Changes in physico-mechanical properties of banana fruit during ripening treatment

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Abstract. In this paper, some physical and mechanical properties of banana fruits at different level of ripeness were investigated. Relation between various stages of ripeness and these properties were determined and correlation coefficients were calculated. The color of the fruit skin was measured as *L**, *a** and *b** in *CIELAB* system. The mechanical properties were extracted from plotted force-deformation curve. A significant difference at 5% level was found between the level of ripeness and these properties. Duncan's multiple range test was conducted and results were reported. Results showed that changes in *L**, *b** and *C* was similar, also variation of color index (*CI*) was similar to *a**. The firmness, rupture energy and hardness decreased as banana fruit ripened. All measured physico-mechanical properties of banana fruit except deformation had High correlation with stage of ripeness. Result of deformation analysis showed no significant difference at various stages of ripeness. The correlation between deformation and stage of ripeness was obtained as 0.2.

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1. Introduction

Banana is one of the popular fruits in the world. Banana fruit is grown in many countries in sub-tropical areas and the big exporters are located in South East Asia, South America and the Caribbean. The Cavendish variety is widely produced by these countries. Banana is subsumed third place in the world fruits volume production after citrus fruit and grapes. Green-mature banana fruits are transported to consumer countries and ripened in controlled conditions. Imported banana fruits are transported to airtight warehouses with ethylene gas control system and are ripened. During ripening process, many changes are occurred in physical and mechanical properties of banana fruits. Knowing the physical and mechanical properties of banana fruit and changes in these parameters in ripening treatment is the most important attributes to design handling, sorting, processing and packaging system. Knowing these properties of agricultural products would help designer engineers to apply forces and dimensions of machine's units properly to protect fruits from bruises, injuries, decay lesions and numerous other defects that emanate as results of post-harvest processing treatments. In many fruits such as banana and mango, the level of ripeness associates with physical and mechanical properties such as firmness, color and dimensions of fruits. These parameters can be applied to predict the quality of fruits. Also in design of processing systems for these fruits, changes occurred in phisyco-mechanical properties must be remarked. Many studies have been reported on the physical and mechanical properties of fruits, such as bergamot (Rafiee et al., 2007), coconut (Terdwongworakul et al., 2009), date fruit (Keramat Jahromi et al., 2008), kiwi fruit (Lorestani and Tabatabaeefar, 2006), melon (Emadi et al., 2009), orange (Khojastehnazhand et al., 2009; Sharifi et al., 2007) and citrus fruits (Omid et al., 2010).

For banana fruit, some researches were accomplished about its physico-mechanical properties. For example, Kachru et al., (1995) investigated physical and mechanical characteristics of two varieties of green-mature banana fruit. Saeed Ahmad et al., (2002) conciliated the temperature effect of ripening treatment on properties of banana fruit. Also investigation on reciprocal effect of storage humidity, temperature and fruit length on characteristics of banana fruit were done (Saeed Ahmad et al., 2006). Salvador et al., (2007) studied the changes in color and texture of banana during storage at 10 ºC and 20 ºC. They found that during storage, the change in peel color from green to yellow was gradual in the *M. Cavendish* samples, whereas the *M. Paradisiacal* variety presented a different pattern, remaining green for the first 8 days and then changing rapidly to a yellow tone from day 12 onwards. While the flesh texture of the *M. Cavendish* type bananas softened quite rapidly during storage, it evolved more slowly in the *M. Paradisiacal* variety and there was little variation in the flesh hardness values over the storage time. As it is found from previous studies, it is necessary to investigate changes in physico-mechanical properties of banana fruit during ripening treatment.

The objectives of this research were to study some physical and mechanical properties of banana fruit and changes in these parameters during ripening treatment. The parameters investigated include L*, a*, b*, CI, C, H, firmness (*F*), rupture energy (R_E), hardness (*Ha*), deformation (*D*).

2. Materials and Methods

Specimens were provided from an airtight warehouse having ripening operation on banana fruit. During ripening, peel color varied from green to yellow. Ripeness is currently assessed visually by comparing the color of the peel with standardized color charts that describe various stages of ripeness. In trade market, seven ripening stages of bananas are usually discerned: stage1: all green; stage 2: green with a trace of yellow; stage 3: more green than yellow; stage 4: more yellow than green; stage 5: yellow with a trace of green; stage 6: all yellow; stage 7: all yellow with brown speckles. Color stage was judged visually using a chart scale to categorize bananas based on their level of ripeness. Banana fruits (*Cavendish* variety) were selected from imported bananas that were ripened in an airtight warehouse with ethylene gas control system. Undamaged bananas of each stage were selected and cut into fingers. The specimens were transferred to the material property laboratory, department of Agricultural Machinery Engineering, Faculty of Engineering and Technology, University of Tehran.

Color of fruit can be described by several color coordinate systems. Some of the most popular systems are CIELAB and RGB. The CIELAB color space is based on the concept that colors can be considered as combinations of red and yellow, red and blue, green and yellow, and green and blue (Figure 1). To determine the exact combination of colors of a product, coordinates of a three dimensional color space are assigned.

The L* coordinate of an object is the lightness intensity as measured on a scale from 0 to 100, where 0 represents black and 100 represents white. The a* coordinate of an object represents the position of the object's color on a pure green and pure red scale, where -127 represents pure green and +127 represents pure red. The *b** coordinate represents the position of the object's color on a pure blue and pure yellow scale, where -127 represents pure blue and +127 represents pure yellow.

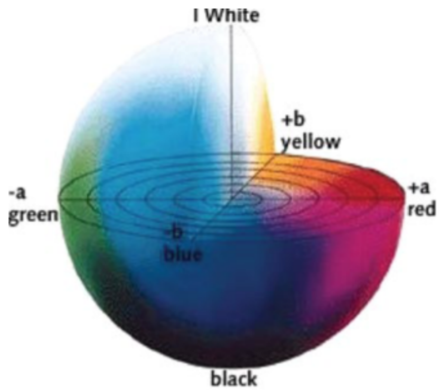

Figure 1. *CILAB* color space.

The color of the fruit skin was measured as *L**, *a** and *b** by a spectrocolorimeter (Model Konica Minolta CR-400, Japan), in *CIELAB* system. The color index (*CI*) was calculated using the following formula (Jimenez-Cuesta et al., 1981):

$$CI = 1000\frac{a^*}{L^*.b^*} \quad (1)$$

The saturation or chroma (*C*) indicates intensity or strength of hue. This parameter was computed by following formula (Ozturk et al., 2009):

$$C = \sqrt{a^{*2} + b^{*2}} \quad (2)$$

The hue angle (*H*) between the color vector and the negative *a** axis was used to characterize the color changes during developmental changes. This hue angle was calculated from the *a** and *b** values as follows:

$$H = \begin{cases} 180° - \tan^{-1}\left(\frac{b^*}{a^*}\right) & if \quad a^* > 0 \\ \tan^{-1}\left(\frac{b^*}{a^*}\right) & otherwise \end{cases} \quad (3)$$

Mechanical properties of specimens were measured by an Instron Universal Testing Machine (Model SANTAM ST 5) controlled by a *PC*- based data acquisition card in a personal computer. A cylindrical probe with 8 mm diameter was used to penetrate in banana fruit (Saeed Ahmad et al., 2006).The penetration speed was set at 50 mm/min. The samples were placed on a fixed plate on its lateral surface and the puncture test was carried out at 2 cm away from the middle of the fruit. The compression test was initiated until rupture occurred as is denoted by a rupture point in the force–deformation curve. As the penetration initiated and progressed, a force-deformation curve was plotted (Figure 2). The rupture point was detected by the break point in the force-deformation curve as shown in Figure 2. When the rupture occurred, the test was stopped. The compression test results and graphs were generated automatically (by software installed on the computer, *ver* 5, *SMT* Machine Linker, SANTAM Co).The mechanical properties of banana fruit were extracted in terms of firmness, rupture energy, rupture deformation and hardness.

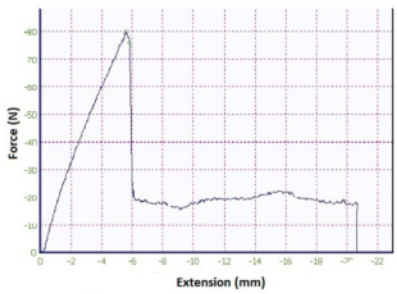

Figure 2. Compressive force versus deformation of banana fruit.

A randomized complete block experiment design was carried out on experiments. For each treatment, three samples were randomly selected and the average values of three experiments were reported. Experimental data were analyzed using analysis of variance (*ANOVA*). Duncan's multiple range test was employed for mean separation. The level of significance was at 5%. The analysis was performed using the Excel Analysis Toolpack Option (*MS* Corporation, Redmond, *WA*, *USA*).

3. Results and Discussion

Mean values and standard deviations of chromatic properties of banana fruit were calculated. There was a significant difference ($P \leq 0.05$) between the levels of banana ripeness for *L**, *a**, *b**, *CI*, *H* and *C*. Results of Duncan's multiple range test for these characteristics are presented in Table 1.

The value of *L** increased between stages one and three and reached to 70.35 and stopped until stage six then decreased rapidly to 48.82 at stage seven. Similarly, *b** varied in this fashion (Figure 3). The saturation or chroma is a function of *a** and *b**. The values of *a** were smaller than *b** values, so the effect of *a** on chroma was poor. Therefore, the values of chroma were approximately equal to *b** (Figure 3). Decrease in these parameters at stage seven was as a result of developing brown spots on banana fruit skins.

Table 1. Mean values of *L**, *a** and *b** at different stages of ripeness.

level	*L**	*a**	*b**	*CI*	*C*	*H*(°)
1	57.4^{c}	-14^{c}	32.6^{c}	-7.6^{a}	35.6^{c}	-66.7^{b}
2	62^{bc}	-9.1^{b}	38.4^{b}	-4.6^{d}	39.9^{bc}	-74.4^{c}
3	70.4^{a}	-4.6^{b}	45.7^{a}	-1.5^{bc}	46^{a}	-84.2^{d}
4	66^{ab}	-7.7^{b}	40.9^{ab}	-3^{cd}	41.7^{ab}	-79.2^{cd}
5	65.4^{ab}	1.2^{a}	40.4^{ab}	0.5^{a}	40.4^{bc}	91.7^{a}
6	67.1^{ab}	0.9^{a}	40.3^{ab}	0.4^{ab}	40.3^{bc}	91.6^{a}
7	48^{d}	2.6^{a}	27.4^{d}	2^{a}	27.5^{bc}	95.6^{a}

In each column, means followed by the same letter are not significantly different ($P \leq 0.05$) according to Duncan's multiple range test.

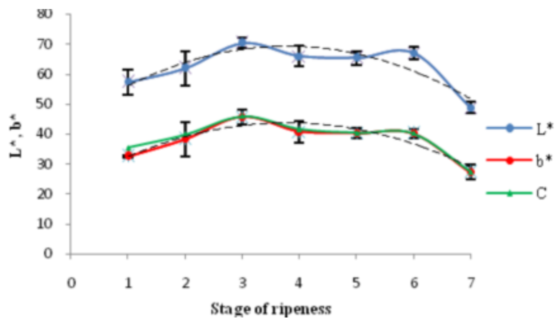

Figure 3. Variation of *L**, *b** and *C vs* stage of ripeness. Vertical lines represent the standard deviation.

The *a** increased when banana fruits reached to a full-ripe stage. A positive correlation was observed between *a** and various stages of ripeness. As it was noted, an increase in *a** means a decrease in the degree of greenness. The maximum value of *a** was 2.6. This point is near of the *b** axis, so the redness of skin color can be neglected. These changes during ripening period (loss of greenness) occurred as a result of the breakdown of the chlorophyll pigments in the peel tissue. The color index (*CI*) is a function of *a**, *b** and *L**, but as perceived from Figure 4, the procedure variation of *CI* and *a** were similar.

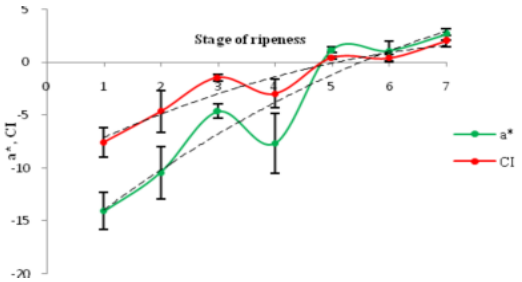

Figure 4. Variation of *a** and *CI vs* stage of ripeness. Vertical lines represent the standard deviation.

The correlation (*R*) between *CI* and *a** was obtained as 0.985. Change in hue angle is presented in Figure 5. After the banana fruit reached to stage four, the color vector transferred from green to yellow region. The time near the inflexion point was the most illustrative of the dynamics of the developmental changes.

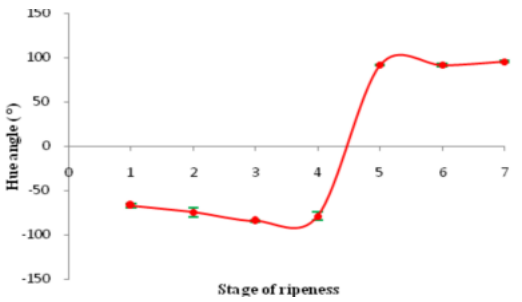

Figure 5. Variation of hue angle *vs* stage of ripeness. Vertical lines represent the standard deviation.

The time when the inflexion point occurs might be suitable for characterising the development process, comparing cultivars, influences of ripening treatment at various conditions and determining the time of appearance of the ripe fruit (Muskovics et al., 2006). The slope of that part of the graph showed the rate of the color changing provides useful information about the number of days during which the color turns from green to yellow (Muskovics et al., 2006). The equations representing the relationship among chromatic properties and ripeness stage of banana fruit and their coefficient of determination (R^2) are given in Table 2. Results of polynomial regression show a quadratic relation between these parameters and stage of ripeness.

Table 2. Equations representing relationship between chromatic properties and stage of banana fruit.

Parameter	Equation	R^2
*L**	$L^* = -1.6651S_r^2 + 12.588S_r^{\wedge} + 45.397$	0.78
*a**	$a^* = -0.1539S_r^2 + 2.6837\ S_r - 9.6171$	0.91
*b**	$b^* = -1.4531S_r^2 + 11\ S_r + 23.027$	0.85
CI	$CI = -0.1912S_r^2 + 4.3479\ S_r - 18.123$	0.90
C	$C = -1.3189S_r^2 + 9.5146\ S_r + 27.092$	0.86

^ S_r is the ripeness level of banana fruit.

There were significant difference (P < 0.05) in firmness, rupture energy and hardness of banana fruit at different stages of ripeness. Results of Duncan's multiple range test for these parameters are presented in Table 3. There was no significant difference (P > 0.05) in the deformation.

Table 3. Mean values of firmness, Rupture energy, and hardness.

Ripeness level	Firmness (N)	Rupture energy (J)	Hardness (N/mm)	Deformation (mm)
1	75 [a]	225 [a]	12.6 [a]	6
2	60.1 [b]	252 [a]	7.2 [b]	8.3
3	46.2 [c]	192 [ab]	5.6 [c]	8.3
4	40.9 [c]	214 [a]	3.9 [d]	10.5
5	26.7 [d]	99.4 [b]	3.6 [d]	7.4
6	28.9 [d]	158 [ab]	2.9 [d]	10
7	27 [d]	91.3 [b]	3.9 [d]	6.8

In each column, means followed by the same letter are not significantly different (P ≤ 0.05) according to Duncan's multiple range test.

A decrease was observed in firmness, rupture energy and hardness as fruit ripened. The firmness degraded from 75.1 N at stage one to 27 N at stage seven. A second degree polynomial relationship was found between firmness and stage of ripeness (Table 4). The similar trends were also reported by Singh *et al.*, (2006) for orange. After stage four, the slope of firmness degradation was slower than before stage four (Figure 6). As noted in previous expression, this stage is inflexion point. In this point the banana converted to ripe status from unripe mood. The variation of rupture energy was irregular, but the green mature banana (stage one) have greater rupture energy than full-ripe (stage seven) one. The rupture energy decreased from 225.8

J to 91.3 J (Figure 7). The hardness of fruit, decreased in quadratic form as banana fruit ripened from 12.6 J.mm^{-1} to 3.9 J.mm^{-1} (Table 4). No relationship was found among deformation of fruit and ripeness level (Figure 9). The correlation between deformation and stage of ripeness was 0.2.

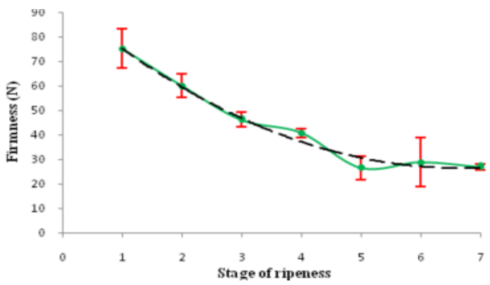

Figure 6. Variation of firmness *vs* stage of ripeness. Vertical lines represent the standard deviation.

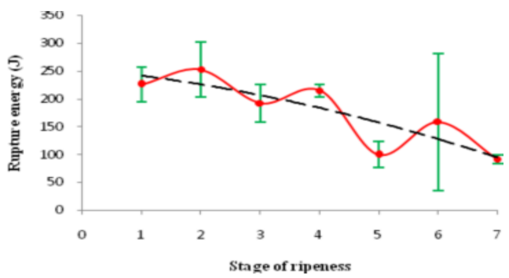

Figure 7. Variation of rupture energy *vs* stage of ripeness. Vertical lines represent the standard deviation.

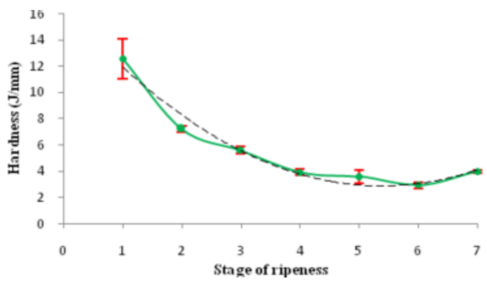

Figure 8. Variation of hardness *vs* stage of ripeness. Vertical lines represent the standard deviation.

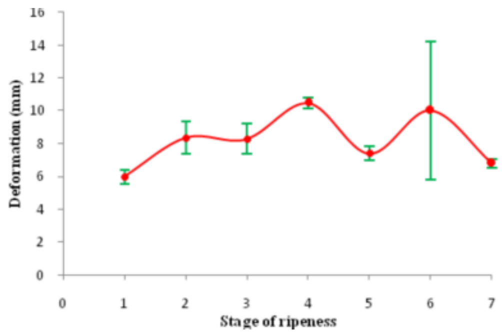

Figure 9. Variation of deformation versus stage of ripeness. Vertical lines represent the standard deviation.

Decreases in mechanical properties were as a result of alteration in the composition of cell wall solubilisation of pectins and hydration of cell walls during ripening. Banana fruit softening is due to alteration in cell wall structure by degrading enzymes (e.g. polyglacteronase) and also to degradation of starch (Seymour, 1993).

The equations representing relationship among mechanical properties and ripeness stage of banana fruit and their coefficient of determination (R^2) are given in Table 4. Results of polynomial regression showed a quadratic relation between these parameters and stage of ripeness.

Table 4. Equations representing relationship between chromatic properties and stage of banana fruit.

Parameter	Equation	R^2
Firmness (F)	$F = 1.5274\ S_r^2 - 20.296\ S_r$^ +94.204	0.98
Rupture energy(R_E)	$R_E = -1.7614\ S_r^2 - 10.29\ S_r$ +252.69	0.73
Hardness (Ha)	$Ha = 0.470\ S_r^2 - 5.0591\ S_r$ +16.509	0.97

^ S_r is the ripeness level of banana fruit.

4. Conclusion

The changes in physical and mechanical properties of banana fruit as a function of ripeness stage were investigated in this study. A significant difference was found in studied properties except deformation. At different levels of ripeness, the relationship of these properties with stages of ripeness and coefficient of determination were found. The $a*$ and CI had a good correlation with the ripeness level of banana, also firmness and hardness had good correlation with ripeness level, so these properties can predict the ripeness level of banana fruit during ripening treatment, but extraction of mechanical properties would result in the destruction of samples. It could only be a good practice in laboratory and not for quality inspection in warehouses. The best method for predicting the level of ripeness is to measure chromatic properties (*a** and *CI*) since this method dose not destroy the fruits. It is also a rapid method of ripeness prediction of banana fruit.

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