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Nutritional composition, physical characteristics, and functional properties of flours from different jackfruit (*Artocarpus heterophyllus*) components

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Abstract
Jackfruit (*Artocarpus heterophyllus*), a tropical fruit widely cultivated in many regions, offers considerable potential for food applications through flours derived from its pulp, seeds, and rind (rag). This study evaluates the nutritional composition, physical characteristics, and functional properties of these jackfruit flour fractions to assess their suitability for food formulations. Nutritional analysis showed that pulp flour had the highest carbohydrate content (80.59±0.02 g/100 g), seed flour was richest in protein (13.05±0.10 g/100 g), and rag flour had the highest crude fibre (5.38±0.33 g/100 g). Physical properties such as bulk density, flour yield, and moisture loss varied among the components, reflecting their distinct structural characteristics. Functional properties, including water and oil absorption capacities, also differed significantly and play a critical role in determining the flour's processing behaviour and application potential. High water absorption capacity and oil absorption capacity was found in rag flour (2.63±0.12 g/100 g) and (1.5±0.29 g/100 g) respectively, which might be suitable in products requiring moisture retention and rich flavour such as doughs and baked goods The seed flour showed the highest flour yield (39.91%) and protein content, making it valuable for protein-enriched formulations. The findings of this research contribute to a broader understanding of jackfruit flour's role as a sustainable and functional food ingredient, offering potential applications in food product development and nutritional enhancement.

Keywords: Jackfruit flour, nutritional value, bulk density, physical characteristics, functional property

1. Introduction

Jackfruit (*Artocarpus heterophyllus*), a tropical fruit belonging to the Moraceae family, is widely cultivated in many Asian, African, and South American countries. It is known for its high yield, versatility, and potential as a sustainable food source. Various parts of the jackfruit, including the pulp, seeds, rags and rind, can be processed into flour, offering an alternative ingredient for food formulations [1]. The transformation of these parts into flour not only extends the shelf life of the fruit but also enhances its usability in various food applications. However, each fraction of jackfruit flour differs in its nutritional composition, physical attributes, and functional properties, which significantly influence its potential use in food industries. The nutritional profile of jackfruit flour varies depending on the part of the fruit used. The pulp-derived flour is primarily rich in carbohydrates, particularly dietary fiber and sugars, making it a potential ingredient in energy-dense food products. Jackfruit seed flour, on the other hand, is notable for its high protein content, resistant starch, and essential minerals such as iron, calcium, and phosphorus [2]. Additionally, the rind, often considered a byproduct, contains high amounts of fiber, polyphenols, and antioxidants, making it a potential functional food ingredient [3]. Understanding these compositional variations is crucial for determining the suitability of different jackfruit flour fractions for specific dietary and industrial applications.

Physical characteristics, such as particle size distribution, bulk density, colour, and water absorption capacity, play a vital role in determining the processing behaviour and consumer acceptability of jackfruit flour. The particle size and bulk density influence the texture, mixing properties, and storage stability of the flour [4]. Colour attributes, primarily influenced by the presence of carotenoids and polyphenols, impact the visual appeal and marketability of food products developed from jackfruit flour [5].

Additionally, the water absorption and swelling properties of different jackfruit flour fractions affect their ability to retain moisture and influence textural properties in food formulations. Functional properties such as water-holding capacity, oil absorption, solubility, gelatinization temperature, and pasting characteristics are essential for determining the usability of jackfruit flour in various food systems. The water-holding capacity is a critical factor in bakery and gluten-free applications, as it affects dough hydration and consistency. Oil absorption capacity determines the flour's suitability for deep-fried products, while solubility and swelling power influence its role in soups, sauces, and emulsified products [6]. Furthermore, the pasting characteristics of jackfruit flour fractions dictate their behaviour during heat processing, affecting their application in processed foods such as porridges, sauces, and extruded snacks.

The growing demand for functional and gluten-free ingredients has led to increased interest in alternative flours derived from underutilized fruits such as jackfruit. By evaluating the nutritional composition, physical attributes, and functional properties of different jackfruit flour fractions, this research aims to provide valuable insights into their potential food applications. Moreover, understanding these properties can aid in developing value-added food products, improving food security, and promoting the sustainable utilization of jackfruit byproducts. This study will contribute to the scientific knowledge on jackfruit flour and its possible role in food innovation and product development. Thus, this research seeks to comprehensively analyze and compare the nutritional, physical, and functional properties of different jackfruit flour fractions to determine their optimal applications in the food industry.

2. Materials and Methods

2.1 Selection and procurement of raw materials

Based on the ease of accessibility, availability, and convenience, the mature and ripe jackfruits were collected from the Horticultural Experimental Farm of Assam Agricultural University, Jorhat-13. After harvesting, the fruits were transported to the laboratory for further processing and analysis. Analytical-grade chemicals and reagents were used in the study which were procured from Jaldhara and Co., Jorhat, Assam.

2.2 Preparation of jackfruit pulp, rag and seed flour

The jackfruits were thoroughly washed and surface moisture was removed by pat drying. Using a sterile stainless-steel knife, the fruits were carefully cut open, and the bulbs, seeds, rags, rind, and core were manually separated. Jackfruit seeds were manually cleaned, and the white aril (seed coat) was carefully removed by hand. To eliminate the thin brown spermoderm covering the cotyledons, the seeds were treated with a 3% sodium hydroxide (NaOH) solution for 3 to 5 minutes. The loosened spermoderm was then removed by gently rubbing the seeds between the hands, followed by thorough rinsing under running water to ensure complete removal of any residual alkali and seed covering. The extracted pulp, rag and seeds were then cut into small pieces approximately 2.0 mm in size, followed by steam blanching for 2 min. Drying was carried out in a tray dryer (Brand: Mevish, Model: GMP) at 60 °C until the samples reached a constant moisture content of 9-10%. The dried sample was ground into a fine powder using a household electric grinder and seived through an 80-mesh sieve to ensure uniform particle size and then stored in airtight containers at-20 °C for future analysis.

2.3 Nutritional composition analysis

The prepared samples were analyzed for determination of moisture, ash, crude protein (Kjeldahl method), crude fat (Soxhlet extraction), crude fiber and carbohydrate (calculated).

2.3.1 Moisture content

A known amount of each sample was added to an empty crucible and weighed. The crucible containing the sample was then placed in an oven at 104-105 °C for 4 hours. After drying, it was transferred to a desiccator to cool and then weighed. This process of heating, cooling, and weighing was repeated until a constant weight was achieved to ensure accuracy [7].

Calculation:

$$\text{Moisture (\%)} = \frac{\text{Initial weight (g)-Final weight (g)}}{\text{Weight of the sample (g)}} \times 100$$

2.3.2 Total ash content

Ash content was measured by the method described by [8]. 5 g portion of each sample was taken in a crucible and was first charred on a heating mantle under a low flame, then transferred to a muffle furnace (IKON Instrument, Model no: WSW-251) and heated at 550 °C until a consistent ash weight was obtained.

Calculation:

$$\text{Total ash (g/100 g)} = \frac{(W_3-W_1)}{(W_2-W_1)} \times 100$$

Where, W_1 =Weight of the crucible (g); W_2= Weight of the crucible + sample (g); W_3 = Weight of the crucible + ash (g)

2.3.3 Crude protein content

Crude protein was analyzed using the Kjeldahl method. 1 g of each ground sample, 1.00 g catalyst mixture (98 parts K_2SO_4, 2 parts CuSO4) and 10 ml of concentrated sulphuric acid were taken in a digestion tube and kept overnight for pre-digestion. The pre-digested samples were digested in a digestion unit (KEL PLUS, model KES 06L) at 420 °C until a colourless solution was obtained. The digested material was then subjected to distillation with 40% sodium hydroxide and 4% boric acid containing a mixed indicator in an automatic Kjeldahl distillation system (KEL PLUS, model DISTYLEM). The distillate was titrated using 0.1 N hydrochloric acid to determine nitrogen content, from which crude protein was calculated using a standard nitrogen-to-protein conversion factor of 6.25 and reported as a percentage [7].

Calculation:

$$\text{Protein (g/100 g of sample)} = \frac{\text{Titrate value x 0.14 x 0.1 x 6.25}}{\text{Weight of the sample (g)}} \times 100$$

2.3.4 Crude fat content
The Soxhlet extraction method was employed to estimate crude fat, using a Soxhlet unit (Socs Plus SOCS 6, Pelican Equipment) as described by [9]. 1 g of each sample was placed in a cellulose thimble and extracted with 80 ml of petroleum ether (boiling range: 40-60 °C). The extraction consisted of two stages: an initial phase at 60 °C for one hour, followed by a second phase at 120 °C for 30 minutes. The remaining residue was dried in a hot air oven (International Commercial Traders) at 105 °C for 30 minutes. Fat content was determined based on the difference between the initial and final weights of the extraction flask.

2.3.5 Crude fibre
2 gm of each sample were boiled with 200 ml of 1.25% sulfuric acid for 30 minutes, using a cold-water condenser to minimize evaporation. The residue was filtered, washed with hot water, and then boiled with 200 ml of 1.25% sodium hydroxide for another 30 minutes. After filtering, the residue was washed with dilute acid, hot water, and alcohol, then transferred to a pre-weighed crucible. It was dried at 130 ± 2 °C for 2 hours, weighed, ignited at 600 ± 15 °C for 30 minutes, and weighed again to determine crude fiber content [10].

Calculation:

$$\text{Crude fibre (g/100 g of sample)} = \frac{\text{Weight of the fibre (g)}}{\text{Weight of the sample (g)}} \times 100$$

2.3.6 Total carbohydrate content
Total carbohydrates were calculated by difference, subtracting the sum of moisture, crude protein, crude fat, crude fiber, and total ash (all per 100 g) from 100 for each sample, as described by [11].

2.4 Physical Properties of Jackfruit
Physical properties of jackfruit such as weight of the whole jackfruit (kg), percentage of edible parts of mature ripe jackfruit and flour yield (%) were weighed, counted and recorded.

$$\text{Percentage of edible part (\%)} = \frac{\text{Weight of total number of each edible part per fruit}}{\text{Weight of the whole fruit}} \times 100$$

2.5 Functional Properties of the Different Parts of Jackfruit Flour
2.5.1 Bulk density
To determine bulk density, 1 g of each sample were placed into a calibrated 25 ml measuring cylinder. The initial volume was noted as the loose volume. The cylinder was then gently tapped on a firm surface until the sample volume no longer changed, and this was recorded as the packed volume. Loose bulk density (LBD) and packed bulk density (PBD) were calculated in g/cm³ by dividing the sample weight by the respective volumes before and after tapping [12].

2.5.2 Water and oil absorption capacity
Water and oil absorption capacities (WAC/OAC) were assessed following the procedure suggested by [10]. 1 g of each flour sample was separately mixed with 40 ml of distilled water and sunflower oil respectively. The mixtures were left to stand at room temperature for 30 minutes, then centrifuged at 5000 rpm for another 30 minutes. The volume of unabsorbed liquid (supernatant) was measured directly from the centrifuge tube. The absorbed amount was calculated by multiplying the volume difference by the liquid's density (water: 1 g/ml; oil: 0.93 g/cm³). Results were expressed as grams of water or oil absorbed per gram of flour.

2.5.3 Statistical Analysis
The experiments were performed in triplicate analyses and the results were reported as the mean values along with their standard deviations. Data from all experiments were statistically analyzed using ANOVA (Analysis of Variance) at the 0.05 probability level to determine significant differences among different jackfruit parts.

3. Results and Discussion
3.1 Proximate composition of the different parts of jackfruit flour
The proximate composition analysis of the different parts of jackfruit flour was performed and is represented in Table 1.

Table 1: Proximate composition of the differ parts of jackfruit flour (in 100 g)

Sl. No.	Sample	Moisture (%)	Ash (g/100 g)	Crude Protein (g/100 g)	Crude fat (g/100 g)	Crude fibre (g/100 g)	Carbohydrates (g/100 g)
1.	JPF	6.87^{b}	1.70±0.14^{c}	4.64±0.11^{c}	5.50±0.99^{a}	0.63±0.18^{c}	80.59±0.02^{a}
2.	JSF	7.97^{a}	2.89±0.14^{a}	13.05±0.10^{a}	2.50±0.71^{c}	1.43±0.04^{b}	72.10±0.01^{c}
3.	JRF	5.64^{c}	2.08±0.12^{ab}	5.25±0.05^{b}	3.50±0.71^{b}	5.38±0.33^{a}	78.18±0.05^{b}

JPF: Jackfruit pulp flour, JSF: Jackfruit seed flour, JRF: Jackfruit rag flour. The values are expressed in Mean ± SD with different letters in the same column are significantly different at the 5% level.

Moisture influences shelf-life and microbial stability. JRF exhibited the lowest moisture content (5.64%), which may enhance its storage stability compared to JSF (7.97%) and JPF (6.87%). Lower moisture generally reduces the risk of microbial spoilage. The moisture content can vary depending on the drying process and the variety of jackfruit used [13]. Ash represents total mineral content. JSF had the highest ash content (2.89%), suggesting it is a better source of minerals, possibly due to the inherent density of seed tissues. JPF had the lowest (1.70%), reflecting the lower mineral content typically found in fruit pulp [14]. JSF stood out with the highest protein content (13.05 g/100 g), aligning with earlier studies highlighting seeds as protein-rich components [15, 4]. In contrast, JPF showed the least protein (4.64 g/100 g), characteristic of fruit pulps which are primarily carbohydrate-rich. JPF had the highest fat content (5.50 g/100 g), possibly due to the presence of lipid-rich pulp constituents. JSF, despite being protein-dense, had relatively low fat (2.50 g/100 g), making it a suitable ingredient for low-fat formulations. Rag flour (JRF) recorded the highest fibre content (5.38 g/100 g), consistent with the fibrous structure of fruit rags. This indicates potential for JRF as a functional ingredient in dietary fiber-enriched food products [16]. JPF had the highest carbohydrate content (80.59 g/100 g), reflecting the sugar-rich nature of ripe jackfruit pulp. JSF, while richer in protein, showed the lowest carbohydrate content (72.10 g/100 g), suggesting a more balanced macronutrient profile.

3.2 Physical properties of jackfruit

The physical properties of the different parts of jackfruit were analysed. The average weight of the whole jackfruit was (3.55±0.37) kg consistent with values reported in tropical varieties [16]. The percentage recovery of bulb was found to be 26.10%. seed was 8.88%, rag was 14.74%. Figure 1 represents the weight of jackfruit pulp, rag and seed at different stages of processing. It was found that there was a significant moisture loss during drying, with the rag showing the highest reduction due to its high initial water content. The seed retained more dry mass, indicating a denser composition, while the pulp also showed substantial weight loss. Milling efficiency from dried to flour was high for all components, particularly for pulp and rag, which converted over 90% of their dried weight into flour which

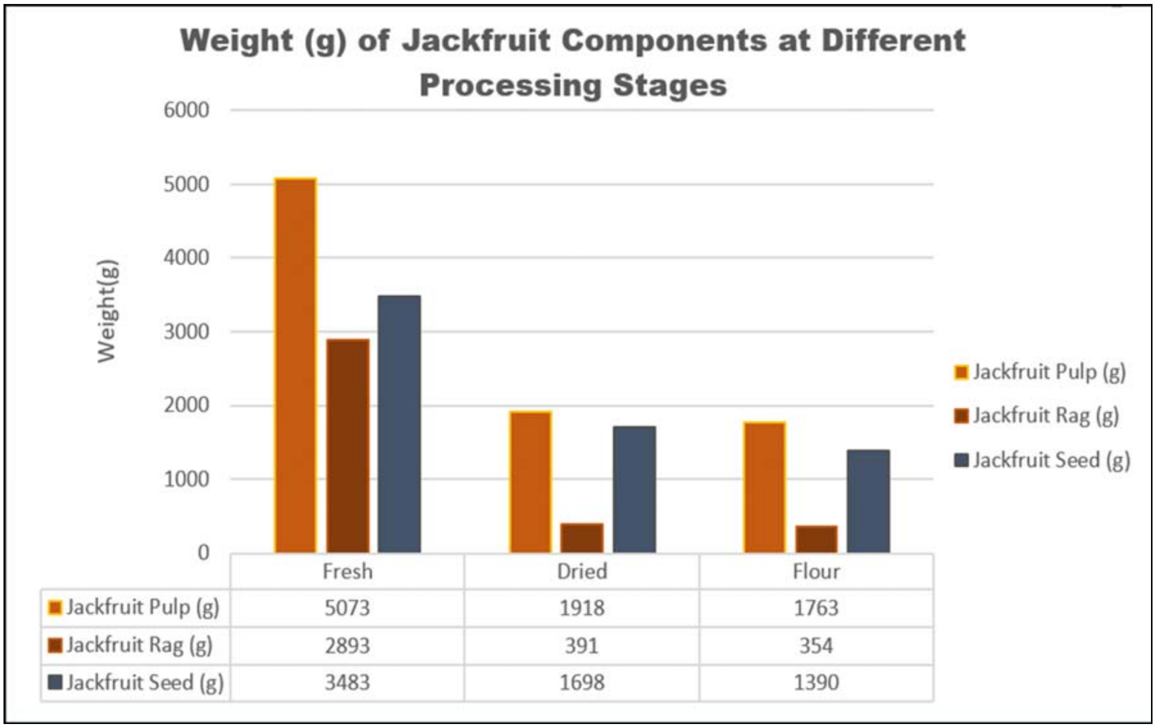

Fig 1: Weight (g) of different components of jackfruit at different processing stages

Moisture loss during drying reflects the initial water content of the raw material and the efficiency of the drying process. Table 2 represents the moisture loss and flour yield of different components of jackfruit. Jackfruit rag showed the highest moisture loss (86.48%), This is expected since rag tissue is spongy and less dense. Jackfruit pulp, with a 62.19% moisture loss, also had significant water content, likely due to its fibrous and fleshy nature. This moisture reduction is essential to prevent microbial spoilage and extend shelf life [17]. Jackfruit seed had the lowest moisture loss (51.25%), suggesting it has a denser structure and lower initial moisture. Jackfruit seed yielded the highest flour output (39.91%), making it the most efficient raw material for flour production. Seeds are rich in starch, which contributes to higher solid retention post drying and milling. This aligns with literature suggesting jackfruit seed flour is a good source of dietary fiber and resistant starch [16]. Jackfruit Pulp with a moderate flour yield (34.75%), makes it a viable flour source. This can be attributed to fiber and soluble sugars, though some material loss may occur during pulping and drying. Jackfruit Rag, despite being a byproduct, had the lowest flour yield (12.24%), indicating high moisture and low solid matter content. However, it could still be explored for value-added applications due to its dietary fiber and polyphenol content. These differences reflect the unique structural and compositional characteristics of each part, influencing their suitability for various food applications—seed for high-yield flour, pulp for sweet formulations, and rag for fiber-rich products.

Table 2: Moisture loss and flour yield of different components of jackfruit

Component	Moisture Loss (%)	Flour Yield (%)
Jackfruit Pulp	62.19%	34.75%
Jackfruit Rag	86.48%	12.24%
Jackfruit Seed	51.25%	39.91%

3.3 Functional Properties of the Different Parts of Jackfruit Flour

3.3.1 Bulk density

Bulk density is a key parameter that reflects the compactness or heaviness of a flour sample. It is primarily influenced by factors such as moisture content and particle size of the flour [4]. The bulk density of different components of the jackfruit flour is presented in table 3. JRF (0.95 g/cm³) had the highest bulk density. Fernando *et al*., (2024) [18] in their study also reported similar results suggesting a compact structure with minimal air space, favourable for transport and storage. JPF with 0.91 g/cm³ is also dense, likely due to sugar-rich dried pulp particles. JSF

(0.61 g/cm³) shows the lowest bulk density. This indicates that it is lighter, has more porous structure possibly due to starch granules and lower compaction after milling. Research on tray-dried jackfruit seed flour samples found bulk density values within this range, with variations attributed to different cultivars. variations in bulk density are influenced by factors such as processing techniques, particle size, and seed variety. Understanding these values is crucial for applications in food formulation, packaging, and storage [19, 20].

Table 3: Functional properties of the different components of jackfruit flour

Sl. No.	Sample	Bulk density (g/cm³)	Water absorption capacity (g/g)	Oil absorption capacity (g/g)
1.	JPF	0.91±0.04[ab]	1.63±0.23[c]	1.3±0.29[b]
2.	JSF	0.61±0.31[c]	2.43±0.31[ab]	1.2±0.25[bc]
3.	JRF	0.95±0.01[a]	2.63±0.12[a]	1.5±0.29[a]

JPF: Jackfruit pulp flour, JSF: Jackfruit seed flour, JRF: Jackfruit rag flour. The values are expressed in Mean ± SD, with different letters in the same column are significantly different at the 5% level.

3.3.2 Water and oil absorption capacity

WAC indicates a flour's ability to retain water, important for texture and moisture in food products. JRF (2.63 g/g) exhibits the highest WAC. This might be due to its high dietary fibre content and porous fibrous matrix, which traps water effectively. JSF (2.43 g/g) also shows good water absorption, associated with its protein and starch content that binds water. JPF (1.63 g/g) has the lowest WAC, which may be due to its higher sugar and lower fibre/protein content that limits water retention. WAC of flour is a crucial processing parameter influencing viscosity, consistency, and baking performance. WAC is largely affected by the protein and carbohydrate content of the flour. Jackfruit by-product flours may exhibit higher WAC than wheat flour due to the more hydrophilic nature of their proteins and the higher carbohydrate content, both of which enhance water binding. These components attract and retain more water, improving the flour's functionality in food applications [10].

OAC reflects how well flour can bind oil, influencing flavour retention and mouthfeel. JRF (1.5 g/ml) shows the highest oil absorption, attributed to the presence of hydrophobic fibre structures that trap oil. JPF (1.3 g/ml) follows, possibly due to its semi-porous matrix. JSF (1.2 g/ml) has slightly lower OAC, potentially due to starch dominance and fewer hydrophobic sites. The OAC flours contributes to a softer texture and enhanced flavour, making oil absorption beneficial for improving mouthfeel and flavour retention in food products. The flours investigated in this study demonstrate promising functional properties for use in food systems, particularly in bakery and meat products, where fat absorption supports improved palatability and shelf-life extension [20].

5. Conclusion

The present study highlights the potential of jackfruit (*Artocarpus heterophyllus*) by-products, including pulp, seed, and rag, as valuable sources of functional flours. Each component exhibited distinct nutritional, physical, and functional properties. Jackfruit seed flour showed the highest protein content and flour yield, making it suitable for high-protein and energy-dense food formulations. Pulp flour, rich in carbohydrates and moderately high in flour recovery, is ideal for sweet and dense food products. Rag flour, despite its lower flour yield, demonstrated high water and oil absorption capacities, suggesting its use in fibre-enriched and functional food applications. The variations in moisture loss during drying reflect the unique structural and compositional characteristics of each part. Overall, jackfruit flours offer promising applications in the development of nutritionally enhanced, gluten-free, and sustainable food products, contributing to the valorisation of agricultural by-products and the reduction of food waste.

4. Declaration of competing interest

The authors declare that they have no conflicts of interest.

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