# CHAPTER 2

## Postharvest Physiological and Biochemical Characteristics of *Jambu Air* (*Syzygium samarangense)* Fruits during Growth and Ripening

### 2.1 Introduction

Fruit harvesting is an important aspect in the fruit growing production industry. This is due to the fact that when fruits are removed from the trees and plants it is 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, 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 (El-Otmani and Coggins Jr, 1991). 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.

In the agricultural industry, knowing when the fruits mature and are ready to be plucked and the subsequent evaluation of its quality are important indices for its

successful management. Several parameters are evaluated and determined to know the maturity in fruits and one such index is 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 and continues during harvesting, handling and storage (Mizrach, 2000; Singh and Reddy, 2006; Ribeiro *et al.*, 2007; Chahidi *et al.*, 2008). Although there are chemical tests available for determining fruit maturity, it is much easier, convenient and quicker to determine fruit firmness which is closely related to maturity (Peacock *et al.*, 1986).

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. In the same light, Mercado-Silva (Mercado-Silva *et al.*, 1998) identified L*, a*, and hue values as being the best parameters for differentiating the different stages of maturation in guava fruits.

Water content is another parameter in quality of fruits. There is water loss during ripening and storage of fruits and vegetables that this related with an increase respiration and transpiration (Javanmardi and Kubota, 2006) and also due to high concentration of sugars in fruits (Bhattarai and Gautam, 2006).

Another physiological factor in ripening of fruit is total soluble solids (TSS). TSS can be correlated to the sugar content that increases during ripening. Increase in soluble solids is normally attributed to the conversion of starch to sugars (Sharaf and El-Saadany, 1987). It has also been attributed to the increase in water-soluble galacturonic acids from the degradation of water insoluble pectic substances by polygalacturonase (PG) (Rees *et al.*, 1981).

Organic acids play an important role in the sugar to acid ratio, which affects the flavor of fruits and vegetables. The distribution of acids within a fruit is not uniform. The most abundant acids in fruits and vegetables are citric and malic acids. The acid content of fruits and vegetables generally decreases during maturation (Kulkarni and Aradhya, 2005; Bhattarai and Gautam, 2006; Chahidi *et al.*, 2008). The acidity or alkalinity of a food is usually expressed as pH. pH and mineral composition, may affect the catalytic activity of cell wall enzymes (Huber and O'Donoghue, 1993; Chun and Huber, 1998; Almeida and Huber, 1999) and also pH has a profound effect on anthocyanin stability and color expression (Holcroft and Kader, 1999).

Sugars are an important parameter for quality measurement in fruits as they ripen as they are a ready source of energy. Monosaccharides are a major part of the total sugars in fruits and glucose and fructose are the major forms of simple sugars in fruits. Another is sucrose, a disaccharide yielding glucose and fructose upon hydrolysis and an important metabolite in most plants. Glucose, fructose and sucrose are water-soluble and together they contain most of the sugars related with the sweet taste of fruits and vegetables (Belitz and Grosch, 1987). There is an increase in the free sugar content of fruits with increasing ripeness (Jordan *et al.*, 2000; Ong *et al.*, 2006).

In this chapter several experiments were conducted to investigate several physico-chemical and mechanical properties of *jambu air* fruits (*Syzygium samarangense*) after harvesting. These include, skin color, weight loss (%), firmness of tissue, total soluble solid (TSS), pH, titratable acidity (TA), total sugar and starch content.

## 2.2 Materials and Methods

### 2.2.1 Plant Material

The material used for the study was freshly harvested reddish pink, red and deep red *jambu air* fruits (*Syzygium samarangense*). The pink and red *jambu air* fruits (*Syzygium samarangense)* were collected from a farm in Shah Alam, Selangor, Malaysia whilst the deep red (*Syzygium samarangense*) were collected from a farm in Raub, Pahang, Malaysia. Between thirty to fifty fruits were randomly selected and harvested in the afternoon at around 3 pm and taken to the laboratory where they were then placed in 0.05% benomyle solution for 5 minutes and placed under a large plastic cover. The fruits were then placed in respiration jars and continuously ventilated with humidified air at a rate of 4.2 L / hour (Fig. 2.1). The data on the different physical and chemical parameters, namely peel color index, weight loss (%), firmness of tissue, total soluble solid (TSS), titratable acidity (TA) and pH of the fruits, were carried out for 9 days, on days 1, 3, 5, 7 and 9, during the storage period. Physiological changes were observed and recorded every day until the fruits over ripened. Fruit samples were freeze-dried with liquid nitrogen and kept in a - 20°C deep freezer for the determination of the biochemical characteristics such as total protein (TP), total sugar content (TSC), starch content (SC), antioxidant activity (AA), total phenolic content (TPC), total flavonoid content (TFC), and the phenylalanine ammonia lyase (PAL) activity. To record the visible changes, photographs were taken. Experiments were maintained at a controlled temperature between 16°C - 20°C.

The physiological experiments were carried out in the Postharvest Laboratory at the Institute of Postgraduate Studies, University of Malaya during the period from 11 to 29 April 2008 and 7 January 2009 to 21 February 2009. Data are means of at least five replicates ± SD.

(a)

(b)

**Figure 2.1** (a) Red and (b) pink *jambu air* fruits in respiration jars.

### 2.2.2 Skin Color Determination

The peel color of the fruits was determined using a Minolta colorimeter, CR-300. Parameters "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 sensor was calibrated with a white tile prior to color measurement. All fruits were numbered for identification and marked equatorially on the peel surface. The changes in color of the same samples were measured every day during storage. Sample averages were calculated and the color was expressed in L*, a*, b* Hunter parameters, using the following formula: (L*× a*) / b*.

### 2.2.3 Determination of Weight Loss (%)

The weight of the fruits 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 was calculated using the following formula:

$$\% \text{ Total weight loss of fruit} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100$$

The weight loss of the same sample was recorded periodically during the storage period.

### 2.2.4 Determination of Fruit Firmness

Fruit firmness was determined with a digital penetrometer by taking three readings per fruit on opposite sides along the fruit equatorial region. The skin of the fruit was removed at the reading spot to ensure that pulp firmness, rather than skin firmness, was assessed. Results were expressed in kg$^{o}$f.

### 2.2.5 Total Soluble Solids (TSS) Measurement

Total soluble solids (TSS) were determined by direct reading of a drop of homogenized pulp in an ATAGO PR-1 Digital Refractometer. Before measurement, a

few drops of water were placed to cover the entire prism surface and the zero setting switches was pressed firmly and released to display "000" readings. The water was wiped off the prism surface with a tissue paper and replaced with a drop of the homogenized fruit sample, ensuring it covered the entire prism surface. Results were expressed as degrees ºBrix.

### 2.2.6 pH Measurement

The pH of *jambu air* juice was recorded by using an electronic pH meter. The pH electrode was placed in a homogenized sample of the fruit. The pH meter was calibrated with the help of a buffer solution prior to measurement.

### 2.2.7. Titratable Acidity Measurement

The fruit juice was titrated with 0.1M NaOH in the usual manner and the results were expressed in percentage of citric acid. It was calculated by following the method employed by Bhattarai (Bhattarai and Gautam, 2006), using the 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, $E_a$= milliequivalent weight of citric acid, $V_S$= volume of sample, d. f. = dilution factor.

### 2.2.8 (a) Preparation of Extract for the Determination of Total Sugar and Starch

One gram of *jambu air* tissue was ground in a mortar and pestle in 4 ml of 0.5M NaOH. The homogenate was then transferred to polypropylene centrifuge tubes and centrifuged at 3500g for 20 minutes. The mixture was next filtered through a Whatman No. 1 filter paper and the supernatant neutralized with 4 ml 0.5M acetic acid. The resulting extracts were diluted to 25 ml with distilled water and stored in the refrigerator (4°C) before further analysis for total sugar and starch.

### 2.2.8 (b) Preparation of Glucose Reagent for Determination of Starch Content

**Reagent I**

1.65g $Na_2HPO_4$, 1.09g $NaH_2PO_4$, 2.4 mg peroxidase (Podsedek) and 3.6 glucose oxidase were dissolved in 150 ml of distilled water.

**Reagent II**

One mg of dianicyanidin hydrochloride was dissolved in 2 ml of distilled water. The glucose reagent was obtained by adding 50 ml of reagent I to 0.5 ml of reagent II.

### 2.2.9 Determination of Total Sugar Content

This was carried out following the method of Dubois (Dubois *et al.*, 1956). To 0.5 ml of the above sample was added 1 ml phenol. Then, 5 ml of concentrated $H_2SO_4$ was added to the mixture. The mixture was left at room temperature for 10 minutes. After that the mixture was shaken thoroughly and incubated in water bath 25 - 30ºC for 10 – 20 minutes. Finally the absorbance was read at 490 nm in triplicates. The concentration of total sugar was determined by referring to the glucose standard curve for total sugar assay.

### 2.2.10 Starch Content Determination

This was carried out following the method of Haissig (Haissig and Dickson, 1979). To 1 ml of the sample was added 4 ml of ethanol and the mixture centrifuged at 12000g for 20 min. The supernatant was discarded and the pellets washed with ethanol (80%) twice before 0.9 ml of 0.2M acetic acid was added to the pellet. The mouth of the test tubes were closed with aluminum foil and the tubes incubated in boiling water for 1 hour. After 1 hour, the tubes were cooled down and 0.1 ml of the enzyme, amyloglucosidase was added to the mixture. After mixing well, 1 ml of 0.6M perchloric acid was added. To 0.2 ml of the mixture was added 5ml glucose reagent and the

mixtures incubated at 37°C for 30 – 40 mins in the water bath. Subsequently, the absorbance was read at 470 nm. Starch content was determined using the glucose standard curve and using the following formula: glucose content × 0.9 and expressed in mg/g fresh weight.

## 2.3 Results

### 2.3.1 Fruit Growth and Ripening

The change in dimensions (length and width) of the fruits was measured over a period of 9 weeks as a means of monitoring its growth pattern, beginning from the formation of fruit buds. A total of 20 fruits from four different trees were measured. The results are shown in Figure 2.2. Both length and width of fruits after anthesis were observed to increase in a similar manner. The length slightly increased from week 1 to week 6 and thereafter it increased steadily from week 6 to week 9. The change in width exhibited a similar trend and increased continuously after week 6 till week 9 (Fig. 2.2).

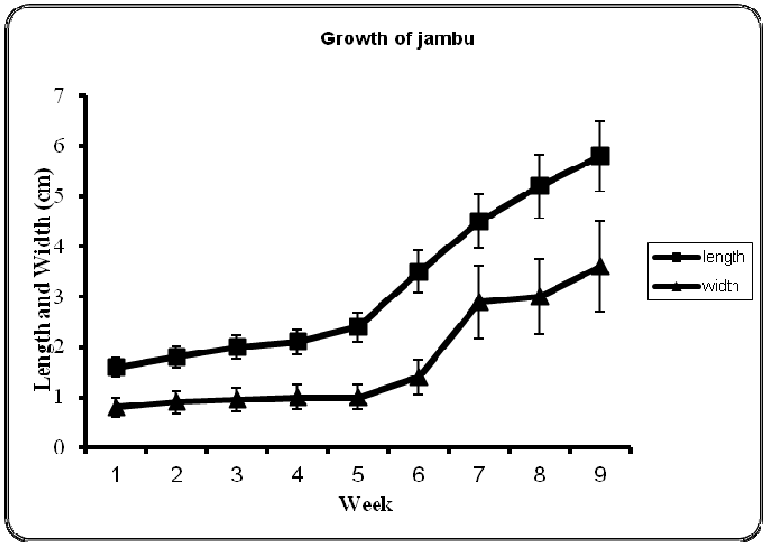


**Figure 2.2** The growth of *jambu air* fruits after anthesis (length and width).

Figures 2.3 to 2.7 show photographs of the developing buds, flowers and fruits of *jambu air* fruits (*Syzygium samarangense*) at different stages of growth after

anthesis. At the beginning, the fruits showed little change in size from anthesis to a small bell-shaped stage and middle stage (from day 1 to day 35). Subsequently it grew rapidly until the big red stage when it is ready to be harvested (from day 35 to day 64).

**Figure 2.3** Flower buds of *jambu air* fruits *(Syzygium samarangense)* 7 days after bud formation.


**Figure 2.4** Fully blossomed flowers of *jambu air* fruit (Anthesis day 0).

**Figure 2.5** Young (bell-shaped) *jambu air* fruits 14 days after anthesis.


**Figure 2.6** Young (middle stage) *jambu air* fruits 35 days after anthesis.

(a)

(b)

**Figure 2.7** Young *jambu air* fruits; (a) 49 days after anthesis and (b) 56 days after anthesis.

Figures 2.8 to 2.10 show photographs of the pink, red and deep red *S. samarangense* of *jambu air* fruits during storage.

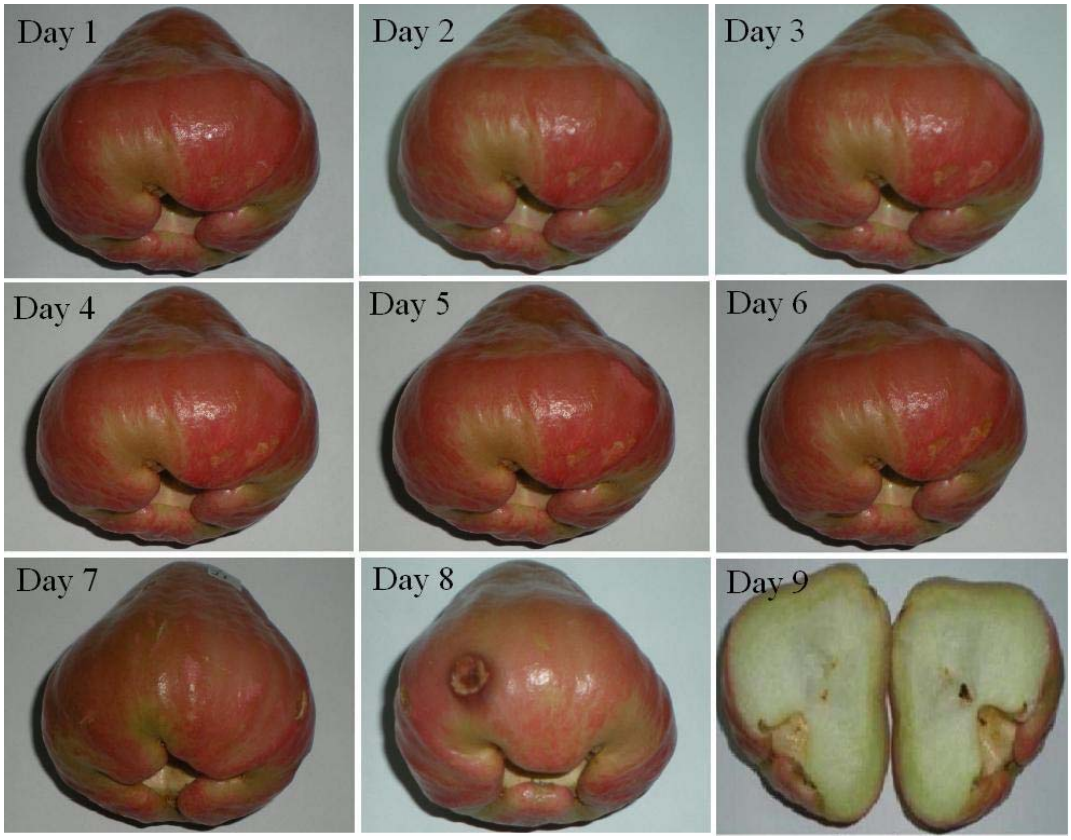


**Figure 2.8** Photographs show pink *S. samarangense jambu air* fruit sample 7 at various periods of storage (day 9 is the cut of sample 7).

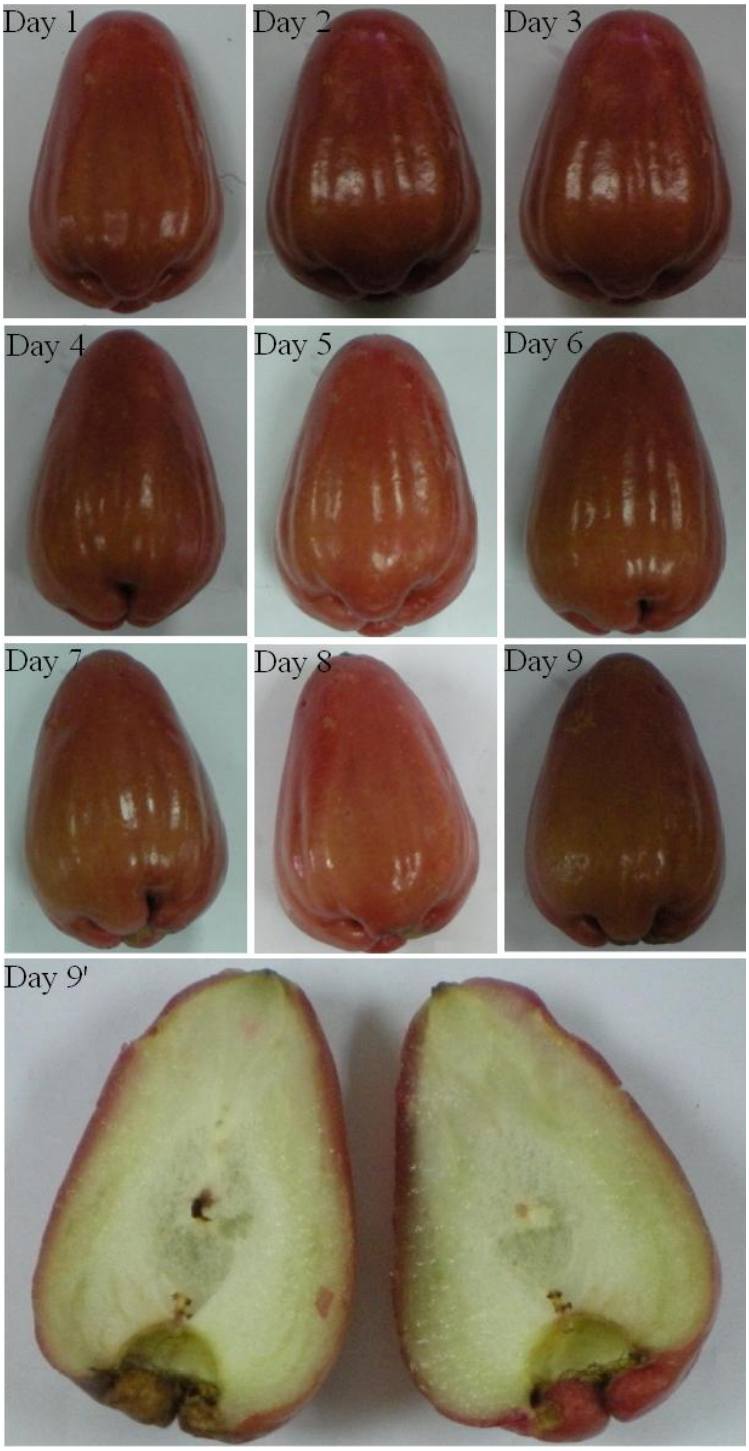


**Figure 2.9** Photographs of red *S. samarangense jambu air* fruit Sample 21 during 9 days of storage.

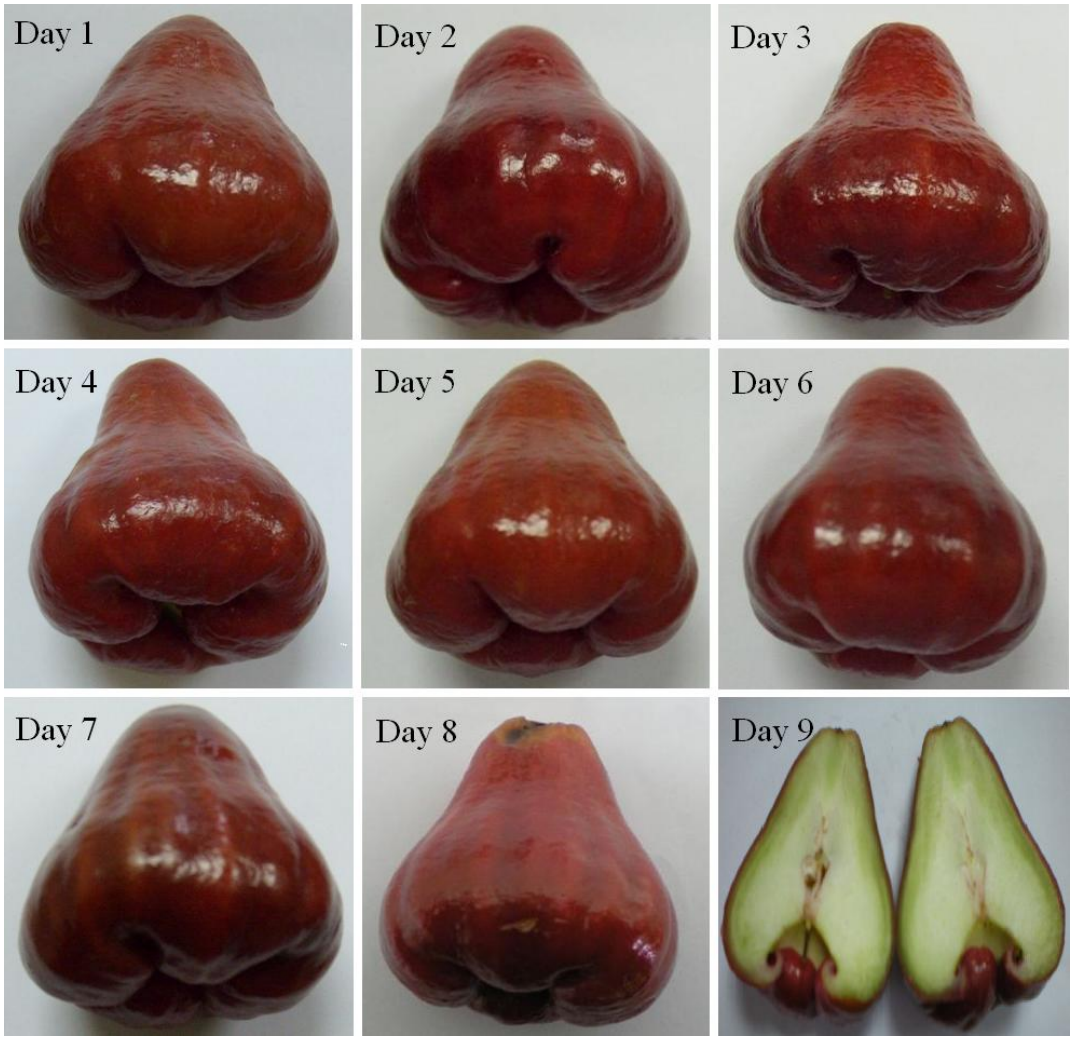


**Figure 2.10** Photographs of deep red *S. samarangense jambu air* fruit sample 4 during 9 days of storage.

### 2.3.2 Skin Color

The change in color and the development of spots on the peel of the *jambu air* fruits which occurred during the process of ripening of the different types of matured fruit is presented in Fig. 2.11. Results showed that the green color in the *jambu air* fruits decreased and red color increased during growth in the red and pink colored fruits.

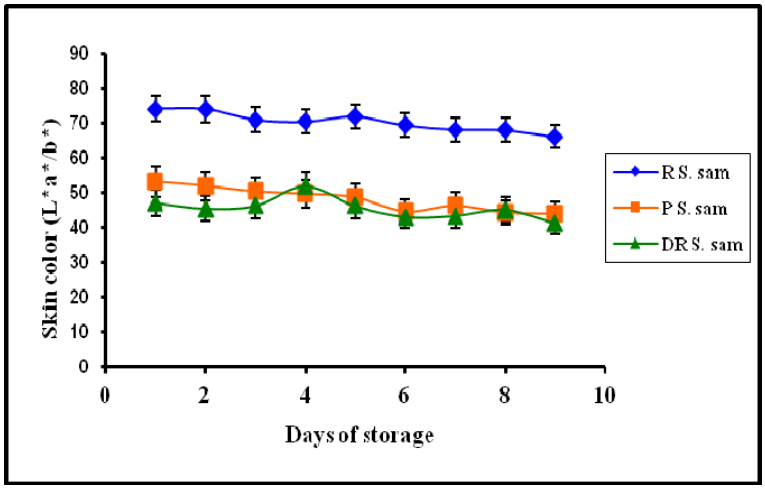


**Figure 2.11** Change in skin color of the three varieties of *jambu air* fruits (*S. samarangense)* during storage under ambient conditions (■ Red,■Pink and ■ Deep red). Values are means of five replications ±S.D (n = 5). Mean values at the same day, are significantly different (P≤0.05, t-test).

### 2.3.3 Weight Loss (%)

The percentage cumulative weight loss of *jambu air* fruits during storage under ambient conditions is presented in Fig. 2.12. The weight loss increased with increasing storage period in all the three varieties of *jambu air* fruits. At the end of storage, the cumulative loss of weight was 5.93% (the S.D at 5% level) for the pink *jambu air* fruits, 9.15% for the red *S. samarangense jambu air* fruits and 4.38% for the deep red fruits.

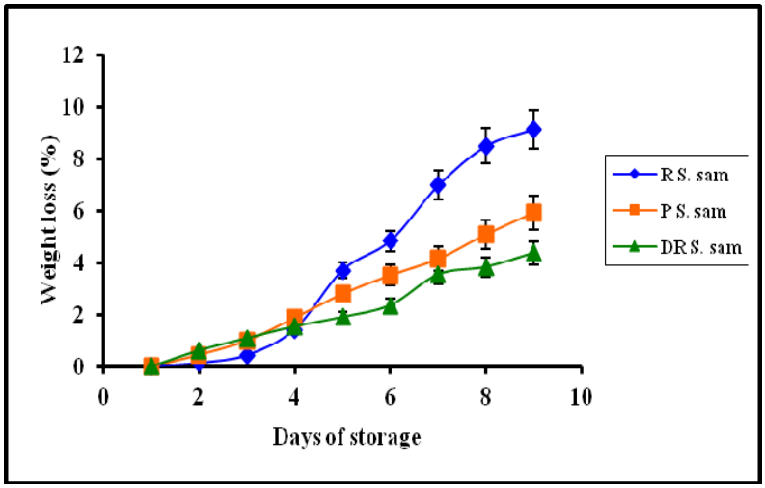


**Figure 2.12** Weight loss (%) of *jambu air* fruits during storage. (■ Red, ■Pink and ■ Deep red).Values are means of five replications ±S.D (n = 5). Mean values at the same day, are significantly different (P≤0.05, t-test).

### 2.3.4 Fruit Firmness

The pulp firmness of *jambu air* fruits during storage under ambient conditions of storage is presented in Fig. 2.13. The results for the three varieties of *jambu air* fruits are similar to each other. Pulp firmness decreased from 0.72 to 0.39 kg°f for the pink *jambu air* fruits, 0.63 to 0.41 kg°f for the red *jambu air* fruits and 0.80 to 0.56 kg°f for the deep red fruits.

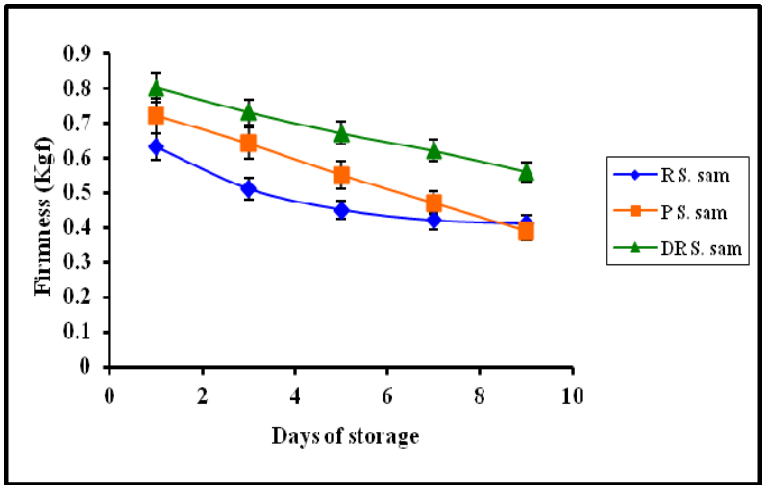


**Figure 2.13** Pulp firmness of *jambu air* fruits during ripening. (■ Red, ■Pink and ■ Deep red *S. samarangense*).Values are means of five replications ±S.D (n = 5). Mean values at the same day, are significantly different (P≤0.05, t-test).

### 2.3.5 Total Soluble Solids (TSS)

TSS is one of the important quality factors used in assessing fruit quality in many fruits. The TSS values of 7.36° to 9.50° Brix for the pink colored *S. samarangense* fruit, 8.1° to 9.15° for the red colored *S. samarangense* fruit and 5.63º to 9.84º Brix for the deep red *S. samarangense* colored fruit indicated the highest quality for the *jambu air* fruits. In the present experiment, the TSS content of *jambu air* fruit juice varied significantly in the fruits at the different maturity stages. Results showed that the fully ripened *jambu air* fruits exhibited the highest quality of TSS (9.50, 9.15 and 9.84° Brix, respectively as indicated above) while it was lowest (7.36, 8.1 and 5.63 °Brix) in day 1 stored fruits (Fig. 2.14). The results also showed that the TSS in the pink *jambu air* fruit was more than red *jambu air* fruits. The changes in Brix from day 1 to day 7 of storage seem to be significant in the red and pink *S. samarangense* fruits. TSS in the red and pink *S. samarangense* fruits gradually increased. The TSS values for mature green fruits in this study were 5.2% and 4% for the pink and red *jambu air* fruits, respectively.

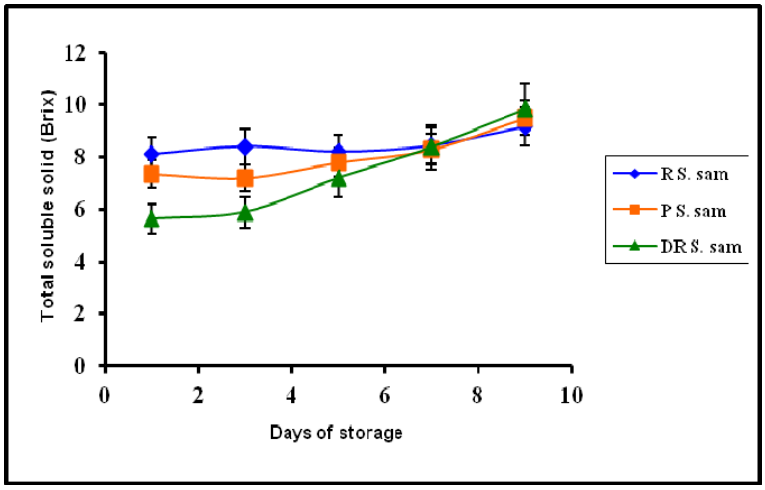


**Figure 2.14** TSS values of *jambu air* fruits during storage.(■ Red, ■Pink and ■ Deep red *S. samarangense*).Values are means of five replications ±S.D (n = 5). Mean values at the same day, are significantly different (P≤0.05, t-test).

### 2.3.6 pH

The pH of the fruit pulp ranged between 3.9 to 4.3 for the pink colored fruits and between 4.6–4.9 for the red colored fruits. The results showed that the pH changes in the pink and red *S. samarangense jambu air* fruits and also in the deep red *S. samarangense jambu air* fruits was not significant.

### 2.3.7 Titratable Acidity

It has been reported that during storage, fruits may utilize their acids and this in turn decreases the acid content of the fruits during storage. The results of the titratable acidity (TA) experiments are presented in Fig. 2.15. The results showed that the TA values in the pink *jambu air* fruit decreased till day 3, after which no change was observed until day 5 and then it decreased again till the end of storage time. The TA values in the red *jambu air* fruit and deep red *jambu air* fruit decreased continuously during storage. The percentage of TA in red and pink *jambu air* fruits was almost same.

The range of change in TA was 0.179 – 0.089, 0.179 – 0.105 and 0.190 – 0.127 in the red, pink and deep red *S. samarangense jambu air* fruits, respectively.

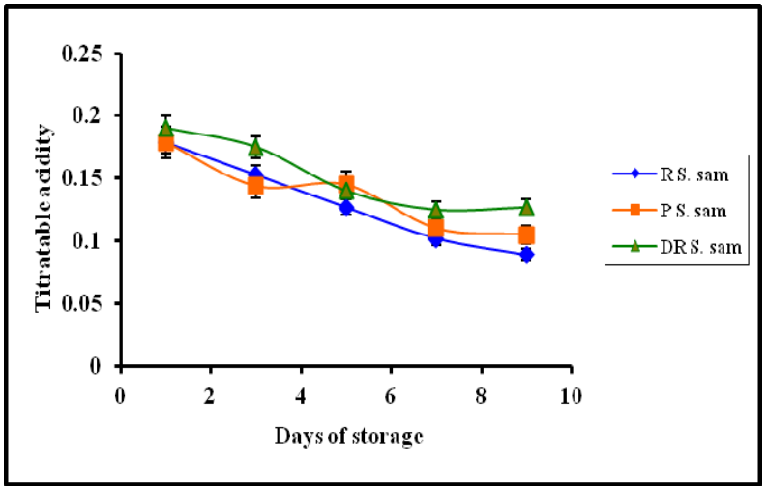


**Figure 2.15** Titratable acidity values of *jambu air* fruits during storage. (■Red, ■Pink *S. samarangense* and ■ Deep red *S.samarangense*).Values are means of five replications ±S.D (n = 5). Mean values at the same day, are significantly different (P≤0.05, t-test).

### 2.3.8 Total Sugar Content (TSC)

Total sugar content (TSC) in the pink, red and deep red *S. samarangense jambu air* fruits is presented in Fig. 2.16. The results for the red *jambu air* fruits showed that, the amount of the total sugar increased slightly during of storage. The change in amount of total sugar ranged between 3.64 – 4.11 g /100g fresh fruit. The average TSC was 3.95 ± 0.18 g / 100g.

The results for the pink *jambu air* fruits showed that the TSC increased more significantly during storage. The range of change in the amount of total sugar was between 3.56 – 5.15 g /100g fresh fruit. On the average the TSC was 4.30 ± 0.67 g / 100g fresh fruit.

For the deep red *S. samarangense jambu air* fruits, the TSC increased slightly during storage that it seems to be significant. The amount of total sugar ranged between 4.52 – 5.37 g /100g fresh fruit and the average TSC was 4.99 ± 0.32 g / 100g fresh fruit.

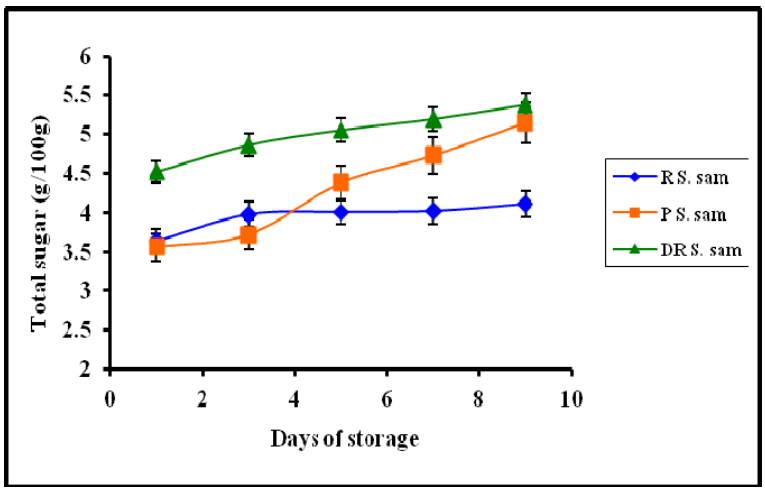


**Figure 2.16** Total sugar content (TSC) of *jambu air* fruits during storage. (■Red, ■Pink and ■ Deep red *S. samarangense*).Values are means of five replications ±S.D (n = 5). Mean values at the same day, are significantly different (P≤0.05, t-test).

### 2.3.9 Starch Content (SC)

The stage of maturity of the *jambu air* fruits during ripening was found to have a significant effect on the starch content in the red, pink and deep red *jambu air* fruits. The starch content (SC) in the fruits is presented in Fig. 2.17. For the red *S. samarangense jambu air* fruits, the amount of starch decreased more rapidly and continuously during storage. The range of change in the amount of starch was between 2.42 – 0.65 g /100g fresh fruit. The average of SC from day 1 to day 9 was 1.42 ± 0.73 g / 100g.

For the pink *S. samarangense jambu air* fruits, the SC decreased continuously during storage between 1.55 – 0.83 g /100g fresh fruit. The average SC from day 1 to day 9 was 1.14 ± 0.28 g / 100g fresh fruit.

The results for the deep red *jambu air* fruits showed a similar pattern of decrease as observed for the pink fruits. The range of change in the amount of total starch was between 2.44 – 1.51 g /100g fresh fruit. In the average SC was 1.94 ± 0.38 g / 100g fresh fruit.

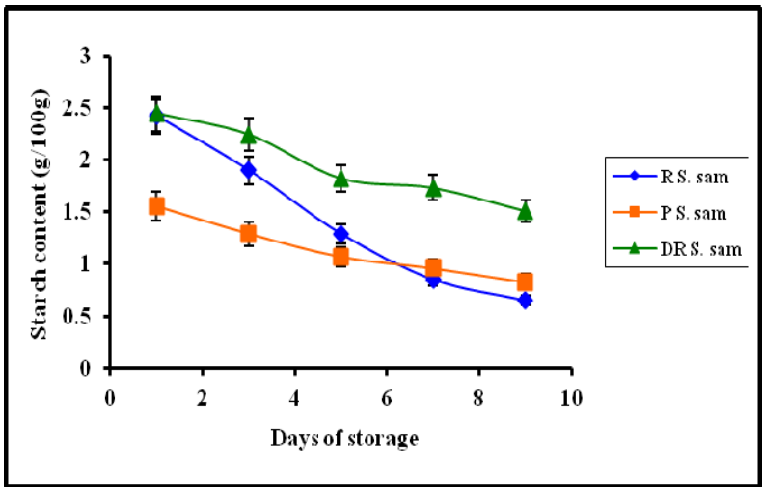


**Figure 2.17** Starch content (SC) of *jambu air* fruits during storage. (■Red, ■Pink and ■ Deep red *S. samarangense*).Values are means of five replications ±S.D (n = 5). Mean values at the same day, are significantly different (P≤0.05, t-test).

## 2.4 Discussion

### 2.4.1 Fruit Growth and Ripening

The growth pattern in different fruits can be anyone of three common types, a single, double, or triple sigmoidal growth curve (Coombe, 1976). Many fruits, such as apple (Dennis, 1986b), banana (Israeli and Lahav, 1986), are reported to have a single sigmoidal growth curve in which there is an initial phase of slow growth, followed by a rapid growth period, and finally a period of declining growth rate in which ripening is often initiated. Other fruits including stone fruits, figs, and grapes show a double sigmoid curve in which there are two rapid growth phases (respectively named periods I and III) interrupted by one period of little or no growth (period II). The growth pattern

of the kiwifruit (*Actinidia chinensis*) has been described as triple sigmoid (Bollard, 1970).

The growth of *jambu air* fruit has been reported to exhibit a single sigmoidal growth curve (Shu *et al.*, 1998). As can be seen from this study (Fig. 2.2), at the beginning, the fruit undergoes cell division with little change in size from anthesis to the small bell stage (Fig. 2.5), but subsequently undergoes rapid growth until it reaches the big red stage, 64 days after anthesis. This makes it similar to fruits like apple and bananas.

### 2.4.2 Skin Color

The skin color is a major post harvest criterion used by farmers, consumers and researchers to determine whether a fruit is ripe or unripe. The intensity of the red or orange color in the pericarp of many fruits, such as apples, peaches, mangos and wax apples, is an important purchasing consideration for many consumers. In the case of the *S. samarangense fruits, the r*ed color plays an important role when *jambu air* fruits are purchased. The red color is due to anthocyanins pigments that are contained in vacuoles (Chang *et al.*, 2003). They are water soluble and are the major determinants of flower and fruit color in many plants (Raven *et al.*, 1992). In the wax apple fruit, the anthocyanin concentration generally increases as the wax apple fruit develops with a simultaneous decrease in chlorophyll concentrations (Chang *et al.*, 2003). Similarly in mango, it has been reported that the green color decreases with ripening (Medlicott *et al.*, 1990). In this study the skin color determination was carried out using the coordinates L*, a*, b*. In this scale, L* measures luminosity that varies from zero (Beaudry et al.) to 100 (pure white) while a* & b* values represent the levels of tonality and saturation, with +a (indicating red), -a (indicating green), +b (indicating yellow) and -b (indicating blue). Positive values of a* and b*, were observed in this work and

are attributed to the carotenoids and/or anthocyanins present in the skin (Ribeiro *et al.*, 2007).

In general, the color changes during ripening of fruits result largely from the loss of chlorophyll, the synthesis of carotenoids and the synthesis of pigmental phenolic compounds such as anthocyanins (Chang *et al.*, 2003; Wang *et al.*, 2005).

### 2.4.3 Weight Loss

Postharvest water loss of fruits and vegetables results in fruit softening, and reduced glossiness and shelf life (Smith *et al.*, 2006). The weight loss observed in the 3 different *jambu air* varieties showed significant variation at each storage duration. The weight loss in these fruits stored under ambient conditions is probably mostly due to water loss. 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). The percentage weight loss increase, observed in this study, is in agreement with reports from previous studies, with orange (Singh and Reddy, 2006), bell pepper (Diaz-Perez *et al.*, 2007) and guava (Begum *et al.*, 2002).

### 2.4.4 Fruit Firmness

The firmness of fruit pulp is an important criterion for fruit traders as the harvest date for a particular fruit is determined with the help of the measurement of fruit pulp firmness. It is important with regard to determine how long it can be stored for, prior to transport and shipment to different customer countries. The fruit firmness test is very reliable and can be performed easily and non-destructively.

The texture or firmness of the fruit pulp is a composite attribute resulting from a combination of factors such as water turgor and structural components of tissues and cell. An indication of firmness is obtained by the force necessary to cause penetration of

a standard probe within a specified distance into product. The values of firmness are effective for evaluating fruit maturity as the fruit ripens (Olmo *et al.*, 2000) and can be used to determine the maturity index (Burns and Albrigo, 1997) and how late the fruit can be harvested to ensure good quality after transport, as has been reported for peaches (Crisosto *et al.*, 1984).

One of the main factors contributing to fruit softening is the modification of the cell walls (Jain *et al.*, 2003). One major change in fruit cell walls during ripening is thought to be the loss of galactose and arabinose in neutral pectin, and an increase of soluble pectin (Seymour and Gross, 1996). These changes are considered to result from the action of cell wall hydrolase enzymes such as polygalacturonase (PG), cellulase, pectinesterase (PE), and β-galactosidase. PG and cellulase have been reported to be absent or inactive in unripe fruits, but have high activities during fruit ripening, especially PG (Harpster *et al.*, 1997), whereas high PE and β-galactosidase activity can be found during both development and ripening of fruits. Thus, the modification of cell wall is regulated through a mechanism involving an interaction of several enzymes (Harpster *et al.*, 2002).

The decrease in firmness observed in this study is probably due to similar factors which accompanies a change in the fruit cell wall fiber orientation, in the pulp of fruit (Wang, 2004). This result is in close agreement with the results obtain in tomato (Wang *et al.*, 2005), avocado and mango fruit (Mizrach, 2000), orange (Singh and Reddy, 2006) and citrus (Chahidi *et al.*, 2008). who all reported similar observations.

### 2.4.5 Total Soluble Solids (TSS)

The total soluble solids content (ºBrix) in a fruit, is an important attribute of the fruit as the TSS is closely associated with the eating quality of a ripe fruit (Mitchell *et al.*, 1991; Crisosto, 1992). Studies have specifically shown that consumers prefer fruits,

such as the kiwifruit, with a higher ripe TSS (Rossiter *et al.*, 2000; Burdon *et al.*, 2004). Soluble solids measured by a refractometer include sugars, organic acids, soluble pectins, anthocyanins and other phenolic compounds, and ascorbic acid.

Increase in soluble solids has been attributed to the decomposition of the cell wall which causes the release of water-soluble components (Rees *et al.*, 1981). Solids also include the soluble sugars sucrose, glucose and fructose as well as acids. Reaves (Reaves, 1959), reported that the increase in total soluble solids may be due to the increase in water-soluble galacturonic acids from the degradation of water insoluble pectic substances by polygalacturonase (PG).

Increase in TSS of a fruit can also be attributed to hydrolysis of starch to sugars and an increase in soluble simple sugars, soluble pectin, soluble organic acids etc (Islam Sariful *et al.*, 2001). In mango increase in total soluble solids (TSS), carotenoid pigments and decrease in acidity are some indicators of sweetness of mango (Lakshminarayana, 1980). It has also been suggested that the increase in TSS may be from water loss during ripening (Corzo and Gomez, 2004) or degradation of starch and subsequent conversion into sucrose, glucose, fructose, and galactose (Villanueva *et al.*, 2004). The increase in TSS reported in this study is in agreement with other reports that have observed that TSS gradually increased during ripening and storage in various types of fruits, including nectarine (Gil *et al.*, 2002), guava (Bashir and Abu-Goukh, 2003), muskmelon/muskmelon (Corzo and Gomez, 2004; Villanueva *et al.*, 2004), Pomegranate arils (Kulkarni and Aradhya, 2005), cherry (Vursavus *et al.*, 2006) and mango (Jha and Matsuoka, 2004; Ribeiro *et al.*, 2007).

### 2.4.6 Titratable Acidity (TA) and pH

Titratable acidity is another important parameter in fruit quality definition. TA measures the amount of acids present and these are generally weak acids such as malic

acid in apple, citric acid in citrus, oxalic acid in rhubarb, tartaric acid in wine and lactic acid in sour milk, which do not contribute many hydrogen ions in solution and thus are weakly acidic and do not change the pH drastically. Organic acids found in the pomegranate include citric, malic, acetic, fumaric, tartaric and lactic acids. However, the major organic weak acid accounting for titratable acidity in fruits is citric acid (Melgarejo *et al.*, 2000). Fruit taste is a balance between acids, sugars, volatiles and other compounds.

A change in total titratable acids during fruit storage can be mainly attributed to the metabolic activities of living tissues, during which depletion of organic acids takes place. A decrease in acidity usually coincides with an increase in sugar concentration. It is well documented that a gradual decrease in acidity, concomitant with increased TSS and total sugar content, is an inherent process during the ripening of many fruits to impart its characteristic flavor (Cordenunsi *et al.*, 2003). In general, it is believed that the level of organic acids decline during fruit ripening, probably due to their utilization in respiratory metabolism (Ezhilarasi and Tamilmani, 2009). In this study, the pH value and total acidity showed little change during storage. The range of pH changes in other fruits that have been reported is 3.05 in Sanguinello orange juices (Kelebek *et al.*, 2008), 4.24 to 4.42 during storage in peaches (Zhou *et al.*, 2008), 3.0 to 3.5 in citrus (Chahidi *et al.*, 2008), 4.053 in tomato (Bhattarai and Gautam, 2006).

The TA in this study slowly decreased with a concomitant increase in TSS and total sugar in during storage.! Decrease in total acidity and increase in total sugars and TSS during storage at room temperature was also observed in mandarin oranges by Ramana (Ramana *et al.*, 1979).

### 2.4.7 Total Sugar Content (TSC) and Starch Content (SC)

Sugars are an important parameter of quality measurement in fruits as they are the main and easily available source of energy when consumed. The sweetness of a fruit depends to a large extent on its sugar to acid ratio. Hence, an increase in the simple sugar content generally brings about a sweeter fruit especially if this is accompanied by a decrease in the organic acid to minimize acidity and astringency (Ong *et al.*, 2006).

In many fruits the increase in total sugar may be attributed to hydrolysis of starch into simple sugars, such as sucrose, glucose and fructose (Biale, 1960). This has been well documented in fruits such as mango, banana (Bashir and Abu-Goukh, 2003) and in pomegranate arils (Kulkarni and Aradhya, 2005). According to Bashir (Bashir and Abu-Goukh, 2003), an increase in total sugars in guava was attributed to an increase in the activity of enzymes responsible for starch hydrolysis and the decline in the rate of sugar breakdown by respiration.

In many fruit species, starch breakdown and the consequent rise in glucose, fructose and sucrose concentration are characteristic ripening events (Kader *et al.*, 2002). Starch breakdown often explains only part of the increase in soluble sugars, especially sucrose (Hubbard *et al.*, 1990; Hubbard and Mason Pharr, 1992). For example, in apple, starch loss only accounted for approximately 50% of the increase in sucrose (Mo *et al.*, 2008). Many of these studies have shown that an increase in amylase parallels a decrease in the starch content of the fruit pulp.

Studies of starch-hydrolyzing enzymes have been described in several fruits such as mango (Biale, 1960; Mattoo, 1969), pear (Pech and Latche, 1972) and tomato (Davies and Cocking, 1967). The main amylolytic enzymes in plants are the α- and ß-amylases and phosphorylase. The reaction products of α-amylase are known to be dextrins, oligosaccharides, maltose and glucose; that of ß-amylase is maltose, and the product of phosphorylase activity is glucose-1-phosphate (de Fekete and Vieweg,

1974). Studies testing the hypothesis that amylase activity might contribute to the pool of substrates for respiration, changes in amylolytic activity during development and ripening of fruits has been well documented.

The decrease in starch content observed in this study may be attributed to hydrolysis of starch into simple sugars. The result showed that the amount of starch in pink *jambu air* variety was more than that in the red *jambu air*. A similar trend was reported in fruits during ripening and storage such as avocado (Huber and O'Donoghue, 1993), tomato (Wang *et al.*, 2005) and banana (Maneenuam *et al.*, 2007).