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Mathematical modelling of colour, texture kinetics and sensory attributes characterisation of ripening bananas for waste critical point determination

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Abstract:

It is vital to correlate the instrumental and non-instrumental analyses of food products so as to determine the product waste critical point. Texture and color (instrumental) were determined by a universal testing machine (UTM) and colorimetry respectively to ascertain the kinetics of bananas during ripening. While deterministic, descriptive and ranking sensory tests were employed for sensory attributes characterization. Seven banana color ripening stages were used for color variation and three temperatures (16, 23 and 30 °C) were used to study the kinetics, L, a, b and ΔE were calculated and axial puncture force, PF determined. Logistic model and first order reaction models were used. The sensory attributes results indicated banana waste critical point from stage 6 while instrumental analyses still indicated a model trend up to stage 7.

Key words: Banana ripening; Modelling; Kinetics; Sensory attributes; Waste critical point

Introduction

In developing countries bananas or plantains serve as a staple food for over 70 millions of people (Jaiswal et al., 2014). Banana crop is harvested as affirm sappy green fruit which during storage also changes color and texture to a yellow soft fruit with high sugar and low acid content. Bio-esters are also generated from amino acid metabolization to produce volatile flavour compound (Salvador et al., 2007). Several equipments like GC, GC-MS, HPLC among others have been used to qualify and quantify these flavour compounds but none has the highest sensitivity like the human nose (Marzec et al., 2010; Boudhrioua et al., 2003; Salmon et al., 1996). Sensory analysis is therefore relevant for consumer palatability. Descriptive and Discriminative, and scaling sensory tests can be used in parallel to determine the different characteristic parameters like sweetness, flavour, springiness and waste critical point (Singh-Ackbarali and Maharaj, 2014). These methods are performed by small numbers of panellists (8 to 12) who provide intensity scaling for a set of selected attributes. This includes three main steps. The first one is acquiring product familiarisation and a comprehensive lexicon that can correctly describe the product space. Panelists are exposed to many variations of the products and asking them to generate sets of terms to discriminate and describe the product. It aims at eliminating hedonic terms and regrouping of synonymous phrases or terms. The second step involves standardisation of the sensory concepts and finally scoring the products on the descriptive and discriminative intensity scale (Marzec et al., 2010. Other common criteria for fruit ripeness are softness of texture and the development of the peel's yellow coloration (Saltveit, 1999). Skin colour is used as a predictor of shelf-life for retail distribution and texture is an important part of eating quality (Marriott et al., 1981).The pulp texture depends on a number of factors such as variety, geographical location, growing practice and the ripening procedure (Kajuna et al., 1997; Vila and Silva, 1999).The ripening stages of bananas have been closely linked with the changes in peel colour and matching of the peel colour against a set of standard colour plates (e.g. SH Pratt's & Co, Luton) (Van-Dijk et al., 2006). Several enzymatic reactions occur to completion like in *Musa cavendish* bananas, starch hydrolysis and sugar synthesis are normally complete on reaching full ripeness, whereas in other types of *Musa*, the processes are slower and less complete and continue in very ripe and senescent fruit (Smith and Thompson, 1987). Loss of firmness or softening during ripening has been linked to two or three processes. The first is the breakdown of the starch into sugars (Wainwright and Hughes, 1990).The second is the breakdown of the cell walls or reduction in the cohesion of the middle lamella due to solubilisation of the pectic substances (Palmers, 1971). The third is that water migrates from the skin to the flesh as a result of osmosis (Iyare and Ekwukoma, 1992)

Several studies have been done on the banana ripening process especially on the variation on skin color and texture during ripening; Textural and rheological properties of ripening bananas were determined by a sonic technique to measure banana firmness (Finney et al., 1967). Peleg and Britto. (1967) using the compression behaviour of cylindrical specimens studied food texture parameters.

Chen and Ramaswamy. (2002) described the Kinetics of Texture and Color Change in Bananas, the results indicated that the time dependence of L, ΔE and puncture force (PF); Textural Changes of Banana and Plantain Pulp during Ripening were compared and significant variations were recorded (Kajuna et al., 1997); Biochemical, physiological and compositional changes associated with ripening and resulting softening of bananas have been reviewed extensively (Srivastava and Dwivedi, 2000; Demirel and Turhan, 2003; Wachiraya et al., 2006; Aremu and Udoessien, 1990; Bugaud et al., 2007; Osma et al., 2007) among others.

Mathematical models are relevant for Engineers to design and optimize processes (Arabshahi and Lund, 1984). Temperature dependant kinetic models have been attempted by Engineers lately for process control optimisation. In the food Industry there is need to ascertain the key Critical Points (CP) of a food product as assessed by the consumers. Sensory analysis has been widely employed as as a non-instrumental method. Using bananas, the aim of the study therefore is to model the colour and texture (instrumental) kinetics and also use sensory (non-instrumental) to determine the banana waste critical point.

Materials and Methods

Bananas ***(Musa acuminata*** **'Grand Nain'**, **AAA Group)** were purchased from local supermarkets and were allowed to ripen in incubators set at three different temperatures: 16^{o}C, 23^{o}C and 30^{o}C. A commercial peel color scale (SH Pratt's & Co, Luton) (Fig 1) was used to select homogenous and high-quality bananas according to the color of the peel. This same scale was used for the different colour stages of the banana during ripening. Three fruits were sampled from the three set temperatures 30, 23 and 16 ^{o}C, every day, 2 days and 3 days respectively. The average days for all measurements were 11 days.

Sensory

A sensory evaluation of the banana fruits at the different storage temperatures (16, 23 and 30 ^{o}C) was done using the descriptive and discriminative tests (Roland and David, 1986). Descriptive scaling test gives a hierarchy scale to a product at different stages in order to determine the best consumer preference stage (O'Mahony, 1986). By presenting the samples simultaneously, assessors can directly compare the samples to one another which allows for slightly better discrimination (Valentin et al., 2012). A semi-trained panel of 10 people was used with a brief training on aims of the experiments and expected terminologies to use. The experiment included filling a questioner with two sections and was completed in 30 minutes. Discriminative, descriptive and scaling questions were set and answered by the panellists. The first section was for observation and the second for tasting the sample. The questions were answered at every step of the experiment. All sections were to be completed by the panellists. Mineral water was provided to rinse the mouth at each set of experiment after eating to avoid confusing the tastes. Seven banana ripening stages were used (Fig 1) and five attributes were analysed (purchase stage, sweetness, flavour, acceptability and Waste Critical Point of rejection). A scale of 1-10 was used to explain the extremely like and dislikes of the product. Each ripening stage was assessed independently by each panellist on the same scale and awarded a scale value from which mean values and LSD multiple range test were done.

Statistical analysis

The latest version of SPSS (Statistical Package for Social Science) Statistics 19.0 was used for statistics: means, T-test, ANOVA and correlations. The results were determined from duplicate measurements. Data analysed by analysis of variance and means was separated by the least significant difference with significant ($p < 0.05$).

Color and Texture determination

Peel color was determined by a colorimeter (Data Processor DP-100, CR-200 series Chroma Meters, Minolta Camera Co. Ltd, Ramsay, NJ, U.S.A). L, a, b and ΔE (total color difference) color system was used to evaluate the color of the bananas. The banana peel color is not uniform over the entire finger surface area therefore three regions i.e. tip, middle and end regions were selected and mean values considered respectively. ΔE values were measured using the equation below;

$$\Delta E = (\Delta L^2 + \Delta a^2 + \Delta b^2)^{1/2}$$

Where Δa, ΔL and Δb represent the individual values deviations from the respective values of a fully ripe banana (fully ripe, L=75.2, a=4.5, b=41.2) (Demirhan and Özbek, 2009). The Texture analysis was carried out using a Universal Testing Machine (UTM) (Zwick Roell, Uk). Texture measurements were made using a hemi-spherical rwick or probe of diameter 139 mm at a speed of 5 mm/min. Single compression cycles, with a deformation of 75% of the original height of the sample were done. The crosshead speed used was 200 mm/min. Several cylindrical segments of banana fruits, 25 cm long were cut from the end middle and tip regions. The mean values of the puncture forces were considered. Each cylindrical sample was used once per measurement. Data analysis was done by TestXpert software that calculated the different compression forces and degrees of deformation. The first biggest peak was considered as the maximum force; this force caused the puncture of the banana skin and also called puncture force, $F_{max.}$

Kinetics considerations

Nutrient degradation kinetics of foods generally follows a first order reaction as highlighted by (Labuza, 1979). He showed how the order and reaction rates affect the loss of the quality factor or a hypothetical nutrient (C) under different sequences of temperature. The rate of loss of quantity (C) is represented by:

$$\frac{dC}{dt} = -k(C)^n \qquad \text{Eqn1}$$

where C is the concentration of a quality factor C at time t, k is the rate constant and n is the order of reaction. Assuming C_0 to be the concentration of substrate at time zero, by integrating equations 1to 4 are generated. These correspond to a zero order, first-order and fractional conversion kinetic models respectively:

$$C = C_0 + kt \qquad \text{Eqn2}$$

$$C = C_0 + \exp(-kt) \qquad \text{Eqn 3}$$

Taking natural logarithm a first order reaction is generated

$$Ln\ C = In\ C_0 - kt \qquad \text{Eqn 4}$$

Plotting *In C* against time, *t* will be a straight time though sometimes it may not necessarily be due to experimental inconsistencies. The slope of the graph is the rate constant, C (degradation factor).

A fractional conversion model can also be generated from equation 3 (Levenspiel, 1972) to give;

$$\frac{C-C_f}{C_0-C_f} = exp(-kt) \qquad \text{Eqn 5}$$

where C_f represent the final equilibrium and C_0 the initial values C (quality factor).

Using Arrhenius equation, we can explain a temperature dependent reaction:

$$k = k_0 exp(-E_a/RT) \qquad \text{Eqn 6}$$

Where R is the universal gas constant (8.314 J/mol/K), k_0 is the frequency factor and T the absolute temperature. Nedler 1962 highlighted a logistic kinetic model, as written below:

$$C = U_0 + \frac{U}{1+exp(-k(t-t_0))} \qquad \text{Eqn 7}$$

where U is the constant value related to the C final, U_0 is the constant value related to the C initial and t_0 is the time taken for C value to increase (decrease) to half the U value.

Kinetics equations 2-5, can be transformed into linear equations and fitted by linear regression methods. Equation 6; the non-linearity of U, U_0, t_0 and k parameters dictated use of SPSS software Sigma Plot in order to obtain the regression parameters.

Results and Discussion

Colour changes during ripening

The experimental results of the colour changes on the banana peel ***(Musa acuminata* 'Grand Nain'**, **AAA Group)** during storage are shown in Fig 2-5. It can be seen that at all the temperatures the colour changed from green yellow to yellow with dark spots. However the experimentation time, as expected at 30 ^oC ripening took less time than at 23 ^oC and 16 ^oC which corresponded to increases in L, a*, b* and the total colour change ΔE.

The results show dependency of color variations at different storage temperature; this means kinetic models can be used to describe these reactions. Since L, a* and b* are sub-sections of ΔE (Mahy et al, 1994) so a logistic model only was used to explain ΔE. Table 1 highlights the regression model results with high correlation coefficients, which suggests a good correlation between models and experimental results.

Texture changes during Ripening

Testing of the banana texture was done using as single compression test cycle. And analysis was done using the in-built food texture analysis method with modifications to fit our sample. Different texture properties can be automatically calculated after every compression cycle; these include puncture force, firmness, springiness, elastic modulus among others. However (Ramaswamy and Tung, 1989; (Mendoza & Aguilera, 2004; (Zhu et al., 2015) highlight in their respective studies that these parameters are highly correlated so any of the parameter measurements can be used to estimate the behaviour of the others. Therefore Puncture force was only considered for modelling and a first order reaction model was used. The large diameter of the probe (139mm) enabled uniform axial compression of the 25cm banana pieces.

From the experimental data, axial puncture force decreases with storage and temperature. At 30^{o}C of storage temperature the force decreased much faster, followed by 23 ^{o}C and then 16 ^{o}C. Results from the model indicate very high correlation coefficients which also suggest good representation between the model and experimental data. Arrhenius equation was also used for both color and texture kinetics to determine their R values and E_a during ripening. Using a non-linear model to determine k at a reference temp 17 ^{o}C, also high regression coefficient values were calculated (Table 2).

Sensory results and Interpretation

Mean values for sensory evaluation of banana ripening during storage at a reference temperature of 23^{0}C were calculated

Temperature 23^{0}C was used as the optimum following series of data analysis for color and texture measurement at also Temp 16^{0}C and 30^{0}C. Samples at different stages of banana ripening were assessed by semi-skilled sensory panel. The key target of the sensory experiment was to determine the rejection point/ waste critical point (CP). Other sensory attributes were inciting sensors to help ascertain a clear description of the CP for bananas. Parameters like flavour and sweetness were assessed as they closely aid palatability of the banana fruit. From the results above the Stage 1-2 were rejected for acceptability but not considered a waste. Stage 3 was most considered for purchase and probably the reason it's higher acceptability than stage 4. Stage 4-6 registered high scores for sweetness and increase in flavour. Most of the panellist preferred purchasing banana at stage 3. Stage 4 however also registered a high mean value though less than stage 5. The most preferred stage for consumption was stage 5. Then stages 6 and 7 was considered by majority of the panellist as a waste though a few disagreed because of it's strong sweetness and flavour. It is clear that the aim of the experiment was achieved as we were able to ascertain that banana critical point begins at stage 6.

From the sensory results stages 6 and 7 are both considered waste for consumption, these stages are usually reached in different days depending on different ripening conditions (e.g. Temperature). From the colorimetry and compression results the mean number of days for the whole ripening process is approximately 11 days. Stage 6 is reached on average in 9 days; the instrumental analysis however still register an exponetional stage of variation in color and texture parameters at this time. The experimental results reach a gradual stationary phase on average at 11 days as seen in L, and b* graphs). The instrumental analyses results were interpreted for banana CP at the point where no further axial force and less L, a*, b* variations were determined. Flavour and sweetness was detected by the group to increase during ripening as detected by many analytical equipments. Therefore by instrumental analysis banana reached CP at a mean of 12 days (stage 7) while by sensory analysis banana reached the CP by mean value of 9 days (Stage 5).

Conclusion

Texture, in terms of puncture force gradually decreased during storage as the color developed from green to yellow. The kinetic models confirmed effects of temperature during storage on color and puncture force as the samples stored at 30^{0}C got softer in a few days and with poor color development. Temp 16^0C and 23^0C registered a better color development with texture variations. The sensory panel showed less interest for a spongy ripe banana as those achieved at temperature 30^0C. It was noted that ripening bananas is vital to be done at normal range temperatures to achieve a longer shelf life and better sensory qualities. In summary color and texture are commonly instrumentally determined in the food industry to qualify shelf life of food products. It is less tedious and more precise results are obtained. Simultaneous sensory characterisation of the product is rarely favoured. However from the results it was determined that the two methods may give slightly different end point (CP for bananas). It is therefore important to use both instrumental and non-instrumental analysis in some cases.

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Figure 1: Temperature and storage time effect on L Values

Figure 2: Temperature and storage time effect on a values*

Figure 3: Temperature and storage time effect on b values*

Figure 4: Temperature and storage time effect on delta E values

Figure 5: Temperature and storage time effect on axial puncture force

Table1. Regression coefficients of time-dependent kinetic models

Temp	**Color Values**	**$C_o(U_o)$**	**(U)**	**k**	**t_o**	**R^2**
16^{o}C	ΔE	30	290	0.1018	7.6324	0.99
	PF	199.2		-0.1516	4.3421	0.98
23^{o}C	ΔE	30	290	0.1698	5.4323	0.99
	PF	195.6		-0.2351	4.6808	0.99
30^{o}C	ΔE	28	292	0.2650	4.2102	0.99
	PF	195.7		-0.5031	3.8674	0.98

ΔE= Total colour change & PF=Puncture force ΔE, Logistic model; PF, First Order model

Table 2.Regression results of Arrhenius model (temperature-dependent Model) for color and texture parameters

Temp	k 17^{0}C (d^{-1})	Ea (KJ/mol)	R
L	0.699	52	0.98
a*	0.351	43	0.99
b*	0.0712	39	0.99
ΔE	-5.0359e1	45	0.91
PF	-4.4654e1	53	0.98

Table 3: Mean Values for sensory attributes at 23^{0}C

Ripening stage of M.cavendish	Mean values for the different sensory test sets				
	Purchase Stage	Sweetness	Flavour	Acceptability	Critical point/Point of rejection
Green (1)	2.2^a	1.7^b	1.7^b	0.9^c	2.3^{bc}
Green Yellow traces (2)	3.6^a	1.7^{ab}	1.3^{ab}	4.3^b	3.8^d
More green than Yellow (3)	5.9^a	5.4^b	3.4^b	5.0^{bc}	4.4^{bc}
More Yellow than Green (4)	4.1^a	5.3^b	5.1^a	6.5^{ab}	4.6^c
Yellow Green traces (5)	2.1^a	6.6^b	5.8^{bc}	7.9^{cd}	5.1^b
Uniform Yellow (6)	1.5^a	6.3^{ab}	6.6^b	6.2^{ab}	7.9^a
Yellow with spots (7)	1.7^a	7.5^{ab}	6.9^a	6.0^a	8.0^d

Means in the same raw without a common superscript (a, b, c and d) differ ($p<0.05$) according to the LSD multiple range test

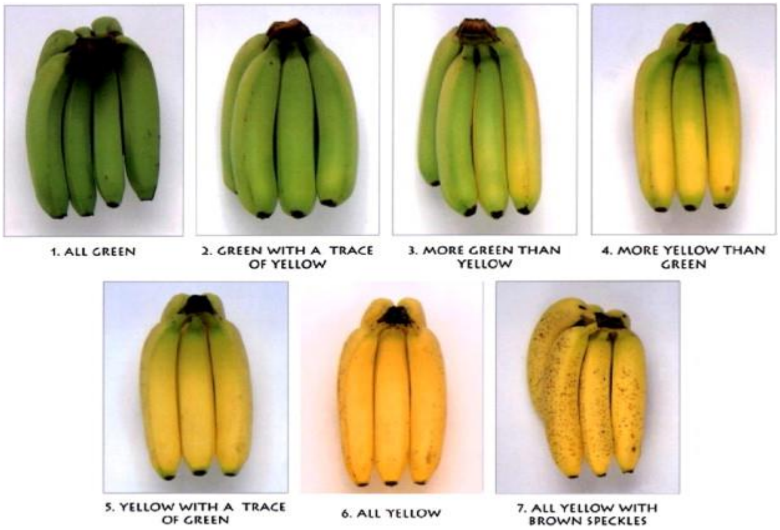
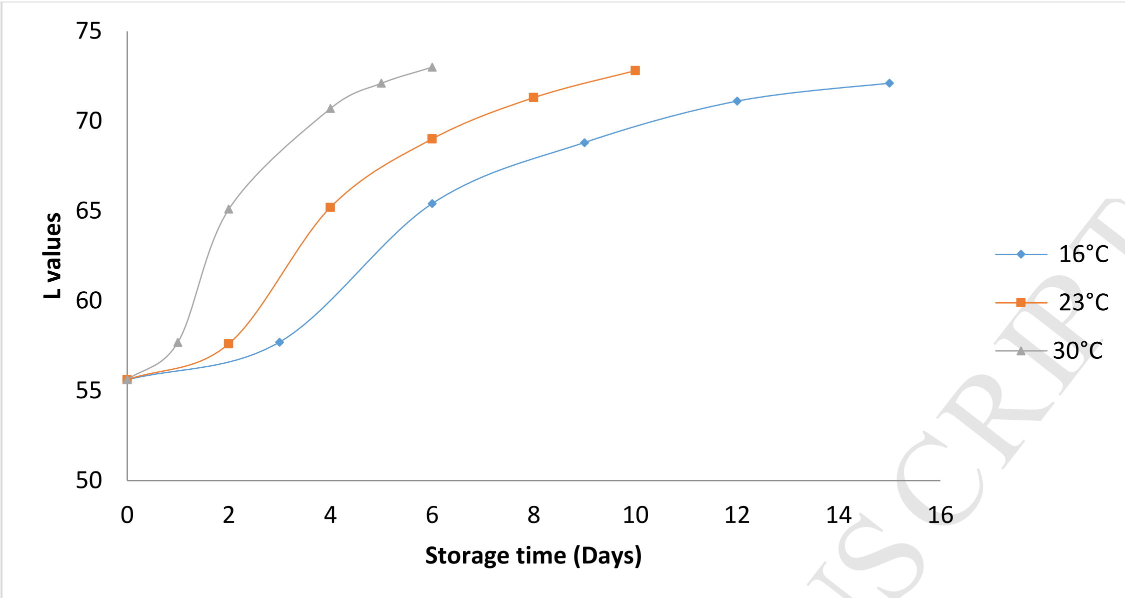


Figure 1. Color chart,SH Pratt's &Co, (Luton,UK)


75
70
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L values
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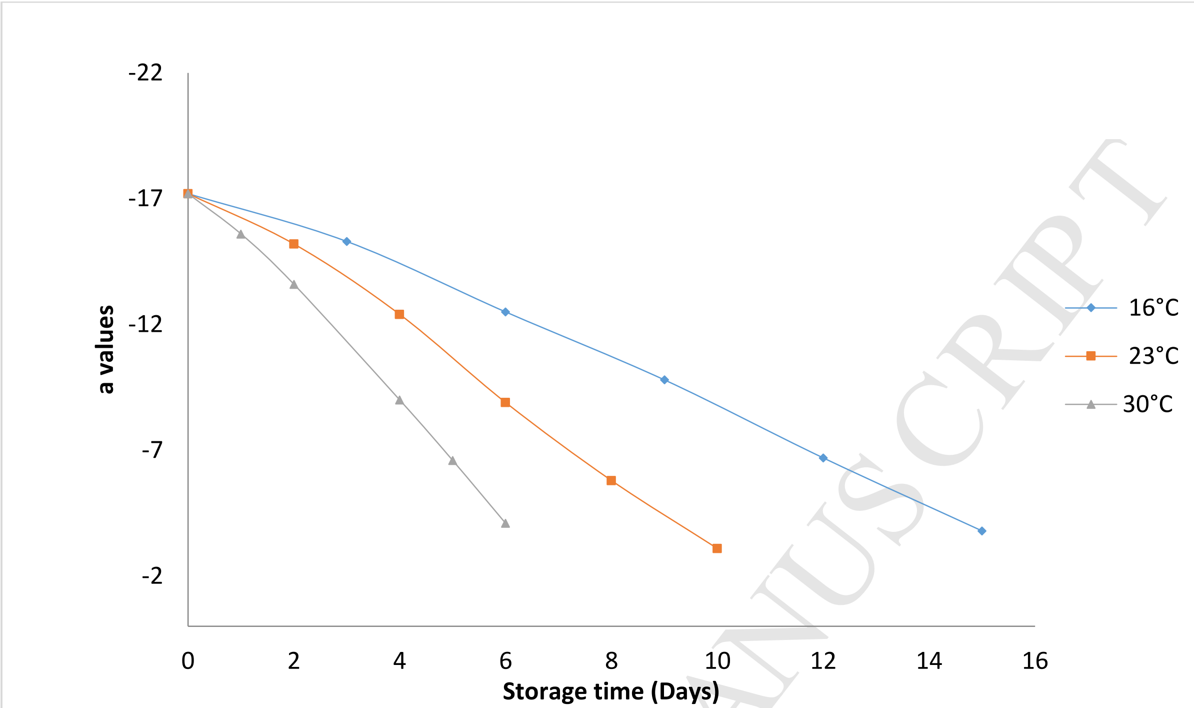
Storage time (Days)
16°C
23°C
30°C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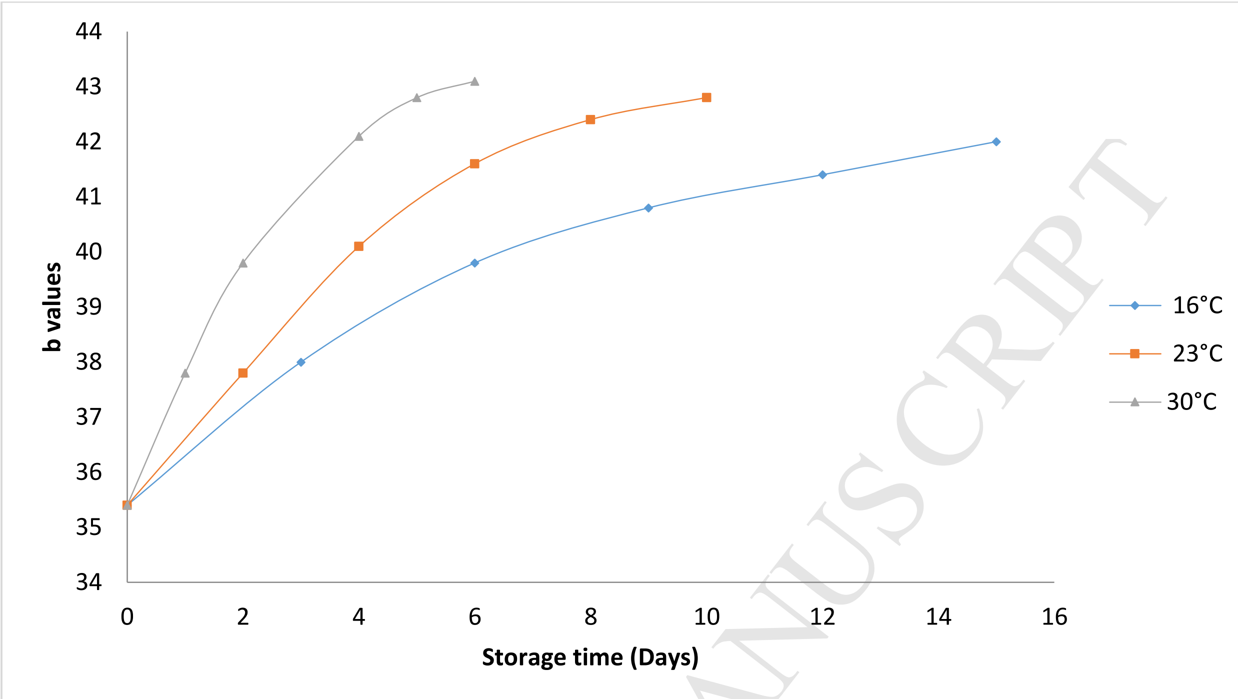
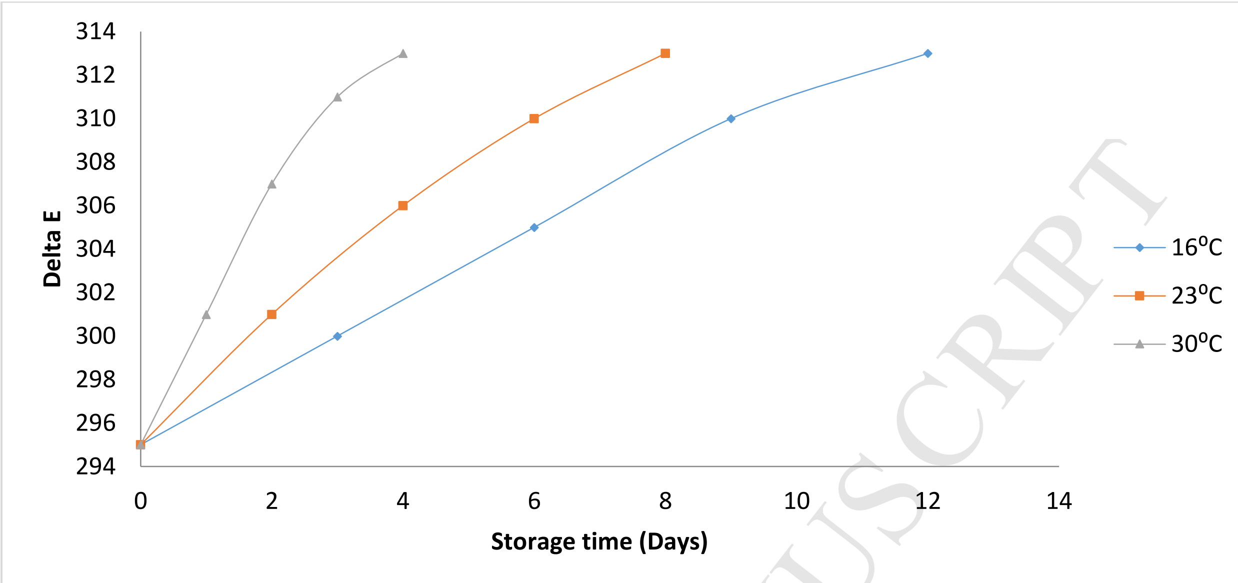
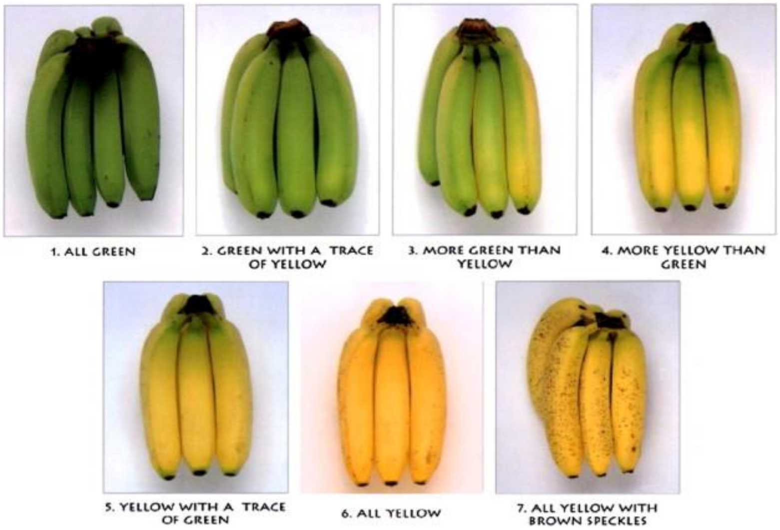
Storage time (Days)
16°C
23°C
30°C

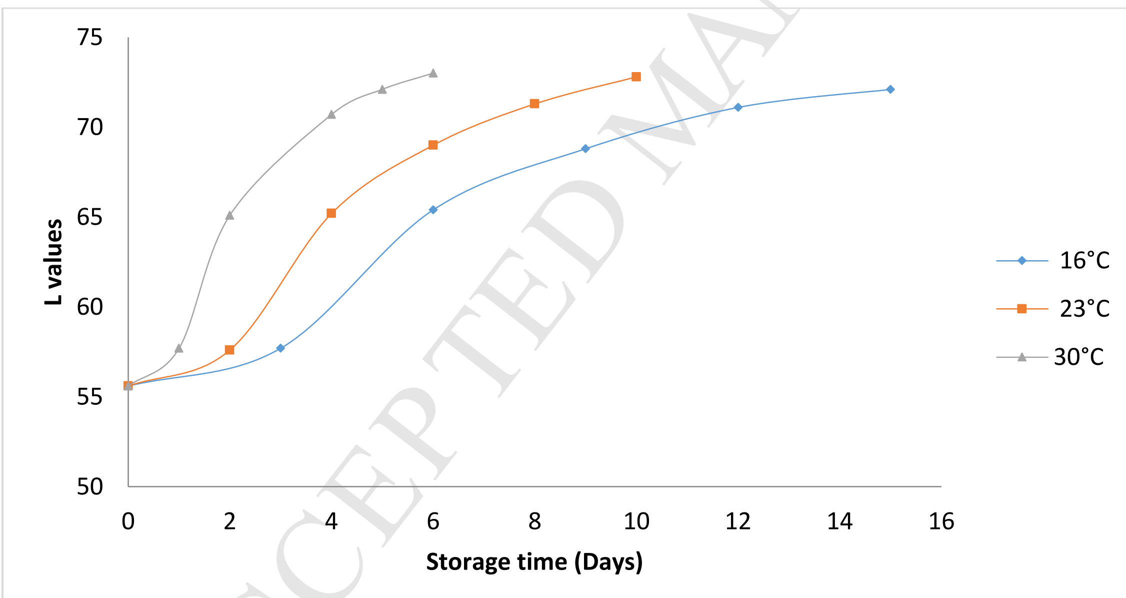


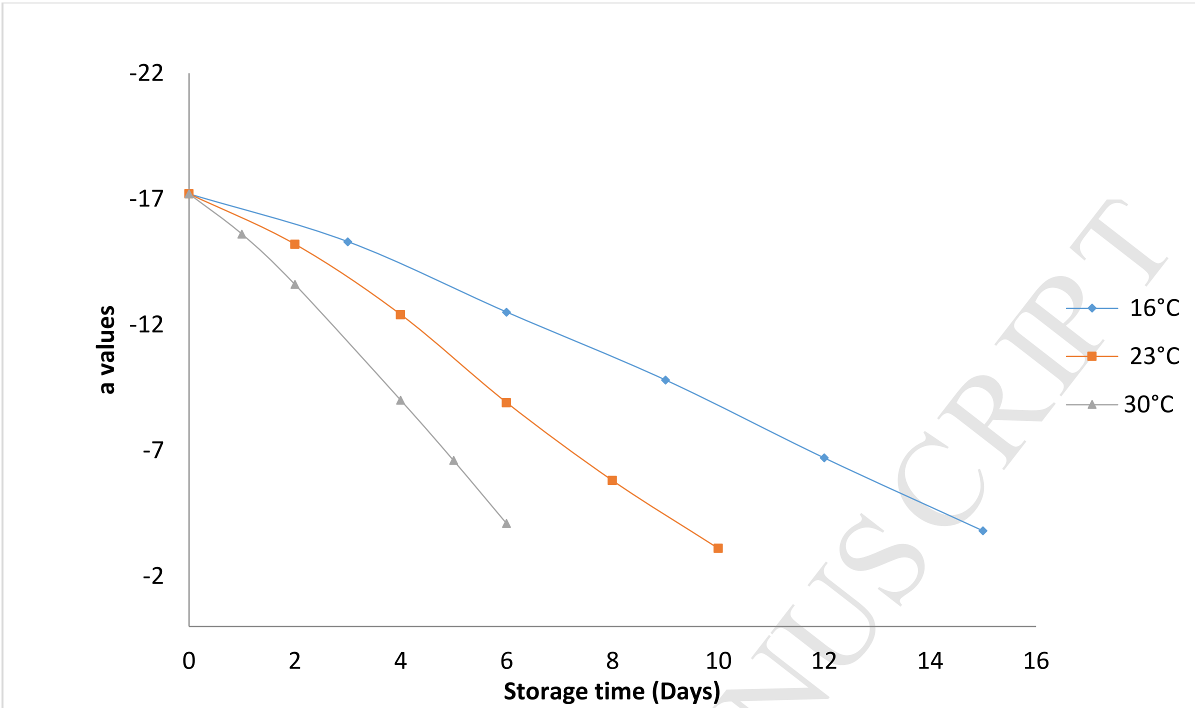
44
43
42
41
40
39
38
37
36
35
34
b values
0
2
4
6
8
10
12
14
16
Storage time (Days)
16°C
23°C
30°C

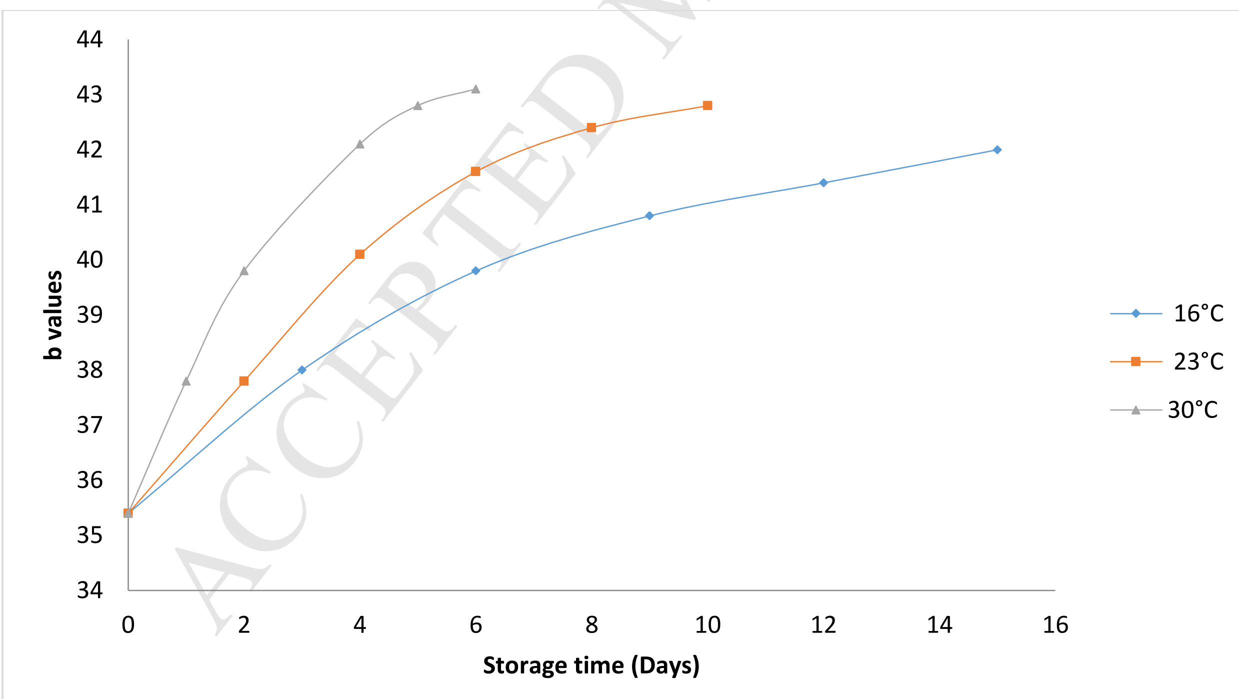


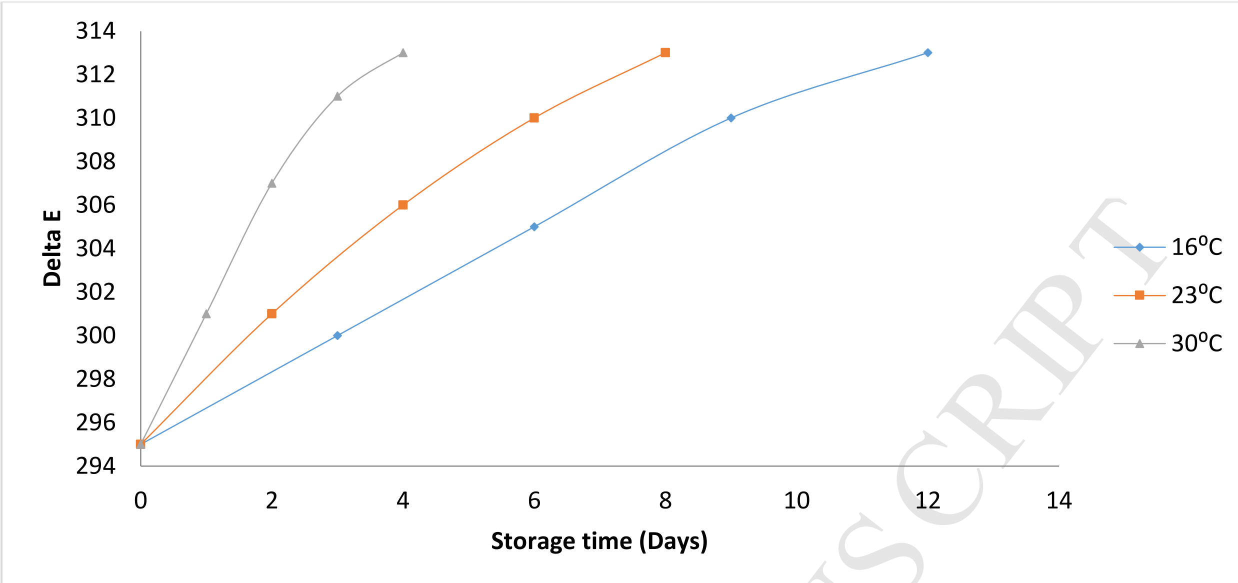
314
312
310
308
306
304
302
300
298
296
294
Delta E
0
2
4
6
8
10
12
14
Storage time (Days)
16oC
23oC
30oC

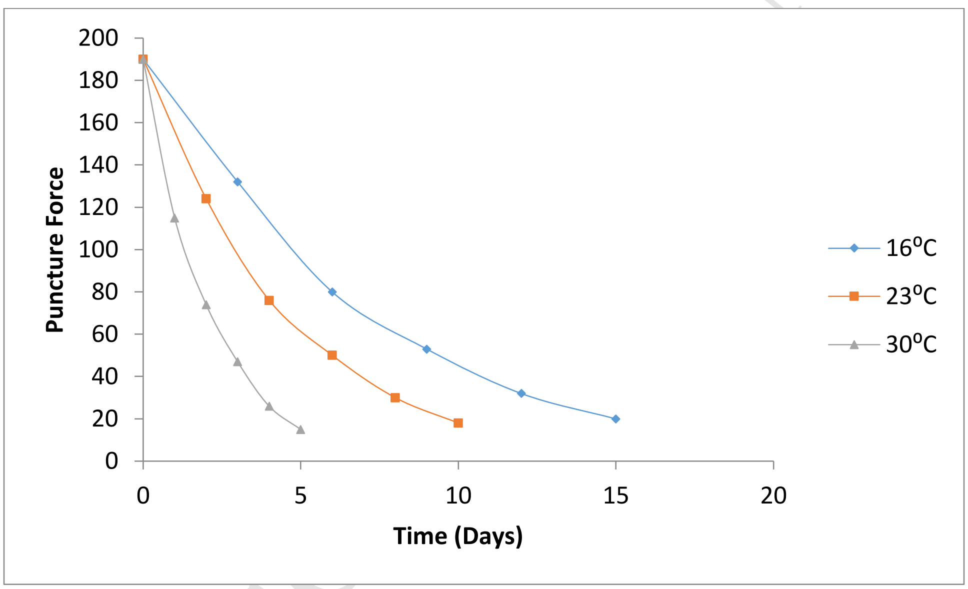

1. ALL GREEN
2. GREEN WITH A TRACE OF YELLOW
3. MORE GREEN THAN YELLOW
4. MORE YELLOW THAN GREEN
5. YELLOW WITH A TRACE OF GREEN
6. ALL YELLOW
7. ALL YELLOW WITH BROWN SPECKLES


75
70
65
60
55
50
L values
0
2
4
6
8
10
12
14
16
Storage time (Days)
16°C
23°C
30°C


-22
-17
-12
-7
-2
a values
0
2
4
6
8
10
12
14
16
Storage time (Days)
16°C
23°C
30°C


44
43
42
41
40
39
38
37
36
35
34
b values
0
2
4
6
8
10
12
14
16
Storage time (Days)
16°C
23°C
30°C


Delta E
314
312
310
308
306
304
302
300
298
296
294
0
2
4
6
8
10
12
14
Storage time (Days)
16°C
23°C
30°C


Puncture Force
200
180
160
140
120
100
80
60
40
20
0
0
5
10
15
20
Time (Days)
16°C
23°C
30°C

- Instrumental analysis (color and texture) using a Universal Testing Machine (UTM)and Colorimetry and non-instrumental (sensory) analysis using descriptive, discriminative and ranking tests
- Mathematical modelling of the enzymatic chemical kinetics during ripening
- Use both instrumental kinetic parameters with sensory attributes to determine the waste critical point of banana during storage