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Physico-chemical changes in "Xiem" banana cultivar (cultivated in Vietnam) during ripening and storage at different temperatures

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Abstract

There are changes in chemical and physical characteristics involved in the ripening of bananas. This study evaluated the changes in physico-chemical and nutritional characteristics of the "Xiêm" banana cultivar at the harvesting (unripe fruit) and ripe stages (ripe fruit). As the pulp to peel ratio and titrable acidity increased, the firmness decreased with an increase in ripening time. A significant increase in total polyphenol content and decrease in beta-carotene and vitamin C content was observed at climacteric peak during ripening. During ripening, the banana peel colour changed from green to yellow, the pulp softened, the flavour develops, and the moisture is lost. "Xiem" banana variety was fully mature after 7 and 22 days of storage at 28-30°C and 13-15°C, respectively. The correlation between various stages of ripeness and these properties were determined and the correlation coefficients were calculated. A very high coefficient of determination (r^2>0.937) was recorded between physical properties (pulp firmness/peel colour) and chemical properties (starch/sugar) of banana fruit with the stage of ripeness.

1. Introduction

Vietnam is blessed with large areas appropriate for banana growing. Large-scale cultivation of bananas for fresh fruit consumption. There are many banana cultivars, in which the "Xiem" cultivar is the most popular in Vietnam. The banana fruit has minerals, vitamins, sugars that are beneficial in maintaining an ideal weight and balanced nutrition. Bananas are also a good source of different types of fibre, such as pectin. Some of the pectin in bananas are water-soluble (Duan *et al.*, 2008).

The "Xiem" bananas are harvested at a specific maturity stage based on the age of the bunch, the interval between flowering and harvesting and the colour of the peel and pulp. Quality is an important factor in the banana market, especially when freshly consumed. Banana in the domestic market is harvested at the maturity stage (unripe fruit) which is important in the quality of bananas. The small difference in the maturity of bananas after harvesting makes a large difference in eating quality and consequently consumer satisfaction.

The ripening of bananas includes both chemicals as well as physical changes. As a banana ripens, in relation to physical properties, the change in the texture of the banana was very obvious as some parts soften while others are destroyed with the formation of new parts. The chemical changes involved the formation of simpler sugars from the complex carbohydrates that constitute raw bananas and the formation of new chemicals that result in the change in colour and taste. When the proportion of water-soluble pectin increases, it results in the soft texture of the bananas as they age. Banana is also a good source of vitamin C, has minimal fat and sodium with cholesterol, is delicious, healthy and nutritious when eaten raw or used in cooking. Similarly, the antioxidants gallocatechin, catechin, and epicatechin were also identified in bananas (Someya *et al*., 2002). Fruit sugars continue to increase through to senescence, these changes in the acid and sugar content during ripening, results in ripe bananas that are sweeter and lightly sour.

However, research on the evaluation of bananas at the ripening stage during storage in Vietnam is still limited. Thus, the purpose of this experiment was to study the influence of storage conditions and the degree of ripening on physico-chemical attributes (colour, L*, a*, b*, total soluble solids, titratable acidity, fibre, moisture content, sugars) of banana fruit. The colour chart of bananas at various stages after harvesting has been established.

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The most important attributes of the fruits, according to the consumer preferences at purchasing banana, are the flavour, shelf life and appearance (length, diameter and colour) (Matsuura *et al*., 2004). Researches describing the physical and chemical properties of different banana cultivars are available in the scientific literature (Gomes and Prado, 2007), however, these studies usually evaluate the pulp of some cultivars only from ripe fruits, not characterizing unripe pulp and peel, which is important due to the high starch content and other antioxidant compounds present in these parts of the unripe fruits that are components of the human diet (Borges *et al*., 2014).

The characterization of the banana is also useful information for its commercial quality. Therefore, the study on physical and chemical parameters related to its fruit quality and seeking to maintain the desirable characteristics required by market standards was very important. In this context, the objective of this work was to assess the physical and chemical characteristics of fruits at two maturation stages, unripened and ripened. The relationship between the various physico-chemical properties of banana ripened at ambient (28-30°C) and low temperature (13-15°C), as a predictive tool for ripening quality and usage was established.

2. Materials and methods

2.1 Materials

Banana (*Musa* spp.) bunches were collected from Ca Mau province, Viet Nam when the fruits were still green but have reached maturity (Figure 1). The fruits were washed in running water and left on an absorbent paper for the latex to coagulate. Then, banana fruits were packed in plastic bags and kept at different temperatures (13-15°C and 28-30°C) until it has achieved stage-7 colour (from all green to all yellow). About 15 kg of raw material was collected for each survey, the maturity of the fruit is determined by physical properties (weight, volume, firmness, colour, diameter) and chemical properties (starch, sugar, β-carotene, total polyphenol content, titratable acidity and minerals).

Figure 1. The bananas bunch is ready for harvest

2.2 Physical characteristics

2.2.1 Weight of the fruit

The weight (g) of the fruit was measured by using a digital balance with a sensitivity of ±0.01 g.

2.2.2 Fruit length, diameter, peel thickness

The fruit length (L), diameter (D) and peel thickness (mm) were measured in the median area of each fruit, perpendicular to its larger axis, with a digital calliper (accuracy of 0.01 mm).

2.2.3 Volume of fruit

The volume (V) of the fruit was defined as the ratio of the mass of a sample to the solid volume accordingly occupied was determined by the liquid displacement method. The amount of displaced water was recorded from the graduated scale of the measuring cylinder (Akbolat *et al*., 2008).

2.2.4 Bulk density

The bulk density is the ratio of the mass of fruit to its total volume and was determined with a weight per hectoliter tester, which was calibrated in $kg.m^{-3}$.

2.2.5 Surface area

The surface area was measured by the peeling method.

2.2.6 Pulp firmness

The firmness of banana pulp was measured using a PenetrometerEY-30 Fruit Firmness, with a tip diameter of 7.9 mm (China).

2.2.7 Ratio of pulp and peel

The pulp-to-peel ratio was obtained by dividing the pulp weight by the peel weight using formula 1.

$$Pulp\ to\ peel\ ratio = \frac{Weight\ of\ pulp}{Weight\ of\ peel} \quad (1)$$

2.2.8 Peel colour

The colour of banana peel was measured by using Colorimeter (Japan), five replicates were taken. L*, a* and b* values were recorded and these values were used to calculate Chroma (C) (equation 2).

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

2.2.9 *Hue angle (H)* value

It is the angle between the *a** and *b** axes (equation 3), indicating the colour saturation of the subject.

$$H = tan^{-1}\left(\frac{b^*}{a^*}\right) \quad (3)$$

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Chroma and Hue angles were used for describing visual colour appearance (Bernalte *et al*., 2003).

2.2.10 Weight loss

Initially, around 200 g of fruit (in transparent plastic boxes) was weighed with HL Electronic Balance, with an accuracy of 0.001 g. Fruits were stored for 8 and 22 days at ambient temperatures (28±2°C) and low temperatures (12±1°C), respectively, they were weighed every 2 days. The results were converted into percentages with equation 4.

$$\%WL = \frac{W_i - W_f}{W_i} \times 100 \quad (4)$$

Where %*WL* is percentage weight loss, W_i is initial fruit weight in g, W_f is final fruit weight in g at the indicated time.

2.3 Determination of chemical characteristics

2.3.1 Titratable acidity

The acid content was determined as % malic acid present in bananas by the method given by the standard AOAC (1980).

2.3.2 Soluble solids content

It was evaluated with a portable digital refractometer (Atago model N1), with readings in the range of 0 to 32°Brix.

2.3.3 Carbohydrate content

The content of carbohydrates was determined according to the method of McCseady (1971) and Dubois *et al.* (1956).

2.3.4 The β-carotene content

The content of carotenes expressed as β-carotene was calculated using equation 5, according to the method of Fikselová *et al.* (2008).

$$\beta - \text{carotene } (\mu g/g) = \frac{A \times d \times V}{E_{1\,cm}^{1\%} \times w} \quad (5)$$

Where A is absorbance, d is dilution (g/mL), $E_{1\,cm}^{1\%}$ is absorption coefficient of β-carotene in petroleum ether (2592), *w* is the weight of the sample (g) and *V* is the total volume of extract (mL). Multiplied by 100 to give the carotene content in µg/100 g.

2.3.5 The vitamin C content

The content of vitamin C was determined by the titration method with iodine using equation 6 (Tran *et al*., 2004).

$$Vitamin\ C\ (mg\%) = \frac{(a-b) \times 0.088 \times 100}{10} \times \frac{100}{m} \quad (6)$$

Where *a* is the volume of 0.001 N KIO_3/KI solution used for vitamin C extract (mL), *b* is the volume of 0.001 N KIO_3/KI solution used for the control sample, 100 is the volume of the volumetric flask (mL), 0.088 is the weight of ascorbic acid corresponds to 1 mL of 0.001 N KIO_3/KI solution (mg), and *m* is the weight of the sample (g).

2.3.6 The content of calcium and potassium

The determination of calcium and potassium was carried out by flame photometry, following the procedure of Arunkumar *et al.* (2015), using an FP6410 Flame Photometer.

2.3.7 Total calories

The total calories of the fruit were calculated by the formula as follows: total calories (kcal) = fat (g) × 9 (kcal/g) + protein (g) × 4 (kcal/g) + total carbohydrate (g) × 4 (kcal/g) (Thompson and Manore, 2017).

2.3.8 The total polyphenols content

The total polyphenols content was determined by the Folin–Ciocalteu (Olsson *et al*., 2006). The results were expressed in milligrams of gallic acid equivalent/100 g of sample.

2.4 Statistical analysis

Data analyses were carried out using STATGRAPHICS Centurion XV (USA). Values were expressed as mean±SD. The significance/non-significance of results was determined using one-way ANOVA and Duncan test.

3. Results and discussion

3.1 Physical properties of banana

Some physical properties of banana fruit ("Xiem" cultivar) were determined as displayed in Table 1. These properties are very important for designing agricultural machinery. Usually, the peel colour is used as a predictor of shelf-life for retail distribution which changes from green to yellow during ripening. There is a significant change in L*, a* and b* value of unripe and ripe bananas. Bananas showed a significant increase in their L* and b* values as the fruit ripened (71.77±1.39 and 57.56±0.69, respectively). The low a* value was recorded in bananas at the unripe stage with a negative value. The chroma and hue colour space values of the fruits were significantly affected by the ripening stages. "Xiêm" banana cultivar gave significantly increased chroma values as the fruit ripens. The observed metric chroma (C) of unripe banana and ripe banana were 36.20±0.42 and 57.62±0.75 and the hue angle (H_o) of banana at the initial and the end of the storage period were in the range of -64.72±1.17 and 87.32±0.23, respectively.

Table 1. Physical properties of banana fruit

Physical properties	Number of replications	Unripe banana	Ripe banana
Length (mm)	10	118.63±1.14	114.87±3.80
Diameter (mm)	10	39.88±0.21	38.51±1.27
Surface area (cm^2)	10	113.92±2.62	110.73±4.68
Mass of fruit (g)	10	111.08±3.23	104.76±6.58
Fruit volume (cm^3)	10	108.67±1.53	102.33±3.21
Fruit density ($kg.m^{-3}$)	10	1.02±0.02	1.02±0.03
Fruit hardness (g force)	10	579.50±12.61	49.00±5.16
L^*	5	57.08±1.66	71.77±1.39
a^*	5	–15.46±0.74	2.66±0.04
b^*	5	32.73±0.42	57.56±0.69
C	5	36.20±0.42	57.62±0.75
H_o	5	–64.72±1.17	87.32±0.23
Mass of peel (g)	5	29.96±1.03	27.11±1.70
Ratio of pulp/peel	5	2.71±0.21	2.86±0.11

Values are expressed as the mean±standard deviation. L*: lightness, a*: the red/green opponent colours, with green at negative a* values and red at positive a* values. b*: the yellow/blue opponent colours, with blue at negative b* values and yellow at positive b* values.

The weight of peel decreased with the increase of storage time as the fruit ripens, corresponding with the pulp to peel ratio ranging from 2.71 for stage 1 (unripe) to 2.86 for stage 7 ripening. Patil and Shanmugasundaram (2015) recorded a similar trend in the pulp to peel ratio of Monthan bananas ranging from 2.5 to 5.95 for stage 1 and 9 ripening, respectively. The slight variations in the values obtained may be due to differences in peel morphology and variations in the atmospheric storage conditions. The water content of the peel reduces by transpiration, this explains the weight loss of the peel as ripening progress. It may be due to the collapse of the cell wall leading to the creation of air spaces in the middle lamella and this causes the thinning of the peel. The physical characteristics analysis of the fruit also showed no significant difference in length, diameter, volume, density, mass, surface area for unripe (stage 1) and ripe bananas (stage 7). However, the textural properties of bananas declined while their colour increased with the ripening period.

3.2 Colour chart of "Xiem" banana variety

In the trade market, the ripening stages of bananas are usually discerned. The banana fruits were stored for 7 and 22 days at 28-30°C and 13-15°C, respectively. Under both temperatures, the banana fruit matures and attains a yellow colour. The percentage of its yellow colour gradually appears on the peel at different levels over time during storage. The colour chart of banana fruits in various stages is illustrated in Figures 2 and 3. The peel colour changes from green to yellow (seven days) at different temperatures due to the synthesis of a few pigments (Yang *et al.,* 2011). The banana fruit is still useful at the onset of senescence (Day 8 and Day 22 at 28-30°C and 13-15°C, respectively) for the preparation of products such as cake, wine and vinegar in order to reduce post-harvest losses significantly.

Chilling injury symptoms vary depending on the

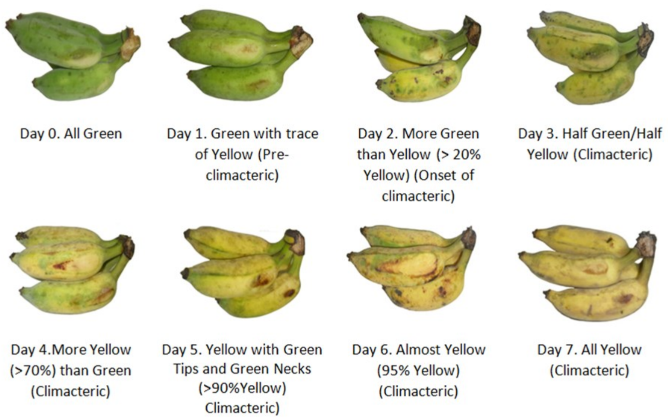

Figure 2. Banana colour chart at ambient temperature storage (28-30°C)

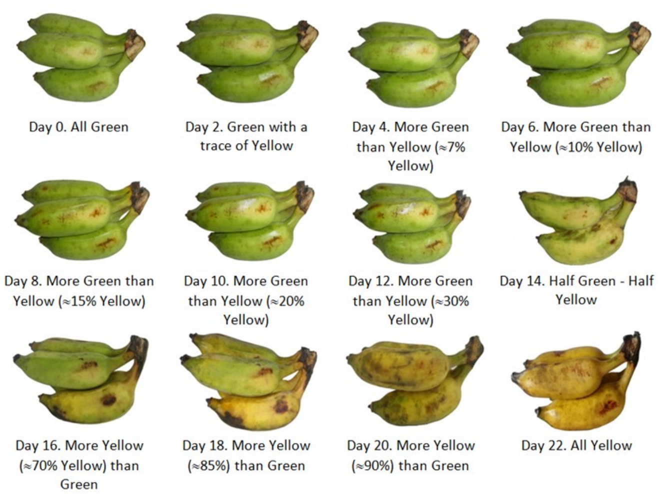

Figure 3. Banana colour chart at low temperature storage (13-15°C)

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banana cultivar and appear to be related to a genomic group (Lichtemberg *et al*., 2001). A temperature of 13°C is effective in delaying the ripening of bananas (cultivar *Nanicão*) stored for 17 days (Fernandes *et al*., 2010). Bananas (cultivar *Prata-Anã*) stored for 35 days at temperatures of 10 to 12°C showed no symptoms of chilling injury (Martins *et al*., 2007). A maximum cold storage period at 14°C was recommended for 'BRS Caipira' of 21 days (Lima *et al*., 2014). Low-temperature storage possibly affected starch to sugar conversion with the accumulation of soluble solids in banana fruits. These results support the necessity to limit the time for low-temperature storage of the "Xiem" banana variety growing in Vietnam to offer better quality banana fruits to the consumers.

3.3 Some chemical characteristics of banana fruit

As indicated in Table 2, one serving of ripe banana (100 g), provides about 23.79 g carbohydrate, 12.96 g sugar (naturally occurring), 1.09 g protein, 0.38 g fat, 376.14 mg potassium, 2.18 g fibre and 94.22 calories.

3.3.1 Moisture content

The selected samples of bananas had a moisture content of 73.10±0.82 and 72.82±1.24 g/100 g for unripe and ripe bananas, respectively.

3.3.2 Carbohydrates

Bananas were a rich source of carbohydrates (23.79±0.40 to 24.61±0.20 g/100 g), which occurs mainly as starch in unripe bananas and sugars in ripe bananas. The main component of unripe bananas was starch (22.12±0.15 g/100 g), they had less sugar, which can be especially beneficial to diabetic people. Bananas have a relatively low glycemic index (GI) of 48–54 (Harvard Health Publishing, 2020), depending on their ripeness. Bananas contain high resistant starch and fibre, which could explain their low GI (Hettiaratchi *et al*., 2011). During ripening, the starch is converted into sugars when the banana is fully ripened. In ripe bananas, the total sugar content could reach 13% of the fresh weight. Although the acid content still tends to increase when the fruit is fully ripe, the high sugar content that is converted from starch also makes the fruit sweeter (sugar/acid ratio). High content of simple sugars in bananas was found in the study of Segundo *et al*. (2017). The yellow banana with brown spots has more sugar and less fibre than a green banana of the same size. The fibre content of unripe and ripe banana pulp were 2.23 and 2.18 g/100 g, respectively.

3.3.3 Acid

It was observed that the titratable acidity of bananas continuously increases after harvest and as the banana ripens. The initial titrable acidity was found to be 0.16% (green banana) and increased throughout its ripening time (0.27% in a ripe banana). These results were in agreement with a previous study, which reported that the concentration of malic acid and citric acid increased until the ripe stage was reached (Chandra *et al*., 2020). Adi *et al*. (2019) also reported that the acidity of the plantain fruit increased from stage 1 (0.06%) to stage 7 (0.29%) where it peaked. According to Von Loesecke (1950), titratable acidity of the pulp increased to a peak during ripening in the case of some varieties.

3.3.4 β-carotene, vitamin C and total polyphenol

The content of β-carotene in the unripe pulp of the

Table 2. Some chemical characteristics (per 100 g) of banana fruit

Parameters	Number of replications	Unripe banana	Fully ripe banana
Moisture content (g)	5	73.10±0.82	72.82±1.24
Total carbohydrate (g)	5	24.61±0.20	23.79±0.40
Starch (g)		22.12±0.15	1.58±0.10
Sugar (g)	5	0	12.96±0.74
Titratable acidity (g)	5	0.16±0.01	0.27±0.02
Sugar/acid ratio	5	-	44.69
Protein (g)	5	1.08±0.01	1.09±0.01
Lipid (g)	5	0.30±0.05	0.38±0.02
β-carotene content (μg/g)	5	343.28±1.77	294.87±2.35
Vitamin C content (mg)	5	10.30±0.58	8.70±0.04
Total polyphenol (mg GAE)	5	23.60±1.53	73.13±1.30
Calcium (mg)	5	7.08±0.35	6.88±0.22
Potassium (mg)	5	368.87±3.26	376.14±2.89
Sodium (mg)	5	1.17±0.02	1.22±0.05
Fibre (g)	5	2.23±0.20	2.18±0.27
Total calories (kcal)	-	96.54	94.22

Values are expressed as the mean±standard deviation.

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"Xiem" banana variety was higher (343.28±1.77 mg/100 g), differing from the content of the ripe pulp (294.87±2.35 mg/100 g). Analysis of three cultivars grouped in Thailand, Malaysia and Micronesia found similar levels (345, 411, and 420 µg of β-carotene equivalents/100 g) (Siong, 1985; Englberger, Wills, Blades *et al*., 2006; Puwastien *et al*., 2020). These results also concurred with Newilah *et al*. (2009) who reported that the principal carotenoids were β-carotene, α-carotene and lutein, the first two nutrients being the major banana and plantain carotenoids. The decreased concentrations of these carotenoids during ripening may be due to their degradation or to the synthesis of other carotenoids such as lutein (Newilah *et al*., 2009). Aquino *et al*. (2018) reported that the reduction of 7.3 and 8.5% in the mean α-carotene and β-carotene concentrations in the ripe pulp, respectively, was due to fruit ripening. Lutein concentration hardly changed due to fruit ripening. However, this decrease did not occur in all the bananas, according to some studies, soil fertilization, which was applied in the experiment during the fruit production cycle, could be one of the factors that affected carotenoid biosynthesis in fruits (Gross, 1987). There are 149 local cultivars of edible bananas in Southeast Asia (Valmayor *et al*., 2002), and some have an average concentration of β-carotene that ranges from 230 to 1370 µg/100 g DW (Englberger *et al*., 2003; Englberger, Wills, Blades *et al*., 2006; Englberger, Schierle, Aalbersberg *et al*., 2006).

Bananas are also a good source of vitamin C. However, ripe bananas had lower concentrations of vitamin C (8.70±0.04 mg/100 g) than unripe bananas (10.30±0.58 mg/100 g). Lee and Kader (2000) also found that the vitamin C content in bananas decreased with maturation and ripeness.

The total polyphenol compounds of unripe and ripe bananas have been identified, at 24.68±0.15 and 68.43±0.25 mg GAE/100 g, respectively. These results were quite similar to the published results of Aquino *et al*. (2018). With fruit ripening, there was an increase in the content of phenolic compounds in the ripe pulp. Phenolics play a significant role in the prevention of many chronic diseases.

3.3.5 Lipid and protein

Bananas were low in fat and protein, with less than 0.38 and 1.09 g per 100 g ripe banana, respectively. These values mostly presented no significant difference between unripe and ripe bananas.

3.3.6 Minerals

The minerals content in banana fruits is primarily consistent with potassium (368.87 to 376.14 mg/100 g, respectively for unripe and ripe bananas). Other minerals present are sodium (1.17 to 1.22 mg/100 g) and calcium (4.8 to 5.1 mg/g).

3.4 Correlations between texture/yellow surface area and starch/sugar contents of banana fruit for during ripening

For bananas, the texture is also an important part of their quality aspects. Texture perception is an important factor for the quality evaluation of fruit and vegetable products (Konopacka and Plocharski, 2004) and critical in determining the acceptability of fresh fruits (Sousa *et al*., 2007).

During maturation, banana fruit accumulates a large amount of starch, generally about 12–35% starch in fruit at commercial harvesting (Soares *et al*., 2011). As they ripen, starch decreases and soluble sugars may reach up to 20% (fresh weight) of the ripe pulp, in which 80% are sucrose and 20% are glucose and fructose (Shiga *et al*., 2011).

The changes in firmness, colour, starch and sugar from the pulp of the "Xiem" banana variety were identified at different ripening stages. It was observed that the firmness of banana fruit decreased significantly at ripening stage 4 (after 4 days of harvesting) and then gradually decreased, at the same time developing yellow coloured peel (Figure 4). Softening of "Xiem" bananas fruits seemed to be more closely related to starch levels. The yellow colour peel gradually increased during ripening and reached the highest value on days 7 and 22, respectively at 28-30 and 13-15°C. It was observed that banana softening is a consequence of starch and cell wall degradation and transformation and the accumulation of soluble sugars in fruit (Figure 5).

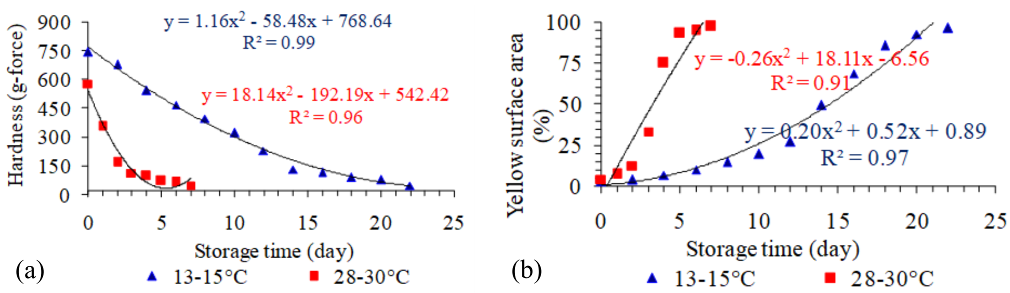

Figure 4. Changes in hardness (a) and yellow surface area (b) of banana fruits during ripening at different storage temperatures

Ripening-associated changes in the amounts of starch, sugars and their contributions to fruit softening and yellow colour development in the "Xiem" banana variety were illustrated.

The polynomial regression analysis was used to describe the correlation between hardness/colour and starch/sucrose content of bananas changes with ripening (7 and 22 days at ambient and low temperature, respectively) (Figure 6 and Figure 7). Their best-fit equations (coefficient of determination, r^2) for "Xiem" bananas variety were estimated.

4. Conclusion

In this study, the physical, chemical properties and nutrients of unripe and ripe banana fruit were evaluated. The colour chart of banana fruit at different ripeness levels and storage temperatures were established. The correlation of physical properties (texture, colour) and chemical properties (starch/sugar content) at ripening stages and coefficient of determination were found. At different levels of ripeness, the starch and sugar content correlated with the hardness and yellow surface areas. Therefore, these physical properties (hardness and yellow surface area) can be used to predict the starch/sugar at different ripeness levels and storage temperatures. It is also a rapid predicting method of the maturity of banana fruit based on the obtained equations with high values of the coefficient of determination (r^2). The knowledge of the physicochemical and nutritional characteristics of banana fruits at each ripening stage allows for better selection depending on the industrial application.

Conflict of interest

The authors declare no conflict of interest.

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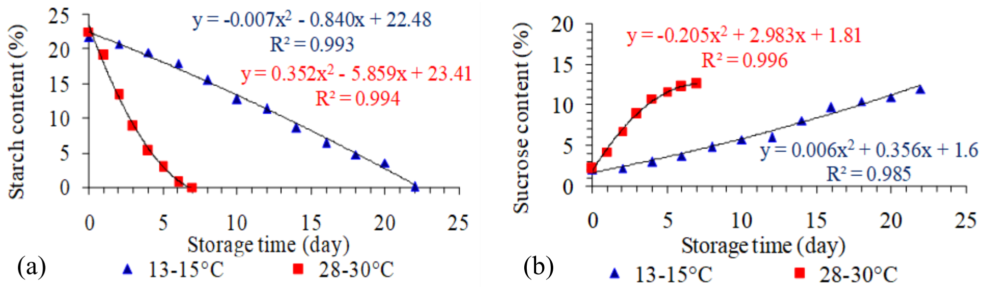

Figure 5. Changes in starch (a) and sucrose (b) content of banana fruits during ripening at different storage temperatures

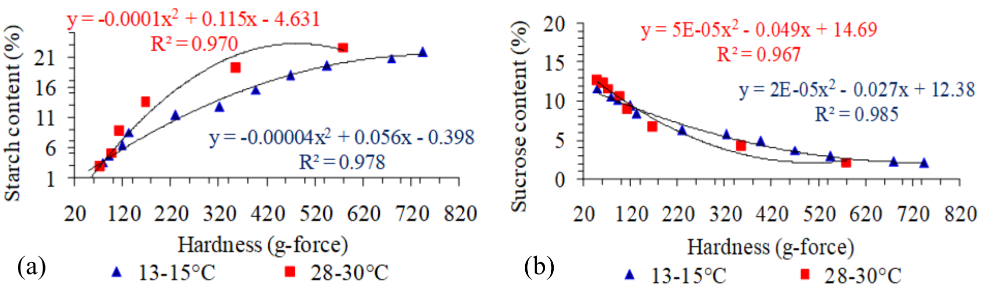

Figure 6. The relationship between hardness and starch (a)/sucrose (b) content of bananas during ripening at different storage temperatures

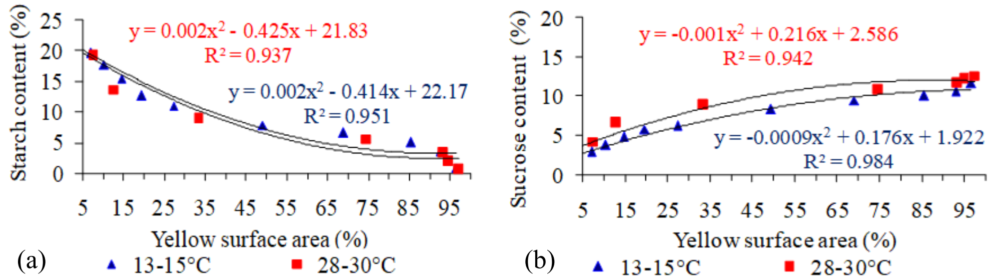

Figure 7. The relationship between yellow colour and starch (a)/sucrose (b) content of bananas during ripening at different storage temperatures

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