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Effect of Maturity Stage on Physicochemical Properties of Jackfruit (*Artocarpus heterophyllus* Lam.) Flesh

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Abstract: Jackfruit (*Artocarpus heterophyllus* Lam.) is one of the popular crops in Sri Lanka. This study was carried out to investigate the changes in physicochemical properties including colour, texture, moisture content, total soluble solids, pH, titratable acidity, vitamin C, total starch and total sugar contents in four maturity stages of jackfruit flesh. The results of the study clearly indicate a significant difference ($p<0.05$) in physicochemical traits at different maturity stages of jackfruit flesh. The colour parameters varied significantly during maturation with a marked increase of a* and b* values and the hardness decreased with maturity. The moisture content ranged between 70.94 - 89.21%. Total soluble solids increased with maturity from 3.4 to 19.6%, corresponding to the increase of total sugar content. pH increased from the immature stage 1 (5.27) to the mature stage (6.25), then decreased during ripening up to 5.76, while the variation of titratable acidity showed the opposite pattern of pH, ranging between 0.17 - 0.29%. The vitamin C content increased with maturity with a range of 2.18 - 8.17 mg $100g^{-1}$. Total starch content increased with maturity from 1.597% to 19.533%, but then decreased with ripening up to 6.237%. The variation of Total Phenolic Content showed a decreasing pattern from the immature stage 1 (46.969 mg GAE/g) to mature stage (3.754 mg GAE/g) and then slightly increased in the fully ripen stage (9.530 mg GAE/g).

Abbreviations: Ta-Titratable Acidity · TPC-Total Phenolic Content · TSS-Total Soluble Solids
Key words: *Artocarpus heterophyllus* · Jackfruit · Maturity Stages · Physicochemical Properties

INTRODUCTION

Jackfruit (*Artocarpus heterophyllus* Lam.), is a tropical tree bearing large fruits, which is native to India and common in Asia, Africa and South America. It belongs to the Genus *Artocarpus* and Moraceae (Mulberry) family [1-3]. It is categorized as a climacteric fruit and considered as the largest known edible fruit [4, 5].

There are two main varieties of jackfruit; firm and soft. In the firm variety, the perianth remains firm even at full ripeness, while in the soft variety, the perianths become soft and fleshy on ripening [6]. The soft variety has fruits with small, fibrous, soft and spongy flakes with very sweet carpels, whereas the firm variety is crunchy with crisp carpels and not sweet as the soft variety [4]. Some studies have reported variations in the starch, total sugar and reducing sugar contents of soft and firm types [6, 7].

A Jacktree can produce 20-250 fruits per year [5] which can reach to a weigh of 10-25kg [8]. It is one of the most droughts tolerant, hardy fruit crop [9] and referred to as poorman's food due to its availability in the monsoon periods and various culinary uses [9, 10].

Mature jackfruits are consumed as curries or in boiled form, while ripe fruits can be eaten raw. In several countries, food products such as juice, jam, jellies, baby food, marmalades and ice cream has been developed from pureed jackfruit [5, 11]. Other than these, new jackfruit-based products are also being produced with the use of advanced processing technologies including freeze-drying, vacuum frying and cryogenic freezing [5, 12].

The jackfruit is an important source of carbohydrate, protein, minerals and vitamins and several studies have revealed antimicrobial, antifungal, anticarcinogenic, hypoglycemic and wound healing effects of the crop [3, 13].

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Despite of its nutritional value and health benefits, the crop is underutilized and not classified as a commercial fruit and is rarely grown on regular plantation scale [9] due to insufficient processing facilities in the regions they are grown [14].

During the maturation and ripening process, jackfruit undergoes many physicochemical changes. Evaluation of these changes during maturity allows making the best use of jackfruit in different applications [2].

The aim of this study was to determine the variations of physicochemical properties in jackfruit flesh of the firm variety throughout different maturity stages in order to use this knowledge to utilize the most suitable stage in various applications.

MATERIALS AND METHODS

Sample Collection: All samples were collected from several jackfruit trees in the Western Province, Sri Lanka. Jackfruits of four maturity stages including immature stage 1 (6-7 weeks), immature stage 2 (8-10 weeks), mature stage (12-14 weeks) and fully ripen stage (14-16 weeks) were selected for the experiment.

Sample Preparation: Just after harvesting the jackfruit, the inedible parts (Peel and the core) were removed manually and the edible part was isolated. Then the seeds were removed and the flesh was stored in the freezing conditions until the analysis.

Colour Determination: Colour was measured at different places of jackfruit flesh as L*a*b* colour scale system by a chromameter (Lovibond® LC100, China).

Determination of Hardness: The hardness of the fruits of the four maturity stages were determined using a Texture Analyzer (CT3, 50kg Brookfield, USA), with TA10 (12.7mm) cylinder probe, 1mm target distance, 1000g load cell, 5g trigger load and a test speed of 1mm/s.

Determination of Moisture Content: The moisture content of the samples was determined according to the method of AOAC [15].

Determination of Total Soluble Solids (TSS) and pH: TSS and pH were determined according to the method described in Tiwari and Vidyarthi [16] with some modifications by digital brix meter (ATAGO Pocket PAL-1, Japan) and digital pH meter (HACH HQ11d, USA) respectively.

Determination of Titratable Acidity (TA): The method described in Ranganna [17] was used for the determination of titratable acidity with some modifications.

Determination of Vitamin C Content: The vitamin C content of the samples was analyzed following the method described in AOAC [15].

Determination of Total Starch Content and Total Sugar Content: Both total starch and total sugar contents of jackfruit flesh were determined by the anthrone method as described in Hossain *et al*. [18] by the Spectrophotometer (UVmini-1240, Japan) 680 nm. The amount of starch and sugar present in fruit flesh was calculated from the standard curve prepared using different concentrations of glucose (SUPELCO, 99.9%) and expressed as g/100 g of fresh fruits.

Determination of Total Phenolic Content (TPC): The total phenolic content (TPC) was determined by the Folin-Ciocalteu assay [19] and expressed as milligram of Gallic acid equivalents per gram (mg GAE g^{-1}).

Statistical Data Analysis: All experiments (Except colour and hardness measurement) were carried out in triplicates and duplicate measurements were taken from each replicate. The statistical analysis of data was carried out for all experiments using one-way ANOVA to test the significance of each variable (á=0.05), followed by comparisons performed using the Tukey test by the statistical software MINITAB®18. Regression analysis was conducted to determine the correlation when constructing standard curves in determining total starch, total sugar and total phenolic contents.

RESULTS AND DISCUSSION

Variation of Colour: The colour of the four maturity stages of jackfruit flesh was measured as L* (Lightness), a* (Redness), b* (Yellowness), C* (Chromaticity) and h° (Hue angle) values.

As shown in the Table 1, the lightness of the four maturity stages of jackfruit ranged from 68.7±5.5 to 85.0±2.6, which increased with maturity, from the immature stage 1 to mature stage and then decreased in the fully ripen stage. ANOVA revealed a significant difference ($p<0.05$) among the L* values of the mature stage and fully ripen stage, but the differences among the other maturity stages were not significant ($p>0.05$).

Table 1: Colour parameters of jackfruit flesh at different stages of maturity

Maturity Stage	L* value	a* value	b* value	C* value	h° value
Immature stage 1	75.4±8.8$^{a, b}$	1.6±2.5^{b}	28.0±2.4^{c}	28.1±2.5^{c}	87.2±4.8^{b}
Immature stage 2	80.1±7.6$^{a, b}$	-1.2±0.7^{b}	23.2±1.8^{c}	23.2±1.8^{c}	92.9±1.9^{a}
Mature stage	85.0±2.6^{a}	1.3±0.6^{b}	35.3±3.5^{b}	35.4±3.5^{b}	87.9±0.9$^{a, b}$
Fully ripen stage	68.7±5.5^{b}	7.2±1.1^{a}	55.1±2.9^{a}	55.6±2.9^{a}	82.6±1.1^{b}

*Data presented as mean values for 8 samples from each maturity stage ± S.D (n=8). abcd letters in the same column are significantly different at (p<0.05) level.

Table 2: Hardness at Different Maturity Stages of Jackfruit Flesh

Maturity Stage	Hardness (g)
Immature stage 1	8052±129^{a}
Immature stage 2	2297±221^{b}
Mature stage	1530±152^{c}
Fully ripen stage	840±5^{d}

*Data presented as mean values for 10 samples from each maturity stage ± S.D (n=10). abcd letters in the same column are significantly different at (p<0.05) level.

The results (Table 1) showed a decrease in a* value in immature stage 2 compared to the immature stage 1 and then increased with the maturity, ranging from -1.2±0.7 to 7.2±1.1. The a* value of the fully ripen stage significantly differed (p<0.05) from the other three stages, but there was no significant difference among the a* values of other three maturity stages.

The b* value decreased from immature stage 1 to immature stage 2 and then gradually increased from the immature stage 2 to fully ripen stage, with a range of 23.1±1.8 - 55.1±2.9, as shown in the table 1. ANOVA showed no significant difference (p>0.05) between the b* values of immature stage 1 and 2, but it varied significantly (p<0.05) among the other stages. Chroma (C*) exhibited a similar pattern of variation as in the b* values (Table 1).

The hue value of the immature stage 2 varied significantly (p<0.05), compared with the immature stage 1 and fully ripen stage, as shown in the Table 1. The differences among other stages were not significant (p>0.05).

Ong *et al*. [20] has observed a significant difference in the hue values of all the portion of the jackfruit with a remarkable increase during ripening. This may be attributed to increase of carotenoid content of the ripe jackfruit flesh. The study also revealed that the top portion had the higher hue values compared with the bottom portion in all maturity stages, indicating that the ripening process initiates at the top portions of the fruit. However, there was no difference in the chroma values. Another study [21] has reported a two-fold increase in jackfruit flesh colour from the mature to ripen stage.

Variation of Hardness: The Table 2 shows that the hardness decreased with maturation of the jackfruit flesh, with the highest in the immature stage 1 and the lowest in the fully ripen stage. ANOVA revealed that there was a significant difference (p<0.05) in the hardness among the four maturity stages.

The decreasing fruit hardness might be associated with fruit softening due to the deterioration of cell wall structure, caused by the hydrolysis of insoluble pectin into soluble forms [22-24]. Similar pattern of variation of firmness of fruits has found in a study conducted with mango and cashew apple [25].

Variation of Moisture Content: The variation of moisture content in different maturity stages of jackfruit flesh is demonstrated in the Table 3. ANOVA results showed a significant difference (p<0.05) between the moisture content of different maturity stages, but the differences of moisture content between two immature stages and mature stage and fully ripen stages were not significant (p>0.05). The moisture content was higher at immature stages and declined in matured stage, then a slight increment was observed in the fully ripen stage. This increase of moisture during ripening has also been reported in Ong *et al.* [20] and it was not significant.

According to Hasan [26], there was a difference between the moisture content of two jackfruit varieties in two harvesting seasons ranging from 74.44% to 81.68% and 74.03% to 74.77%. Goswami *et al.* [27] has found a difference in moisture content of flesh of five jackfruits types in fully ripen stage ranging from 79.62% to 84.44%. The moisture content of three varieties of jackfruit fleshes were found to range between 79.25-81.12% by Mortuza *et al.* [28] and these variations were not noticeable. When comparing the results of the current study with the values recorded in literature, a slight difference can be observed. These variations may be due to differences in types and locations [20].

Variation of Total Soluble Solids (TSS): The variation of TSS in different maturity stages of jackfruit flesh is shown in Figure 1.

Table 3: Changes in chemical parameters of jackfruit flesh with the stage of maturity

Maturity Stage	Moisture Content (%)	pH	Titratable acidity (% of Citric Acid)	Vitamin C (mg/100g)	Total Starch Content (g/100g)	Total Sugar Content (g/100g)
Immature stage 1	86.18±0.85[a]	5.27±0.15[c]	0.29±0.06[a]	2.18±0.34[c]	1.597±0.295[c]	3.055±0.967[d]
Immature stage 2	89.21±2.29[a]	5.66±0.03[b]	0.24±0.05[a, b]	3.14±0.98[c]	1.918±0.267[c]	5.125±1.268[c]
Mature stage	70.94±2.09[b]	6.25±0.06[a]	0.17±0.07[b]	4.91±1.22[b]	19.533±0.354[a]	14.668±0.968[b]
Fully ripen stage	74.22±1.83[b]	5.76±0.03[b]	0.21±0.06[a, b]	8.17±0.39[a]	6.237±1.285[b]	25.498±0.495[a]

*Data presented as mean values for triplicates with duplicate measurements in each replicate ± S.D (n=6). a, b, c, d letters in same column are significantly different at (p<0.05) level.

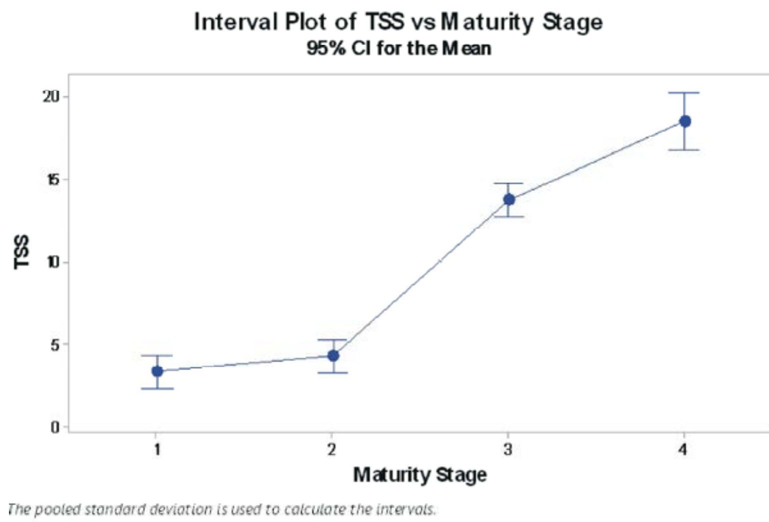

Fig. 1: Variation of TSS in different maturity stages of jackfruit flesh (Maturity stage 1=immature stage 1, 2=immature stage 2, 3= matured stage, 4=fully ripen stage)

The TSS of jackfruit flesh at different maturity stages ranged between 3.4±0.7-19.6±1.1%, with the lowest in the immature stage 1 and the highest in the fully ripen stage. A huge increment of TSS was observed from immature stage 2 (4.3±1.3%) to matured stage (13.7±1.1%). ANOVA results showed a significant difference ($p<0.05$) in the TSS among different maturity stages, but the difference between the two immature stages was not significant ($p>0.05$).

The increase of TSS may be attributed to the conversion of starch to sugar during ripening [2, 29] disintegration of the cell wall which cause the release of water-soluble components [30] and increase in water-soluble galacturonic acids from the degradation of water insoluble pectic substances by polygalacturonase [31].

A similar trend of variation of TSS has been reported in several studies [2, 16, 20]. Higher Brix values ranging from 18° to 29° has been reported in Tiwari and Vidyarthi [16]. In Shamsudin *et al.* [2] the TSS content of jackfruit ranged from 19.03° to 32.53° Brix during ripening and then decreased to 29.33° Brix during further storage due to over ripening. Ong *et al.* [20] has found the TSS to range from 16° to 20° in different portions of the fully ripened jackfruit and these values are agreeable with the results of our study.

Mortuza *et al*. [28] has reported the TSS of three varieties of fully ripe jackfruit fleshes to range between 18.70-20.03°. TSS of 24 jackfruit types in edible ripens stage ranged between 19.87-35.00° Brix [1]. A variation of TSS of fully ripen jackfruit from 19.3 to 27.0% has been reported by Goswami *et al.* [27]. It has been reported that the TSS of different clones on jackfruit to range between 24.8 -40.5° [9]. The variations may be due to the differences in varieties, location and harvesting time [27].

Variation of pH and Titratable Acidity (TA): The TA and pH values of jackfruit are mainly related to the predominant organic acids including malic and citric acids.

The results (Table 3) showed that the pH increased gradually from immature stage 1 to matured stage, but then decreased in the fully ripen stage. The lowest pH was observed in the immature stage 1, while the highest in the matured stage. ANOVA, revealed a significant difference ($p<0.05$) among the pH values of different maturity stages of jackfruit flesh, but the difference was not significant ($p>0.05$) between the immature stage 2 and the fully ripen stage.

A similar pattern of variation of pH of jackfruit has been reported in Shamsudin *et al.* [2] but the values observed in this study was higher (5.27 to 6.25) compared to former, which was 4.70 to 5.72. There, the average pH showed an increasing trend during the early ripening stages and then decreased. The variation may be due to differences in variety, harvesting time, location and the climatic conditions. Another study [27] has reported that the pH value of different varieties of fully ripen jackfruit ranged from 5.61 to 6.45, which is more agreeable with the values found in our study.

According to Ong *et al.* [20] the pH value was highest in unripe jackfruit and decreased significantly in all fruit portions (Top, middle and bottom) during the early stage of ripening. In Hasan [26] the pH of the jackfruit flesh ranged from 5.18 to 5.51 depending on the harvesting season and the variety.

As shown in table 3, the titratable acidity of jackfruit flesh ranged from 0.17±0.07% to 0.29±0.06% as a percentage of citric acid. The highest TA was observed in the immature stage 1, while the lowest in the matured stage. There was a significant difference ($p<0.05$) in the titratable acidity between immature stage 1 and mature stage, but the differences among the other stages were not significant ($p>0.05$). Apparently, TA is negatively correlated with the pH. The decrease in TA during maturity may be due to the rapid utilization of organic acids by respiration [32] and the increase in acidity during ripening can be attributed to formation of acid by degradation of polysaccharides and oxidation of reducing sugars or by breakdown of pectic substances and uronic acid [33, 34].

In Reddy *et al*. [9] the variation of acidity of different clones of jackfruit was in the range of 0.18% to 0.68%, while Shamsudin *et al.* [2] has found that the acidity in jackfruit to vary from 0.27% to 0.75%. According to Ong *et al*. [20] the titratable acidity of top, middle and bottom portions increased significantly, ranging between 0.3-0.9%. In Jagadeesh *et al.* [1] the titratable acidity of 24 types of jackfruit in edible ripe stage varied between 0.190-0.595% (as a % of citric acid). Lower values (0.15-0.2%) have been reported in Selvaraj and Pal [21] which is agreeable with our study.

The results of this study were much lower compared to Shamsudin *et al*. [2], Reddy *et al*. [9] and Ong *et al.* [20]. The variations may be due to differences in variety, location and harvesting times.

Variation of Vitamin C Content: The vitamin C content of jackfruit flesh increased during maturation, ranging from 2.18±0.34 - 8.17±0.39 mg $100g^{-1}$, with the lowest in the immature stage 1 and the highest in the fully ripen stage as shown in table 3. ANOVA depicted a significant difference ($p<0.05$) in the vitamin C content of the four maturity stages, but the difference between the immature stage 1 and 2 was not significant ($p>0.05$).

A study conducted by Krishnan *et al.* [35] has recorded the ascorbic acid content to range between 1.50-10.55 mg/100g in the fully ripen stage among 10 firm flesh jackfruit types in Kerala. According to Goswami *et al.* [27] the vitamin C content of three jackfruit varieties collected from two regions varied from 4.57 to 8.18 mg/100g in the fully ripen stage. These values are agreeable with the findings of our study. The findings of Hasan [26] has recorded that the vitamin C content of jackfruit flesh ranged from 2.87 mg/100g to 4.26 mg/100g depending on the variety and the season. Another study has found increasing vitamin C content of jackfruit flesh during maturation from 18.5 mg/100g to 24.03 mg/100g and then a slight decrement during ripening up to 22.5 mg/100g [16]. These values are higher compared to the findings of our study and the variations can be attributed to difference in locations, varieties and the harvesting times.

Variation of Total Starch Content: The total starch content ranged from 1.60±0.30 to 19.53±0.35g/100g at different maturity stages (Table 3). The starch content increased markedly from immature stage 2 to mature stage and then declined during ripening. The increase of starch content with maturity can be attributed to increased starch deposition when the fruit become larger in size and weight and the decline of total starch during ripening may be due to the hydrolysis of starch and generation of free sugars and other soluble carbohydrates during ripening [21, 27].

ANOVA results showed a significant difference ($p<0.05$) among the starch contents of the four maturity stages, but the difference between the immature stage 1 and 2 was not significant ($p>0.05$).

Goswami *et al.* [27] has reported the variation of starch content of ripen jackfruit flesh, depending on both type and location to be in the range of 6.11% - 8.34%, which agrees with the values obtained in the present study. Tiwari and Vidyarthi [16] have found that the total starch content of whole jackfruit increased from 10.46 to 20.93% during maturation. Another study has reported the total starch content of 24 jackfruit types harvested from Western Ghats of Karnataka to range

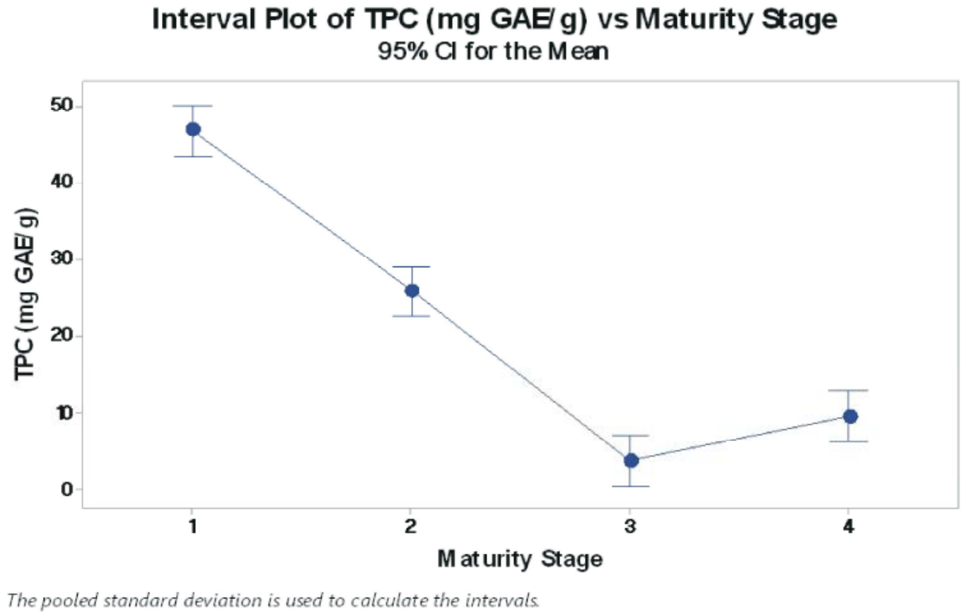

Fig. 2: Variation of total phenolic content in different maturity stages of jackfruit flesh (Matirity stage 1=immature stage 1, 2=immature stage 2, 3= matured stage, 4=fully ripen stage)

between 0.63-5.13% in edible ripen stage and the variations in results may be attributed to differences in inherent capacity to accumulate starch and amylase activity in the bulb tissues, leading to differences in the rates of hydrolysis of starch of genetically dissimilar jackfruit selections [1].

Variation of Total Sugar Content: The results (Table 3) shown that the total sugar content of different maturity stages of jackfruit flesh increased during maturation, with the lowest in immature stage 1 and the highest in the fully ripen stage. There was a huge increment of sugar content during ripening, corresponding to the decline of total starch content. This may be attributed to the hydrolysis of starch to sugar during ripening [27]. The increase of total sugar content can be associated with the increase of TSS with maturity. As revealed by ANOVA, there was a significant difference in the total sugar content among the four maturity stages of jackfruit.

Similar pattern of variation of total sugar content has been reported in several studies [16, 20, 36] during the maturity of jackfruit. There, the total sugar content has been increased exponentially with the maturity age of the fruit. Jagadeesh *et al*. [1] has reported the total sugar content of 24 jackfruit types harvested from Western Ghats of Karnataka to range between 19.1-32.1% in edible ripen stage. Another study has found that the location and variety to influence the total sugar content of jackfruit flesh [27]. According to the study, the total sugar content of three varieties jackfruit in fully ripen stage, which were harvested from two areas ranged from 11.29% to 17.89%. The variation of total sugar content with the harvesting season and the variety was investigated in Hassan [26]. According to the results of the study, the total sugar content of jackfruit flesh ranged from 14.07-18.0%.

The values observed in the former studies are lower compared to the findings of the present study. The variations may be attributed to the differences in sugar isolation and sampling procedures, degree of fruit maturity and plant growth conditions [36].

Variation of Total Phenolic Content (TPC): As shown in Figure 2, TPC decreased with maturity and then slightly increased in the fully ripen stage. The highest TPC was observed in the immature stage 1 (46.97±1.62 mg GAE/g) and the lowest in the matured stage (3.75±0.33 mg GAE/g). ANOVA revealed that the TPC significantly differed ($p<0.05$) with maturity, but the difference of TPC between mature stage and fully ripen stage was not significant ($p>0.05$).

Mahmood *et al.* [37] states that the maturation of fruit or other plant tissues involves a series of complex reactions, which leads to changes in the phytochemistry of the plants. Several studies have found two distinct phenomena of change in phenolic contents during maturation; either steady decrease [38, 39] or rise at the end of maturation [40-42].

Jagtap *et al.* [19] has determined the TPC of ripe jackfruit flesh to be 0.46 mg GAE/g, while another study has recorded TPC of jackfruit as 162.79±0.12 mg GAE/kg [43]. Soong and Barlow [44] have found that the seeds of jackfruit showed higher amounts of total phenolic content (27.7 mg GAE/g) than the flesh. In the immature stages, the seeds and the flesh are inseparable. Therefore, the TPC of immature stages has a higher value. The phenolic acid contents in different parts of raw and ripe jackfruit has been studied by Singh *et al.* [45] and it states that the flesh of raw jackfruit to contain three phenolic acids; gallic, ferulic and tannic acids, where gallic acid (9.7 µg/g) was found maximum, followed by ferulic (8.04 µg/g) and tannic (4.87 µg/g) acids. However, in flesh of ripe fruit, the amount of gallic acid (19.31µg/g) was almost double, while ferulic acid (2.66 µg/g) was drastically reduced, but tannic acid (5.24 µg/g) increased a little as compared to raw flesh.

The TPCs found in former studies are much lower compared with the findings of the present study. Different authors have reported great variations in the TPC of the different fruit varieties or same fruit variety, due to the complex nature of these groups of compounds and the methods of extraction and analysis [46]. Also, these variations may exist as phenolic content of plants are influenced by a number of intrinsic (Genus, spices, cultivar) and extrinsic (Agronomic, environmental, handling and storage) factors [47].

CONCLUSION

The study was carried out to investigate the variation of physicochemical properties in different maturity stages of jackfruit flesh. According to the results, it can be concluded that physicochemical properties including colour, texture, moisture content, pH, Total soluble solids, titratable acidity, vitamin C, total starch, total sugar and total phenolic contents changed significantly with maturity. TSS, pH, vitamin C content, total starch content and total sugar content usually increased with maturity, but the titratble acidity and TPC showed a decreasing pattern.

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