In vitro Study of the Functional, Physicochemical, Antioxidant and Shelf-life Profile of Processed Jackfruit (*Artocarpus heterophyllus*) Seed Flour

R. Arivuchudar[1], S. Parameshwari[1]

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ABSTRACT

Background: *Artocarpus heterophyllus* (Jackfruit seed) has great potential as an edible food produ ct. If properly processed, the seeds can be added into various foods to enhance their nutritional value. Moderate consumption of jack fruit seeds in any form is useful for minimizing the risk of cardiovascular disease, lower toxic effect in the colon and helps in muscle building.

Methods: The study resolves to determine the functional traits, physical characteristics, nutritional properties, antioxidant activity and shelf life of raw, roasted and boiled *Artocarpus heterophyllus* seed flour.

Result: The present study revealed that roasting before flour production yielded the best results. Roasted jackfruit seed flour was rich in energy (357.93 kcal), protein (16.72%), carbohydrates (71.72%) and essential minerals such as calcium (44.8 mg/100 g), magnesium (104.6 mg/100 g), phosphorus (89.9 mg/100 g) and sodium (15.2 mg/100 g). Additionally, it exhibited the highest levels of antioxidants including total phenols (863.15 mg GAE/100 g), flavonoids (54.32 mg CE/100 g), DPPH assay (101.1%) and reducing power (2996.43 mg TE/100 g), making it suitable for formulating value-added food products.

Key words: Antioxidants, Functional properties, Jack fruit seed flour, Nutrients, Processing.

INTRODUCTION

Jackfruit (*Artocarpus heterophyllus*) is a climacteric fruit and the largest edible fruit from *Moraceae* family, it is commonly grown in Bangladesh, Burma, India, Indonesia, Malaysia and Thailand (Hossain *et al*., 2014). India is the leading cultivator of jackfruit, specifically Kerala, Karnataka and Maharashtra, often known as the “poor man’s fruit” (Maurya *et al*., 2016). Various parts of the jack tree, namely the fruit, leaves and bark have been extensively used in ancient medicine due to their therapeutic properties (Waghmare *et al*., 2019).

The ripe jack fruit comprises pulp as 29%, seeds as 12% and rind as 54% and it is understood that only 29% of the jackfruit is edible Waghmare *et al*. (2019). It is a common practice in India to consume boiled or roasted jackfruit seeds (Banerjee *et al*., 2015). The seeds are light brown, oval, oblong, or rounded shape, typically measuring 2-3 cm in length and 1-1.5 cm in diameter with every fruit comprises around 500 seeds. These seeds are great source of carbohydrates 38 g and protein 7 g, offering 184 kcal of energy and 1 g of fat/100 g. They are also rich in vitamins, minerals and provide 3.9 g of fiber. Additionally, the seeds are good source of resistant starch, which aid in controlling blood sugar levels. The magnesium present in jackfruit seed helps lower blood pressure in hypertensive patients and thus supports bone health (Maurya *et al*., 2016).

Since jackfruit is seasonal, the fruits were matured between March and September and perishable and its seeds have a shorter shelf life, they are often preserved for later use. Jacalin, a lectin found in the jackfruit seeds, aids to assess the immunity. Rich in vitamin A, vitamin C and pectin, jackfruit assists in ease pancreatic diseases and aids in purifies the blood (Butool *et al*., 2015).

The gloomy part is that, jackfruit seeds, which are rich in nutrients, are often thrown away as waste. Literature states that, due to increase in awareness in the field of food processing, concepts of wealth or health from waste, a number of value-added bakery products like bread (Hossain *et al*., 2014; Butool *et al*., 2015; Tulyathan *et al*., 2002), biscuits (Butool *et al*., 2015; Islam *et al*., 2015), cakes (Arpit *et al*., 2015; David *et al*., 2016; Khan *et al*., 2016), muffins (Faridah *et al*., 2012), chocolates Molu (Rammya *et al.,* 2021), whey beverage (Bhalekar *et al.,* 2022), value-added extruded products namely expanded snacks (Gat *et al*., 2015). pasta Albi (Abraham *et al*., 2014), noodles

[1]Department of Nutrition and Dietetics, Periyar University, Salem-636 011, Tamil Nadu, India.

Corresponding Author: R. Arivuchudar, Department of Nutrition and Dietetics, Periyar University, Salem-636 011, Tamil Nadu, India. Email: achudar24@gmail.com

ORCIDs: https://orcid.org/0000-0002-6420-3590, https://orcid.org/0000-0002-8053-9780

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(Nandkule *et al*., 2015; Divakar *et al*., 2017) and snack bars Meethal *et al*. (2017) had been formulated by incorporating jackfruit seed flour in different propositions. The replacement of starch flour with jackfruit seed flour in food preparations is considered commendable due to its nutritional benefits (Suzihaque *et al*., 2022). The addition of jackfruit seed in fish meal showed significant difference in weight gain, RBC and hematocrit values of nile tilapia (Cuevas-Rodríguez *et al.,* 2024).

MATERIALS AND METHODS

Jackfruit seed flour was prepared by following a standard procedure with slight modifications (Tulyathan *et al*., 2002). Fresh jackfruit was purchased from the market in Salem district, of Tamil Nadu, India. The seed and the pulp were properly fractioned.

Processing of jack fruit seed flour

Drying

To prepare raw jackfruit seed flour (RJSF), the seeds were washed, sun dried for 24 hours and the seed coat was peeled off. After complete removal of moisture, the seeds were milled into flour (Tulyathan *et al*., 2002).

Roasting

To prepare roasted jackfruit seed flour (RoJSF), the seeds were washed, roasted at 160°C for 1 hour. After removing the seed coat, the roasted seeds were milled into flour (Eke-Ejiofor *et al*., 2014).

Boiling

To prepare boiled jackfruit seed flour (BJSF), the seeds were thoroughly washed and boiled in clean water for 45 minutes. After boiling, the seed coat was removed and the boiled seeds were dried until the moisture was reduced to 4%. Finally, the dried seeds were milled into flour (Hajj *et al*., 2022). The differently processed *Artocarpus heterophyllus* seed flours are shown in (Fig 1).

RESULTS AND DISCUSSION

Functional characteristics of processed jackfruit seed flour

The functional characteristics of processed seed flour are outlined in (Table 1). The solubility values of the seed flour variations fluctuated from 9.1% to 13.6%, with RoJSF showing the lowest solubility and BJSF showing the maximum. These values are similar with (Eke-Ejiofor *et al*., 2014), which ranged from 9.72% to 14.47%. The swelling capacity ranged from 5.96% in BJSF to 7.9% in RJSF, which is more than that 4.77% testified by Ocloo *et al*. (2010). In this study, For BJSF, the highest bulk density value recorded was 0.29 g/ml for BJSF, while RoJSF had the lowest at 0.23 g/ml. These values are lower than the 0.26% to 0.33% range reported by (Eke-Ejiofor *et al*., 2014). The water absorption capacity (WAC) ranged from 423% to 506%, with RJSF having the lowest and RoJSF having the highest values, exceeding the 203.4% WAC for raw and blended jackfruit seed flour documented by (Chowdhury *et al*., 2012). The oil absorption capacity ranged from 149% for RoJSF to 309% for RJSF, surpassing the 164.76% fat absorption capacity of baked jackfruit seed flour reported by Borgis and Bharati (2020). The flour's dispersibility increased from 51% to 60.30%, with BJSF having the lowest value and RJSF the highest. These values are highest than the 30% dispersibility reported by Airani (2007).

Physicochemical properties of processed jackfruit seed flour

Pasting properties

Pasting properties are summarized in Table 2. The results revealed that peak viscosity ranged from 163.12 to 259.61, with RJSF at the lower end and RoJSF at the higher end. These values are lower than the 798 BU peak viscosity reported by Ocloo *et al*. (2010). Higher peak viscosity indicates a better thickening capacity for starch (Hajj *et al*., 2022).

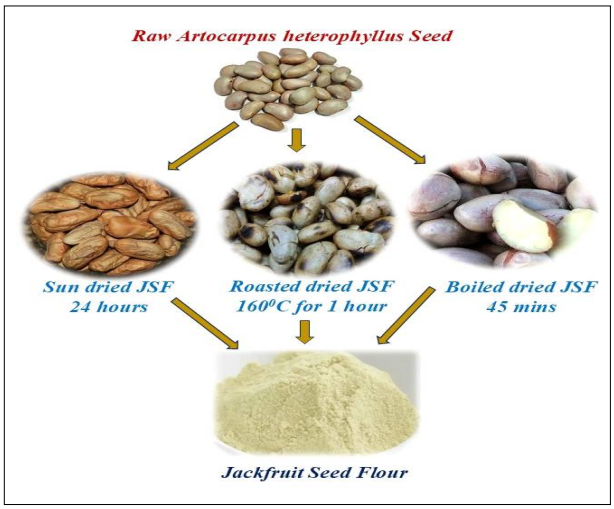


Fig 1: Processed jackfruit seed flour.

The trough viscosity of the processed samples ranged from 103.71 to 120.37. A lower trough viscosity value indicates higher paste stability Hajj *et al*. (2022). In this study, RoJSF had the lowest trough viscosity, followed by BJSF and RJSF.

Eke-Ejiofor *et al*. (2014), which reported through viscosity values ranging from 696 RVU to 3126 RVU for jackfruit seed flour with autoclaved samples having the lowest and roasted samples the highest the values, these values are higher than those obtained in the present study. RJSF had the highest breakdown viscosity at 78.46, which might suggest instability of the paste. BJSF and RoJSF had the lowest values, at 34.41 and 33.77 respectively, which are lower than the 186 BU reported by Ocloo *et al*. (2010). The final viscosity of processed jackfruit seed flour ranged from 151.25 to 216.32. The results indicated that RoJSF had the highest final viscosity, followed by BJSF and RJSF. These values are relatively low compared to the 364.13 reported for jackfruit seed starch by (Rengsutthi and Charoenrein 2011). The setback viscosity ranged from 42.12 to 77.47. Among all the flours, RJSF had the lowest setback viscosity, while both RoJSF and BJSF had the highest. The low setback value of 42.12 for RJSF indicates that the paste has non-cohesive properties. The current values are higher than the 18.53 RVU and 10.56 RVU reported for wet and dry jackfruit seed flour by Mukprasirt and Sajjaanantakul (2004). The peak time for the processed jackfruit seed flour samples ranged from 6.18 minutes to 7.46 minutes, with RJSF having the shortest time and BJSF and RoJSF having the longest. Similar peak time values, ranging from 5.29 minutes to 8.46 minutes for different processed jackfruit seed flours, were recorded by Eke-Ejiofor *et al*. (2014). The highest pasting temperature was observed for RJSF at 98.5°C, followed by BJSF at 80.5°C and RoJSF at 76.1°C. These pasting temperatures are slightly higher than the 88.2°C reported by Ocloo *et al.* (2010) for jackfruit seed flour.

Table 1: Functional properties of processed jackfruit seed flour.

Functional properties	RJSF	RoJSF	BJSF
Solubility (%)	12.8 ± 1.6^{a}	9.1 ± 1.1^{b}	13.6 ± 1.6^{a}
Swelling capacity (%)	7.9 ± 2.2^{b}	6.2 ± 0.5^{a}	5.96 ± 0.3^{a}
Bulk density (g/ml)	0.24 ± 0.1^{a}	0.23 ± 0.5^{a}	0.29 ± 0.3^{a}
WAC (%)	423 ± 2.3^{c}	506 ± 2.5^{a}	454 ± 1.8^{b}
OAC (%)	309 ± 3.1^{a}	149 ± 1.7^{c}	211 ± 0.3^{b}
Dispersibility (%)	60.3 ± 0.4^{a}	56 ± 0.3^{b}	51 ± 0.1^{c}

Values with different superscripts in the same row are significantly different ($p\geq0.05$).

RJSF-Raw jackfruit seed flour; RoJSF-Roasted jackfruit seed flour; BJSF-Boiled jackfruit seed flour.

Table 2: Pasting properties of processed jackfruit seed flour.

Pasting properties	RJSF	RoJSF	BJSF
Peak viscosity	163.12	259.61	195.60
Trough viscosity	103.71	120.37	109.36
Breakdown viscosity	78.46	33.77	34.41
Final viscosity	151.25	216.32	162.51
Set back viscosity	42.12	75.31	77.47
Peak time (Min)	6.61	7.46	6.18
Pasting temperature (°C)	98.5	76.1	80.5

Table 3: Colour of processed jackfruit seed flour.

Parameters	RJSF	RoJSF	BJSF
L*	56.19 ± 0.59^{b}	68.16 ± 0.72^{a}	51.3 ± 0.63^{b}
a*	7.1 ± 0.41^{a}	8.39 ± 0.13^{a}	6.93 ± 0.61^{b}
b*	16.11 ± 0.14^{b}	28.41 ± 0.18^{a}	11.4 ± 0.18^{c}

Colour attributes

Colour significantly influences consumer preferences and perceived product quality, reflecting external characteristics of jackfruit seed flour. Colour indexes L*, a* and b* for RJSF, RoJSF and BJSF was outlined in Table 3. Hunter color 'L' values for jackfruit seed flour varied significantly ($p<0.05$) among the processed flour types, with RoJSF having the highest value of 68.16 and BJSF the lowest at 51.3, indicating their respective degrees of lightness. The highest L* parameter for RoJSF at 68.16 indicates it is lighter in colour than the other jackfruit seed flours. RoJSF had the highest Hunter colour 'a' value of 8.39, significantly different from RJSF at 7.1 and BJSF at 6.93. RoJSF also had the highest 'b' value of 28.41, showing a greater degree of yellowness, being significantly different ($p<0.05$) from RJSF at 16.11 and BJSF at 11.4.

Proximate composition of processed jackfruit seed flour

Proximate composition of raw, roasted and boiled *Artocarpus heterophyllus* seed flour illustrated in Table 4. The moisture content for RoJSF, RJSF and BJSF jackfruit seed flour was 4.98%, 5.23% and 6.01%, respectively. It was noted that RoJSF had a lower moisture content than both RJSF and BJSF. According to Suzihaque *et al*. (2022), dry and wet milled jackfruit seed flour had moisture contents of 6.34% and 8.57%, respectively. The ash content in various processed jackfruit seed flours ranged from 2.41% and 2.82%, with no significant differences observed between RoJSF, RJSF and BJSF. The ash content for both raw and processed jackfruit seed flour was between 2.45% and 2.56%, aligning with the findings of Eke-Ejiofor *et al*. (2014). The findings of this study align with the results reported by Albi Abraham and Jayamuthunagai (2014), who reported an ash content of 2.47% for jackfruit flour. Processed jackfruit seed flour was found to have a considerable amount of energy. The total energy values ranged from 337.9 kcal/100 g for RJSF to 357.93 kcal/100 g for RoJSF. Sulaiman *et al*. (2019) reported an energy value of 344.99 kcal per 100 grams, which is very close to the value obtained in the present study and Sultana *et al*. (2015) reported similar calorific values for jackfruit seed flour, ranging from 367.08 to 371.01 kcal/100 g. The carbohydrate content in both RoJSF and BJSF was found to be 71.72% and 72.03%, respectively,

while RJSF had a carbohydrate content of 69.99%. These results are similar to the values reported by Eke-Ejiofor *et al*. (2014), which were 72.05% and 72.16%. RoJSF had a protein content of 16.79%, which was higher than the 13.14% found in BJSF and the 11.56% in RJSF seed flour. This study reported a higher protein value compared to the 13.67% noted by Sulaiman *et al*. (2019). The fat content in jackfruit seed flour varied from 0.41% to 1.3%, with the highest in RJSF (1.3%), followed by BJSF (0.78%) and RoJSF (0.41%). These findings align with Tulyathan *et al*. (2002), who reported that jackfruit seed flour contained between 0.99% and 1.01% crude lipid, depending on whether the brown spermoderm was included.

The crude fibre content of RJSF, at 3.69%, is lower than that of RoJSF and BJSF, which have 4.01% and 5.12% respectively. This suggests that both roasting and boiling the seeds increase their crude fibre content. These results are similar to the 4.68% reported by Hajj *et al*. (2022) reported.

Nutritional composition of processed jackfruit seed flour

The nutritional composition was presented in Table 5. RJSF had the highest vitamin A content 64 mg/100 g, followed by RoJSF at 53.3 mg/100 g and BJSF at 51.5 mg/100 g. These values significantly surpass the 16.58% vitamin A content in jackfruit flour reported by Arefin *et al*. (2020). Thus, 100 g of processed jackfruit seed flour, including RJSF, RoJSF and BJSF, provides approximately 90.3 mg, 89.9 mg and 86.8 mg of phosphorus per 100 g respectively. These values are nearly identical to the 93.78% phosphorus content reported by Hajj *et al*. (2022). The results also indicate that processed jackfruit seed powder has higher magnesium content, ranging from 93.4 mg/100 g to 104 mg/100 g, with RoJSF showing the highest value compared to RJSF and BJSF. This study's magnesium values are higher than the 48.1 mg/100 g reported by Arefin *et al*. (2022). The study found that calcium levels ranged from 41.6 to 44.8 mg/100 g and iron levels varied between 1.8 to 2.9 mg/100 g. These results are higher than the calcium and iron contents reported by Arefin *et al*. (2020), which were 37.54 mg/100 g and 1.02 mg/100 g, respectively. RoJSF had the highest sodium content at 15.2 mg/100 g, followed by RJSF at 14.6 mg/100 g and BJSF at 10.6 mg/100 g. These sodium values exceed those reported by Hajj *et al*. (2022) for soft and firm varieties of jackfruit seed flour, which were 3.07 mg/100 g and 4.86 mg/100 g, respectively. In the present study, potassium levels ranged from 766 mg to 912 mg per 100 g, making it the most abundant minerals. RJSF had the highest potassium content, followed by BJSF and RoSJF. These levels are significantly higher than the 705.71 mg/100 g reported by Sultana *et al*. (2017) for jackfruit seed flour.

Antioxidant properties of processed jackfruit seed flour

Antioxidant properties of different processed jackfruit seed flours presented in Table 6. The total phenolic content

Table 4: Proximate composition of processed jackfruit seed flour.

Proximate composition	RJSF	RoJSF	BJSF
Moisture (%)	5.23±0.4^{a}	4.98±0.1^{a}	6.01±0.2^{a}
Ash (%)	2.65±0.5^{a}	2.41±0.5^{a}	2.82±0.5^{a}
Energy (Kcal)	337.9±0.1^{a}	357.93±0.4^{a}	347.7±0.4^{a}
Carbohydrate (%)	69.99±0.1^{a}	71.72±0.3^{a}	72.03±0.1^{a}
Protein (%)	11.56±0.2^{c}	16.79±0.3^{a}	13.14±0.3^{b}
Fat (%)	1.3±0.3^{a}	0.41±0.1^{b}	0.78±0.4^{b}
Crude fibre (%)	3.69±0.7^{b}	4.01±0.2^{b}	5.12±0.1^{a}

Table 5: Nutritional composition of processed jackfruit seed flour.

Vitamin and Minerals (mg/100 g)	RJSF	RoJSF	BJSF
Vitamin A	64±0.32^{a}	53.3±0. 2^{b}	51.5±0.14^{b}
Phosphorus	90.3±0.01^{a}	89.9±0.01^{a}	86.8±0.01^{b}
Magnesium	98.1±0.16^{b}	104.6±0.03^{a}	93.4±0.12^{b}
Calcium	43.5±0.21^{a}	44.8±0.11^{a}	41.6±0.15^{b}
Iron	2.3±0.31^{a}	1.8±0.1^{a}	2.9±0.11^{a}
Sodium	14.6±0.09^{a}	15.2±0.04^{a}	10.6±0.01^{b}
Potassium	912±0.12^{b}	766±0.02^{b}	813±0.031^{b}

Table 6: Antioxidant properties of processed jackfruit seed flour.

Antioxidant properties per 100 gm	RJSF	RoJSF	BJSF
Total phenolic content (mg GAE)	720.2±1.30^{b}	863.15±1.82^{a}	686.21±1.26^{c}
Total flavonoid content (mg CE)	36.13±1.81^{b}	54. 32±0.63^{a}	33.74±0.35^{b}
DPPH Assay (% inhibition)	83.20±2.32^{b}	101.1±0.87^{a}	76.51±0.69^{b}
Reducing power (mg TE)	2400.51±1.26^{b}	2996.43±1.38^{a}	2123.19±0.87^{c}

Table 7: Shelf-life estimation of processed jackfruit seed flour.

Parameters	Intervals (months)	RJSF	RoJSF	BJSF
TPC (cfu/g)	0	0.1×10^{-6}	0.1×10^{-6}	0.1×10^{-6}
	2	0.1×10^{-6}	0.1×10^{-6}	0.2×10^{-6}
	4	0.1×10^{-6}	0.1×10^{-6}	0.2×10^{-6}
	6	0.2×10^{-6}	0.1×10^{-6}	0.3×10^{-6}
Fungi (cfu/g)	0	0.1×10^{-6}	0.1×10^{-6}	0.1×10^{-6}
	2	0.1×10^{-6}	0.1×10^{-6}	0.2×10^{-6}
	4	0.1×10^{-6}	0.1×10^{-6}	0.2×10^{-6}
	6	0.2×10^{-6}	0.1×10^{-6}	0.3×10^{-6}
Mold (cfu/g)	0	0.1×10^{-6}	0.1×10^{-6}	0.1×10^{-6}
	2	0.1×10^{-6}	0.1×10^{-6}	0.2×10^{-6}
	4	0.1×10^{-6}	0.1×10^{-6}	0.3×10^{-6}
	6	0.2×10^{-6}	0.1×10^{-6}	0.3×10^{-6}

ranged from 686.21 mg GAE/100 g to 863.15 mg GAE/100 g, with RoJSF having the highest value, followed by RJSF and BJSF. These levels are higher than the 750.98 mg GAE/100 g reported by Kamal *et al*. (2023) for cabinet-dried jackfruit seed flour at 50°C. The total flavonoid content ranged from 33.74 mg CE/100 g to 54.30 mg CE/100 g, with BJSF having the lowest and RoJSF the highest. These results are higher than the 21.06 mg CE/100 g reported by Bossi *et al*. (2024) for roasted jackfruit seed in aqueous extract. The DPPH assay results for processed jackfruit seed flour were 76.51% for BJSF, 83.20% for RJSF and 101.1% for RoJSF. The DPPH radical, known for generating free radicals, is widely used to evaluate the antioxidant capacity of compounds. These results are lower than the DPPH assay values reported by Trejo Rodriguez *et al*. (2021), which varied from 1579 to 1617 µmol Trolox/ 100 g. The current study found that RoJSF had the highest reducing power at 2996.43 mg TE/100 g, followed by RJSF at 2400.51 mg TE/100 g and BJSF at 2123.19 mg TE/100 g. These values are significantly higher than the reducing power values for jackfruit seed and pulp powder incorporated crackers, reported by Ooi (2024) at 43.12 mg FeSO4E/100 g dry solids. Among all the processed jackfruit seed flours, RoJSF exhibited the highest levels of all antioxidant properties.

Microbial analysis of processed jackfruit seed flour

The findings of the microbial analysis were shown in Table 7. A high microbial count can threaten consumers' health and contribute to the decomposition and nutrient depletion of the food. For RJSF the TPC, fungi and mold values ranged from 0.1×10^{-6} cfu/g to 0.2×10^{-6} cfu/g and for RoSJF, the TPC, fungi and mold values ranged from 0.1×10^{-6} cfu/g to 0.1×10^{-6} cfu/g. The jack fruit seed flour TPC and fungi and mold were periodically estimated during the 6 months storage period. According to the findings, the TPC, fungi and mold significantly rose RJSF and RoJSF having the same TPC, fungi and mold values as the amount of storage days increased. The study revealed that for BJSF, both TPC and fungal counts ranged from 0.1×10^{-6} cfu/g to 0.3×10^{-6} cfu/g over the period of 0 to 6 months. However, mold counts significantly increased to 0.3×10^{-6} cfu/g during the 4th and 6th months. During the storage period, no significant microbial load was detected and the studies showed that jackfruit seed flour has excellent storage stability. Among the three processed jackfruit seed flours, RoJSF has the lowest TPC, fungi and mold values compared to RJSF and BJSF. The results were similar to the shelf life of tamarind seed flour by Hemalatha and Parameshwari (2023).

CONCLUSION

In populous countries, the demand for food exceeds the supply of seasonal vegetables. Here, the jackfruit seeds can serve as an effective substitute for protective foods. Because jackfruit seeds have a short shelf life and often go to trash during peak season, however, processing these seeds into flour offers a viable nutritious alternative. The current study, concludes that roasted jackfruit seed flour is rich in energy, protein, carbohydrates and minerals. Moreover, this value-added product exhibited the highest antioxidant levels and can be safely included in the human diet as a daily nutritional supplement. Roasted jackfruit seed flour possesses excellent functional, physicochemical and shelf-life properties, making it ideal for value-added applications at domestic, commercial and industrial scales. It can substitute cereal flours in traditional and conventional products or be utilized to develop innovative new products with health benefits, which can help combat malnutrition.

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Conflict of interest

The authors state that there are no conflicts of interest.

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