

ORIGINAL ARTICLE

Food Chemistry, Engineering, Processing and Packaging | Functional and Novel Foods

Evaluation of Phytochemical, Functional and Mineral Composition of Extruded Breakfast Cereals Made from *Zea mays*, *Sorghum bicolor* and *Bryophyllum pinnatum* BlendsMusa Omotayo Jimoh¹ Oyindamola Comfort Olatunde² Omolara Folakemi Adeniji³ ¹ College of Engineering, Department of Agricultural and Biosystems Engineering, Food Processing Laboratory, Bells University of Technology, Ota, Bells University of Technology, Ota, Nigeria, Km 8, Idiroko Road, Benja Village, P.M.B. 1015, Ota, Ogun State, Nigeria. jmotayo@bellsuniversity.edu.ng² College of Food, Agricultural Science and Technology, Department of Food Science and Technology, Food Processing Laboratory, Bells University of Technology, Ota, Bells University of Technology, Ota, Nigeria, Km 8, Idiroko Road, Benja Village, P.M.B. 1015, Ota, Ogun State, Nigeria. Olatundeoyindamola046@gmail.com³ College of Natural and Applied Sciences, Department of Biological Sciences, Biology Laboratory, Bells University of Technology, Km 8, Idiroko Road, Benja Village, P.M.B. 1015, Ota, Ogun State, Nigeria. ofadeniji@bellsuniversity.edu.ng

ABSTRACT

Background: Breakfast cereals are a staple food that provides nutritional and sensory benefits. Incorporating plant-based ingredients with bioactive properties may enhance their nutritional and functional value.**Aims:** This study aimed to evaluate the effect of *Bryophyllum pinnatum* leaf powder on the functional, pasting, mineral, phytochemical, and sensory properties of extruded breakfast cereals produced from maize (*Zea mays*) and sorghum (*Sorghum bicolor*) flour blends.**Methods:** Five samples (MSB1, MSB2, MSB3, MSB4, and MSB5) were formulated from maize flour, sorghum flour and *Bryophyllum pinnatum* leaf powder at ratios of 70:28:2, 73:23:4, 78:16:6, 60:32:8, and 66:24:10 respectively, and were extruded. The functional, pasting, mineral, phytochemical, and sensory properties of the extrudates were determined.**Results:** Bulk density, water absorption capacity, oil absorption capacity, swelling power, and solubility index ranged from 0.67 to 0.71 g/cm³, 1.70 to 1.88 g/g, 1.68 to 1.83 g/g, 9.07 to 11.19%, and 19.84 to 27.51%, respectively. Peak, trough, breakdown, final, setback viscosities ranged from 160 to 401.50 RVU, 140.50 to 357.50 RVU, 14.50 to 44 RVU, 337.50 to 828 RVU, 190.50 to 470.50 RVU, while pasting time ranged from 6.97 to 7.00 min. Sodium, potassium, calcium, iron, and zinc content ranged from 41.62 to 56.73 mg/100 g, 290.15 to 317.75 mg/100 g, 61.47 to 65.57 mg/100 g, 0.75 to 0.95 mg/100 g, and 0.44 to 0.66 mg/100 g respectively. Total phenolic content, total flavonoid content, and antioxidant activity ranged from 36 to 80.80 mg/mL, 101.10 to 201.90 mg/mL, and 28.91 to 306 µg/mL, respectively. Sensory evaluation revealed no significant differences ($p > 0.05$) in overall acceptability among MSB1, MSB2, and MSB3. The regression models yielded R² values of 0.86 for phenolic content and 0.99 for flavonoid content.**Conclusions:** The inclusion of *B. pinnatum* leaf powder significantly influenced the functional, pasting, mineral, and phytochemical properties of the extruded breakfast cereals, and the formulations with lower inclusion levels (MSB1–MSB3) remained equally acceptable to panelists.**Keywords:** Extrusion; Breakfast Cereal; Phytochemicals; Functional Properties; Nutrition.

Article Information

✉ **Corresponding authors:** Musa Omotayo Jimoh
E-mail : omotayojimoh50@gmail.com /
jmotayo@bellsuniversity.edu.ng
Tel. (+234) 7039394673**Received:** August 18, 2025**Revised:** June 17, 2026**Accepted:** September 05, 2026**Published:** October 09, 2026Cite this article as: Jimoh, M. O. Olatunde, O. C., & Adeniji, O. F. (2026). Evaluation of Phytochemical, Functional and Mineral Composition of Extruded Breakfast Cereals Made from *Zea mays*, *Sorghum bicolor* and *Bryophyllum pinnatum* Blends. *The North African Journal of Food and Nutrition Research*, 10 (22): 99 – 108.
<https://doi.org/10.51745/najfnr.10.22.99-108>© 2026 The Author(s). This is an open-access article. This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The images or other third-party material in this article are included in the article's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit <http://creativecommons.org/licenses/by/4.0/>

1 INTRODUCTION

Maize (*Zea mays* L.) is an annual crop belonging to the family Poaceae, with its center of origin in Mexico and Central America. Maize is a versatile and multi-purpose crop of considerable global agricultural significance, utilized extensively as both a human food and an animal feed ingredient. A wide range of food products can be derived from maize, including flour, starch, breakfast cereals, snacks, and cornmeal. Yellow maize varieties are particularly noteworthy for their abundance of carotenoid pigments,

which have been associated with protective effects against certain forms of cancer (Ujong *et al.*, 2023). In livestock nutrition, maize serves as a primary energy source, additionally providing crude protein, dietary fiber, and carbohydrates. Whilst maize contributes a range of essential amino acids to the diet, it is characteristically deficient in certain critical amino acids — most notably lysine and tryptophan. Beyond its carbohydrate and protein fractions, maize provides an array of nutritionally essential nutrients, including minerals, vitamins, and antioxidant compounds,

with notably high concentrations of potassium, sodium, chlorine, and sulfur (Revilla *et al.*, 2022). Despite its relatively lower content of certain essential amino acids, maize remains a nutritionally significant food source by virtue of its rich diverse composition of other essential nutrients.

Sorghum (*Sorghum bicolor* L.) is a major cereal crop belonging to the family Poaceae, originating in Africa, where it continues to constitute a dietary staple for numerous rural populations. The crop is primarily cultivated on shallow, heavy clay soils under dry climatic conditions, with an optimal growth temperature of approximately 25 °C (Mundia *et al.*, 2019). Globally, sorghum ranks as the fifth most extensively produced cereal grain after maize, wheat, rice, and barley. Its high yield potential and pronounced tolerance to heat and drought stress have facilitated the progressive substitution of maize by sorghum in certain arid and semi-arid production areas. Sorghum grain is available in a range of color variants, spanning cream, lemon-yellow, red, and black. This crop represents a cost-effective, high-yield cereal with numerous potential health benefits attributable to its slow starch digestibility, antioxidant activity, and anticancer properties — characteristics that confer upon regular sorghum consumers a measurably reduced risk of type 2 diabetes mellitus and certain cancers (Espitia-Hernández *et al.*, 2022). Whilst sorghum is relatively straightforward to produce and economically accessible, global per capita consumption of sorghum grain remains lower than that of wheat and maize. Nevertheless, growing global interest in functional and health-promoting foods, combined with the crop's environmental resilience and sustainability credentials, has created new and expanding opportunities for sorghum as a primary raw material for human food formulation. Sorghum possesses higher gross energy content than several other cereal grains, alongside appreciable concentrations of protein, complex carbohydrate, and fat. Its rich nutritional profile and gluten-free composition have contributed to the rapid growth in its popularity as a viable alternative grain for individuals with wheat allergy or celiac disease.

Bryophyllum Pinnatum (Lam.) Oken, a member of the family Crassulaceae, is a perennial succulent herb of considerable ethnopharmacological significance, widely regarded as one of the most promising medicinal plants for health promotion and disease amelioration. The plant grows wild and is cultivated for both traditional medicinal and ornamental purposes across tropical Africa, China, Australia, tropical America, and India, where it is grown as a decorative house plant in gardens and on rocky substrates. Commonly known under the vernacular designations of life plant, air plant, Canterbury bells, cathedral bells, and resurrection plant, *B. pinnatum* has demonstrated broad pharmacological utility in the treatment of a diverse array of conditions, including wound healing, peptic ulcer, diabetes mellitus,

inflammation, pain, and bacterial infections (Sharma *et al.*, 2024). The principal pharmacologically active constituents of the plant include flavonoids, alkaloids, saponins, and triterpenoid compounds, which collectively underpin its well-documented bioactive properties and its longstanding use in traditional medicine systems across multiple continents (Selvakumar, 2022).

Breakfast cereals are defined as processed food products manufactured from cereal grains that have been subjected to swelling, crushing, rolling, or flaking operations and are conventionally consumed as the first meal of the day (Ezegbe *et al.*, 2025). Breakfast cereals are broadly categorized into two principal product types: ready-to-eat cereals, typically consumed with milk or cream without further preparation, and traditional hot cereals, which require cooking or heating prior to consumption (Ujong *et al.*, 2023). Wheat and maize constitute the most widely utilized raw materials in breakfast cereal manufacture, predominantly processed into refined flours containing limited concentrations of vitamins, minerals, and dietary fiber (Lima *et al.*, 2023). For a substantial proportion of consumers who forego breakfast due to time constraints, demanding schedules, or reduced morning appetite, breakfast cereals represent a convenient, nutritionally valuable, and easily preparable dietary option. Their growing popularity across all age groups reflects their high nutritional density and ease of preparation. Breakfast cereals supply a range of essential nutrients, including protein, energy, and dietary fiber, minerals, amino acids, and other micronutrients, critical to the maintenance of health and the prevention of diet-related conditions such as protein-energy malnutrition and hypercholesterolemia (Akinyemi *et al.*, 2022).

Against this background, the development of an innovative breakfast cereal formulation incorporating *Bryophyllum pinnatum* as a bioactive functional ingredient — offering a unique nutrient-enriched blend beyond the limitations of conventional cereal products — represents a scientifically compelling and practically relevant research direction. The present study therefore focused on the evaluation of the mineral composition, phytochemical profile, functional properties, and pasting characteristics of composite cereal flours prepared from blends of maize, sorghum and *B. pinnatum* leaf powder, as well as the sensory acceptability of extruded breakfast cereal sweetened with date palm fruit powder.

2 MATERIALS AND METHODS

2.1 Raw Materials and Study Site

Yellow maize, sorghum grain, and date palm fruits were procured from Atan market, Ogun State, Nigeria. Mature

Bryophyllum pinnatum leaves were sourced from the Botanical Garden, Department of Botany, University of Lagos, Nigeria. All experiment procedures, including composite flour preparation and product formulation, were carried out in the Food Processing Laboratory and Central Research Laboratory, Bells University of Technology, Ota, Nigeria. Extrusion processing was performed using a KE19 Brabender single-screw extruder.

2.2 Preparation of *Bryophyllum Pinnatum* Leaf Powder

Fresh *B. pinnatum* leaves were carefully sorted to remove damaged, diseased, or senescent material. The selected leaves were immersed in boiling water for 2 to 3 minutes to facilitate the removal of thermolabile toxic compounds, after which the water was drained completely and the leaves were cut into smaller pieces to reduce particle size and facilitate drying. The prepared leaf pieces were spread in a single layer on stainless steel trays and dried in a hot-air oven at 40°C for 6 hours until complete moisture removal was achieved (Selvakumar, 2022). The dried leaves were allowed to cool to ambient temperature, finely ground using a laboratory electric grinder, and sieved to obtain a uniform fine powder. The resulting *B. pinnatum* leaf powder was sealed in polyethylene bags and stored at ambient temperature until further use.

2.3 Experimental Design and Extrusion Processing

Five composite flour blends were formulated, in which sucrose was substituted with date palm fruit powder at a fixed inclusion level of 400 g per blend. The composite flour formulations were developed using an optimal mixture experimental design generated by Design Expert software (Version 11; Stat-Ease Inc., Minneapolis, MN, USA). The five experimental blends — designated MSB1 through MSB5—were formulated by combining maize flour, sorghum flour, and *B. pinnatum* leaf powder at the following mass ratios: MSB1 (70:28:2), MSB2 (73:23:4), MSB3 (78:16:6), MSB4 (60:32:8), and MSB5 (66:24:10) respectively. A formulation comprising 100% maize flour served as the control.

Prior to extrusion, each composite flour blend was conditioned with distilled water to a moisture content of 20% (wet basis) and thoroughly mixed to ensure homogeneity. The extruder barrel was preheated to 175°C, and the extruder screw was operated at 100 rpm throughout the extrusion process. Each conditioned flour blend was introduced into the feed hopper and discharged into the barrel at a screw speed of 50 rpm. The extrudates were collected on stainless steel trays and dried in a hot-air oven at 100°C for 3 hours. Following drying, the extrudates were cooled to 30°C and milled employing an attrition mill to obtain the final extruded

breakfast cereal powder. The complete processing flow for extruded breakfast cereal production is illustrated in Figure 1.

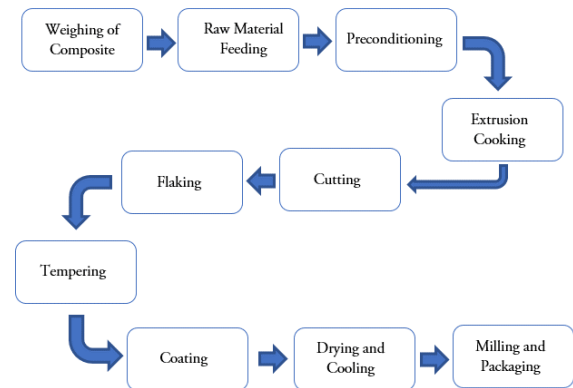


Figure 1. Flowchart For the Extruded Breakfast Cereal Production

2.4 Determination of Functional Properties

2.4.1 Water Absorption Capacity (WAC)

One gram of each flour blend was combined with 15 mL of distilled water in a 25 mL centrifuge tube and vortexed for 2 minutes at 4,000 rpm, followed by centrifugation for 20 minutes. The supernatant was carefully decanted and discarded, and the weight of the remaining hydrated residue was recorded (Adepeju et al., 2024). Water absorption capacity (WAC) was calculated as follows:

$$WAC_{(g/g)} = \frac{\text{Weight of swollen residue}}{\text{Weight of sample}} \dots\dots\dots(1)$$

2.4.2 Oil Absorption Capacity (OAC)

One gram of each flour sample was combined with 10 mL of commercial vegetable oil in a centrifuge tube and thoroughly mixed. This mixture was maintained at $30 \pm 2^\circ\text{C}$ for 60 minutes prior to centrifugation at $2,000 \times g$ for 30 minutes. The unabsorbed oil was carefully transferred to a 10 mL graduated cylinder and its volume was recorded (Oladele et al., 2023). OAC was calculated as follows:

$$OAC_{\left(\frac{mL}{g}\right)} = \frac{\text{Volume of oil used} - \text{Volume of supernatant}}{\text{Weight of sample}} \dots\dots\dots(2)$$

2.4.3 Swelling Capacity

One gram of each flour sample was transferred to a centrifuge tube and combined with 10 mL of distilled water. The suspension was heated to 90°C for 30 minutes with occasional agitation to ensure uniform gelatinization of the starch granules. The heated mixture was subsequently

centrifuged at 3,500 rpm for 20 minutes, the supernatant was decanted, and the weight of the resulting paste or precipitate was recorded (Ratnaningsih and Arovah, 2025).

$$\text{Swelling capacity \%} = \frac{\text{Weight of precipitate}}{\text{Weight of dry flour}} \dots\dots\dots(3)$$

2.4.4 Bulk Density

Five grams of each flour sample were carefully transferred to a 50 mL graduated cylinder. The base of the cylinder was tapped repeatedly on a firm surface until no further reduction in sample volume was observed. Bulk density was calculated as follows:

$$\text{Bulk density (g/mL)} = \frac{\text{Weight of sample}}{\text{Volume in the cylinder}} \dots\dots\dots(4)$$

2.5 Determination of Pasting Properties

Pasting properties were determined employing Rapid Visco Analyzer (RVA-3C; Newport Scientific, Warriewood, Australia). For each analysis, 2 g of flour sample was weighed into a new aluminum canister containing 25 ml of distilled water, and the resulting slurry was heated to 50°C for 2 minutes as an initial equilibration step. Subsequent heating and cooling cycles were applied at a constant rate of 11.25 °C min⁻¹ (Oladele *et al.*, 2023). The following pasting parameters were recorded: peak viscosity, trough viscosity, breakdown viscosity, setback viscosity, final viscosity, and pasting temperature.

2.6 Determination of Mineral Composition

The concentrations of selected mineral elements — specifically sodium (Na), calcium (Ca), iron (Fe), potassium (K), and zinc (Zn) — were determined in each composite flour blend by flame atomic absorption spectrophotometry (AAS), using an AA670 atomic absorption spectrophotometer (Shimadzu Corporation, Kyoto, Japan), in accordance with AOAC, (2019) standard procedures.

2.7 Determination of Phytochemical Composition

Phytochemical extraction was performed using 95% ethanol as the extraction solvent. Fifty grams of each flour sample were dissolved in 100 mL of ethanol-based solvent (Thakur *et al.*, 2025) and the resulting mixture was in an orbital shaker incubator at 60 °C and 140 rpm for 4 hours to facilitate thorough extraction of phytochemical constituents. The mixture was filtered through Whatman No. 1 filter paper and the resulting filtrate was concentrated at 30 ± 2°C under reduced pressure. The concentrated extract was stored at 4°C until further analysis. The percentage extraction yield was calculated for each sample.

2.7.1 Total Phenolic Content (TPC)

Total phenolic content was determined using Folin-Ciocalteu (FC) colorimetric method as described by Thakur *et al.* (2025). Absorbance was spectrophotometrically measured at 765 nm. Results were calculated against a gallic acid standard calibration curve and expressed as milligrams of gallic acid equivalent per milliliter of extract (mg GAE/mL).

2.7.2 Total Flavonoids Content (TFC)

An aliquot of 0.0125 mL of ethanol extract was dissolved in 1 mL of methanol and diluted with 10 mL of distilled water. The following reagents were subsequently added sequentially: 0.5 mL of ethanol extract, 0.1 mL of aluminum chloride (AlCl₃) solution, 0.1 mL of sodium acetate (CH₃COONa) solution, and 2.85 mL of distilled water. The mixture was thoroughly homogenized and incubated in the dark for 20 minutes. Absorbance was measured at 510 nm employing a UV-Vis spectrophotometer. Results were calculated against a quercetin standard calibration curve and expressed as milligrams of quercetin equivalent per gram of extract (mg QE/g).

2.7.3 DPPH Radical Scavenging Activity

The free radical scavenging activity of each flour extract was assessed using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging assay, as previously described by Nguyen *et al.* (2023). The reaction mixture, containing composite flour extract and a DPPH working solution (0.1 mM in ethanol), was incubated in the dark for 30 minutes, and absorbance was measured at 517 nm. Ferulic acid served as the reference standard, and results were expressed as milligrams of ferulic acid equivalent per gram of fresh weight (mg FAE/g).

2.7.4 Sensory Evaluation

Sensory acceptability of extruded breakfast cereal formulations was evaluated by a semi-trained panel of 50 assessors comprising male and female staff members of Bells University of Technology, Ota, Nigeria aged between 25 and 60 years. Each panelist independently evaluated all samples using a structured nine-point Hedonic scale, where a score of 9 indicated extreme liking and a score of 1 indicated extreme dislike. Samples were presented to panelists in coded containers, with randomized sample presentation order to minimize order and carry-over bias. The following sensory attributes were assessed: appearance, aroma, taste, mouthfeel, color, and overall acceptability.

2.8 Statistical Analysis

All data were subjected to one-way analysis of variance (ANOVA), and statistically significant differences among treatment means were identified using Duncan's Multiple Range Test (DMRT) at a significance level of $p < 0.05$. All

statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS, Version 23.0; IBM Corp., Armonk, NY, USA).

3 RESULTS

3.1 Functional Properties of the Flour Blends

The functional properties of the flour blends are presented in Table 1. The lowest bulk density (0.67 g/cm^3) was recorded for MSB1 and MSB4, whereas MSB2, MSB3, and MSB5 exhibited the highest value (0.71 g/cm^3), which was comparable to that of the standard breakfast cereal flour. Water absorption capacity (WAC) was lowest in MSB1 (2% *B. pinnatum*; 170.15 g/100g) and highest in MSB5 (10% *B. pinnatum*; 188.29 g/100 g); both values exceeded that of the control (134.09 g/100 g). Conversely, oil absorption capacity (OAC) was lowest in MSB5 (168.78 g/100g) and highest in MSB1 (183.02 g/100 g), the latter being marginally lower than the control (184.12 g/100 g). These results indicate that the incorporation of *B. pinnatum* enhanced the water

3.2 Pasting Properties of the Flour Blends

MSB4, which contained the highest proportion of sorghum (32%), exhibited the highest peak, trough, breakdown, final, and setback viscosities, at 401.50, 357.50, 44.00, 828.00, and 470.50 RVU, respectively (Table 2). However, these differences were statistically significant ($p > 0.05$). Pasting viscosities tended to increase with increasing *B. pinnatum* content beyond 8% and to decline thereafter. Peak viscosity ranged from 160.00 to 401.50 RVU, and trough viscosity ranged from 140.50 to 357.50 RVU, the latter being close to that of the control (150.00 RVU). Breakdown viscosity ranged from 14.50 to 44.00 RVU; such low values suggest that the starch in the blends was relatively resistant to heat and shear, possibly owing to restricted granule swelling or starch cross-linking interactions. Final viscosity ranged from 337.50 to 828.00 RVU, and setback viscosity ranged from 190.50 to 470.50 RVU. Pasting time did not differ significantly among the flour samples.

Table 1. Functional Properties of Flour Blends

Sample	Bulk density (g/cm ³)	Water absorption capacity (g/100 g)	Oil absorption capacity (g/100 g)	Swelling power capacity (%)	Solubility index (%)
MSB1	0.67 ± 0.06^a	170.15 ± 0.02^e	183.02 ± 0.03^b	10.72 ± 0.06^a	22.42 ± 1.51^{abc}
MSB2	0.71 ± 0.00^a	176.38 ± 0.03^d	180.25 ± 0.04^c	11.05 ± 0.03^a	27.20 ± 0.99^{ab}
MSB3	0.71 ± 0.00^a	179.16 ± 0.03^c	176.09 ± 0.03^d	11.19 ± 0.08^a	27.05 ± 4.60^{ab}
MSB4	0.67 ± 0.00^a	184.34 ± 0.04^b	171.30 ± 0.04^e	11.12 ± 0.04^a	27.51 ± 3.10^a
MSB5	0.71 ± 0.00^a	188.29 ± 0.04^a	168.78 ± 0.08^f	9.07 ± 1.06^b	19.84 ± 3.16^c
MF	0.71 ± 0.00^a	134.09 ± 0.03^f	184.12 ± 0.04^a	8.78 ± 0.11^b	20.34 ± 1.18^{bc}

Note: Values are presented in mean $\pm$ standard deviation. Values with different superscripts within a column are significantly different ($p < 0.05$)

MSB1: 70% Maize + 28% Sorghum + 2% *B. pinnatum*; MSB2: 73% Maize + 23% Sorghum + 4% *B. pinnatum*; MSB3: 78% Maize + 16% Sorghum + 6% *B. pinnatum*; MSB4: 60% Maize + 32% Sorghum + 8% *B. pinnatum*; MSB5: 66% Maize + 24% Sorghum + 10% *B. pinnatum*; MF: 100% Maize flour.

absorption capacity but reduced the oil absorption capacity of the flour blends. Swelling power ranged from 9.07% (MSB5) to 11.19% (MSB3), values that were higher than that of the control (8.78%). The solubility index ranged from 19.84% (MSB5) to 27.51% (MSB4), compared with 20.34% for the control.

3.3 Mineral Composition of the Flour Blends

The mineral composition of the breakfast cereal flours produced from maize, sorghum, and *B. pinnatum* blends is presented in Table 3. The content of sodium, potassium, calcium, iron, and zinc ranged from 41.62 to 56.73, 290.15 to 317.75, 61.47 to 65.57, 0.75 to 0.95, and 0.44 to 0.66

Table 2. Pasting Properties of Flour Blends

Sample	Peak viscosity (RVU)	Trough viscosity (RVU)	Breakdown Viscosity (RVU)	Pasting Time (min)	Final Viscosity (RVU)	Set Back Viscosity (RVU)
MSB1	161.50 ± 3.54^a	147.00 ± 2.83^a	14.50 ± 0.71^b	7.00 ± 0.00^a	337.50 ± 1.61^a	190.50 ± 7.78^a
MSB2	160.00 ± 4.25^a	143.50 ± 3.54^a	16.50 ± 0.71^{ab}	6.97 ± 0.05^a	339.00 ± 8.49^a	195.50 ± 4.95^a
MSB3	162.50 ± 6.36^a	140.50 ± 4.95^a	22.00 ± 1.41^{ab}	7.00 ± 0.00^a	349.00 ± 8.38^a	208.50 ± 3.44^a
MSB4	401.50 ± 7.82^a	357.50 ± 3.95^a	44.00 ± 6.87^a	7.00 ± 0.00^a	828.00 ± 4.57^a	470.50 ± 2.62^a
MSB5	186.50 ± 3.54^a	163.00 ± 2.83^a	23.50 ± 0.71^{ab}	7.00 ± 0.00^a	395.00 ± 4.24^a	232.00 ± 1.41^a
MF	184.00 ± 9.90^a	150.00 ± 5.66^a	34.00 ± 4.24^{ab}	7.00 ± 0.00^a	422.50 ± 9.09^a	272.50 ± 3.44^a

Note: Values are presented in mean $\pm$ standard deviation. Values with different superscripts within a column are significantly different ($p < 0.05$)

MSB1: 70% Maize + 28% Sorghum + 2% *B. pinnatum*; MSB2: 73% Maize + 23% Sorghum + 4% *B. pinnatum*; MSB3: 78% Maize + 16% Sorghum + 6% *B. pinnatum*; MSB4: 60% Maize + 32% Sorghum + 8% *B. pinnatum*; MSB5: 66% Maize + 24% Sorghum + 10% *B. pinnatum*; MF: 100% Maize flour.

Table 3. Mineral Composition of Flour Blends

Sample	Sodium (mg/100 g)	Potassium (mg/100 g)	Calcium (mg/100 g)	Iron (mg/100 g)	Zinc (mg/100 g)
MSB1	41.62±0.01 ^f	290.15±0.06 ^f	61.47±0.02 ^f	0.75±0.05 ^d	0.44±0.01 ^e
MSB2	44.88±0.02 ^e	298.17±0.01 ^e	62.93±0.02 ^e	0.79±0.01 ^{cd}	0.48±0.01 ^d
MSB3	47.67±0.01 ^d	304.44±0.01 ^c	63.87±0.02 ^d	0.83±0.01 ^c	0.55±0.01 ^c
MSB4	51.58±0.02 ^b	311.53±0.02 ^b	64.92±0.02 ^c	0.91±0.03 ^{ab}	0.61±0.02 ^b
MSB5	56.73±0.02 ^a	317.75±0.02 ^a	65.57±0.02 ^b	0.95±0.03 ^a	0.66±0.01 ^a
MF	51.40±0.02 ^c	301.44±0.01 ^d	65.68±0.02 ^a	0.86±0.01 ^{bc}	0.64±0.01 ^{ab}

Note: Values are presented in mean ± standard deviation. Values with different superscripts within a column are significantly different ($p < 0.05$)

MSB1: 70% Maize + 28% Sorghum + 2% *B. pinnatum*; MSB2: 73% Maize + 23% Sorghum + 4% *B. pinnatum*; MSB3: 78% Maize + 16% Sorghum + 6% *B. pinnatum*; MSB4: 60% Maize + 32% Sorghum + 8% *B. pinnatum*; MSB5: 66% Maize + 24% Sorghum + 10% *B. pinnatum*; MF: 100% Maize flour

mg/100 g, respectively. MSB5 and MSB1 displayed the highest and lowest mineral contents respectively. The mineral contents of the blends increased significantly as the proportion of *B. pinnatum* content increases from 2% to 10%.

3.4 Phytochemical Composition of the Flour Blends

The phytochemical composition of the samples is summarized in Table 4. Total phenolic content and antioxidant activity were highest in MSB2, at 80.80 mg GAE/mL GAE and 306 µg/mL, respectively, whereas total flavonoid content was highest in MSB4 (219.90 mg QE/mL). MSB1, which contained the lowest proportion of *B. pinnatum* content (2%), exhibited the lowest TPC (36.00 mg GAE/mL) and TFC (101.10 mg QE/mL). The antioxidant activity of the control was relatively high (354.10 µg/mL), suggesting that maize flour possesses considerable antioxidant capacity. Total flavonoid content increased significantly as *B. pinnatum* inclusion increased from 2% to 8%, whereas total phenolic content decreased as inclusion increased from 4% to 8%. The phenolic content observed here was higher than that reported by Allai et al. (2022) for whole-grain products containing Indian horse chestnut flour (10.66–29.38 mg GAE/g). This difference may be attributed to the inclusion of *B. pinnatum*, as phenolic content differed significantly among the samples ($p < 0.05$).

Table 4. Phytochemical Composition of Flour Blends

Sample	TPC (mg/mL GAE)	TFC (mg/mL QE)	Antioxidant Activity (µg/mL)
MSB1	36.00±0.14 ^f	101.10±0.14 ^f	28.91±0.14 ^e
MSB2	80.80±0.14 ^a	139.90±0.14 ^d	306.00±0.14 ^b
MSB3	68.45±0.14 ^c	159.60±0.14 ^b	27.49±0.14 ^f
MSB4	61.98±0.14 ^d	219.90±0.14 ^a	44.00±0.14 ^d
MSB5	76.10±0.14 ^b	144.00±0.14 ^c	210.20±0.14 ^c
MF	44.90±0.14 ^e	118.70±0.14 ^e	354.10±0.14 ^a

Note: Values are presented in mean ± standard deviation. Values with different superscripts within a column are significantly different ($p < 0.05$). MSB1: 70% Maize + 28% Sorghum + 2% *B. pinnatum*; MSB2: 73% Maize + 23% Sorghum + 4% *B. pinnatum*; MSB3: 78% Maize + 16% Sorghum + 6% *B. pinnatum*; MSB4: 60% Maize + 32% Sorghum + 8% *B. pinnatum*; MSB5: 66% Maize + 24% Sorghum + 10% *B. pinnatum*; MF: 100% Maize flour

3.5 Sensory Attributes of the Extruded Product

The sensory evaluation of the extruded breakfast cereals produced from maize and sorghum flours fortified with *B. pinnatum* (Figure 2) exhibited significant decrease in color (6.48–4.30), appearance (6.52–4.80), aroma (7.30–5.54), taste (6.30–4.00), mouthfeel (6.30–4.00), and overall acceptability (6.30–4.00) as the proportion of *B. pinnatum* increased from 2% to 10%. However, no significant differences ($p > 0.05$) were observed in any sensory attribute among MSB1, MSB2, and MSB3, and the control (MF).

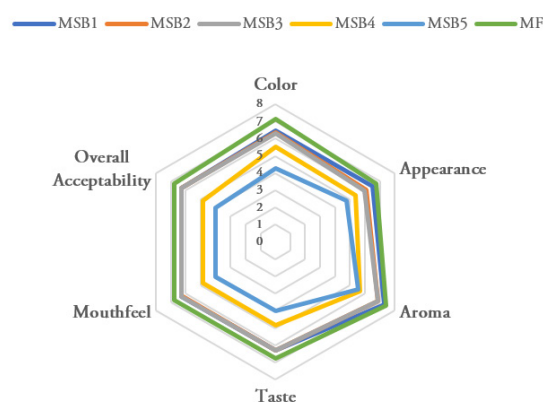


Figure 2. Sensory Evaluation of Extruded Breakfast Cereal

MSB1: 70% Maize + 28% Sorghum + 2% *B. pinnatum*; MSB2: 73% Maize + 23% Sorghum + 4% *B. pinnatum*; MSB3: 78% Maize + 16% Sorghum + 6% *B. pinnatum*; MSB4: 60% Maize + 32% Sorghum + 8% *B. pinnatum*; MSB5: 66%

4 DISCUSSION

A comprehensive assessment of the technical and economic feasibility of inclusion of *Bryophyllum pinnatum* into extruded cereals is lacking in the literature, which hinders informed decisions on the viability of such formulations. With the increasing demand for healthier food options, innovative approaches are required to enhance the nutritional value of breakfast cereals and to meet evolving consumer preferences. There optimal blending ratios of maize, sorghum, and *B. pinnatum* for extruded cereal production,

and their combined effects on nutritional quality, remain insufficiently understood. Furthermore, the sensory attributes of extruded cereals combining these three ingredients have scarcely been explored, which raises questions about consumer acceptance of their taste, texture, and aroma.

Orngu and Mbaeyi-Nwaoha (2022) reported bulk densities ranging from 0.60 to 0.77 g/cm³ for instant breakfast cereals made from blends of yellow maize, sesame, and oyster mushroom flours; the values obtained in the present study fall within this range. Bulk density provides useful information on the porosity of food products. Porous cereal flours are generally characterized by irregularly shaped particles and increased compressibility, and they tend to exhibit poor flowability and high cohesiveness. Determining bulk density is also relevant for processing and packaging, as it indicates the volume that a given mass of composite flour will occupy and how the flour will behave during handling and storage, which supports product quality and consistency (Adepeju et al., 2024).

WAC of the blends (170.15 to 188.29 g/100 g) exceeded that of the control (134.09 g/100 g). This increase may be attributed to hydrophilic constituents, such as free carbohydrate and protein groups, which are readily available to interact with water molecules (Bala et al., 2020). Fiber from the added *B. pinnatum* leaf powder may also have contributed, since WAC rose with increasing inclusion levels. Oil absorption capacity (OAC) decreased from 183.02 to 168.78 g/100 g as *B. pinnatum* inclusion increased from 2% to 10%, whereas the control recorded 184.12 g/100 g; the differences among the blends were significant ($p < 0.05$). Additionally, the incorporation of dates likely contributed to the higher OAC, further improving its ability to absorb oil (Hassain et al., 2020). The relatively high OAC of the blends may be associated with the fiber and carbohydrate contents of maize and sorghum, which favor oil retention. OAC is an important functional attribute because oil retention contributes to flavor retention and mouthfeel, which enhance palatability, particularly in bakery-type products in which fat absorption is desirable (Juliante et al., 2017).

MSB3 exhibited the highest swelling power capacity, which may be attributed to its high proportion of maize (78%). Swelling power reflects the capacity of a product to absorb water and increase in volume. Swelling power did not differ significantly among the samples ($p > 0.05$), except for MSB5, and the values were higher than those reported for breakfast cereals made from millet, soybean, and dates probably because of the relatively high starch content of maize and sorghum.

The pasting properties of starch are influenced by amylose content, by non-starch components such as proteins and lipids, and by processing conditions. These factors affect

govern the behavior of starch during heating and mixing and, consequently, the textural properties of the final product. The peak viscosity of the blends (160 to 401.50 RVU) covered a wide range, which may be related to the gradual increase in sorghum. These interactions could affect the gelatinization process, leading to a weaker paste formation.

Breakdown viscosity reflects the flour's capacity to withstand heat and shear stress during processing (Mubaiwa et al., 2018), whereas trough viscosity indicates the resistance of the cooked paste to disintegration during cooling. The pasting time recorded here was similar to that reported for breakfast cereals made from yellow maize, soybean, and pumpkin flours (6.80 to 7 minutes; Asaam et al., 2018). Final viscosity is employed to assess the gel-forming ability of flour after progressive cooking and subsequent cooling, and it provides information about on the texture and structural stability of the product. Setback viscosity indicates the tendency toward retrogradation and gel stability. The setback values obtained here were lower than those reported for cassava and chia seed flour blends (727 to 948 RVU; Katunzi-Kilewela et al., 2023), which suggests low degree of retrogradation and slow down rate of spoilage, thus guarantee food safety.

The mineral content increased significantly as the inclusion of *B. pinnatum* increases from 2% to 10%, which is consistent with the mineral richness of the plant. The potassium content of the cereals is relevant to physiological functions such as muscle contraction, intracellular cation balance, and osmotic pressure regulation (Adepeju et al., 2024). The calcium content of the cereals was lower than recommended daily allowance, indicating that additional dietary sources of calcium would be required to meet daily needs. The iron content was comparable to values reported for blends of acha and fermented soybean (0.45 to 1.10 mg/100 g; Mbaeyi and Uchendu, 2016). In contrast, the zinc content was relatively low compared with that reported for flour blends of yellow maize, sorghum, and date palm (4.11 to 5.36 mg/100 g; Adepeju et al., 2024). Such differences may arise from processing methods, soil characteristics, and the season of harvest.

Phenolic compounds can neutralize free radicals and thereby protect cells against oxidative stress and damage, contributing to the prevention of various diseases. The total flavonoid content of the samples was similar to that reported for a composite flour containing baobab pulp (208.06 mg QE/mL; Dossa et al., 2023). The highest flavonoid content was recorded in MSB4, which may be attributed to its high proportion of sorghum; sorghum has been widely studied for its substantial flavonoid content and for the variation in flavonoid accumulation among varieties. Flavonoids are also reported to potentiate the effects of ascorbic acid (Vitamin

C). Flavonoid content and antioxidant activity differed significantly among the flour blends at the 5% level of significance.

Color, appearance, aroma, taste, and mouthfeel scores decreased significantly as the proportion of *B. pinnatum* increased, and the control (MF), which contained no *B. pinnatum*, received the most favorable sensory scores. These findings indicate that the leaf powder adversely affected sensory quality at higher inclusion levels. Nevertheless, the overall acceptability of MSB1, MSB2, and MSB3 did not differ significantly ($p > 0.05$). The higher proportion of maize (78%) and lower proportion of sorghum (16%) in MSB3 may partly explain its sensory stability. The absence of *Bryophyllum pinnatum* in sample MF might be attributed to progressive performance in the sample's sensory attributes. Overall, MSB1, MSB2, and MSB3 were well accepted, with all ratings above 5, the minimum acceptable score on the nine-point hedonic scale used by the panelists.

5 CONCLUSIONS

Extrusion promotes effective mixing and heating of composite cereal flours, and it offers opportunities for value addition and for promoting food security and sustainable development. The inclusion of *Bryophyllum pinnatum* significantly increased water absorption capacity and the contents of sodium, potassium, calcium, iron, zinc, phenolics, and flavonoids. However, no significant difference in the pasting properties of extruded breakfast cereal samples was observed. A decrease in oil absorption capacity was noticed as the inclusion level increased. No significant differences were observed in the pasting properties of the samples. Extrusion at high temperature may have attenuated the pungent taste associated with *B. pinnatum*, and formulations containing up to 6% leaf powder (MSB1–MSB3) remained acceptable to the panelists. This study highlights the potential use of medicinal plants in functional foods. Further research should optimize the formulation variables for nutritional quality and evaluate the safety of the leaf powder for food applications. Optimizing the formulation variables for nutritional quality is recommended for further study.

Acknowledgment: There are no acknowledgments.

Source of funding: There was no support or funding for this study.

Acknowledgement: The authors would like to appreciate management, Bells University of Technology, Ota, Nigeria for providing facilities for this study.

Authors' Contribution: **Jimoh M.O.:** Conceptualization, Methodology, Project administration, Data curation, Investigation, Writing – review and editing, Supervisor, Validation. **Olatunde C.O.:** Writing – original draft, Visualization, Data curation, Formal analysis and software. **Adeniji, O.F.:** Data Curation, Review and editing, Formal analysis and software.

Artificial Intelligence (AI) Use Statement: The authors declare that no artificial intelligence (AI)-assisted tools, large language models (LLMs), or AI-generated content were employed in any stage of the preparation of this manuscript, including the conception and design of the study, data collection and analysis, interpretation of results, or the writing, editing, and revision of the manuscript text. All intellectual content presented in this article is the sole and original work of the listed authors, who take full and collective responsibility for its accuracy, integrity, and originality.

Conflicts of Interest: The authors declare no conflict of interest in this work.

Preprint deposit: None.

REFERENCES

- Adepeju, A. B., Aluko, D. M., Olugbuyi, A. O., Oyinloye, A. M., & Adeniran, O. O. (2024). Assessment of mineral content, techno-functional properties and color of an extruded breakfast cereals using yellow maize, sorghum and date palm. *Helvion*, 10(6), Article e27650. <https://doi.org/10.1016/j.helivon.2024.e27650> [Crossref] [PubMed] [Google Scholar] [Publisher]
- Akinyemi, T. Y., Akinyede, A. I., & Oluwajuyitan, T. D. (2022). Extruded breakfast cereal from finger millet flour blends: Nutritional composition, in-vivo protein quality assessment and biochemical indices of rat fed. *NFS Journal*, 29, 35–42. <https://doi.org/10.1016/j.nfs.2022.10.001> [Crossref] [Google Scholar] [Publisher]
- Allai, F. M., Azad, Z. R., Dar, B. N., & Gul, K. (2022). Effect of extrusion processing conditions on the techno-functional, antioxidant, textural properties and storage stability of wholegrain-based breakfast cereal incorporated with Indian horse chestnut flour. *Italian Journal of Food Science*, 34(3), 105–123. <https://doi.org/10.15586/ijfs.v34i3.2238> [Crossref] [Google Scholar] [Publisher]
- AOAC. (2019). *Official methods of analysis* (18th ed.). Association of Official Analytical Chemists. [Publisher]
- Asaam, E. S., Adubofuor, J., Amoah, I., & Apeku, O. D. (2018). Functional and pasting properties of yellow maize-soya bean-pumpkin composite flours and acceptability study on their breakfast cereals. *Cogent Food & Agriculture*, 4(1), Article 1501932. <https://doi.org/10.1080/23311932.2018.1501932> [Crossref] [Google Scholar] [Publisher]
- Bala, M., Handa, S., Mridula, D., & Singh, R. K. (2020). Physicochemical, functional and rheological properties of grass pea (*Lathyrus sativus* L.) flour as influenced by particle size. *Helvion*, 6(11), Article e05471. <https://doi.org/10.1016/j.helivon.2020.e05471> [Crossref] [PubMed] [Google Scholar] [Publisher]
- Dossa, S., Negrea, M., Cocan, I., Berbecea, A., Obistioiu, D., Dragomir, C., Alexa, E., & Ravis, A. (2023). Nutritional, physico-chemical, phytochemical, and rheological characteristics of composite flour substituted by baobab pulp flour (*Adansonia digitata* L.) for bread making. *Foods*, 12(14),

- Article 2697. <https://doi.org/10.3390/foods12142697> [Crossref] [PubMed] [Google Scholar] [Publisher]
- Espitia-Hernández, P., Chávez González, M. L., Ascacio-Valdés, J. A., Dávila-Medina, D., Flores-Naveda, A., Silva, T., Ruelas-Chacón, X., & Sepúlveda-Torre, L. (2022). Sorghum (*Sorghum bicolor* L.) as a potential source of bioactive substances and their biological properties. *Critical Reviews in Food Science and Nutrition*, 62(8), 2269–2280. <https://doi.org/10.1080/10408398.2020.1852389> [Crossref] [PubMed] [Google Scholar] [Publisher]
- Ezegbe, C. C., Nkhata, S. G., Ukpong, E. S., Ezech, M. C., Okocha, K. S., & Pedro, B. F. (2025). Physicochemical and sensory quality of breakfast cereals produced from flour blends of maize and pigeon pea. *Heliyon*, 11(4), e42612. <https://doi.org/10.1016/j.heliyon.2025.e42612> [Crossref] [PubMed] [Google Scholar] [Publisher]
- Hussain, M. I., Farooq, M., & Syed, Q. A. (2020). Nutritional and biological characteristics of the date palm fruit (*Phoenix dactylifera* L.): A review. *Food Bioscience*, 34, Article 100509. <https://doi.org/10.1016/j.fbio.2019.100509> [Crossref] [PubMed] [Google Scholar] [Publisher]
- Julianti, E., Rusmarilin, H., Ridwansyah, & Yusraini, E. (2017). Functional and rheological properties of composite flour from sweet potato, maize, soybean and xanthan gum. *Journal of the Saudi Society of Agricultural Sciences*, 16(2), 171–177. <https://doi.org/10.1016/j.jssas.2015.05.005> [Crossref] [PubMed] [Google Scholar] [Publisher]
- Katunzi-Kilewela, A., Rweyemamu, L. M. P., Kaale, L. D., Kibazohi, O., & Fortunatus, R. M. (2023). Proximate composition, pasting and functional properties of composite flour blends from cassava and chia seeds flour. *Food Science and Technology International*, 29(3), 217–227. <https://doi.org/10.1177/10820132211069471> [Crossref] [PubMed] [Google Scholar] [Publisher]
- Lima, C. T., dos Santos, T. M., de Andrade Neves, N. A., Lavado-Cruz, A., Paucar-Menacho, L. M., Clerici, M. T. P. S., Meza, S. L. R., & Schmiele, M. (2023). New breakfast cereal developed with sprouted whole ryegrass flour: Evaluation of technological and nutritional parameters. *Foods*, 12(21), Article 3902. <https://doi.org/10.3390/foods12213902> [Crossref] [PubMed] [Google Scholar] [Publisher]
- Mbaeyi, I. E., & Uchendu, N. O. (2016). Production and evaluation of breakfast cereals from blends of acha and fermented soybean paste (Okara). *Journal of Food Science and Technology*, 53(1), 50–70. <https://doi.org/10.1007/s13197-015-2032-8> [Crossref] [PubMed] [Google Scholar] [Publisher]
- Mubaiwa, J., Fogliano, V., Chidewe, C., & Linnemann, A. R. (2018). Bambara groundnut (*Vigna subterranea* (L.) Verdc.) flour: A functional ingredient to favour the use of an unexploited sustainable protein source. *PLOS ONE*, 13(10), e0205776. <https://doi.org/10.1371/journal.pone.0205776> [Crossref] [PubMed] [Google Scholar] [Publisher]
- Mundia, C. W., Secchi, S., Akamani, K., & Wang, G. (2019). A regional comparison of factors affecting global sorghum production: The case of north America, Asia and Africa's Sahel. *Sustainability*, 11(7), 2135. <https://doi.org/10.3390/su11072135> [Crossref] [Google Scholar] [Publisher]
- Nguyen, T. H. D., Nguyen, L. L. P., & Baranyai, L. (2023). Influence of sprouting on phenolic acids, carotenoids, and antioxidant activity of millet varieties. *Journal of Agriculture and Food Research*, 14, Article 100810. <https://doi.org/10.1016/j.jafr.2023.100810> [Crossref] [Google Scholar] [Publisher]
- Oladele, A. K., Liman, A. A., Abass, M. F., & Ekawu, B. (2023). Chemical, techno-functional and antioxidant properties of tigernut (*Cyperus esculentus* L.) residue flour. *Fudma Journal of Agriculture and Agricultural Technology*, 9(1), 179–188. <https://doi.org/10.33003/jaaf.2023.0901.24> [Crossref] [Google Scholar] [Publisher]
- Orngu, O. A., & Mbaeyi-Nwaoha, I. E. (2022). Assessment of the anti-nutritional, functional and microbiological properties of instant breakfast cereals from yellow maize (*Zea mays*), sesame (*Sesamum indicum*) and oyster mushroom (*Pleurotus ostreatus*) flour blends. *Journal of Food Chemistry and Nanotechnology*, 8(3), 83–92. <https://doi.org/10.17756/jfcn.2022-130> [Crossref] [Google Scholar] [Publisher]
- Ratnaningsih, N., & Arovah, N. I. (2025). Structural, physicochemical properties, and resistant starch content of autoclaved arenga starch (*Arenga pinnata* (Wurmb) Merr). *Food Chemistry Advances*, 8(101090), 101090. <https://doi.org/10.1016/j.focha.2025.101090> [Crossref] [Google Scholar] [Publisher]
- Revilla, P., Alves, M. L., Andelkovic, V., Balconi, C., Dinis, I., Moreira, P. M., Redaelli, R., de Galarreta, J. I., Vas Patto, M. C., Zilic, S., & Malvar, R. A. (2022). Traditional foods from maize (*Zea mays* L.) in Europe. *Frontiers in Nutrition*, 8, Article 683399. <https://doi.org/10.3389/fnut.2021.683399> [Crossref] [PubMed] [Google Scholar] [Publisher]
- Selvakumar, P. (2022). Phytochemical and pharmacological profile review of *Bryophyllum pinnatum*. *Biomedical and Biotechnology Research Journal*, 6(3), 295–301. https://doi.org/10.4103/bbrj.bbrj_126_22 [Crossref] [Google Scholar] [Publisher]
- Sharma, G., Jangra, A., Sihag, S., Chaturvedi, S., Yadav, S., & Chhokar, V. (2024). *Bryophyllum pinnatum* (Lam.) Oken: unravelling therapeutic potential and navigating toxicity. *Physiology and Molecular Biology of Plants*, 30(9), 1413–1427. <https://doi.org/10.1007/s12298-024-01509-7> [Crossref] [PubMed] [Google Scholar] [Publisher]
- Thakur, M., Verma, R., Kumar, D., Sivakumar, M., & Malik, T. (2025). Investigation into the impact of solvents on the phytochemical composition, antioxidant capacities, and antihyperglycemic activities of *Erigeron annuus* (L.) Pers.

- BioMed Research International*, 2025(1), 6650124.
<https://doi.org/10.1155/bmri/6650124> [Crossref]
[PubMed] [Google Scholar] [Publisher]
- Ujong, A. E., Aniefiok, I. E., & Onyekwe, J. C. (2023). Nutrient composition and sensory properties of breakfast cereal made from yellow maize and enriched with soybean and groundnut flours. *Turkish Journal of Agriculture - Food Science and Technology*, 11(4), 651–656.
<https://doi.org/10.24925/turjaf.v11i4.651-656.5369>
[Crossref] [Google Scholar] [Publisher]