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Comparative Nutritional and Functional Assessment of Germinated Jackfruit Seeds Treated via Roasting and Microwave Drying

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ABSTRACT

The present study investigated the effect of conventional and microwave drying methods on the functional and nutritional properties of germinated jackfruit seed flour (*Koozha* variety). Fresh seeds were germinated and subsequently dried via roasting and microwave drying, resulting in three sample groups: GR (germinated and roasted), GM (germinated and microwave) and C (control). Further, seeds were milled into flour and analyzed for proximate composition, functional properties, flour yield and sensory attributes. Significant differences were observed among the samples in sugar content, dispersibility and oil absorption capacity. Moisture content was significantly lower in GM (7%) and C (6.8%) compared to GR (7.8%). Sensory evaluation revealed that GM and GR samples received higher taste and overall acceptability scores than the C sample. The findings suggested that jackfruit seed flour, particularly when processed through germination and microwave drying, possessed desirable functional and sensory qualities. Thus, this study demonstrated the nutritional potential of germinated and microwave dried jackfruit seed flour to be served as functional ingredient in diverse food formulations at commercial and domestic levels.

Key words: Germination, jackfruit seed flour, microwave drying, roasting, sensory evaluation

INTRODUCTION

Jackfruit (*Artocarpus heterophyllus*), a tropical fruit widely cultivated across south-east Asia, contains between 100 and 400 seeds per fruit depending on its size. Despite its nutritional potential, only about 10% of jackfruit seeds are currently utilized for processing and human consumption, leaving the remaining 90% under exploited. Jackfruit seed is rich in several vitamins (Vitamin-C, Vitamin-A, Vitamin-B6, niacin, riboflavin and folic acid), minerals (Calcium, magnesium, manganese, iron and copper), protein, dietary fibers and phytonutrients (Shajahan *et al*., 2024). With growing emphasis on sustainable food systems, there is growing interest in alternative nutrition sources. The plant-based proteins have emerged as essential in mitigating ecological and health-related risks. Jackfruit seed can be explored for diverse food applications by converting into a more acceptable and nutritionally enhanced form. Food processing techniques not only enhance quality and shelf life but also diversify food application. Processed foods are generally better accepted due to enhanced nutritional quality, digestibility, antioxidant activity and shelf life, along with reduced levels of antinutritional factors (Borgis and Bharati, 2020). Recent studies show that germinating seeds significantly enhance their nutritional and functional quality, making the resulting flours more suitable for diverse food applications. For instance, germinated millets exhibit a 142-437% increase in phenolics and flavonoids, along with boosted protein solubility and mineral content, supporting their use in functional beverages and food formulations (Chethan Kumar *et al*., 2022). Similarly, germination of sorghum for 72/ h reduces anti-nutrients (phytic acid and tannins), increases protein digestibility from ~50 to ~75%, and enhances antioxidants, indicating its suitability for health oriented food products (Singh *et al*., 2024).

Heat treatment is a widely adopted industrial technique for modifying the functional properties of starch and other food constituents (Kumar *et al*., 2021); however, conventional thermal methods such as roasting and convective air drying, which depend on the conduction and convection for heat transfer, were constrained by the low thermal conductivity of food matrices, necessitating prolonged exposure to elevated surface temperatures that may lead to quality deterioration and increased energy consumption (Verma *et al*., 2020). Microwave drying, by contrast, offers advantages such as rapid volumetric heating, precise control, energy efficiency and instant operation. This method generates internal heat through ionic motion (movement of charged particles) and dipolar rotation (rearrangement of water molecules) induced by microwave electromagnetic energy typically at 2450 MHz for domestic applications and 915 MHz for industrial use thus enabling shorter processing times and better quality retention (Verma *et al*., 2020; Najib *et al*., 2023).

Roasting has significant effect, as it improves quality, colour, and decreases the amount of anti-nutrients present in the seeds. Flavour, colour and texture were enhanced after the processing (Amadi *et al*., 2019). Antinutritional factors decreased and protein/starch digestibility, and antioxidant activity of processed seed flour are increased upon the heat treatment. The functional properties like water/oil absorption capacity, foaming capacity, etc. were greatly improved upon processing, thus allowing its' utility in various food applications (Li *et al*., 2022; Manikpuri *et al*., 2024; Simic *et al*., 2024,). The germinated seeds moisture content was removed or reduced through drying so that its enhanced nutrition and enzyme profile could be maintained, which ultimately preserve the flour from microbial deterioration and enabling its utilization in a variety of product formulations such as porridge and bakery. Drying stops enzyme activity at an optimal point, preserving increased protein solubility, vitamins and antioxidants (e.g., germinated millets showed 142-437% higher phenolic/ flavonoid levels) while maintaining functional properties like water absorption and shelf stability (Chethan Kumar *et al*., 2022).

Previous studies examined jackfruit seed processing through methods such as autoclaving, boiling, oven drying, germination, roasting and fermentation (Abiola, 2018; Reddy *et al*., 2022). While germination and roasting individually had shown beneficial effects, limited research has explored their combined impact or evaluated microwave drying as an alternative post-germination treatment. To bridge this gap, the present study was designed to investigate the effects of both conventional (roasting) and novel green microwave drying technologies on the proximate and functional properties of germinated jackfruit seed flour. By evaluating these methods within a comparable thermal range, the study seeked to promote the valorization of jackfruit seeds as a viable functional ingredient in domestic, commercial and industrial food applications.

MATERIALS AND METHODS

Fresh, high quality ripe jackfruit (*Artocarpus heterophyllus* var. *Koozha*) seeds (6 kg) were procured online from Basil Spices, Vadattupara, Kuttampuzha Village, Ernakulam district, Kerala. The seeds were manually sorted to ensure uniformity in size and divided into three equal groups (2 kg each): Control (C), Germinated-Roasted (GR) and Germinated-Microwave (GM). For the preparation of control jackfruit seed flour, the seeds were washed and disinfected using a 0.07% sodium hypochlorite solution for 30 min, followed by three thorough rinses with clean water. The cleaned seeds were then subjected to lye peeling by immersing them in a 2% NaOH solution at 80°C for 5 min, manually rubbed for 2 min, and rinsed with clean water to eliminate excess alkali (Reddy *et al*., 2022). Post-peeling, the seeds were dried in a hot air oven at 50°C for 24 h (Reddy *et al*., 2022). The dried seeds were ground twice using a Philips HL7756/00 mixer grinder (750/ W) to obtain fine flour, sieved through a 250/ ìm (60 mesh) sieve (Goh *et al*., 2024), and stored in airtight poly bags at 8°C until further analysis. For the preparation of processed jackfruit seed flours, seeds in GR and GM groups were first disinfected using the same sodium hypochlorite treatment and rinsing procedure. These seeds were then soaked and incubated in transparent sealable poly bags lined with cotton, which was periodically moistened to maintain humidity. The seeds were germinated at room temperature (28-29°C) for 96 h (Anusha *et al*., 2023), followed by sun drying for 72 h (3 days). Germinated seeds in the GR group were pan roasted on a Philips Viva Collection HD4928/01 induction cook top at a fixed temperature of 160°C until cracking occurred. For the GM group, dried germinated seeds were microwaved using an IFB 20SC2 oven (1200/ W, 2 min), and weight differences were recorded before and after treatment. After thermal processing, seeds from both GR and GM groups were subjected to the same lye peeling procedure used for the control group, followed by drying in a hot air oven at 50°C for 24 h, grinding with the Philips HL7756/00 mixer grinder, sieving through a 250/ µm mesh, and storage in poly bags at 8°C for further use. A schematic representation of the control and processed jackfruit seed flour preparation steps has been provided in Fig. 1. Proximate composition including crude protein, fat content, ash content, moisture content, total sugar and iron content was determined using standard methods (A. O. A. C., 2023). All analyses were performed in triplicate to ensure accuracy and reproducibility. The two processed groups, GR and GM, were compared to the results obtained for the control sample (C). The following functional properties were evaluated: dispersibility according to Palamthodi *et al*. (2021), bulk density (BD), water absorption capacity (WAC), oil absorption capacity (OAC) and swelling power (SP) following Sulaiman (2019). Foam capacity (FC) and foam stability (FS) were determined following Odimegwu *et al*. (2019). All jackfruit seed flour (JSF) samples underwent sensory assessment conducted by a panel of semi-trained members from the Department of Food Technology at Guru Jambheshwar University of Science and Technology, Hisar. This evaluation utilized a 9-point hedonic scale to assess different parameters of sensory such as aroma, texture, taste, appearance and overall acceptability. To assess the effects of treatments on various JSF parameters, a complete randomised design (CRD) was adopted. The data were taken in triplicate, analyzed and reported as means±standard deviation (SD) using one-way ANOVA (Analysis of variance) at 5% level of significance.

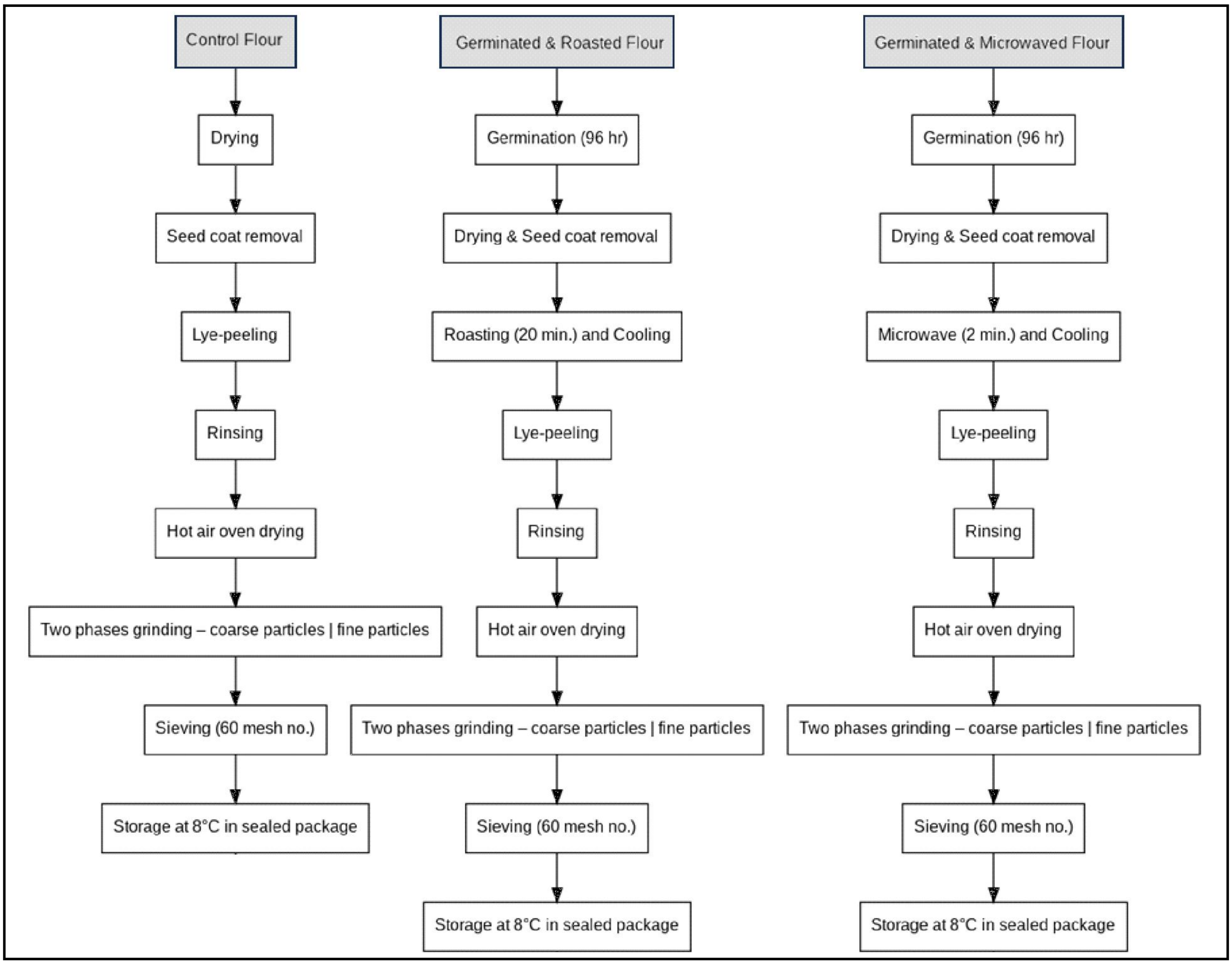

Fig. 1. Preparation of jackfruit seed flour.

RESULTS AND DISCUSSION

As illustrated in Fig. 2, the treated jackfruit seed samples (GR and GM) produced a significantly higher yield of fine flour (passing through a 60-mesh sieve) compared to the control (C). Among the processed samples, the GM sample exhibited the highest flour yield (Fig. 3). This enhanced yield can be attributed to the reduced loss of solids and water soluble components, which were more likely to leach out during conventional treatment processes. Flour yield was influenced by several factors, including the type and variety of raw material, initial moisture content, composition, seed size, pre-treatment method, processing technique and the equipment employed. The lower flour yield in the control sample could be partly attributed to a higher proportion of coarse particles and retained brown spermoderm.

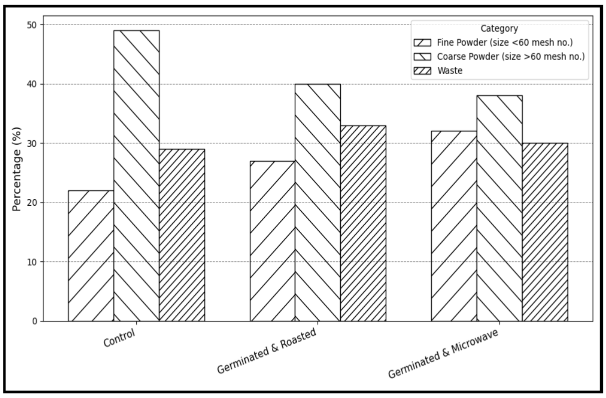

Fig. 2. Yield (%) of jackfruit seed flour.

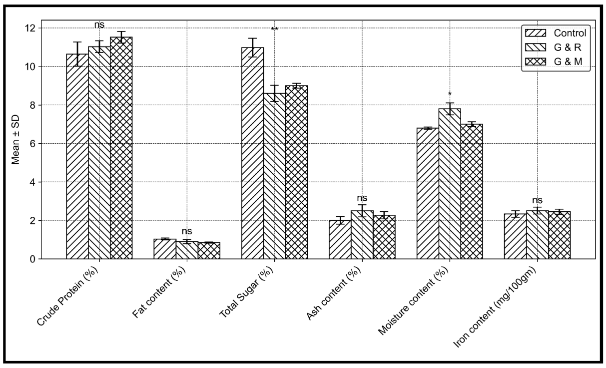

Fig. 3. Proximate composition of control (C), germinated and roasted (GR) and germinated and microwaved (GM) jackfruit seed flour.

Notably, visual differences in flour colour were also observed across samples (Fig. 4). The control (C) flour appeared dark brown GR flour was medium brown and GM flour exhibited a light brown to off-white colour. These variations could be due to the removal percentage of brown spermoderm and white arils from the seeds while processing, as well as the extent of thermal treatment used that affected the pigment development. Final flour yield was impacted by the processing of seed, which resulted in flour that was free from coarse particles, thus producing clean flour. The germinated and microwave (GM) processed flour was found to be effective method for producing the flour of superior sensory attributes and increased yield.

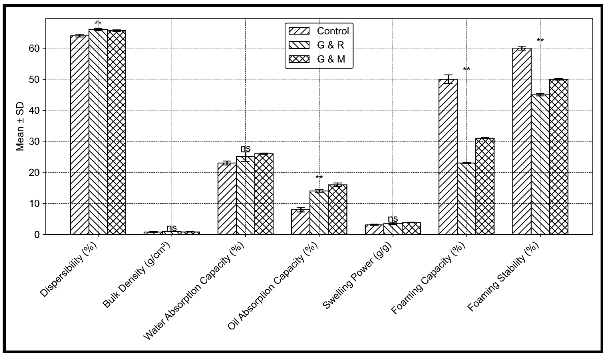

Fig. 4. Functional properties of control (C), germinated and roasted (GR) and germinated and microwaved (GM) jackfruit seed flour.

Germinated microwaved seed flour was observed to have 11.52% crude protein content followed by germinated and roasted (11.03%) and control (10.65%) sample (Table 1). The values of protein content were found similar to Amadi *et al.* (2019) and de Farias Leite *et al.* (2020) suggesting that protein availability enhanced after thermal processing of germinated seeds. Enzymes such as endo and exoproteinases transformed stored complex proteins into peptides during the germination process. Enhanced protein content of the processed seeds could be due to the sequential process of germination and heating (roasting and microwave). When the seeds were subjected to germination, proteins were hydrolyzed by the enzymes (protease) which increased the content of peptides and amino acids. Sun-drying was employed for halting the germination process of seeds which enhanced the amount of degraded protein. The protein content of GR and GM did not differ significantly, but the processed seed flour had more protein than the control (C) flour. This might be due to the application of germination and thermal processing that increased the

Table 1. Proximate composition of jackfruit seed flour

Parameter	Control	Germinated and roasted (GR)	Germinated and microwaved (GM)	F value	C. D.
Crude protein (%)	10.65^{a}±0.63	11.03^{a}±0.30	11.52^{a}±0.30	0.99^{ns}	1.51
Fat content (%)	1.03^{a}±0.05	0.90^{a}±0.11	0.85^{a}±0.03	1.74^{ns}	0.23
Total sugar (%)	10.98^{a}±0.49	8.60^{b}±0.42	9.00^{b}±0.12	11.52**	1.29
Ash content (%)	2.00^{a}±0.20	2.50^{a}±0.31	2.27^{a}±0.19	1.10^{ns}	0.82
Moisture content (%)	6.80^{b}±0.06	7.80^{a}±0.31	7.00^{b}±0.12	7.64*	0.66
Iron content (mg/100 g)	2.34^{a}±0.17	2.51^{a}±0.18	2.45^{a}±0.13	0.29^{ns}	0.55

*,**Significant at P=0.05 and P=0.01, respectively. NS–Non-significant. Different superscripts in a row differ significantly (P<0.05).

amino acid content availability, which may help in meeting daily protein requirements, supplementing protein-deficient diets and enhancing the bioavailability of protein. Likewise, radio-frequency technique also leads to least nutritional reduction owing to minimum food interaction with heat waves generated (Dewan *et al.,* 2023).

Thermal processing of seeds decreased the fat content in the samples, with the lowest being 0.85% (GM) and the highest 1.03% (C) flour sample though the difference was not significant. de Farias Leite *et al*. (2020) also observed that germination reduced the amount of lipids/fat in the seed flour. Germination and heat processing reduced lipid content, which was similar to the findings of Zuwariah *et al*. (2018). In the process of germination, seeds metabolic activity increased, requiring more energy which was derived from the fat content, therefore, the amount of fat content in the processed flour sample reduced. Sulaiman (2019) research showed that processed flour was also found to be less prone to lipid degradation due to its low-fat content.

The total sugar content value of processed samples decreased and differed significantly (<0.05) from the values obtained of the control samples. The control (C) had the highest total sugar content (10.98%) and GR flour had the lowest (8.60%). de Farias Leite *et al*. (2020) observed a 2.18% increase in total sugar in germinated seed (24 h) attributed to the alpha-amylase activity during germination, which contributed to the modification of starch into simple sugars, thereby increasing total sugar in germinated seed. The obtained results contrasted with de Farias Leite *et al*. (2020). This divergence from previous findings could be attributed to the fact that prior germination was only permitted for 24 h, whereas in this study germination was permitted for 96 h. The long duration of germination allowed the seed to utilize simple carbohydrates for seed development. The prolonged germination reduced the total sugar level of the processed flour, allowing it to be used in food products requiring low sugar content, such as diabetic food products.

The total ash/mineral content of GR flour sample (2.50%) was observed to be greater than that of GM flour sample (2.27%) and followed by unprocessed/control (2.00%) seed flour (Table 1). This study is in line with Amadi *et al*. (2019), who observed that roasted and germinated breadnut seed flour had higher ash content than raw breadnut seed flour. The rise in ash and mineral content of the processed flour sample could be attributed to the germination process, which made the immobile water into a more bioavailable form for metabolic activities in seeds, potentially enhancing the availability of various minerals, thereby increasing the ash content. During heat processing via roasting and microwave, germination was halted in between which concentrated minerals due to water loss during drying in the processed flour.

Both processed seed flours had high moisture content, though it was lower in microwaved (7.00%) seed flour than in roasted (7.80%) seed flour, perhaps due to variations in heat transmission processes in dielectric (microwave) and conventional (roasting) heating. The control (C) and GM flour samples varied significantly (P < 0.05) from the GR sample. The heat treatment influenced these differences, as roasting relying on conductive heat transfer while microwave processing relying on volumetric heating, which resulted in varying moisture retention. The higher moisture levels in the processed samples probably arose from the germination process, which introduced water into the seed. The inclusion of the germination step led to an increase in the base moisture content, which affected the final result, even though final drying reduced overall moisture. Even with the increase, all samples remained well under the 11.05% moisture threshold mentioned by Amadi *et al*. (2019) for breadnut seed flour, showing that the processed flours were storage-friendly and less susceptible to microbial spoilage. During the triplicate moisture content analysis, it was observed that cocoa-like essence developed and increased with each successive heating stage. These observations aligned with results obtained by the Zainal Abidin *et al*. (2024) who found that roasted jackfruit seeds had high level of trimethyl-pyrazine (malty, cocoa scent) and 2,3-diethyl-5-methyl-pyrazine (cocoa aroma). However, current study didn't identify or quantified the aroma compounds responsible for cocoa essence. Further studies can be done to analyze the compound responsible for this essence by utilizing the GC-MS for evaluating their application in the flavour development or cocoa free products.

Iron content followed a similar trend to ash content, with the GR sample showing the highest iron concentration (2.51/ mg/100/ g), followed by GM (2.45/ mg/100/ g) and the control (2.34 mg/100/ g). Though the differences were not statistically significant, the results align with findings by Amadi *et al*. (2019), indicating enhanced mineral bioavailability after germination and thermal processing. Germination activated endogenous phytase enzymes, which degraded phytic acid that otherwise chelated minerals like iron, reducing their bioavailability. Unlike other studies where substrate absorption was a factor during germination, this study used a non-substrate germination approach (damp cotton), suggesting internal redistribution and concentration of minerals rather than external absorption.

Dispersibility reflects the ability of flour particles to suspend in water, often associated with particle size: finer particles exhibit higher dispersibility. In this study, dispersibility improved significantly ($P < 0.05$) in the processed samples compared to the control (C). Values ranged from 64.00% in the control to 66.00% in the GR flour, the latter showing the highest dispersibility (Table 2).

The BD (Bulk Density) ranged from 0.78 to 0.90 g/cm^3 and the difference observed was not significant. The BD of GR samples was higher than germinated and microwave (GM) and control (C) samples (Table 2). The BD of a flour sample is a measure of its heaviness. It is imperative for the evaluation of packaging specifications, material handling protocols and application considerations in the wet processing domain within the food industry. The obtained value was consistent with values of the earlier literature. The findings observed were in line with the results obtained by Reddy *et al.* (2022), who reported that increase in BD could be due to the high protein content and thermal processing. Given that high density bulk flours could function as thickeners in food products, the analyzed jackfruit seed flour could be utilized as a thickening agent.

The water absorption capacity (WAC) of control (C) was found to be 23%, whereas the GR and GM had values of 25 and 26%, with no significant difference. WAC was mainly associated with the high concentration of hydrophilic substances such as proteins and carbohydrates, which had a high affinity for water molecules. The obtained values were

Table 2. Functional properties of control and processed jackfruit seed flour

Parameter	Control	Germinated and roasted	Germinated and microwaved	F value	C. D.
Dispersibility (%)	$64.00^{b}\pm0.45$	$66.00^{a}\pm0.33$	$65.67^{a}\pm0.24$	9.44**	1.20
Bulk density (g/cm^3)	$0.78^{a}\pm0.15$	$0.90^{a}\pm0.04$	$0.81^{a}\pm0.04$	0.44^{ns}	0.32
Water absorption capacity (%)	$23.00^{a}\pm0.60$	$25.00^{a}\pm1.55$	$26.00^{a}\pm0.17$	2.50^{ns}	3.34
Oil absorption capacity (%)	$8.00^{b}\pm0.75$	$14.00^{a}\pm0.44$	$16.00^{a}\pm0.58$	47.72**	2.08
Swelling power (g/g)	$3.13^{a}\pm0.19$	$3.58^{a}\pm0.34$	$3.79^{a}\pm0.11$	2.13^{ns}	0.80
Foaming capacity (%)	$50.00^{a}\pm1.39$	$23.00^{c}\pm0.25$	$31.00^{b}\pm0.16$	286.71**	2.83
Foaming stability (%)	$60.00^{a}\pm0.65$	$45.00^{c}\pm0.36$	$50.00^{b}\pm0.25$	283.78**	1.56

*,**Significant at P=0.05 and P=0.01, respectively. NS–Non-significant. Different superscripts in a row differ significantly (P<0.05).

comparable to those examined by Borgis and Bharati (2020) pertaining to the processed JSF. WAC exhibited variability contingent upon the molecular structure of the flour, protein concentration, water interaction dynamics, conformational characteristics, hydrophilic group distribution, particle size, milling degree, presence of husk, damaged starch percentage, as well as content of protein and carbohydrate (Borgis and Bharati 2020). The enhanced WAC of GR and GM flours indicated their application in high moisture retaining products such as dough or batter formulations where WAC impacted the texture and mouth feel (Sulaiman, 2019; Trejo *et al.,* 2021).

The control (C) JSF had an oil absorption capacity (OAC) of 8%, which improved after processing and differed significantly (<0.05). The oil absorption capacity of microwaved germinated (GM) jackfruit seed flour (16%) was significantly higher than that of roasted germinated (GR) jackfruit seed flour (14%). Trejo *et al*. (2021) found that the high drying temperature caused more protein denaturation. The differences in drying temperatures likely caused this value to be lower than those reported by Trejo Rodriguez *et al*. (2021); the high amount of protein denaturation led to increased oil absorption capacity (OAC). The increase in hydrophobicity of denatured proteins could result in enhanced oil absorption, which was also influenced by surface properties, charge distribution and hydrophobic nature of dietary fibers. Dietary fiber's fat-retention capacity has been linked to wellness benefits including lowering serum cholesterol and aiding in weight loss. Higher OAC in the processed flour samples indicates their utilization in the foods that requires fat retention, such as plant-based meat or emulsification-based products. This attribute enhances the taste, texture and mouth feel.

Swelling power increased with processing but remained statistically non-significant. The values ranged from 3.13 g/g (control) to 3.79 g/g (GM). This observation aligned with the report by Kushwaha *et al*. (2021), which indicated that swelling power generally improved with rising temperature and starch gelatinization. The enhanced swelling observed in the GM and GR samples could be linked to the additional heat exposure during processing, which likely facilitated starch granule expansion. The swelling behaviour of flour could be associated with the interaction between amorphous amylose and crystalline amylopectin constituents of starch. This characteristic played a significant role in bakery products, as it contributed to the effects on water absorption, texture and the rheological performance of doughs and batters.

The foaming capacity (FC) ranged from 23 to 50.00%, with control (C) having the greatest value and GR having the lowest value (Table 2). The foaming stability (FS) ranged from 45 to 60.00%, with C having highest and GR having lowest value. Both FC and FS varied significantly (**<**0.05) when the control was compared with processed flour samples (GR, GM). It was probable that the denaturation of thermolabile proteins caused by heat lea to the decrease in foaming properties in processed samples, which could affect their ability to trap and stabilize air. Residual alkalinity from the sodium hydroxide (NaOH) treatment and heat could also cause pH changes, which could affect protein functionality. The high pH (alkaline) conditions known for increased protein solubility thus stabilized the formed foams. The FC and FS results from this study align with Juárez-Barrientos *et al*. (2017), who found that jackfruit seed flour had a reduced foaming after thermal processing. Interestingly, the GM sample had a moderate FC of 31%, suggesting that microwave heating could be more effective as preserving protein structure than roasting because of its shorter heating time.

The sensory evaluation scores for the various jackfruit seed flour samples have been displayed in Table 3, and visually compared in Fig. 5. All attributes examined, including colour, taste, texture and overall acceptability, were significantly different between control (C), GR and GM samples. GM flour was the most acceptable among the three samples with the highest scores for colour (7.29), taste (7.48), texture (7.57) and overall acceptability (7.72). These findings indicated that the sensory panel had a positive reaction to the sample that was treated with microwaves. Microwave drying's ability to generate heat internally through dipole movement and ionic friction can be the cause of the improved scores for GM flour. It assisted in conserving the natural qualities and appealing sensory traits of the flour. Moreover, this technique supported environmental sustainability due to its energy efficient and rapid processing nature.

Table 3. Effect of processing on the acceptability of jackfruit seed flour

Sample	Control	Germinated and roasted (GR)	Germinated and microwaved (GM)	F value	C. D.
Appearance	$6.73^{a}\pm0.29$	$6.87^{a}\pm0.33$	$7.38^{a}\pm0.22$	1.47^{ns}	0.97
Colour	$7.17^{a}\pm0.20$	$7.00^{a}\pm0.13$	$7.29^{a}\pm0.31$	0.41^{ns}	0.78
Taste	$6.20^{b}\pm0.21$	$7.1^{a}\pm0.12$	$7.48^{a}\pm0.13$	17.69**	0.54
Texture	$6.37^{b}\pm0.09$	$6.67^{b}\pm0.13$	$7.57^{a}\pm0.22$	15.92**	0.54
Overall acceptability	$6.00^{b}\pm0.25$	$7.20^{a}\pm0.21$	$7.72^{a}\pm0.14$	18.57**	0.7

*,**Significant at P=0.05 and P=0.01, respectively. NS–Non-significant. Different superscripts in a row differ significantly (P<0.05).

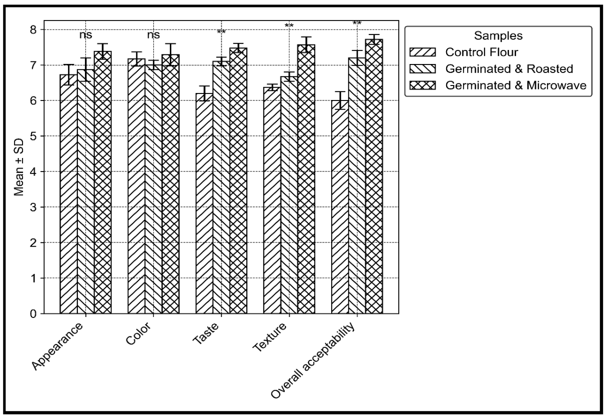

Fig. 5. Effect of processing on the acceptability of jackfruit seed flour.

In contrast, the control sample recorded the lowest overall acceptability (6), while the GR sample received intermediate values for colour (7), taste (7.10), texture (6.67) and overall acceptability (7.20). The slightly lower ratings for GR flour could be due to the texture hardening and uneven heat distribution associated with conventional roasting. It was also noted that when each sample was exposed to the high temperature drying during moisture content analysis cocoa aroma arose. Likewise, roasting of flaxseeds not only reduced the anti-nutrients compounds but also enhanced the sensory profile hence overall acceptability of oilseeds get increased due to this dry roasting technique (Yadav *et al.*, 2020). The sensory characteristics were observed regularly, but the active compounds responsible for this aroma were not analytically identified and quantified. This can be further investigated in future studies aiming for the analysis of flavour compounds produced upon germination and processing.

Overall, both processed flours (GR and GM) fell within the “liked moderately” to “liked very much” range on the 9-point hedonic scale. However, GM flour was clearly preferred across all attributes, suggesting that microwave-assisted processing could offer the best balance between nutritional, functional and sensory qualities for jackfruit seed flour.

CONCLUSION

The study demonstrated that germination followed by thermal processing via roasting or microwave drying significantly improved the nutritional, functional and sensory qualities of jackfruit seed flour. The observed variations in flour characteristics were primarily attributed to differences in germination induced biochemical changes and the distinct heat transfer mechanisms involved in conventional and microwave treatments. Proximate analysis revealed a significant reduction in total sugar and moisture content in processed samples, alongside slight but meaningful increases in protein, ash and iron content. Functional property assessment showed a notable improvement in dispersibility and oil absorption capacity, particularly in GM flour, suggesting its potential suitability for bakery and meat-based applications.

Sensory evaluation further supported the viability of processed flours, especially the microwaved sample, which achieved higher scores in taste, texture and overall acceptability. Interestingly, processed jackfruit seed flour also exhibited a cocoa-like aroma, which intensified with each heat treatment cycle. Though observed aroma was notable, identification of chemical components was beyond this study scope, therefore, future studies can be conducted for uncovering the novel application in the vegan chocolate or flavouring industry.

With enhanced mineral content, future studies should explore *in vitro* and *in vivo* bioavailability assessments and investigate the mineral bio-enhancing potential of processed jackfruit seed flour. These findings will open multiple avenues for the valorization of jackfruit seeds into nutritionally enriched and functionally versatile ingredients for diverse food applications such as meat analogue and as a cocoa replacer.

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