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Mathematical modelling of color, 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 characterisation. 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.

1. 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, discriminative, and consumer 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 can be performed by small numbers of panellists 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 color 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 color and matching of the peel color against a set of standard color 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

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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 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 a non-instrumental method. Using bananas, the aim of the study therefore is to model the color and texture (instrumental) kinetics and also use sensory (non-instrumental) to determine the banana waste critical point.

2. Materials and methods

2.1. Sample preparation

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 °C, 23 °C and 30 °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 color stages of the banana during ripening. Three fruits were sampled from the three set temperatures 30, 23 and 16 °C, every day, 2 days and 3 days respectively. The average days for all measurements were 11 days.

2.2. Sensory

A sensory evaluation of the banana fruits at the different storage temperatures (16, 23 and 30 °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 et al., 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 min. 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.

2.3. 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 ($p < 0.05$).

2.4. 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;

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

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 hemispherical 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, $F_{max.}$

2.5. 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:

$$\frac{dC}{dt} = -k(C)^n \tag{1}$$

where C is the concentration of a quality factor C at time t, k is the