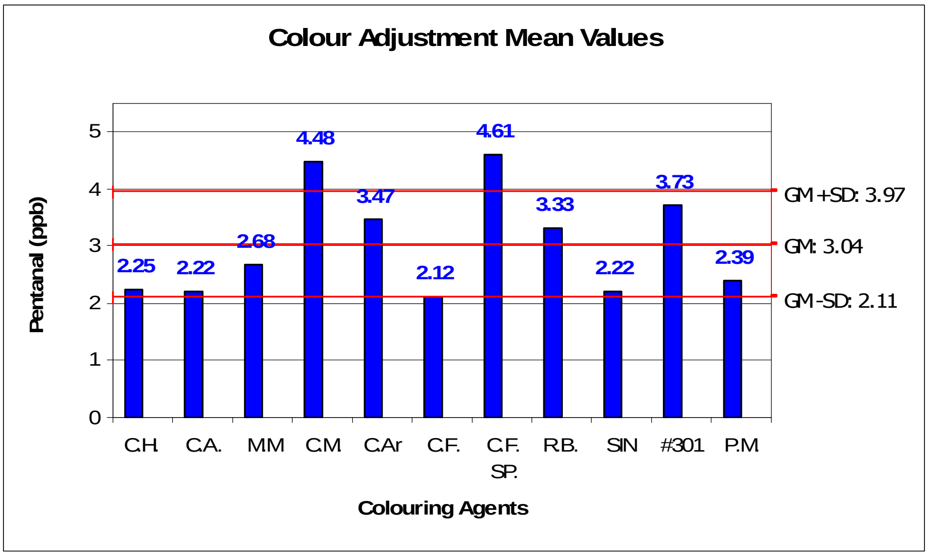

Chart B.4.3 Concentration of pentanal on spontaneously aged locally-brewed beers

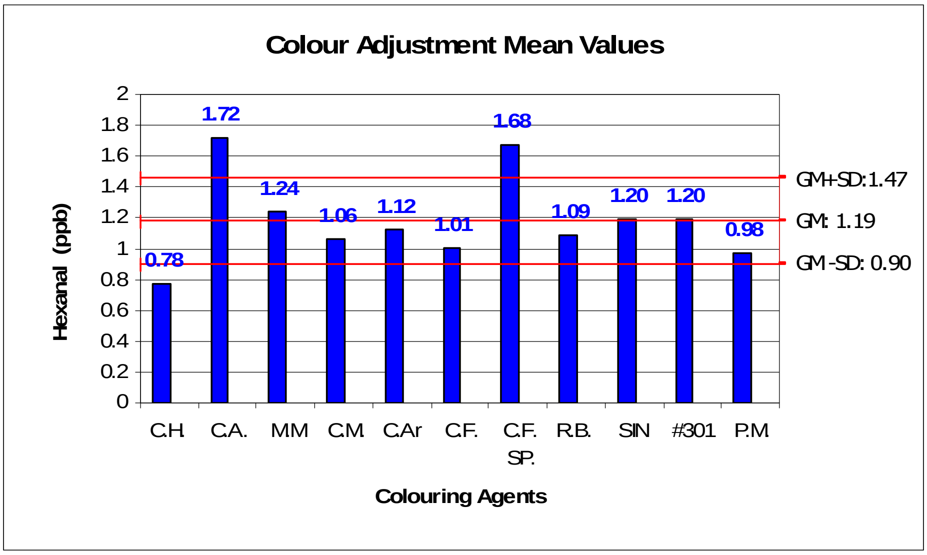

Chart B.4.4 Concentration of hexanal on fresh locally-brewed beers

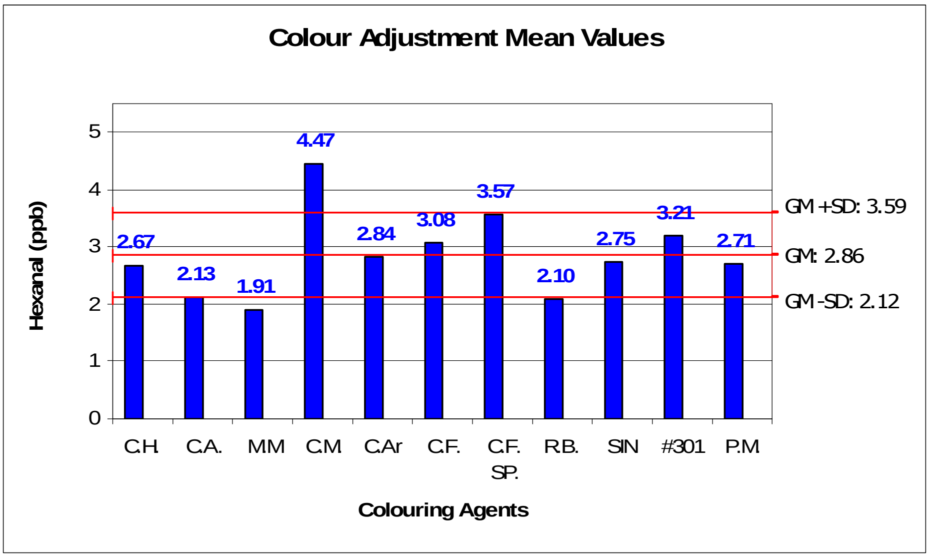

Chart B.4.5 Concentration of hexanal on forced aged locally-brewed beers

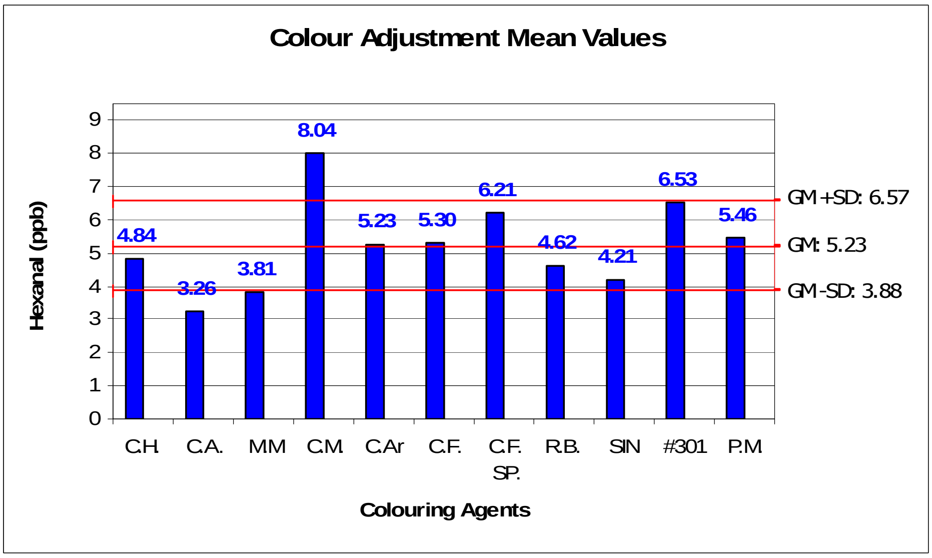

Chart B.4.6 Concentration of hexanal on spontaneously aged locally-brewed beers

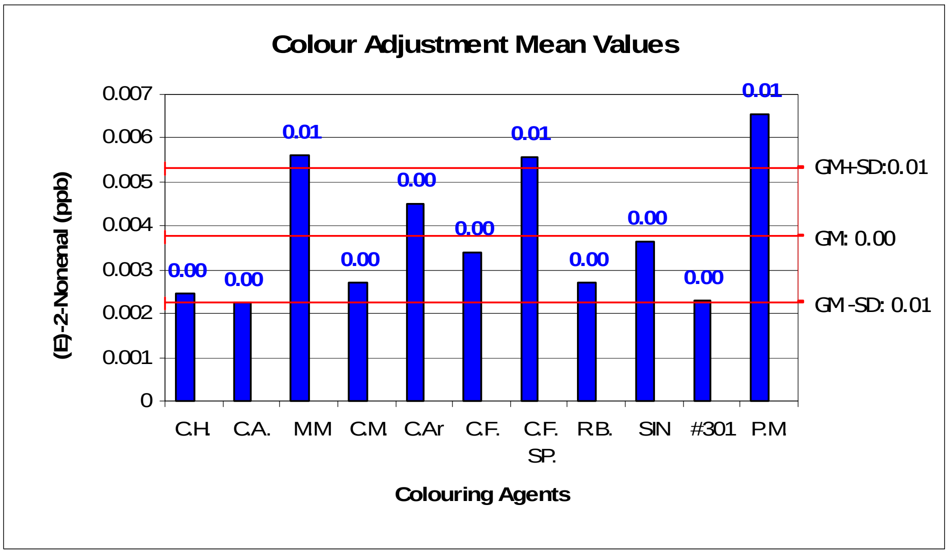

Chart B.4.7 Concentration of (*E*)-2-nonenal on fresh locally-brewed beers

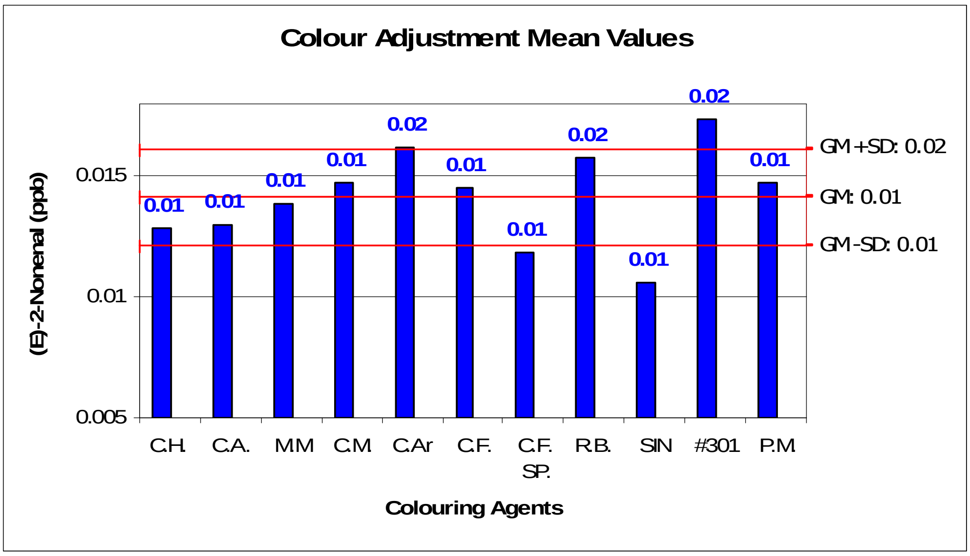

Chart B.4.8 Concentration of (*E*)-2-nonenal on forced aged locally-brewed beers

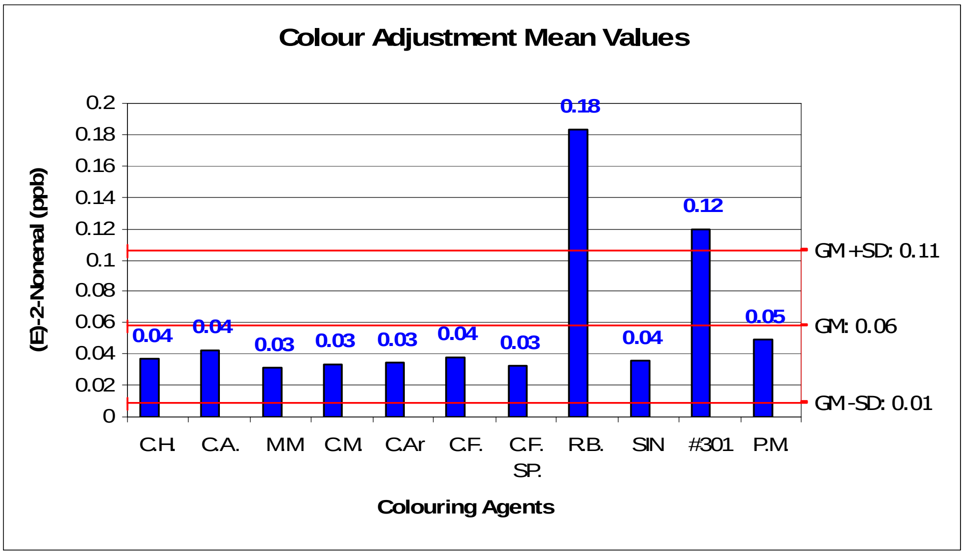

Chart B.4.9 Concentration of (*E*)-2-nonenal on spontaneously aged locally-brewed beers

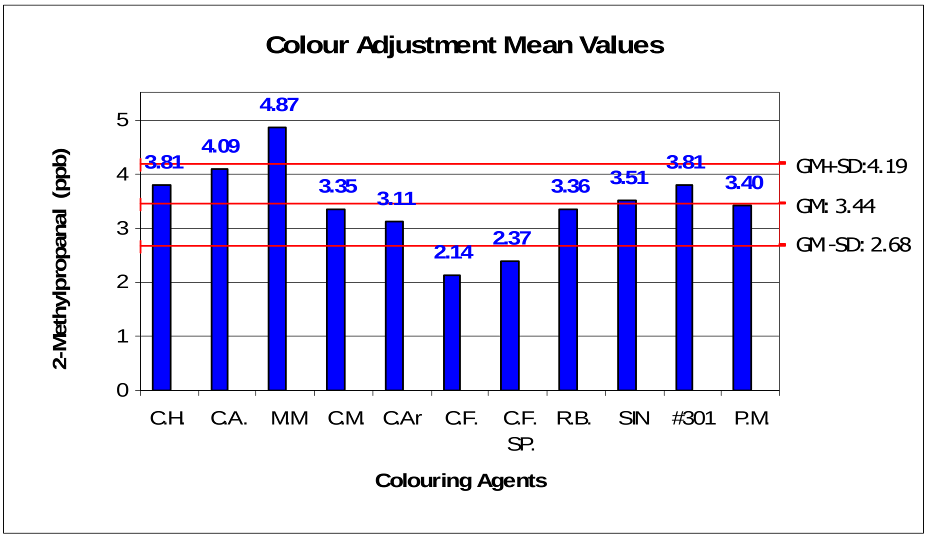

Chart B.4.10 Concentration of 2-methylpropanal on fresh locally-brewed beers

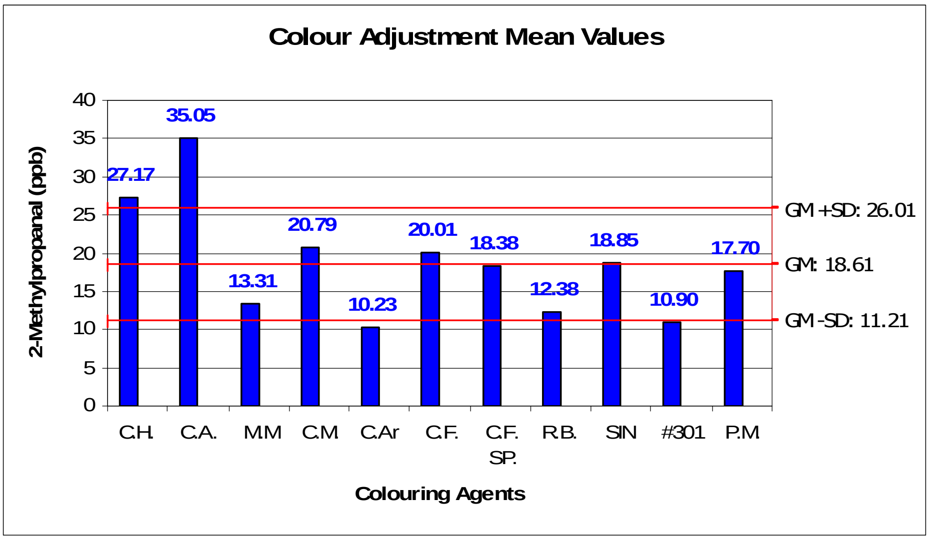

Chart B.4.11 Concentration of 2-methylpropanal on forced aged locally-brewed beers

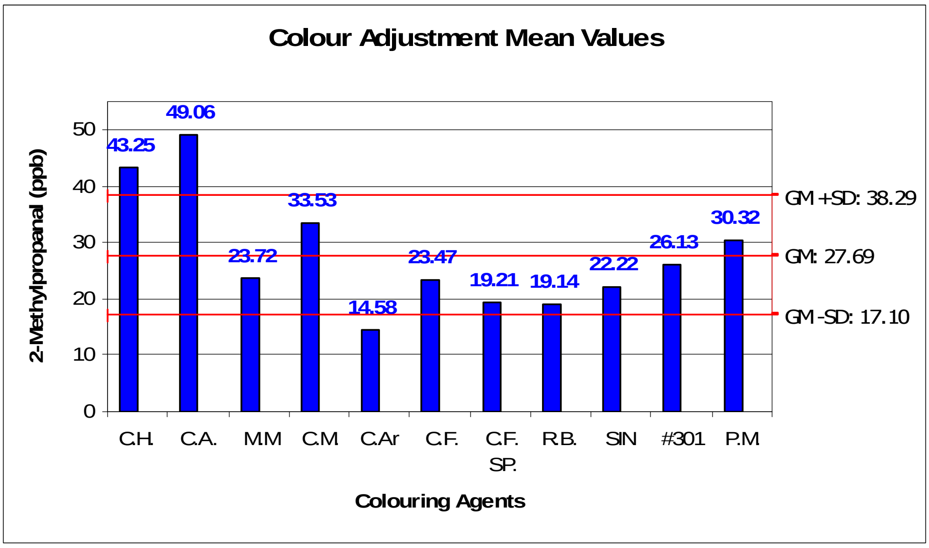

Chart B.4.12 Concentration of 2-methylpropanal on spontaneously aged locally-brewed beers

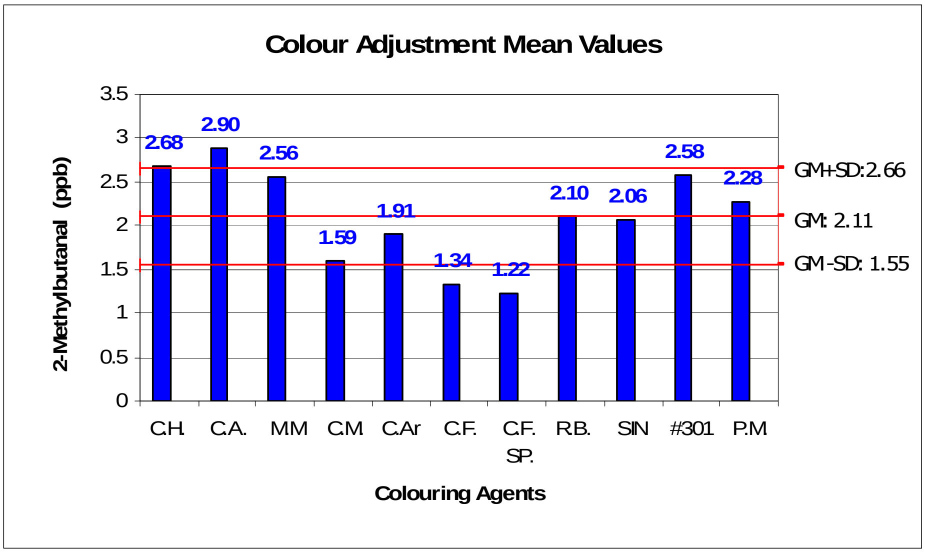

Chart B.4.13 Concentration of 2-methylbutanal on fresh locally-brewed beers

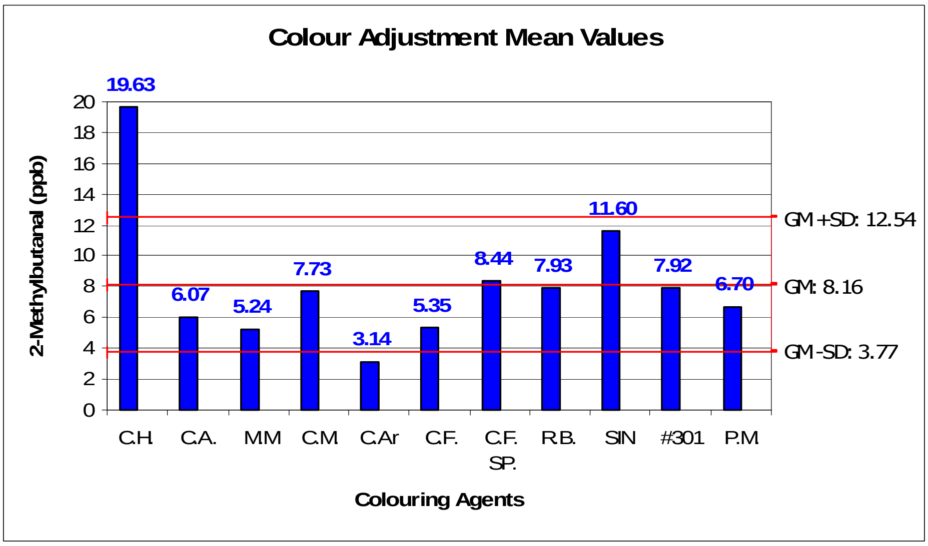

Chart B.4.14 Concentration of 2-methylbutanal on forced aged locally-brewed beers

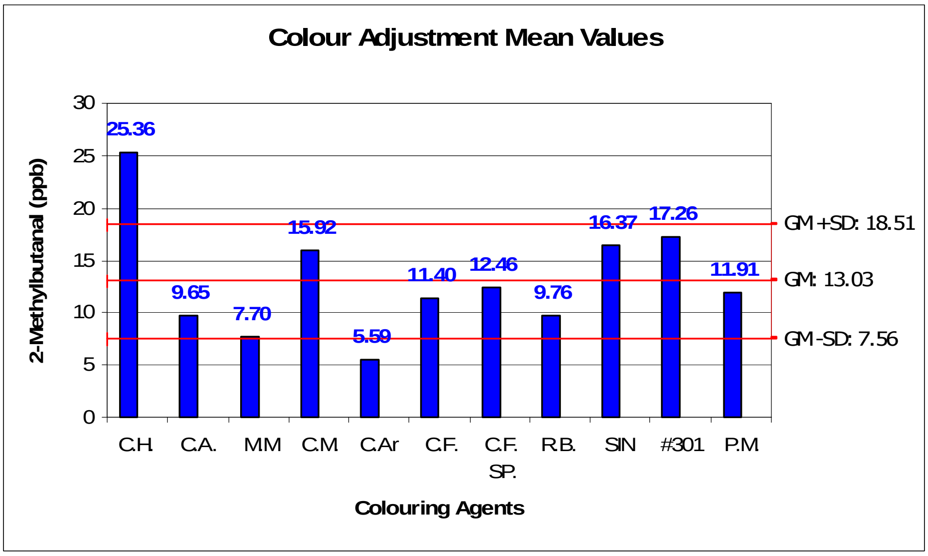

Chart B.4.15 Concentration of 2-methylbutanal on spontaneously aged locally-brewed beers

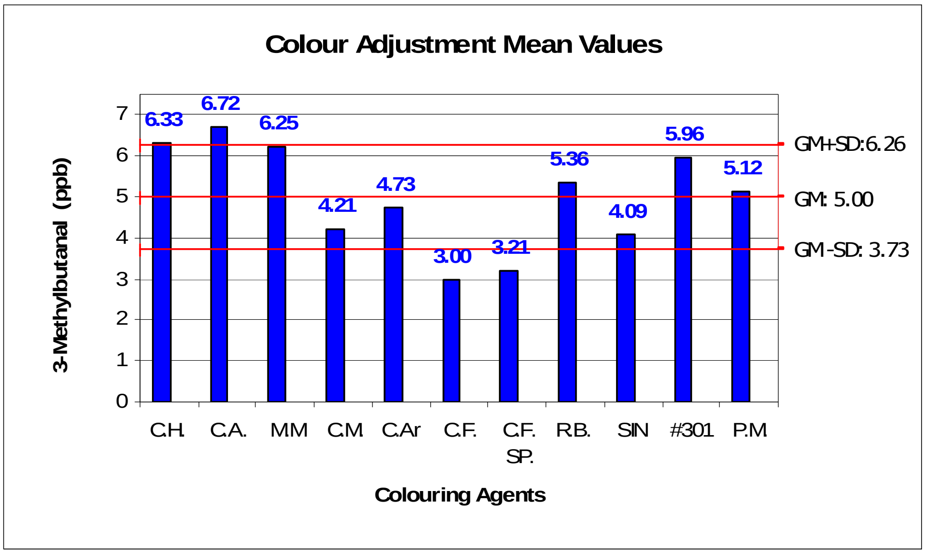

Chart B.4.16 Concentration of 3-methylbutanal on fresh locally-brewed beers

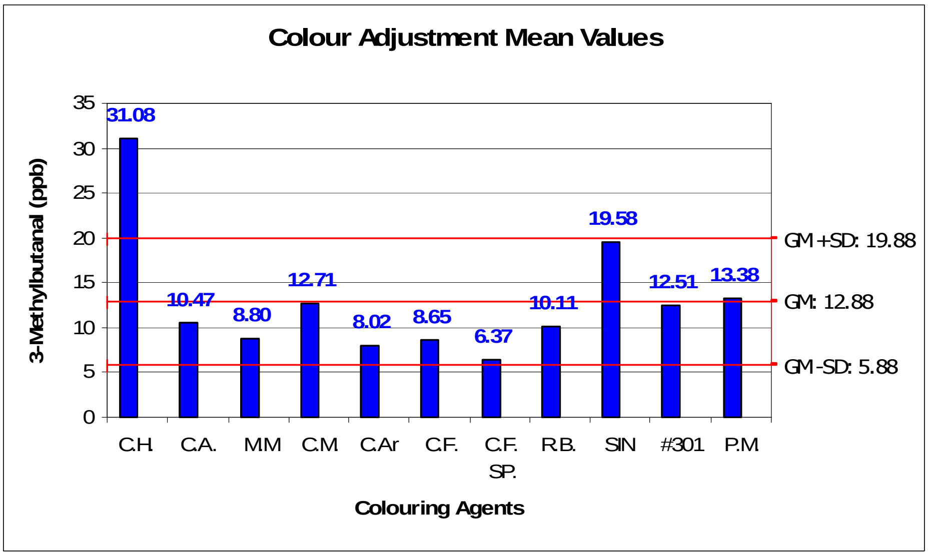

Chart B.4.17 Concentration of 3-methylbutanal on forced aged locally-brewed beers

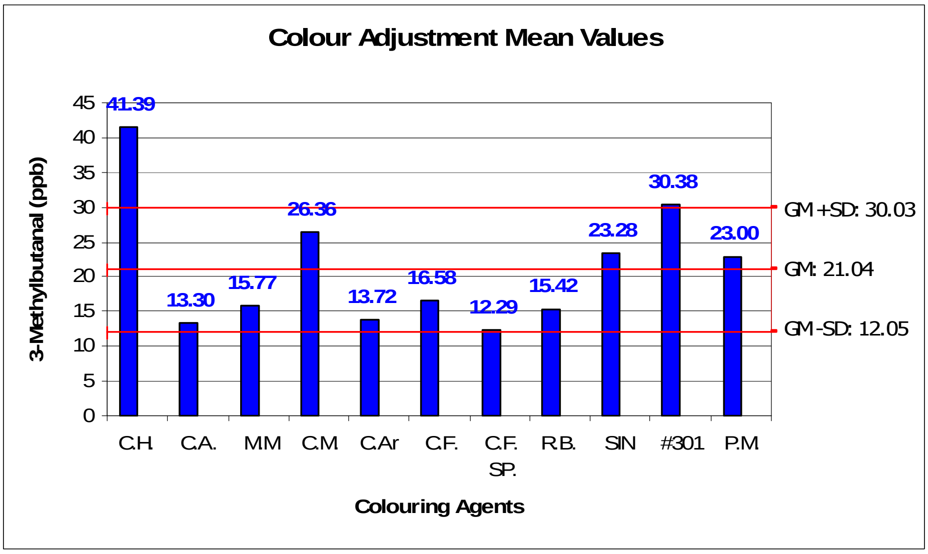

Chart B.4.18 Concentration of 3-methylbutanal on spontaneously aged locally-brewed beers

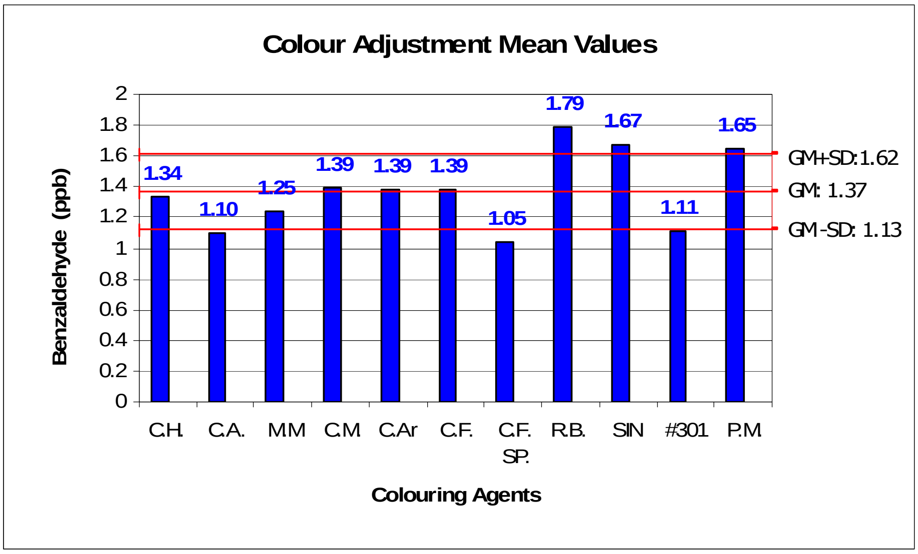

Chart B.4.19 Concentration of benzaldehyde on fresh locally-brewed beers

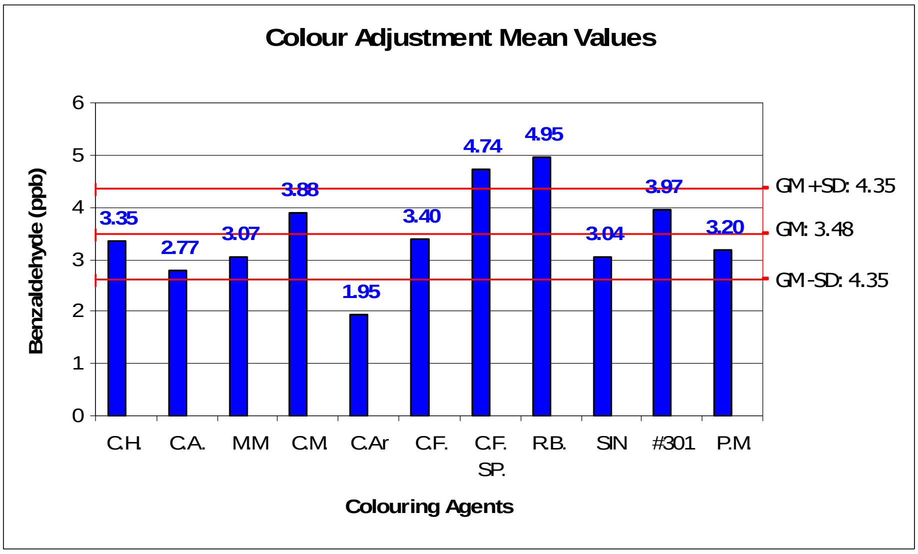

Chart B.4.20 Concentration of benzaldehyde on forced aged locally-brewed beers

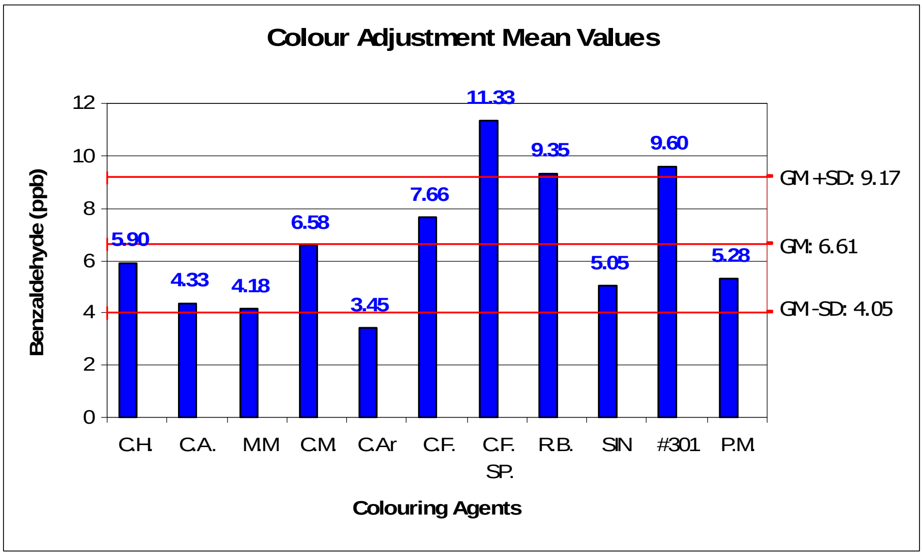

Chart B.4.21 Concentration of benzaldehyde on spontaneously aged locally-brewed beers

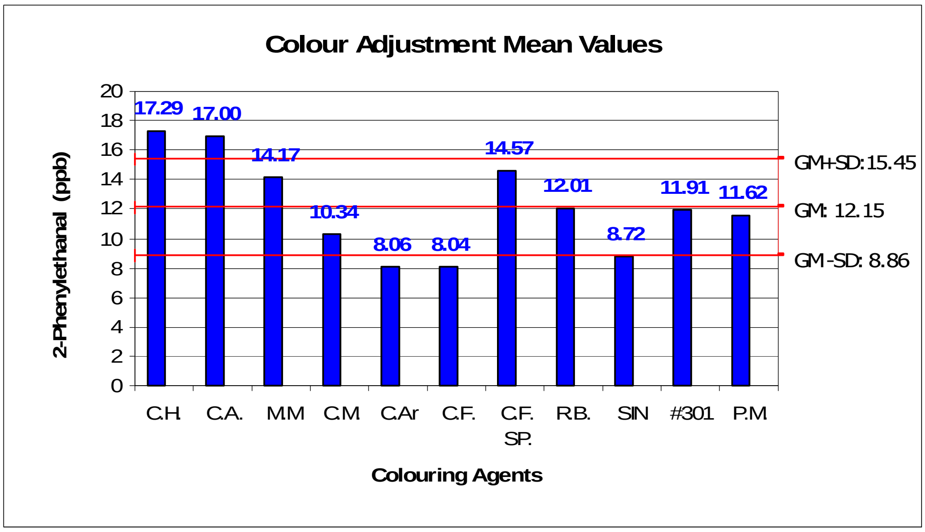

Chart B.4.22 Concentration of 2-phenylethanal on fresh locally-brewed beers

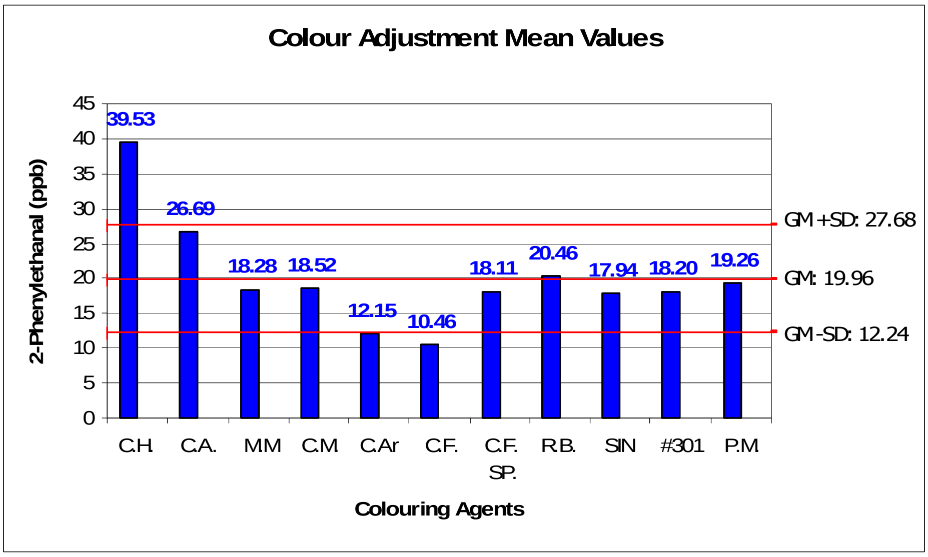

Chart B.4.23 Concentration of 2-phenylethanal on forced aged locally-brewed beers

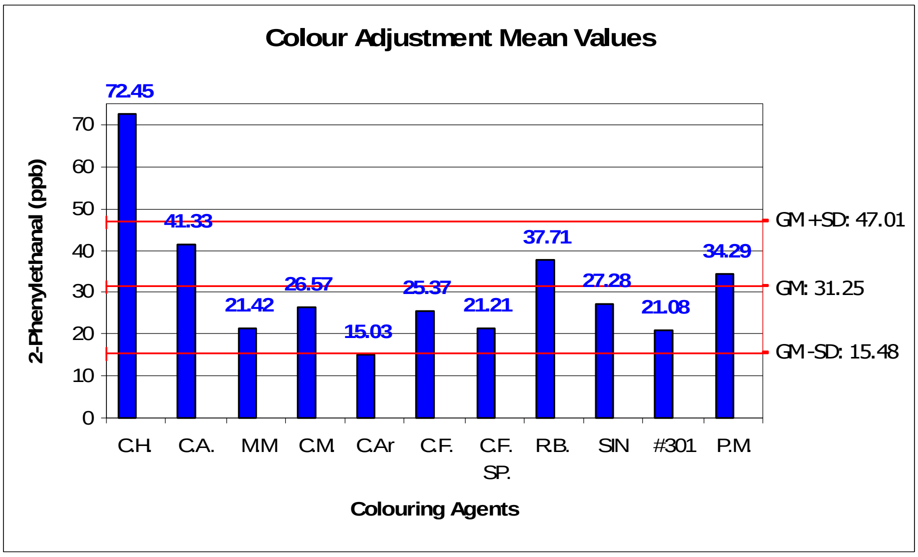

Chart B.4.24 Concentration of 2-phenylethanal on spontaneously aged locally-brewed beers

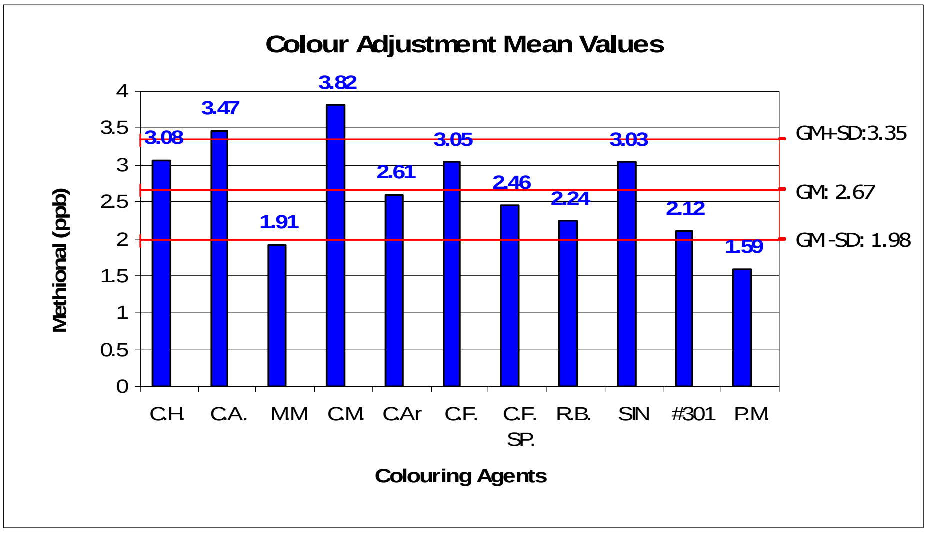

Chart B.4.25 Concentration of methional on fresh locally-brewed beers

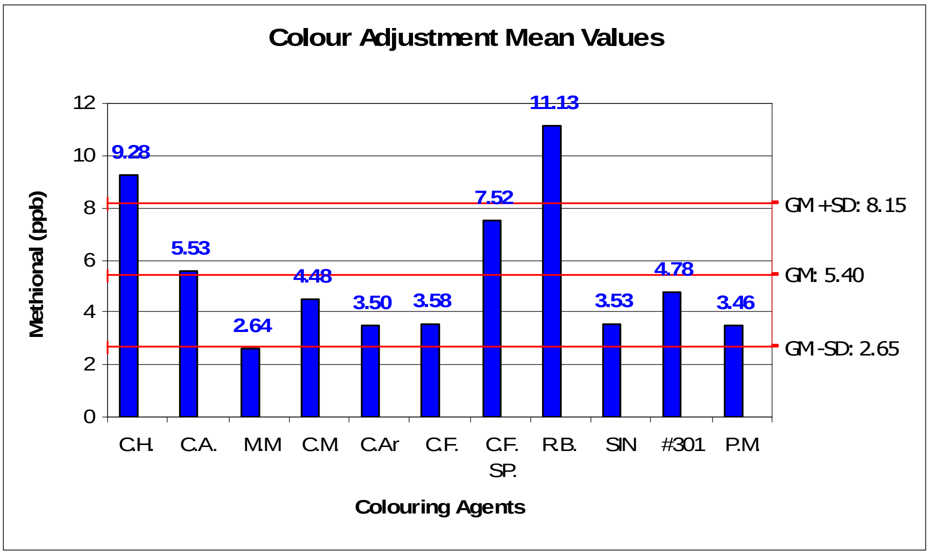

Chart B.4.26 Concentration of methional on forced aged locally-brewed beers

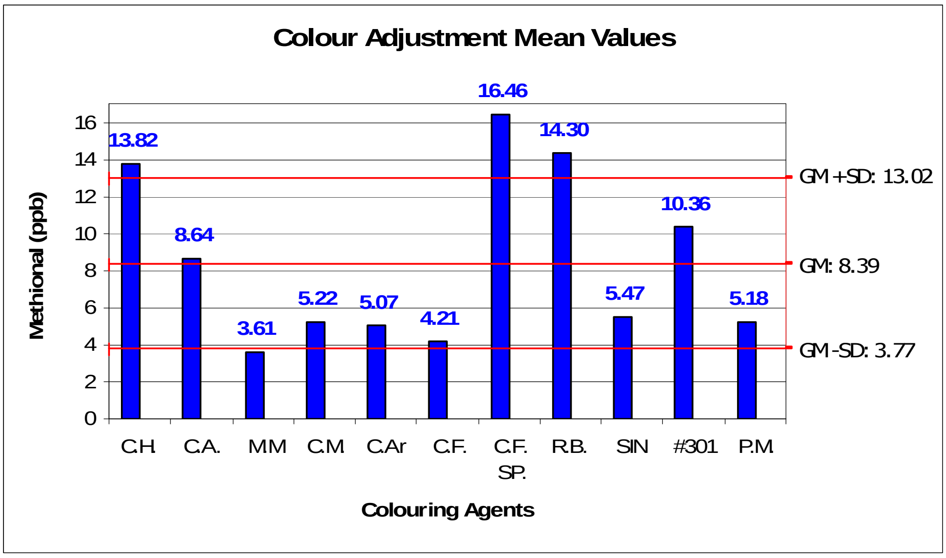

Chart B.4.27 Concentration of methional on spontaneously aged locally-brewed beers

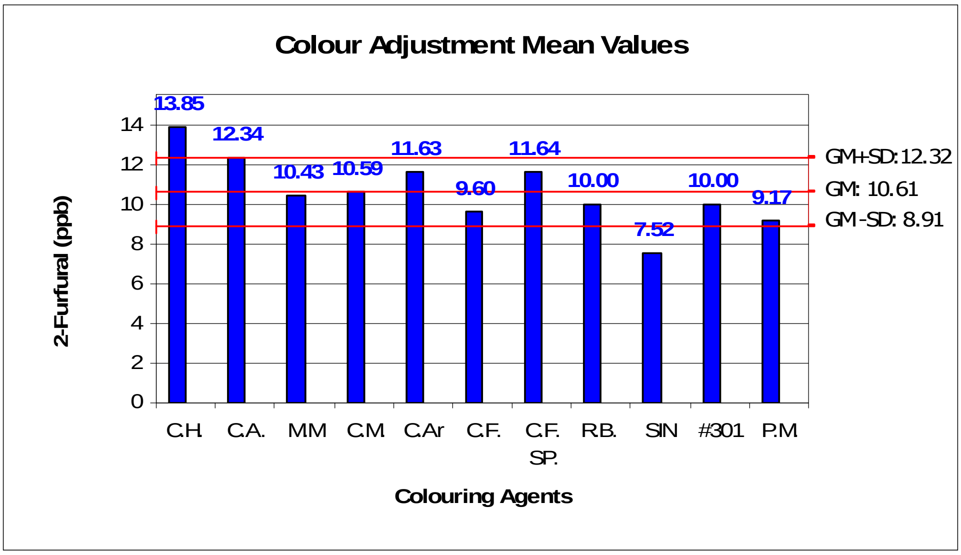

Chart B.4.28 Concentration of 2-furfural on fresh locally-brewed beers

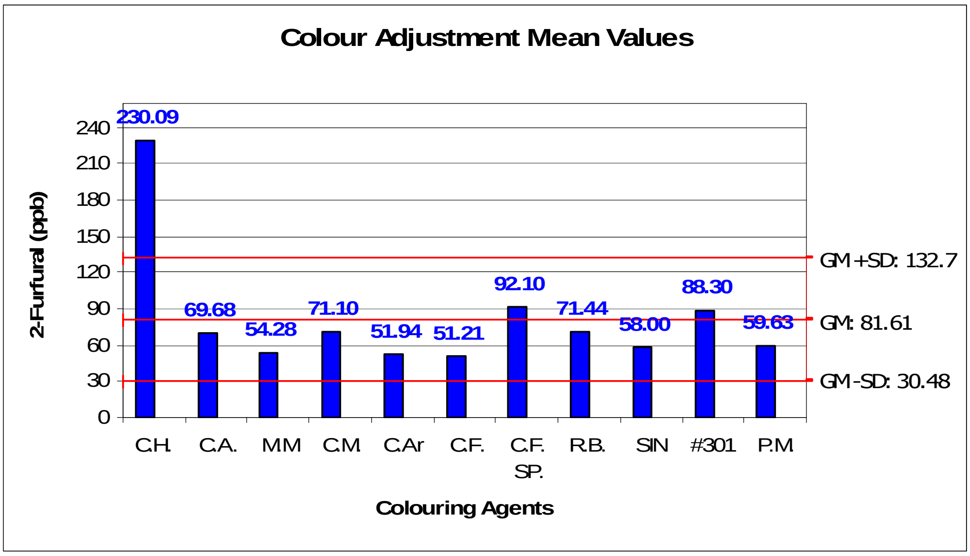

Chart B.4.29 Concentration of 2-furfural on forced aged locally-brewed beers

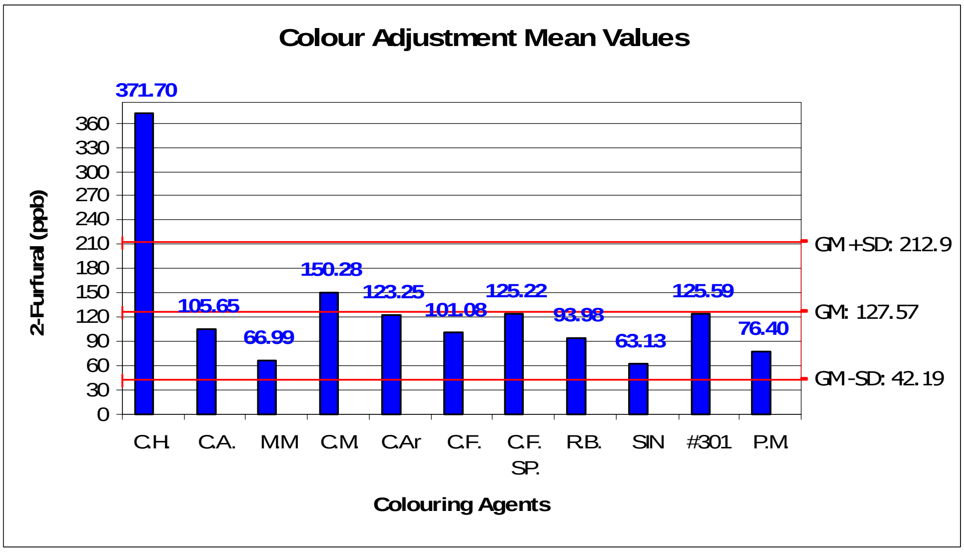

Chart B.4.30 Concentration of 2-furfural on spontaneously aged locally-brewed beers

APPENDIX C. Brew control sheets

BREW CONTROL SHEET

Name: Andrés Furukawa S.	**Date:** 17.07.07
Brew no. 1 (ICBD No. 0751A1)	**Target volume:** 2 hL
Beer style: CARAHELL®	**Target gravity:** 1.04840 (12 °P)

Mill	CARAHELL®	3.45 kg (10 %)
	PILSNER MALT	31.05 kg (90%)
Total		34.5 kg (100%)

Brew liquor total hardness (°dH)	14.23
Strike temperature (°C)	60.5
Volume (L)	104
Flow rate (L/h)	600
Liquor: Grist ratio	3:1
Mash feed rate (kg/min)	4.5

Mashing	Process stage	Temp (°C)	Start	Duration (min)	Notes
	Mash-in	**60.5**	9:50	10	
	1. Rest	**55.0**	10:00	**10**	
	Heat-up		10:10	7	
	2. Rest	**62.2**	10:17	**60**	
	Heat-up		11:17	10	
	3. Rast	**72**	11:27	**20**	
	Heat-up		11:47	3	
	Mash-out	**78**	11:50	5	
	Iodine Test ok?	**(yes)/not**			

Lautering / Mash filtration	Process stage	Pressure (bar)	Start	Duration (min)	Notes
	Start filling	0.80	11:50	-	
	Mash filter full	0.80	11:52	2	
	Recirculation start	0.80	11:52	6	
	Start collection	0.82	11:58	14	
	Mash all-in Start pre-compression	0.60	12:12	6	
	Pre-compression end- Sparge on	0.90	12:18	7	
	End sparge-Start final compression	0.90	12:25	8	
	End collection	0.90	12:33	7	
	Total sparge liquor (hL)	1.0	**Sparge temperature (℃)**	78.3	

Mash Filter Run Off					
Time (min)	**Volume Collected (L)**	**Run off rate (L/h)**	**Gravity SG (°P)**	**Inlet pressure (bar)**	**Outlet pressure (bar)**
0	0	410	1.0943 (22.52)	0.82	**0.62**
6	30	385	1.0953 (22.75)	0.81	0.60
14	60	350	1.0928 (22.19)	0.75	0.40
20	80	175	1.0930 (22.24)	0.60	0.10
27	100	225	1.0500 (12.39)	0.90	0.16
34	120	240	1.0358 (8.98)	0.91	0.20
41	140	235	1.0169 (4.31)	0.90	0.20
47	160	250	1.0059 (1.52)	0.94	0.21
50	170	240	1.0036 (0.93)	0.94	0.21
0	210	40 L brew liquor added			

Boiling		Gravity SG (°P)	Time	Duration	Notes
	Heat -up		12:33	17	
	Calandria temperature ℃	105.0 .± 2			
	Kettle-full	**1.052 (12.8)**	12.45		
	Boiling start		12:50	**60**	
	Boiling stop		13:50		
	Cast wort	**1.0493 (12.22)**			

1. Hop dosage	**85.5 g (60 min)**	**Type:** Hallertauer-Magnum	**12.7 % α-acids**
2. Hop dosage	**100 g (10 min)**	**Type:** Saaz (Slovakia)	**6.0 % α-acids**
Apparent IBU	**22**		

	Temperature (℃)	Time	Duration (min)	Notes
Whirlpool		13:50	**30**	
Casting start		14:20	**55**	
Casting end		15:15		
Pitching	11.2	14:30	5	

Fermentor No.	3	**Pre-cooled?**	**(yes)/not**

Yeast type	Saflager S-23
Viability (%)	96.5
Pitching quantity (kg)	3.05
Pitching rate (10^6 cells/mL)	15.27
Attenuation limit (%)	84.20

	Date	Time	SG (°P)	Temp, Set-up (℃)	Real temp. (℃)	Pressure (bar)	Yeast cells (10^6 cells/mL)	pH	Colour (EBC)
Primary fermentation	17.07.07	15:20	1.0493 (12.22)	**12.0**	11.2	0.2	15.2	5.40	15.3
	18.07.07	16:30	1.0462 (11.48)	**12.0**	11.9	0.2	34.8	5.18	
	19.07.07	17:00	1.0427 (10.64)	**12.0**	11.8	0.2	49.5	4.67	
	20.07.07	16:45	1.0384 (9.61)	**12.0**	12.3	0.2	80.7	4.56	
	21.07.07	17:50	1.0282 (7.12)	**12.0**	12.5	0.2	60.5	4.51	
	22.07.07	20:30	1.0251 (6.35)	**12.0**	12.3	0.2	43.5	4.41	
	23.07.07	10:36	1.0247 (6.25)	**12.0**	12.0	0.2	32.8	4.33	
	24.07.07	9:00	1.0215 (5.46)	**12.0**	11.7	0.2	25.5	4.21	
	25.07.07	10:30	1.0164 (4.18)	**12.0**	11.8	0.2	22.4	4.20	
Yeast collection	26.07.07	10:58	1.0150 (3.83)	**4.0**	4.0	0.2	20.5	4.20	
	27.07.07	8:13	1.0145 (3.70)	**4.0**	3.9	0.2	18.2	4.20	
Diacetyl rest	28.07.07	10:00	1.0136 (3.48)	**Cool off**	9.0	0.5	N/A	4.20	
	29.07.07	11:00	1.0123 (3.15)	**Cool off**	12.2	1.0	N/A	4.20	
Maturation	30.07.07	10:10	1.0115 (2.95)	**2.0**	2.0	1.0	N/A	4.20	11.8
	31.07.07	10:21	1.0110 (2.82)	**2.0**	2.0	1.0	N/A	4.20	

	Date	Time	SG (°P)	Temp, Set-up (°C)	Real temp. (°C)	Pressure (bar)	Yeast cells (10^6 cells/mL)	pH	Colour (EBC)
	01.08.07	10:25	1.0105 (2.69)	**2.0**	2.0	1.0	N/A	4.20	
	02.08.07	7:50	1.0095 (2.44)	**2.0**	2.0	1.2	N/A	4.20	
	03.08.07	17:04	1.0085 (2.18)	**2.0**	1.9	1.2	N/A	4.20	
	04.08.07	11:01	1.0075 (1.93)	**2.0**	1.8	1.2	N/A	4.20	
	05.08.07	9:05	1.0075 (1.93)	**2.0**	1.8	1.2	N/A	4.20	
	06.08.07	11:05	1.0075 (1.93)	**2.0**	1.8	1.2	N/A	4.20	
	07.08.07	7:40	1.0075 (1.93)	**2.0**	1.7	1.3	N/A	4.20	
	08.08.07	13:00	1.0075 (1.93)	**2.0**	2.0	1.3	N/A	4.20	
	09.08.07	11:53	1.0075 (1.93)	**2.0**	1.9	1.2	N/A	4.20	
Filtration	10.08.07	11:52	1.0075 (1.93)	**2.0**	1.9	1.2	N/A	4.20	7.8
Conditioning Tank No:	CT1								

Beer Filtration		
	Beer stabilizers	(yes) / no
	Type of beer stabilizer	Lucilite TR Silica Gel/PVP INEOS Silicas Ltd
	Stabilizer rate (mg/L)	50
	Filtration unit	Carlson Ltd
	Number of filters	9
	Filter grade	XE400
	Porous size (µm)	0.5

Kegging			
	Keg No.	0751A	0751B
	Date	10.08.07	10.08.07
	Pressure of filling (bar)	1.0	1.0
	Volume of beer (L)	50	50
	Volume of water (L)	0	0
	Total volume (L)	50	50

Bottling					
	Keg No.	0751B	Bottle type & size	British 0.5 L	Euro 0.33 L
	Date	17.08.07	No. of bottles	24	48

BREW CONTROL SHEET

Name: Andrés Furukawa S.	**Date:** 27.07.07
Brew no. 2 (ICBD No. 0755A2)	**Target volume:** 2 hL
Beer style: CARAAMBER®	**Target gravity:** 1.04840 (12 °P)

Mill	CARAAMBER®	1.35 kg (96.1%)
	PILSNER MALT	31.05 kg (3.9 %)
Total		34.5 kg (100%)

Brew liquor total hardness (°dH)	15.40
Strike temperature (°C)	60.5
Volume (L)	103
Flow rate (L/h)	600
Liquor: Grist ratio	3:1
Mash feed rate (kg/min)	4.5

Mashing	Process stage	Temp (°C)	Start	Duration (min)	Notes
	Mash-in	**60.5**	8:30	7	
	1. Rest	**55.1**	8:37	**10**	
	Heat-up		8:47	11	
	2. Rest	**62.0**	8:58	**60**	
	Heat-up		9:58	5	
	3. Rast	**72.0**	10:03	**20**	
	Heat-up		10:23	5	
	Mash-out	**77.9**	10:28	2	
	Iodine Test ok?	**(yes)/not**			

Lautering / Mash filtration	Process stage	Pressure (bar)	Start	Duration (min)	Notes
	Start filling	0.80	10:28	-	
	Mash filter full	0.80	10:30	2	
	Recirculation start	0.80	10:30	4	
	Start collection	0.82	10:34	14	
	Mash all-in Start pre-compression	0.60	10:48	6	
	Pre-compression end- Sparge on	0.90	10:54	13	
	End sparge-Start final compression	0.90	11:07	8	
	End collection	0.90	11:13	6	
	Total sparge liquor (hL)	1.0	**Sparge temperature (℃)**	77.8	

Mash Filter Run Off					
Time (min)	**Volume Collected (L)**	**Run off rate (L/h)**	**Gravity SG (°P)**	**Inlet pressure (bar)**	**Outlet pressure (bar)**
0	0	430	1.0850 (20.46)	0.81	**0.64**
5	20	390	1.0861 (20.70)	0.81	0.62
9	40	390	1.0850 (20.46)	0.80	0.60
14	60	390	1.0837 (20.16)	0.80	0.60
20	80	270	1.0807 (19.49)	0.60	0.26
25	100	360	1.0493 (12.22)	0.93	0.51
30	120	350	1.0264 (6.67)	0.93	0.46
35	140	370	1.0134 (3.43)	0.90	0.45
39	160	350	1.0042 (1.08)	0.90	0.30
0	210	50 L brew liquor added			

Boiling		Gravity SG (°P)	Time	Duration	Notes
	Heat -up		11:20	25	
	Calandria temperature ℃	106.3 .± 2			
	Kettle-full	**1.0461 (11.46)**	12:13		
	Boiling start		11:20	**60**	
	Boiling stop		12:20		
	Cast wort	**1.0509 (12.60)**			

1. Hop dosage	**85.5 g (60 min)**	**Type:** Hallertauer-Magnum	**12.7 % α-acids**
2. Hop dosage	**100 g (10 min)**	**Type:** Saaz (Slovakia)	**6.0 % α-acids**
Apparent IBU	**22**		

	Temperature (℃)	Time	Duration (min)	Notes
Whirlpool		12:20	**25**	
Casting start		12:45	**35**	
Casting end		13:20		
Pitching	11.2	13:00	3	

Fermentor No.	4	**Pre-cooled?**	**(yes)/not**

Yeast type	Saflager S-23
Viability (%)	93.0
Pitching quantity (kg)	3.00
Pitching rate (10^6 cells/mL)	18.22
Attenuation limit (%)	83.98

	Date	Time	SG (°P)	Temp, Set-up (℃)	Real temp. (℃)	Pressure (bar)	Yeast cells (10^6 cells/mL)	pH	Colour (EBC)
Primary fermentation	27.07.07	13:20	1.0499 (12.36)	**12.0**	11.2	0.2	18.2	5.40	16.5
	28.07.07	10:00	1.0415 (10.36)	**12.0**	11.9	0.2	40.5	4.80	
	29.07.07	11:00	1.0274 (6.92)	**12.0**	11.8	0.2	73.6	4.52	
	30.07.07	10:12	1.0165 (4.21)	**4.0**	11.8	0.2	86.3	4.32	
Yeast collection	31.07.07	10:22	1.0128 (3.27)	**4.0**	4.1	0.2	28.8	4.28	
Diacetyl rest	01.08.07	10:26	1.0123 (3.15)	**Cool off**	3.9	0.2	20.7	4.15	
	02.08.07	7:50	1.0118 (3.02)	**Cool off**	6.6	0.1	N/A	4.10	
	03.08.07	17:05	1.0115 (2.95)	**Cool off**	12.6	0.1	N/A	4.10	
	04.08.07	10:49	1.0113 (2.89)	**Cool off**	14.2	0.1	N/A	4.10	
Maturation	05.08.07	9:25	1.0110 (2.82)	**2.0**	2.0	0.1	N/A	4.10	13.4
	06.08.07	11:05	1.0107 (2.74))	**2.0**	2.0	0.1	N/A	4.10	
	07.08.07	7:40	1.0095 (2.44)	**2.0**	2.0	1.0	N/A	4.10	
	08.08.07	13:00	1.0088 (2.26)	**2.0**	2.0	0.8	N/A	4.10	
	09.08.07	11:55	1.0080 (2.06)	**2.0**	2.0	0.7	N/A	4.10	
	10.08.07	11:53	1.0077 (1.98)	**2.0**	2.2	0.6	N/A	4.10	
	11.08.07	21:00	1.0077 (1.98)	**2.0**	2.0	0.6	N/A	4.10	

	Date	Time	SG (°P)	Temp, Set-up (°C)	Real temp. (°C)	Pressure (bar)	Yeast cells (10^6 cells/mL)	pH	Colour (EBC)
	12.08.07	17:25	1.0077 (1.98)	**2.0**	1.9	0.6	N/A	4.10	
	13.08.07	7:30	1.0077 (1.98)	**2.0**	1.9	0.6	N/A	4.10	
	14.08.07	11:20	1.0077 (1.98)	**2.0**	2.0	1.0	N/A	4.10	
	15.08.07	8:17	1.0077 (1.98)	**2.0**	1.9	1.0	N/A	4.10	
	16.08.07	10:21	1.0077 (1.98)	**2.0**	1.8	1.0	N/A	4.10	
	17.08.07	11:20	1.0077 (1.98)	**2.0**	1.8	0.9	N/A	4.10	
	18.08.07	14:50	1.0077 (1.98)	**2.0**	1.9	0.9	N/A	4.10	
	19.08.07	10:45	1.0077 (1.98)	**2.0**	1.8	0.9	N/A	4.10	
Filtration	20.08.07	9:20	1.0077 (1.98)	**2.0**	1.9	0.9	N/A	4.10	7.6
Conditioning Tank No:	CT2								

Beer Filtration		
	Beer stabilizers	(yes) / no
	Type of beer stabilizer	Lucilite TR Silica Gel/PVP INEOS Silicas Ltd
	Stabilizer rate (mg/L)	50
	Filtration unit	Carlson Ltd
	Number of filters	9
	Filter grade	XE400
	Porous size (μm)	0.5

Kegging			
	Keg No.	0755A	0755B
	Date	20.08.07	20.08.07
	Pressure of filling (bar)	1.0	1.0
	Volume of beer (L)	50	50
	Volume of water (L)	0	0
	Total volume (L)	50	50

Bottling					
	Keg No.	0755B	Bottle type & size	British 0.5 L	Euro 0.33 L
	Date	23.08.07	No. of bottles	24	48

BREW CONTROL SHEET

Name: Andrés Furukawa S.	**Date:** 02.08.07
Brew no. 3 (ICBD No. 0758A3)	**Target volume:** 2 hL
Beer style: MELANOIDIN MALT	**Target gravity:** 1.04840 (12 °P)

Mill	MELANOIDIN MALT	1.35 kg (3.9 %)
	PILSNER MALT	31.05 kg (96.1 %)
Total		34.5 kg (100%)

Brew liquor total hardness (°dH)	12.3
Strike temperature (°C)	60.5
Volume (L)	103
Flow rate (L/h)	600
Liquor: Grist ratio	3:1
Mash feed rate (kg/min)	4.5

Mashing	Process stage	Temp (°C)	Start	Duration (min)	Notes
	Mash-in	**60.5**	8:41	5	
	1. Rest	**55.2**	8:46	**10**	
	Heat-up		8:56	7	
	2. Rest	**62.1**	9:03	**60**	
	Heat-up		10:03	10	
	3. Rast	**72.0**	10:13	**20**	
	Heat-up		10:33	6	
	Mash-out	**78.0**	10:39	2	
	Iodine Test ok?	**(yes)/not**			

Lautering / Mash filtration	Process stage	Pressure (bar)	Start	Duration (min)	Notes
	Start filling	0.85	10:39	-	
	Mash filter full	0.85	10:41	2	
	Recirculation start	0.85	10:41	2	
	Start collection	0.85	10:45	4	
	Mash all-in Start pre-compression	0.60	10:58	13	
	Pre-compression end- Sparge on	0.80	11:02	4	
	End sparge-Start final compression	0.80	11:18	6	
	End collection	0.80	11:25	7	
	Total sparge liquor (hL)	0.90	**Sparge temperature (℃)**	77.8	

Mash Filter Run Off					
Time (min)	**Volume Collected (L)**	**Run off rate (L/h)**	**Gravity SG (°P)**	**Inlet pressure (bar)**	**Outlet pressure (bar)**
0	0	420	1.0796 (19.24)	0.85	**0.67**
5	20	410	1.0812 (19.60)	0.85	0.62
9	40	400	1.0797 (19.26)	0.84	0.62
13	60	315	1.0788 (19.06)	0.61	0.38
18	80	340	1.0776 (18.79)	0.80	0.50
24	100	360	1.0474 (11.77)	0.80	0.50
29	120	350	1.0250 (6.33)	0.78	0.48
33	140	350	1.0108 (2.77)	0.76	0.48
37	160	380	1.0050 (1.29)	0.81	0.51
0	200	50 L brew liquor added			

Boiling		Gravity SG (°P)	Time	Duration	
	Heat -up		11:05	34	
	Calandria temperature ℃	105.5 .± 2			
	Kettle-full	**1.0454 (11.29)**	11:32		
	Boiling start		11:39	**60**	
	Boiling stop		12:39		
	Cast wort	**1.0511 (12.65)**			

1. Hop dosage	**85.5 g (60 min)**	**Type:** Hallertauer-Magnum	**12.7 % alpha**
2. Hop dosage	**100 g (10 min)**	**Type:** Saaz (Slovakia)	**6.0 % alpha**
Apparent IBU	**22**		

	Temperature (℃)	Time	Duration (min)	Notes
Whirlpool		12:39	**25**	
Casting start		13:04	**36**	
Casting end		13:40		
Pitching	11.4	13:15	2	

Fermentor No.	3	**Pre-cooled?**	**(yes)/not**

Yeast type	Saflager S-23
Viability (%)	89.6
Pitching quantity (kg)	3.22
Pitching rate (10^6 cells/mL)	19.70
Attenuation limit (%)	82.7

	Date	Time	SG (°P)	Temp, Set-up (℃)	Real temp. (℃)	Pressure (bar)	Yeast cells (10^6 cells/mL)	pH	Colour (EBC)
Primary fermentation	02.08.07	13:47	1.0485 (12.03)	**12.0**	11.4	0.2	19.7	5.21	12.1
	03.08.07	17:02	1.0332 (8.34)	**12.0**	11.7	0.2	48.8	4.65	
	03.08.07	10:48	1.0242 (6.13)	**12.0**	11.8	0.2	78.6	4.32	
	04.08.07	22:10	1.0164 (4.18)	**4.0**	11.7	0.2	72.5	4.10	
	05.08.07	9:22	1.0125 (3.20)	**4.0**	8.0	0.2	55.5	4.00	
	06.08.07	11:05	1.0118 (3.02)	**4.0**	3.9	0.15	42.3	4.00	
Yeast collection	07.08.07	7:40	1.0111 (2.84)	**4.0**	4.0	0.15	N/A	4.00	
Diacetyl rest	08.08.07	13:00	1.0105 (2.69)	**Cool off**	8.8	0.4	N/A	4.00	
	09.08.07	11:55	1.0095 (2.44)	**Cool off**	11.3	0.5	N/A	4.00	
Maturation	10.08.07	11:54	1.0092 (2.36)	**2.0**	13.3	0.7	N/A	4.00	9.3
	11.08.07	21:00	1.0087 (2.23)	**2.0**	2.0	0.7	N/A	4.00	
	12.08.07	17:25	1.0085 (2.18)	**2.0**	2.0	0.9	N/A	4.00	
	13.08.07	7:31	1.0084 (2.16)	**2.0**	2.0	0.9	N/A	4.00	
	14.08.07	11:20	1.0083 (2.13)	**2.0**	2.3	0.9	N/A	4.00	
	15.08.07	8:20	1.0083 (2.13)	**2.0**	1.8	0.9	N/A	4.00	
	16.08.07	10:20	1.0081 (2.08)	**2.0**	2.2	0.9	N/A	4.00	

	Date	Time	SG (°P)	Temp, Set-up (°C)	Real temp. (°C)	Pressure (bar)	Yeast cells (10^6 cells/mL)	pH	Colour (EBC)
	17.08.07	11:20	1.0081 (2.08)	**2.0**	2.0	0.9	N/A	4.00	
	18.08.07	14:50	1.0081 (2.08)	**2.0**	1.7	0.9	N/A	4.00	
	19.08.07	10:50	1.0081 (2.08)	**2.0**	1.8	0.9	N/A	4.00	
	20.08.07	9:20	1.0081 (2.08)	**2.0**	2.2	0.9	N/A	4.00	
	21.08.07	10:41	1.0081 (2.08)	**2.0**	2.0	0.9	N/A	4.00	
	22.08.07	9:00	1.0081 (2.08)	**2.0**	1.5	0.9	N/A	4.00	
	23.08.07	9:50	1.0081 (2.08)	**2.0**	1.7	0.9	N/A	4.00	
Filtration	24.08.07	8:05	1.0081 (2.08)	**2.0**	1.8	0.9	N/A	4.00	6.8
Conditioning Tank No:	CT1								

Beer Filtration		
	Beer stabilizers	(yes) / no
	Type of beer stabilizer	Lucilite TR Silica Gel/PVP INEOS Silicas Ltd
	Stabilizer rate (mg/L)	50
	Filtration unit	Carlson Ltd
	Number of filters	9
	Filter grade	XE400
	Porous size (µm)	0.5

Kegging			
	Keg No.	0758A	0758B
	Date	24.08.07	24.08.07
	Pressure of filling (bar)	1.0	1.0
	Volume of beer (L)	50	50
	Volume of water (L)	0	0
	Total volume (L)	50	50

Bottling					
	Keg No.	0758B	Bottle type & size	British 0.5 L	Euro 0.33 L
	Date	28.08.07	No. of bottles	24	48

BREW CONTROL SHEET

Name: Andrés Furukawa S.	**Date:** 02.08.07
Brew no. 4 (ICBD No. 0760A4)	**Target volume:** 2 hL
Beer style: CARAMUNICH® Type III	**Target gravity:** 1.04840 (12 °P)

Mill	CARAMUNICH® Type III	0.72 kg (1.9 %)
	PILSNER MALT	33.78 kg (98.1 %)
Total		34.5 kg (100%)

Brew liquor total hardness (°dH)	13.17
Strike temperature (°C)	59.7
Volume (L)	103
Flow rate (L/h)	600
Liquor: Grist ratio	3:1
Mash feed rate (kg/min)	4.5

Mashing	Process stage	Temp (°C)	Start	Duration (min)	Notes
	Mash-in	**59.7**	8:30	5	
	1. Rest	**55.7**	8:35	**10**	
	Heat-up		8:45	8	
	2. Rest	**61.9**	8:53	**60**	
	Heat-up		9:53	8	
	3. Rast	**71.8**	10:01	**20**	
	Heat-up		10:21	6	
	Mash-out	**77.8**	10:27	2	
	Iodine Test ok?	**(yes)/not**			

Lautering / Mash filtration	Process stage	Pressure (bar)	Start	Duration (min)	Notes
	Start filling	0.85	10:27	-	
	Mash filter full	0.85	10:29	2	
	Recirculation start	0.85	10:29	2	
	Start collection	0.85	10:31	2	
	Mash all-in Start pre-compression	0.60	10:43	12	
	Pre-compression end- Sparge on	0.80	10:49	6	
	End sparge-Start final compression	0.80	11:08	19	
	End collection	0.90	11:13	5	
	Total sparge liquor (hL)	1.0	**Sparge temperature (°C)**	78.2	

Mash Filter Run Off					
Time (min)	**Volume Collected (L)**	**Run off rate (L/h)**	**Gravity SG (°P)**	**Inlet pressure (bar)**	**Outlet pressure (bar)**
0	0	435	1.0833 (20.08)	0.84	0.65
5	20	420	1.0842 (20.28)	0.84	0.65
9	40	420	1.0834 (20.10)	0.84	0.62
13	60	325	1.0819 (19.76)	0.64	0.36
19	80	285	1.0808 (19.51)	0.83	0.30
25	100	270	1.0505 (12.51)	0.83	0.28
31	120	275	1.0269 (6.80)	0.80	0.27
37	140	255	1.0098 (2.51)	0.80	0.25
44	160	250	1.0034 (0.88)	0.84	0.30
0	200	40 L brew liquor added			

Boiling		Gravity SG (°P)	Time	Duration	Notes
	Heat –up		10:43	30	
	Calandria temperature °C	105.5 .± 2			
	Kettle-full	**1.0446 (11.10)**	11:13		
	Boiling start		11:30	**60**	
	Boiling stop		12:30		
	Cast wort	**1.0494 (12.25)**			

1. Hop dosage	**85.5 g (60 min)**	**Type:** Hallertauer-Magnum	**12.7 % α-acids**
2. Hop dosage	**100 g (10 min)**	**Type:** Saaz (Slovakia)	**6.0 % α-acids**
Apparent IBU	**22**		

	Temperature (℃)	Time	Duration (min)	Notes
Whirlpool		12:30	**25**	
Casting start		12.55	40	
Casting end		13:35		
Pitching	11.0	13:05	3	

Fermentor No.	2	**Pre-cooled?**	**(yes)/not**

Yeast type	Saflager S-23
Viability (%)	92.6
Pitching quantity (kg)	2.95
Pitching rate (10^6 cells/mL)	17.73
Attenuation limit (%)	80.66

	Date	Time	SG (°P)	Temp, Set-up (℃)	Real temp. (℃)	Pressure (bar)	Yeast cells (10^6 cells/mL)	pH	Colour (EBC)
Primary fermentation	07.08.07	13:30	1.0475 (11.79)	**12.0**	11.0	0.2	17.7	5.28	14.6
	08.08.07	12:55	1.0398 (9.92)	**12.0**	11.8	0.2	39.8	4.82	
	09.08.07	11.55	1.0312 (7.86)	**12.0**	11.8	0.2	58.6	4.51	
	10.08.07	11:56	1.0275 (6.92)	**12.0**	11.8	0.2	53.4	4.42	
	11.08.07	21:00	1.0131 (3.35)	**4.0**	11.9	0.2	45.1	4.20	
	12.08.07	17:20	1.0109 (2.79)	**4.0**	6.1	0.2	38.5	4.13	
Yeast collection	13.08.07	7:30	1.0095 (2.44)	**4.0**	4.0	0.15	22.8	4.07	
Diacetyl rest	14.08.07	11:20	1.0092 (2.36)	**Cool off**	9.0	0.9	N/A	4.07	
	15.08.07	8:20	1.0091 (2.34)	**Cool off**	11.9	0.9	N/A	4.05	
Maturation	16.08.07	10:20	1.0091 (2.34)	**2.0**	2.0	1.0	N/A	4.05	11.3
	17.08.07	11:17	1.0090 (2.31)	**2.0**	2.0	1.0	N/A	4.05	
	18.08.07	14:50	1.0090 (2.31)	**2.0**	2.1	1.0	N/A	4.05	
	19.08.07	10:45	1.0090 (2.31)	**2.0**	2.1	1.0	N/A	4.05	
	20.08.07	9:20	1.0089 (2.28)	**2.0**	2.0	1.0	N/A	4.05	
	21.08.07	10:39	1.0089 (2.28)	**2.0**	2.0	0.8	N/A	4.05	
	22.08.07	9:05	1.0089 (2.28)	**2.0**	2.1	1.1	N/A	4.00	

	Date	Time	SG (°P)	Temp, Set-up (°C)	Real temp. (°C)	Pressure (bar)	Yeast cells (10^6 cells/mL)	pH	Colour (EBC)
	23.08.07	9:55	1.0089 (2.28)	**2.0**	2.1	1.1	N/A	4.00	
	24.08.07	10:30	1.0089 (2.28)	**2.0**	2.1	1.1	N/A	4.00	
	25.08.07	10:12	1.0089 (2.28)	**2.0**	2.0	1.0	N/A	4.00	
	26.08.07	3:20	1.0089 (2.28)	**2.0**	2.0	1.0	N/A	4.00	
	27.08.07	11:50	1.0089 (2.28)	**2.0**	2.1	1.0	N/A	4.00	
Filtration	28.08.07	9:00	1.0089 (2.28)	**2.0**	2.1	1.0	N/A	4.00	7.0
Conditioning Tank No:	BBT								

Beer Filtration		
	Beer stabilizers	(yes) / no
	Type of beer stabilizer	Lucilite TR Silica Gel/PVP INEOS Silicas Ltd
	Stabilizer rate (mg/L)	50
	Filtration unit	Carlson Ltd
	Number of filters	9
	Filter grade	XE400
	Porous size (µm)	0.5

Kegging			
	Keg No.	0760A	0760B
	Date	28.08.07	28.08.07
	Pressure of filling (bar)	1.0	1.0
	Volume of beer (L)	50	50
	Volume of water (L)	0	0
	Total volume (L)	50	50

Bottling					
	Keg No.	0760B	Bottle type & size	British 0.5 L	Euro 0.33 L
	Date	28.08.07	No. of bottles	24	48

BREW CONTROL SHEET

Name: Andrés Furukawa S.	**Date:** 13.08.07
Brew no. 5 (ICBD No. 0762A5)	**Target volume:** 2 hL
Beer style: CARAAROMA®	**Target gravity:** 1.04840 (12 °P)

Mill	CARAAROMA®	0.28 kg (0.8 %)
	PILSNER MALT	34.22 kg (99.2 %)
Total		34.5 kg (100%)

Brew liquor total hardness (°dH)	15.82
Strike temperature (°C)	60.2
Volume (L)	103
Flow rate (L/h)	600
Liquor: Grist ratio	3:1
Mash feed rate (kg/min)	4.5

Mashing	Process stage	Temp (°C)	Start	Duration (min)	Notes
	Mash-in	**60.2**	8:40	7	
	1. Rest	**55.1**	8:47	**10**	
	Heat-up		8:57	7	
	2. Rest	**62.1**	9:04	**60**	
	Heat-up		10:04	8	
	3. Rast	**72.2**	10:11	**20**	
	Heat-up		10:31	4	
	Mash-out	**77.8**	10:35	2	
	Iodine Test ok?	**(yes)/not**			

Lautering / Mash filtration	Process stage	Pressure (bar)	Start	Duration (min)	Notes
	Start filling	0.80	10:35	-	
	Mash filter full	0.80	10:37	2	
	Recirculation start	0.80	10:37	2	
	Start collection	0.80	10:41	4	
	Mash all-in Start pre-compression	0.60	10:53	12	
	Pre-compression end- Sparge on	0.80	10:59	6	
	End sparge-Start final compression	0.80	11:16	17	
	End collection	0.90	11:20	4	
	Total sparge liquor (hL)	1.0	**Sparge temperature (℃)**	78.0	

Mash Filter Run Off					
Time (min)	**Volume Collected (hL)**	**Run off rate (L/h)**	**Gravity SG (°P)**	**Inlet pressure (bar)**	**Outlet pressure (bar)**
0	0	410	1.0831 (20.03)	0.80	0.65
5	20	390	1.0844 (20.32)	0.79	0.62
9	40	380	1.0835 (20.12)	0.79	0.60
12	60	340	1.0821 (19.81)	0.62	0.40
19	80	320	1.0802 (19.38)	0.80	0.40
24	100	300	1.0483 (11.98)	0.80	0.36
29	120	300	1.0266 (6.72)	0.75	0.35
35	140	290	1.0114 (2.92)	0.70	0.35
40	160	310	1.0040 (1.03)	0.80	0.50
0	200	40 L brew liquor added			

Boiling		Gravity SG (°P)	Time	Duration	
	Heat –up		10:53	31	
	Calandria temperature ℃	106.0 .± 2			
	Kettle-full	**1.0470 (11.47)**	11:20		
	Boiling start		11:24	**60**	
	Boiling stop		12:24		
	Cast wort	**1.0538 (13.29)**			

1. Hop dosage	**85.5 g (60 min)**	**Type:** Hallertauer-Magnum	**12.7 % α-acids**
2. Hop dosage	**100 g (10 min)**	**Type:** Saaz (Slovakia)	**6.0 % α-acids**
Apparent IBU	**22**		

	Temperature (℃)	Time	Duration (min)	Notes
Whirlpool		12:30	**25**	
Casting start		12.55	40	
Casting end		13:35		
Pitching	11.0	13:05	3	

Fermentor No.	3	**Pre-cooled?**	**(yes)/not**

Yeast type	Saflager S-23
Viability (%)	98.3
Pitching quantity (kg)	3.24
Pitching rate (10^6 cells/mL)	15.82
Attenuation limit (%)	80.26

	Date	Time	SG (°P)	Temp, Set-up (℃)	Real temp. (℃)	Pressure (bar)	Yeast cells (10^6 cells/mL)	pH	Colour (EBC)
Primary fermentation	13.08.07	13:30	1.0478 (11.86)	**12.0**	11.7	0.2	15.8	5.22	13.9
	14.08.07	11:20	1.0401 (10.02)	**12.0**	11.8	0.2	39.8	4.65	
	15.08.07	8:20	1.0296 (7.46)	**12.0**	11.9	0.2	58.6	4.30	
	16.08.07	18:45	1.0155 (3.96)	**12.0**	11.9	0.2	53.4	4.13	
	17.08.07	11:20	1.0124 (3.17)	**4.0**	6.6	0.2	45.1	4.08	
	18.08.07	15:00	1.0111 (2.84)	**4.0**	3.9	0.15	38.5	4.05	
Yeast collection	19.08.07	10:50	1.0101 (2.59)	**4.0**	3.8	0.15	22.8	4.05	
Diacetyl rest	20.08.07	8:15	1.0094 (2.41)	**Cool off**	7.5	0.15	N/A	4.00	
	21.08.07	10:40	1.0093 (2.39)	**Cool off**	11.6	1.1	N/A	3.98	
Maturation	22.08.07	9:05	1.0092 (2.36)	**2.0**	2.0	0.8	N/A	3.96	10.4
	23.08.07	9:10	1.0091 (2.34)	**2.0**	2.0	0.8	N/A	3.96	
	24.08.07	10:30	1.0091 (2.34)	**2.0**	2.0	0.8	N/A	3.96	
	25.08.07	10:13	1.0091 (2.34)	**2.0**	2.0	0.9	N/A	3.96	
	26.08.07	3:20	1.0091 (2.34)	**2.0**	1.9	0.8	N/A	3.96	
	27.08.07	11:50	1.0091 (2.34)	**2.0**	2.2	0.8	N/A	3.96	
	28.08.07	9:00	1.0091 (2.34)	**2.0**	1.8	0.9	N/A	3.96	

	Date	Time	SG (°P)	Temp, Set-up (°C)	Real temp. (°C)	Pressure (bar)	Yeast cells (10^6 cells/mL)	pH	Colour (EBC)
	29.08.07	8:20	1.0091 (2.34)	**2.0**	1.9	0.9	N/A	3.96	
	30.08.07	21:40	1.0091 (2.34)	**2.0**	2.1	0.9	N/A	3.96	
	31.08.07	11:30	1.0091 (2.34)	**2.0**	2.0	0.9	N/A	3.96	
	03.09.07	23:10	1.0091 (2.34)	**2.0**	2.0	0.8	N/A	3.96	
Filtration	04.09.07	10:15	1.0091 (2.34)	**2.0**	1.9	0.9	N/A	3.96	7.0
Conditioning Tank No:	CT2								

Beer Filtration		
	Beer stabilizers	(yes) / no
	Type of beer stabilizer	Lucilite TR Silica Gel/PVP INEOS Silicas Ltd
	Stabilizer rate (mg/L)	50
	Filtration unit	Carlson Ltd
	Number of filters	9
	Filter grade	XE400
	Porous size (µm)	0.5

Kegging			
	Keg No.	0762A	0762B
	Date	04.09.07	04.09.07
	Pressure of filling (bar)	1.0	1.0
	Volume of beer (L)	50	50
	Volume of water (L)	0	0
	Total volume (L)	50	50

Bottling					
	Keg No.	0762B	Bottle type & size	British 0.5 L	Euro 0.33 L
	Date	13.09.07	No. of bottles	24	48

BREW CONTROL SHEET

Name: Andrés Furukawa S.	**Date:** 20.08.07
Brew no. 6 (ICBD No. 0765A6)	**Target volume:** 2 hL
Beer style: CARAFA® Type III	**Target gravity:** 1.04840 (12 °P)

Mill	CARAFA® Type III	0.18 kg (0.2 %)
	PILSNER MALT	34.32 kg (99.8 %)
Total		34.5 kg (100%)

Brew liquor total hardness (°dH)	13.45
Strike temperature (°C)	58.7
Volume (L)	103
Flow rate (L/h)	600
Liquor: Grist ratio	3:1
Mash feed rate (kg/min)	4.5

Mashing	Process stage	Temp (°C)	Start	Duration (min)	Notes
	Mash-in	**58.7**	8:30	5	
	1. Rest	**54.9**	8:35	**10**	
	Heat-up		8:45	8	
	2. Rest	**62.2**	8:53	**60**	
	Heat-up		9:53	5	
	3. Rast	**72.0**	9:58	**20**	
	Heat-up		10:18	6	
	Mash-out	**77.9**	10:24	2	
	Iodine Test ok?	**(yes)/not**			

Lautering / Mash filtration	Process stage	Pressure (bar)	Start	Duration (min)	Notes
	Start filling	0.80	10:24	-	
	Mash filter full	0.80	10:26	2	
	Recirculation start	0.80	10:26	2	
	Start collection	0.83	10:30	4	
	Mash all-in Start pre-compression	0.60	10:42	12	
	Pre-compression end- Sparge on	0.80	10:48	6	
	End sparge-Start final compression	0.80	11:09	21	
	End collection	0.80	11:15	6	
	Total sparge liquor (hL)	1.0	**Sparge temperature (℃)**	77.9	

Mash Filter Run Off					
Time (min)	**Volume Collected (hL)**	**Run off rate (L/h)**	**Gravity SG (°P)**	**Inlet pressure (bar)**	**Outlet pressure (bar)**
0	0	440	1.0841 (20.25)	0.83	0.68
4	20	400	1.0858 (20.64)	0.80	0.63
9	40	390	1.0845 (20.34)	0.80	0.60
13	60	325	1.0824 (19.87)	0.62	0.40
18	80	220	1.0809 (19.53)	0.55	0.25
25	100	250	1.0512 (12.67)	0.80	0.22
32	120	245	1.0275 (6.95)	0.82	0.22
39	140	235	1.0107 (2.74)	0.82	0.22
45	160	200	1.0033 (0.85)	0.81	0.20
0	200	40 L brew liquor added			

Boiling		Gravity SG (°P)	Time	Duration	Notes
	Heat –up		10:42	38	
	Calandria temperature ℃	104.6 .± 2			
	Kettle-full	**1.0480 (11.91)**	11:15		
	Boiling start		11:16	**60**	
	Boiling stop		12:16		
	Cast wort	**1.0518 (12.81)**			

1. Hop dosage	**85.5 g (60 min)**	**Type:** Hallertauer-Magnum	**12.7 % α-acids**
2. Hop dosage	**100 g (10 min)**	**Type:** Saaz (Slovakia)	**6.0 % α-acids**
Apparent IBU	**22**		

	Temperature (℃)	Time	Duration (min)	Notes
Whirlpool		12:16	29	
Casting start		12.45	40	
Casting end		13:25		
Pitching	10.8	12:55	3	

Fermentor No.	4	**Pre-cooled?**	**(yes)/not**

Yeast type	Saflager S-23
Viability (%)	89.4
Pitching quantity (kg)	3.37
Pitching rate (10^6 cells/mL)	16.15
Attenuation limit (%)	81.84

	Date	Time	SG (°P)	Temp, Set-up (℃)	Real temp. (℃)	Pressure (bar)	Yeast cells (10^6 cells/mL)	pH	Colour (EBC)
Primary fermentation	20.08.07	13:25	1.0491 (12.17)	**12.0**	10.8	0.2	16.1	5.35	15.7
	21.08.07	10:50	1.0417 (10.40)	**12.0**	11.8	0.2	33.4	4.89	
	22.08.07	8:40	1.0312 (7.89)	**12.0**	11.6	0.2	58.8	4.31	
	23.08.07	21:00	1.0160 (4.08)	**12.0**	11.9	0.2	85.2	4.15	
	24.08.07	9:51	1.0137 (3.50)	**4.0**	5.0	0.2	78.1	4.10	
Yeast collection	25.08.07	10:22	1.0117 (3.00)	**4.0**	3.9	0.2	58.5	4.05	
Diacetyl rest	26.08.07	3:22	1.0109 (2.79)	**Cool off**	5.6	0.4	N/A	4.00	
	27.08.07	11:50	1.0103 (2.64)	**Cool off**	10.7	0.7	N/A	4.00	
	28.08.07	9:00	1.0098 (2.51)	**Cool off**	13.2	1.0	N/A	4.00	
Maturation	29.08.07	9:05	1.0093 (2.39)	**2.0**	2.0	1.0	N/A	4.00	12.2
	30.08.07	2:06	1.0089 (2.28)	**2.0**	2.0	1.0	N/A	3.99	
	31.08.07	11:30	1.0087 (2.23)	**2.0**	1.7	1.0	N/A	3.99	
	03.08.07	23:15	1.0086 (2.21)	**2.0**	1.9	1.0	N/A	3.98	
	04.08.07	20:15	1.0086 (2.21)	**2.0**	1.8	1.0	N/A	3.98	
	05.08.07	7:44	1.0086 (2.21)	**2.0**	2.3	1.0	N/A	3.98	
	06.08.07	9:00	1.0086 (2.21)	**2.0**	2.0	1.0	N/A	3.98	

	Date	Time	SG (°P)	Temp, Set-up (°C)	Real temp. (°C)	Pressure (bar)	Yeast cells (10^6 cells/mL)	pH	Colour (EBC)
	07.08.07	7:17	1.0086 (2.21)	**2.0**	1.7	1.0	N/A	3.98	
	08.09.07	10:00	1.0086 (2.21)	**2.0**	1.8	1.0	N/A	3.98	
	09.09.07	9:35	1.0086 (2.21)	**2.0**	1.8	1.0	N/A	3.98	
	10.09.07	7:40	1.0086 (2.21)	**2.0**	1.8	1.0	N/A	3.98	
Filtration	11.09.07	7:07	1.0086 (2.21)	**2.0**	1.9	1.0	N/A	3.98	7.7
Conditioning Tank No:	CT1								

Beer Filtration		
	Beer stabilizers	(yes) / no
	Type of beer stabilizer	Lucilite TR Silica Gel/PVP INEOS Silicas Ltd
	Stabilizer rate (mg/L)	50
	Filtration unit	Carlson Ltd
	Number of filters	9
	Filter grade	XE400
	Porous size (µm)	0.5

Kegging			
	Keg No.	0765A	0765B
	Date	12.09.07	12.09.07
	Pressure of filling (bar)	1.0	1.0
	Volume of beer (L)	50	50
	Volume of water (L)	0	0
	Total volume (L)	50	50

Bottling					
	Keg No.	0765B	Bottle type & size	British 0.5 L	Euro 0.33 L
	Date	13.09.07	No. of bottles	24	48

BREW CONTROL SHEET

Name: Andrés Furukawa S.	**Date:** 22.08.07
Brew no. 7 (ICBD No. 0766A7)	**Target volume:** 2 hL
Beer style: CARAFA® SPECIAL Type III	**Target gravity:** 1.04840 (12 °P)

Mill	CARAFA® SPECIAL Type III	0.18 kg (0.2 %)
	PILSNER MALT	34.32 kg (99.8 %)
Total		34.5 kg (100%)

Brew liquor total hardness (°dH)	12.98
Strike temperature (°C)	57.8
Volume (L)	103
Flow rate (L/h)	600
Liquor: Grist ratio	3:1
Mash feed rate (kg/min)	4.5

Mashing	Process stage	Temp (°C)	Start	Duration (min)	Notes
	Mash-in	**57.8**	8:42	5	
	1. Rest	**54.8**	8:47	**10**	
	Heat-up		8:57	7	
	2. Rest	**62.1**	9:04	**60**	
	Heat-up		10:04	6	
	3. Rast	**71.9**	10:11	**20**	
	Heat-up		10:31	5	
	Mash-out	**77.9**	10:36	2	
	Iodine Test ok?	**(yes)/not**			

Lautering / Mash filtration	Process stage	Pressure (bar)	Start	Duration (min)	Notes
	Start filling	0.80	10:36	-	
	Mash filter full	0.80	10:38	2	
	Recirculation start	0.80	10:38	2	
	Start collection	0.83	10:41	3	
	Mash all-in Start pre-compression	0.60	10:54	12	
	Pre-compression end- Sparge on	0.80	11:00	6	
	End sparge-Start final compression	0.80	11:20	20	
	End collection	0.80	11:30	10	
	Total sparge liquor (hL)	1.0	**Sparge temperature (℃)**	78.1	

Mash Filter Run Off					
Time (min)	**Volume Collected (L)**	**Run off rate (L/h)**	**Gravity SG (°P)**	**Inlet pressure (bar)**	**Outlet pressure (bar)**
0	0	425	1.0839 (20.21)	0.85	0.68
4	20	415	1.0858 (20.64)	0.85	0.66
9	40	395	1.0851 (20.48)	0.84	0.62
13	60	330	1.0841 (20.25)	0.65	0.40
18	80	200	1.0834 (20.10)	0.56	0.15
25	100	250	1.0484 (12.01)	0.82	0.28
32	120	260	1.0298 (7.51)	0.80	0.25
39	140	240	1.0149 (3.80)	0.80	0.25
45	160	240	1.0043 (1.11)	0.80	0.24
0	200	40 L brew liquor added			

Boiling		Gravity SG (°P)	Time	Duration	
	Heat –up		10:54	38	
	Calandria temperature ℃	105.2 .± 2			
	Kettle-full	**1.0493 (12.22)**	11:30		
	Boiling start		11:35	**60**	
	Boiling stop		12:35		
	Cast wort	**1.0536 (13.24)**			

1. Hop dosage	**85.5 g (60 min)**	**Type:** Hallertauer-Magnum	**12.7 % α-acids**
2. Hop dosage	**100 g (10 min)**	**Type:** Saaz (Slovakia)	**6.0 % α-acids**
Apparent IBU	**22**		

	Temperature (℃)	Time	Duration (min)	Notes
Whirlpool		12:35	25	
Casting start		13.00	40	
Casting end		13:40		
Pitching	11.2	13:10	3	

Fermentor No.	3	**Pre-cooled?**	**(yes)/not**

Yeast type	Saflager S-23
Viability (%)	89.4
Pitching quantity (kg)	3.72
Pitching rate (10^6 cells/mL)	18.21
Attenuation limit (%)	82.25

	Date	Time	SG (°P)	Temp, Set-up (℃)	Real temp. (℃)	Pressure (bar)	Yeast cells (10^6 cells/mL)	pH	Colour (EBC)
Primary fermentation	22.08.07	13:45	1.0491 (12.17)	**12.0**	11.2	0.2	18.2	5.30	14.8
	23.08.07	10:03	1.0417 (10.40)	**12.0**	11.9	0.2	33.5	4.72	
	24.08.07	10:33	1.0332 (8.34)	**12.0**	11.6	0.2	45.4	4.29	
	25.08.07	19:40	1.0195 (4.96)	**12.0**	11.9	0.2	78.6	4.11	
	26.08.07	4:30	1.0165 (4.21)	**12.0**	11.9	0.2	75.7	4.10	
	27.08.07	11:50	1.0124 (3.17)	**4.0**	4.1	0.2	61.8	4.08	
Yeast collection	28.08.07	9:00	1.0114 (2.92)	**4.0**	4.1	0.2	45.2	4.03	
Diacetyl rest	29.08.07	8:20	1.0105 (2.69)	**Cool off**	8.6	0.5	N/A	4.01	
	30.08.07	4:20	1.0096 (2.46)	**Cool off**	11.4	1.0	N/A	3.97	
Maturation	31.08.07	11:30	1.0093 (2.39)	**2.0**	2.0	1.0	N/A	3.97	11.4
	03.08.07	23:10	1.0090 (2.31)	**2.0**	1.9	1.0	N/A	3.97	
	04.08.07	20:25	1.0089 (2.28)	**2.0**	2.0	1.0	N/A	3.97	
	05.08.07	7:45	1.0087 (2.23)	**2.0**	2.0	1.0	N/A	3.97	
	06.08.07	9:00	1.0085 (2.18)	**2.0**	2.0	1.0	N/A	3.97	
	07.08.07	7:18	1.0084 (2.16)	**2.0**	2.0	1.0	N/A	3.97	
	08.08.07	10:00	1.0084 (2.16)	**2.0**	2.0	1.0	N/A	3.97	

	Date	Time	SG (°P)	Temp, Set-up (°C)	Real temp. (°C)	Pressure (bar)	Yeast cells (10^6 cells/mL)	pH	Colour (EBC)
	09.08.07	7.40	1.0084 (2.16)	**2.0**	2.0	1.0	N/A	3.97	
	10.09.07	7:40	1.0084 (2.16)	**2.0**	2.0	1.0	N/A	3.97	
	11.09.07	7:08	1.0084 (2.16)	**2.0**	2.0	1.0	N/A	3.97	
Filtration	12.09.07	7:35	1.0084 (2.16)	**2.0**	2.0	1.0	N/A	3.97	7.2
Conditioning Tank No:	BBT								

Beer Filtration		
	Beer stabilizers	(yes) / no
	Type of beer stabilizer	Lucilite TR Silica Gel/PVP INEOS Silicas Ltd
	Stabilizer rate (mg/L)	50
	Filtration unit	Carlson Ltd
	Number of filters	9
	Filter grade	XE400
	Porous size (μm)	0.5

Kegging			
	Keg No.	0766A	0766B
	Date	12.09.07	12.09.07
	Pressure of filling (bar)	1.0	1.0
	Volume of beer (L)	50	50
	Volume of water (L)	0	0
	Total volume (L)	50	50

Bottling					
	Keg No.	0766B	Bottle type & size	British 0.5 L	Euro 0.33 L
	Date	13.09.07	No. of bottles	24	48

BREW CONTROL SHEET

Name: Andrés Furukawa S.	**Date:** 29.08.07
Brew no. 8 (ICBD No. 0768A8)	**Target volume:** 2 hL
Beer style: ROASTED BARLEY	**Target gravity:** 1.04840 (12 °P)

Mill	ROASTED BARLEY	0.18 kg (0.2 %)
	PILSNER MALT	34.32 kg (99.8 %)
Total		34.5 kg (100%)

Brew liquor total hardness (°dH)	11.1
Strike temperature (°C)	58.2
Volume (L)	103
Flow rate (L/h)	600
Liquor: Grist ratio	3:1
Mash feed rate (kg/min)	4.5

Mashing	Process stage	Temp (°C)	Start	Duration (min)	Notes
	Mash-in	**57.8**	7:59	10	
	1. Rest	**55.4**	8:09	**10**	
	Heat-up		8:19	5	
	2. Rest	**62.2**	8:24	**60**	
	Heat-up		9:24	6	
	3. Rast	**72.4**	9:30	**20**	
	Heat-up		9:50	4	
	Mash-out	**77.7**	9:54	2	
	Iodine Test ok?	**(yes)/not**			

Lautering / Mash filtration	Process stage	Pressure (bar)	Start	Duration (min)	Notes
	Start filling	0.85	9:54	-	
	Mash filter full	0.85	9:56	2	
	Recirculation start	0.85	9:56	2	
	Start collection	0.85	10:00	4	
	Mash all-in Start pre-compression	0.60	10:14	4	
	Pre-compression end- Sparge on	0.80	10:20	6	
	End sparge-Start final compression	0.80	10:34	14	
	End collection	0.90	10:39	5	
	Total sparge liquor (hL)	1.0	**Sparge temperature (℃)**	78.0	

Mash Filter Run Off					
Time (min)	**Volume Collected (L)**	**Run off rate (L/h)**	**Gravity SG (°P)**	**Inlet pressure (bar)**	**Outlet pressure (bar)**
0	0	425	1.0825 (19.90)	0.85	0.68
4	20	415	1.0847 (20.39)	0.85	0.67
9	40	415	1.0840 (20.23)	0.83	0.64
14	60	330	1.0820 (19.78)	0.68	0.46
18	80	295	1.0800 (19.33)	0.60	0.31
25	100	315	1.0478 (11.86)	0.80	0.33
29	120	315	1.0302 (7.61)	0.80	0.33
34	140	305	1.0160 (4.08)	0.78	0.34
39	160	300	1.0062 (1.60)	0.80	0.33
0	200	40 L brew liquor added			

Boiling		Gravity SG (°P)	Time	Duration	Notes
	Heat –up		10:14	33	
	Calandria temperature ℃	106.3 .± 2			
	Kettle-full	**1.0465 (11.55)**	10:39		
	Boiling start		10:47	**60**	
	Boiling stop		11:47		
	Cast wort	**1.0524 (12.96)**			

1. Hop dosage	**85.5 g (60 min)**	**Type:** Hallertauer-Magnum	**12.7 % α-acids**
2. Hop dosage	**100 g (10 min)**	**Type:** Saaz (Slovakia)	**6.0 % α-acids**
Apparent IBU	**22**		

	Temperature (℃)	Time	Duration (min)	Notes
Whirlpool		11:47	25	
Casting start		12:12	33	
Casting end		12:45		
Pitching	11.6	12:22	3	

Fermentor No.	1	**Pre-cooled?**	**(yes)/not**

Yeast type	Saflager S-23
Viability (%)	88.9
Pitching quantity (kg)	3.72
Pitching rate (10^6 cells/mL)	18.12
Attenuation limit (%)	81.15

	Date	Time	SG (°P)	Temp, Set-up (℃)	Real temp. (℃)	Pressure (bar)	Yeast cells (10^6 cells/mL)	pH	Colour (EBC)
Primary fermentation	29.08.07	12:45	1.0484 (12.1)	**12.0**	11.6	0.15	18.1	5.12	13.6
	30.08.07	21:50	1.0458 (11.39)	**12.0**	11.8	0.1	28.1	4.81	
	31.08.07	11:30	1.0302 (7.61)	**12.0**	11.8	0.1	36.6	4.22	
	03.09.07	23:15	1.0228 (5.78)	**12.0**	11.5	0.1	42.7	4.18	
	04.08.07	20:15	1.0175 (4.46)	**12.0**	12.0	0.1	37.4	4.13	
	05.08.07	7:45	1.0154 (3.93)	**4.0**	8.0	0.1	26.2	4.11	
Yeast collection	06.08.07	9:00	1.0142 (3.63)	**4.0**	3.9	0.1	22.2	4.08	
Diacetyl rest	07.08.07	11:32	1.0125 (3.20)	**Cool off**	7.9	0.5	N/A	4.01	
	08.08.07	7:15	1.0104 (2.67)	**Cool off**	12.2	1.0	N/A	4.01	
Maturation	09.08.07	10:00	1.0098 (2.51)	**2.0**	1.6	1.1	N/A	4.01	10.5
	10.08.07	7:40	1.0098 (2.51)	**2.0**	1.6	1.0	N/A	4.01	
	11.08.07	7:05	1.0095 (2.44)	**2.0**	1.9	0.9	N/A	4.01	
	12.08.07	7:35	1.0092 (2.36)	**2.0**	1.8	0.9	N/A	4.01	
	13.08.07	17:25	1.0089 (2.28)	**2.0**	1.9	1.0	N/A	4.01	
	14.08.07	9:02	1.0089 (2.28)	**2.0**	2.0	1.0	N/A	4.01	
	15.09.07	9:19	1.0089 (2.28)	**2.0**	1.8	1.0	N/A	4.01	

	Date	Time	SG (°P)	Temp, Set-up (°C)	Real temp. (°C)	Pressure (bar)	Yeast cells (10^6 cells/mL)	pH	Colour (EBC)
	16.09.07	9:42	1.0089 (2.28)	**2.0**	1.9	1.1	N/A	4.01	
	17.09.07	9:11	1.0089 (2.28)	**2.0**	1.8	1.1	N/A	4.01	
	18.09.07	7:15	1.0089 (2.28)	**2.0**	1.8	1.1	N/A	4.01	
	19.09.07	9:15	1.0089 (2.28)	**2.0**	1.8	1.1	N/A	4.01	
	20.09.07	9:06	1.0089 (2.28)	**2.0**	1.8	1.1	N/A	4.01	
Filtration	21.09.07	8:30	1.0089 (2.28)	**2.0**	1.8	1.2	N/A	4.01	7.1
Conditioning Tank No:	CT2								

Beer Filtration		
	Beer stabilizers	(yes) / no
	Type of beer stabilizer	Lucilite TR Silica Gel/PVP INEOS Silicas Ltd
	Stabilizer rate (mg/L)	50
	Filtration unit	Carlson Ltd
	Number of filters	9
	Filter grade	XE400
	Porous size (μm)	0.5

Kegging			
	Keg No.	0768A	0768B
	Date	21.09.07	21.09.07
	Pressure of filling (bar)	1.0	1.0
	Volume of beer (L)	50	50
	Volume of water (L)	0	0
	Total volume (L)	50	50

Bottling					
	Keg No.	0768B	Bottle type & size	British 0.5 L	Euro 0.33 L
	Date	26.09.07	No. of bottles	24	48

BREW CONTROL SHEET

Name: Andrés Furukawa S.	**Date:** 05.09.07
Brew no. 9 (ICBD No. 0770A9)	**Target volume:** 2 hL
Beer style: SINAMAR®	**Target gravity:** 1.04840 (12 °P)

Mill	SINAMAR®	0.085 kg (0.245 %)
	PILSNER MALT	34.5 kg (99.755 %)
Total		34.585 kg (100%)

Brew liquor total hardness (°dH)	12.79
Strike temperature (°C)	57.2
Volume (L)	103
Flow rate (L/h)	600
Liquor: Grist ratio	3:1
Mash feed rate (kg/min)	4.5

Mashing	Process stage	Temp (°C)	Start	Duration (min)	Notes
	Mash-in	**57.2**	8:18	6	
	1. Rest	**55.6**	8:24	**10**	
	Heat-up		8:34	6	
	2. Rest	**62.1**	8:40	**60**	
	Heat-up		9:40	8	
	3. Rast	**71.8**	9:48	**20**	
	Heat-up		10:08	5	
	Mash-out	**78.1**	10:13	2	
	Iodine Test ok?	**(yes)/not**			

Lautering / Mash filtration	Process stage	Pressure (bar)	Start	Duration (min)	Notes
	Start filling	0.85	9:54	-	
	Mash filter full	0.85	9:56	2	
	Recirculation start	0.85	9:56	2	
	Start collection	0.85	10:00	4	
	Mash all-in Start pre-compression	0.60	10:14	4	
	Pre-compression end- Sparge on	0.80	10:20	6	
	End sparge-Start final compression	0.80	10:34	14	
	End collection	0.90	10:39	5	
	Total sparge liquor (hL)	1.0	**Sparge temperature (°C)**	78.0	

Mash Filter Run Off					
Time (min)	**Volume Collected (L)**	**Run off rate (L/h)**	**Gravity SG (°P)**	**Inlet pressure (bar)**	**Outlet pressure (bar)**
0	0	430	1.0831 (20.3)	0.85	0.66
5	20	410	1.0848 (20.41)	0.85	0.65
9	40	410	1.0846 (20.37)	0.85	0.62
13	60	350	1.0831 (20.01)	0.68	0.43
18	80	215	1.0814 (19.65)	0.56	0.17
26	100	240	1.0523 (12.93)	0.83	0.23
32	120	240	1.0274 (6.92)	0.83	0.23
39	140	240	1.0102 (2.62)	0.82	0.21
45	160	255	1.0034 (0.88)	0.88	0.25
0	200	40 L brew liquor added			

Boiling		Gravity SG (°P)	Time	Duration	Notes
	Heat –up		10:20	19	
	Calandria temperature °C	105.5 ± 2			
	Kettle-full	**1.0484 (12.01)**	10:39		
	Boiling start		11:03	**60**	
	Boiling stop		12:03		
	Cast wort	**1.0537 (13.26)**			

1. Hop dosage	**85.5 g (60 min)**	**Type:** Hallertauer-Magnum	**12.7 % α-acids**
2. Hop dosage	**100 g (10 min)**	**Type:** Saaz (Slovakia)	**6.0 % α-acids**
Apparent IBU	**22**		

	Temperature (℃)	Time	Duration (min)	Notes
Whirlpool		12:03	25	
Casting start		12:28	42	
Casting end		13:10		
Pitching	11.3	12:13	3	

Fermentor No.	2	**Pre-cooled?**	**(yes)/not**

Yeast type	Saflager S-23
Viability (%)	91.5
Pitching quantity (kg)	3.25
Pitching rate (10^6 cells/mL)	16.47
Attenuation limit (%)	80.27

	Date	Time	SG (°P)	Temp, Set-up (℃)	Real temp. (℃)	Pressure (bar)	Yeast cells (10^6 cells/mL)	pH	Colour (EBC)
Primary fermentation	05.08.07	13:10	1.0493 (12.22)	**12.0**	11.3	0.2	16.4	5.34	15.3
	06.08.07	9:00	1.0465 (11.55)	**12.0**	11.8	0.2	28.4	4.92	
	07.08.07	11:32	1.0383 (9.58)	**12.0**	11.9	0.2	39.9	4.53	
	08.09.07	7:20	1.0325 (8.17)	**12.0**	11.8	0.2	52.8	4.45	
	09.08.07	10:00	1.0266 (6.72)	**12.0**	11.9	0.2	68.3	4.32	
	10.08.07	7:40	1.0223 (5.66)	**12.0**	11.9	0.2	62.4	4.25	
	11.08.07	7:08	1.0208 (5.28)	**12.0**	11.8	0.2	54.2	4.25	
	12.08.07	7:35	1.0165 (4.21)	**4.0**	11.8	0.2	44.6	4.25	
	13.08.07	17:28	1.0147 (3.75)	**4.0**	3.8	0.2	33.6	4.25	
Yeast collection	14.08.07	9:00	1.0139 (3.55)	**4.0**	3.8	0.2	18.5	4.25	
Diacetyl rest	15.08.07	9:20	1.0128 (3.27)	**Cool off**	8.4	0.4	N/A	4.25	
	16.08.07	9:43	1.0115 (2.95)	**Cool off**	11.0	0.8	N/A	4.25	
	17.08.07	9:11	1.0103 (2.64)	**Cool off**	12.6	1.0	N/A	4.25	
Maturation	18.08.07	7:15	1.0097 (2.49)	**2.0**	2.4	0.9	N/A	4.25	11.4
	19.08.07	9:15	1.0094 (2.41)	**2.0**	2.0	0.9	N/A	4.25	
	20.09.07	9:07	1.0094 (2.41)	**2.0**	2.0	0.9	N/A	4.25	

	Date	Time	SG (°P)	Temp, Set-up (°C)	Real temp. (°C)	Pressure (bar)	Yeast cells (10^6 cells/mL)	pH	Colour (EBC)
	21.09.07	8:30	1.0094 (2.41)	**2.0**	2.0	0.9	N/A	4.25	
	22.09.07	10:30	1.0094 (2.41)	**2.0**	2.0	0.9	N/A	4.25	
	23.09.07	9:20	1.0094 (2.41)	**2.0**	2.0	0.9	N/A	4.25	
	24.09.07	7:56	1.0094 (2.41)	**2.0**	2.0	0.9	N/A	4.25	
	25.09.07	8:00	1.0094 (2.41)	**2.0**	2.0	0.9	N/A	4.25	
	26.09.07	9:30	1.0094 (2.41)	**2.0**	2.0	0.9	N/A	4.25	
	27.09.07	23:05	1.0094 (2.41)	**2.0**	2.0	0.9	N/A	4.25	
	28.09.07	10:28	1.0094 (2.41)	**2.0**	2.0	0.9	N/A	4.25	
	29.09.07	15:50	1.0094 (2.41)	**2.0**	2.0	1.0	N/A	4.25	
	30.09.07	13:53	1.0094 (2.41)	**2.0**	2.0	1.0	N/A	4.25	
	01.10.07	9:38	1.0094 (2.41)	**2.0**	2.0	1.0	N/A	4.25	
	02.10.07	18:50	1.0094 (2.41)	**2.0**	2.0	1.0	N/A	4.25	
Filtration	03.10.07	10:33	1.0094 (2.41)	**2.0**	2.0	1.0	N/A	4.25	7.1
Conditioning Tank No:	BBT								

Beer Filtration		
	Beer stabilizers	(yes) / no
	Type of beer stabilizer	Lucilite TR Silica Gel/PVP INEOS Silicas Ltd
	Stabilizer rate (mg/L)	50
	Filtration unit	Carlson Ltd
	Number of filters	9
	Filter grade	XE400
	Porous size (µm)	0.5

Kegging			
	Keg No.	0770A	0770B
	Date	03.10.07	03.10.07
	Pressure of filling (bar)	1.0	1.0
	Volume of beer (L)	50	50
	Volume of water (L)	0	0
	Total volume (L)	50	50

Bottling					
	Keg No.	0770B	Bottle type & size	British 0.5 L	Euro 0.33 L
	Date	06.10.07	No. of bottles	24	48

BREW CONTROL SHEET

Name: Andrés Furukawa S.	**Date:** 29.08.07
Brew no. 10 (ICBD No. 0771A10)	**Target volume:** 2 hL
Beer style: CARAMEL #301	**Target gravity:** 1.04840 (12 °P)

Mill	CARAMEL #301	0.020 kg (0.058 %)
	PILSNER MALT	34.5 kg (99.94 %)
Total		34.52 kg (100%)

Brew liquor total hardness (°dH)	13.42
Strike temperature (°C)	57.0
Volume (L)	103
Flow rate (L/h)	600
Liquor: Grist ratio	3:1
Mash feed rate (kg/min)	4.5

Mashing	Process stage	Temp (°C)	Start	Duration (min)	Notes
	Mash-in	**57.0**	8:18	7	
	1. Rest	**54.8**	8:25	**10**	
	Heat-up		8:35	7	
	2. Rest	**62.0**	8:42	**60**	
	Heat-up		9:42	6	
	3. Rast	**72.0**	9:48	**20**	
	Heat-up		10:08	5	
	Mash-out	**78.1**	10:13	2	
	Iodine Test ok?	**(yes)/not**			

Lautering / Mash filtration	Process stage	Pressure (bar)	Start	Duration (min)	Notes
	Start filling	0.85	10:13	-	
	Mash filter full	0.85	10:15	2	
	Recirculation start	0.85	10:15	2	
	Start collection	0.85	10:18	3	
	Mash all-in Start pre-compression	0.60	10:30	12	
	Pre-compression end- Sparge on	0.80	10:36	6	
	End sparge-Start final compression	0.80	10:50	14	
	End collection	0.80	10:53	3	
	Total sparge liquor (hL)	1.0	**Sparge temperature (℃)**	78.1	

Mash Filter Run Off					
Time (min)	**Volume Collected (L)**	**Run off rate (L/h)**	**Gravity SG (°P)**	**Inlet pressure (bar)**	**Outlet pressure (bar)**
0	0	420	1.0839 (20.21)	0.84	0.66
5	20	400	1.0856 (20.59)	0.84	0.65
9	40	410	1.0852 (20.50)	0.84	0.64
12	60	345	1.0840 (20.23)	0.64	0.44
18	80	370	1.0819 (19.76)	0.83	0.55
23	100	370	1.0515 (12.74)	0.82	0.52
27	120	370	1.0272 (6.87)	0.80	0.53
32	140	370	1.0130 (3.33)	0.82	0.55
35	160	390	1.0048 (1.24)	0.83	0.55
0	200	40 L brew liquor added			

Boiling		Gravity SG (°P)	Time	Duration	Notes
	Heat –up		10:30	33	
	Calandria temperature ℃	106.3 ± 2			
	Kettle-full	**1.0478 (11.86)**	10:53		
	Boiling start		11:03	**60**	
	Boiling stop		12:03		
	Cast wort	**1.0514 (12.72)**			

1. Hop dosage	**85.5 g (60 min)**	**Type:** Hallertauer-Magnum	**12.7 % α-acids**
2. Hop dosage	**100 g (10 min)**	**Type:** Saaz (Slovakia)	**6.0 % α-acids**
Apparent IBU	**22**		

	Temperature (°C)	Time	Duration (min)	Notes
Whirlpool		12:03	25	
Casting start		12:28	39	
Casting end		13:07		
Pitching	11.2	12:38	3	

Fermentor No.	3	**Pre-cooled?**	**(yes)/not**

Yeast type	Saflager S-23
Viability (%)	92.5
Pitching quantity (kg)	3.82
Pitching rate (10^6 cells/mL)	15.33
Attenuation limit (%)	80.35

	Date	Time	SG (°P)	Temp, Set-up (°C)	Real temp. (°C)	Pressure (bar)	Yeast cells (10^6 cells/mL)	pH	Colour (EBC)
Primary fermentation	06.09.07	13:07	1.0495 (12.27)	**12.0**	11.2	0.2	22.0	5.20	14.8
	07.09.07	11:35	1.0434 (10.81)	**12.0**	11.9	0.2	28.1	5.05	
	08.09.07	7:20	1.0401 (10.02)	**12.0**	11.9	0.2	36.6	4.66	
	09.09.07	10:00	1.0353 (8.86)	**12.0**	11.8	0.2	42.7	4.41	
	10.09.07	7:40	1.0286 (7.22)	**12.0**	11.9	0.2	58.4	4.35	
	11.09.07	7:08	1.0238 (6.03)	**12.0**	11.9	0.2	51.3	4.25	
	12.09.07	7:35	1.0202 (5.13)	**12.0**	11.9	0.2	45.6	4.21	
	13.09.07	1730	1.0168 (4.28)	**4.0**	11.7	0.2	28.8	4.19	
	14.09.07	9:00	1.0163 (4.16)	**4.0**	6.6	0.2	23.9	4.16	
	15.09.07	9:17	1.0157 (4.01)	**4.0**	3.8	0.2	18.3	4.16	
Yeast collection	16.09.07	9:45	1.0151 (3.86)	**4.0**	3.9	0.4	N/A	4.16	
Diacetyl rest	17.09.07	9:12	1.0145 (3.70)	**Cool off**	8.1	0.85	N/A	4.16	
	18.09.07	7:15	1.0137 (3.50)	**Cool off**	10.5	1.1	N/A	4.16	
	19.09.07	9:17	1.0119 (3.05)	**Cool off**	12.8	1.1	N/A	4.16	
Maturation	20.09.07	9:07	1.0112 (2.87)	**2.0**	2.0	1.1	N/A	4.16	10.9
	21.09.07	8:35	1.0108 (2.77)	**2.0**	2.0	1.1	N/A	4.16	

	Date	Time	SG (°P)	Temp, Set-up (°C)	Real temp. (°C)	Pressure (bar)	Yeast cells (10^6 cells/mL)	pH	Colour (EBC)
	22.09.07	10:30	1.0106 (2.72)	**2.0**	1.9	1.1	N/A	4.16	
	23.09.07	9:20	1.0103 (2.64)	**2.0**	2.0	1.1	N/A	4.16	
	24.09.07	7:56	1.0100 (2.57)	**2.0**	2.0	1.1	N/A	4.16	
	25.09.07	8:00	1.0096 (2.46)	**2.0**	2.2	1.1	N/A	4.16	
	26.09.07	13:08	1.0094 (2.41)	**2.0**	1.7	0.8	N/A	4.16	
	27.09.07	23:10	1.0094 (2.41)	**2.0**	1.7	1.0	N/A	4.16	
	28.09.07	10:30	1.0094 (2.41)	**2.0**	1.8	1.0	N/A	4.16	
	29.09.07	15:56	1.0094 (2.41)	**2.0**	2.1	1.2	N/A	4.16	
	30.09.07	13:50	1.0094 (2.41)	**2.0**	2.3	1.2	N/A	4.16	
	01.10.07	9:40	1.0094 (2.41)	**2.0**	1.8	1.2	N/A	4.16	
	02.10.07	18:55	1.0094 (2.41)	**2.0**	2.3	1.2	N/A	4.16	
Filtration	03.10.07	10:35	1.0094 (2.41)	**2.0**	2.9	1.2	N/A	4.16	6.7
Tank No:	CT1								

Beer Filtration		
	Beer stabilizers	(yes) / no
	Type of beer stabilizer	Lucilite TR Silica Gel/PVP INEOS Silicas Ltd
	Stabilizer rate (mg/L)	50
	Filtration unit	Carlson Ltd
	Number of filters	9
	Filter grade	XE400
	Porous size (μm)	0.5

Kegging			
	Keg No.	0771A	0771B
	Date	03.10.07	03.10.07
	Pressure of filling (bar)	1.0	1.0
	Volume of beer (L)	50	50
	Volume of water (L)	0	0
	Total volume (L)	50	50

Bottling					
	Keg No.	0771B	Bottle type & size	British 0.5 L	Euro 0.33 L
	Date	06.10.07	No. of bottles	24	48

BREW CONTROL SHEET

Name: Andrés Furukawa S.	**Date:** 18.09.07
Brew no. 11 (ICBD No. 0774A11)	**Target volume:** 2 hL
Beer style: PILSNER MALT	**Target gravity:** 1.04840 (12 °P)

Mill	PILSNER MALT	34.5 kg (100 %)
Total		34.5 kg (100 %)

Brew liquor total hardness (°dH)	15.45
Strike temperature (°C)	57.0
Volume (L)	103
Flow rate (L/h)	600
Liquor: Grist ratio	3:1
Mash feed rate (kg/min)	4.5

Mashing	Process stage	Temp (°C)	Start	Duration (min)	Notes
	Mash-in	**57.0**	8:23	9	
	1. Rest	**55.5**	8:32	**10**	
	Heat-up		8:42	8	
	2. Rest	**62.1**	8:50	**60**	
	Heat-up		9:50	11	
	3. Rast	**71.8**	10.01	**20**	
	Heat-up		10.21	7	
	Mash-out	**78.1**	10.28	2	
	Iodine Test ok?	**(yes)/not**			

Lautering / Mash filtration	Process stage	Pressure (bar)	Start	Duration (min)	Notes
	Start filling	0.85	10.28	-	
	Mash filter full	0.85	10.30	2	
	Recirculation start	0.85	10.30	2	
	Start collection	0.85	10.35	5	
	Mash all-in Start pre-compression	0.60	10.49	14	
	Pre-compression end- Sparge on	0.80	10.55	6	
	End sparge-Start final compression	0.80	11.20	25	
	End collection	0.80	11.29	9	
	Total sparge liquor (hL)	1.0	**Sparge temperature (℃)**	78.1	

Mash Filter Run Off					
Time (min)	**Volume Collected (L)**	**Run off rate (L/h)**	**Gravity SG (°P)**	**Inlet pressure (bar)**	**Outlet pressure (bar)**
0	0	420	1.0841 (20.25)	0.85	0.67
4	20	410	1.0857 (20.61)	0.83	0.63
10	140	390	1.0845 (20.34)	0.81	0.63
14	60	250	1.0831 (20.03)	0.40	0.60
20	80	233	1.0817 (19.71)	0.60	0.38
27	100	245	1.0573 (14.11)	0.70	0.25
34	120	225	1.0299 (7.54)	0.70	0.22
39	140	220	1.0130 (3.33)	0.75	0.22
48	160	220	1.0046 (1.19)	0.80	0.22
0	200	40 L brew liquor added			

Boiling		Gravity SG (°P)	Time	Duration	
	Heat –up		11:10	35	
	Calandria temperature ℃	103 ± 3			
	Kettle-full	**1.0481 (11.94)**	11.29		
	Boiling start		11.45	**60**	
	Boiling stop		12:45		
	Cast wort	**1.0533 (13.17)**			

1. Hop dosage	**85.5 g (60 min)**	**Type:** Hallertauer-Magnum	**12.7 % α-acids**
2. Hop dosage	**100 g (10 min)**	**Type:** Saaz (Slovakia)	**6.0 % α-acids**
Apparent IBU	**22**		

	Temperature (℃)	Time	Duration (min)	Notes
Whirlpool		12:45	25	
Casting start		13:10	40	
Casting end		13:50		
Pitching	11.2	13:20	4	

Fermentor No.	4	**Pre-cooled?**	**(yes)/not**

Yeast type	Saflager S-23
Viability (%)	88.7
Pitching quantity (kg)	2.94
Pitching rate (10^6 cells/mL)	19.2
Attenuation limit (%)	79.98

	Date	Time	SG (°P)	Temp, Set-up (℃)	Real temp. (℃)	Pressure (bar)	Yeast cells (10^6 cells/mL)	pH	Colour (EBC)
Primary fermentation	18..09.07	13:50	1.0475 (11.79)	**12.0**	11.2	0.2	19.2	5.29	7.8
	19.09.07	9:15	1.0438 (10.91)	**12.0**	11.6	0.2	25.3	5.01	
	20.09.07	9:08	1.0343 (8.61)	**12.0**	11.8	0.2	52.8	4.63	
	21.09.07	8:40	1.0261 (6.61)	**12.0**	11.9	0.25	77.6	4.31	
	22.09.07	10:30	1.0200 (5.08)	**12.0**	11.9	0.25	71.3	4.10	
	23.09.07	9:30	1.0152 (3.88)	**4.0**	11.9	0.25	66.5	4.03	
Yeast collection	24.09.07	7:58	1.0117 (3.00)	**4.0**	3.9	0.25	52.3	4.02	
Diacetyl rest	25.09.07	8:00	1.0105 (2.69)	**Cool off**	7.6	0.4	N/A	4.00	
	26.09.07	13:06	1.0099 (2.54)	**Cool off**	11.8	0.9	N/A	3.94	
Maturation	27.09.07	23:15	1.0098 (2.51)	**2.0**	1.9	0.9	N/A	3.94	5.5
	28.09.07	10:30	1.0098 (2.51)	**2.0**	1.9	0.9	N/A	3.92	
	29.09.07	15:55	1.0095 (2.44)	**2.0**	2.0	1.2	N/A	3.92	
	30.09.07	13:52	1.0093 (2.39)	**2.0**	2.3	1.2	N/A	3.92	
	01.10.07	9:40	1.0093 (2.39)	**2.0**	1.9	1.2	N/A	3.92	
	02.10.07	18:50	1.0093 (2.39)	**2.0**	1.9	1.2	N/A	3.92	
	03.10.07	10:34	1.0092 (2.36)	**2.0**	1.8	0.8	N/A	3.92	

	Date	Time	SG (°P)	Temp, Set-up (°C)	Real temp. (°C)	Pressure (bar)	Yeast cells (10^6 cells/mL)	pH	Colour (EBC)
	04.10.07	8:27	1.0092 (2.36)	**2.0**	1.9	1.0	N/A	3.92	
	05.10.07	10:35	1.0092 (2.36)	**2.0**	1.9	1.0	N/A	3.92	
	06.10.07	12:33	1.0092 (2.36)	**2.0**	1.9	1.0	N/A	3.92	
	07.10.07	9:13	1.0092 (2.36)	**2.0**	1.8	1.0	N/A	3.92	
Filtration	08.10.07	10:02	1.0092 (2.36)	**2.0**	1.9	1.0	N/A	3.92	3.6
Conditioning Tank No:	CT2								

Beer Filtration		
	Beer stabilizers	(yes) / no
	Type of beer stabilizer	Lucilite TR Silica Gel/PVP INEOS Silicas Ltd
	Stabilizer rate (mg/L)	50
	Filtration unit	Carlson Ltd
	Number of filters	9
	Filter grade	XE400
	Porous size (μm)	0.5

Kegging			
	Keg No.	0774A	0774B
	Date	10.10.07	10.10.07
	Pressure of filling (bar)	1.0	1.0
	Volume of beer (L)	50	50
	Volume of water (L)	0	0
	Total volume (L)	50	50

Bottling					
	Keg No.	0774B	Bottle type & size	British 0.5 L	Euro 0.33 L
	Date	12.10.07	No. of bottles	24	48

BREW CONTROL SHEET

Name: Andrés Furukawa S.	**Date:** 22.07.08
Brew no. 12 (ICBD No. 0846A12)	**Target volume:** 2 hL
Beer style: PILSNER MALT	**Target gravity:** 1.04840 (12 °P)

Mill	PILSNER MALT	34.5 kg (100 %)
Total		34.5 kg (100 %)

Brew liquor total hardness (°dH)	18.33
Strike temperature (°C)	61.0
Volume (L)	104
Flow rate (L/h)	600
Liquor: Grist ratio	3:1
Mash feed rate (kg/min)	4.5

Mashing	Process stage	Temp (°C)	Start	Duration (min)	Notes
	Mash-in	**61.0**	8:23	98	
	1. Rest	**55.2**	9:31	**10**	
	Heat-up		9:41	7	
	2. Rest	**62.2**	9:48	**60**	
	Heat-up		10:48	7	
	3. Rast	**71.7**	10.55	**20**	
	Heat-up		10.15	10	
	Mash-out	**77.8**	11.25	2	
	Iodine Test ok?	**(yes)/not**			

Lautering / Mash filtration	Process stage	Pressure (bar)	Start	Duration (min)	Notes
	Start filling	0.85	11.24	-	
	Mash filter full	0.85	11.27	2	
	Recirculation start	0.85	11.27	2	
	Start collection	0.85	11.30	5	
	Mash all-in Start pre-compression	0.60	11.42	14	
	Pre-compression end- Sparge on	0.85	11.48	6	
	End sparge-Start final compression	0.80	12.10	25	
	End collection	0.80	12.16	9	
	Total sparge liquor (hL)	1.0	**Sparge temperature (℃)**	78.1	

Mash Filter Run Off					
Time (min)	**Volume Collected (L)**	**Run off rate (L/h)**	**Gravity SG (°P)**	**Inlet pressure (bar)**	**Outlet pressure (bar)**
0	0	320	1.0815 (19.67)	0.85	0.64
5	20	380	1.0831 (20.03)	0.85	0.65
9	140	408	1.0822 (19.81)	0.85	0.65
13	60	415	1.0809 (19.53)	0.70	0.40
18	80	210	1.0798 (19.29)	0.60	0.15
26	100	220	1.0476 (11.82)	0.70	0.20
32	120	210	1.0257 (6.50)	0.80	0.20
40	140	250	1.0117 (3.00)	0.90	0.23
46	160	225	1.0039 (1.01)	0.80	0.22
0	200	40 L brew liquor added			

Boiling		Gravity SG (°P)	Time	Duration	
	Heat –up		11.42	38	
	Calandria temperature ℃	103 ± 3			
	Kettle-full	**1.0470 (11.67)**	12.12		
	Boiling start		12:20	**60**	
	Boiling stop		12:45		
	Cast wort	**1.0522 (12.91)**			

1. Hop dosage	**85.5 g (60 min)**	**Type:** Hallertauer-Magnum	**12.7 % α-acids**
2. Hop dosage	**100 g (10 min)**	**Type:** Saaz (Slovakia)	**6.0 % α-acids**
Apparent IBU	**22**		

	Temperature (℃)	Time	Duration (min)	Notes
Whirlpool		13.20	25	
Casting start		13:45	35	
Casting end		14.20		
Pitching	11.4	14:35	3	

Fermentor No.	2	**Pre-cooled?**	**(yes)/not**

Yeast type	Saflager S-23
Viability (%)	Up to 95%
Pitching quantity (kg)	3.05
Pitching rate (10^6 cells/mL)	13.48
Attenuation limit (%)	80.03

	Date	Time	SG (°P)	Temp, Set-up (℃)	Real temp. (℃)	Pressure (bar)	Yeast cells (10^6 cells/mL)	pH	Colour (EBC)
Primary fermentation	22..07.08	14:23	1.0476 (11.82)	**12.0**	11.4	0.2	13.48	5.57	8.3
	23.07.08	18:05	1.0449 (11.17)	**12.0**	11.8	0.25	19.54	5.18	
	24.07.08	7:10	1.0435 (10.84)	**12.0**	11.7	0.25	55.6	5.02	
	25.07.08	16:45	1.0346 (8.69)	**12.0**	11.8	0.25	88.8	4.55	
	26.07.08	10:20	1.0283 (7.14)	**12.0**	11.9	0.25	73.1	4.37	
	27.07.08	11:15	1.0226 (5.73)	**12.0**	11.8	0.25	52.7	4.28	
	28.07.08	7:50	1.0165 (4.21)	**4.0**	11.8	0.2	39.1	4.20	
	29.07.08	16:25	1.0132 (3.38)	**4.0**	4.0	0.2	22.9	4.20	
	30.07.08	17:12	1.0126 (3.22)	**4.0**	4.0	0.2	18.7	4.20	
Yeast collection	31.07.08	9:50	1.0113 (2.89)	**4.0**	4.0	0.2	N/A	4.20	
Diacetyl rest	01.08.08	17:50	1.0108 (2.77)	**Cool off**	6.7	0.2	N/A	4.18	
	02.08.08	15:38	1.0103 (2.64)	**Cool off**	13.1	0.5	N/A	4.18	
Maturation	03.08.08	14:35	1.0097 (2.49)	**2.0**	3.9	0.8	N/A	4.18	5.8
	04.08.08	13:42	1.0096 (2.46)	**2.0**	2.0	0.8	N/A	4.17	
	05.08.08	17:40	1.0095 (2.44)	**2.0**	2.0	0.55	N/A	4.17	
	06.08.08	7:30	1.0092 (2.36)	**2.0**	2.0	1.0	N/A	4.16	

	Date	Time	SG (°P)	Temp, Set-up (°C)	Real temp. (°C)	Pressure (bar)	Yeast cells (10^6 cells/mL)	pH	Colour (EBC)
	07.08.08	17:42	1.0092 (2.36)	**2.0**	1.9	1.0	N/A	4.16	
	08.08.08	7:15	1.0092 (2.36)	**2.0**	1.9	0.8	N/A	4.16	
	09.08.08	13:26	1.0092 (2.36)	**2.0**	1.9	1.0	N/A	4.16	
	10.08.08	11:10	1.0092 (2.36)	**2.0**	1.9	1.0	N/A	4.16	
	11.08.08	8:56	1.0092 (2.36)	**2.0**	1.9	1.0	N/A	4.16	
	12.08.08	9:00	1.0092 (2.36)	**2.0**	2.3	1.0	N/A	4.16	
	13.08.08	10:00	1.0092 (2.36)	**2.0**	1.9	0.8	N/A	4.16	
	14.08.08	13:45	1.0092 (2.36)	**2.0**	2.0	0.8	N/A	4.16	
	15.08.08	0:53	1.0092 (2.36)	**2.0**	1.8	0.75	N/A	4.16	
	16.08.08	18:54	1.0092 (2.36)	**2.0**	1.9	0.75	N/A	4.16	
	17.08.08	12:50	1.0092 (2.36)	**2.0**	2.0	1.0	N/A	4.16	
	18.08.08	9:13	1.0092 (2.36)	**2.0**	2.2	1.0	N/A	4.16	
	19.08.08	10:00	1.0092 (2.36)	**2.0**	2.3	1.0	N/A	4.16	
Filtration	08.10.07	10:02	1.0092 (2.36)	**2.0**	1.9	1.0	N/A	4.16	4.1
Conditioning Tank No:	CT2								

Beer Filtration		
	Beer stabilizers	(yes) / no
	Type of beer stabilizer	Lucilite TR Silica Gel/PVP INEOS Silicas Ltd
	Stabilizer rate (mg/L)	50
	Filtration unit	Carlson Ltd
	Number of filters	9
	Filter grade	XE400
	Porous size (µm)	0.5

Kegging			
	Keg No.	0846A	0846B
	Date	19.08.08	19.08.08
	Pressure of filling (bar)	1.0	1.0
	Volume of beer (L)	50	50
	Total volume (L)	50	50

Bottling					
	Keg No.	0846B	Bottle type & size	British 0.5 L	Euro 0.33 L
	Date	23.09.08	No. of bottles	N/A	96

BREW CONTROL SHEET

Name: Andrés Furukawa S.	**Date:** 31.07.08
Brew no. 13 (ICBD No. 0851A13)	**Target volume:** 2 hL
Beer style: CARAHELL®	**Target gravity:** 1.04840 (12 °P)

Mill	CARAHELL®	3.45 kg (10 %)
	PILSNER MALT	31.05 kg (90%)
Total		34.5 kg (100%)

Brew liquor total hardness (°dH)	19.46
Strike temperature (°C)	60.6
Volume (L)	104
Flow rate (L/h)	600
Liquor: Grist ratio	3:1
Mash feed rate (kg/min)	4.5

Mashing	Process stage	Temp (°C)	Start	Duration (min)	Notes
	Mash-in	**60.6**	8:35	6	
	1. Rest	**55.2**	8:41	**10**	
	Heat-up		8:51	6	
	2. Rest	**62.5**	8:57	**60**	
	Heat-up		9:57	8	
	3. Rest	**71.7**	10:05	**20**	
	Heat-up		10:25	8	
	Mash-out	**77.8**	10:33	2	
	Iodine Test ok?	**(yes)/not**			

Lautering / Mash filtration	Process stage	Pressure (bar)	Start	Duration (min)	Notes
	Start filling	0.85	10:33	-	
	Mash filter full	0.85	10:35	2	
	Recirculation start	0.85	10:35	2	
	Start collection	0.85	10:39	12	
	Mash all-in Start pre-compression	0.60	10:51	6	
	Pre-compression end- Sparge on	0.85	10:57	26	
	End sparge-Start final compression	0.80	11:23	7	
	End collection	0.80	11:30	5	
	Total sparge liquor (hL)	1.0	**Sparge temperature (℃)**	78.1	

Mash Filter Run Off					
Time (min)	**Volume Collected (L)**	**Run off rate (L/h)**	**Gravity SG (°P)**	**Inlet pressure (bar)**	**Outlet pressure (bar)**
0	0	430	1.0840 (20.23)	0.90	**0.70**
8	20	415	1.0855 (20.57)	0.90	0.65
12	40	380	1.0848 (20.41)	0.85	0.60
19	60	280	1.0840 (20.23)	0.70	0.30
25	80	210	1.0834 (20.10)	0.80	0.30
33	100	233	1.0526 (13.00)	0.85	0.25
40	120	210	1.0265 (6.70)	0.90	0.25
46	140	225	1.0102 (2.62)	0.80	0.30
52	160	190	1.0036 (0.93)	0.80	0.25
0	200	40 L brew liquor added			

Boiling		Gravity SG (°P)	Time	Duration	Notes
	Heat -up		10:51	17	
	Calandria temperature ℃	104.0 .± 2			
	Kettle-full	**1.0485 (12.03)**	11.24		
	Boiling start		11:30	**60**	
	Boiling stop		12:30		
	Cast wort	**1.0537 (13.26)**			

1. Hop dosage	**85.5 g (60 min)**	**Type:** Hallertauer-Magnum	**12.7 % α-acids**
2. Hop dosage	**100 g (10 min)**	**Type:** Saaz (Slovakia)	**6.0 % α-acids**
Apparent IBU	**22**		

	Temperature (°C)	Time	Duration (min)	Notes
Whirlpool		12:30	**25**	
Casting start		12:55	**35**	
Casting end		13:30		
Pitching	11.9	13:10	5	

Fermentor No.	3	**Pre-cooled?**	**(yes)/not**

Yeast type	Saflager S-23
Viability (%)	91.3
Pitching quantity (kg)	3.10
Pitching rate (10^6 cells/mL)	18.8
Attenuation limit (%)	80.62

	Date	Time	SG (°P)	Temp, Set-up (°C)	Real temp. (°C)	Pressure (bar)	Yeast cells (10^6 cells/mL)	pH	Colour (EBC)
Primary fermentation	31.07.08	13:35	1.0487 (12.08)	**12.0**	11.9	0.0	18.8	5.19	14.7
	01.08.08	17:50	1.0363 (9.10)	**12.0**	11.9	0.0	45.7	4.65	
	02.08.08	16:30	1.0241 (6.11)	**12.0**	11.9	0.0	83.4	4.31	
	03.08.08	14:30	1.0145 (3.70)	**12.0**	11.9	0.0	62.1	4.25	
	04.08.08	12:35	1.0124 (3.17)	**12.0**	11.9	0.0	37.6	4.24	
	05.08.08	17:40	1.0109 (2.79)	**4.0**	3.9	0.4	25.5	4.23	
Yeast collection	06.08.08	7:20	1.0097 (2.49)	**4.0**	3.9	0.4	N/A	4.22	
Diacetyl rest	07.08.08	17:42	1.0093 (2.39)	**Cool off**	7.9	0.5	N/A	4.22	
	08.08.08	7:05	1.0091 (2.34)	**Cool off**	12.9	0.8	N/A	4.18	
Maturation	09.08.08	13:26	1.0091 (2.34)	**2.0**	2.1	1.0	N/A	4.16	11.3
	10.08.08	11:00	1.0091 (2.34)	**2.0**	2.2	1.0	N/A	4.16	
	11.08.08	13:54	1.0091 (2.34)	**2.0**	2.0	1.0	N/A	4.16	
	12.08.08	9:05	1.0091 (2.34)	**2.0**	2.0	0.9	N/A	4.16	
	13.08.08	7:54	1.0091 (2.34)	**2.0**	2.2	0.9	N/A	4.16	
	14.08.08	14:15	1.0091 (2.34)	**2.0**	2.1	0.9	N/A	4.15	
	15.08.08	12:45	1.0091 (2.34)	**2.0**	2.0	0.8	N/A	4.15	

	Date	Time	SG (°P)	Temp, Set-up (°C)	Real temp. (°C)	Pressure (bar)	Yeast cells (10^6 cells/mL)	pH	Colour (EBC)
	16.08.08	9:45	1.0091 (2.34)	**2.0**	2.0	1.0	N/A	4.15	
	17.08.08	10:00	1.0091 (2.34)	**2.0**	2.2	1.0	N/A	4.15	
	18.08.08	15:26	1.0091 (2.34)	**2.0**	2.2	0.9	N/A	4.15	
	19.08.08	9:50	1.0091 (2.34)	**2.0**	2.0	0.9	N/A	4.15	
	20.08.08	16:50	1.0091 (2.34)	**2.0**	2.2	0.9	N/A	4.15	
	21.08.08	7:20	1.0091 (2.34)	**2.0**	2.2	0.9	N/A	4.15	
	22.08.08	19:25	1.0091 (2.34)	**2.0**	2.2	0.9	N/A	4.15	
	23.08.08	16:00	1.0091 (2.34)	**2.0**	1.9	0.9	N/A	4.15	
	24.08.08	18:30	1.0091 (2.34)	**2.0**	1.9	0.9	N/A	4.15	
	25.08.08	18:23	1.0091 (2.34)	**2.0**	1.9	0.9	N/A	4.15	
Filtration	26.08.08	7:20	1.0091 (2.34)	**2.0**	2.0	0.9	N/A	4.15	7.4
Conditioning Tank No:	CT1								

Beer Filtration		
	Beer stabilizers	(yes) / no
	Type of beer stabilizer	Lucilite TR Silica Gel/PVP INEOS Silicas Ltd
	Stabilizer rate (mg/L)	50
	Filtration unit	Carlson Ltd
	Number of filters	9
	Filter grade	XE400
	Porous size (µm)	0.5

Kegging			
	Keg No.	0851A	0851B
	Date	26.08.08	26.08.08
	Pressure of filling (bar)	1.0	1.0
	Volume of beer (L)	50	50
	Volume of water (L)	0	0
	Total volume (L)	50	50

Bottling					
	Keg No.	0851B	Bottle type & size	British 0.5 L	Euro 0.33 L
	Date	23.09.07	No. of bottles	N/A	96

BREW CONTROL SHEET

Name: Andrés Furukawa S.	**Date:** 06.08.08
Brew no. 14 (ICBD No. 0852A14)	**Target volume:** 2 hL
Beer style: MELANOIDIN MALT	**Target gravity:** 1.04840 (12 °P)

Mill	MELANOIDIN MALT	1.35 kg (3.9 %)
	PILSNER MALT	31.05 kg (96.1 %)
Total		34.5 kg (100%)

Brew liquor total hardness (°dH)	15.61
Strike temperature (°C)	58.6
Volume (L)	104
Flow rate (L/h)	600
Liquor: Grist ratio	3:1
Mash feed rate (kg/min)	4.5

Mashing	Process stage	Temp (°C)	Start	Duration (min)	Notes
	Mash-in	**58.6**	8:50	4	
	1. Rest	**55.0**	8:54	**10**	
	Heat-up		9:04	6	
	2. Rest	**61.9**	9:12	**60**	
	Heat-up		10:12	5	
	3. Rast	**72.1**	10:17	**20**	
	Heat-up		10:37	5	
	Mash-out	**77.8**	10:42	2	
	Iodine Test ok?	**(yes)/not**			

Lautering / Mash filtration	Process stage	Pressure (bar)	Start	Duration (min)	Notes
	Start filling	0.85	10:42	-	
	Mash filter full	0.85	10:44	2	
	Recirculation start	0.85	10:44	2	
	Start collection	0.85	10:47	3	
	Mash all-in Start pre-compression	0.60	11:00	13	
	Pre-compression end- Sparge on	0.85	11:06	6	
	End sparge-Start final compression	0.80	11:23	17	
	End collection	0.80	11:28	5	
	Total sparge liquor (hL)	100	**Sparge temperature (℃)**	78.1	

Mash Filter Run Off					
Time (min)	**Volume Collected (L)**	**Run off rate (L/h)**	**Gravity SG (°P)**	**Inlet pressure (bar)**	**Outlet pressure (bar)**
0	0	438	1.0824 (19.87)	0.90	0.70
4	20	438	1.0835 (20.12)	0.95	0.75
8	40	388	1.0824 (19.87)	0.95	0.65
13	60	347	1.0814 (19.65)	0.95	0.65
19	80	202	1.0810 (19.56)	0.65	0.20
25	100	283	1.0485 (12.03)	0.95	0.35
30	120	298	1.0281 (7.09)	0.90	0.40
47	140	315	1.0143 (3.65)	0.90	0.40
42	160	197	1.0068 (1.75)	0.90	0.30
0	200	40 L brew liquor added			

Boiling		Gravity SG (°P)	Time	Duration	
	Heat –up		11:00	34	
	Calandria temperature ℃	103.5 .± 2			
	Kettle-full	**1.0476 (11.82)**	11.28		
	Boiling start		11:34	**60**	
	Boiling stop		12:34		
	Cast wort	**1.0519 (12.84)**			

1. Hop dosage	**85.5 g (60 min)**	**Type:** Hallertauer-Magnum	**12.7 % α-acids**
2. Hop dosage	**100 g (10 min)**	**Type:** Saaz (Slovakia)	**6.0 % α-acids**
Apparent IBU	**22**		

	Temperature (℃)	Time	Duration (min)	Notes
Whirlpool		12:34	**25**	
Casting start		12:59	**34**	
Casting end		13:35		
Pitching	11.7	13:15	5	

Fermentor No.	4	**Pre-cooled?**	**(yes)/not**

Yeast type	Saflager S-23
Viability (%)	94.7
Pitching quantity (kg)	2.85
Pitching rate (10^6 cells/mL)	12.8
Attenuation limit (%)	82.13

	Date	Time	SG (°P)	Temp, Set-up (℃)	Real temp. (℃)	Pressure (bar)	Yeast cells (10^6 cells/mL)	pH	Colour (EBC)
Primary fermentation	06.08.08	13:48	1.0492 (12.20)	**12.0**	11.7	0.0	12.8	5.34	15.2
	07.08.08	17:42	1.0378 (9.46)	**12.0**	11.9	0.2	32.9	4.95	
	08.08.08	7:20	1.0306 (7.71)	**12.0**	11.8	0.2	51.8	4.55	
	09.08.08	13:26	1.0212 (5.38)	**12.0**	11.8	0.2	83.3	4.29	
	10.08.08	11:00	1.0134 (3.43)	**12.0**	11.8	0.2	70.9	4.22	
	11.08.08	10:41	1.0117 (3.00)	**4.0**	4.0	0.2	43.3	4.21	
	12.08.08	9:00	1.0105 (2.69)	**4.0**	3.9	0.3	34.5	4.21	
Yeast collection	13.08.08	8:13	1.0093 (2.39)	**4.0**	4.0	0.3	21.1	4.21	
Diacetyl rest	14.08.08	16:38	1.0087 (2.23)	**Cool off**	8.5	0.5	N/A	4.21	
	15.08.08	12:45	1.0085 (2.18)	**Cool off**	11.3	0.5	N/A	4.20	
Conditioning	16.08.08	13:45	1.0085 (2.18)	**2.0**	2.0	0.65	N/A	4.20	12.3
	17.08.08	11.11	1.0085 (2.18)	**2.0**	2.0	0.7	N/A	4.20	
	18.08.08	12:00	1.0085 (2.18)	**2.0**	2.0	0.75	N/A	4.20	
	19.08.08	9:52	1.0085 (2.18)	**2.0**	2.0	1.0	N/A	4.20	
	20.08.08	16:50	1.0085 (2.18)	**2.0**	2.0	1.0	N/A	4.20	
	21.08.08	7:22	1.0085 (2.18)	**2.0**	2.0	1.0	N/A	4.20	

	Date	Time	SG (°P)	Temp, Set-up (°C)	Real temp. (°C)	Pressure (bar)	Yeast cells (10^6 cells/mL)	pH	Colour (EBC)
	22.08.08	19:25	1.0085 (2.18)	**2.0**	2.4	1.0	N/A	4.20	
	23.08.08	16:00	1.0085 (2.18)	**2.0**	2.2	1.0	N/A	4.20	
	24.08.08	18:30	1.0085 (2.18)	**2.0**	2.1	1.0	N/A	4.20	
	25.08.08	18:23	1.0085 (2.18)	**2.0**	2.2	1.0	N/A	4.20	
	26.08.08	7:20	1.0085 (2.18)	**2.0**	2.2	1.0	N/A	4.20	
	27.08.08	16:45	1.0085 (2.18)	**2.0**	2.2	1.0	N/A	4.20	
	28.08.08	8:00	1.0085 (2.18)	**2.0**	2.4	1.0	N/A	4.20	
Filtration	29.08.08	8:15	1.0085 (2.18)	**2.0**	2.4	1.0	N/A	4.20	7.9
Conditioning Tank No:	BBT								

Beer Filtration		
	Beer stabilizers	(yes) / no
	Type of beer stabilizer	Lucilite TR Silica Gel/PVP INEOS Silicas Ltd
	Stabilizer rate (mg/L)	50
	Filtration unit	Carlson Ltd
	Number of filters	9
	Filter grade	XE400
	Porous size (μm)	0.5

Kegging			
	Keg No.	0852A	0852B
	Date	29.08.08	29.08.08
	Pressure of filling (bar)	1.0	1.0
	Volume of beer (L)	50	50
	Volume of water (L)	0	0
	Total volume (L)	50	50

Bottling					
	Keg No.	0852B	Bottle type & size	British 0.5 L	Euro 0.33 L
	Date	23.09.08	No. of bottles	N/A	96

BREW CONTROL SHEET

Name: Andrés Furukawa S.	Date: 19.08.08
Brew no. 15 (ICBD No. 0856A15)	Target volume: 2 hL
Beer style: CARAFA® SPECIAL Type III	Target gravity: 1.04840 (12 °P)

Mill	CARAFA® SPECIAL Type III	0.18 kg (0.2 %)
	PILSNER MALT	34.32 kg (99.8 %)
Total		34.5 kg (100%)

Brew liquor total hardness (°dH)	14.03
Strike temperature (°C)	57.6
Volume (L)	104
Flow rate (L/h)	600
Liquor: Grist ratio	3:1
Mash feed rate (kg/min)	4.5

Mashing	Process stage	Temp (°C)	Start	Duration (min)	Notes
	Mash-in	57.6	8:52	6	
	1. Rest	55.2	8:58	10	
	Heat-up		9:08	6	
	2. Rest	61.9	9:14	60	
	Heat-up		10:14	10	
	3. Rast	72.0	10:24	20	
	Heat-up		10:44	6	
	Mash-out	77.8	10:50	4	
	Iodine Test ok?	(yes)/not			

Lautering / Mash filtration	Process stage	Pressure (bar)	Start	Duration (min)	Notes
	Start filling	0.90	10:52	-	
	Mash filter full	0.90	10:54	2	
	Recirculation start	0.90	10:54	2	
	Start collection	0.90	10:57	3	
	Mash all-in Start pre-compression	0.70	11:08	11	
	Pre-compression end- Sparge on	0.85	11:15	7	
	End sparge-Start final compression	0.80	11:37	22	
	End collection	0.80	11:45	8	
	Total sparge liquor (hL)	1.0	**Sparge temperature (°C)**	77.8	

Mash Filter Run Off					
Time (min)	**Volume Collected (L)**	**Run off rate (L/h)**	**Gravity SG (°P)**	**Inlet pressure (bar)**	**Outlet pressure (bar)**
0	0	425	1.0816 (19.69)	0.90	0.68
6	20	398	1.0835 (20.12)	0.90	0.65
11	40	387	1.0829 (19.98)	0.90	0.65
16	60	388	1.0817 (19.71)	0.90	0.55
21	80	352	1.0810 (19.56)	0.65	0.25
30	100	198	1.0473 (11.75)	0.80	0.15
35	120	200	1.0233 (5.91)	0.90	0.16
40	140	177	1.0084 (2.16)	0.77	0.15
48	160	130	1.0028 (0.72)	0.85	0.15
0	200	40 L brew liquor added			

Boiling		Gravity SG (°P)	Time	Duration	
	Heat –up		11:15	38	
	Calandria temperature °C	103.0.± 2			
	Kettle-full	**1.0471 (11.70)**	11:46		
	Boiling start		11:53	**60**	
	Boiling stop		12:53		
	Cast wort	**1.0522 (12.91)**			

1. Hop dosage	**85.5 g (60 min)**	**Type:** Hallertauer-Magnum	**12.7 % α-acids**
2. Hop dosage	**100 g (10 min)**	**Type:** Saaz (Slovakia)	**6.0 % α-acids**
Apparent IBU	**22**		

	Temperature (℃)	Time	Duration (min)	Notes
Whirlpool		12:53	25	
Casting start		13.18	42	
Casting end		14:00		
Pitching	11.2	13:38	3	

Fermentor No.	2	**Pre-cooled?**	**(yes)/not**

Yeast type	Saflager S-23
Viability (%)	90.5
Pitching quantity (kg)	2.5
Pitching rate (10^6 cells/mL)	21.60
Attenuation limit (%)	79.59

	Date	Time	SG (°P)	Temp, Set-up (℃)	Real temp. (℃)	Pressure (bar)	Yeast cells (10^6 cells/mL)	pH	Colour (EBC)
Primary fermentation	19.08.08	14:00	1.0482 (11.96)	**12.0**	11.2	0.0	21.6	5.48	16.5
	20.08.08	17:35	1.0372 (9.32)	**12.0**	11.8	0.2	35.9	5.34	
	21.08.08	7:23	1.0310 (7.81)	**12.0**	11.8	0.2	57.3	4.65	
	22.08.08	19:22	1.0152 (3.88)	**12.0**	11.9	0.2	89.2	4.42	
	23.08.08	15:56	1.0126 (3.22)	**4.0**	4.0	0.2	75.5	4.35	
Yeast collection	24.08.08	18:30	1.0108 (2.77)	**4.0**	3.9	0.2	39.9	4.30	
Diacetyl rest	25.08.08	18:23	1.0096 (2.46)	**Cool off**	7.5	0.35	N/A	4.30	
	26.08.08	13:23	1.0095 (2.44)	**Cool off**	11.4	0.4	N/A	4.30	
Maturation	27.08.08	16:45	1.0095 (2.44)	**2.0**	2.2	1.0	N/A	4.30	
	28.08.08	8:00	1.0095 (2.44)	**2.0**	2.2	1.0	N/A	4.30	13.0
	29.08.08	17:25	1.0095 (2.44)	**2.0**	1.9	1.0	N/A	4.30	
	30.08.08	15:23	1.0095 (2.44)	**2.0**	1.8	1.0	N/A	4.30	
	31.08.08	14:14	1.0095 (2.44)	**2.0**	1.7	1.0	N/A	4.30	
	01.09.08	17:26	1.0095 (2.44)	**2.0**	1.9	1.0	N/A	4.30	
	02.09.08	17:45	1.0095 (2.44)	**2.0**	1.9	1.0	N/A	4.30	
	03.09.08	7:13	1.0095 (2.44)	**2.0**	1.9	1.0	N/A	4.30	

	Date	Time	SG (°P)	Temp, Set-up (°C)	Real temp. (°C)	Pressure (bar)	Yeast cells (10^6 cells/mL)	pH	Colour (EBC)
	04.09.08	18:45	1.0095 (2.44)	**2.0**	1.9	1.1	N/A	4.30	
	05.09.08	16:45	1.0095 (2.44)	**2.0**	1.9	1.1	N/A	4.30	
	06.09.08	12:00	1.0095 (2.44)	**2.0**	1.9	1.1	N/A	4.30	
	07.09.08	14:15	1.0095 (2.44)	**2.0**	1.9	1.1	N/A	4.30	
	08.09.08	9:38	1.0095 (2.44)	**2.0**	1.9	1.1	N/A	4.30	
	09.09.08	17:45	1.0095 (2.44)	**2.0**	2.0	1.1	N/A	4.30	
	10.09.08	13:24	1.0095 (2.44)	**2.0**	2.0	1.1	N/A	4.30	
Filtration	11.09.08	9:05	1.0095 (2.44)	**2.0**	2.0	1.1	N/A	4.30	7.6
Conditioning Tank No:	CT1								

Beer Filtration		
	Beer stabilizers	(yes) / no
	Type of beer stabilizer	Lucilite TR Silica Gel/PVP INEOS Silicas Ltd
	Stabilizer rate (mg/L)	50
	Filtration unit	Carlson Ltd
	Number of filters	9
	Filter grade	XE400
	Porous size (µm)	0.5

Kegging			
	Keg No.	0856A	0856B
	Date	11.09.08	11.09.08
	Pressure of filling (bar)	1.0	1.0
	Volume of beer (L)	50	50
	Volume of water (L)	0	0
	Total volume (L)	50	50

Bottling					
	Keg No.	0856B	Bottle type & size	British 0.5 L	Euro 0.33 L
	Date	23.09.08	No. of bottles	N/A	96

BREW CONTROL SHEET

Name: Andrés Furukawa S.	**Date:** 26.08.08
Brew no. 16 (ICBD No. 0859A16)	**Target volume:** 2 hL
Beer style: CARAMEL #301	**Target gravity:** 1.04840 (12 °P)

Mill	CARAMEL #301	0.020 kg (0.058 %)
	PILSNER MALT	34.5 kg (99.94 %)
Total		34.52 kg (100%)

Brew liquor total hardness (°dH)	16.67
Strike temperature (°C)	57.6
Volume (L)	104
Flow rate (L/h)	600
Liquor: Grist ratio	3:1
Mash feed rate (kg/min)	4.5

Mashing	Process stage	Temp (°C)	Start	Duration (min)	Notes
	Mash-in	**57.6**	8:47	7	
	1. Rest	**55.0**	8:54	**10**	
	Heat-up		9:04	6	
	2. Rest	**62.2**	9:10	**60**	
	Heat-up		10:10	8	
	3. Rast	**72.0**	10:18	**20**	
	Heat-up		10:38	4	
	Mash-out	**78.0**	10:42	2	
	Iodine Test ok?	**(yes)/not**			

Lautering / Mash filtration	Process stage	Pressure (bar)	Start	Duration (min)	Notes
	Start filling	0.86	10:42	-	
	Mash filter full	0.86	10:44	2	
	Recirculation start	0.86	10:44	2	
	Start collection	0.86	10:48	4	
	Mash all-in Start pre-compression	0.70	11:01	12	
	Pre-compression end- Sparge on	0.85	11:07	6	
	End sparge-Start final compression	0.80	11:23	16	
	End collection	0.80	11:28	5	
	Total sparge liquor (hL)	1.0	**Sparge temperature (°C)**	77.9	

Mash Filter Run Off					
Time (min)	**Volume Collected (L)**	**Run off rate (L/h)**	**Gravity SG (°P)**	**Inlet pressure (bar)**	**Outlet pressure (bar)**
0	0	344	1.0837 (20.16)	0.80	0.60
6	20	408	1.0847 (20.39)	0.80	0.60
10	40	365	1.0836 (20.14)	0.85	0.50
15	60	333	1.0829 (19.98)	0.80	0.40
21	80	213	1.0824 (19.87)	0.85	0.20
26	100	181	1.0483 (11.98)	0.85	0.15
33	120	162	1.0232 (5.88)	0.80	0.15
39	140	152	1.0085 (2.18)	0.85	0.15
44	160	145	1.0033 (0.85)	0.90	0.15
0	200	40 L brew liquor added			

Boiling		Gravity SG (°P)	Time	Duration	Notes
	Heat –up		11:01	50	
	Calandria temperature °C	104.5 ± 2			
	Kettle-full	**1.0467 (11.60)**	11:43		
	Boiling start		11:51	**60**	
	Boiling stop		12:51		
	Cast wort	**1.0513 (12.70)**			

1. Hop dosage	**85.5 g (60 min)**	**Type:** Hallertauer-Magnum	**12.7 % α-acids**
2. Hop dosage	**100 g (10 min)**	**Type:** Saaz (Slovakia)	**6.0 % α-acids**
Apparent IBU	**22**		

	Temperature (℃)	Time	Duration (min)	Notes
Whirlpool		12:51	25	
Casting start		13:16	34	
Casting end		13:50		
Pitching	11.3	13:30	3	

Fermentor No.	3	**Pre-cooled?**	**(yes)/not**

Yeast type	Saflager S-23
Viability (%)	96.6
Pitching quantity (kg)	2.4
Pitching rate (10^6 cells/mL)	19.6
Attenuation limit (%)	80.77

	Date	Time	SG (°P)	Temp, Set-up (℃)	Real temp. (℃)	Pressure (bar)	Yeast cells (10^6 cells/mL)	pH	Colour (EBC)
Primary fermentation	26.08.08	13:55	1.0491 (12.17)	**12.0**	11.3	0.0	19.6	5.25	14.6
	27.08.08	16:45	1.0403 (10.07)	**12.0**	12.0	0.0	65.8	4.89	
	28.08.08	8:00	1.0310 (7.81)	**12.0**	11.9	0.0	92.3	4.72	
	29.08.08	17:50	1.0163 (4.16)	**12.0**	11.9	0.0	68.1	4.35	
	30.08.08	15:36	1.0128 (3.27)	**4.0**	4.0	0.0	37.2	4.33	
Yeast collection	31.08.08	14:18	1.0109 (2.79)	**4.0**	3.9	0.0	N/A	4.33	
Diacetyl rest	01.09.08	17:26	1.0096 (2.46)	**Cool off**	11.2	0.5	N/A	4.33	
	02.09.08	17:45	1.0092 (2.36)	**Cool off**	12.0	0.7	N/A	4.33	
	03.09.08	7:11	1.0092 (2.36)	**Cool off**	12.6	1.0	N/A	4.33	
Maturation	04.09.08	8:45	1.0091 (2.34)	**2.0**	2.2	0.9	N/A	4.31	11.3
	05.09.08	16:45	1.0091 (2.34)	**2.0**	1.9	0.9	N/A	4.31	
	06.09.08	12:05	1.0091 (2.34)	**2.0**	1.9	0.9	N/A	4.31	
	07.09.08	9:58	1.0091 (2.34)	**2.0**	2.0	0.9	N/A	4.31	
	08.09.08	10:34	1.0091 (2.34)	**2.0**	2.1	0.9	N/A	4.30	
	09.09.08	7:56	1.0091 (2.34)	**2.0**	2.0	1.0	N/A	4.30	
	10.09.08	14:56	1.0091 (2.34)	**2.0**	1.9	1.0	N/A	4.30	

	Date	Time	SG (°P)	Temp, Set-up (°C)	Real temp. (°C)	Pressure (bar)	Yeast cells (10^6 cells/mL)	pH	Colour (EBC)
	11.09.08	11:07	1.0091 (2.34)	**2.0**	1.5	1.0	N/A	4.30	
	12.09.08	13:45	1.0091 (2.34)	**2.0**	1.7	1.0	N/A	4.30	
	13.09.08	17:21	1.0091 (2.34)	**2.0**	1.8	1.0	N/A	4.30	
	14.09.08	16:45	1.0091 (2.34)	**2.0**	1.9	1.0	N/A	4.30	
	15.09.08	9:45	1.0091 (2.34)	**2.0**	1.9	1.0	N/A	4.30	
	16.09.08	13:37	1.0091 (2.34)	**2.0**	1.9	1.0	N/A	4.30	
	17.09.08	15:13	1.0091 (2.34)	**2.0**	1.9	1.0	N/A	4.30	
Filtration	18.09.08	10:05	1.0091 (2.34)	**2.0**	1.9	1.0	N/A	4.30	7.1
Tank No:	CT2								

Beer Filtration		
	Beer stabilizers	(yes) / no
	Type of beer stabilizer	Lucilite TR Silica Gel/PVP INEOS Silicas Ltd
	Stabilizer rate (mg/L)	50
	Filtration unit	Carlson Ltd
	Number of filters	9
	Filter grade	XE400
	Porous size (µm)	0.5

Kegging			
	Keg No.	0859A	0859B
	Date	18.09.08	18.09.08
	Pressure of filling (bar)	1.0	1.0
	Volume of beer (L)	50	50
	Volume of water (L)	0	0
	Total volume (L)	50	50

Bottling					
	Keg No.	0859B	Bottle type & size	British 0.5 L	Euro 0.33 L
	Date	23.09.08	No. of bottles	N/A	96

APPENDIX D. Description and specifications of the I.C.B.D pilot brewery

9. PUBLICATIONS

Furukawa A. and Hughes P.S. (2009). Impact of colour adjustment on flavour stability of pale lager beers with a range of distinct colouring agents. In: *Proc. Congr. Eur. Brew. Conv*. Hamburg.: (CD-ROM).

Furukawa A., Kunz T., Cortés N., MacKinlay J., Hughes P.S. and Methner F-J. (2009). Impact of colour adjustment on flavour stability of pale lager beers with a range of distinct colouring agents. *Food Chem*. (publication submitted)