Prediction of textural attributes using color values of banana (*Musa sapientum*) during ripening

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Abstract Banana is an important sub-tropical fruit in international trade. It undergoes significant textural and color transformations during ripening process, which in turn influence the eating quality of the fruit. In present study, color ('L', 'a' and 'b' value) and textural attributes of bananas (peel, fruit and pulp firmness; pulp toughness; stickiness) were studied simultaneously using Hunter Color Lab and Texture Analyser, respectively, during ripening period of 10 days at ambient atmosphere. There was significant effect of ripening period on all the considered textural characteristics and color properties of bananas except color value 'b'. In general, textural descriptors (peel, fruit and pulp firmness; and pulp toughness) decreased during ripening except stickiness, while color values viz 'a' and 'b' increased with ripening barring 'L' value. Among various textural attributes, peel toughness and pulp firmness showed highest correlation (r) with 'a' value of banana peel. In order to predict textural properties using color values of banana, five types of equations (linear/polynomial/exponential/logarithmic/power) were fitted. Among them, polynomial equation was found to be the best fit (highest coefficient of determination, R^2) for prediction of texture using color properties for bananas. The pulp firmness, peel toughness and pulp toughness showed R^2 above 0.84 with indicating its potentiality of the fitted equations for prediction of textural profile of bananas non-destructively using 'a' value.

Keywords Color values · Prediction · Textural attributes · Ripening period

Introduction

Banana is the main fruit in international trade and most popular in the world. In terms of volume, they are ranked first among the exported fruit and second after citrus fruit in terms of value (FAO 2009). It is the fourth most important food crop in the world, after rice, wheat and maize, in terms of gross domestic product, with a world production of about 70 million tons in 2003 (UNCTAD 2003). India is the largest producer of banana (*Musa* sp) in the world with an annual production of 26.217 million MT from an area of 0.709 million ha (NHB 2009). Bananas are also a very important staple commodity for many developing countries, hence having relevance for its role in food security. The emerging paradigm shift in dietary needs of the people with rise in income, demands more horticultural products and banana is in the forefront amongst them (Mohapatra et al. 2011).

Banana is a climacteric fruit and exhibits a respiratory peak during natural ripening at 20 °C after harvest. Most of the banana bunches are harvested at complete maturity while they are green and unripe and subsequently allowed to ripen at ambient conditions (Ram et al. 1979). The common criteria for fruit ripeness are softness of texture and the development of the peel's yellow coloration (Marriot et al. 1981; Kudachikar et al. 2011; Mahajan et al. 2011; Kulkarni et al. 2011). Skin colour is used as a predictor of shelf-life for retail distribution and texture is an important part of eating quality. External skin colour changes during ripening often reflect changes in flesh colour (Deullin 1963; Wainwright and Hughes

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1990). As the yellowing of the skin intensifies, the flesh colour changes from the typical ‘opaque white’ of a product with a high starch content to a ‘very soft yellow’. Loss of firmness or softening during ripening has been linked to the breakdown of starch into sugars, breakdown of cell walls or reduction in cohesion of the middle lamella due to solubilisation of pectic substances (Palmer 1971; Smith et al. 1989) and finally migration of water from the skin to the flesh as a result of osmosis.

Besides skin color, texture is also an important factor in the eating quality of bananas. Flesh texture depends on a number of factors, such as variety, growing practices and the ripening procedure (Charles and Tung 1973). Hydrolysis of starch to sugar during ripening causes an increase in osmotic pressure in the banana flesh. The increase in osmotic pressure is usually associated with a decrease in turgor pressure which may account for softening during ripening and would cause the firmness to decrease (Finney et al. 1967). Texture perception is an important factor for quality evaluation of fruit and vegetable products (Konopacka and Plochanski 2004) and critical in determining the acceptability of fresh fruits (Sousa et al. 2007). However, the textural aspects of bananas during ripening have received little attention in literature (Ramaswamy and Tung 1989; Kajuna et al. 1997; Chen and Ramaswamy 2002; Salvador et al. 2007). Therefore, current investigation was conducted to study changes in color and textural attributes of banana with

ripening (10 days) and to evaluate their possible correlations (r) and best fit equations (coefficient of determination, r^2) for bananas.

Materials and methods

Sample preparation and storage Freshly harvested unripe banana (*Musa acuminata*) bunches were procured from the orchard of Punjab Agricultural University, Ludhiana. Whole bunch of banana was plucked with 10–20 cm stalk and brought to laboratory within half an hour in an A.C. car. Individual bananas were taken from the bunch and those free from any external injury/blemish and of visually similar size and color were selected. The sorted bananas were stored at ambient room conditions (26–30 °C, RH 60–70%) for 9 days. Nine bananas from each storage day (0, 2, 4, 6, 8 and 10) were randomly chosen for experimentation to have samples of varied textural attributes and colour. Altogether 104 bananas were used in the experiment (54 for calibration and 50 for validation studies). Bananas were examined simultaneously for color (‘L’, ‘a’ and ‘b’ value) and textural attributes (peel, fruit and pulp firmness; pulp toughness; stickiness) during ripening period of 10 days. Both characteristics were measured on equatorial region as it gives more consistent results than any other region on the fruit surface (Gunnness et al. 2009).

Fig. 1 Variations in instrumental textural qualities [a firmness of banana peel (×) & pulp (□); b toughness of banana peel (×) & pulp (□); c firmness (×) & stickiness (□) of banana fruit] and [d Hunter color values ‘L’ (Δ); ‘a’ (×); ‘b’ (□) of banana peel during ripening ($n=9$)]

Colour The instrumental measurement of banana peel colour was carried out with a HunterLab miniScan XE Plus colorimeter (HAL, USA, Model 45/0-L). The color was determined in terms of 'L', 'a' and 'b' values by positioning the nose cone in the surface of fruit directly such that the light thrown by the colorimeter is not leaked. 'L' denotes the lightness or darkness; 'a-' denotes greenness while 'a+' for redness; and 'b-' denotes blueness while 'b+' for yellowness colour of the samples. Care was taken to put a "clean" colour part of the banana on the colorimeter diaphragm avoiding the dark spots that were evaluated visually by means of the sensory analysis. The colour was measured in four places of each sample and average values were recorded for the study. Before measuring, the colorimeter was standardized with black and white calibration tiles provided with the instrument.

Texture Changes in textural parameters during ripening were measured by puncturing each sample thrice at equal distance of about 4 mm on equatorial region and were averaged out to get an overall impression of quality of fruit and nullifying chances of error. The instrumental study was conducted using texture analyzer (TA-Hdi, Stable Micro systems, UK) equipped with 50 kg load cell and stainless steel probe of 2 mm diameter in compression mode. The operating parameters of texture analyser were: pre-test speed, 2 mms^{-1} , test speed, 1 mms^{-1} and post-test speed, 2 mms^{-1} . The maximum force applied to break up the peel was taken as peel firmness (N) (Jha et al. 2010a). Fruit firmness (N/s) has been ascertained from the slope of the force-time curve, as described by Breene (1975). The pulp firmness (N) was computed as mean of the force applied on the pulp after breaking peel (Bugaud et al. 2006) and work required to cause breakage of peel was assumed to be peel toughness (Ns), while work required to cause rupture in pulp was taken as pulp toughness (Ns) (Mohsenin 1986). Stickiness (N) defined as the negative force to pull the probe from the sample after the first compression. Average of nine readings of each parameter for each ripening period was noted.

Statistical analyses All the observations were made in nine replication ($n=9$) and values were subjected to Analysis of Variance (ANOVA) using Statistica software version 6.0 (StatSoft India Pvt. Ltd., New Delhi, India) (Jha et al. 2010b) to evaluate the influence of ripening period on sensory and color characteristics.

To establish a relationship between color and textural attributes, whole samples were divided into two groups. Data obtained from the sample collected in the year 2009 were used for calibration and those obtained in year 2010 for testing (validation) of the selected equations. Five standard forms of equations viz. linear, polynomial, exponential, logarithmic and power were fitted to average values of

Table 1 Univariate tests of significance for different textural attributes and peel color value of banana fruit studied for ripening period of 10 days

$F_{\text{Calculated}}$ Calculated F value, * Significant at $p \leq 0.05$, ** Significant at $p \leq 0.01$, NS Non-significant

Response	$F_{\text{Calculated}}$
Peel Firmness (N)	2.50*
Peel Toughness (Ns)	3.58**
Fruit Firmness (N/s)	10.24**
Pulp Firmness (N)	37.85**
Pulp Toughness (Ns)	2.74*
Stickiness (N)	39.03**
Color Value 'L'	8.97**
Color Value 'a'	11.79**
Color Value 'b'	1.42 ^{NS}

textural attributes as independent variables and sensory parameters as dependent variables using MS – Excel software on calibration set of samples. The best equations based on their coefficient of determination (R^2) were selected for validation studies.

Results and discussion

Effect of ripening period on textural properties Texture is an important property to be considered while evaluating the eating quality of bananas. Flesh texture depends upon a number of factors, such as variety, growing practices and the ripening procedure (Charles and Tung 1973). In the current experiment, changes in textural characteristics (peel and pulp firmness) with ripening period were studied. The peel firmness of banana peel declined slowly with ripening period (Fig. 1a). The percent decline from 1st to 10th day of storage was found to be 16% only. Structural changes in pectin, hemicellulose and cellulose together are considered to be responsible for the alteration of cell wall structure during ripening related loss of firmness (Huber 1983; Seymour et al. 1990). These changes include not only solubilisation and depolymerisation of the polysaccharides but also rearrangements of

Table 2 Correlations between textural properties and color parameters of banana fruit for 10 days of ripening period

Textural attributes	Color value		
	<i>L</i>	<i>a</i>	<i>b</i>
Peel Firmness (N)	-0.18	-0.06	-0.27*
Peel Toughness (Ns)	-0.13*	-0.48*	0.01
Fruit Firmness (N/s)	0.09	-0.24*	0.10
Pulp Firmness (N)	-0.12*	-0.48*	-0.08
Pulp Toughness (Ns)	-0.04*	-0.40*	-0.17*
Stickiness (N)	0.08*	0.41*	0.05

*Significant at $p < 0.05$

Table 3 Best fit equation corresponding to highest coefficient of determination between color value 'a' and textural attributes of banana fruit

Independent variable (x)	Dependent variable	Best fit equation	R ²
Color value 'a'	Peel Firmness (N)	$0.0223 \times^2 + 0.0609 \times + 17.931$	0.025
	Peel Toughness (Ns)	$0.006 \times^2 - 0.1075 \times + 5.8269$	0.865
	Fruit Firmness (N/s)	$0.1535 \times^2 + 0.9814 \times + 6.7549$	0.319
	Pulp Firmness (N)	$4.0823 \times^2 + 31.454 \times + 78.629$	0.849
	Pulp Toughness (Ns)	$0.0536 \times^2 + 0.3304 \times + 5.1093$	0.869
	Stickiness (N)	$-0.161 \times^2 - 1.2536 \times - 3.3223$	0.786

R² Coefficient of Determination

their associations (Redgwell et al. 1997; Rose et al. 1998). Jha et al. (2011) also reported decline in peel firmness of various mango cultivars with ripening period.

Pulp firmness of banana fruits decreased significantly during the ripening period (Fig. 1a) from an initial value (0 day) of 38.04 N to 14.00 N on the 10th day of experimentation. A rapid decline in pulp firmness was observed after 4th day of storage. This might be attributed to many physiological and biochemical modifications that include hydrolysis of starch to sugars during ripening causing an increase in osmotic pressure in banana flesh, which is usually associated with a decrease in turgor pressure accounting for softening during ripening, resulting in decrease in firmness (Finney et al. 1967). Jha et al. (2010a) also observed decrease in pulp firmness of mango hybrids from 5.0 to 0.3 N during 12 days of storage. Analysis of variance (ANOVA) indicated that there was significant effect of ripening period on firmness of banana peel and pulp (Table 1).

The variation in peel and pulp toughness of bananas with ripening period (10 days) is presented in (Fig. 1b). Peel toughness of bananas declined gradually till 6th day of ripening period and thereafter it became almost constant. The similar trend was observed in pulp toughness of bananas with ripening period. The percent decline in peel and pulp

toughness from 1st to 10th day of storage was found to be only 9.66% and 11.00%, respectively. However, the changes in peel and pulp toughness of bananas were found to be statistically significant as evident from the results of one way ANOVA (Table 1). Jha et al. (2011) also reported decline in peel and pulp toughness of various mango cultivars with ripening period.

Fruit firmness of bananas showed a gradual decline till 4th day of ripening and thereafter the decline became very slow or negligible (Fig. 1c). Jha et al. (2011) also reported decline in fruit firmness of various mango cultivars with ripening period. An increase in stickiness of bananas was observed till 6th day of ripening, which became almost stable thereafter (Fig. 1c). This may be attributed to the tendency of banana fruits to become sticky due to its mucilaginous nature which increases during ripening with simultaneous decrease in stringency associated with un-ripened banana (Chauhan et al. 2006). ANOVA indicated that variation in fruit firmness and stickiness of banana fruit with ripening period was significant (Table 1).

Effect of ripening period on color of banana peel Banana peel colour changed from green to yellow with ripening period. 'L' value showed a slow decline for banana peel

Table 4 Validation of best fitted equations with independent data sets of banana fruits

Peel toughness ($0.006 \times^2 - 0.1075 \times + 5.8269$)				Pulp firmness ($4.0823 \times^2 + 31.454 \times + 78.629$)			Pulp toughness ($0.0536 \times^2 + 0.3304 \times + 5.1093$)		
'a' values	Predicted	Actual	% deviation	Predicted	Actual	% deviation	Predicted	Actual	% deviation
-3.82	6.25	6.43	2.81	18.05	17.21	4.87	4.65	4.64	0.20
-4.15	6.40	6.38	0.19	18.40	17.90	2.83	4.66	4.23	10.20
-4.27	6.62	6.77	2.23	18.75	18.83	0.43	5.20	5.61	7.32
-4.33	6.43	6.66	3.48	18.96	16.73	13.32	4.68	4.32	8.49
-4.96	6.66	6.62	0.66	23.00	20.29	13.39	4.79	4.82	0.59
-5.79	7.10	6.90	2.95	33.41	32.91	1.51	4.75	4.53	4.91
-5.86	6.85	6.94	1.26	34.53	36.90	6.40	4.89	5.40	9.43
-6.03	7.02	7.33	4.25	37.40	33.82	10.57	4.61	4.13	11.73
-6.09	6.60	6.52	1.16	38.52	34.61	11.31	5.77	5.79	0.37
-6.47	6.54	6.55	0.23	46.06	40.50	13.74	5.51	5.01	10.06

N=10

throughout the ripening period. The color evolution of banana in terms of 'a' value showed linear increase (from −5.86 on the first day of experimentation to −2.59 on the 10th day of ripening) throughout the ripening period indicating the reduction in green color of bananas during ripening period while a gradual increase was observed in 'b' value till 6th day of storage, which stabilized thereafter, representing an increase in yellow color of banana peel. It may be concluded that gradually the color of banana peel changed from green to yellow with ripening period. Similar results have been reported for bananas ripening at different temperatures for different storage times (Ward and Nussinovitch 1996; Chen and Ramaswamy 2002; Mendoza and Aguilera 2004). These changes during the ripening period (loss of greenness, increase in reddish and yellowish tones) took place as a result of the breakdown of the chlorophyll in the peel (Salvador et al. 2007). It was found after applying ANOVA that variation in color value 'L' and 'a' with ripening period was statistically significant while change in 'b' value was found to be non-significant (Table 1).

Relationship between Color and Textural Attributes In order to find out which color attribute of banana can be used to describe its textural property or vice-versa, correlation studies (Coefficient of Correlation, r and Coefficient of Determination, R^2) were conducted between color ('L', 'a' and 'b' value) and textural attributes (peel firmness, peel toughness, fruit firmness, pulp firmness, pulp toughness and stickiness) of banana. Among the color characteristics, 'a' value showed highest correlation ($r \sim 0.48$) with peel toughness and pulp firmness (Table 2). Though 'L' value also showed significant correlation with various textural attributes, correlation value was low as compared to 'a' value. Also, the peel color value 'a' of was found to be negatively correlated with almost all the textural parameters (peel, fruit and pulp firmness; peel and pulp toughness) except stickiness, which may be due to decline in textural attributes, with increase in aesthetic appeal of banana peel till optimal stage of ripening. Further, five standard forms of equations (linear, polynomial, exponential, logarithmic and power) were fitted to data and the best fit equation based on R^2 (Coefficient of determination) were selected (Table 3). The results showed ripening period specific variation with respect to textural and color attributes. It was noticed that pulp toughness of banana could best associated ($R^2=0.869$) with color value 'a'. Good association of value 'a' was also found with pulp firmness ($R^2=0.849$) and peel toughness ($R^2=0.865$). Interestingly, among five standard equations (linear/polynomial/exponential/logarithmic/power), all the three above mentioned best R^2 values were obtained with polynomial equation. Hence, it can be concluded that color value 'a' alone has the potential to predict major textural

attributes (peel toughness and pulp firmness and toughness) and vice-versa. The performance of the fitted equations were validated with independent set of data (color and textural properties) obtained from samples collected in different year than those used for formulation of equations. Percent deviation between actual and predicted textural attributes (Table 4) showed that peel and pulp toughness could be successfully predicted with less than 10% deviation using color value 'a'. Pulp firmness of banana although showed good association with colour value 'a' ($R^2=0.849$) but percent deviation between actual and predicted values were slightly variable (0.19–13.74) indicating possibility of instability of predictions.

Conclusion

Color values ('L' and 'a') and textural properties (fruit, peel and pulp firmness; toughness of peel and pulp; and stickiness) of bananas were found to be significantly influenced by the ripening period except color value 'b' which was found non-significant. In general, the textural properties of bananas except stickiness declined while color values 'a' and 'b' except value 'L' showed an increasing trend with ripening period. 'a' value showed low but statistically significant correlation with peel toughness and pulp firmness ($r \sim 0.48$). The very high coefficient of determination (R^2) was recorded between peel toughness, pulp toughness and pulp firmness. Further validation studies have shown that peel and pulp toughness, the two major criteria for determining the ripening stage of fruit could be successfully predicted using color value 'a' of banana peel with the fitted equations. Therefore, it can be concluded that 'a' value of banana can be used to predict the textural properties and the ripening stage of fruit non-destructively.

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