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Processing and Quality Evaluation of Tender Jackfruit (*Artocarpus heterophyllus* L.) Flour

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Abstract

Jackfruit (*Artocarpus heterophyllus* L.) is a widely cultivated crop in Southeast Asia, yet it remains underutilized despite of its nutritional potential. Particularly in its tender stage, jackfruit is a good source of dietary fiber, antioxidant and phytochemical compounds and that contribute to various health benefits. Present study focused on evaluating the physico-chemical, functional, nutritional and shelf life properties of tender jackfruit flour from two tender jackfruit varieties namely, HV2 and TCV located at UAS, GKVK, Bengaluru. The HV2 and TCV varieties had length (25.27 cm and 26.09 cm), width (12.52 cm and 16.18 cm) and weight (1497.73 g and 1661.73 g), respectively. Both varieties were greenish-yellow in color and ellipsoid shape. The tender jackfruit was subjected to ten different pretreatments. Based on the browning index the optimal pretreatment consisted of 0.5 per cent potassium metabisulphite (T9) with drying temperature of 60°C. In terms of physico-chemical, nutritional properties of the tender jackfruit flour of HV2 showed a significantly lower pH (4.98) and titratable acidity (0.18 g/100g), higher bulk density (0.73 g/ml). HV2 exhibited lower moisture (5.76% vs. 6.16% in TCV), higher protein (5.86 g vs. 5.15 g in TCV) and less fiber (11.43 g vs. 13.21 g in TCV). The carbohydrate content of HV2 and TCV was 84.39 g and 84.87 g, respectively with energy contents of 369 kcal and 371 kcal.Storage over 180 days indicated that both varieties of jackfruit flour maintained acceptable moisture (7.84 to 8.62 %) and microbial levels (3.30 to 4.70 CFU×10^2/g), demonstrating their suitability for six months storage period. Overall, tender jackfruit flour from both HV2 and TCV varieties offers promising nutritional and functional properties, making it a valuable ingredient for food applications.

Keywords : Tender jackfruit flour, Nutritional composition, Functional properties, Shelf life

In recent years, there has been a research focus on exploring lesser-known and underutilized crops, many of which hold potential value as human foods. *Artocarpus heterophyllus* L. commonly known as jackfruit is one such underutilized fruit belonging to the Moraceae family (Krishnan *et al.,* 2015). It is an evergreen tropical fruit tree renowned for its numerous scientifically documented medicinal uses. Jackfruit is also known as the largest tree-borne fruit in the world (FAO, 2012). India is considered as the homeland of the jackfruit. For centuries, jackfruits have played a vital role in Indian agriculture. Primarily cultivated as a shade crop, they are widespread across the country (Ghosh and Venkatachalapathy, 2014). According to the National Horticultural Board (NHB) database in 2016-2017, India produced approximately 1,852 thousand tones of jackfruit from an area of 156 thousand hectares. In Japan and the southern parts of Asia, it is often referred to as the 'poor man's fruit' (Rana *et al.,* 2018). Jackfruit evolves through four stages of maturity: tender, slightly grown, unripe and ripe (Swami, 2012). Tender jackfruit, finds popularity as a vegetable, especially in the eastern and southern parts of India. The meat-like texture of tender jackfruit has made it popular as vegetarian's meat (Pawar and Giri, 2024). The nutritional value of tender jackfruit per every 100g edible portion includes 26 k cal of energy, 3.48 g of carbohydrate, 7.69 g of dietary fiber, 7.15 g of insoluble dietary fiber, 0.54 g of soluble dietary fiber 1.98 g of protein, 0.35 g of fat, 17.6 IU of Vitamin A, 17.51 mg of Vitamin C, 327 mg of potassium and 45.7 mg of calcium (Longvah *et al.,* 2017). Jackfruit plays versatile role in human cuisine, serving as a vegetable, fruit and even a substitute for staple foods. Furthermore, jackfruit contains valuable antioxidant compounds, phytochemicals, particularly phenolic and flavonoid compounds, sterols and prenylflavones, which can help to prevent and delay the onset of non-communicable diseases (NCDs) (Baliga *et al.,* 2011). Jackfruit showcases favorable nutritional attributes, notably its low to medium glycemic index (GI) of 50 to 60, which can be credited to the synergistic impact of dietary fiber and slowly digestible glucose. Hence, the fruit is known to have many beneficial effects in preventing and managing certain diseases like heart diseases, chronic inflammations, diabetes and many more (Bashetti, 2022). The bulbs of Jackfruit contain simple sugars (fructose and sucrose) that doesn't spike blood sugar levels, it is proven to be good source to manage diabetes as it contains good amount of fiber and protein which are digested and absorbed by the body slowly (Tejpal and Amrita, 2016). Despite its abundant nutritional and medicinal benefits, 50-70 per cent of jackfruit often goes as waste (Mittal *et al.,* 2018). Jackfruit processing has not received as much attention as other fruits due to several challenges, including difficulties in harvesting, separating the edible bulbs from the rind and managing the variations in yield and quality. Additionally, the fruit's unique composition and texture contribute to a short shelf life, making it challenging for long-term storage. As a result, a substantial amount of jackfruit, particularly those harvested during the peak season goes to waste annually. However, the processing of tender jackfruit is still under exploration for its better quality, extended shelf life of minimally processed fresh-cut jackfruit and flour production (Pawar and Giri, 2024). In view of its important properties, flour could be produced by drying tender jackfruit and used to produce value added products, with months-long shelf life. Hence, the current investigation was conducted to study the processing and evaluation of the physico-chemical, functional, nutritional and shelf life characteristics of jackfruit flour.

Material and Methods

Sample Selection

Two varieties of tender jackfruit (6-8 weeks old), HV2 (Horticulture Vegetable-2) and TCV (Tissue Culture Variety) were selected for the experiment from the Department of Horticulture, College of Agriculture, GKVK, Bengaluru. The fruitlets were tagged and horticulturists were consulted to determine the right maturity stage. Food-grade preservatives and other ingredients were bought from Bengaluru super markets.

Physical Properties of Fresh Tender Jackfruit

The physical properties of a vegetable or fruit are critical factors influencing its marketability and consumer acceptance. The physical properties of the fresh tender jackfruit including length, breadth, weight, edible portion, non-edible portion, recovery, color and shape were recorded. The length of selected jackfruits was determined by placing the fruit lengthwise on paper, marking the ends and measuring with a scale (Chandra and Bharati, 2020). The breadth was measured using a measuring tape and the average was calculated and expressed in centimeters (Chandra and Bharati, 2020). The weight of the jackfruits was obtained by randomly selecting five fruits and weighing them with a digital balance. The average weight was expressed in kilograms (kg) (Rana *et al.,* 2018). The weight of the edible portion was calculated by subtracting the weight of the whole fruit from the weight of the tender jackfruit after removing the thorny green peel and recorded in grams (Chandra and Bharati, 2020). The recovery percentage was determined by dividing the weight of the tender jackfruit after removing the peel by the weight of the whole tender jackfruit and then multiplying the result by 100 (Dileep *et al.,* 2023). The colour of the tender jackfruit was compared to the Munsell colour chart for plant tissues and the corresponding colour notation was recorded. The fruit's shape was documented according to the descriptors outlined by the International Plant Genetic Resource Institute (IPGRI, 2000).

Chemical Properties Analysis of Fresh Tender Jackfruit

The chemical properties of tender jackfruit, including moisture content, pH and total soluble solids (TSS), were assessed. To determine moisture content, 10g of the sample was placed in a moisture cup and dried in an oven at 105°C. After drying, the cup was cooled in a desiccator and weighed until two consistent weights were obtained. The moisture content was then calculated as a percentage (AOAC, 2005). For pH measurement, 10g of fresh jackfruit extract was mixed with 100 ml of distilled water in a 250 ml beaker. After stirring for 5 minutes and allowing the mixture to sit for 15 minutes, the supernatant was transferred to a 100 ml beaker and the pH was measured using a digital pH meter (Tawo *et al.,* 2009). To measure TSS, 0.3 ml of the supernatant was placed on the prism surface of an Erma hand refractometer and the value was recorded in degrees Brix (°B) (AOAC, 1980).

Processing of Tender Jackfruit

Tender jackfruit with uniform size, free from spoilage were sorted and washed with running tap water to remove adhering dirt and soil. Further they were slit into uniform slices of 1.5-2 cm thickness manually and used for further studies (Fig. 1).

Pre Treatments and Dehydration of Jackfruit Slices

Sliced tender jackfruit were subjected to different pretreatments and these pretreated samples were tray dried at three different temperatures *i.e.,* at 50°C, 55°C and 60°C until constant moisture content was attained in the dehydrated samples.

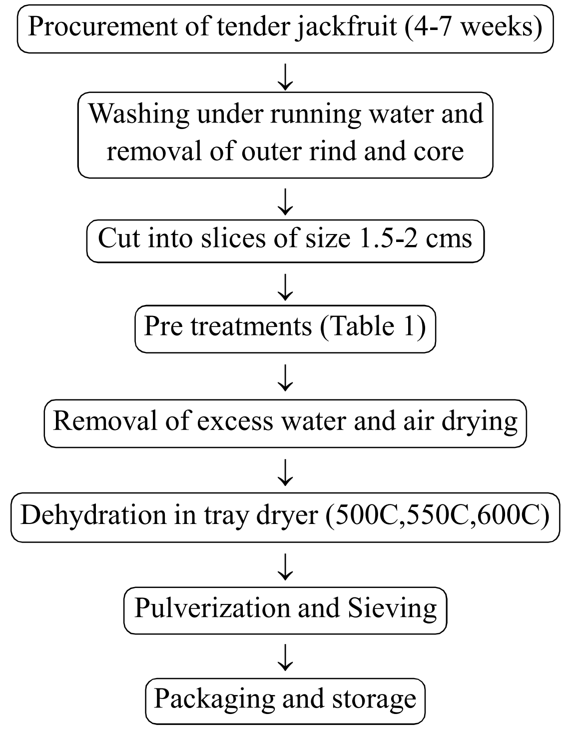

Fig. 1 : Flow chart for the production of tender jackfruit flour

Browning Index of Tender Jackfruit Flour

The browning index of tender jackfruit flour was determined using the method described by Palou *et al*. (1999). Color measurements ($L^*a^*b^*$ values) were taken with a Hunter Lab Colorimeter. The browning index was then calculated using the following formula:

$$\text{Browning Index (BI)} = [100 (x - 0.31)] / 0.17$$

where $x = (a^* + 1.75L^*) / (5.645L^* + a^* - 0.3012b^*)$

Physico-Chemical and Functional Characteristics of Tender Jackfruit Flour

The bulk density of the tender jackfruit flour was determined by weighing a calibrated centrifuge tube, then filling it with flour up to 10 ml mark by tapping until the volume stopped changing. The content was weighed and the bulk density was calculated from the weight difference with the result expressed in g/ml (Narayana and Rao, 1982). To measure pH, 10g of dehydrated tender jackfruit flour was added to 250 ml beaker with 100 ml of distilled water. The mixture

TABLE 1

The pretreatments were as follows

T_1	Untreated (control)
T_2	Slices were subjected for water blanching at 80 ^{0}C for1 minute
T_3	Slices were subjected for water blanching at 80 ^{0}C for 2 minutes
T_4	Slices were subjected for water blanching at 80 ^{0}C for 3 minutes
T_5	Blanching at 80 ^{0}C with 0.1 per cent citric acid for 1 minute
T_6	Blanching at 80 ^{0}C with 0.25 per cent citric acid for 1 minute
T_7	Blanching at 80 ^{0}C with 0.5 per cent citric acid for 1 minute
T_8	Blanching at 80 ^{0}C with 0.1 per cent potassiumm etabisulphate for 1 minute
T_9	Blanching at 80 ^{0}C with 0.25 per cent potassiumm etabisulphate for 1 minute
T_{10}	Blanching at 80 ^{0}C with 0.5 per cent potassiumm etabisulphate for 1 minute

was stirred for 5 minutes using a glass rod and allowed to settle for 15 minutes. The supernatant was then transferred to 100 ml beaker and the pH was measured using a digital pH meter (Tawo *et al.,* 2009). For titratable acidity, the sample was titrated with 0.1 N sodium hydroxide solution, using phenolphthalein as an indicator. The results were expressed as percentage of citric acid (Ranganna, 1986).

Functional Characteristics of Tender Jackfruit Flour

The functional characteristics of tender jackfruit flour, including water and oil absorption capacities, swelling power and solubility were measured. For water and oil absorption capacities, one gram of the sample was mixed with 10 ml of distilled water or 15 ml of oil for 30 minutes. The mixture was heated in a water bath at 30°C for 30 minutes and then centrifuged at 3000-5000 rpm for 20-30 minutes. The volume of the supernatant was recorded to determine the absorption capacities, expressed in milliliters per gram of the sample (Rosario and Flores, 1981). Swelling power and solubility were measured by taking 100 mg of jackfruit flour and adding 5 ml of distilled water. The mixture was heated at 90°C for 30 minutes with occasional stirring. After cooling, the mixture was centrifuged at 5000 rpm for 10 minutes. The supernatant was carefully decanted, dried and weighed. The swelling power and solubility were calculated by comparing the weight of the sample before and after the process, considering the water and supernatant volumes (Schoch, 1964).

Nutrient Composition of Tender Jackfruit Flour

The nutritional properties of tender jackfruit flour were assessed in terms of moisture content, fat, protein, crude fiber, ash, carbohydrates and energy. Moisture content was determined by drying the sample at 105°C until constant weight was achieved (AOAC, 2005). Fat content was measured by extracting ether from moisture-free samples and protein content was estimated using the Micro-Kjeldahl method with the nitrogen content multiplied by a factor of 6.25 (AOAC, 2005). Crude fiber was quantified by removing moisture and fat from the sample by acid alkali method, while ash content was determined by heating the sample at 600°C in a muffle furnace (AOAC, 2005). Carbohydrates were calculated by subtracting the values of protein, fat, fiber, ash and moisture from 100 (AOAC, 2005). The energy was estimated by considering the amounts of protein, carbohydrate and fat, with 4 kcal per gram for protein and carbohydrate and 9 kcal per gram for fat (AOAC, 2005).

Shelf Life Study of Tender Jackfruit Flour

The moisture content of tender jackfruit flour, stored in high-density polyethylene and metallized polyethylene packaging at ambient temperature was evaluated using moisture analyzer over a period of 180 days. The microbial analysis of the tender jackfruit flour was carried out by standard plate count method using Eosin Methylene Blue Agar (EMBA) for coliforms, Nutrient Agar (NA) for bacteria and Yeast Potato Dextrose Agar (YEPDA) for yeast. Ten grams of each sample was mixed in 100 ml water blank to give 10^{-2} dilutions. The population of *Escherichia coli*, bacteria and yeast were estimated by transferring one ml of dilutions to the sterile petriplates containing 20 ml of medium. The plates were rotated twice in a clockwise and anti-clockwise direction for uniform distribution of inoculum. After solidification of the medium, plates were incubated in an inverted position at 28 ± 2°C for 24 hours and results were recorded.

Statistical Analysis

All analyses were conducted in triplicate and the data were processed using MS Excel and OPSTAT software. The Critical Difference and t-test were employed for data analysis. To assess the differences between varieties, Student's independent t-test was applied. The F-test was used to evaluate the impact of packaging material on moisture content, utilizing a Completely Randomized Design (CRD). Differences between means were determined using Duncan's Multiple Range Test.

Results and Discussion

Physical and Chemical Properties of Fresh tender Jackfruit

Understanding the physical characteristics of agricultural produce is essential for designing machinery used in harvesting, cleaning and storage. This information aids in efficient conversion into food, feed and fodder. For jackfruit, factors like appearance, color and weight are important for marketability and consumer appeal (Krishnakumar, 2019).

The physical characteristics of the jackfruit varieties, HV2 and TCV were evaluated and presented in Table 2. The length of HV2 variety was 25.27 cm and TCV was 26.09 cm with TCV being slightly longer than HV2. However, these results contrast with findings of Rana *et al*. (2018) and Chandra & Bharati (2020). The width of HV2 was 12.52 cm and TCV was 16.18 cm. The broader fruit profile of TCV could enhance its marketability and appeal to consumers. In terms of weight, HV2 weighed 1497.73 g, whereas TCV weighed 1661.73 g ($t = 8.58$, $^{*}p < 0.05$). This indicates that TCV is a more robust fruit, potentially offering higher yields for producers, which is comparable to the findings of Rana *et al*. (2018), who reported fruit weights ranging from 1.42 kg to 3.14 kg between stage 1 and stage 4. The significant differences between HV2 and TCV are primarily due to genetic variations and stage of harvest. The edible fruit weight of HV2 was 787.89 g, where as TCV was 879.92 g ($t= 7.95$, $^{*}p < 0.05$). This difference suggests that TCV not only has a higher overall weight but also a greater proportion of edible flesh, which is essential for consumer satisfaction and culinary applications. The non-edible fruit weight of HV2 was 703.38 g, while TCV was 768.23 g and this difference was statistically significant ($t = 4.51$, $^{*}p < 0.05$). The recovery percentage for HV2 was 53.28 per cent, while TCV was 52.81 per cent. This suggests that both varieties yield a similar proportion of usable fruit, despite the observed differences in weight dimensions.

Table 2

Physical characteristics of fresh tender jackfruit

Physical characteristics	HV2	TCV	t-value
Length (cm)	25.27 ± 0.50	26.09 ± 0.74	1.29 NS
Width (cm)	12.52 ± 0.75	16.18 ± 0.43	5.94 *
Weight (g)	1497.73 ± 24.47	1661.73 ± 11.50	8.58 *
Edible fruit weight (g)	787.89 ± 7.61	879.92 ± 14.50	7.95 *
Non edible fruit weight (g)	703.38 ± 9.35	768.23 ± 18.06	4.51 *
Recovery percentage	53.28 ± 0.37	52.81 ± 0.57	0.97 NS
Colour	Greenish yellow		
Fruit shape	Ellipsoid		

Values are means (Mean±SD) of triplicates, * Significant @5%, NS: Non significant

TABLE 3

Chemical characteristics of fresh tender jackfruit

Parameter	HV2	TCV	t-value
Moisture	79.31 ± 2.15	78.73 ±2.58	1.08 NS
pH	6.20 ± 0.28	5.71 ±0.21	1.92 NS
Total soluble solids (°Brix)	0.1 ±0.012	0.1 ±0.002	11.32 NS

Values are means (Mean±SD) of triplicates, * Significant @5%, NS: Non significant

Both varieties exhibited a greenish-yellow color and an ellipsoid shape which is consistent with findings of Dileep *et al.,* 2023 and Valeeta *et al.,* 2023. In contrast, Goswami & Chakrabati (2016) and Rana *et al.* (2018) reported that jackfruits are typically oblong to cylindrical in shape, highlighting the diversity within jackfruit types. This variation in shape is influenced by both genetic factors and cultivation practices across different varieties.

Chemical Parameters of Jackfruit

Chemical parameters, such as titratable acidity, pH, total soluble solids and total suspended solids, play a crucial role in the preparation, processing and storage of food, as well as in determining its sensory characteristics.

The chemical characteristics of HV2 and TCV jackfruit varieties were evaluated and are summarized in Table 3. The moisture content for the HV2 variety was 79.31 per cent and TCV was 78.73 per cent. This comparable moisture content suggests that both varieties exhibit similar water retention properties. The findings align with studies by Ibrahim *et al.* (2013) reported 76.62 per cent, while Mortuza *et al.* (2014) found values between 79.25 per cent and 81.12 per cent. Ranasinghe and Marapana (2019) observed moisture ranging from 70.94 per cent to 89.21 per cent, and Hasan (2002) noted 74.44 per cent to 81.68 per cent. These findings indicate that HV2 and TCV fall within the typical moisture range for jackfruit with variations influenced by environmental factors, different seasons, growing conditions and maturity stages. The pH of HV2 and TCV was 6.20 and 5.71, respectively aligns with Ranasinghe and Marapana (2019), who observed pH changes from 5.27 at the immature stage to 6.25 at maturity. Rana *et al.* (2018) reported pH levels of 6.78 to 6.56 in tender jackfruit, highlight variability in jackfruit pH, influenced by jackfruit type, genetic, environmental and maturity factors. The total soluble solids (TSS) of HV2 and TCV were 0.1° Brix, which is lower compared to the 2.70 to 7.10° Brix, reported by Rana *et al.* (2018) for tender jackfruit at various maturity stages. Ranasinghe and Marapana (2019) also noted that TSS increases with maturity from 3.4 to 19.6 per cent, reflecting higher sugar content. The low TSS in this study suggests that both varieties were harvested at an earlier stage of maturity, as higher TSS is typically associated with ripe fruit.

Browning Index of Tender Jackfruit Flour

Processes like washing, sorting, peeling and cutting can increase oxidative stress in pre-cut fruits, leading to microbial contamination, tissue softening, phyto-chemical loss and browning (Rana *et al*., 2018). To address these issues in fresh-cut tender jackfruit, ten pretreatments were applied to the slices before tray drying at 50°C for 8.5 hours, 55°C for 7.5 hours and 60°C for 6.5 hours until constant moisture content was achieved. The browning index (BI), was calculated and intensity of browning was measured as a key indicator of color change (Palou *et al.,* 1999).

Fig. 2 presents the impact of various pre-treatments on the browning index of tender jackfruit flour at different drying temperatures (50°C, 55°C and 60°C) for both HV2 and TCV varieties. For HV2 variety, at 50°C the highest browning was observed in T_4 (9.68), and the lowest in T_{10} (1.26). At 55°C, T_4 again

A

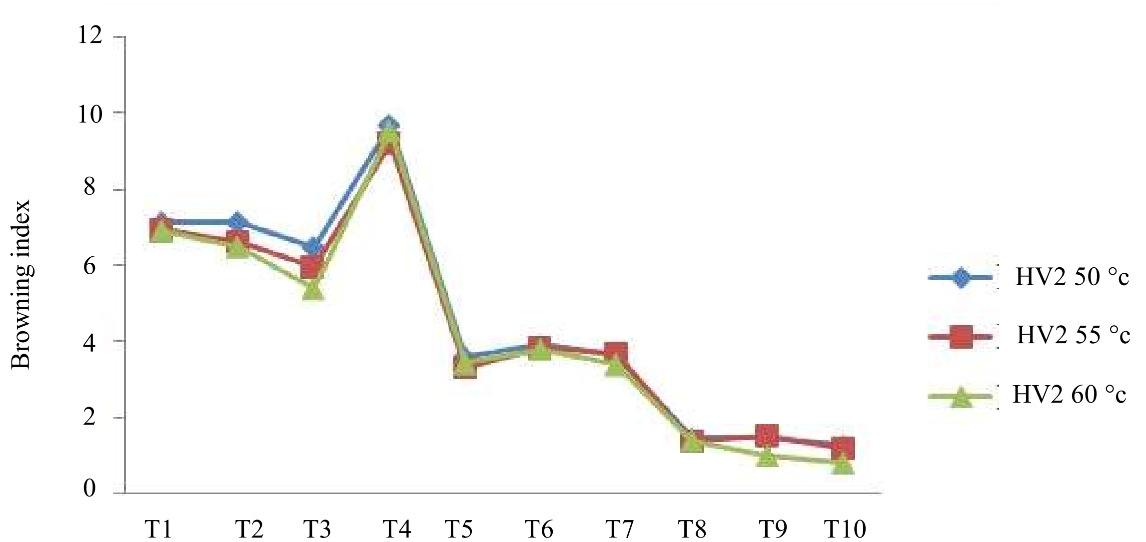

Fig. 2A : Effect of pre treatments on Browning index of tender jackfruit flour of HV2 variety

B

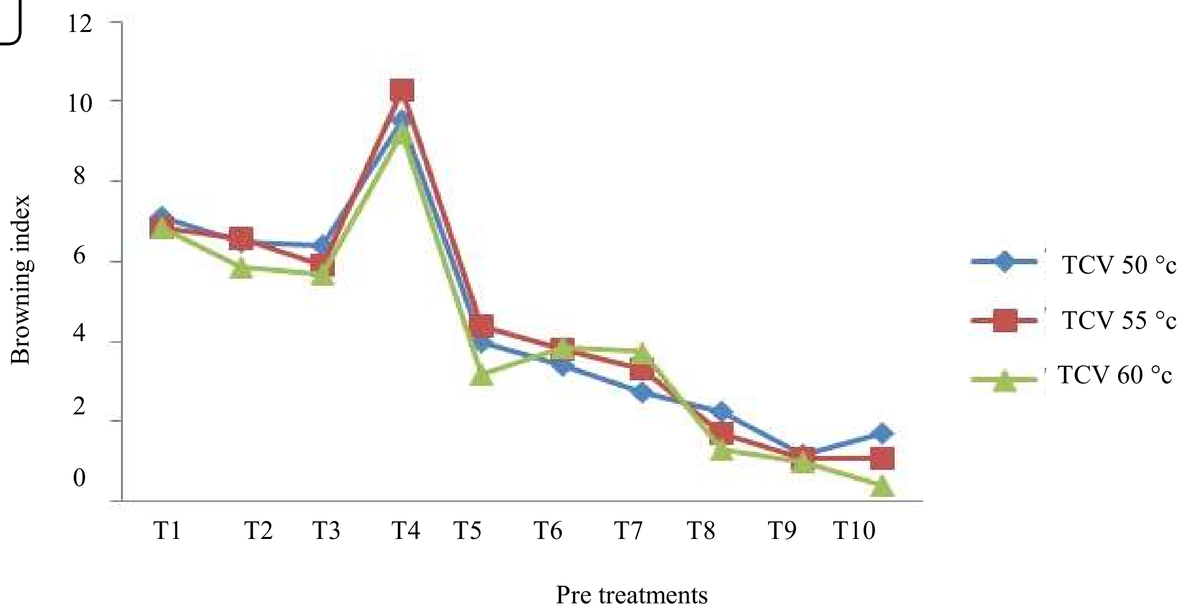

Fig. 2B : Effect of pre treatments on Browning index of tender jackfruit flour of TCV variety

T_1 : Untreated, T_2 : Water blanching (1 min), T_3 : Water blanching (2 min), T_4 : Water blanching (3 min), T_5 : Citric acid blanching (0.1 %) T_6 : Citric acid blanching (0.25%), T_7 : Citric acid blanching (0.5%), T_8 : KMS blanching (0.1%), T_9 : KMS blanching (0.25%), T_{10} : KMS blanching (0.5%)

exhibited highest browning (9.54), while T_{10} had the lowest (1.19). At 60°C, T_4 recorded the highest browning (9.22) and T_{10} had the lowest browning (0.81). Extending the blanching time resulted in increased browning, as prolonged water blanching may exacerbate browning due to prolonged exposure to heat and oxygen. Similarly for TCV variety, at 50°C, the highest browning was found in T_4 (9.52) and the lowest in T_{10} (1.72). At 55°C, T_4 exhibited the highest browning (10.30) with the lowest in T_{10} (1.07). At

60°C, the highest browning occurred in T_4 (9.21), while T_{10} recorded the lowest (0.40). This highlights the strong inhibitory effect of KMS on browning enzymes. Specifically, 0.5 per cent concentration of KMS was the most effective pre-treatment for controlling browning in tender jackfruit flour. Hence, it was determined that pretreating the tender jackfruit slices with potassium metabisulfite pretreatment and drying at 60°C is the most favorable approach for future research. Rana *et al.* (2018) reported browning index ranging from 0.035 to 0.057. However, the lower values observed in their study compared to the present findings may be due to variations in the concentrations and combinations of treatments used. The study by Babu and Sudheer (2020) found that the browning index of sterilized tender jackfruit samples was 43.81 and 22.42 for pasteurized samples. This discrepancy suggests that the higher temperatures used during sterilization may promote increased enzymatic activity or browning, which negatively impacts the color quality of the product.

Physico-Chemical and Functional Characteristics of Tender Jackfruit Flour

Physico-chemical and functional characteristics are important for food processing and product formulation, as they affect the final product's quality, including its nutrition, taste, texture and appearance. The water and oil absorption, solubility and swelling power help to determine how food components interact and how suitable they are for different uses. They also provide insights into how best to handle the product. These characteristics are influenced by the food composition and the conditions under which they are tested (Kinsella, 1976).

Table 4 depicts the chemical and functional characteristics of dehydrated tender jackfruit flour. The tender jackfruit flour of HV2 variety demonstrated a bulk density of 0.73 g/ml, significantly higher than TCV (0.64 g/ml). This difference is attributed to particle size and density, which also affect packing requirements and material handling. Foods with lower bulk density are ideal for creating nutrient-dense formulations. Kumar (2021) reported higher bulk densities in both carrot powder (1.042 g/cc) and guava powder (0.980 g/cc) compared to the present study. HV2 variety displayed a pH of 4.98, while the TCV variety had a pH of 5.43, indicating significant difference (t = 42.73*). In terms of titratable acidity, HV2 exhibited a value of 0.18g/100g, whereas TCV showed 0.26 g/100g (t = 5.08*). This significant difference suggests that TCV is more acidic, which may influence its flavor and preservation qualities. Water Absorption Capacity (WAC) is important in enhancing volume and consistency of product, it gives an indication of the amount of water available for gelatinization (Edema *et al.,* 2005). The water

TABLE 4

Physico-chemical and functional characteristics of dehydrated tender jackfruit flour

Properties	HV2	TCV	t-value
	Physico- chemical characteristics		
Bulkdensity (g/ml)	0.73 ± 0.002	0.64 ± 0.02	4.80 *
pH	4.98 ± 0.05	5.43 ± 0.01	42.73 *
Titratable acidity (g/100g)	0.18 ± 0.011	0.26 ± 0.8	5.08 *
	Functional characteristics		
Water absorption capacity (g/ml)	7.80 ± 0.40	7.12 ± 0.39	1.95 NS
Oil absorption capacity (g/ml)	2.81 ± 0.18	2.83 ± 0.19	0.18 NS
Swelling power (g/g)	6.76 ± 0.76	6.31 ± 0.25	0.96 NS
Per cent Solubility	19.81 ± 0.40	18.80 ± 1.51	1.09 NS

Values are means (Mean±SD) of triplicates, * Significant @5% , NS: Non Significant absorption capacity of flour varies based on several factors, including the molecular structure of the flour sample, protein concentration, water interactions, the presence of hydrophilic groups, configuration properties, the degree of grinding, the presence of husk, and the levels of damaged starch, protein and carbohydrates (Kaushal *et al.,* 2012). HV2 absorbed 6.8 ml/g of water, while TCV absorbed 6.12 ml/g. The oil absorption capacity in food depends on the intrinsic factors such as protein conformation, amino acid composition and surface polarity or hydrophobicity (Suresh and Samsher, 2013). However, the oil absorption capacity of flours enhances flavor and mouth feel in food preparations, making them particularly suitable for various culinary applications (Abe-Inge *et al.,* 2018). The oil absorption capacities, of HV2 was 1.8 ml/g and for TCV 1.83 ml/g. This indicates that oil absorption is comparable between the two samples. Moorthy and Ramanujam (1986) noted that the swelling power of granules reflects the strength of the associative forces within them and this property is significantly influenced by amylopectin. The elevated swelling power of the flours and starches may be attributed to the formation of complexes between proteins and amylase (Reddy *et al.,* 2022). HV2 demonstrated a swelling power of 6.76, while TCV showed a swelling power of 6.31. The reason for the higher swelling power could be attributed to the lower amylose content (Clement and Singh, 2008) and higher associative forces (Moorthy and Ramanujam, 1986). In terms of solubility, HV2 had a solubility of 19.81 per cent, while TCV recorded 18.8 per cent indicating no significant difference ($t=1.09^{NS}$). The higher amylopectin content enhances the mobility of starch chains at elevated temperatures, leading to better dispersion and improved solubility of starch molecules (Adebowale *et al.,* 2005). This phenomenon is affected by various factors, including temperature, water availability, starch species and the presence of other carbohydrates and proteins. Reddy *et al.* (2022) found that jackfruit seed flour (JSF) had water absorption capacity of 184.27 ml/ 100 g, oil absorption capacity of 87.65 ml/100 g, bulk density of 0.73 g/ml and moderate dispersibility at 32 per cent. Chowdhury *et al.* (2012) reported that the water absorption capacity of the blends of jackfruit seed flour ranged from 65.5 per cent to 203.4 per cent, while the oil absorption varied from 86 per cent to 90.2 per cent. The bulk density ranged from 0.80 g/ml to 0.73 g/ml. Kumar *et al.* (2021) found that carrot powder had a water absorption capacity of 379 per cent, oil absorption of 80 per cent and swelling power of 58.00 ml. Guava powder had a water absorption capacity of 97 per cent oil absorption of 72 per cent and swelling power of 63 ml.

Proximate Composition of Tender Jackfruit Flour

Proximate analysis involves determining the major components of food, including moisture, ash, crude fat, crude protein, carbohydrates and crude fiber (Ekwumemgbo *et al.,* 2014 and Aja *et al.,* 2016). Understanding the proximate composition, which encompasses both macro and micronutrients, is essential for assessing the nutritional benefits of food. Macronutrients carbohydrates, proteins and fats perform fundamental functions in the body, while micronutrients vitamins and minerals support and enhance the roles of macronutrients.

Table 5, reveals the nutrient composition of tender jackfruit flour from HV2 and TCV varieties. The moisture content of HV2 was 5.76 per cent, TCV had 6.16 per cent. The protein content of HV2 was 5.86 g, while TCV had 5.15 g. This contrasts with findings from Konsue *et al.,* 2023 who reported higher protein content ranging from 9.68–12 per cent (Stage-1 to Stage-3 maturity), highlighting variability across jackfruit developmental stages. Ojwang *et al.* (2018) identified higher crude protein levels in jackfruit pulp from Kenya and Uganda (11.53% to 12.50%), indicating that regional differences may impact protein availability. However, Amadi *et al.* (2018) found jackfruit bulbs containing 10.06 per cent protein, which is substantially higher compared to present findings. Which emphasizes the influence of variety, region and ripeness on the nutritional profile of jackfruit. HV2 variety contains 1.16 g of fat, whereas TCV containing 1.01 g aligns with Amadi *et al.* (2018), who reported a fat content of 1.49

TABLE 5
Proximate composition of dehydrated tender jackfruit flour

Nutrients	HV2	TCV	t-value
Moisture (%)	5.76 ± 0.04	6.16 ± 0.43	0.83 NS
Protein (g)	5.86 ± 0.40	5.15 ± 0.16	2.10 NS
Fat (g)	1.16 ± 0.06	1.01 ± 0.02	3.23 *
Totalash (g)	2.82 ± 0.16	2.88 ± 0.01	0.43 NS
Crudefiber (g)	11.43 ± 0.47	13.21 ± 0.88	0.81 NS
Total Carbohydrate (g)#	84.39 ± 0.77	84.87 ± 2.13	0.299 NS
Energy (Kcal)**	371	3690.10 NS	

Values are means of triplicate * Significant @5%, NS: Non Significant #By difference method,**By computation method

per cent in jackfruit bulbs, In contrast, Konsue *et al.,* 2023 reported fat content ranging from 3.85 to 4.75 per cent through developmental stages. Ojwang *et al.* (2018) found lower crude fat levels in jackfruit pulps from Kenya and Uganda, ranging from 0.10 per cent to 0.11 per cent, highlighting regional differences in fat composition. Similarly, Okudu (2017) reported a crude fat content of 0.76 per cent in jackfruit pulp harvested from Nigeria. The total ash content of HV2 and TCV was found to be 2.82 g and 2.88 g, respectively suggesting that both varieties have similar mineral content. Goswami *et al.* (2011), reported ash content ranging from 0.7 per cent to 1.0 per cent. Similarly, Amadi *et al.* (2018) and Okudu (2017) reported ash contents of 1.02 per cent and 1.1 per cent in jackfruit bulbs, respectively which falls within the lower spectrum compared to the values observed in present study. This difference may be influenced by factors such as variety, environmental conditions and processing methods. Regarding crude fiber, HV2 had 11.43 g, while TCV had 13.21 g both varieties contains a good amount of fiber beneficial for digestive health. Higher values were reported in the study by Konsue *et al.,* 2023 where fiber ranged from 19.61–20.10 per cent from immature stage-1 to immature stage-3. In terms of carbohydrates, HV2 had a slightly lower total carbohydrate content (84.39 g) than TCV (84.87 g), though this difference was not significant. The energy values of HV2 was 371 Kcal and TCV was 369 Kcal, reflecting negligible differences. Paul and Isaac (2017) found that the carbohydrate content (84.63 g) was comparable to the current findings. However, lower fiber content (10 g) and a lower protein content (4.99 g) was recorded compared to the present results. Mehta *et al.* (2023) reported that *Artocarpus altilis* and its hybrid flour contain 7.66 per cent moisture, 2.85 per cent ash, 350.75 kcal energy, 77.09 per cent carbohydrates, 2.85 per cent fat, 5.16 per cent protein, and 10.31 per cent fiber. Overall, HV2 and TCV varieties have higher protein, fiber and energy content, but lower moisture, ash and fat levels. Meenakshi *et al.* (2024) reported that breadfruit flour contains 11.4 per cent dietary fiber and 5.2 per cent protein. These findings are in line with present findings.

Moisture and Microbial Analysis for Shelf Life Study

The shelf life of a food product refers to the duration between its packaging and consumption, during which it retains desirable sensory qualities and remains microbiologically safe. Factors such as storage temperature, relative humidity and water activity significantly impact the shelf life of food (Ebabhamiegbebho *et al.,* 2011). Moisture content is a critical indicator of the shelf stability of food products, as an increase in moisture can promote microbial growth, leading to spoilage (Adejumo, 2013). For optimal storage of flours and powdered foods, the recommended moisture content range is between 12 and 14 per cent (Sanni *et al.*, 2005 and Standard Organization of Nigeria, 2004).

The shelf life of any food product is significantly impacted by its moisture content. This moisture level can vary based on the storage conditions and packaging materials used, ultimately affecting the product's quality and acceptability. When assessing the long-term utilization potential of tender jackfruit flour, the storage quality is a crucial factor. The mean moisture values during the 180-day storage period at ambient temperature for both HV2 and TCV varieties of tender jackfruit flour are presented in Table 6.

For the HV2 variety, the moisture content in HDPE packaging ranged from 6.54 per cent to 8.62 per cent, whereas in MPP packaging, it ranged from 6.83 per cent to 7.84 per cent. For the TCV variety, the moisture content in HDPE packaging ranged from 5.87 per cent to 7.95 per cent, whereas in MPP packaging, it ranged from 6.73 per cent to 8.01 per cent. Over this period, a significant increase in moisture content was observed for samples in both MPE and HDPE packaging materials ($p < 0.05$). However, the interaction between variety and packaging material, as well as the storage duration was found to be non-significant. This indicates that both HV2 and TCV varieties exhibited similar shelf life stability over the 180 days, although MPE packaging performed better by showing a smaller increase in moisture due to its superior moisture barrier properties which are highly effective in limiting moisture ingress, thereby preserving the quality of the flour and extending its shelf life. The gradual and consistent variation in the moisture content of the samples across all packaging materials may be attributed to the varying moisture permeability of these materials (Adebowale *et al.,* 2017). However, the moisture content of the samples remained within the

TABLE 6

Influence of packaging material on the moisture content (%) of tender jackfruit flour during storage

Storage period (C)	Moisture (%)			
	HV2 (A)		TCV (A)	
	P_1 (B)	P_2 (B)	P_1 (B)	P_2 (B)
0th day	6.54 ± 0.12 ^{c}	6.83 ± 0.5 ^{b}	5.87 ± 0.26 ^{c}	6.73 ± 0.02 ^{b}
30th day	6.77 ± 0.37 ^{bc}	7.13 ± 0.4 ^{ab}	6.00 ± 0.04 ^{c}	6.76 ± 0.39 ^{b}
60th day	7.01 ± 0.44 ^{bc}	7.23 ± 0.0 ^{ab}	6.24 ± 0.22 ^{bc}	6.80 ± 0.15 ^{b}
90th day	7.29 ± 0.40 ^{bc}	7.58 ± 0.0 ^{ab}	6.62 ± 0.15 ^{bc}	7.48 ± 0.01 ^{ab}
120th day	7.74 ± 0.25 ^{ab}	7.83 ± 0.6 ^{ab}	7.07 ± 0.07 ^{ab}	7.93 ± 0.68 ^{a}
150th day	8.41 ± 0.8 ^{a}	7.84 ± 0.5 ^{a}	7.74 ± 0.02 ^{a}	8.00 ± 0.05 ^{a}
180th day	8.62 ± 0.48 ^{a}	7.84 ± 0.2 ^{a}	7.95 ± 0.52 ^{a}	8.01 ± 0.47 ^{a}

Factors	F-value	SE (m)	C.D. @5%
A	*	0.057	0.162
B	*	0.057	0.162
A X B	*	0.081	0.229
C	*	0.107	0.303
A X C	NS	0.151	N/A
B X C	*	0.151	0.428
A X B X C	NS	0.214	N/A

A: Variety, B: Packaging material, C: Storage duration P_1-HDPE (High Density Poly Ethylene), P_2-MPE (Metallic Poly Propylene) permissible range for up to 180 days of storage, indicating that the flour stored under these conditions is unlikely to experience significant deterioration (FSSAI, 2003). In a study by Pua *et al.* (2008), ALP packaging showed superior performance compared to Biaxially Oriented Polypropylene, particularly at 28°C and relative humidity levels below 75 per cent, highlighting its effective barrier properties in reducing moisture absorption. Similarly, Hyndavi *et al.* (2022) found that aluminium foil pouches out performed both Low Density Polyethylene and High Density Polyethylene in maintaining lower moisture content with a recorded value of just 8.59 per cent.

The microbiological quality of food products is vital for achieving an adequate shelf-life. The microbiological status of food is largely determined by water activity and moisture content that enable micro-organisms to multiply and cause spoilage (Lorenzo *et al.,* 2018). In this present study, shelf life assessments by microbial load (including bacteria, yeast and coliforms) in tender jackfruit flour was assessed using the standard plate count method. The total plate counts for bacteria, yeast and coliforms in tender jackfruit flour from HV2 and TCV varieties, stored at room temperature in HDPE and MPP packaging were analyzed and are presented in Table 7. The microbial population was evaluated at intervals of 0, 30, 60, 90, 120 and 180 days of storage. Initially, no microbial growth was detected in either the HV2 or TCV varieties, suggesting that effective preservation techniques were implemented to maintain the quality of the tender jackfruit flour. The total bacterial count in the HV2 variety ranged from 0.00 to 4.30 cfu × 10^2/g (HDPE) and 0.00 to 3.30 cfu × 10^2/g (MPE) over the 180-day period. For TCV variety, the count ranged from 0.00 to 4.70 cfu × 10^2/g (HDPE) and 0.00 to 4.67 cfu × 10^2/g (MPE) which indicated gradual increase over the study period. Yeast counts and coliforms were not detected in any samples throughout the study. Both HV2 and TCV varieties stored at ambient temperature in both MPE and HDPE packaging materials remained within the standard permissible safe limits (Bacterial count: not more than 50,000 per g; Yeast/mold count: absent

TABLE 7

Effect of storage on microbial population of tender jackfruit flour

Duration (days)	Group of microorganisms (CFU ×10^2/g)											
	Total Bacterial Count				Yeast count				Coliform			
	HV2		TCV		HV2		TCV		HV2		TCV	
	MPE	HDPE	MPE	HDPE	MPE	HDPE	MPE	HDPE	MPE	HDPE	MPE	HDPE
0th day	0.00 (0.71) ᵉ	0.00 (0.71) ᵉ	0.00 (0.71) ᵉ	0.00 (0.71) ᵉ	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)
30th day	0.00 (0.71) ᵉ	0.00 (0.71) ᵉ	0.00 (0.71) ᵉ	0.00 (0.71) ᵉ	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)
60th day	0.67 (1.08) ᵈ	1.33 (1.35) ᵈ	0.00 (0.71) ᵉ	0.00 (0.71) ᵉ	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)
90th day	1.00 (1.22) ᶜ	2.33 (1.68) ᶜ	0.67 (1.08) ᵈ	3.30 (1.96) ᶜ	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)
120th day	1.70(1.50) ᵇ	3.33 (2.00) ᵇ	2.33 (1.68) ᶜ	3.70(2.00) ᵇ	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)
150th day	2.33 (1.68) ᵇ	3.70(2.04) ᵇ	4.33 (2.2) ᵇ	4.33 (2.20) ᵇ	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)
180th day	3.30 (1.96) ᵃ	4.30 (2.20) ᵃ	4.67 (2.27) ᵃ	4.70(2.27) ᵃ	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)

Numerical values are $\sqrt{x + 0.5}$ transformed values and expressed as mean of three replicates. Different letters represent a significant difference of the same columns as determined by DMRT ($p \leq 0.05$)

in 0.1 g or not more than 100 per g; Coliform count: absent in 10 g) as per the Food Safety and Standards Regulations (2010). Similar findings were reported by Morshed *et al.* (2016) in jackfruit flour stored at ambient temperatures (25-35°C) for 336 days. They observed no detectable microorganisms at the start of the storage period, but by the 126th day, the total colony count had increased to 4-6 cfu/ml. Similarly, Sowmiya and Swarnalatha, 2022 found that Total Bacterial Count (TBC) of jackfruit seed flour to be 1.09 × 10t cfu/g, with no presence of coliforms, Salmonella or Shigella in the flour.

Tender jackfruit, the unripe form of jackfruit, is a nutritious and versatile fruit. However, its processing is still being explored. Therefore, a study was conducted to process two varieties of tender jackfruit (HV2 and TCV) and evaluated for quality parameters. Both HV2 and TCV varieties of tender jackfruit exhibited notable differences in physical characters, which could have implications for processing and consumer preference. The application of potassium metabisulphite for pre-treatment minimized browning during drying, enhancing the flour appearance. The flour from two varieties showed similar nutritional profiles, including carbohydrate, fiber and energy content, which suggests that both types can serve as viable alternatives in food applications. Flour maintained stable moisture levels during storage, particularly when packaged in MPE and Microbial growth remained minimal throughout the storage period, staying within safe limits ensures the products safety and shelf life. Overall, both HV2 and TCV jackfruit flours are well-suited for a variety of food applications, offering excellent functional and nutritional benefits. As a sustainable and versatile ingredient, they hold great potential for inclusion in gluten-free, fiber-rich, and diabetic-friendly diets, making them ideal for the development of healthy snacks and other food products.

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