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Physiochemical Changes during Growth and Development of Pineapple (*Ananas comosus* L. Merr. cv. Sarawak)

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ABSTRACT

The physical and physiological characteristics of Sarawak pineapple were studied at five different stages of growth from one to five months after anthesis. Changes in fruit length, diameter, pulp color, pulp firmness, pH, total soluble solids, titratable acidity, ascorbic acid content and antioxidant activity were monitored. The Sarawak pineapple exhibited a sigmoid growth pattern during fruit development. The pulp firmness decreased while the total soluble solids increased as the fruit developed, thus improving its edibility and acceptability to the consumers. A reduction in pH and an increase in titratable acidity contributed to the distinct flavor and taste of the Sarawak pineapple. While ascorbic acid content reduced throughout growth and development, the overall antioxidant activity increased in the fruit suggesting a later period of harvesting as the most appropriate. The changes that occurred extrinsically as well as intrinsically suggest that the best time for harvesting the Sarawak pineapple is five months after anthesis.

Keywords: Anthesis, Antioxidant activity, Fruit growth, Harvesting maturity, Sarawak pineapple.

INTRODUCTION

Pineapple, botanically known as *Ananas comosus* (L.) Merr, is the leading edible member of the Bromeliaceae family. Pineapple is ranked third in the world tropical fruit production (De Poel *et al*., 2009). Pineapples can be consumed fresh or processed as condiments, sweets, savories, cakes, pastries, yoghurt, punches and ice creams (Medina and Garcia, 2005). Besides its vibrant tropical flavor, pineapple is also known for its various nutritional and health benefits. It contains a considerable amount of calcium, potassium, fiber and vitamin C. Pineapples possess potential anti-inflammatory and digestive benefits, antioxidant protection, and immune support as well as protection against macular degeneration (Joy, 2010).

The production of pineapples in Malaysia increased by 44% from 288,938 metric tons in 2001 to 416,070 metric tons in 2010 (FAO, 2012). As reported by the Malaysian Pineapple Industry Board (MPIB) in 2008, cultivar Johor produced the highest yield of pineapple with 143,963.00 metric tons, followed by Kelantan and Kedah with 8,209.60 and 1,121.17 metric tons, respectively. These pineapples comprise different varieties which include Morris, Sarawak, Josaphine, MD 2 and N36 (Anon, 2010). Of these varieties, the Sarawak pineapple is the least studied up to date. The Sarawak pineapple variety is mainly consumed as fresh fruit, desserts, and used for canned products due to its sweet taste and crunchy texture. Unlike the other varieties, the Sarawak pineapple is much larger in size and weighs an average of 1.5 to 2.5 kilograms up to a maximum of 4.0 kilograms. However, the size of the Sarawak pineapple is highly dependent on the soil that it is planted on. It has been reported that the Sarawak pineapples planted on peat soil are slightly larger (average

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of 2.3 kg) than those planted on mineral oils (average of 1.5 kg) (Jaman, 2009).

In general, pineapples can be harvested at 130-150 days after anthesis and the Sarawak pineapple is no exception (Sanewski and Scott, 2000). Pineapple fruits harvested at different maturity stages are not of uniform quality (Dhar *et al*., 2008). Rosnah *et al*. (2009) reported that many researchers have identified indicators of fruit maturity based on measurement of size, weight or density, physical attributes; such as color, firmness and moisture content; as well as other chemical attributes such as starch, sugar or acid contents. Consumer preferences of pineapple may vary widely. Some consumers may base their preferences solely on sensory attributes (taste, aroma, texture and appearance) while others may base their preferences on nutritional attributes (ascorbic acid content, antioxidants, vitamins and minerals).

This research aimed to study the physicochemical changes of the Sarawak pineapple (*Ananas comosus* L. Merr. cv. Sarawak) during growth and development.

MATERIALS AND METHODS

Plant Material

Pineapple fruit (*Ananas comosus* L. Merr) at five different maturity stages was harvested from a farm in Batu Pahat, Johor. The pineapples under study were tagged once it started flowering. Fruits of different developmental stages at monthly intervals were harvested beginning from 1 to 5 months after anthesis. The harvesting stages were after anthesis as follows: Stage I (SI)= One month, Stage II (SII)= Two months, Stage III (SIII)= Three months, Stage IV (SIV)= Four months, and Stage V (SV)= Five months. Harvested pineapples were transferred to the postharvest laboratory for further analyses. Meteorological data during experimental periods were obtained from the Malaysian Meteorological Department.

Fruit Growth (Length, Diameter, Fresh Weight)

Twenty harvested fruits at each maturity stages were selected for growth measurement. Fruit length was measured from the base of the fruit to the base of the crown using a measuring tape. Fruit diameter was measured using a digital caliper (MO 34260001, 1–125 mm, Vernier, Japan). Fruit fresh weight was determined by an electronic balance (A and D GR-200).

Physical Properties (Pulp Color, Pulp Firmness)

Each fruit at different maturity stages was cut in half along the equatorial plane. Flesh or pulp color was determined using a Chroma Meter (CR-200, Minolta Corp., Japan) and expressed in chromaticity values of Lightness (L*), redness/greenness (a*) and yellowness/blueness (b*). Pulp firmness was determined using a fruit hardness tester (Fujiwara KM) and expressed in kilogram force (kg f).

Chemical Properties

Moisture Content

Five grams of peel and pulp tissues of the different maturity stages of the pineapple were weighed using an electronic balance (A and D GR-200). The peel and pulp was dried in an oven at 100±2°C for 7 days. After one week, the peel and pulp were weighed separately, and the moisture content was calculated using the following equation:

Moisture content (%)= [5 g (Fresh weight)–(Dried weight/5 g)]×100%.

pH, TSS, and TA

The pulp of each fruit of different stages was mashed into a paste and the pH was determined using a pH meter (Hanna

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Microprocessor pH 211, Italy) at 25±2°C. Juice was extracted from the pineapple samples using a juice extractor (Philips Juice Extractor HR 2820, Holland) and total soluble solids were determined using a digital refractometer (Atago PR-1 digital refractometer, Tokyo, Japan) at 25±2°C and results were expressed in standard °Brix unit. Titratable acidity was determined as described by George *et al.* (2015).

Ascorbic Acid Content

The ascorbic acid content in the samples were determined based on the 2,6-DiChloroPhenol IndoPhenol (DCPIP) visual titration method (Ranganna, 1977). Sample paste was diluted with 3% metaphosphoric acid and filtered and the filtrate was titrated with a standardized dye solution (2,6-dichlorophenol indophenol and sodium bicarbonate) to a pink end point (color should persist for at least 15 seconds). The results obtained were expressed as milligrams of ascorbic acid per 100 g sample.

Antioxidant Activity

Preparation of Extract

The extraction method was performed according to Xu *et al*. (2008) with minor modifications. Equal parts of pineapple sample paste were added to 80% acetone to purify the sample. The mixture was placed in a shaking incubator (Shellab Orbital Shaking Incubator S14, OR, USA) at 250 rpm for 30 minutes at room temperature, and then centrifuged. The supernatant was used for the analysis of antioxidant activity.

Total Polyphenol

Total polyphenol content of the different maturity stages of the Sarawak pineapple fruit was determined using Folin–Ciocalteu assay modified to a microscale as described by George *et al.* (2015). A standard curve of gallic acid (y= 0.0057x, R^2= 0.989) was prepared and results were reported as milligrams of Gallic Acid Equivalent (GAE) per 100 g of sample.

DPPH Radical Scavenging Assay

The DPPH assay is based on the method described by Bae and Suh (2007). A standard curve of ascorbic acid (y= 10.143x, R^2= 0.9907) was prepared and results were reported as micrograms of Ascorbic Acid Equivalent (AAE) per g fruit sample. The radical scavenging activity was calculated accordingly: $\%\ DPPH\ inhibition = [A_{control} - (A_{sample}/A_{control})] \times 100$

Total Antioxidant Capacity

The total antioxidant capacity of the different maturity stages of the Sarawak pineapple was measured via a spectrophotometric method described by Prieto *et al*. (1999). A standard curve of ascorbic acid (y= 0.0018x, R^2= 0.9981) was prepared and results were reported as micrograms of Ascorbic Acid Equivalent (AAE) per mL fruit extract.

Statistical Analysis

The data obtained were subjected to statistical analysis using SPSS 19.0 software (SPSS Inc., IBM). Data were represented as mean values±Standard Deviation (SD). The significant differences between mean values of fruit samples were determined by Analysis Of Variance (one way-ANOVA) using Tukey's HSD (Honestly Significant Difference) test at a significance level of $P< 0.05$.

RESULTS AND DISCUSSION

Fruit Growth

Irregular meteorological conditions such as rainfall, air temperature, soil temperature,

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soil water content and relative humidity may affect the growth and development of fruits. However, there were no significant differences observed in the meteorological conditions during the period of this study. Therefore, meteorological conditions were not a factor of the growth and development pattern observed in this study (Table 1). The Sarawak pineapple exhibited a sigmoid type of growth pattern as measured by length, diameter, and fresh weight during fruit development (Figure 1 and 2). The growth pattern of the Sarawak pineapples was characterized by a slow growth phase at Stage I, which lasted for 4 weeks after anthesis, followed by an exponential increase of growth from Stage II to stage IV. The slow increase in fruit fresh weight, length, and diameter, especially during Stage I, were due to the low production of endogenous hormones such as auxins, gibberellins and cytokinins, which are responsible for the growth of fruit at young stages (Singh, 1998). However, there was no significant growth during Stage IV to stage V, which occurred during the 4th and 5th month after anthesis. The rapid growth of the pineapple fruits during Stage II may have been due to the production of hormones at the optimum level. The production of hormones decreases as the fruit matures (Ozga and Reinecke, 2003). Thus, fruit growth slowed down and became constant when the fruits matured during Stage V. The growth pattern of the Sarawak pineapple was similar to those observed by Dhar *et al.* (2008).

Physical Characteristic

Structural Changes

The growth and development of the Sarawak pineapple from inflorescence to mature fruit resulted in a series of changes in its structure (Figure 3). An approximate 20

Table 1. Meteorological conditions of different harvesting stages of Sarawak pineapple.

Stages	TR (mm) [a]	AT (°C) [b]	ST (°C) [c]	ARH (%)[d]	SWC (%)[e]
Stage I	220 ± 25[a]	28.0 ± 5[a]	29.5 ± 4[a]	79 ± 10[a]	46 ± 6[a]
Stage II	235 ± 20[a]	26.0 ± 4[a]	28.0 ± 5[a]	74 ± 8[a]	50 ± 8[a]
Stage III	215 ± 22[a]	27.5 ± 6[a]	29.0 ± 4[a]	80 ± 10[a]	48 ± 7[a]
Stage IV	225 ± 25[a]	25.5 ± 5[a]	27.5 ± 5[a]	82 ± 10[a]	45 ± 7[a]
Stage V	227 ± 20[a]	27.0 ± 4[a]	29.0 ± 4[a]	76 ± 8[a]	47 ± 6[a]

[a] Total rainfall; [b] Air temperature; [c] Soil temperature; [d] Air relative humidity; [e] Soil water content. Values followed by different letters within the same column are significantly different.

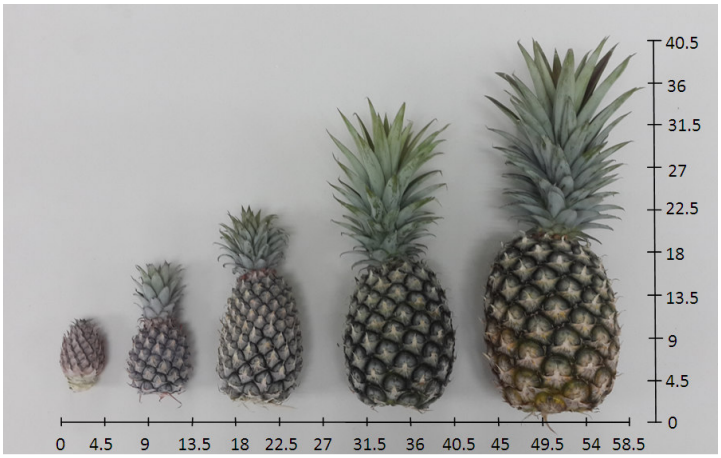

Figure 1. Fruit developmental of Sarawak pineapple. From left : (Stage I), (Stage II), (Stage III), (Stage IV), (Stage V).

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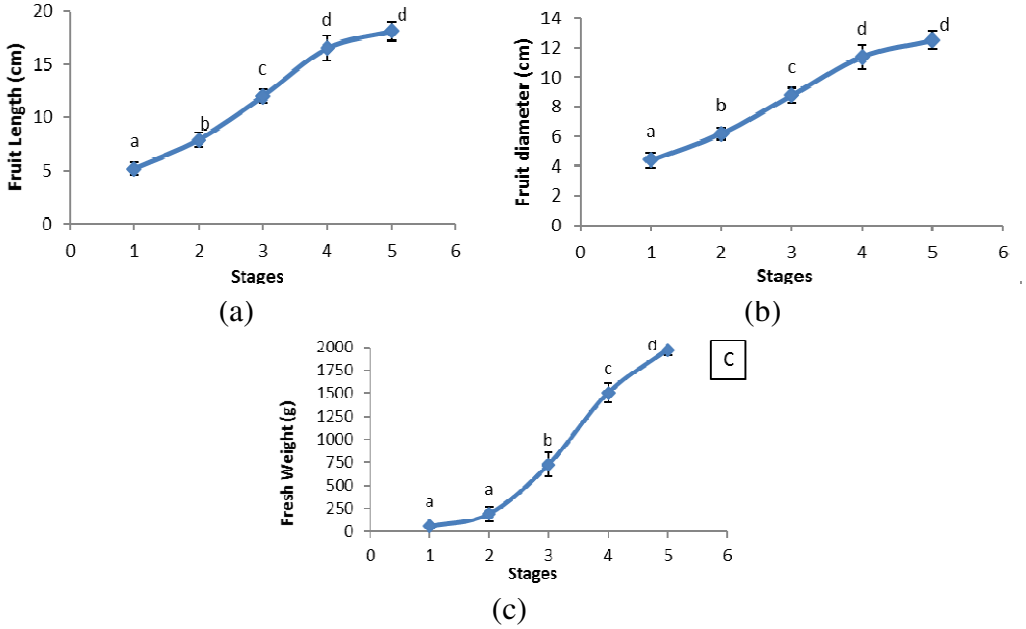

Figure 2. Cumulative growth of Sarawak pineapple, (a) length, (b) diameter, (c) fresh weight of different harvesting stages. Values followed by different letters are significantly different ($p < 0.05$) ($n = 20$).

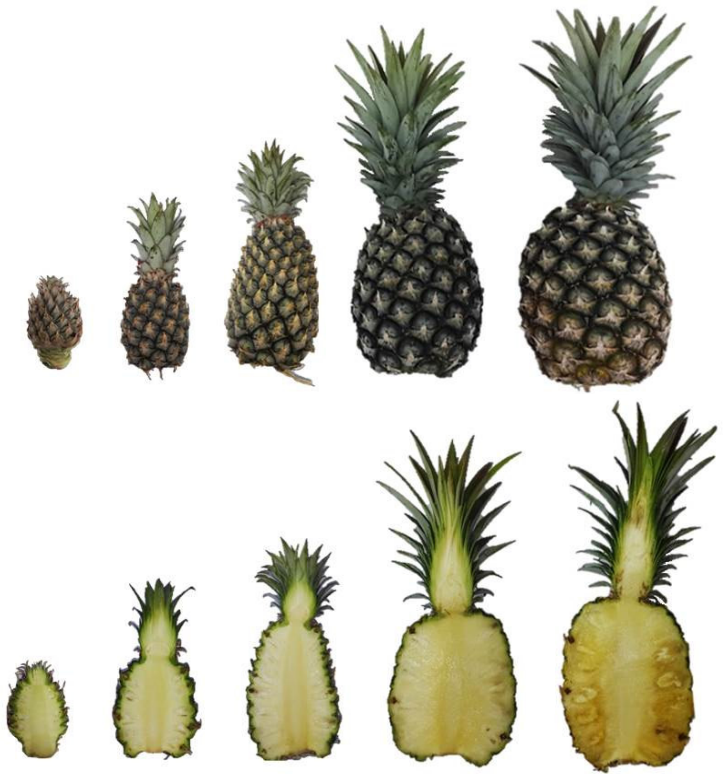

Figure 3. Structural changes of the Sarawak Pineapple during growth and development. From left: (stage I); (stage II); (stage III); (stage IV); (stage V).

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fold increase in weight of the Sarawak pineapple was recorded which contributed to the changes in its structure. The increase in weight was similar to previous report of Smooth Cayenne pineapples (Krauss, 1948). Unlike other fruits, there was no floral abscission during development as the entire blossom developed into a fruitlet. Prominent structures in the mature Sarawak pineapple include the bract, sepal and ovary tissues (including the glands) (Figure 4). At stage I pineapples, the core makes up the majority of the Sarawak pineapple while the ovary, sepal and bract bases are not prominent. The shell of the pineapple was thickest at stage I and decreased gradually as the fruit developed. Enlargement was observed in the placenta bearing abortive ovules but far less proportional to that of the sepal tissue. This enlargement, which contributes to the increase in fresh weight of the fruit, is a result of continued growth by cellular division and expansion of adjacent tissues, especially of the septa (Bartholomew *et al.*, 2003). Increase in size and enlargement of prominent structures were most significant from stage I to stage IV, while minimal changes were observed as the fruit developed from stage IV to stage V.

Color

There was a significant change in pulp color of the five different maturity stages of the Sarawak pineapple. The pulp color became more intense and darker yellow as the fruit developed. Significant changes in Lightness (L*), redness/greenness (a*), as well as yellowness/blueness (b*) was also observed as the fruit developed ($P \leq 0.05$) (Table 2). An increase in the *b** values of the pulp color was observed as the fruit developed, which contributed to the increase in the intensity of yellow color of the pulp. According to Purseglove (1972) the flesh of pineapples ranges from white to yellow, depending on the stage of maturity. The

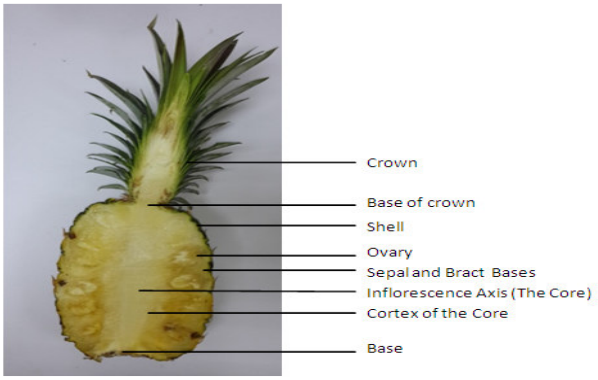

Figure 4. Gross morphological structure of the Sarawak Pineapple fruit.

Table 2. Physical properties (colour and firmness) of different harvesting stages of Sarawak pineapple. Values followed by different letters within the same column are significantly different ($p < 0.05$) ($n = 20$).

Stages	Color parameter [a]			Pulp firmness
	*L**	*a**	*b**	(kg f)
Stage I	83.38 ± 0.08[a]	-2.80 ± 0.02[a]	18.28 ± 0.03[a]	0.92 ± 0.09[a]
Stage II	80.56 ± 0.06[b]	-2.84 ± 0.03[a]	19.30 ± 0.05[b]	0.88 ± 0.07[a]
Stage III	77.96 ± 0.04[c]	-2.90 ± 0.01[b]	20.25 ± 0.03[c]	0.81 ± 0.03[b]
Stage IV	70.43 ± 0.03[d]	-3.28 ± 0.07[c]	23.44 ± 0.05[d]	0.53 ± 0.04[c]
Stage V	67.69 ± 0.06[e]	-3.92 ± 0.04[d]	26.05 ± 0.06[e]	0.44 ± 0.06[d]

[a] *L** value of Lightness (brightness) , *a**: value of Hue (Shade of colour), *b**: value of chrome (saturation or vividness)

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change in color from white to yellow in this study could be a result of biochemical changes such as accumulation of sugars and carotenoids (Okimoto, 1948).

Pulp Firmness

There were significant differences ($P \leq 0.05$) in pulp firmness as the fruit developed and matured (Table 2). The pulp was firm with 0.88 kg f during stage I and the pulp firmness gradually decreased during development and maturation. The decrease in firmness was perhaps due to cell growth, including an increase in cell number and accumulation of water content during fruit development. A rapid reduction in pulp firmness was observed during stage IV to stage V. Previous studies have reported several factors that contribute to the softening in matured fruits prior to ripening. Sane *et al*. (2007) reported that the expansin genes were involved in the softening of mature Dwarf Cavendish banana fruits. Moreover, cell wall breakdown caused by the conversion of insoluble pectin into soluble forms is also a factor for loss of firmness (Verlent *et al*., 2005; Nikolic and Mojovic, 2007). Cell wall loosening and disintegration is caused by the depolymerization and solubilization of pectins, which ultimately results in fruit softening (Fischer and Bennett, 1991). Enzymatic cell wall pectin degradation is catalyzed by various pectinases, such as PectinMethylEsterase (PME) and PolyGalacturonase (PG) (Adams, 1991).

Chemical Characteristics

Moisture Content

The moisture content of the peel and pulp of the Sarawak pineapple exhibited opposite trends during development (Figure 5). An increasing trend was observed in the pulp of the pineapple while a decreasing trend was observed in the peel of the fruit. A total decrease of up to 8% in the peel was observed while an increase of up to 5.5% was observed in the pulp as the pineapple developed. This phenomenon may have been caused by changes in the osmotic pressure of the fruit. Water has the tendency of moving from the peel to the pulp (Asiedu, 1987). Furthermore, water is often lost from the peel through transpiration as the fruit develops.

pH

The pH of Sarawak pineapple decreased as the fruit developed (Table 3). The pH decreased gradually and was at the lowest at stage V with a mean pH of 3.88±0.18. pH is an internal ripeness indicator and can be used as a destructive measurement for determination of the best harvesting period (Vinson *et al*., 2010). The pH of the Sarawak pineapple observed in this study was higher than that of the pineapple

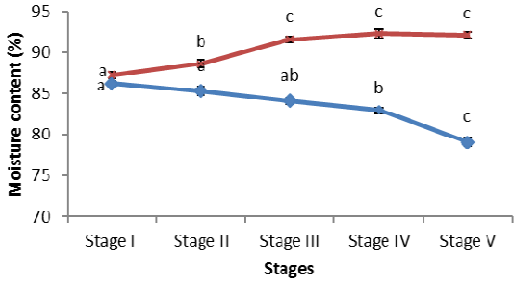

Figure 5. Peel and Pulp moisture contents of Sarawak pineapple. Values followed by different letters within the same line are significantly different ($p < 0.05$) ($n = 20$).

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Table 3. Chemical changes in Sarawak pineapple during growth and development. Values followed by different letters within the same column are significantly different ($p < 0.05$) ($n = 20$).

Stages	pH	Total Soluble Solids (TSS, °Brix)	Titratable Acidity (%TA)
Stage I	5.41 ± 0.22^{a}	4.8 ± 0.15^{a}	0.2 ± 0.09a
Stage II	4.83 ± 0.21^{b}	6.2 ± 0.23^{b}	0.31 ± 0.07^{b}
Stage III	4.52 ± 0.28^{b}	8.3 ± 0.37^{c}	0.86 ± 0.06^{c}
Stage IV	4.08 ± 0.13^{c}	10.9 ± 0.18^{d}	1.23 ± 0.03^{d}
Stage V	3.88 ± 0.18^{c}	12.7 ± 0.52^{e}	1.44 ± 0.02^{e}

cultivars Cayenne, Abachi, Queen, Natal, and N36, whilst being lower than the Red Spanish cultivar (Nadzirah *et al.,* 2013).

Total Soluble Solids (TSSs)

The total soluble solids content increased as the Sarawak pineapple developed (Table 3). An increase of up to 2.6 times was observed in the total soluble solids at the final stage (V) of pineapples as compared to stage I. Previous researches suggest that during the development of fruits, the total sugar content increases progressively throughout maturation and ripening (Beltran and Macklin, 1962; Winsor *et al*., 1962). Hence, the increase in the total soluble solids of the Sarawak pineapple may be due to the increase of total sugar content which makes up about half of the water soluble portion of fruit dry matter (Davies and Hobson, 1981). High TSS content is a desirable fruit characteristic for processed fruit (Ercisli, 2007), which makes the pineapple with its considerably high TSS content of about 12.7 °Brix in mature fruits suitable for processing. Moreover, the 'flesh brix' determination is a reliable way of establishing the maturity and the best time of harvest. A minimum of 12 °Brix or 12% total soluble solids is required to guarantee consumer acceptance (Coppens d'Eeckenbrugge *et al.*, 1997). The total soluble solids content of the pineapple observed in this study was higher than pineapple cultivars such as the Red Spanish, Cayenne and Abachi (Miller, 1950) while being lower than the Mauritius, Winter, Queen and Natal pineapple cultivars (Wijesinghe and Sarananda, 2002; Lu *et al.,* 2011).

Titratable Acidity (TA)

The titratable acidity of the pineapple increased as the fruits developed (Table 3). The titratable acidity increased from 0.2% in stage I to 1.44 % in stage V. Increasing trend of titratable acidity in the Sarawak pineapple as the fruit develops is in agreement with previous research on strawberry and mulberry (Mahmood *et al*., 2012). Tritratable acidity is responsible for the distinct sour taste and flavor of most fruits (Yamaki, 1989) and is often regarded as a reliable indicator to evaluate the overall quality of fruits (Bhat *et al.,* 2011). High titratable acidity in the Sarawak pineapple contributes to its distinct sour taste and flavor. On the contrary, it is suggested by a previous study that, after maturation and as the fruit ripens, a noticeable decrease in titratable acidity of pineapples is observed (Dhar *et al*., 2008). This reduction of titratable acidity might be due to the utilization of these constituent acids (citric and malic acid) in the fruit respiratory process (Nagar, 1994). The titratable acidity of the Sarawak pineapple observed in this study was higher than the Red Spanish, Cayenne, Abachi, Queen, Natal, Mauritius, Winter and the N36 pineapple cultivars (Wijesinghe and Sarananda, 2002; Lu *et al.,* 2011; Nadzirah *et al.,* 2013).

Ascorbic Acid Content

Ascorbic acid is one of the most abundant antioxidants in plants and is a cofactor of

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many plant dioxygenases. Ascorbic acid is also known to play important regulatory roles indirectly throughout the entire body due to its involvement in the synthesis of hormones, hormone-releasing factors, and neurotransmitters (Groff *et al*., 1995; Jacoba, 1999). In this study, a significant decrease was observed in the ascorbic acid content of the different maturity stages of the Sarawak pineapple (Figure 6). The ascorbic acid content of the Sarawak pineapple decreased from 26.75 to 17.98 mg 10 g^{-1} recording a loss of 32.79%. The most significant reduction was seen as the fruit developed from stage III to stage IV (16.99%). A decrease in ascorbic acid content in the Sarawak pineapple observed is similar to the observation in other fruits such as apples (Davey and Keulemans, 2004; Davey *et al*., 2007). The decrease may be attributed to sink-source relations within the plant. Ascorbic acid gains access to the fruit through the vasculature, and diffuses from that point. As the fruit develops and matures, it is plausible that it utilizes less ascorbic acid. This leads to a decrease in the import of ascorbic acid from the plant and the decrease is apparent in matured fruits (Felicetti *et al*., 2010). In addition, Selvarajah *et al*. (2001) and Vilaplana *et al*. (2006) suggested that ethylene may be involved in the metabolism of ascorbic acid. This explains the loss of ascorbic acid in matured fruits as the production of ethylene increases as the fruit matures (Vanoli *et al*., 2007). The ascorbic acid content of the matured (Stage V) pineapple observed in this study was higher than other pineapple cultivars, namely, the Red Spanish, Cayenne, Abachi, Queen, Natal, and the Winter pineapple (Lu *et. al.,* 2011).

Antioxidant Activity

Phenolic compounds are one of the major contributors to antioxidant activity in fruits. Polyphenols possess several biological properties and exhibit anticancer, antioxidant, antiviral and anti-inflammatory actions (Alothman *et al*., 2009). In this study, a significant decrease in the total polyphenol content was observed as the fruit developed, with stage V recording the lowest i.e. 38.83 mg GAE 100 g^{-1} (Table 4). A decrease in total polyphenol content of up to 34.3% was observed as the Sarawak pineapple matured. Likewise, Wang *et al*. (2009) observed a decrease in phenolic compounds as the fruit developed. They reported that the total phenolic content in raspberry showed a decrease from the 5% green to the 100% ripe stage and concluded that fruits harvested at their greener stages (5 and 20%) consistently yielded higher antioxidant activities and total phenolics than those harvested during the 50–80% mature stages.

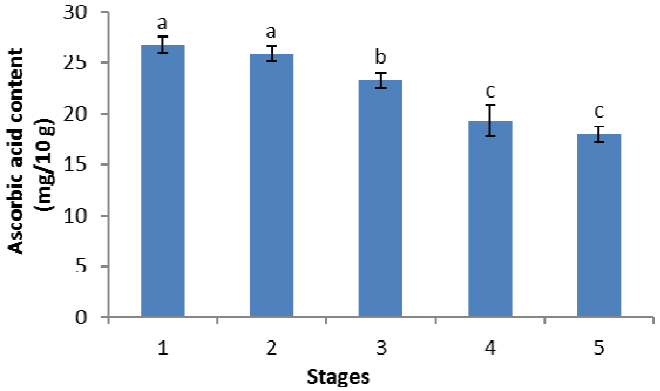

Figure 6: Ascorbic acid content of different maturity stages of Sarawak Pineapple. Values followed by different letters are significantly different ($p < 0.05$) ($n = 20$).

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Table 4: Antioxidant acitivity in Sarawak pineapple during growth and development. Values followed by different letters within the same column are significantly different ($p < 0.05$) ($n = 20$).

Stages	Total polyphenol content (mg GAE 100 g^{-1})	DPPH radical scavenging sctivity (µg AAE g^{-1})	Total antioxidant capacity (µg AAE g^{-1})
Stage I	64.07 ± 2.04a	5.96 ± 0.22a	187.78 ± 10.94a
Stage II	59.42 ± 1.08^{b}	6.50 ± 0.18^{b}	200.00 ± 7.84^{a}
Stage III	51.89 ± 1.16^{c}	7.85 ± 0.19^{c}	242.22 ± 7.78^{b}
Stage IV	46.54 ± 1.5^{d}	8.89 ± 0.20^{d}	425.74 ± 14.21^{c}
Stage V	38.83 ± 1.57^{e}	9.31 ± 0.17^{e}	539.26 ± 14.87^{d}

A total increase of up to 56% in the DPPH radical scavenging activity was observed as the Sarawak pineapple developed from stage I to stage V, with the most significant increase from stage II to stage III (Table 4). The radical scavenging activity increased from 6.50 µg AAE g-^{1} in stage II to7.85 µg AAE g^{-1} in stage III, an increase of up to 21%. DPPH radicals are often used in the investigation of natural compounds scavenging (Salmanian, 2014).The DPPH radical scavenging assay further confirms the antioxidant activity in the Sarawak pineapple.

Total antioxidant capacity analysis was carried out via quantitation of antioxidant capacity through the formation of a phosphomolybdenum complex (Gupta and Sharma, 2006). The total antioxidant capacity test quantifies antioxidant capacity of water and fat soluble compounds (Nedamani, 2014). An overall increase of up to 1.87 times was observed from stage I (187.78 µg AAE g^{-1}) to stage V (539.26 µg AAE g^{-1}) in the total antioxidant capacity. The highest increase was observed as the Sarawak pineapple developed from stage III (242.22 µg AAE g^{-1}) to stage IV (425.74 µg AAE g^{-1}), recording an increase of 75.77%. Results suggest that the best harvesting period for the Sarawak pineapple would be at stage V (five months after anthesis).

CONCLUSION

The Sarawak pineapple exhibited a sigmoid type of growth pattern during fruit development. The pulp firmness decreased while the total soluble solids increased as the fruit developed, thus, improving its edibility and acceptability to the consumers. A reduction in pH and an increase in titratable acidity contributed to the distinct flavor and taste of the Sarawak pineapple. While ascorbic acid content decreased during growth and development, the overall antioxidant activity increased in the fruit, suggesting a later period of harvesting as the most appropriate. The changes that occurred extrinsically as well as intrinsically suggest that the best time for harvesting the Sarawak pineapple is five months after anthesis.

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تغییرات فیزیوشیمیایی آناناس(*Ananas comosus* L. Merr. cv. Sarawak) در طی رشد و تکامل

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چکیده

در این پژوهش، ویژگی های فیزیکی و فیزیولوژیکی آناناس Sarawak درطی یک تا پنج ماه بعد از مرحله گلدهی بررسی شد.به این منظور، تغییرات طول میوه، قطر میوه، رنگ بافت گوشت میوه و سفتی آن، واکنش(pH)، کل جامدات محلول، کل اسید ها، محتوای اسید اسکوربیک و فعالیت های آنتی اکسیدانی میوه پایش شد. منحنی رشد آناناس Sarawak در طی رشد میوه به صورت سیگموید (S) بود. با تکامل رشد میوه، سفتی بافت گوشت کاهش یافت ولی کل جامدات محلول افزایش یافت و در نتیجه باعث افزایش خوش خوراکی و پسند مصرف کننده شد. با کاهش واکنش (pH) و افزایش کل اسید ها، طعم و بوی ویژه آناناس Sarawak تقویت شد. از سوی دیگر، در طی رشد و تکامل میوه ، مقدار اسکوربیک اسید کم شد در حالیکه فعالیت های آنتی اکسیدانی در میوه افزایش یافت. این امر حاکی از آن بود که بهتر است میوه دیر تر برداشت شود. نتیجه این که با توجه به تغییرات بیرونی و درونی (ذاتی) میوه در این پژوهش می توان گفت که بهترین زمان برای برداشت آناناس Sarawak پنج ماه پس از گلدهی و گرده افشانی است.

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