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Compositional Changes during Papaya Fruit Ripening

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Abstract: The objective of this study was to investigate compositional changes during ripening of 'Baladi', 'Ekostika I' and 'Ekostika II' papaya fruit cultivars at 20 ±1 °C and 85% - 90% relative humidity. The fruits of the three cultivars exhibited a typical climacteric pattern of respiration with peak of respiration of 82, 92 and 98 mg CO_2 / kg-hr, reached after 10 days in the three cultivars, respectively. Weight loss, total soluble solids (TSS), total sugars and ascorbic acid content progressively increased during ripening of the three papaya cultivars. More increase in TSS and total sugars was observed after the climacteric peak of respiration. Fruit tissue firmness and total phenolic compounds decreased continuously during ripening in the three cultivars. Reducing sugars, total protein and titratable acidity steadily increased to reach a peak, which coincided with the climacteric peak of respiration, and subsequently decreased afterwards. The local 'Baladi' cultivar had a lower respiration rate, more firm and less weight loss during ripening, which may indicate a longer shelf-life than the other two introduced cultivars. On the other hand, the introduced cultivars were higher in TSS, total and reducing sugars and ascorbic acid content and lower in titratable acidity and phenolic compounds, which may reflect a better eating quality.

Key words: Papaya fruit; compositional changes; fruit ripening

INTRODUCTION

Papaya fruit (*Carica papaya* L.) is one of the most important fruit crops in the world. It is native of tropical America, but has spread all over the tropical world (Nakasone and Paull 1998). It is produced in 54 countries with annual production of about 6.5 million metric tons (FAO 2010). Nutritionally, the papaya is a good source of calcium (30 mg) and an excellent source of provitamin A (1093 IU) and ascorbic acid (84 mg /100 g) (Nakasone and Paull 1998).

In Sudan, papaya fruit is grown in the Blue Nile and Sennar states and can be found in most markets all year round. Papayas have shown an increasing trend in popularity among consumers (Abu-Goukh *et al.* 2010). This could be due to the increased awareness to the nutritional and medicinal value of papaya fruits.

Although Sudan has great potential to produce high quality papayas and to export them to other countries, its marketability is still limited to local markets. This is due to the delicate nature of the fruit, poor handling practices and inadequate transportation and storage facilities (Abu-Goukh *et al.* 2010). Therefore, proper handling techniques and control of the ripening process are crucial for the development of a sound papaya industry in Sudan.

Compositional changes of the fruit are of concern for understanding metabolic processes, such as fruit ripening, fruit softening and general senescence. Moreover, they are of importance in determining commercial practices and post harvest requirements (Wills *et al.* 1998). This study was conducted to investigate compositional changes during papaya fruit ripening and to provide base-line information regarding these biochemical changes, to assist in development of sound programmes for controlling fruit ripening and/or loss of flesh firmness during transport and storage.

MATERIALS AND METHODS

Experimental Material

Mature-green papaya fruits of 'Baladi', 'Ekostika I' and 'Ekostika II' cultivars were harvested from the Demonstration Farm, Faculty of Agriculture, University of Sennar, Abu- Naama (12° 44' N, 38° 08' E). Fruits were selected for uniformity of size, maturity and freedom from blemishes. They were washed, air-dried to remove water from the surface, packed in carton boxes (67x35x10 cm) lined with polyethylene sheets and transported to the ripening rooms at the Faculty of Agriculture, University of Khartoum. The fruits were ripened at 20 ± 1 ºC and 85% - 90% relative humidity.

Studied Parameters

Respiration rate and weight loss were determined in ten fruits from each replication every two days during the ripening period. Respiration rate (in mg CO_2 / kg-hr.) was determined using the total absorption method (Mohamed-Nour and Abu-Goukh 2010). Weight loss in fruits was determined according to the formula: $w_1= [(w_0 - w_t)/w_0] \times 100$, where w_1 is the percentage weight loss at the designated time, w_0 is the initial weight of fruits, and w_t is the weight of fruits at the designated time.

Firmness of fruit flesh, total soluble solids (TSS), total and reducing sugars, titratable acidity, total protein, total phenolics and ascorbic acid content were determined at two days intervals in two fruits picked randomly from each replication, other than those used for respiration and weight loss determination. Fruit firmness was measured by Magness and Taylor firmness tester (D-Ballautf Meg. Co.) equipped with an 8 mm-diameter plunger tip. Two readings were taken from opposite sides of each fruit after the peel was removed, and firmness was expressed in kg/cm^2. TSS was determined directly from the fruit juice extracted by pressing the fruit pulp in a garlic press, using a Kruss hand refractometer (Model HRN-32). Two readings were taken from each fruit, and the mean values were calculated and corrected according to the refractometer chart.

Thirty grammes of fruit pulp were homogenized in 100 ml of distilled water for one minute in a Sanyo Solid State Blender (Model SM 228P) and then centrifuged at 10 000 rpm for 10 minutes using a Gallen-kamp portable centrifuge (CF-400). The volume of the supernatant, which constituted the pulp extract, was measured. Total sugars were determined according to the anthrone method of Yemm and Willis (1954). Reducing sugars were determined according to the technique described by Somogyi (1952). Total and reducing sugars were expressed in g/100 g fresh weight. Titratable acidity was measured according to the method described by Ranganna (1979) and was expressed as percent citric acid. The protein dye-binding procedure of Bradford (1976) was used for total protein determination. Total phenolic compounds were measured by the Folin-Ciocalteu method (Singleton and Rossi 1965). Total protein and total phenolics were expressed in mg/ 100g fresh weight. Ascorbic acid content in the pulp extracts was determined, using the 2, 6 -dichlorophenol- indophenol titration method of Ruck (1963), and expressed in mg /100g fresh weight.

Statistical Analysis

Analysis of variance and Fisher's protected LSD test with a significance level of $P \leq 0.05$ were performed on the data (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

Effect on Respiration Rate

The respiration curves of the three papaya cultivars exhibited a typical climacteric pattern with peak of respiration of 82, 92 and 98 mg CO_2 / kg-hr for ‘Baladi’, ‘Ekostika I’ and ‘Ekostika II’ fruits, respectively (Fig. 1-A). Similar pattern was reported during growth and development of mango (Abu-Goukh *et al*. 2005) and papaya (Abu-Goukh *et al.* 2010) and during ripening of mango (Mohamed and Abu-Goukh 2003), guava (Bashir and Abu-Goukh 2003) and banana (Osman and Abu-Goukh 2008). Respiration rate was lowest in ‘Baladi’ papayas, compared with ‘Ekostika I’ and ‘Ekostika II’ at all stages of ripening. The climacteric was lower in ‘Baladi’ by 10.9% and 16.3%, compared with ‘Ekostika I’ and ‘Ekostika II’ cultivars, respectively (Fig. 1-A). Respiration rate is an excellent indicator of metabolic activity of the tissues, and thus is a useful guide for the potential storage life of fresh fruits and vegetables (Wills *et al.* 1998). Respiration rate is inversely proportional to shelf-life of the product, the lower rate the longer was shelf-life (Day 1993). Fruits of ‘Baladi’ cultivar with the lowest respiration rate (Fig. 1-A; Abu-Goukh *et al.* 2010) and the highest flesh firmness (Shattir and Abu-Goukh 2010) at all stages of development could have a longer shelf-life than the other two introduced cultivars.

Effect on Weight Loss

Weight loss progressively increased during ripening of the three papaya cultivars (Fig. 1-B). Weight loss was significantly higher by 5.3% and 8.2% in ‘Ekostika I’ and ‘Ekostika II’, respectively, than ‘Baladi’ papayas. By the end of the ripening period (after 16 days), weight loss was 17.0 % in the ‘Baladi’, 17.9 % in ‘Ekostika I’ and 18.4 % in ‘Ekostika II’. That was most probable due to differences in fruit size, which is reflected in surface to volume ratio. The volume of 'Baladi' fruit at the mature-green stage was 35.1% and 31.1% larger than 'Ekostika I' and 'Ekostika II', respectively (Shattir and Abu-Goukh 2010). The larger the volume, the smaller was surface to volume ratio and the smaller weight loss (Wills *et al.* 1998).

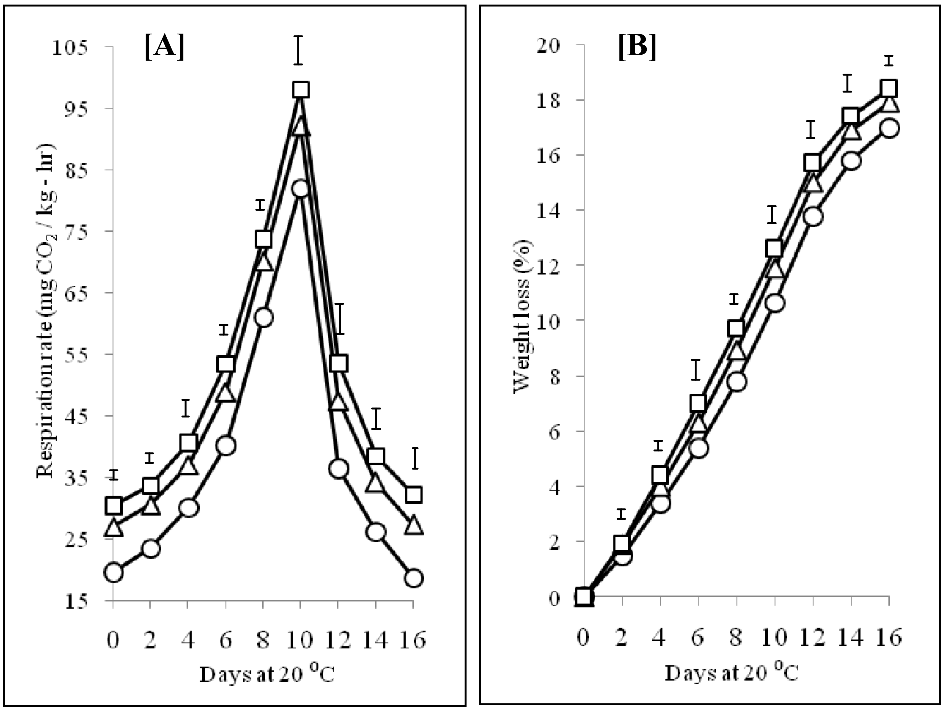

Fig. 1. Changes in respiration rate [A] and weight loss [B] during ripening of 'Baladi' (○), 'Ekostika I' (△) and 'Ekostika II' (□) papaya fruits at 20 ±1 °C and 85% - 90% relative humidity. Vertical bars represent LSD (5%).

Effect on Fruit Flesh Firmness

Fruit flesh firmness declined sharply in the three cultivars during ripening in a similar manner (Fig. 2-A). Most of that decline occurred during four days. The drop in fruit flesh firmness during the ripening period was 14.5-, 24.6- and 32.0-folds in fruits of 'Baladi', 'Ekostika I' and 'Ekostika II' cultivars, respectively (Fig. 2-A). Similar results were reported during growth and development of guava (Rodriguez *et al*. 1971), mango (Abu-Goukh *et al*. 2005) and papaya (Shattir and Abu-Goukh 2010), and during ripening of mango (Mohamed and Abu-Goukh 2003), guava (Bashir and Abu- Goukh 2003), tomato (Ahmed and Abu-Goukh 2003) and banana (Osman and Abu-Goukh 2008). At the end of storage period (day sixteen), 'Baladi' cultivar showed the highest share resistance of 0.150 $kg/cm^{2,}$ compared with that of 0.085 kg/cm^2 and 0.64 kg/cm^2 for 'Ekostika I' and 'Ekostika II' papayas, respectively (Fig. 2-A).

The decrease in fruit flesh firmness reflects chemical and physical changes in cell walls. It is associated with the action of the hydrolytic enzymes on the cell wall in mango (Abu–Sarra and Abu-Goukh 1992), guava (Abu-Goukh and Bashir 2003) and tomato (Ali and Abu-Goukh 2005). The progressive loss of firmness with ripening is the result of gradual solublization of protopectin in the cell wall to form soluble pectins and other products (Ali and Abu-Goukh 2005).

Effect on Total Soluble Solids

Total soluble solids (TSS) sharply increased during the ripening of the three cultivars; the increase was 111.1%, 97.1% and 95.2% in 'Baladi', 'Ekostika I' and 'Ekostika II' cultivars, respectively (Fig. 2-B). Similar trends were reported during growth and development in mango (Abu-Goukh *et al*. 2005) and papaya (Abu-Goukh *et al.* 2010) and during ripening in mango (Mohamed and Abu-Goukh 2003), guava (Bashir and Abu-Goukh 2003), tomato (Ahmed and Abu-Goukh 2003) and banana (Osman and Abu-Goukh, 2008). TSS were significantly higher in the introduced 'Ekostika I' and 'Ekostika II' cultivars by 12.9% and 16.9%, respectively, compared with the local 'Baladi' cultivar (Fig. 2-B).

Effect on Total Sugars

Changes in total sugars during ripening of the three papaya cultivars were similar to those of TSS. Total sugars steadily increased in the fruits of the three papaya cultivars with advancement of ripening period. Most of that increase was pronounced after the climacteric peak (Fig. 2-C).

That increase was 6.2-, 5.0- and 4.4-folds in the 'Baladi', 'Ekostika I' and 'Ekostika II' cultivars, respectively (Fig. 2-C). This is in agreement with earlier reports that total sugars slightly increased up to physiological maturity (120 days after anthesis) of papaya fruits and then sharply increased afterwards (Abu-Goukh *et al.* 2010). Similar pattern was found in guava (Stivastava and Narasimham 1967), banana (Munasque and Mendoza 1991) and mango (Abu-Goukh *et al.* 2005). The remarkable increase in total sugars observed during the ripening phase may be attributed to the increase in starch hydrolysis or sugars conversion. Chan and Kwok (1975) attributed the increase in total sugars to the action of papaya-invertase enzyme (β fructofuranoside enzyme) that catalyzes the conversion of sucrose. Total sugars were significantly higher in the introduced 'Ekostika I' and 'Ekostika II' cultivars by 13.9% and 17.9%, respectively, than in the local 'Baladi' cultivar (Fig. 2-C).

Effect on Reducing Sugars

Reducing sugars sharply increased, reaching a peak at day ten, which coincided with the climacteric peak of respiration, and subsequently decreased thereafter (Fig. 2-D). The increase was 3.9%, 3.7% and 3.6% in 'Baladi', Ekostika I' and 'Ekostika II' papaya fruits, respectively. Similar trends were reported during growth and development in mango (Abu-Goukh *et al*. 2005) and papaya (Abu-Goukh *et al.* 2010) and during ripening in banana (Leopold and Kriedemann 1975), mango (Abu-Goukh and Abu-Sarra 1993), guava (Bashir and Abu-Goukh 2003) and tomato (Ahmed and Abu-Goukh 2003). During ripening, starch and sucrose are converted to glucose (Wills *et al*. 1998), which is the main substrate utilized in respiration (Phan *et al*. 1975). This suggests that reducing sugars produced during papaya fruit ripening are devoted merely to run the respiration process. The peak of reducing sugars was 15.1% and 24.9% higher in 'Ekostika I' and 'Ekostika II' papaya fruits, respectively, compared with 'Baladi' fruits (Fig. 2-D).

Changes in Total Protein

Total protein increased progressively to reach a peak, which coincided with the climacteric peak of respiration at day ten, and finally dropped (Fig. 3-A). The increase in total protein during the climacteric rise was

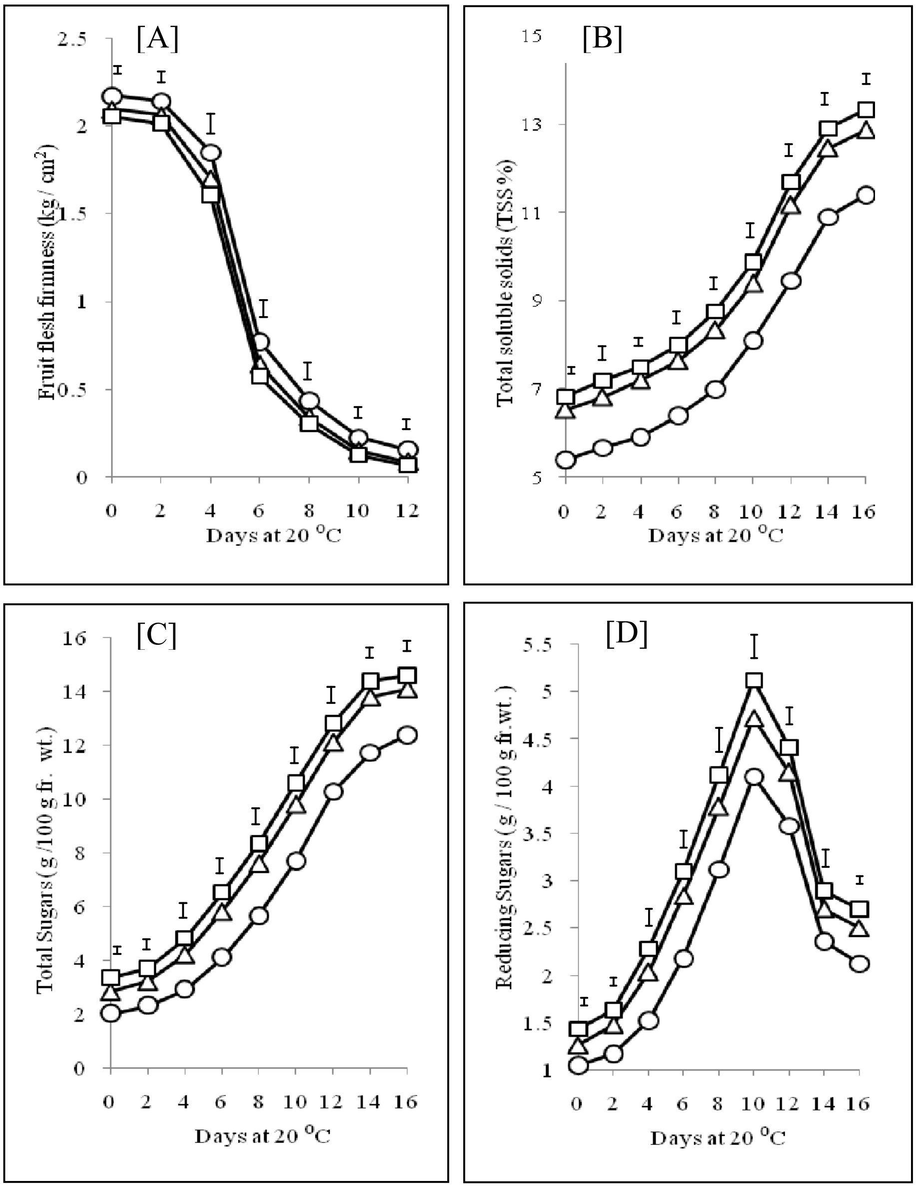

Fig. 2. Changes in fruit flesh firmness [A], total soluble solids [B], total sugars [C] and reducing sugars [D] during ripening of 'Baladi' (○), 'Ekostika I' (△) and 'Ekostika II' (□) papaya fruits at 20 ±1 ºC and 85% - 90% relative humidity . Vertical bars represent LSD (5%).

3.6-, 3.5- and 3.4-folds in 'Baladi', 'Ekostika I' and 'Ekostika II' papayas, respectively. Quantitative changes in soluble protein during fruit ripening have been repeatedly demonstrated (Mattoo and Modi 1969). Abu-Goukh and Abu-Sarra (1993) reported that total protein in pulp and peel of three mango cultivars increased up to the full-ripe stage and then decreased at the over-ripe stage. Similar results were reported in banana (Leopold and Kriedemann 1975), guava (Bashir and Abu-Goukh 2003) and tomato (Ali and Abu-Goukh 2005). During the climacteric phase of respiration, there is a decrease in free amino acids, which reflects an increase in protein synthesis, while during senescence, the level of free amino acids increases reflecting, breakdown of enzymes and decrease in metabolic activity (Wills *et al*. 1998). This supports the view that proteins in ripening fruits are mainly enzymes required for the ripening process (Frenkel *et al.* 1968; Abu-Goukh and Bashir 2003; Ali and Abu-Goukh 2005).

Proteins and free amino acids are minor constituents of fruits and not known to have a role in determining the eating quality. Proteins in fruits are mostly functional, such as enzymes, rather than acting as a storage pool, as in grains and nuts. Changes in their content indicate variation in metabolic activities during development of the fruit (Wills *et al*. 1998). The observation that the amino acid methionine may be possibly acting as an immediate precursor of ethylene in fruits (Yung *et al*. 1982), signifies the importance of amino acids metabolism in fruit ripening. The increase in protein content during the climacteric phase coincides with increased activity of polygalacturenase and cellulase enzymes in mango (Abu-Sarra and Abu-Goukh 1992), guava (Abu-Goukh and Bashir 2003) and tomato (Ali and Abu-Goukh 2005). Chen and Paull (2005) reported that the endoxylanase (EC 3.2.18) and A32.5-kDa xylanase (Cpa EXY1) activities increases progressively during ripening and softening of papaya fruits. The decline in the protein at the over-ripe stage was explained as breakdown of protein during senescence, which again supports the view that proteins in ripening fruits are mainly enzymes required for the ripening process (Abu-Goukh and Bashir 2003; Ali and Abu-Goukh 2005).

Changes in Titratable Acidity

Titratable acidity in fruits of the three cultivars followed exactly the pattern of respiration. Titratable acidity increased systematically to reach a peak, which coincided with the climacteric peak of respiration at day ten, and then declined sharply thereafter (Fig. 3-B). Similar trends were reported during growth and development in mango (Abu-Goukh *et al*. 2005) and papaya (Abu-Goukh *et al.* 2010) and during ripening in banana (Munasque and Mendoza 1991), mango (Abu-Goukh and Abu-Sarra 1993), guava (Bashir and Abu-Goukh 2003) and tomato (Ahmed and Abu-Goukh 2003). These results support the view that acids can be used as substrates for respiration when sugars have been consumed or participated in the synthesis of phenolic compounds, lipids and volatile aromas and provide in addition, a series of metabolites which are used in many processes that reflect dominance of sweet flavour in papaya fruit (Ulrich 1970).

Changes in Phenolic Compounds

Phenolic compounds progressively decreased in the fruits of the three papaya cultivars (Fig.3-C). By the end the ripening period (16 days), the drop of total phenolics was 7.1- , 10.4- and 11.6-folds in 'Baladi', 'Ekostika I' and 'Ekostika II', respectively. Similar results were reported during growth and development in mango (Abu–Goukh *et al*. 2005) and papaya (Abu-Goukh *et al.* 2010) and ripening in banana (Ibrahim *et al.* 1994), mango (Abu-Goukh and Abu-Sarra 1993), guava (Bashir and Abu-Goukh 2003) and tomato (Ahmed and Abu-Goukh 2003). The introduced 'Ekostika I' and 'Ekostika II' cultivars were significantly lower in total phenolics than the local 'Baladi' papayas (Fig. 3-C). Phenolic are responsible for the astringent taste in unripe fruits. The decrease in astringency in fruits during ripening was associated with increased polymerization of leucoanthcanidins and hydrolysis of the stringent arabinose easter of hexahydrodiphenic acid (Misra and Swshadri 1968).

Phenolic compounds have been repeatedly demonstrated to play a vital role in plant resistance and protect fruits and vegetables against insect pests (Abu-Goukh *et al.* 2003) and diseases (Raa 1968). Abu-Goukh *et al.* (2003) found a negative correlation between phenolic compounds and insect infestation during storage of dry dates. A key role was proposed for phenolics in resistance of dates to insect infestation during storage (Abu-Goukh *et al.* 2003). Phenolics were reported to be higher in peel than pulp of mango (Abu-Goukh and Abu-Sarra 1993) and guava (Bashir and Abu-Goukh 2003).

Changes in Ascorbic Acid Content

Ascorbic acid or vitamin C increased gradually during ripening of fruits of the three cultivars (Fig. 3-D). That increase was 43.6 %, 47.7 % and 49.9 % in fruits of 'Baladi', 'Ekostika I' and 'Ekostika Π', respectively. Similar pattern was reported earlier (Arriola *et al.* 1975; Abu-Goukh *et al.* 2010). The increasing trend of ascorbic acid during ripening of papaya fruits is an exception to what is generally found in many fruits such as guava (Bashir and Abu-Goukh 2003) and mango (Mohamed and Abu-Goukh 2003), where ascorbic acids demonstrated declining trend during fruit ripening. The introduced 'Ekostika I' and 'Ekostika II' cultivars had higher ascorbic acid content, throughout the ripening period, than the local 'Baladi' fruits. At the final ripening stage, ascorbic acid content was 13.9 % and 19.3 % higher in the two introduced cultivars, respectively, than in the 'Baladi' one (Fig. 3-D). Such differences were obtained earlier during ripening of different papaya cultivars (Selvaraj *et al*. 1982; Abu-Goukh *et al.* 2010), which could be due to genetic differences.

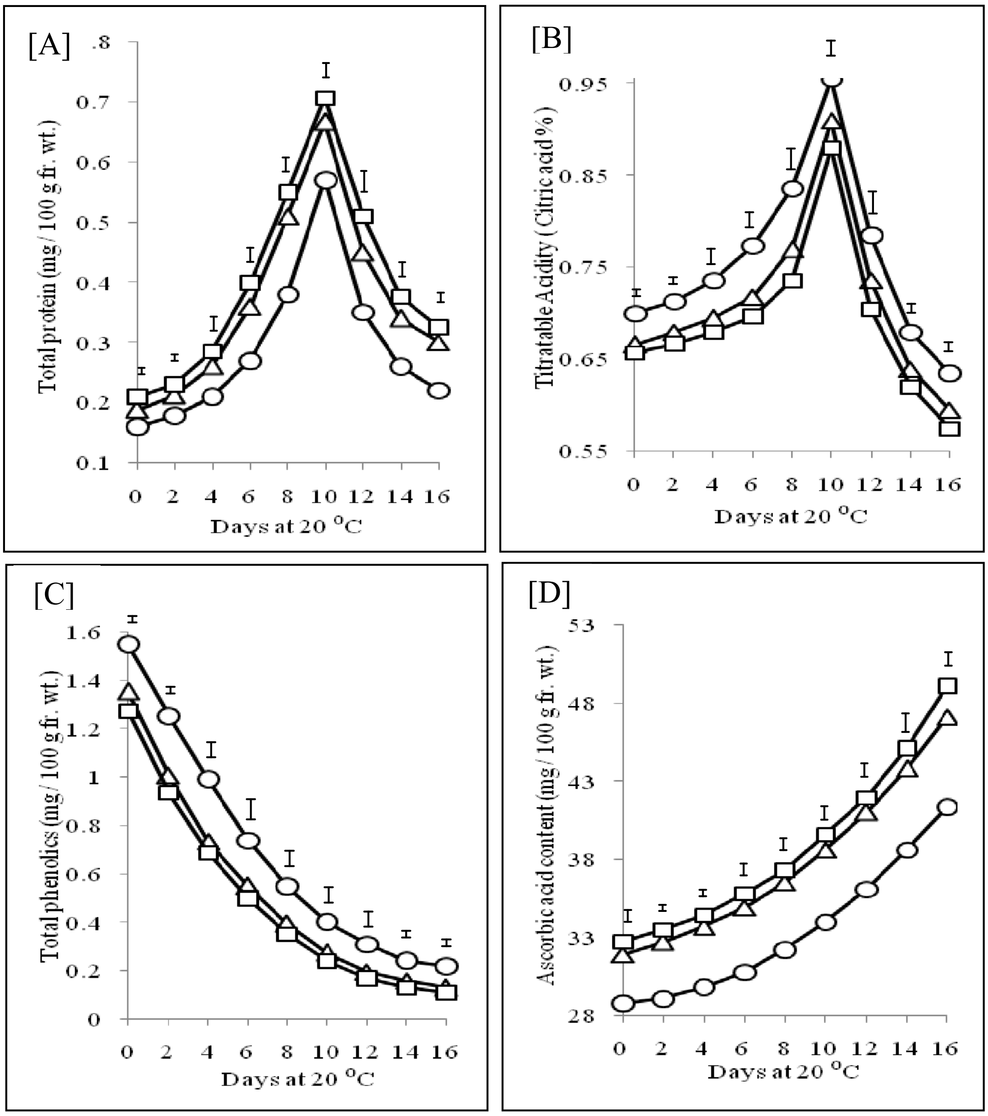

Fig. 3. Changes in total protein [A], titratable acidity [B], phenolic compounds [C] and ascorbic acid content [D] during ripening of 'Baladi' (○), 'Ekostika I' (△) and 'Ekostika II' (□) papaya fruits at 20 ±1 °C and 85% - 90% relative humidity. Vertical bars represent LSD (5%).

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التغيرات الكيميائية أثناء نضج ثمار الباباي

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المستخلص: الهدف من هذه الدراسة هو تقويم التغيرات الكيميائية أثناء نضج ثمار ثلاثة من أصناف الباباي: 'البلدي' و'إكوستيكا I' و'إكوستيكا II' في درجة حرارة 20±1 درجة مئوية و85% - 90% رطوبة نسبية. تبع معدل التنفس في الأصناف الثلاثة نمط التنفس الكلايماكتيري بذروة تنفس بلغت 82.0 و92.0 و98.0 ملجم / كلجم – ساعة في الأصناف الثلاثة على التوالي بعد 10 أيام. أظهرت الدراسة أن فقد الوزن والمواد الصلبة الكلية الذائبة والسكريات الكلية وحمض الأسكوربيك قد زادت زيادة مضطردة أثناء نضج الثمار في الأصناف الثلاثة. وكانت الزيادة فيها بصورة أكثر بعد وصول الثمار لذروة التنفس. تناقصت درجة الصلابة في الثمار والمواد الفينولية فيها باستمرار في الأصناف الثلاثة مع تقدمها في النضج. أما كمية السكريات المختزلة والبروتينات الكلية والحموضة القابلة للتعادل فقد زادت حتى وصلت ذروة توافقت في الوقت مع حدوث ذروة التنفس ثم انخفضت بعد ذلك. كان الصنف المحلي 'البلدي' أدنى في معدل التنفس و أكثر صلابة وأقل فقداً للوزن أثناء النضج، مما يعكس عمراً تسويقياً أطولاً من الصنفين الآخريين المستوردين. في الجانب الآخر، فقد تميز الصنفان المستوردان بارتفاع محتواهما من السكريات الكلية والمختزلة وحمض الأسكوربيك، وانخفاض الحموضة القابلة للتعادل والمواد الفينولية فيها، مما يشير إلى أفضلية جودتهما الغذائية.