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ORIGINAL ARTICLE

Variation in properties of tender jackfruit during different stages of maturity

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Abstract This research was conducted on two varieties of tender jackfruit [hard (HV) and soft variety (SV)]. The tender jackfruit was divided into four stages (i.e. Stage 1, 2, 3 and 4) and their physical, mechanical, chemical and textural properties were determined for both the varieties. Physical properties like weight, length, diameter, geometric mean and arithmetic mean diameter were increases with increase in size for both the varieties. There was a significant increase in TSS in both the varieties (HV: 1.5 ± 0.02 to 5.1 ± 0.03; SV: 2.7 ± 0.05 to 7.1 ± 0.05 °Brix) from stage 1 to 4 because of ripening of fruit. The hardness, fracturability and springiness increases with maturity but on the counterpart, there is a decrease in adhesiveness, cohesiveness, chewiness and gumminess. The nutritional properties and the energy (kj) values were inevitable increases whereas vitamins content was decreases from stage 1 to 4 in both the varieties. The measured properties will be helpful in planning, design and fabrication of post-harvest processing equipment for tender jackfruits.

Keywords Tender jackfruit · Geometric mean diameter · Arithmetic mean diameter · Soft variety · Hard variety

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Introduction

Jackfruit (*Artocarpus heterophyllus*), is native to Southeast Asia and possibly originated from India (South-western rain forests) (Boning 2006). Jackfruit tree is mainly a low land tropical tree and can be grown in sub-tropical areas. Hence it is widely spread all over the India. Jackfruit is also known as the largest tree-borne fruit in the world (FAO 2012). India is believed to be the land of Jackfruit. From centuries the Jackfruits play a significant role in the Indian agriculture and culture. It is mainly grown as a shade crop and is available throughout the country (Ghosh and Venkatachalapathy 2014). In Japan and southern part of Asia it is referred as poor man's fruit. The young and premature fruit (tender jackfruit) can be use as vegetable, which contains high amount of vitamins and mineral.

In general, the jackfruits are classified in two types. The first one is based on its fruit sizes (smaller fruit type—Barka and larger fruit type—Kapa) and the second type is based on the basis appearance and texture of bulbs or pulp (i.e. soft and hard variety) (Manjunath 1948; Mukprasirt and Sajjaanantakul 2004). All these varieties of jackfruits are edible in tender as well as in ripen forms. In India, more than 34 different varieties of jackfruit were identified (Haq 2006; Baliga et al. 2011). Sidhu (2012) suggested some scientific criteria for grading of tender jackfruits, which are shown in Table 1. The various stages of tender jackfruits are used for different products such as pickle, vegetables, chips and other value added products.

Prior to the preparation of various products post-harvest operation plays an important role for all agricultural produces. Post-harvest operations such as cleaning, washing, drying, peeling, cutting, storage, etc. are necessary for tender jackfruits. To perform these unit operations, knowledge of various physio-chemical properties are

Table 1 Grading of tender jackfruit on the basis of maturity (Sidhu 2012)

Form	Stages	Description
Tender	Stage 1	No formation of seeds or fruit lets. Texture similar to chicken and used for cooking and pickle making
	Stage 2	Seeds and fruit lets are just started to grow and can find very small or baby seeds while cutting. Best used as vegetable
	Stage 3	Seeds and fruit lets are immature and fully developed but testa in seed is not developed yet. Seeds are edible as vegetable without cleaning
	Stage 4	Fully developed seeds and fruit lets. Testa of seed is developed. Best stage for making chips and use for various curry preparations

essential for tender jackfruits. The unit operations such as drying, dehydration, milling, storage, etc. were carried out by many researchers or scientists for preparation of various value added products for different fruits and vegetables (Liu et al. 2015; Sidhu 2012; Srimagal et al. 2017; Yi et al. 2016). Matthew (1995) studied some physical characteristics of 29 types of jackfruit and found a broad range of variation in edible and non-edible parts. Joseph and Kumaran (1996) studied the fruit set, fruit drop and fruit development in two types of jackfruit and did not find any significant difference in those varieties of tender jackfruit. However detailed study on tender Jackfruit at various maturity stages is still not done.

For this research, the tender jackfruit was selected from hard and soft varieties. Attempts were made to determine the physiochemical and nutritional properties of tender jackfruit of soft and hard variety at different stages. These properties are helpful in design and development of equipment or structure for transportation, handling, processing, storage, value addition and quality control of agricultural products including jackfruit. Due to the lack of these basic data on properties there is no technology or equipment available for post-harvest processing of tender jackfruit. The traditional processing of this fruit is done by manual methods which is tedious and consumed more time. Also the manual operation results lower capacity and less efficiency. Therefore, the study was conducted to determine the various physical and chemical properties of tender jackfruit during different stages of maturity. So an honest attempt was made to fulfill the research gap. The physical, chemical, nutritional, textural and colour properties were determined at all four maturity stages for two varieties and their trends during maturity were also discussed statistically.

Materials and methods

Jackfruit sample

The research was carried out at the National Institute of Technology, Rourkela, Orissa, India. The fully grown jackfruit trees were marked inside the campus and five trees of both hard and soft variety were selected randomly from different sites. These trees were kept under constant observation after the flowering season. Once the fruit started maturing the samples were collected at various stages from the marked trees. The samples collected from the marked trees were free from any mechanical injuries or microbial infection and thus used for further research.

Physical properties

The weight of the sample was taken in triplicate by using an electronic weighing balance (precision = 0.001 g; Indosaw Pvt. Ltd., India). The parameters like length and diameter were determined with the help of a digital vernier caliper (Fisher Scientific, India). The other parameter like sphericity, percentage of consumable matter, percentage of non-edible matter and surface area were determined by the standard method (Pradhan et al. 2009; Bianchi et al. 2016). From the principal dimensions, the arithmetic mean and geometric mean diameter were calculated and expressed as size. Arithmetic mean (AM), geometric mean (GM) and spherecity ($\emptyset$) were calculated by the given formula (Sharma et al. 1985; Sreenarayan et al. 1985).

$$\mathrm{AM} = \frac{l + 2w}{3}$$

$$\mathrm{GM} = \left(l{*}w^2\right)^{\frac{1}{3}}$$

$$\emptyset = \frac{(l * w * w)^{\frac{1}{3}}}{l}$$

where l is the length of the fruit and w is the diameter of the fruit.

Proximate and chemical properties

Moisture content, ash, carbohydrate, total sugar, fat, protein and ascorbic acid were measured using AOAC (2000) methods. Elico pH meter was used to determine pH of the sample. Hand refractometer was used to find total Soluble Solids (TSS, ^{o}Brix). Total Dissolved Solids (TDS) was measured with a TDS meter (HM Digital, New Delhi, India) and expressed as ppm. Analysis of nutrients and minerals such as sodium, calcium, potassium, fibre, vitamin A, vitamin C, total minerals, phosphorus and potassium was done using AOAC (2000) methods.

Textural properties

Texture profile of jackfruit were measured using CT3 texture analyser [probe: needle probe (TA9, 20 mm L), pre-test speed: 1.00 mm/s, test speed: 0.50 mm/s, post-test speed: 0.5 mm/s; load cell: 10000 g]. The resistance of the material to the applied forces is measured by a calibrated load cell, and results were shown in either grams or Newton (Ghosh et al. 2017; Yi et al. 2016). The compression test was performed for five replications. The results were taken from the installed Texture Pro CT Software.

Colour properties

The visual colour values were determined after washing the tender jackfruits with warm water and removed the surface moisture with the help of cotton clothes or tissue. This was done before analysis of physio-chemical properties of the sample. Triplicate of colour values were measured and the average was reported to represent its colour. The colour measurement was done with the help of a colorimeter (ColorFlex EZ, Hunter Lab, USA). The values were expressed in term of L* (black to white), a* (red to green) and b* (yellow to blue) (Yi et al. 2016).

Statistical analysis

All the experiments were done according to complete randomized design. Analyses of variance and the significance of mean difference were analyzed by SPSS for Windows version 10 (SPSS Inc., Illinois, USA). The statement of significance was based on $P < 0.05$ unless otherwise indicated.

Results and discussion

Physical properties

Weight and dimensions

The average values of the tender jackfruit in term of major dimensions (i.e. length and diameter) and weight at different stages are tabulated in Table 2. The shape of both the varieties were found to be oblong (near to cylindrical). In both the varieties, the major dimensions and the weight were found to be linearly dependent on stages of maturity. It was also observed that the tender jackfruit expanded for both the varieties from stage 1 to 4. For hard variety, there was a significant ($P < 0.05$) increases of 121.12, 46.09 and 75.93% in the mean values of weight, length, and diameter, respectively, from stage 1 to 4. Similarly, a significant ($P < 0.05$) increases of 60.80, 57.63 and 119.77% was observed in the mean values of weight, length and diameter, respectively, for soft variety.

In Table 2, the average values of GM and AM were calculated in both hard and soft varieties. The average diameter increases with maturity of fruit from stage 1 to 4 ($P < 0.05$). For hard variety, the GM and AM increased from 9.65 to 15.37 cm and 9.55 to 15.49 cm, as the stage changes from 1 to 4, respectively. For soft variety, the GM and AM were recorded smaller than the hard variety, but similar type of trend was observed in both the varieties. For soft variety, the GM and AM increased from 5.15 to 10.11 cm and 5.75 to 11.12 cm, respectively, as the stage changes from 1 to 4.

Sphericity

The shape of jackfruit can be determined in terms of sphericity, which is directly influences the flow characteristic of the product. The sphericity of the jackfruit is highly influenced by its stage of maturity for both the varieties. For both the varieties the sphericity decreases with increase in stages ($P < 0.05$). The fruit of hard variety is believed to be a sphere in its initial stages i.e. 1 and 2 because the sphericity values were 0.91 and 0.89, respectively, whereas it decreases to 0.83 at stage 4. In the case of soft variety, the jackfruit was almost cylindrical in its initial stages and retain oblong in stage 4. The sphericity values for soft variety in stage 1 and 4 were 0.78 and 0.89, respectively.

Percentage edible matter and percentage non-edible matter

It was observed that the tender jackfruit at earlier stage has higher percentage of edible matter than the later stage.

Table 2 Physical properties of two varieties of tender jackfruit at different stages of maturity

Properties	Stage 1	Stage 2	Stage 3	Stage 4
Hard variety				
Weight (kg)	1.42 ± 0.76^{a}	2.57 ± 0.53^{b}	3.05 ± 0.62^{c}	3.14 ± 0.83^{c}
Shape	Sphere	Sphere	Oblong	Oblong
Length (cm)	12.54 ± 5.78^{a}	16.04 ± 4.92^{b}	18.08 ± 6.69^{c}	18.32 ± 7.43^{c}
Diameter (cm)	8.02 ± 3.22^{a}	11.97 ± 2.99^{b}	14.15 ± 4.34^{c}	14.11 ± 3.96^{c}
Geometric mean diameter (cm)	9.65 ± 3.12^{a}	12.39 ± 3.12^{b}	$15..06 \pm 2.11^{c}$	15.37 ± 2.31^{c}
Arithmetic mean diameter (cm)	9.55 ± 2.65^{a}	12.67 ± 3.78^{b}	15.24 ± 3.12^{c}	15.49 ± 4.66^{c}
Sphericity	0.91 ± 0.03^{a}	0.89 ± 0.01^{b}	0.81 ± 0.06^{c}	0.83 ± 0.06^{d}
% edible matter	63.41 ± 3.54^{a}	59.11 ± 1.40^{b}	54.98 ± 3.21^{c}	55.57 ± 4.60^{c}
% non edible matter	35.44 ± 4.56^{a}	38.88 ± 4.20^{b}	43.15 ± 2.17^{c}	43.63 ± 0.25^{c}
Surface area (cm^2)	980.6 ± 113.30^{a}	1304.9 ± 97.40^{b}	1507.9 ± 163.30^{c}	1534.5 ± 189.50^{c}
Soft variety				
Weight (kg)	1.25 ± 0.52^{a}	1.44 ± 0.63^{b}	1.73 ± 0.47^{c}	2.01 ± 0.51^{d}
Shape	Oblong	Oblong	Oblong	Oblong
Length (cm)	8.45 ± 4.54^{a}	10.64 ± 3.68^{b}	12.59 ± 4.98^{c}	13.32 ± 5.16^{d}
Diameter (cm)	4.45 ± 1.72^{a}	6.32 ± 1.67^{b}	7.65 ± 2.11^{c}	9.78 ± 2.99^{d}
Geometric mean diameter (cm)	5.15 ± 1.19^{a}	7.19 ± 1.43^{b}	8.54 ± 1.98^{c}	10.11 ± 2.99^{d}
Arithmetic mean diameter (cm)	5.75 ± 1.61^{a}	6.97 ± 2.13^{b}	9.14 ± 2.14^{c}	11.12 ± 2.62^{d}
Sphericity	0.78 ± 0.02^{a}	0.74 ± 0.04^{b}	0.81 ± 0.02^{a}	0.89 ± 0.04^{c}
% consumable matter	66.45 ± 3.23^{a}	60.21 ± 3.12^{b}	58.48 ± 4.89^{b}	52.38 ± 6.21^{c}
% non edible matter	32.41 ± 4.33^{a}	41.88 ± 4.23^{b}	41.15 ± 3.33^{b}	46.66 ± 2.75^{c}
Surface Area (cm^2)	603.6 ± 145.40^{a}	804.9 ± 112.10^{b}	1007.9 ± 178.30^{c}	1331.6 ± 162.60^{d}

Values in the same rows followed by different superscript letters (a–d) are significantly different ($P < 0.05$)

Hence for stage 1, percentage of edible matter for both hard and soft variety were 63.41 and 66.45%, and it decreases by 12.36 and 21.17%, respectively, at stage 4 ($P < 0.05$). The reason behind this trends could be the thickness of peel and amount of seeds (percentage non-edible matter) were lesser in initial stages and it increases with increase in maturity (Ulloa et al. 2017).

Surface area

From Table 2, it was clear that surface area is dependent on the maturity stage of fruit. For hard variety, surface area increased from 980.6 ± 113.3 to 1534.5 ± 189.5 cm^2 and recorded an increase of 56.48% as the stage changes from 1 to 4. On the other side, for soft variety, surface area increased from 603.6 ± 145.4 to 1331.6 ± 162.6 cm^2 and recorded an increase of 120.6% as the stage changes from 1 to 4. This is due to the fact that surface area is directly proportional to the dimensions of the fruit from stage 1 to 4.

Proximate properties

Moisture content

In Table 3, the mean moisture content (%, w.b.) at different stages are reported. As the fruit maturity increases from stage 1 to 4 the moisture content decreases for both hard and soft varieties ($P < 0.05$). For hard variety, moisture content (w.b.) decreases from 89.5 to 74.4% as the stage changes from 1 to 4. For soft variety, moisture content (w.b.) recorded higher than that of hard variety, but similar type of trend can be observed in both the varieties. For soft variety, the moisture content (w.b.) decreased from 92.8 to 78.8%, as the stage changes from 1 to 4, respectively.

Ash content, total solids and pH

From the Table 3, it is seen that the ash content, total solid content, and pH of hard variety of jackfruit are not showing any significant deviation from its means ($P < 0.05$). Tulyathan et al. (2002) found similar results for jackfruit seeds. A similar type of trend was observed in soft variety of jackfruit. The values of ash content, total solids and pH are higher for soft variety than that of hard variety. By

Table 3 Proximate properties of two varieties of tender jackfruit at different stages of maturity

Properties	Stage 1	Stage 2	Stage 3	Stage 4
Hard variety				
Moisture content (%)	89.40 ± 4.60^{a}	84.20 ± 3.60^{b}	76.10 ± 6.20^{c}	74.40 ± 3.30^{c}
Ash content (%)	98.64 ± 0.02^{a}	98.88 ± 0.03^{ab}	99.12 ± 0.02^{bc}	99.48 ± 0.04^{c}
Total solids (%)	0.12 ± 0.03^{a}	0.14 ± 0.02^{b}	0.15 ± 0.02^{c}	0.15 ± 0.02^{c}
pH	6.08 ± 0.04^{a}	6.21 ± 0.02^{b}	6.13 ± 0.03^{c}	6.11 ± 0.02^{ac}
TSS (^{o}Brix)	1.50 ± 0.02^{a}	2.40 ± 0.04^{b}	2.80 ± 0.02^{b}	5.10 ± 0.03^{c}
TDS (ppm)	1.22 ± 0.18^{a}	1.73 ± 0.32^{b}	1.96 ± 0.21^{c}	2.33 ± 0.58^{d}
Soft variety				
Moisture content (%)	92.80 ± 4.60^{a}	91.10 ± 3.60^{a}	84.90 ± 4.60^{b}	78.80 ± 5.60^{c}
Ash content (%)	99.14 ± 0.05^{a}	99.12 ± 0.02^{a}	99.38 ± 0.03^{b}	99.31 ± 0.06^{b}
Total solids (%)	0.18 ± 0.01^{a}	0.20 ± 0.01^{b}	0.22 ± 0.01^{c}	0.22 ± 0.01^{c}
pH	6.78 ± 0.02^{a}	6.06 ± 0.06^{b}	6.44 ± 0.05^{c}	6.56 ± 0.06^{ac}
TSS (^{o}Brix)	2.70 ± 0.05^{a}	4.90 ± 0.07^{b}	6.30 ± 0.12^{c}	7.10 ± 0.05^{d}
TDS (ppm)	1.03 ± 0.26^{a}	1.11 ± 0.78^{a}	2.66 ± 0.41^{b}	2.53 ± 0.20^{b}

Values in the same rows followed by different superscript letters (a–d) are significantly different ($P < 0.05$)

considering all the values from stage 1 to 4, the average values of ash content, total solids, and pH for hard variety were 99.12, 0.14%, 6.13 and for soft variety 99.12, 0.20% and 6.44, respectively.

TSS and TDS

Tender Jackfruit in its initial stages had a lower amount of TSS and TDS than the later stage. Hence for stage 1, TSS and TDS for both hard and soft variety were 1.5 ± 0.02 ^{o}Brix, 1.22 ± 0.18 ppm, 2.7 ± 0.05 ^{o}Brix and 1.03 ± 0.26 ppm, and it increases by 240, 90.98, 162.96, and 145.63%, respectively, at stage 4 ($P < 0.05$).

Nutritional properties

The nutritional properties at different stages are reported in Table 4. As the fruit maturity in hard variety increases from stage 1 to 4, there was a decrease in Vitamin A and C from 39.4 ± 3.6 to 27.0 ± 3.1 IU and 18.65 ± 0.24 to 12.06 ± 0.68 mg, respectively, ($P < 0.05$). Whereas carbohydrates, calcium, sodium, phosphorus, potassium, energy values showed a significant ($P < 0.05$) increase from 54.6 ± 2.6 to 57.5 ± 1.6 g, 1.46 ± 0.43 to 43.6 ± 0.93 mg, 26.1 ± 2.5 to 22.8 ± 1.6 mg, 254.4 ± 2.5 to 412.6 ± 4.9 mg and 159.1 ± 11.4 to 444.8 ± 39.6 kj, respectively. The other properties like fat, fibre, protein and mineral content did not show any significant relation with various stages of the jackfruit. These properties were almost unchanged or constant with change in stage of maturity from 1 to 4.

In case of soft variety of the tender jackfruit the nutritional properties were shown similar type of trends as in hard varieties. As the fruit maturity in soft variety of tender jackfruit increases from stage 1 to 4 there was a decrease in Vitamin A and C from 44.4 ± 2.6 to 22.5 ± 0.3 IU and 12.12 ± 1.12 to 7.04 ± 1.10 mg, respectively, ($P < 0.05$). Whereas carbohydrates, calcium, sodium, phosphorus, potassium, energy values shown a significant ($P < 0.05$) increase from 19.6 ± 0.5 to 25.8 ± 0.3 g, 43.8 ± 1.8 to 57.5 ± 1.6, 12.1 ± 0.38 to 43.6 ± 0.93, 2.3 ± 0.6 to 22.8 ± 1.6, 190.6 ± 4.5 to 412.6 ± 4.9 mg, and 312.8 ± 22.4 to 444.8 ± 39.6 kj, respectively. The other properties like fat, fibre, protein and mineral content did not show any significant relation with aging of jackfruit. A similar types of observation was reported for Begonia Nelumbiifolia (Villa-Ruano et al. 2017).

Textural properties

Hardness for both the hard and soft varieties increased from 9.8 ± 1.2 to 14.9 ± 1.1 and 5.1 ± 1.3 to 8.4 ± 0.8 N, respectively. Hardness can be defined as resistance of a material to deformation, indentation, or penetration by means such as abrasion, drilling, impact, scratching, or wear. Changes in firmness and hardness during ripening of jackfruit were found closely associated with alcohol insoluble solid (AIS). These solids are considered the primary structural materials in tender jackfruit and composed mainly of starches, pectic acids, hemicelluloses, and celluloses (Sayyad and Ghomi 2017). Some other factors which influence the texture of fruit and vegetables are turgidity of cells, occurrence of supporting tissues, cohesiveness of cells and assimilation such as conversion of starch and sugar, etc.

Table 4 Nutritional properties of two varieties of tender jackfruit at different stages of maturity (Per 100 g of sample)

Nutrients	Stage 1	Stage 2	Stage 3	Stage 4
Hard variety				
Protein (g)	2.1 ± 0.43^{a}	2.4 ± 0.64^{b}	2.4 ± 0.33^{b}	2.6 ± 0.78^{c}
Fat (g)	0.14 ± 0.03^{a}	0.09 ± 0.07^{a}	0.3 ± 0.21^{b}	0.61 ± 0.12^{c}
Carbohydrate (g)	12.4 ± 0.90^{a}	12.5 ± 0.90^{a}	14.2 ± 0.80^{b}	16.5 ± 0.30^{c}
Fibre (g)	4.4 ± 0.20^{ac}	3.1 ± 0.50^{b}	4.1 ± 0.10^{cd}	3.9 ± 0.50^{d}
Vitamin A (IU)	39.4 ± 3.60^{a}	31.2 ± 4.30^{b}	28.6 ± 2.70^{bc}	27.0 ± 3.10^{c}
Vitamin C (mg)	18.65 ± 0.24^{a}	16.98 ± 0.36^{b}	13.62 ± 0.48^{c}	12.06 ± 0.68^{d}
Total minerals (g)	0.80^{a}	0.90^{b}	0.90^{b}	0.90^{b}
Calcium (mg)	54.6 ± 2.60^{a}	63.4 ± 3.00^{b}	68.6 ± 2.20^{c}	75.8 ± 1.40^{d}
Sodium (mg)	1.46 ± 0.43^{a}	8.43 ± 0.32^{b}	22.67 ± 0.81^{c}	26.1 ± 0.87^{d}
Phosphorus (mg)	26.1 ± 2.50^{a}	35.2 ± 1.60^{b}	48.6 ± 1.50^{c}	50.2 ± 2.20^{c}
Potassium (mg)	254.4 ± 2.50^{a}	226.6 ± 4.10^{b}	294 ± 3.10^{c}	303.0 ± 1.40^{c}
Energy (kj)	159.1 ± 11.40^{a}	183.4 ± 19.50^{b}	198.5 ± 5.30^{c}	212.4 ± 11.90^{d}
Soft variety				
Protein (g)	1.1 ± 0.56^{a}	1.3 ± 0.44^{a}	1.7 ± 0.21^{b}	1.9 ± 0.88^{b}
Fat (g)	0.92 ± 0.22^{a}	1.60 ± 0.42^{b}	0.36 ± 0.14^{c}	0.44 ± 0.11^{d}
Carbohydrate (g)	19.6 ± 0.50^{a}	18.3 ± 0.70^{a}	22.5 ± 0.50^{b}	25.8 ± 0.30^{c}
Fibre (g)	2.1 ± 0.10^{a}	2.1 ± 0.10^{a}	2.3 ± 0.20^{b}	2.3 ± 0.10^{b}
Vitamin A (IU)	44.4 ± 2.60^{a}	32.8 ± 1.60^{b}	24.4 ± 1.70^{c}	22.5 ± 2.40^{c}
Vitamin C (mg)	12.12 ± 1.22^{a}	9.84 ± 1.32^{b}	7.78 ± 0.98^{c}	7.04 ± 1.10^{c}
Total minerals (g)	0.70^{a}	0.60^{b}	0.80^{c}	0.60^{b}
Calcium (mg)	43.8 ± 1.80^{a}	49.6 ± 1.40^{b}	52.1 ± 1.20^{c}	57.5 ± 1.60^{d}
Sodium (mg)	12.1 ± 0.38^{a}	19.4 ± 0.86^{b}	44.3 ± 0.45^{c}	43.6 ± 0.93^{c}
Phosphorus (mg)	2.3 ± 0.60^{a}	14.3 ± 1.80^{b}	19.7 ± 1.60^{c}	22.8 ± 1.60^{d}
Potassium (mg)	190.6 ± 4.50^{a}	220.8 ± 3.60^{b}	288.6 ± 7.50^{c}	412.6 ± 4.90^{d}
Energy (kj)	312.8 ± 22.40^{a}	244.8 ± 19.90^{b}	387.0 ± 31.80^{c}	444.8 ± 39.60^{d}

Values in the same rows followed by different superscript letters (a–d) are significantly different ($P < 0.05$)

With hardness the other two properties i.e. Fracturability and springiness also increases with stage of maturity from 0.38 ± 1.03 to 11.09 ± 1.16 N and 15.85 ± 0.52 to 19.49 ± 0.36 mm for hard variety and 0.48 ± 0.13 to 6.45 ± 0.56 N and 16.51 0.27 to 27.77 ± 0.15 for soft variety, respectively. Fracturability is defined as the force at the first significant break in first positive bite area. Springiness is defined as the height to which the food recovers during the time that elapses between end of the first bite and start of the second bite. The reason for this increased in fracturability and springiness may be because of increased rigidity of tender jackfruit which is directly proportional to the calcium content of the sample. Calcium was increasing in both varieties with maturity. Calcium apparently plays an essential role in the structure of cell walls (Joshi et al. 2016).

The properties like cohesiveness and gumminess were decreases as the maturity stages increases. The values for cohesiveness and gumminess for hard and soft varieties of jackfruit were decreased from 0.93 ± 0.04 to 0.21 ± 0.03; 1.49 ± 0.33 to 0.76 ± 0.29 and 5.15 ± 0.32 to 0.51 ± 0.61 N; 19.53 ± 0.66 to 5.78 ± 0.78 N, respectively. The other two properties i.e. adhesiveness and chewiness are independent of stages of maturity for both the varieties (Table 5).

Colour

The colour change in jackfruit pulp was also explained by Selvaraj and Pal (1989). They reported a two fold increase in jackfruit pulp colour (carotenoid pigments) from harvest to the ripen stage. In comparison, the top portions have higher hue values at all ripening stages as compared to the bottom portions of the fruit. This indicated that the ripening process occurred initially at the top portion.

Colour measurement (Table 6) revealed that tender jackfruit of both the varieties were bright green. The a* values which signifies green colour of samples were 2.33 ± 0.35 for hard variety and 4.97 ± 0.99 for soft variety during stage 1. By analogy with senescence in most green tissues such as leaves, fruit, etc., colour changes is typically involves due to chlorophyll loss and an increase in production of yellow, orange, red or purple pigments

Table 5 Textural properties of two varieties of tender jackfruit at different stages of maturity

Properties	Stage 1	Stage 2	Stage 3	Stage 4
Hard variety				
Hardness (N)	9.8 ± 1.20[a]	10.2 ± 1.60[a]	13.7 ± 0.90[b]	14.9 ± 1.10[b]
Adhesiveness (j)	0.07 ± 0.01[a]	0.06 ± 0.01[ab]	0.04 ± 0.01[c]	0.06 ± 0.01[ab]
Fracturability (N)	0.38 ± 1.03[a]	4.66 ± 1.11[b]	8.84 ± 0.72[c]	11.09 ± 1.16[d]
Cohesiveness	0.93 ± 0.04[a]	0.62 ± 0.02[b]	0.49 ± 0.02[c]	0.21 ± 0.03[d]
Springiness (mm)	15.85 ± 0.52[a]	15.94 ± 0.44[a]	18.82 ± 0.41[b]	19.49 ± 0.36[c]
Chewiness (j)	0.14 ± 0.02[a]	0.11 ± 0.02[b]	0.17 ± 0.01[c]	0.13 ± 0.02[ab]
Gumminess (N)	5.15 ± 0.32[a]	4.11 ± 0.28[b]	1.15 ± 0.61[c]	0.51 ± 0.61[d]
Soft variety				
Hardness (N)	5.1 ± 1.30[a]	6.7 ± 0.70[b]	7.3 ± 0.80[c]	8.4 ± 0.80[d]
Adhesiveness (j)	0.02 ± 0.01[a]	0.02 ± 0.01[a]	0.04 ± 0.01[b]	0.05 ± 0.01[c]
Fracturability (N)	0.48 ± 0.13[a]	3.69 ± 0.41[b]	5.17 ± 0.44[c]	6.45 ± 0.56[d]
Cohesiveness	1.49 ± 0.33[a]	0.84 ± 0.10[b]	0.73 ± 0.09[c]	0.76 ± 0.29[c]
Springiness (mm)	16.51 ± 0.27[a]	20.16 ± 0.53[b]	24.88 ± 0.42[c]	27.77 ± 0.15[d]
Chewiness (j)	0.17 ± 0.02[a]	0.15 ± 0.02[b]	0.12 ± 0.02[c]	0.17 ± 0.01[a]
Gumminess (N)	19.53 ± 0.66[a]	15.98 ± 0.82[b]	9.13 ± 0.79[c]	5.78 ± 0.78[d]

Values in the same rows followed by different superscript letters (a–d) are significantly different ($P < 0.05$)

Table 6 Colour properties of two varieties of tender jackfruit at different stages of maturity

Properties	Stage 1	Stage 2	Stage 3	Stage 4
Hard variety				
L*	24.49 ± 2.43[a]	32.38 ± 3.35[b]	34.49 ± 1.41[c]	38.65 ± 2.99[d]
a*	2.33 ± 0.35[a]	1.12 ± 0.41[b]	0.33 ± 0.31[c]	0.11 ± 0.31[d]
b*	19.88 ± 0.74[a]	16.39 ± 3.76[b]	14.83 ± 0.34[c]	10.34 ± 2.13[d]
Soft variety				
L*	35.55 ± 2.35[a]	41.49 ± 4.33[b]	44.49 ± 2.33[c]	52.31 ± 1.88[d]
a*	4.97 ± 0.99[a]	4.69 ± 0.71[a]	3.33 ± 1.33[b]	1.12 ± 0.41[a]
b*	23.12 ± 2.13[a]	20.14 ± 4.10[a]	17.23 ± 1.94[c]	16.39 ± 2.86[c]

Values in the same rows followed by different superscript letters (a–d) are significantly different ($P < 0.05$)

(Rengsutthi and Charoenrein 2011). The soft variety of jackfruit was having more eye catching colour at stage 1 and 2 of maturity (a* value is above 4 i.e. for stage 1 it was 4.97 ± 0.99 and during stage 2 it was 4.69 ± 0.71). As the maturity stages increases, the colour of both the varieties of jackfruit becomes dull and tends to pale yellowish since b* values was decreases (Srimagal et al. 2017). A significant changes ($P < 0.05$) in colour value was found in both the varieties of jackfruit. It is preferable to sell the jackfruit during stage 1 and 2 because of the appearance (more eye catching) at these stages.

Conclusion

As the maturity stage of tender jackfruits shifted from 1 to 4, the physical properties like weight, length, and diameter of soft and hard varieties were changed. The soft variety of jackfruit found to be smaller in weight, length, and diameter than that of hard variety. Jackfruit from both the varieties tends towards oblong shape and moisture content decreases as the maturity increases from stage 1 to 4. While other parameters like pH, total solids and ash content are independent with respect to maturity stages. TSS and TDS increased by 240, 90.98, 162.96 and 145.63% for both hard and soft variety, respectively, at stage 1 to 4. The soft variety of jackfruit at any stage has shown higher nutritional properties than that of hard variety. The mechanical and textural properties of the tender jackfruits of both varieties are depends on the stage of maturity. All these basic properties will be helpful to various researchers, scientists, food processing industries, etc. for the post-harvest processing of the tender jackfruit.

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