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Postharvest physico-chemical and mechanical changes in *jambu air* (*Syzygium aqueum* Alston) fruits

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Abstract

Little data is available in the scientific literature on postharvest changes taking place in *Syzygium aqueum* fruits, an increasingly popular fruit in the Asian region. In this study the postharvest physico-chemical and mechanical properties, namely, fruit color, weight loss, pulp firmness, total soluble solids, pH and titratable acidity were determined during the postharvest storage period under ambient conditions of *Syzygium aqueum* fruits. It was observed that weight loss, total soluble solids (TSS) and pH of the *jambu air* fruits increased with time whilst pulp firmness and the color index of the fruits decreased. Analysis of the antioxidant activity, determined in the methanol extracts of the *jambu* fruit extracts over a period of 18 days after harvesting, using the DPPH (2,2-diphenyl-1-picrylhydrazyl) method, showed that the antioxidant activity increased gradually during postharvest ripening. The total phenol content determined by the Folin-Ciocalteau method revealed a high concentration of phenol content in the *jambu air* fruits, with values around 344.25±107.68 mg gallic acid equivalent (GAE) / 100g fresh fruit. Similarly, the flavonoid content measured spectrophotometrically, using the aluminium chloride colorimetric assay, also showed an increasing trend over the same period. The results were expressed as mg of ascorbic acid equivalent (AAE), gallic acid equivalent (GAE) and catechin equivalent (CE) per 100g of sample. These results represent new data on postharvest changes occurring in *Syzygium aqueum* fruits and show that this increasingly popular fruit has great potential for future development in the agriculture sector.

Keywords: *Syzygium aqueum, postharvest physico-chemical changes, antioxidant, flavonoid and phenolic content*
Abbreviations: AAE_ascorbic acid equivalent; CE_catechin equivalent; DPPH_2,2-diphenyl-1-picrylhydrazyl); F&C_Folin–Ciocalteau; GAE_gallic acid equivalent; TA_titratable acidity; TFC_total flavonoid content; TPC_total phenolic content; TSS_total soluble solids;

Introduction

The *jambu air*, literally translated as water guava or water apple, fruit is a tropical fruit that is fairly widely cultivated and grown throughout Malaysia, on a small scale, where the climate is very suitable for its production all year round. It belongs to the genus *Syzygium* in the family Myrtaceae. There are four types of wax *jambu air* fruits, namely, pink, red, pale green and green. The fruits are pear shaped, often juicy, with a subtle sweet taste and an aromatic flavor. There is great scope to develop the potential wax *jambu air* fruits which can fulfill the local as well as foreign demands for it. Currently in Malaysia it is cultivated mainly as smallholdings ranging from 1 to 5 ha with its hectare age estimated at 1,500 ha in 2005. Fruit harvesting is an important aspect in the fruit growing production industry. This due to the fact that when fruits are removed from the trees and plant it starts to age and ripen and is also naturally susceptible to damage, when it is plucked from the branches and also when it comes into contact with other fruits. This is also true for fruits that fall to the ground. These injuries to the fruits are usually in the form of bruises, punctures and splits. Furthermore additional damage can occur when fruits are raked, collected, loaded and shipped to distant destinations. As transportation of the fruits can take several days, it will bring about changes in several physico-chemical and mechanical properties of fruits as it ripens. Fruit growth and development involves many changes to its morphology, anatomy and physiology and biochemistry (El-Otmani et al., 1987). When a fruit matures the changes associated with it includes changes in rind texture, juice composition and taste (Chahidi et al., 2008). For the fruit grower it is important to have information on the differences in fruit quality among the selections available and the changes occurring in fruit quality parameters over time. These changes and their rate of occurrence with time will inform the fruit growers and sellers, on the best possible strategies and logistics to employ to ensure its successful production and marketing. Thus the post harvest physico-chemical characteristics of the fruits are important in determining the adoption and design of various handling, packaging, storage and transportation systems. Several parameters in fruits have been evaluated and studied to determine the maturity in fruits and one such index is fruit firmness. In most fruits there is a change in firmness during ripening and the softening process which begins whilst the fruits are on the tree continues during harvesting, handling and storage (Joseph and Aworh 1991; Mizrach, 2000; Singh and Reddy, 2006; Chahidi et al., 2008). Another important external factor and parameter that is used to determine fruit quality is its color. To prospective consumers the appearance of the fruit can have a great influence and is an important determining factor. The relationship between color and degree of maturation in many fruits have been widely studied, such as in tomatoes (Choi et al., 1995), peaches, and nectarines (Luchsinger and Walsh, 1993) and is well documented. Water content is another parameter that affects fruit quality and during ripening and storage of fruits water loss takes place. Other physiological factors important in ripening of fruit are total soluble solids (TSS), organic acids, which play an important role in the sugar to acid ratio and affect the flavor of fruits. Furthermore, pH and mineral composition may also affect the catalytic activity of cell wall enzymes and can have a profound effect on anthocyanin stability and color expression (Huber and O'Donoghue, 1993; Almeida and Huber, 1999; Holcroft and Kader 1999). An important category of naturally occurring chemicals that has been widely studied in fruits and vegetables are antioxidants as they have the potential to reduce the risk of free radical-related health problems (Bjelakovic, et al. 2007). In this study we investigated several physico-chemical and mechanical properties of the *jambu air* (*Syzygium aqueum Alston*) fruit after harvesting, namely, skin color, weight loss, firmness of tissue, TSS, pH and titratable acidity. Antioxidant activity, total phenol and total flavonoid content were also determined throughout the storage period.

Materials and methods

Plant Material

The material used for the study was freshly harvested *jambu air* fruits (*Syzygium aqueum*). The fruits were collected from a farm in Raub, Pahang, Malaysia. They were harvested in the afternoon at around 1 pm and quickly transferred to the laboratory. The fruits were then placed in Benomyle solution 0.05% for 5min and after that placed under a large plastic cover. They were then placed in respiration jars (Fig. 1) and continuously ventilated with humidified air at a rate of 0.45 to 0.55 L / hour. The data on the different physical and chemical parameters were carried for 8 days, on days 1, 5, 7, 9, 11, 13, 15 and 18 during the storage period. Data are means of five replicates ± SD.

Skin Color Measurement

The peel color of the fruits was measured using a Minolta colorimeter (CR-300, Konica, Japan). Parameters such as "L" (lightness), "a" (greenness to redness) and "b" (blueness to yellowness) were determined at three different spots around the top, middle and end of the fruits. The change in color of the same samples was measured every day for 18 days during storage. Sample averages were calculated and the color was expressed in L*, a*, b* Hunter parameter, using the following formula (L* x a*) / b*.

Determination of Weight Loss (%)

The weight of the fruit was measured during the storage period with an electronic balance (Fx-3000, A&D Company, Japan) with an error range of 0.01 g. The loss in weight was expressed as percentage of the original fresh weight of the fruit. The weight loss of *jambu air* fruit samples were calculated by differences between initial weight and final weight divided by initial weight (Moneruzzaman,et al; 2009). The weight loss of the same sample was recorded periodically during the storage period.

Determination of Fruit Firmness

Fruit firmness was determined with a digital hand held penetrometer (Model KM-1, Fujiwara, Japan) by taking five readings per fruit on opposite sides along the fruit equatorial region. The skin of the fruit was removed at the reading spot

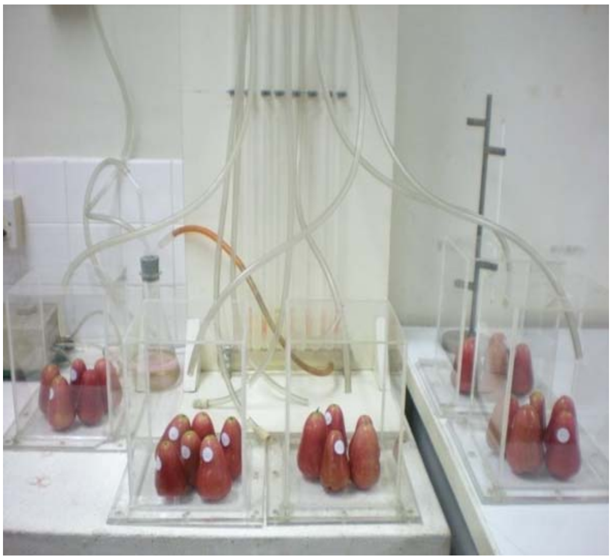

Fig 1. *Jambu air* fruits in respiration jars.

to ensure that pulp firmness, rather than skin firmness, was assessed. Firmness was expressed in Newton (N).

TSS Measurement

Total soluble solids were determined by taking a direct reading of a drop of the homogenized pulp in a digital refractometer (ATAGO PR-1, Japan). Results were expressed in ºBrix.

pH Measurement

The pH of the *jambu air* juice was recorded by using a pH meter (Hanna pH 211, Italy). The pH meter was standardized with the help of a standard buffer solution prior to measurement.

Titratable Acidity (TA) Measurement

The fruit juice was titrated with 0.1M NaOH and the results are expressed in terms of percentage citric acid. It was calculated by following Bhattarai and Gautam (2006) formula:

$$TA\,(\%) = \frac{N_b \times V_b \times E_a \times d.f. \times 100}{V_s}$$

Where, N_b = normality of the base, V_b = volume of the base, E_a= miliequivalent weight of citric acid, V_S= volume of sample, d. f. = dilution factor.

Preparation of Fruit Extract

Fruit extracts for total phenolics, total flavonoids and antioxidant activity were prepared following the method of Swain and Hillis (1959) with some modifications. Firstly, 1.5 grams of fruit tissue was mixed with methanol and homogenized and then transferred to polypropylene tubes. The samples were vortexed and allowed to stand for 1 h at room temperature to allow for complete solvent extraction. Extracts were centrifuged at 2000g for 15 min at 20 °C. The supernatant was filtered through a Whatman no. 1 filter, after which the filtrate samples were diluted to 25 ml with distilled water.

Total Phenolic Content (TPC)

The level of TPC was determined using the Folin–Ciocalteau (F&C) colorimetric reaction method (Singleton and Rossi, 1965). One ml of the fruit extract was added to 10 ml water and 0.5 ml F&C reagent. After 5 min, 2ml of 7.5% sodium carbonate solution was added. The solution was allowed to sit for 2 h after which readings were taken at 765 nm using a spectrophotometer (UK, Pharmacia Novaspec II Biotech). A calibration curve was prepared with gallic acid and the results were expressed as mg GAE/100 g fresh weight. A range of gallic acid concentrations from 0.25 to 0.005 mg/ml was used to prepare the calibration curve.

Total Flavonoids Content (TFC)

The TFC was determined according as the aluminum chloride colorimetric method of Kim et al. (2003). To 0.3 ml sodium nitrite solution (5%) was added 1 ml of the fruit extraction, followed by 0.3 ml of 10% aluminum chloride solution. The test tubes were incubated at ambient temperature for 5 min, and then 2 ml of 1M sodium hydroxide were added to the mixture. The mixture was thoroughly vortexed and the absorbance of the pink color developed was determined at 510 nm. A calibration curve was prepared with catechin and the results were expressed as mg CE/100 g sample. A range of catechin concentrations from 10 to 100 µg /ml was used to prepare the calibration curve.

DPPH Free Radical-Scavenging Assay

The DPPH free radical scavenging activity was determined as in Yang et al. (2008) with minor modifications. To each different concentration of sample in methanol (0.25 ml) was added 2 ml of methanolic solution containing 4×10^{-4} M DPPH. The mixture was mixed vigorously and left to stand for 30 min in the dark. The absorbance was then determined at 517 nm. The absorbance of the control was obtained by replacing the sample with methanol. DPPH radical scavenging activity of the sample was calculated as follows:

$$\text{DPPH radical scavenging activity (\%)} = \frac{1 - A_s}{A_c} \times 100$$

Where, A_s= absorbance of sample, A_c= absorbance of control IC50 values were determined as the effective concentration at which DPPH radical was scavenged by 50%. The IC50 value was obtained by interpolation from linear regression analysis. All tests were performed in triplicates.

Results

Skin Color

As mentioned above fruit color is considered to be one of the important external factors in determining fruit quality, as the appearance of the fruit greatly influences consumers. As can be seen in Fig. 2, fruit color in *jambu air* fruits decreased by about 20% over the 18 days storage period. The determination of the coordinates L*, a*, b* characterizes skin color. At this scale, L* measures luminosity that varies from zero (black) to 100 (pure white); a* and b* values represent the levels of tonality and saturation, with +a (indicating red), -a (indicating green), +b (indicating yellow) and -b (indicating blue) (William, 1962).

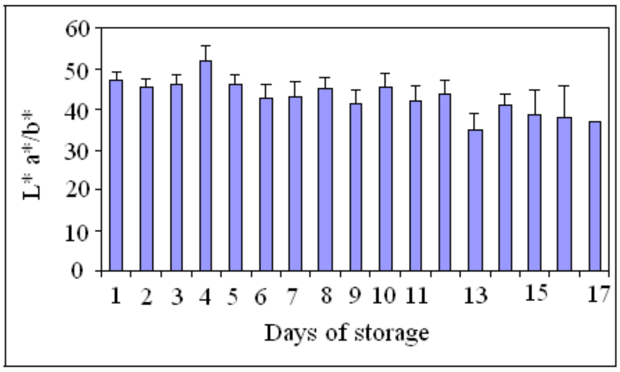

Fig 2. Changes in skin color of *jambu air* fruits during 18 days storage. Vertical bars represent the L.S.D at 5% level.

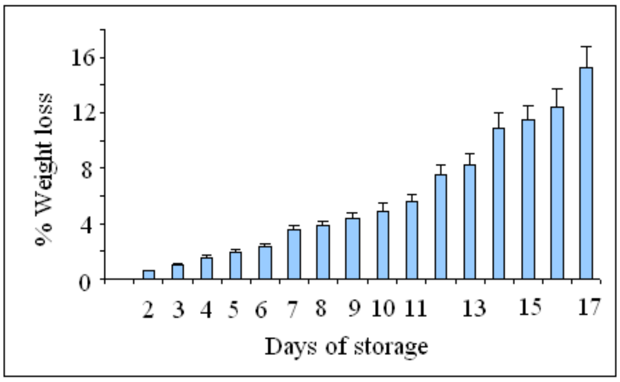

Fig 3. Weight loss (%) in jambu air fruit during 18 days of storage. Vertical bars represent the L.S.D at 5% level.

Weight Loss

The percentage cumulative weight loss of *jambu air* fruits during storage under ambient conditions after 18 days of storage is presented in Fig. 3. The weight loss increased with increasing storage period and at the end of 18 days of storage, the cumulative loss of weight was about 15.3%.

Pulp Firmness

Fruit firmness is an effective way for evaluating fruit maturity as the fruit ripens (Olmo et al., 2000). It has been shown and reported for clementine and peaches, firmness can be used as a maturity index and also to determine how late the fruits can be harvested and still ensure good quality after transport (Crisosto, 1994). The pulp firmness of *jambu air* fruits during storage under ambient conditions for 18 days of storage is presented in Fig. 4. As can be seen pulp firmness decreased from 7.84 to 4.31(N) with increasing age.

Total Soluble Solids (TSS)

TSS is an important quality factor attribute for many fresh fruits during ripening (Lu, 2004). The solids include, soluble sugars sucrose, glucose and fructose as well as acids. In the present experiment, the TSS content of the *jambu air* juice varied significantly in fruits of different maturity ranging from 5.6% to 10.5% (Fig. 5). Our results showed that full ripened *jambu air* fruits contained the highest TSS value of 10.5%, whilst it was lowest (5.6%) in the day 1 fruits, although on day 7 a value of almost 10% was recorded.

pH

As can be seen in Fig. 6, the pH of the fruit juice throughout the experimental storage period was within the narrow range of pH 4.3 – pH 4.9. In other studies reported, fruit pH changes have been in the region of 3.0 in Sanguinello orange juices (Kelebek et al., 2008), 4.2 to 4.4 during storage in peaches (Zhang et al., 2008), 3.0 to 3.5 in citrus fruits (Chahidi et al., 2008) and 4.0 in tomatoes (Bhattarai and Gautam, 2006).

Titratable Acidity (TA)

The results for the TA experiments are shown in Fig. 7. The juice TA of all the fruits stored over a period of 18 days, decreased from 0.245 to 0.105%.

Total Phenolic Content (TPC) and Total Flavonoids Content (TFC)

As can be seen in Fig. 8 (a) and (b), the TPC and TFC content exhibited a gradual increase, followed by a decrease from day 7 to day 9 and finally an increase till day 18. For the total phenolic content the average amount on the first day was 218 mg GAE/100g fresh weight whilst the average amount on the last day was 452 mg GAE/100g fresh weight. However the highest recorded amount of TPC was 456 mg GAE/100g on day 11. The average amount of TPC in the *jambu air* extracts was 344.25±107.68 mg GAE/100g fruit. The amount of TFC showed a similar pattern with the average amount on the first day being 10.65 mg CE/100g fresh weight and 32.89 mg CE/100g on day 18 of storage, which was the highest amount of TFC recorded. The average amount of TFC in the *jambu air* extracts was 22.87 ± 8.59 mg CE/100g.

The DPPH Radical Scavenging Activity

The DPPH radical scavenging activity of the *jambu air* fruit extracts is shown in Fig. 8 (c). Overall we could say that the IC50 of DPPH-radical scavenging activity increased with the number of days in storage, although it decreased at the beginning and then increased, followed by another decrease before finally increasing till day 18. The results of the DPPH assay showed that the *jambu air* fruit extracts had the highest antioxidant capacity (69.97%) on day 11.

Discussion

Skin Color

During fruit ripening, peel color has been reported to be an important characteristic which often serves as one of the major criteria used to determine whether a fruit is ripe or unripe (Agoreyo, 2010). Maturation of jambu fruit is accompanied by a series of the physiological and biochemical changes, including texture, color, reduction of acidity and accumulation of sugars. As mentioned above, fruit color is considered to be one of the important external factors in determining fruit quality, as the appearance of the fruit greatly influences consumers. The development of the red pigmentation with maturity in jambu peel color is the result of massive accumulation of anthocyanin content and chlorophyll degradation during the maturing period (Zhang, et al., 2008). Positive values of a* and b*, as observed in this work, are attributed to the carotenoids or anthocyanins present in the skin (Ribeiro, Quiroz et al., 2007).

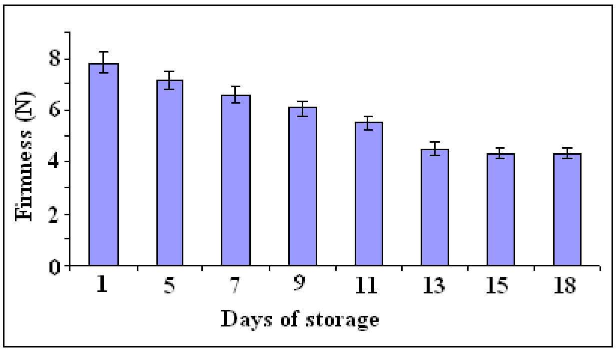

Fig 4. Pulp firmness in jambu air fruits during 18 days storage. Data are means of five replicates ± SD. Vertical bars represent the L.S.D at 5% level.

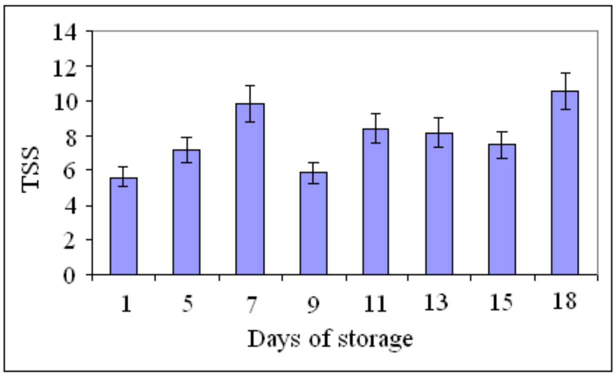

Fig 5. TSS content in jambu air fruits during 18 days storage. Data are means of five replicates ± SD.
Vertical bars represent the L.S.D values at P≤0.05.

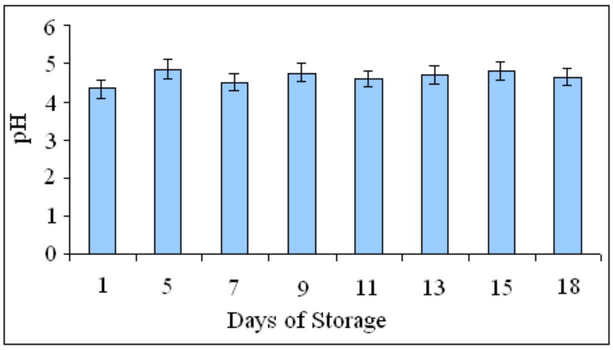

Fig 6. pH changes in jambu air fruits during 18 days storage. Vertical bars represent the L.S.D at 5% level.

Weight Loss

The weight loss in these fruits stored under ambient conditions, is probably mostly due to the loss of water. It may also be attributed to a change in soluble sugar concentration as the monosaccharides are used up for respiratory purposes during storage (Singh and Reddy 2006). There is a relationship between fruit weight and volume of the fruit. Fruit weight increased above values of the volume. In such fruits, starch is as carbohydrate (Travers et al., 2002). The density of starch is very much higher than the density of the sugars. Density of more mature fruit is usually higher. The increase in weight is generally attributed to the increase in water content and during the storage weight loss increased after each period of storage (Crisosto 1994; Ladaniya, Singh et al., 2003) that it could be due to the water loss and leads to higher concentration of sugars in fruits (Bhattarai and Gautam 2006). The increase of percentage in weight loss, observed in this study, is in agreement with reports from previous studies (Singh and Reddy 2006).

Pulp Firmness

Firmness is widely used as a ripeness test for many fruits. The values of firmness are effective for evaluating fruit maturity as the fruit ripens (Olmo, Nadas et al., 2000). It has been shown and reported for Clementine and peaches that firmness can be used as a maturity index (Crisosto 1994) and also to determine how late the fruit can be harvested and still ensure good quality after transport. Pulp firmness decreases while increasing ripening as the pectin content decreases. . It has been reported that textural changes in ripening fruits is related with changes in cell wall composition and particularly to the loss of pectic substances. Recently Abu-Goukh and Bashir (2003) reported the increased production of pectic degrading enzymes during ripening in guava (*jambu batu*) fruits.

Total Soluble Solids (TSS)

TSS is an important quality factors for attributes for many fresh fruits (Lu, 2004) because solids include the soluble sugars sucrose, glucose and fructose as well as acids. Increase of TSS in jambu air probably due to the hydrolysis of starch to soluble sugars such as glucose, sucrose and fructose (Elspeth, Judith et al., 1989; Abu-Goukh and Bashir; 2003, Soltani et al., 2010). During fruit ripening and softening process, starch is broken down to the simple soluble sugars and also the amount of soluble pectin will increase, leading to fruit softening (Afshar-Mohammadian and Rahimi-Koldeh, 2010).

Titratable Acidity (TA)

Decrease in total acidity and increase in total sugars and TSS during storage at room temperature was also reported recently by Policegoudra and Aradhya (2007) in mangoes. It has been suggested that during storage, fruits utilize organic acids for metabolic activities and this results in a decrease in the TA content during the storage periods. Various organic acids have been reported in fruits and in the pomegranate, these include include citric, malic, acetic, fumaric, tartaric and lactic acids although the main acid accounting for titratable acidity in fruits is citric acid (Melgarejo et al., 2000). They reported the decrease in acidity coincided with an increase in sugar concentration in the pomegranate fruits. Kulkarni and Aradhya (2005) suggested that a slow decrease in acidity, concomitant with increased TSS and total sugar content, is an intrinsic process during ripening of fruits to impart the flavor.

Total Phenolic Content (TPC) and Total Flavonoids Content (TFC)

The amount of TPC in jambu air is similar but less than blue berries (670.9 mg GAE/100g), dogwood berries (432.0 mg GAE/100g), sour cherry (429.5 mg GAE/100g) and black berry (355.3 mg GAE/100g), although it was more than that in plum (303.6 mg GAE/100g) and black grape (213.3 mg GAE/100g) (Marinova et al., 2005). The amount of TFC in jambu air is more than apple, yellow (20.9 mg CE/100g), fig (20.2 mg CE/100g) and sweet cherry (19.6 mg CE/100g)

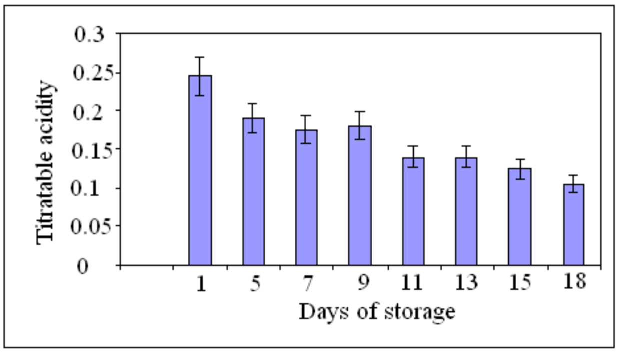

Fig 7. Changes of titratable acidity in jambu fruits during 18 days storage. Vertical bars represent the L.S.D at 5% level.

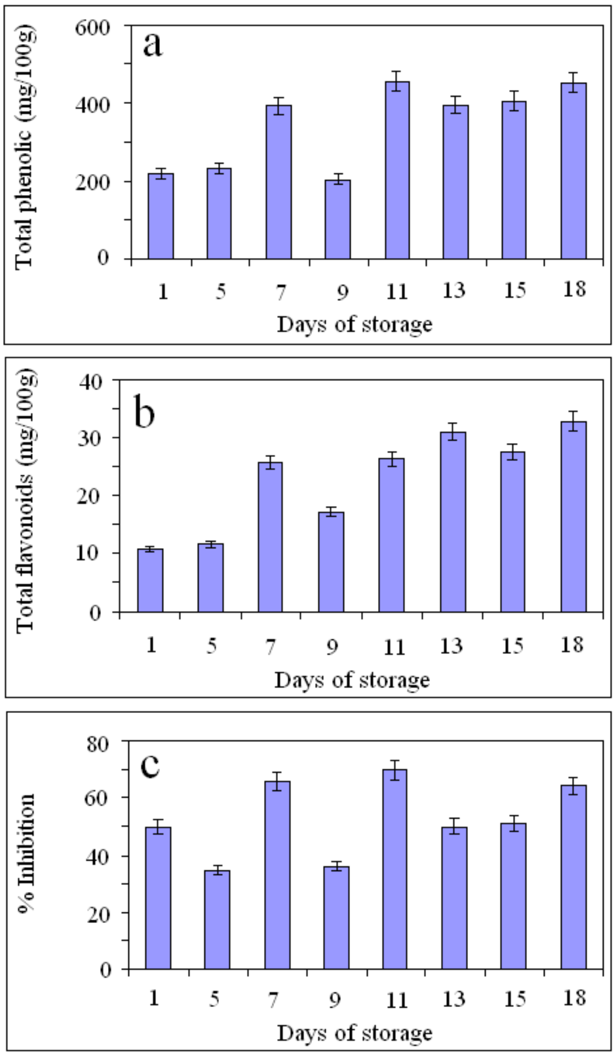

Fig 8. Changes of: a) TPC, b) TFC and c) antioxidant assay in jambu fruits during 18 days storage. Vertical bars represent the L.S.D at 5% level.

(Marinova, Ribarova et al. 2005). From these data it can be seen that the *jambu air* fruits is rich in total phenolics and flavonoids. Marinova et al. (2005) has suggested that this is probably due to the rich abundance of anthocyanidines in combination with the other flavonoids in fruits. TPC and TFC were increased during storage. Changes in TPC and TFC during fruit ripening have been associated with pigment development of anthocyaninsin fruit tissue and increase in fruit color (Zhang, et al., 2008).

The DPPH Radical Scavenging Activity

The pattern of antioxidant activity correlated well with the total phenolic and flavonoid content in the fruits shown in Fig. 8 (a) and (b) earlier. These correlations indicated that probably the phenolic and flavone compounds could be the main cause of antioxidant power in the *jambu air* fruit samples, in agreement with previous findings, that many phenolic compounds in plants are good sources of natural antioxidants (Stratil et al., 1992). Recently Kulkarni and Aradhya (2005) reported six pomegranate juices showed higher ascorbic acid values than pomegranate juice from Ganesh variety (>10 mg/100 g) and attributed the increase to a higher concentration of anthocyanin pigments.

Conclusion

From this study it can be concluded that weight loss, total soluble solids (TSS) and pH of the *jambu air* fruits increased with time whilst pulp firmness and the color index of the fruits decreased. Analysis of the antioxidant activity showed that the antioxidant activity generally increased gradually during postharvest ripening and correlated well with the increases in total phenolic and flavonoid content. The amount of total phenolic and flavonoid content also showed high values comparable with that reported in many popular fruits previously studied. These results present new postharvest data on the *Syzygium aqueum* fruits, an increasingly popular fruit in the Asian region.

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