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Impact on the physicochemical and sensory properties of salt reduced corned beef formulated with and without the use of salt replacers

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Abstract

The aim of this study was to investigate physicochemical and microbiological properties as well as a sensory (affective and descriptive) driven sodium reduction (0.2 g/100 g - 1.0 g/100 g product) strategy for a cured meat product (corned beef). A second aim was to use the same methodology to further reduce salt, using salt replacers. Significant differences in colour, hardness and cooking loss were measured. Corned beef samples low in sodium (0.2 g/100 g, 0.4 g/100 g) showed reduced ($P < 0.05$) saltiness perception, but were positively correlated ($P > 0.05$) to liking of flavour and overall acceptability. Samples formulated with $CaCl_2$, $MgCl_2$ and KCl scored higher ($P < 0.01$) in saltiness perceptions, but correlated negatively ($P > 0.05$) to liking of flavour and overall acceptability. However, a sodium reduction in corned beef was determined to be achievable as assessors liked ($P < 0.05$) the flavour of the sodium reduced corned beef containing 0.4 g/100 g sodium and formulated with potassium lactate and glycine (KLG), even with the noticeable lower salty taste. Sodium reduction in corned beef (packaged under modified atmosphere) did not negatively impact on the microbiological shelf-life.

1. Introduction

Corned beef is a traditional cured meat product from Western Europe and America which is popular in Ireland and the United Kingdom. The term "corned" comes from the treatment with large grained rock salt, which looks like a wheat kernel known as a corn of salt. Corned beef is first mentioned in the old Irish Gaelic poem Aeslinge Meic Conglinne "The Vision of MacConglinne" in the 12th century, which describes corned beef as a delicacy given to a king. In the 19th century corned beef was a festive dish in Ireland, served with cabbage and potatoes at Christmas, Halloween, weddings, wakes and on St. Patrick's Day. This tradition was transferred all over the world, especially to North America, by the emigrants of the 18th /19th centuries (Mahon, 1998). Corned beef in its canned form was an important food source during World War II. Nowadays, corned beef is still available in its two forms: full piece of beef –brisket/round– or canned, though the recipes, and therefore the taste differs extremely. Ingredients employed in corned beef manufacture, besides beef (50 g/100 g - 95 g/100 g), sodium chloride and nitrite, can also consist the following: thickeners (starches, flours), stabilisers (phosphate derivate), antioxidants (ascorbate derivate), flavour enhancers (glutamate derivate), dextrose and spices. The sodium content of the available corned beef in Ireland ranges from 0.7 g/100 g to 1.0 g/100 g (unpublished data, 2014). Even though the specific inhibitory mechanisms of nitrite are not well known, its effectiveness as an antimicrobial is dependent on several factors including residual nitrite level, pH, salt concentration, reductants present, iron content, and others (Tompkin, 2005). Salt is one of the most important ingredients which increases the antibotulinal effectiveness of nitrite. (Roberts and Gibson, 1986).

According to the IUNA (Irish Universities Nutrition Alliance) 47 % of 18-64 year olds consume processed meat products and 30 % of the over 65 age cohort consume processed meat products (Conroy, O'Sullivan, Hamill and Kerry, 2018). The North/South Ireland Food Consumption Survey 2001 showed an average daily intakes of red meat and processed meat were 51 g and 26 g which gives an overall intake of 77 g per capita (IUNA, 2011; Safefood, 2001). Corned beef is a traditional meat product commonly consumed by the Irish population particularly senior citizens. This may be due to its high salt content which may appeal to those with a decline in sensory perception as the aging process occurs. The Food Safety Authority has recommended a salt reduction to 1.63 g (650 mg sodium) (Salt-Targets 2017, 2016). (Conroy, O'Sullivan, Hamill and Kerry, 2018).

On the basis that the processed is responsible for a relevant part of the average daily sodium intake by consumers, the meat processing industry is trying to develop low-salt meat products to address consumer concerns and adhere to health recommendations. Already, different strategies have been attempted to achieve this objective including: reducing the total amount of salt or by (partly) substitution of sodium chloride with potassium, magnesium and calcium chloride, glutamate, glycine and potassium lactate (Aaslyng, Vestergaard, & Koch, 2014;

Aliño, Grau, Toldrá, & Barat, 2010a; Aliño, Grau, Toldrá, Blesa, et al., 2010b; Fellendorf, O'Sullivan, & Kerry, 2015, ; Fellendorf, O'Sullivan, & Kerry, 2016abc; Fellendorf, O'Sullivan, & Kerry, 2017; Gou, Guerrero, Gelabert, & Arnau, 1996; Guàrdia, Guerrero, Gelabert, Gou, & Arnau, 2008; Tobin, O'Sullivan, Hamill, & Kerry, 2012ab, Tobin, O'Sullivan, Hamill, & Kerry, 2013). The most efficient outcome is the substitution of sodium by potassium to simultaneously increase potassium intake.

An excessive sodium intake is linked with mortality and the risk of developing coronary heart diseases (Bibbins-Domingo et al., 2010; Ezzati, Lopez, Rodgers, Vander Hoorn, & Murray, 2002; Qizilbash et al., 1995). Sodium chloride is the main additive used in manufacturing processed meat as it contributes to developing the texture and flavour, and furthermore extension of shelf-life (Toldrá, 2007). A survey in UK calculated that the processed meat sector, with 18 %, is the largest contributor of sodium in food, followed by bread and bakery products (13 %), dairy products (12 %), and sauces and spreads (11 %) (Ni et al., 2011). The Irish Universities Nutrition Alliance carried out a national adult nutritional survey and determined that the mean daily salt intake from food (excluding salt added in cooking and at the table) for the Irish population (age of 18 to 64) was estimated as 7.4 g (men 8.5 g salt/day and women 6.2 g salt/day). Elderly people aged 65 years and over, had a lower salt mean daily intake of 6.3 g. Furthermore, breads, and cured and processed meats were the main contributors to the daily salt intake in the Irish population (Irish Universities Nutrition Alliance, 2011). The World Health Organization (WHO) recommends a daily sodium consumption for adults of less than 2 grams (<5 g salt/day) (WHO, 2012b). Furthermore, the WHO suggests for adults an increase in potassium intake from food (3.5 g potassium/day) to reduce blood pressure, the risk of cardiovascular diseases and stroke (WHO, 2012a). Therefore, a "Salt Reduction Programme" (SRP) set up by the Food Safety Authority of Ireland (FSAI) provides guidelines for maximum sodium levels for uncured cooked meat products, cured uncooked meat products, black & white puddings, sausages and burgers. Although, no regulations are defined for cured cooked meat products like corned beef and cooked ham (FSAI, 2011). The Food Standard Agency (FSA) takes responsibility for protecting the public health associated with food throughout the UK. The FSA, includes in their sodium reduction plan, ham and other cured meats, (which commenced in 2010) a recommended level of 800 mg (FSA, 2010), and since 2012, the sodium target level was set as 650 mg/100 g. No further reductions are planned until 2017 (FSA, 2014). It is only a matter of time before the FSAI will also include in their Irish salt reduction program guidelines for cooked cured meat products.

Due to their high contribution of the daily salt intake in the Irish population the salt level of cured meat products, such as corned beef, has to be reduced (Irish Universities Nutrition Alliance, 2011). Additionally, any optimised products must fulfil the sensory expectations of consumers. There has been no research to date on effective salt reduction in corned beef that employs an affective (hedonic) and descriptive sensory-driven sodium reduction strategy. Thus, the aim of this study was to investigate firstly sodium reduction and then to use the same methodology to further reduce salt, using salt replacers. Physicochemical and microbiological properties were also investigated to ensure that variants are still viable from a shelf life perspective. This sensory-driven approach allowed the development of a healthier, reduced sodium, and more consumer acceptable product.

2. Materials and Methods

2.1 Sample preparation

The beef used in this study was the eye of round (Semitendinosus, Na 60 mg/100 g ± 10 mg; K 365 ± 10 mg/100 g) and was purchased from a local supplier (Feoil O Criostoir Teo, Ballincollig, Cork, Ireland). Before commencing with injection of the brine, visible fat was removed and the beef was portioned in order that all meat pieces had the same starting weight (2.0 kg). Semitendinosus muscles within the pH range from 5.5 ± 0.1 were taken for production. Firstly, five brine solutions with a constant concentration of potassium nitrite and different levels of sodium chloride were prepared using the following calculation:

$$\%\text{ ingredient in brine} = \frac{\%\text{ ingredient in final product x } (100 + \text{injection rate})}{\text{injection rate}}$$

This ensured a residual potassium nitrite level of 0.0185 g/100 g and a range of sodium contents from 1.0, 0.8, 0.6, 0.4 to 0.2 g/100 g in the final product (Table 1). In the second part of this study, salt replacer combinations were added to the brine solution to achieve acceptable low salt (0.44 g Na/100 g) corned beef samples (Table 1). Table 1 includes molar concentrations of NaCl and KCl for each formulation. The following seven combinations were chosen: potassium chloride and sodium chloride 50/50 g/100 g (CB_KCl); mixture of potassium lactate, potassium chloride and sodium chloride 10/40/50 g/100 g (CB_KLCl); mixture of potassium citrate, potassium phosphate, potassium chloride and sodium chloride 20/20/20/40 g/100 g (CB_KCPCl); mixture of potassium lactate, glycine and sodium chloride 20/20/60 g/100 g (CB_KLG); mixture of calcium chloride, magnesium chloride, potassium chloride and sodium chloride 15/5/45/35 g/100 g (CB_CaMgKCl1); mixture of calcium chloride, magnesium chloride, potassium chloride and sodium chloride 15/5/25/55 g/100 g

(CB_CaMgKCl2) and a mixture of potassium chloride, glycine and sodium chloride 30/20/50 g/100 g (CB_KClG).

With the help of a hand injector (Friedr. Dick GmbH & Co. KG, Deizisau, Germany), the homogenized brine solution was injected into the standardised beef until an injection rate of 20 g/100 g was reached. Afterwards the beef was vacuum packed, stored into the chiller at 4°C for 24 hours and then cooked in a Zanussi convection oven (C. Batassi, Conegliano, Italy) with 100 % steam at 85 ºC for 3 hours. After cooking, the samples were transferred immediately into the chill at 4 °C. Thirteen test runs (in total 39 muscles used) were conducted using multi-needle injector and hand injector equipment to determine the most suitable manufacturing process. The focus was directed on producing replicable corned beef samples. During these test runs, muscles (raw) were also analysed for protein, fat, moisture and pH. Small ranges in protein (22.0 ± 1.0 g), fat (2.5 ±0.5 g) and water levels (72.0 ± 1.0 g) were found. Values for pH were in the range from 5.5 ± 0.1, and few outliers were recorded. Only muscles in the pH range (5.5 ± 0.1) were used in the study. Semitendinosus muscle used in this study had a sodium (Na) content of 60 mg/100 g ±5mg and a potassium content (K) of 365±10 mg/100 g. Once standardization was complete all corned beef samples were produced in duplicate (two independent samples per treatment) and were then analysed in duplicate.

2.2 Sensory evaluation

Sensory acceptance testing was conducted using untrained assessors (n = 25 - 29) (Stone, Bleibaum & Thomas, 2012a; Stone & Sidel, 2004) who ranged in age from 19 – 56 yeas of ageand who consumed corned beef regularly. The experiment was conducted in panel booths, which conformed to International Standards (ISO, 1988). The samples were taken from the refrigerator (4°C) and then after 15 minutes at ambient temperature (~20°C) served as 30 g, 3 mm thick slices, coded in randomised order and presented in duplicate to assessors (Stone, Bleibaum & Thomas, 2012b) with separate sessions undertaken for studies 1 and 2 (Table 1). The assessors were asked to assess samples using the sensory acceptance test, on a continuous line scale from 0 cm, extremely dislike to 10 cm, extremely like, in relation to the following hedonic attributes: liking of appearance, liking of flavour, liking of texture, liking of colour. Overall acceptability was also evaluated using the scale for 0 cm, extremely unacceptable to 10 cm, extremely acceptable. The assessors were then trained (O'Sullivan, 2017abc) and participated in a separate ranking descriptive analysis (RDA) according to the method of Richter, Almeida, Prudencio & Benassi, 2010. This RDA method used the consensus list of sensory descriptors; fatness, spiciness, saltiness, juiciness, toughness, corned beef flavour, cured flavour and off-flavour (intensity), which was also measured on a 10 cm continuous line scale with the term "none" used as the anchor point for the 0 cm end of the scale to "extreme" for the 10 cm end of the scale. The descriptors were selected from panel discussion as the most appropriate and reflected the main variation in the samples profiled. The samples were also taken from the refrigerator (4°C) and after 15 minutes at ambient temperature (~20°C) served as 30 g, 3 mm thick slices, coded in randomised order and presented simultaneously to assessors (Stone et al., 2012b) with separate sessions undertaken for duplicates and for studies 1 and 2 (Table 1).

2.3 Fat and moisture analysis

Approximately 1.0 g of each homogenised vacuum packed corned beef sample was measured in triplicate using the SMART Trac system (CEM GmbH, Kamp-Lintfort, Germany) for analysing moisture and fat, respectively (Bostian, Fish, Webb & Arey, 1985).

2.4 Protein analysis

Protein content was determined in triplicate using the Kjeldahl method (Suhre, Corrao, Glover & Malanoski, 1982). Approximately 0.8 - 1.0 g of homogenised sample was weighed into a digestion tube to which 2 catalyst tabs (3.5 g potassium sulphate and 3.5 mg selenium per tab), 15 ml concentrated sulphuric acid and 10 ml of 30 g hydrogen peroxide /100 g H_2O were added. Additionally, a blank tube was prepared similarly to serve as a control. The tubes were then placed in a digestion block (FOSS, Tecator ™ digestor, Hillerød, Denmark), heated up to 410 ºC and held for 1 hour. After cooling, 50 ml of distilled water were added to each tube, which were then placed into the distillation unit (FOSS, Kjeltec ™ 2100, Hillerød, Denmark) along with a receiver flask containing 50 ml 4 g/100 g boric acid with indicator (bromcresol green and methyl red). A total of 70 ml of 30 g/100 g sodium hydroxide was added to the tube before the 5 min distillation started. The content of the receiver flask was titrated with 0.1 mol/l hydrochloric acid until the green colour reverted back to red.

2.5 Ash analysis

The ash content was determined in triplicate for samples using a muffle furnace (Nabertherm GmbH, Lilienthal, Germany) (AOAC, 1923). Approximately 5.0 g of homogenized samples were weighed into crucibles and heated up to 600 ºC stepwise until a white ash was presented.

2.6 Salt analysis

2.6.1 Potentiometer

Salt content of corned beef samples, containing chloride ions bound only to sodium, were obtained in triplicate using the potentiometric method (Fox, 1963) by utilising a chloride sensitive electrode (Ag electrode in combination with a reference electrode Ag/AgCl buffered with KCl (M295 and pH C3006, Radiometer Analytical SAS, Lyon, France)). Approximately 2.0 g of blended samples were weighed into a flask to which 100 ml of 0.1 ml/100 ml nitric acid was added. The solutions were mixed, covered and placed in a 60 ºC water bath for 15 min. After cooling down, the flasks were potentiometrically titrated with 0.1 mol/l silver nitrate until a current of +255 mV was achieved. By means of the ratio to chloride, sodium chloride concentrations were calculated, as was sodium content.

2.6.2 Flame photometer

Sodium content was determined (in triplicate) using the flame photometer for samples containing chloride ions bounding not only to sodium (AOAC, 1988). Firstly, 5.0 g of homogenized sample was ashed (section 2.5.) The obtained ash was dissolved with 40 ml concentrated HCl (9 mol/l) until boiling, transferred to a 50 ml volumetric flask and then filled up. After this step, the solution was filtered. Subsequently, the filtrate was diluted within the range of the sodium standard concentrations. The diluted filtrate was then measured using the flame photometer (Jenway PFP7, Dunmow, Essex, England).

2.7 Cooking loss analysis

Before cooking (section 2.1), sample weights were recorded. After cooking, samples were allowed to cool down overnight and then weighed again to obtain the cooking loss.

2.8 Colour analysis

Colour analysis was undertaken on six corned beef slices of each sample by utilising a Minolta CR 400 Colour Meter (Minolta Camera Co., Osaka, Japan) with 11 mm aperture and D_{65} illuminant. The tristimulus values were expressed in L* (lightness), a* (red-green dimension) and b* (yellow-blue dimension) (International Commission on Illumination, 1976). Firstly, a white tile (Y=93.6, x=0.3130, y=0.3193) was applied for calibration the colorimeter, afterwards ten readings were taken per slice.

2.9 Texture analysis

The instrumental texture of corned beef was evaluated using shear force, which was measured utilizing a Texture Analyzer 16 TA-XT2i (Stable Micro Systems, Godalming, U.K) attached with a Warner-Bratzler blade (connected to a 25 kg load cell) (Bratzler, 1932). Each corned beef sample was assessed 15 times. For that, 12mm diameter core samples were cut with a test speed of 3.0 mm/s by a Warner-Bratzler blade (pre-test speed 3.0 mm/s; post-test speed 10.0 mm/s). The recorded force peak represents the hardness of the product.

2.10 Shelf-life test

Total Viable Counts (TVC) (ICMSF, 2011) were carried out for corned beef samples containing 1.0 g/100 g sodium, 0.4 g/100 g sodium and 0.4 g/100 g sodium formulated with potassium lactate, glycine and sodium chloride (CB_KLG) (section 2.1). Three slices of corned beef sample (in duplicate) with thicknesses of 3 mm were packed for each shelf-life test run. Two different packaging configurations were utilized: vacuum packaging (VP) and modified atmosphere packaging (MAP) (70 g N_2: 30 g CO_2/100 g gas). On the day of commencing the shelf-life test, a 10 g sample was placed into a stomacher bag with sterile 90 ml Maximum Recovery Diluent (MRD) and homogenised in a paddle blender (STOMACHER 400, Colworth, UK) for 3 min. Appropriate sample dilutions were prepared as followed: 1 ml aliquot was transferred into sterile screw-capped tubes containing 9 ml MRD and then mixed (Vortex mixer SA 7, Stuart, Staffordshire, UK). Afterwards, 0.1 ml of each dilution were plated in duplicate onto Plate Count Agar (PCA). All plates were aerobically incubated at 37°C for 48 hours. The results were expressed as Colony Forming Unit per g sample (CFU/ g). Following the guideline for cooked meat, including cured products, by the International Commission on Microbiological Specifications for Foods (ICMSF) (ICMSF, 2011), the acceptable limit in this study was defined as $< 10^5$ CFU/ g of sample.

2.11 Data analysis

For evaluating the results of the RDA and the sensory acceptance test, ANOVA-Partial Least Squares regression (APLSR) was used to process the data accumulated using Unscrambler software version 10.3. The X-matrix was designed as 0/1 variables for salt content and the Y-matrix sensory variables. Regression coefficients were analyzed by Jack-knifing, which is based on cross-validation and stability plots (Martens & Martens, 2001). Table 2 displays corresponding P values of the regression coefficients. The validated and calibrated explained variances were 34 % and 14 % respectively.

For evaluation of the technological data, Tukey's multiple comparison analysis (one-way ANOVA) was carried out, using Minitab 16 software, to separate the averages ($P < 0.05$).

3. Results and discussion

3.1 Sensory evaluation

3.1.1 Salt reduction in corned beef

The results of the sensory evaluation of corned beef with varied salt levels are displayed in the APLSR plot in Figure 1 and the corresponding ANOVA values, including significance and correlation factors presented in Table 2 for hedonic and descriptive sensory assessments, respectively.

As can be seen in Table 2 varying the sodium chloride levels in corned beef did not significantly affect either liking of colour or appearance. The curing agent potassium nitrite, amongst others, was responsible for developing the red colour, as it reacts with myoglobin to form the heat-stable NO-myoglobin (Fe^{2+}) (Haldane, 1901; Kisskalt, 1899; Lehmann, 1899). Potassium nitrite was added at a constant concentration to the brine for all five corned beef formulations (Table 1), therefore no major differences in colour were expected.

From Figure 1, in the right hand quadrant of the plot, liking of texture correlated positively to corned beef samples low in sodium (0.2 g/100 g, 0.4 g/100 g). Furthermore, these samples correlated negatively to juiciness and toughness. Samples with higher sodium contents were assessed inversely to this data by assessors. No significant differences were determined between formulations (Table 2). Hamm (1972) and Honikel (2010) postulated the theory that the injected sodium chloride penetrates into the meat cells, which causes a swelling of myofibrillar proteins. Furthermore, more water molecules are able to move between the proteins chains. During heating, the swollen myofibrillar proteins become softer, the added water remains and the meat becomes juicy. This is in agreement with Desmond (2006), who correlated an increase in water holding capacity of myofibrillar proteins in processed meat to an increase in juiciness and tenderness. This theory that salt increases juiciness and tenderness of meat products can be confirmed partly in the present study, as lower salt samples were found to be drier, but also more tender. Aaslyng et al. (2014) similarly reported in a study that very low salted (1.3 g/100 g NaCl) boiled ham decreased juiciness and firmness, although low salted (1.8 g/100 g NaCl) boiled ham was rated positively for juiciness and firmness.

Lower sodium corned beef samples (0.4, 0.2 g/100 g) were rated lower ($P < 0.05$) for saltiness and corned beef with 1.0 g Na/100 g product were found to be ($P < 0.001$) more salty (Table 2). Furthermore, samples low in sodium correlated negatively to corned beef flavour and cured flavour. Reverse outcomes were recorded for the higher sodium samples (0.6 - 1.0 g/100 g product), though no significant results were achieved for any of the five formulations assessed. However, these results are in consistent agreement with the theory that salt plays a key role in enhancing the flavour, besides developing the salty taste (Hutton, 2002), which had been well confirmed in previous studies over the last 10 years (Aaslyng et al., 2014; Fellendorf et al., 2015; Ruusunen et al., 2005; Tobin et al., 2012a).

In spite of decreased saltiness ($P < 0.05$), corned beef flavour and cured flavour perceptions, samples containing 0.2 g/100 g and 0.4 g/100 g sodium, respectively, correlate positively to liking of flavour and overall acceptability (Figure 1, Table 2). It is probable that because of the positive correlations to off-flavour, assessors did not accept ($P > 0.05$) corned beef samples high in sodium (0.6 - 1.0 g/100 g). They detected off-flavours in samples high in sodium. This off-flavour was not caused by rancidity developing over time since all samples were served immediately after production to guarantee freshness. A positive correlation to off-flavour was also noted by Tobin et al. (2012a, 2012b) for higher salt frankfurters (3.0, 2.5, 2.0 g/100 g) and beef patties (1.5, 1.25 g/100 g). However, the lower sodium corned beef samples (0.4, 0.2 g/100 g) were correlated to acceptance by the assessors, even with decreased flavour perceptions.

3.1.2 Salt replacers in corned beef

Seven different salt replacer combinations were added to corned beef samples containing 0.4 g Na/100 g product, with the target of improving the flavour profile (section 3.1.1) and producing a consumer-acceptable end product. The sensory evaluation of these sodium-reduced corned beef samples are shown in an APLSR plot (Figure 2) in conjunction with the ANOVA values for hedonic and descriptive sensory assessments (Table 2).

As can be seen in Figure 2, only the corned beef sample containing 0.4 g/100 g sodium (control) is located on the y-axis. In contrast, samples formulated with replacers are scattered around the plot (Figure 2), therefore the addition of replacers in corned beef impacted upon sensory properties.

The attributes; liking of appearance and colour are located close to the center of the plot (Figure 2) which indicates that the added replacers to corned beef did not affect appearance or colour. Consequently, no significant results were achieved (Table 2). It is well known that the agent potassium nitrite develops the typical cured meat colour (Haldane, 1901; Kisskalt, 1899; Lehmann, 1899). However, in a previous study by Fellendorf, O'Sullivan, & Kerry et al. (2016c) also found no changes in either colour or appearance for low salt and low fat (uncured) black pudding samples formulated with 11 different ingredient replacer combinations.

As can be seen in Figure 2, sodium-reduced corned beef samples formulated with KLG and KClG, respectively, correlate positively to liking of texture and toughness, and negatively for juiciness. However, no significant differences in results for texture attributes, juiciness, toughness and liking of texture were observed across all treatments (Table 2). In summary, adding salt replacers to lower sodium corned beef resulted in unnoticeable effects on product texture by assessors. However, dependent upon the ratio of salt-replacers used, significant changes in texture were reported (Gelabert, Gou, Guerrero & Arnau 2003) through the substitution of sodium chloride in fermented sausages formulated with potassium lactate and glycine, and accordingly, with potassium chloride and glycine.

In the present study, the lower sodium corned beef sample formulated with KClG were rated even lower ($P < 0.05$) in saltiness perception by assessors. This outcome is in agreement with Gelabert et al. (2003) who reported that all five different ratio combinations of potassium chloride and glycine added to fermented sausages were not able to mask the decreased salty taste of products.

Corned beef formulations containing KCl, KLCl and accordingly KCPCl were rated similarly by assessors. These samples were positively correlated to saltiness, and negatively correlated to intensity of corned beef and cured flavour. Furthermore, these samples showed a negative correlation to liking of flavour and overall acceptability. However, no significant results were achieved. Guàrdia et al. (2008) reported on small caliber fermented sausages with a 50 g/100 g substitution of NaCl with 50 g/100 g KCl and accordingly, a mixture of KCl/potassium lactate (40/10 g/100 g), and concluded that these samples scored similarly to the control with respect to overall acceptability. However, Vadlamani, Friday, Broska & Miller (2012) published contradicting data for eight different ratio combinations with KCl, potassium phosphate and potassium citrate in chicken broth, which significantly increased overall flavour scores.

Assessors rated the low sodium samples formulated with CaMgKCl1 and CaMgKCl2 higher (*P* < 0.001) in saltiness (Table 2). Hence, these salt replacers appeared to have the capacity to enhance the saltiness perception in corned beef. No significant results were obtained for the sensory attributes of corned beef flavour and cured flavour. Furthermore, these samples displayed negative correlations to liking of flavour and overall acceptability (Figure 2), which confirm the results reported in section 3.1.1, where assessors preferred corned beef products with a less salty taste. However, Armenteros, Aristoy, Barat & Toldrá (2009) reported that the addition of CaMgKCl2 to dry-cured loins can be used to reduce the sodium content without negatively affecting product sensory qualities. Two other ratio combinations of sodium, magnesium, calcium and potassium chloride were tested without success. Armenteros, Aristoy, Barat & Toldrá (2012) prepared dry-cured hams with $NaCl/KCl/CaCl_2/MgCl_2$ (55/25/15/5 g/100g) which were scored lower in aroma and taste compared to the control and the sample formulated with sodium and potassium chloride (50/50 g/100 g). All things considered, these results demonstrate that for each meat product, the sodium chloride level and the type and ratio of salt replacer has to be adjusted to reach a highly accepted end product.

Sodium-reduced corned beef samples formulated with KLG achieved positive (*P* < 0.05) correlations to liking of flavour and additionally displayed a positive directional correlation to overall acceptability. This sample was scored very low (*P* < 0.001) in saltiness perception and no off-flavours were detected (*P* < 0.05). Previously, significantly lower scores for saltiness were also reached for fermented sausages formulated with a mixture of sodium chloride, potassium lactate and glycine (60/20/20 g/100 g product) (Gelabert et al., 2003). Nevertheless, in the present study, assessors preferred corned beef samples with the lowest salty taste, which is similar to the results reported in section 3.1.1.

In summary, a sodium reduction of 60 g/100 g in corned beef is achievable based on assessors' feedback. Assessors liked (*P* < 0.05) the flavour of sodium-reduced corned beef containing only 0.4 g/100 g sodium and formulated with potassium lactate and glycine (CB_KLG), even with the noticeable lower salty taste.

3.2 Characterization of corned beef

3.2.1 Characterization of salt reduced corned beef

The compositional properties of corned beef samples containing different sodium levels are presented in Table 3. In the present study the average protein content of corned beef was 30 g/100 g, which is 20 g/100 g higher compared to the literature (American corned beef), as the fat was initially removed to standardize the beef pieces used in this study. For this reason, the fat content was one third lower (Souci, Fachmann, & Kraut, 2004). The sodium levels in all final corned beef samples were slightly lower than targeted levels (Table 3), because of the curing process (injection) and the resulting exudative losses. The higher salt addition (CB_S1.0, CB_S0.8) reflects a higher mineral ash content, as to be expected in these samples, which contributed to reducing percent fat levels. These samples also displayed slightly higher protein levels and slightly lower moisture, which could be the result of the greater myofibrillar protein extraction, due to the action of salt, which resulted in more chemically bound water to actin and myosin. This does not appear to have effected sensory response as only the sensory attribute saltiness was found to increase significantly with increasing salt level in sample CB_S1.0 (study 1) with all other hedonic and descriptive attributes determined to be non-significantAverage lightness (L) values of 59 ± 3, redness (a) values of 17 ± 1 and yellowness (b) values of 12 ± 1 were measured for the five corned beef samples containing different sodium levels (Table 4). Furthermore, significant differences in colour were recorded. The curing agent potassium nitrite and the protein myoglobin found in muscle tissue react with NO-Myoglobin (Fe^{2+}), which is responsible for the typical red colour of cured meat (Honikel, 2010). Hence, cured colour is dependent upon the amount of curing agent used, resting period employed and on meat quality selected, among other factors. Before curing, differences in meat colour can already be caused by the kind of muscle selected, animal species, age, feeding, pH, stress (before slaughtering) and shelf-life (Potthast, 1987; Renerre, 1990). Added salt affects the pH, water activity and shelf-life of the meat (Barat & Toldrá, 2011; Durack, Alonso-Gomez, & Wilkinson, 2008; Honikel, 2010), although in the present study, no trend was observed between different salt levels employed and colour. Since potassium nitrite was added at a constant level, it is assumed that the meat quality itself caused the observed differences in colour. However, these colour changes did not influence assessors' liking of meat colour (Table 2).

The measured hardness of the salt-reduced corned beef samples ranged from 20 N to 26 N (Table 4). Significant differences in shear force values were noted. However, different salt levels did not account for differences in hardness values obtained in the present study. Similar to the present study, Lee & Chin (2011a) did not achieve higher Allo-Kramer shear values for salt-reduced pork loins. King, Wheeler, Shackelford & Koohmaraie (2009) reported that tenderness is also influenced by complex interactions of multiple ante-mortem and post-mortem factors.

One concern of the meat industry with respect to salt reduction in meat products is the possible decrease in water-holding capacity, thereby adversely affecting processing yields and product sensory qualities (Barat & Toldrá, 2011). In the present study, cooking losses from 38 to 41 g/100 g were recorded, though no significant differences were achieved between samples (Table 4). Hence, allaying the concerns of the meat industry, different salt levels employed in corned beef manufacture in this study did not negatively alter cooking losses and therefore, processing yields. In contrast, Lee & Chin (2011b) reported significant increases in cooking loss for salt-reduced (0.5 - 1.0 g/100 g) restructured pork hams.

3.2.2 Characterization of sodium reduced corned beef formulated with salt replacers

The measured protein, fat and moisture contents of salt-reduced corned beef samples formulated with salt replacers are comparable to corned beef samples containing different salt levels (Table 3). Again, measured sodium levels were slightly lower than target level.

Physicochemical data (colour, hardness and cooking loss) are presented in Table 4. Average lightness (L) values of 57 ± 2, redness (a) values of 18 ± 0 and yellowness (b) values of 13 ± 1 were recorded for sodium-reduced corned beef samples formulated with salt replacers. The measured shear force of corned beef samples formulated with salt replacers ranged from 19 N to 29 N. Significant differences in colour and hardness values were obtained between each formulation. Aliño et al. (2010b) reported that dry-cured loins containing 30 % NaCl, 50 % KCl, 15 % $CaCl_2$ and 5% $MgCl_2$ had significantly higher hardness values than dry-cured loins containing a salt formulation consisting of 55 % NaCl, 25 % KCl, 15 % $CaCl_2$ and 5 % $MgCl_2$. Similar results were found in the present study. The highest shear force was recorded for CB_CaMgKCl1, while the lowest force was determined for CB_CaMgKCl2. Recently, Aliño et al. (2010a) also reported that dry-cured hams salted with NaCl/KCl (50/50 %) were significantly harder compared to hams salted with NaCl/KCl/$CaCl_2$/$MgCl_2$ (55/25/15/5 %). No significant differences in lightness, redness or yellowness values were determined. In the present study, the corned beef sample CB_KCl also showed higher (not significant) shear force values compared to corned beef sample CB_CaMgKCl2. Furthermore, no significant differences in redness or yellowness were recorded, although sample CB_KCl was darker ($P < 0.05$).

As shown in Table 4, cooking losses for corned beef samples formulated with salt replacers ranged from 37 g/100 g to 42 g/100 g. Significant differences compared to the control were observed. The lowest cooking loss was achieved for corned beef sample CB_CaMgKCl1. Guàrdia et al. (2008) recorded for small caliber fermented sausages an average weight loss of 47.4 g per 100g of product. Fermented sausages with a 50 g/100 g substitution of NaCl with 50 g/100 g KCl and accordingly a substitution of 10 g/100g potassium lactate with 40 g/100g KCl showed no significant differences in weight loss. Similar results were found in the present study for corned beef samples CB_KCl and CB_KLCl when comparing similar salt replacers.

3.3 Shelf-life test

The TVC-test was conducted for corned beef samples containing 1.0 g/100 g sodium, 0.4 g/100 g sodium and 0.4 g/100 g sodium formulated with potassium lactate, glycine and sodium chloride (CB_KLG). The vacuum packaged corned beef samples containing 0.4 g/100 g sodium possessed the shortest shelf-life from all examined samples, as a total viable count of $\geq 10^5$ CFU/ g per sample was recorded after 21 days of storage. After 56 days of storage, vacuum packaged corned beef samples formulated with 1.0 g/100 g sodium, and accordingly CB_KLG, were also deemed to have expired. Hence, corned beef with the lowest sodium content, not surprisingly, had the shortest shelf-life. It is well known that salt acts as a food preservative by reducing the water activity of food, thereby inhibiting the growth of microorganisms. However, adding salt replacers like potassium lactate and glycine to corned beef with 0.4 g/100 g sodium (CB_KLG) extended product shelf-life. This result corroborates the theory that glycine and lactate are able to decrease the water activity, and additionally, act as salt enhancer for various types of sausages (Gelabert et al., 2003; Gou et al., 1996; Kilcast & Angus, 2007). All three corned beef samples packaged with MAP recorded no microbial growth until day 82 of chilled storage. No further tests were conducted as the achieved storage life was already 4- to 6-times longer than that currently available for commercial MAP corned beef (unpublished data, 2014). The gas mixture employed in the present study consisted of 70 g N_2 : 30 g CO_2/100 g gas, which is typical for cooked meats (Smiddy, Papkovskaia, Papkovsky, & Kerry, 2002). As no oxygen was used, the growth of aerobic bacteria was inhibited, which is consistent with the literature (Cutter et al., 2012). Presumably, the shorter shelf-life of commercial corned beef products is caused by sensory deterioration rather than by exceeding the limit of 10^5 CFU/ g per sample for total viable count. However, it is well known that the shelf-life of refrigerated meat can be prolonged by packaging with nitrogen and carbon dioxide (Gill & Molin, 1991).

In summary, sodium reduction in corned beef using MAP did not negatively affect the shelf-life of corned beef samples. Even the shelf-life of vacuum packaged sodium-reduced corned beef samples lasted similarly to commercially-available corned beef.

4. Conclusion

Significant differences in colour and hardness were measured for corned beef samples containing varying sodium levels (0.2 - 1.0 g/100 g), although there was no connection found between these quality parameters and sodium levels. Corned beef samples low in sodium (0.2, 0.4 g/100 g) showed reduced ($P < 0.05$) saltiness perceptions, but were positively correlated to liking of flavour and overall acceptability. Assessor liked ($P < 0.05$) the flavour of sodium-reduced corned beef containing 0.4 g/100 g sodium and formulated with potassium lactate and glycine (CB_KLG), even with the noticeable lower salty taste. Therefore, the sodium target level of 650 mg/100 g set by Food Standards Agency (FSA, 2017), and as applied within the UK and Ireland, was obtained in this study. The sensory (hedonic) driven salt reduction strategy employed in this study was effective in identifying optimal samples and combined with the descriptive data allowed for quantitative determination of the main sensory drivers in the experimental variants. Finally, sodium reduction in corned beef did not negatively affect product shelf-life when combined with MAP.

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Table 2
P-values of regression coefficients from ANOVA-Partial Least Squares regression (APLSR) for hedonic and intensity sensory terms of corned beef samples with different sodium contents with and without using salt replacers.

Sample	Hedonic term					Intensity term					
	Appearance	Colour	Flavour	Texture	Acceptability	Saltiness	Juiciness	Toughness	CB flavour	Cured flavour	Off-flavour
Study I: Salt reduction											
CB_S1.0	-0.6192 ns	-0.4784 ns	-0.7595 ns	-0.9116 ns	-0.4384 ns	0.0001 ***	0.2159 ns	0.9653 ns	0.8548 ns	0.0627 ns	0.7792 ns
CB_S0.8	-0.9959 ns	-0.8485 ns	-0.5040 ns	-0.5995 ns	-0.4102 ns	0.6390 ns	0.7557 ns	0.5679 ns	0.7527 ns	0.8209 ns	0.7732 ns
CB_S0.6	-0.4469 ns	-0.4632 ns	-0.4353 ns	-0.3090 ns	-0.8979 ns	0.2684 ns	0.2374 ns	0.3377 ns	0.6520 ns	0.4375 ns	0.4971 ns
CB_S0.4	0.9572 ns	0.5692 ns	0.5048 ns	0.1846 ns	0.7899 ns	-0.0228 *	-0.6258 ns	-0.0596 ns	-0.9043 ns	-0.2533 ns	-0.4289 ns
CB_S0.2	0.7096 ns	0.4637 ns	0.2240 ns	0.5230 ns	0.8615 ns	-0.0003 ***	-0.4770 ns	-0.9070 ns	-0.9670 ns	-0.0666 ns	-0.6279 ns
Study II: Salt replacer											
CB_Control S0.4	0.6468 ns	0.8080 ns	0.7584 ns	0.5782 ns	0.6930 ns	-0.9137 ns	-0.5498 ns	0.9427 ns	0.9587 ns	-0.8608 ns	-0.7586 ns
CB_KCl	-0.7696 ns	-0.8632 ns	-0.2471 ns	0.6709 ns	-0.3889 ns	0.2839 ns	0.1494 ns	-0.6876 ns	-0.9712 ns	0.5906 ns	0.3352 ns
CB_KLCl	-0.9862 ns	-0.8894 ns	-0.7386 ns	-0.8497 ns	-0.7771 ns	0.8884 ns	0.8586 ns	-0.8705 ns	-0.9596 ns	0.9883 ns	0.8005 ns
CB_KCPCl	-0.1512 ns	-0.5546 ns	-0.2325 ns	-0.2107 ns	-0.0854 ns	0.6127 ns	0.2242 ns	-0.3482 ns	-0.4131 ns	0.3520 ns	0.3925 ns
CB_KLG	0.4990 ns	0.7805 ns	0.0198 *	0.4033 ns	0.0714 ns	-0.0001 ***	-0.7983 ns	0.5719 ns	0.9771 ns	-0.2589 ns	-0.0123 *
CB_CaMgKCl 1	-0.9599 ns	-0.9480 ns	-0.3911 ns	-0.9754 ns	-0.6161 ns	0.0018 **	0.5168 ns	-0.9175 ns	-0.9433 ns	0.2033 ns	0.3330 ns
CB_CaMgKCl 2	-0.8159 ns	-0.7783 ns	-0.9220 ns	-0.7406 ns	-0.8592 ns	0.0033 **	0.7714 ns	-0.4834 ns	-0.5773 ns	0.1156 ns	0.6585 ns
CB_KClG	0.8082 ns	0.9233 ns	0.1322 ns	0.8314 ns	0.3510 ns	-0.0116 *	-0.0791 ns	0.9770 ns	0.7495 ns	-0.3537 ns	-0.2120 ns

Sample code: CB = corned beef, S = sodium. KCl = potassium chloride, KLCl = mixture of potassium lactate and potassium chloride, KCPCl = potassium citrate, potassium phosphate, potassium chloride, KLG = mixture of potassium lactate and glycine, CaMgKCl 1 = mixture of calcium chloride, magnesium chloride, potassium chloride (15/5/45), CaMgKCl 2 = mixture of calcium chloride, magnesium chloride, potassium chloride (15/5/25), KClG = mixture of potassium chloride and glycine.
Significance of regression coefficients: ns = not significant, * = P < 0.05, ** = P < 0.01, *** = P < 0.001.

Table 3
Compositional properties of corned beef samples (g / 100 g product)

Samples	Protein	Fat	Moisture	Sodium	Ash [%]
Study I: Salt reduction					
CB_S1.0	30.3 ± 0.5	3.1 ± 0.5	64.9 ± 0.4	0.95 ± 0.06	3.4 ± 0.1
CB_S0.8	30.6 ± 0.5	3.1 ± 0.2	65.3 ± 0.5	0.70 ± 0.11	2.8 ± 0.3
CB_S0.6	29.6 ± 0.0	3.8 ± 0.5	65.0 ± 0.4	0.51 ± 0.04	2.2 ± 0.1
CB_S0.4	29.8 ± 0.5	4.4 ± 0.1	65.4 ± 0.4	0.28 ± 0.00	1.7 ± 0.0
CB_S0.2	29.9 ± 0.3	4.9 ± 0.2	63.9 ± 1.4	0.09 ± 0.01	1.1 ± 0.0
Study II: Salt replacer					
CB_Control S0.4	31.5 ± 0.4	2.7 ± 0.0	65.6 ± 0.5	0.32 ± 0.01	1.5 ± 0.2
CB_KCl	30.6 ± 0.5	2.8 ± 0.2	64.9 ± 0.2	0.34 ± 0.00	2.8 ± 0.3
CB_KLCl	30.1 ± 0.1	4.3 ± 0.5	63.5 ± 0.3	0.33 ± 0.01	2.5 ± 0.1
CB_KCPCl	31.4 ± 0.2	3.5 ± 0.2	63.5 ± 0.1	0.34 ± 0.01	3.1 ± 0.1
CB_KLG	31.4 ± 0.5	4.7 ± 0.4	64.4 ± 0.3	0.33 ± 0.01	1.9 ± 0.2
CB_CaMgKCl 1	30.1 ± 0.4	4.4 ± 0.4	64.4 ± 0.2	0.35 ± 0.01	3.4 ± 0.1
CB_CaMgKCl 2	29.0 ± 0.1	3.4 ± 0.2	66.5 ± 0.2	0.34 ± 0.01	2.3 ± 0.0
CB_KClG	30.2 ± 0.1	4.0 ± 0.2	65.3 ± 0.5	0.34 ± 0.01	2.2 ± 0.1

Sample code: CB = corned beef, S = sodium. KCl = potassium chloride, KLCl = mixture of potassium lactate and potassium chloride, KCPCl = potassium citrate, potassium phosphate, potassium chloride, KLG = mixture of potassium lactate and glycine, CaMgKCl 1 = mixture of calcium chloride, magnesium chloride, potassium chloride (15/5/45), CaMgKCl 2 = mixture of calcium chloride, magnesium chloride, potassium chloride (15/5/25), KClG = mixture of potassium chloride and glycine.
All values are averages ± standard errors.

Table 4

Colour, hardness and cooking loss values of corned beef samples.

Sample	Colour			Shear force	Cooking loss [g/ 100g]
	L*	a*	b*	Hardness [N]	
Study I: Salt reduction					
CB_S1.0	60.3 ± 0.0 [b]	16.0 ± 0.0 [b]	12.3 ± 0.0 [b]	23.6 ± 0.1 [a, b]	39.2 ± 0.1 [a]
CB_S0.8	64.0 ± 0.1 [a]	15.1 ± 0.0 [c]	12.9 ± 0.0 [a]	19.7 ± 0.1 [c]	38.3 ± 0.6 [a]
CB_S0.6	57.2 ± 0.0 [c]	18.1 ± 0.1 [a]	12.1 ± 0.1 [b]	23.5 ± 0.1 [a, b, c]	41.4 ± 0.4 [a]
CB_S0.4	57.9 ± 0.0 [c]	18.2 ± 0.0 [a]	12.6 ± 0.0 [a, b]	19.9 ± 0.1 [b, c]	40.0 ± 0.4 [a]
CB_S0.2	58.0 ± 0.1 [c]	18.2 ± 0.0 [a]	11.3 ± 0.1 [c]	26.3 ± 0.1 [a]	41.1 ± 0.7 [a]
Study II: Salt replacer					
CB_Control S0.4	60.2 ± 0.0 [a]	17.2 ± 0.0 [b, c]	12.4 ± 0.0 [c]	21.7 ± 0.1 [b, c, d]	42.4 ± 0.5 [a]
CB_KCl	55.9 ± 0.0 [d]	17.7 ± 0.1 [a. b]	13.3 ± 0.0 [b]	23.5 ± 0.1 [a, b, c, d]	41.9 ± 0.2 [a, b]
CB_KLCl	58.4 ± 0.1 [b]	17.1 ± 0.0 [c]	13.8 ± 0.1 [b]	26.8 ± 0.1 [a, b]	40.0 ± 0.4 [a, b]
CB_KCPCl	56.2 ± 0.2 [c, d]	18.0 ± 0.0 [a]	13.7 ± 0.1 [a, b]	25.1 ± 0.1 [a, b, c, d]	40.1 ± 0.3 [a, b, c]
CB_KLG	56.5 ± 0.0 [c, d]	17.1 ± 0.1 [b, c]	13.3 ± 0.0 [b]	27.9 ± 0.1 [a]	40.1 ± 0.3 [a, b, c]
CB_CaMgKCl 1	55.6 ± 0.0 [d]	17.8 ± 0.0 [a]	14.0 ± 0.0 [a]	28.5 ± 0.1 [a]	37.2 ± 0.7 [c]
CB_CaMgKCl 2	58.6 ± 0.0 [b]	17.9 ± 0.0 [a]	13.6 ± 0.0 [a, b]	18.6 ± 0.1 [d]	38.9 ± 0.4 [b, c]
CB_KClG	57.2 ± 0.1 [c]	18.1 ± 0.0 [a]	12.7 ± 0.1 [c]	20.1 ± 0.1 [c, d]	39.4 ± 0.3 [a, b, c]

[a-d] Averages sharing different letters in the same column are significantly different ($P < 0.05$).

Sample code: CB = corned beef, S = sodium. KCl = potassium chloride, KLCl = mixture of potassium lactate and potassium chloride, KCPCl = potassium citrate, potassium phosphate, potassium chloride, KLG = mixture of potassium lactate and glycine, CaMgKCl 1 = mixture of calcium chloride, magnesium chloride, potassium chloride (15/5/45), CaMgKCl 2 = mixture of calcium chloride, magnesium chloride, potassium chloride (15/5/25), KClG = mixture of potassium chloride and glycine.

All values are averages ± standard errors.

Table 1

Corned beef formulations with different sodium contents with and without using salt replacers.

Sample	g in 100 g final product NaCl	Na	Moles NaCl	K(nitrite)	KCl	Moles KCl	K(phosphate)	K(citrate)	K(lactate)	$CaCl_2$	$MgCl_2$	Glycine
Study I: Salt reduction												
CB_S1.0	2.54	1.00	0.017	0.0185	-	-	-	-	-	-	-	-
CB_S0.8	2.03	0.80	0.014	0.0185	-	-	-	-	-	-	-	-
CB_S0.6	1.52	0.60	0.01	0.0185	-	-	-	-	-	-	-	-
CB_S0.4	1.02	0.40	0.007	0.0185	-	-	-	-	-	-	-	-
CB_S0.2	0.51	0.20	0.003	0.0185	-	-	-	-	-	-	-	-
Study II: Salt replacer												
CB_Control S0.4	1.02	0.40	0.007	0.0185	-	-	-	-	-	-	-	-
CB_KCl	1.02	0.40	0.007	0.0185	1.02	0.014	-	-	-	-	-	-
CB_KLCl	1.02	0.40	0.007	0.0185	0.81	0.011	-	-	0.20	-	-	-
CB_KCPCl	1.02	0.40	0.007	0.0185	0.51	0.007	0.51	0.51	-	-	-	-
CB_KLG	1.02	0.40	0.007	0.0185	-	-	-	-	0.34	-	-	0.34
CB_CaMgKCl 1	1.02	0.40	0.007	0.0185	1.31	0.018	-	-	-	0.44	0.15	-
CB_CaMgKCl 2	1.02	0.40	0.007	0.0185	0.46	0.006	-	-	-	0.28	0.09	-
CB_KClG	1.02	0.40	0.007	0.0185	0.61	0.008	-	-	-	-	-	0.41

Sample code: CB = corned beef, S = sodium. KCl = potassium chloride, KLCl = mixture of potassium lactate and potassium chloride, KCPCl = potassium citrate, potassium phosphate, potassium chloride, KLG = mixture of potassium lactate and glycine, CaMgKCl 1 = mixture of calcium chloride, magnesium chloride, potassium chloride (15/5/45), CaMgKCl 2= mixture of calcium chloride, magnesium chloride, potassium chloride (15/5/25), KClG = mixture of potassium chloride and glycine.

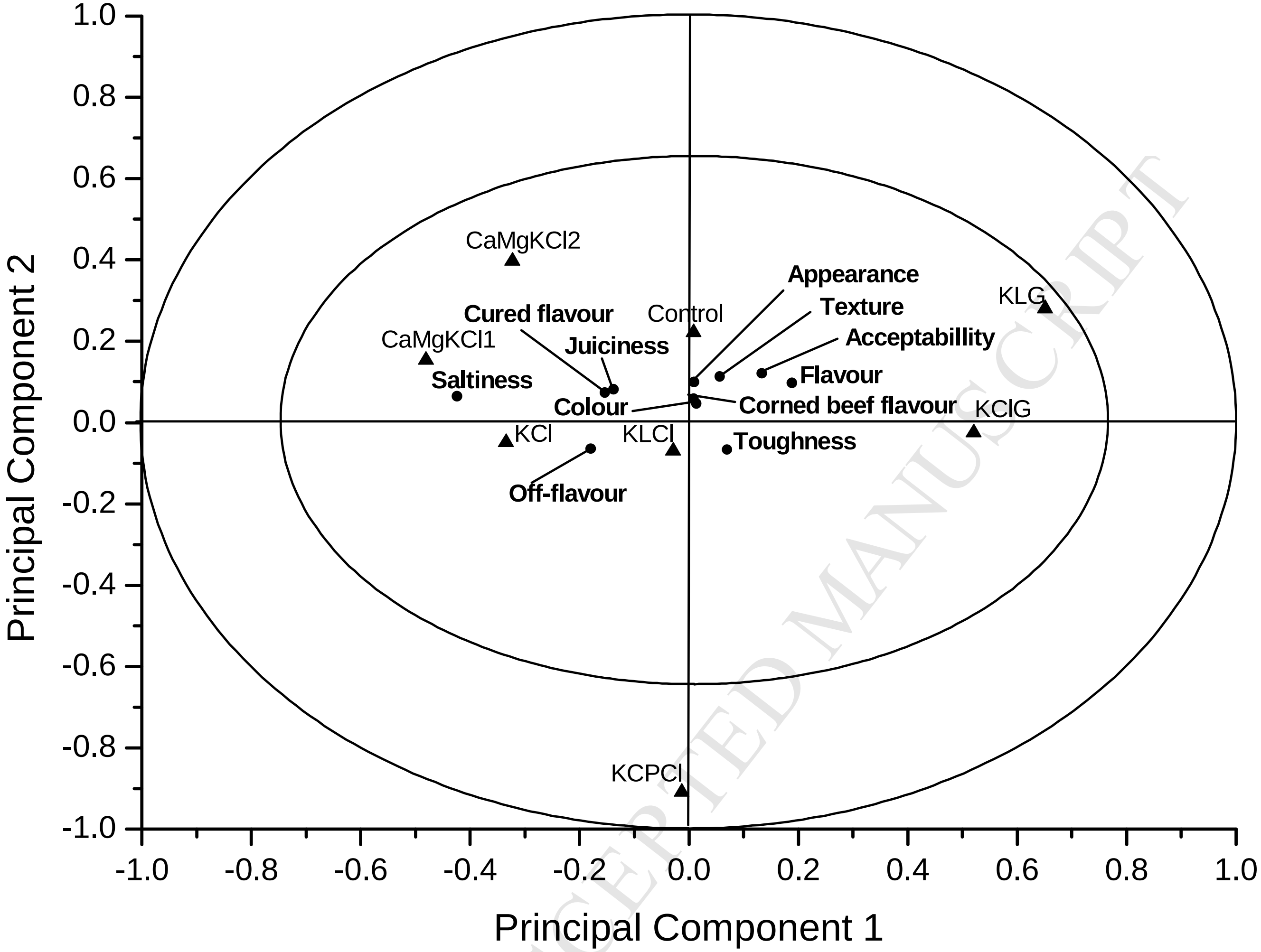

Figure 2

ANOVA-Partial Least Squares regression (APLSR) for the corned beef formulations. ▲ = Samples (code: Control = corned beef (0.4% sodium); KCl = potassium chloride; KLG = mixture of potassium lactate and glycine; KClG = mixture of potassium chloride and glycine; KLCl = mixture of potassium lactate and potassium chloride; KCPCl = mixture of potassium chloride, potassium phosphate, potassium chloride, CaMgKCl1 = mixture of calcium chloride, magnesium chloride, potassium chloride (15/5/45); CaMgKCl2 = mixture of calcium chloride, magnesium chloride, potassium chloride (15/5/25), ● = sensory attributes. Factor-1 (25%, 3%), Factor-2 (25%, 0%).

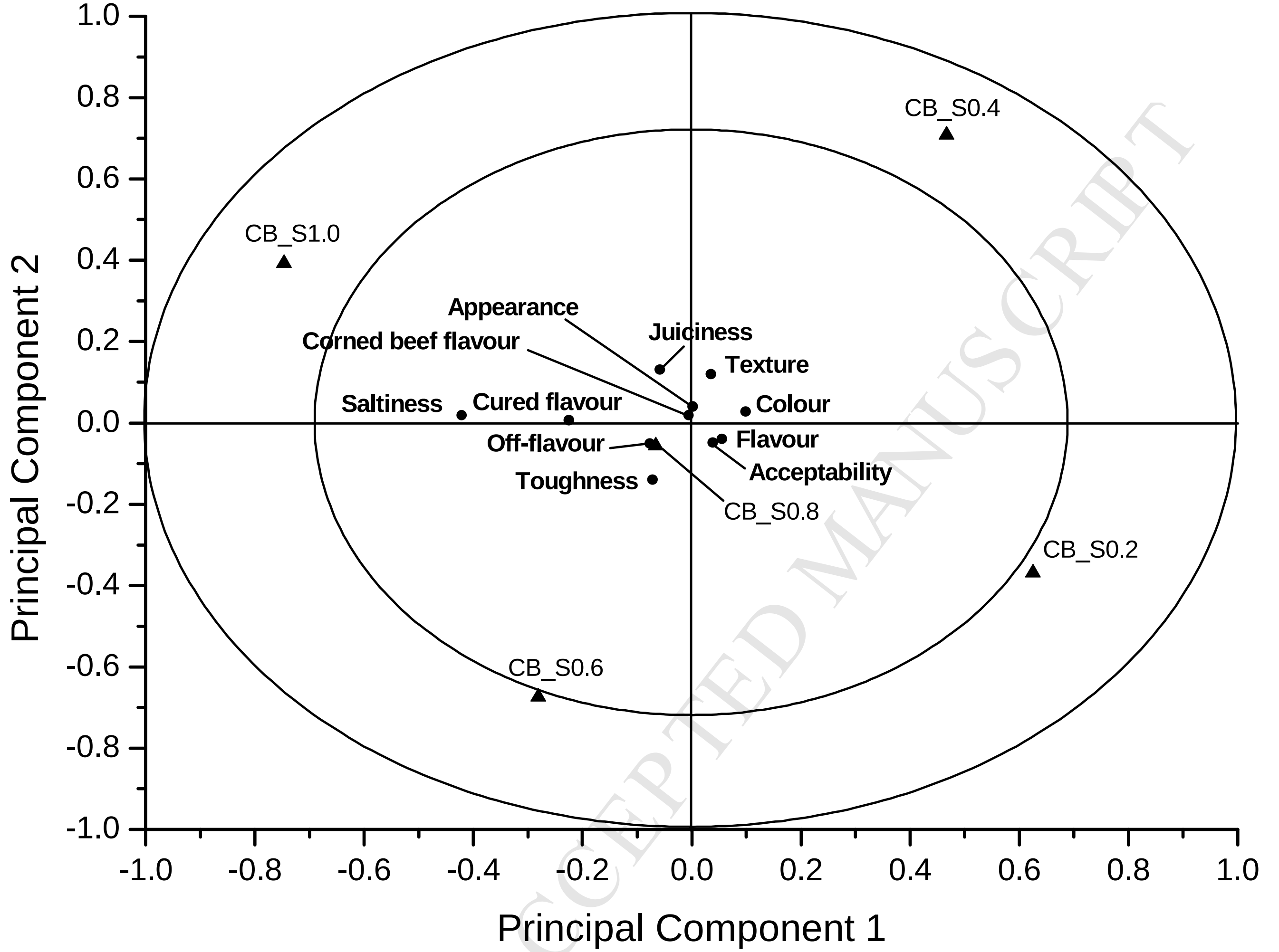

Figure 1

ANOVA-Partial Least Squares regression (APLSR) for the corned beef formulations. ▲ = Samples (code: CB = corned beef, S = sodium), ● = sensory attributes. Factor-1 (25%, 2%), Factor-2 (25%, 1%).

Highlights

Samples containing 0.4 g/100g sodium displayed significantly reduced salt perception < Assessors significantly liked the flavor of corned beef containing 0.4 g/100g sodium < Sodium was significantly reduced compared to current levels in commercial products < Reduced sodium product shelf-life was maintained when combined with MAP.