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Development and quality evaluation of jackfruit seed milk fortified with microencapsulated *Moringa* (*Moringa oleifera*) leaf extract

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Abstract

The present study was conducted to develop a functional plant-based beverage using jackfruit seed milk fortified with microencapsulated *Moringa* (*Moringa oleifera*) leaf extract. Microencapsulation of *Moringa* extract achieved an efficiency of 79.12%, indicating effective protection of bioactive compounds. Four treatments (T₀-T₃) were prepared and evaluated for their physicochemical, functional, and microbial characteristics. Fortification improved the nutritional quality of the beverage, with protein content increasing from 3.18% to 4.05%, calcium from 11.20 to 13.50 mg/100 mL, total soluble solids from 10.2 to 12.6°Brix, and ash content from 0.68% to 1.03%. Functional properties were also enhanced, as total phenolic content increased from 19.74 to 76.58 µg GAE/100 mL and antioxidant activity from 31.11% to 83.33%. Microbial analysis showed the absence of bacterial, yeast, and mold growth, confirming the microbiological safety of the product. Among all treatments, T₃ exhibited the highest nutritional and functional values. The study concludes that microencapsulated *Moringa* leaf extract can be effectively incorporated into jackfruit seed milk to produce a nutritious, antioxidant-rich, and safe functional beverage with potential as a plant-based dairy alternative.

Keywords: Jackfruit seed milk, *Moringa oleifera*, microencapsulation, functional beverage, total phenolic content, antioxidant activity, plant-based milk

Introduction

The growing demand for sustainable and nutritious plant-based foods has encouraged the exploration of underutilized agricultural resources for the development of functional food products. Among these, jackfruit (*Artocarpus heterophyllus* Lam.) seeds have attracted attention due to their rich nutritional composition, including carbohydrates, proteins, dietary fiber, minerals, and various bioactive compounds. These components contribute to antioxidant, cardioprotective, anticancer, and immune-enhancing properties. Despite their nutritional value, jackfruit seeds are often discarded as waste during fruit processing, resulting in the loss of a potentially valuable food resource.

Recent studies have demonstrated the successful utilization of jackfruit seed flour in bakery and confectionery products, improving both nutritional quality and consumer acceptability. The seeds also contain important bioactive proteins such as jacalin and artocarpin, further enhancing their functional value. Their abundance, low cost, and nutrient density make jackfruit seeds a promising raw material for the development of plant-based milk alternatives.

Plant-based milk alternatives have gained significant popularity due to increasing consumer interest in vegan diets, lactose-free products, and environmentally sustainable food systems. While soy, almond, and oat beverages dominate the market, concerns regarding allergenicity, cost, and nutritional limitations have prompted the search for alternative plant sources. Jackfruit seed milk offers a novel dairy-free beverage with a desirable texture, mild flavor, and valuable nutritional profile.

Moringa oleifera, popularly known as the “miracle tree,” is renowned for its rich nutrient content and numerous health-promoting properties. Its leaves are rich in proteins, vitamins, minerals, carotenoids, and phenolic compounds and exhibit antioxidant, antimicrobial, anti-inflammatory, antidiabetic, and anticancer activities. Due to its high nutrient density,

Moringa has been extensively explored as a functional ingredient for food fortification and nutritional enhancement. However, many bioactive compounds present in *Moringa* leaves are highly sensitive to environmental factors such as temperature, oxygen, light, and humidity, leading to reduced stability during processing and storage. Microencapsulation has emerged as an effective technique for protecting these sensitive compounds, improving their stability, bioavailability, and controlled release. Freeze-drying with suitable wall materials has been reported to effectively preserve *Moringa* phytochemicals and enhance encapsulation efficiency. Therefore, the present study aimed to develop a plant-based milk beverage using jackfruit seed milk fortified with microencapsulated *Moringa* leaf extract. The incorporation of microencapsulated *Moringa* was expected to improve the nutritional and functional quality of the beverage while maintaining the stability of its bioactive compounds during storage. Furthermore, the study evaluated the physicochemical, antioxidant, microbial, and sensory characteristics of the developed beverage during refrigerated storage. This research contributes to the value addition of jackfruit seeds, promotes the utilization of sustainable plant resources, and supports the development of innovative functional beverages for consumers seeking nutritious dairy alternatives.

Material and methods

"The study was conducted from January to May 2026 at the Department of Processing and Food Engineering, VIEAT, SHUATS, Prayagraj."

Tools and materials

Materials

The materials used in the present study included fresh jackfruit (*Artocarpus heterophyllus*) seeds, fresh *Moringa* (*Moringa oleifera*) leaves, maltodextrin, and gum arabic as encapsulating agents. Other ingredients used for the preparation of jackfruit seed milk included potable water and food-grade additives as required. Chemicals and reagents used for physicochemical and antioxidant analyses included Folin-Ciocalteu reagent, gallic acid standard, DPPH (2,2-diphenyl-1-picrylhydrazyl), sodium carbonate, methanol, and other analytical-grade chemicals. Nutrient agar and potato dextrose agar (PDA) were used for microbial analysis.

Tools and equipment

The major equipment used during the study included a weighing balance, mixer grinder/blender, hot air oven, freeze dryer, homogenizer, water bath, refrigerator, pH meter, digital thermometer, centrifuge, UV-Visible spectrophotometer, colony counter, autoclave, incubator, and glassware such as beakers, measuring cylinders, conical flasks, pipettes, and Petri dishes.

Treatment and experimental design

Four treatments were prepared by incorporating different levels of microencapsulated *Moringa* leaf extract into jackfruit seed milk.

Table 1: Formulation table

Sample	Jackfruit seed milk	Microencapsulated <i>Moringa</i>	Sugar	Vanilla essence
T_0 Controlled	100 ml	0%	10g	3 drops
T_1	100 ml	1%	10g	3 drops
T_2	100 ml	2%	10g	3 drops
T_3	100 ml	3%	10g	3 drops

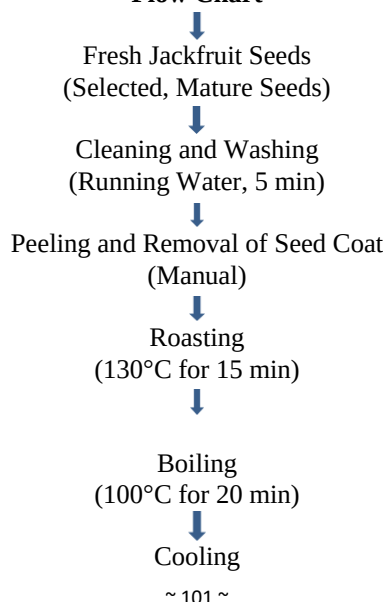
The prepared formulations were homogenized, pasteurized, packed in sterilized containers

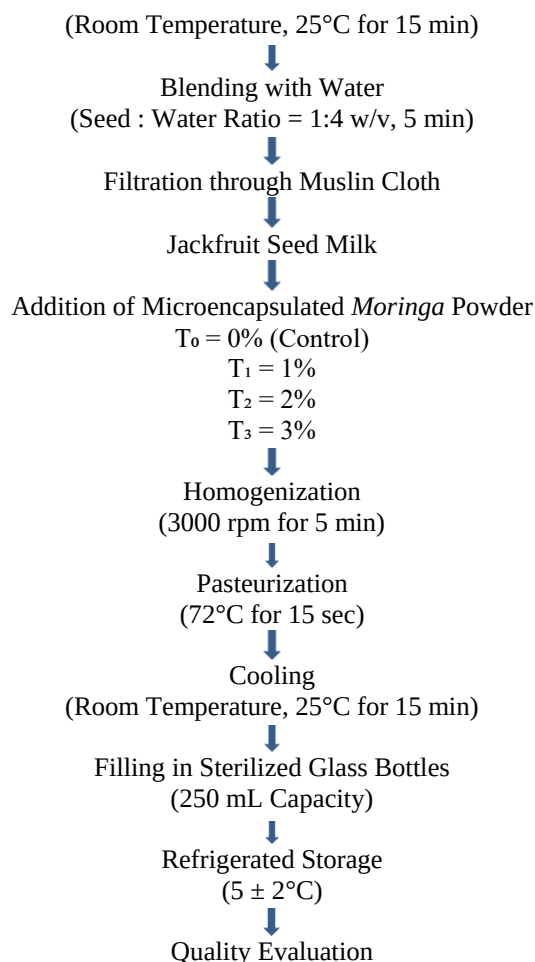
The experiment was conducted using a Completely Randomized Design (CRD) with four treatments and three

replications. The study aimed to evaluate the effect of different levels of microencapsulated *Moringa* leaf extract on the quality characteristics of jackfruit seed milk during storage.

Process of preparation

Flow Chart





Observations

Throughout the study, the developed jackfruit seed milk fortified with microencapsulated *Moringa* leaf extract was closely monitored to evaluate its quality. Observations were recorded for physicochemical properties (protein, pH, TSS, calcium, and ash content), antioxidant activity, Total phenolic content and microbial quality.

Research analysis

Determination of microencapsulation efficiency (me)

Microencapsulation efficiency was determined to evaluate the effectiveness of maltodextrin and gum arabic in entrapping the phenolic compounds present in *Moringa* leaf extract. The total phenolic content (TPC) and surface phenolic content (SPC) of the microcapsules were measured using the Folin-Ciocalteu method. Microencapsulation efficiency was calculated using the following formula:

$$ME(\%) = \frac{TPC - SPC}{TPC} \times 100$$

Where:

- ME = Microencapsulation Efficiency (%)
- TPC = Total Phenolic Content
- SPC = Surface Phenolic Content

Determination of protein content

Protein content was estimated using the Kjeldahl method. The nitrogen content obtained after digestion, distillation, and titration was multiplied by a conversion factor of 6.25 to obtain crude protein content.

Formula:

$$Protein(\%) = Nitrogen(\%) \times 6.25$$

Where:

- Nitrogen (%) = Percentage nitrogen present in the sample
- 6.25 = Protein conversion factor

Determination of calcium content

Calcium content was determined by titrimetric analysis using EDTA as described by AOAC methods.

Formula:

$$Calcium (mg/100mL) = \frac{T \times N \times 20.04 \times V_t \times 100}{V_a \times W}$$

Where:

- T = Volume of EDTA used (mL)
- N = Normality of EDTA
- V_t = Total volume made up
- V_a = Aliquot volume taken
- W = Weight/Volume of sample

Determination of ash content

Ash content was determined by incinerating the sample in a muffle furnace at 550°C until a white ash residue was obtained.

Formula:

$$Ash(\%) = \frac{Weight\ of\ Ash}{Weight\ of\ Sample} \times 100$$

Determination of pH

The pH of the beverage samples was measured using a calibrated digital pH meter at room temperature. The pH

meter was standardized using buffer solutions of pH 4.0 and 7.0 before analysis.

Determination of total phenolic content (tpc)

Total phenolic content of the microencapsulated *Moringa* leaf extract and fortified jackfruit seed milk samples was determined using the Folin-Ciocalteu colorimetric method. An aliquot of the sample extract was mixed with Folin-Ciocalteu reagent and sodium carbonate solution. The reaction mixture was incubated in the dark for a specified period, and the absorbance was measured using a UV-Visible spectrophotometer at 765 nm. Gallic acid was used as the standard for calibration, and the results were expressed as milligrams of gallic acid equivalents per 100 mL of sample (mg GAE/100 mL).

Formula:

$$TPC = \frac{C \times V}{M}$$

Where:

- TPC = Total Phenolic Content (mg GAE/mL)
- C = Concentration obtained from gallic acid standard curve
- V = Volume of extract (mL)
- M = Weight or volume of sample analyzed

Determination of antioxidant activity (dpph radical scavenging assay)

The antioxidant activity of the samples was evaluated using the DPPH (2, 2-diphenyl-1-picrylhydrazyl) radical scavenging method. Different concentrations of the sample extract were mixed with DPPH solution and incubated in the dark for 30 minutes at room temperature. The absorbance was measured at 517 nm using a UV-Visible spectrophotometer. The antioxidant activity was expressed as percentage inhibition of DPPH radicals.

Formula:

$$DPPH\ Inhibition(\%) = \frac{A_c - A_s}{A_c} \times 100$$

Where:

- A_c = Absorbance of control
- A_s = Absorbance of sample

Determination of standard plate count (spc)

The Standard Plate Count was determined to assess the total viable bacterial population present in the beverage samples

during storage. Serial dilutions of the sample were prepared using sterile distilled water, and 1 mL aliquots of appropriate dilutions were poured into sterile Petri plates. Molten nutrient agar was added, mixed thoroughly, and incubated at 37°C for 24-48 hours. Colonies developed on the plates were counted using a colony counter and expressed as colony-forming units per milliliter (CFU/mL).

Formula:

$$SPC = \frac{\text{Number of Colonies} \times \text{Dilution Factor}}{\text{Volume Plated (mL)}}$$

Where:

- Number of Colonies = Colonies counted on the plate
- Dilution Factor = Reciprocal of the dilution used
- Volume Plated = Sample volume inoculated onto the plate (mL)

Determination of yeast and mold count (ymc)

Yeast and mold count was determined using the pour plate method on Potato Dextrose Agar (PDA). Appropriate serial dilutions of the sample were prepared and plated aseptically. The plates were incubated at 25-28°C for 3-5 days. Colonies of yeast and molds were counted and expressed as colony-forming units per milliliter (CFU/mL).

Formula:

$$YMC(CFU/mL) = \frac{\text{Number of Colonies} \times \text{Dilution Factor}}{\text{Volume Plated (mL)}}$$

Where:

- Number of Colonies = Total yeast and mold colonies counted
- Dilution Factor = Reciprocal of dilution
- Volume Plated = Volume of sample plated (mL)

Result and discussion

The microencapsulation efficiency of *Moringa* leaf extract was determined by measuring the Total Phenolic Content (TPC) and Surface Phenolic Content (SPC). The average TPC of the encapsulated extract was found to be 174.84 µg GAE/mL, while the SPC was 36.51 µg GAE/mL. Based on the above equation, the microencapsulation efficiency of the *Moringa* leaf extract was calculated to be 79.12%.

Table 2: Physicochemical analysis

Treatment	Protein	pH	TSS	Ash %	Calcium
To Controlled	3.18	5.92	10.2	0.68	11.20
T_1	3.42	6.04	11.0	0.79	11.90
T_2	3.71	6.18	11.8	0.91	12.70
T_3	4.05	6.31	12.6	1.03	13.50

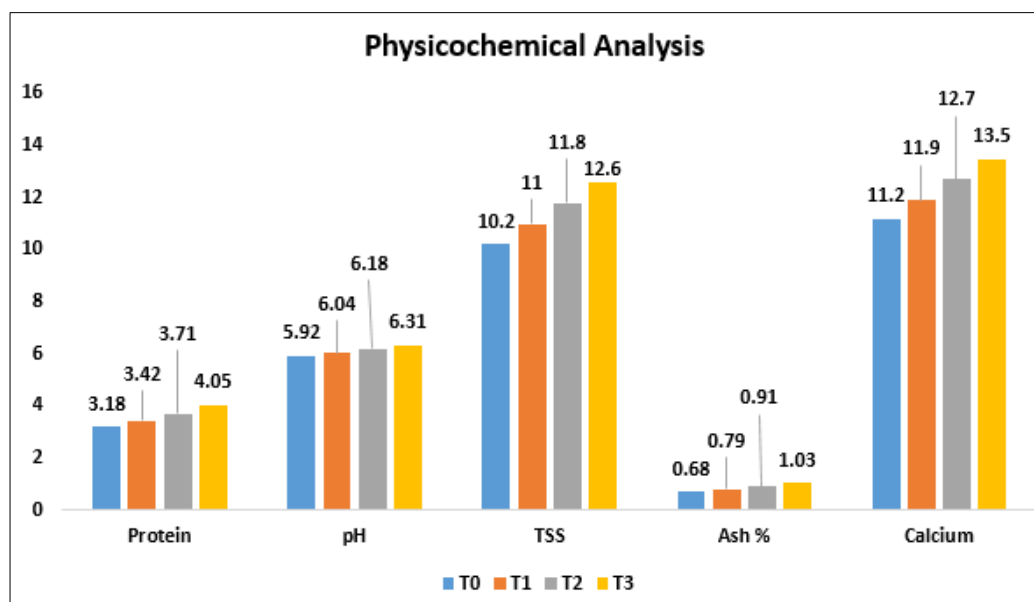


Fig 1: Physicochemical analysis

The physicochemical properties of jackfruit seed milk improved significantly ($p \leq 0.05$) with increasing levels of microencapsulated *Moringa* leaf extract. Protein content increased from 3.18% (T_0) to 4.05% (T_3), while pH increased from 5.92 to 6.31. TSS values showed a gradual rise from 10.2°Brix to 12.6°Brix. Ash content increased from 0.68% to 1.03%, indicating enhanced mineral content.

Similarly, calcium content increased from 11.20 mg /100 mL in T_0 to 13.50 mg /100 mL in T_3 . The results demonstrate that fortification with microencapsulated *Moringa* leaf extract significantly enhanced the nutritional quality of jackfruit seed milk, with T_3 showing the highest values for all parameters.

Table 3: Bioactive compound analysis

Treatment	Total Phenolic Content	Antioxidant %
To Controlled	19.74	31.11
T_1	39.90	58.89
T_2	58.74	72.22
T_3	76.58	83.33

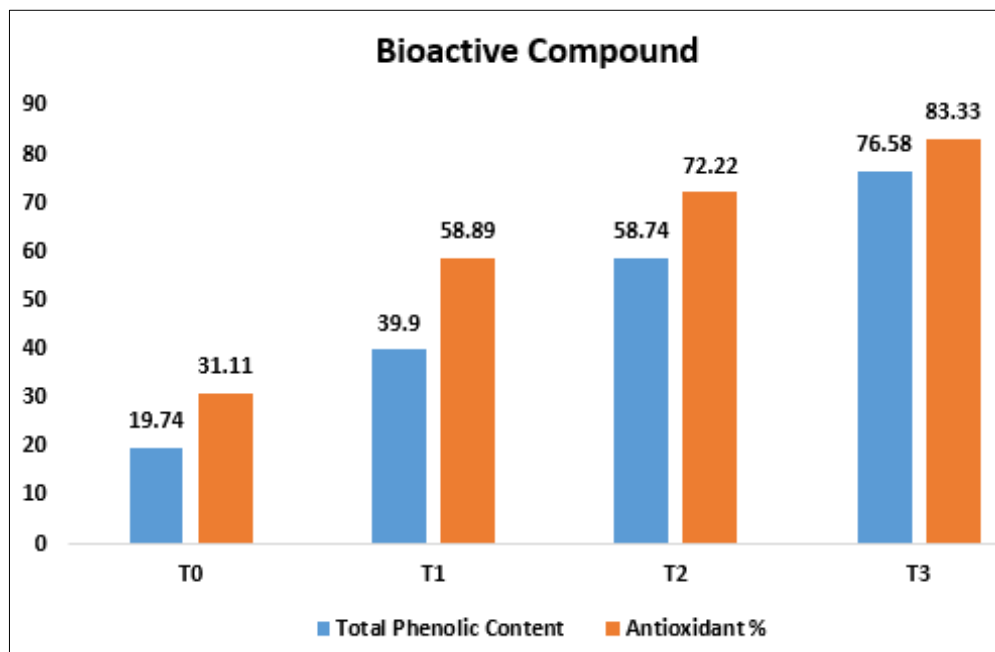


Fig 2: Bioactive compound analysis

A significant ($p \leq 0.05$) increase in total phenolic content and antioxidant activity was observed with increasing levels of microencapsulated *Moringa* leaf extract. Total phenolic content increased from 19.74 μ g GAE/100 mL in T_0 to 76.58 μ g GAE/100 mL in T_3 , while antioxidant activity

increased from 31.11% to 83.33%. The enhancement in these functional properties can be attributed to the rich phenolic compounds and natural antioxidants present in *Moringa* leaves.

Table 4: Microbial analysis

Treatment	Standard plate count	Yeast & mold Count
T_0 Controlled	ND	ND
T_1	ND	ND
T_2	ND	ND
T_3	ND	ND

No bacterial growth was detected in the Standard Plate Count (SPC), and no yeast or mold colonies were observed in any of the treatments throughout the study period. The absence of microbial growth indicates that the jackfruit seed milk fortified with microencapsulated *Moringa* leaf extract was microbiologically safe and remained within acceptable quality standards. This may be attributed to good hygienic processing practices, effective heat treatment, proper packaging, and refrigerated storage conditions, which helped maintain the microbial stability of the beverage.

Conclusion

Jackfruit seed milk fortified with microencapsulated *Moringa* leaf extract was successfully developed as a functional plant-based beverage. The microencapsulation efficiency of the *Moringa* extract was 79.12%, indicating effective protection of bioactive compounds. Fortification significantly ($p \leq 0.05$) improved the nutritional and functional properties of the beverage, with protein increasing from 3.18% to 4.05%, calcium from 11.20 to 13.50 mg/100 mL, total phenolic content from 19.74 to 76.58 µg GAE/100 mL, and antioxidant activity from 31.11% to 83.33%. The highest values were observed in treatment T_3 . No bacterial, yeast, or mold growth was detected, confirming the microbiological safety of the product. These findings suggest that microencapsulated *Moringa*-fortified jackfruit seed milk has considerable potential as a nutritious and functional dairy alternative.

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