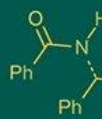


International Journal of Advanced Biochemistry Research



ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating (2026): 5.29
IJABR 2026; SP-10(8): 417-426
www.biochemjournal.com
Received: 13-06-2026
Accepted: 18-07-2026

Shobhi Choudhary
Ph.D. Scholar, College of
Technology, SVPUA&T,
Meerut, Uttar Pradesh, India

Dr. Neelesh Chauhan
Professor, College of
Technology SVPUA&T,
Meerut, Uttar Pradesh, India

Dr. Jaivir Singh
Professor, College of
Technology SVPUA&T,
Meerut, Uttar Pradesh, India

Dr. Suresh Chandra
Professor, College of
Technology SVPUA&T,
Meerut, Uttar Pradesh, India

Dr. Vineet Kumar Sharma
Associate Professor, College of
Technology, SVPUA&T,
Meerut, Uttar Pradesh, India

Dr. Gennitha Immanuel
Professor, CPH&T,
SVPUA&T, Meerut, Uttar
Pradesh, India

Dr. VP Singh
Department of Livestock
Product Technology,
SVPUA&T, Meerut, Uttar
Pradesh, India

Corresponding Author:
Shobhi Choudhary
Ph.D. Scholar, College of
Technology, SVPUA&T,
Meerut, Uttar Pradesh, India

Physicochemical and techno-functional characterization of a composite flour for biodegradable edible spoons

Shobhi Choudhary, Neelesh Chauhan, Jaivir Singh, Suresh Chandra, Vineet Kumar Sharma, Gennitha Immanuel and VP Singh

DOI: <https://www.doi.org/10.33545/26174693.2026.v10.i8Se.9512>

Abstract

The growing environmental burden of single-use plastic cutlery has intensified interest in biodegradable, edible alternatives derived from nutrient-rich plant sources. This Study presents a new composite flour prepared by mixing cereal (sorghum and finger millet), pulse (Bengal gram) and vegetables (carrot, turnip and bathua). Sorghum flour, finger millet flour, Bengal gram flour, carrot powder, turnip powder, and bathua powder were evaluated in a composite for its physical (bulk density, tapped density and moisture and ash content) and functional properties (water absorption capacity (WAC), oil absorption capacity (OAC), water absorption index (WAI), water solubility index (WSI), foaming capacity, foaming stability and emulsion activity) by one way ANOVA. The study revealed significant differences ($p < 0.05$) in the physical and functional properties of the flours, indicating that the botanical origin influences the hydration, emulsion, and foaming properties of the composite flours. Beyond its techno-functional suitability, composite flour offers a nutrient-dense, sustainable alternative to conventional single-ingredient edible cutlery and plastic disposables, while promoting the valorization of underutilized cereals, legumes, and vegetable powders. These findings establish a scientific foundation for tailoring composite flour formulations to specific structural food applications and support further development toward commercially viable, environmentally responsible food-service products.

Keywords: Composite flour, Sorghum flour, Finger millet, Bengal gram, Bathua powder, carrot powder, turnip powder, physicochemical properties, techno-functional properties, water absorption capacity, oil absorption capacity

1. Introduction

Recently, the rising demand for nutritious, wholesome, and sustainable food items has stimulated significant interest in developing composite flours from various plant-based raw materials. Composite flour technology involves the mixing of cereals, legumes, and vegetables into different flour formulations that have better nutritional value and functional properties than normal milled wheat flour. In addition to providing greater sources of fiber, minerals, vitamins, antioxidants, bioactive compounds, and other nutraceutical ingredients, composite flours help overcome the reliance on one cereal grain, which is associated with food security and agriculture [1, 2, 3]. Owing to their superior physicochemical and functional properties, composite flours have great potential for use in bakery goods, snacks, pasta products, and other functional foods. The use of nutrient-rich raw materials in flour formulation is a useful approach for developing new-value food products that can fulfill today's dietary requirements and exhibit good technological properties [1, 2, 3].

Sorghum (*Sorghum bicolor*) and finger millet (*Eleusine coracana*) are cereal grains that have received much interest because of their good nutritional and health benefits. Sorghum is a gluten-free cereal that consists of complex carbohydrates, dietary fiber, phenolic compounds, and minerals, which are used to prepare foods for patients with celiac disease while improving gut health and antioxidant activity. Finger millet is a source of calcium, iron, phosphorus, and polyphenols that are used in the preparation of foods with a low glycemic index and bioavailability.

Bengal gram (*Cicer arietinum*), an excellent plant source, is rich in proteins, amino acids, and polysaccharides that are used in increasing the hydration, emulsification, and texture of foods. Cereals and legumes are used in combination to obtain complementary nutritional and technological benefits [4, 5, 6].

Carrot powder is an important dietary source of β -carotene, dietary fiber, and antioxidants; turnip powder is known for its contribution of minerals, fiber, and phytochemicals; and bathua leaves (*Chenopodium album*) are rich in iron, calcium, vitamin C, folates, and antioxidants, which can provide substantial levels of micronutrients in food products. In addition to their nutritional benefits, vegetable-based flours significantly affect water absorption capacity, oil absorption capacity, water solubility index, water absorption index, foaming capacity, and emulsion activity, which determine dough properties, product texture, shelf stability, and product acceptance [2, 7, 8].

2. Methodology

2.1 Study Design and Experimental Framework

A single factor completely randomized design (CRD) was used to analyze the effect of the ingredient type on various physicochemical and techno-functional parameters such as bulk and tapped densities, moisture and ash content, water absorption capacity (WAC), oil absorption capacity (OAC), water absorption index (WAI), water solubility index (WSI), foaming capacity (FC), foaming stability (FS), and emulsion activity (EA). Six samples of cereal-, legume-, leafy vegetable-, and root vegetable-based flours were prepared following standard methods and tested under the same

experimental conditions to ensure that any differences between the ingredients were solely a result of the unique inherent physicochemical composition of each ingredient, rather than any external factor.

To analyze these differences, the investigation was conducted in four major phases. The first phase involved the purchase of raw materials and preparation of test samples. The second phase was carried out to obtain values of the bulk and tapped densities, moisture, and ash contents. In the third phase, the techno-functional properties of the test flour samples were investigated to obtain their processing and product quality-related properties. The fourth phase used Design-Expert® statistical software for one-factor analysis of variance (ANOVA).

Figure below summarizes the overall experimental procedure adopted in this study

- Material selection
- Sample preparation and storage
- Analysis of selected functional properties
- Determination of techno-functional properties
- Analysis of the variance
- Comparison of the flours

All ingredients were prepared at their best quality. The samples were carefully checked for the presence of any debris and foreign material before the start of experimental analyses. Samples were then stored in airtight moisture-proof polyethylene bags in ambient conditions (25 ± 2 °C) for further testing and analysis in order to prevent any possible changes in their composition due to exposure to air and moisture.

Table 1: Raw materials used in the investigation

S. No.	Raw Material	Scientific Name	Food Category	Major Nutritional Characteristics
1	Sorghum Flour	<i>Sorghum bicolor</i>	Cereal	Dietary fiber, phenolic compounds, minerals
2	Finger Millet Flour	<i>Eleusine coracana</i>	Millet	Calcium, iron, polyphenols
3	Bengal Gram Flour	<i>Cicer arietinum</i>	Legume	High protein, essential amino acids
4	Carrot Powder	<i>Daucus carota</i>	Root vegetable	β -carotene, antioxidants, dietary fiber
5	Turnip Powder	<i>Brassica rapa</i>	Root vegetable	Minerals, glucosinolates, fiber
6	Bathua Powder	<i>Chenopodium album</i>	Leafy vegetable	Iron, calcium, vitamins and antioxidants

2.2 Sample Preparation

To obtain reliable physicochemical and functional data, it is crucial that all samples undergo the exact same pre-treatment to ensure consistent preparation. Hence, prior to all lab tests, the initial flour samples underwent the same pre-treatment procedure. All the raw ingredients (Sorghum, ragi, carrot, turnip and bathua) washed away and pretreated then dried in tray drier at the range of temperature $45-65^{\circ}\text{C}$ then grind all in pulveriser in the lab of svpu&at Meerut. The powders were then carefully combined by sterilized stainless steel spatulas into airtight high density polyethylene jars. Before all lab testing, all samples were stored at room temperature for around 24 h so that any difference due to storage temperature of the raw material on water absorption of flour could be minimized. Every experiment was conducted as a triplicate. The result was calculated as the mean ($\pm$ S.D.) to minimize any experimental error and increase statistical reliability of the results.

2.3 Chemicals, Reagents and Laboratory Equipment

All chemicals were of analytical grade and all reagents were of laboratory grade in SVPUAT Meerut. Laboratory water

generated from a laboratory water purification system was used for all hydration experiments. Commercially available, refined edible vegetable oil was used for oil absorption and emulsion activity experiments. No additional ingredients or preservatives were added to the flour sample for any experiment. The equipment used for experimentation included an analytical weighing balance ($\pm 0.001\text{g}$), hot air oven, laboratory muffle furnace, centrifuge, vortex mixer, graduated measuring cylinders, desiccator, stainless-steel crucibles, moisture dishes, volumetric glassware, pipettes, magnetic stirrer, laboratory blender, and Design-Expert® software.

2.4 Determination of Physicochemical Properties

Physicochemical characterization is essential for generating the initial data needed to assess flour performance in terms of processing, storage, handling, and product quality. In this study, four physicochemical parameters were measured including bulk density, tapped density, moisture content, and ash content. These are important because they can affect flour packaging, transportation, mixing, water absorption properties and its shelf-life stability.

2.4.1 Determination of bulk density (BD)

The bulk density was determined as described in Eleazu *et al.*, (2014) ^[14] by adding 50 g of flour sample to a graduated cylinder, and the volume recorded. The bulk density was calculated as weight per unit volume of sample

$$\text{Bulk Density (g/mL)} = \frac{\text{Weight of Sample (g)}}{\text{Bulk Volume (mL)}} \quad \text{Eq (3.1)}$$

2.4.2 Determination of Tapped Density (TD)

The flour samples were gently filled into 10 mL graduated plastic cylinders. The bottom of the cylinder was gently tapped on a laboratory bench covered with foam several times until there was no further diminution of the sample level. The weight of the sample was calculated and the bulk density was calculated as weight of sample per unit volume of sample (Kaur *et al.*, 2005) ^[15].

$$\text{Tapped Density (g/mL)} = \frac{\text{Weight of Sample (g)}}{\text{Tapped Volume (mL)}} \quad \text{-Eq (3.2)}$$

2.4.3 Determination of Moisture Content

Moisture contents of flours samples were determined in a standard manner (AOAC, 2012) ^[16] by drying the product in a hot air oven. About 5 g of flour samples were accurately weighed into the pre-heated and pre-weighed moisture dishes then placed into hot air oven which is thermostatically controlled. Samples were dried at $105 \pm 2^\circ\text{C}$ in the oven for a period of approximately 4-6 hr, with constant weight attained. The hot-dried sample in the moisture dishes was then cooled in the desiccators containing dry silica gel to cool down to room temperature, followed by reweighing on an analytical balance. The moisture content of each sample was determined using equation 3.

$$\text{Moisture Content (\%)} = \frac{W_1 - W_2}{W_1} \times 100 \quad \text{-Eq (3.3)}$$

Where:

- W_1 = Initial weight of flour sample (g)
- W_2 = Final oven-dried weight (g)

2.4.4 Determination of Ash Content

Ash content was analyzed in dry ashing as per standard (AOAC, 2012) ^[16] procedure. About 2 g of flour samples were accurately weighed into previously ignited and weighed porcelain crucibles. The sample material was first charred over a low flame to avoid loss of the materials during charring then, it was placed inside the laboratory muffle furnace at 550°C until 5-6 h of light grey or white colored ash was obtained. The crucibles were removed from the furnace and placed inside a desiccator for cooling to ambient temperature and the weighed ash residue was weighed using an analytical balance. Ash was obtained from the following formula.

$$\text{Ash Content (\%)} = \frac{\text{Weight of Ash}}{\text{Sample Weight}} \times 100 \quad \text{-Eq (3.4)}$$

2.5 Determination of Techno-Functional Properties

Flour's techno-functional properties are crucial in determining whether they are useful for food processing

operations. These functional properties of the flour are mainly influenced by the starch, protein, dietary fiber, lipids and naturally occurring polysaccharides. The techno-functional characteristics of flour are particularly important for composite flour technology in which cereal starch, legume protein and vegetable fiber interact to form a matrix, which may change in water holding, oil binding, viscosity, foaming, emulsifying and texture attributes. Thus, techno-functional properties of composite flours are important for their application in bakery products, noodles, snacks, gluten free foods, beverages, soups, infant foods and nutritional supplements. ^[9] ^[10].

2.5.1 Determination of water absorption capacity (WAC)

Water absorption capacity was examined using the technique stated by Okaka and Potter (1979) ^[17]. One gram of each flour sample was weighed & mixed with 10 mL of distilled water in a centrifuge tube. The mixture was centrifuged for 30 min at 2000 rpm while remaining at room temperature for the first 30 min ($28^\circ\text{C} \pm 2^\circ\text{C}$). The supernatant was decanted at the end. The difference between the volume of the supernatant & the initial volume of water given to the sample was used to compute the water absorption capacity (WAC).

$$\text{WAC (\%)} = \frac{\text{Weight of hydrated sediment} - \text{Original sample weight}}{\text{Original sample weight}} \times 100 \quad \text{-Eq (3.5)}$$

2.5.2 Determination of Oil Absorption Capacity (OAC)

The oil absorption capacity was determined using the procedure stated by Okaka and Potter (1979) ^[17]. One gram (1 g) of each sample was measured using a weighing balance in an already-weighed centrifuge tube. 10 mL of refined vegetable oil (Soyabean oil, Sp. Gravity 0.9092) were mixed with the sample & allowed to stand for 30 min at 2000 rpm. Oil absorption capacity is expressed as% oil bound per gram flour. The unabsorbed oil was poured out, and the sediment weighed. The oil absorption capacity was calculated using Eq. (3.6).

$$\text{OAC (\%)} = \frac{\text{Volume of oil absorbed} \times \text{density}}{\text{Original sample weight}} \times 100 \quad \text{-Eq (3.6)}$$

2.5.3 Determination of Water Absorption Index (WAI)

Water absorption index (WAI) determine by the method of Suraiya Jamal *et al.* (2016) ^[18]. 1 g of sample was weighed and placed in a centrifuge tube. Then 6 ml of distilled water was added for suspension. The tubes along with the samples were heated in shaking water bath at the temperature of 80°C for 30 minutes. The solution was centrifuged at 2500rpm for 10 minutes. After the centrifugation, the supernatants were carefully poured into Petri dish for drying at 105°C for 10 hours in an oven, while the sediments were weighed as such. Water absorption index was calculated on the basis of wet sediments.

$$\text{WAI} \left(\frac{\text{g}}{\text{g}} \right) = \frac{\text{Weight of hydrated gel}}{\text{Weight of dry flour}} \quad \text{-Eq (3.7)}$$

Where

- Hydrated gel = Weight after centrifugation
- Dry flour = Initial flour weight

2.5.4 Determination of Water Solubility Index (WSI)

The water solubility index of starches was carried out as described by Anderson and Sefa-dede (2001) [19] with little modification. 1 g each of the starches and 10 ml of water were mixed in a 15 ml plastic centrifuge tube and were immersed in water bath for 30 min at 37 °C. This was then centrifuged at 4000 rpm for 10 min after which the supernatant was collected in a pre-weighed beaker and the residue was weighed after the water was evaporated at 105 °C; the percentage of residue with respect to the amount of starch used was taken as the water solubility index.

$$\text{WSI (\%)} = \frac{\text{Weight of dried soluble solids}}{\text{Original flour weight}} \times 100 \quad \text{-Eq (3.8)}$$

2.5.5 Determination of Foaming Capacity (FC) and Foaming Stability (FS)

The foam capacity (FC) and Foam stability (FS) by Narayana and Narsinga Rao (1982) [20] were determined as described with slight modification. The 1.0 g flour sample was added to 50 mL distilled water at 30±2 °C in a graduated cylinder. The suspension was mixed and shaken for 5 min to foam. The volume of foam at 30 s after whipping was expressed as foam capacity. Foaming capacity was calculated as described in equation below.

$$\text{Foaming Capacity (\%)} = \frac{V_2 - V_1}{V_1} \times 100 \quad \text{-Eq (3.9)}$$

Where

- V_1 = Initial volume before whipping (mL)
- V_2 = Final foam volume immediately after whipping (mL)

The volume of foam was recorded 1 hour after whipping to determine foam stability as per percent of initial foam volume

2.5.6 Determination of Emulsion Activity (EA)

Emulsifying activity was determined as described by Okaka and Potter (1979) [17]. The sample (0.5 g) was added to 10 ml distilled water and shaking the mixture for 3 min in a centrifuge tube. The mixture was made up to 12.5 ml by adding oil and homogenized for 3 min. The resulting emulsion was centrifuged at 2000 RPM for 5 min and then the emulsion volume was measured. After the mixture has been spun, 3 layers were formed, i.e. top (oil), middle (emulsion), and the bottom (water) layers. The total height of each phase was then measured in the graduated tube. Below Equation was used to calculate the emulsion activity.

$$\text{Emulsion Activity (\%)} = \frac{\text{Height of emulsified layer}}{\text{Total height of mixture}} \times 100 \quad \text{-Eq (3.10)}$$

Where

- Emulsified layer = Stable emulsion formed after centrifugation
- Total height = Total liquid column

Table 2: Functional properties determined during the present investigation

Functional Property	Unit	Principle	Major Industrial Application
Water Absorption Capacity	%	Water binding by starch, proteins and fiber	Bakery, dough formulation, moisture retention
Oil Absorption Capacity	%	Lipid binding by proteins	Bakery, meat analogues, flavour retention
Water Absorption Index	g/g	Hydration and swelling of starch granules	Soups, porridges, infant foods
Water Solubility Index	%	Solubilization of carbohydrates and proteins	Instant foods, beverages
Foaming Capacity	%	Air incorporation by proteins	Cakes, muffins, desserts
Foaming Stability	%	Stability of protein foam	Bakery, whipped products
Emulsion Activity	%	Oil-water emulsion formation	Sauces, dressings, bakery fillings

2.6 Statistical Analysis

In order to evaluate the significance of the differences found among the physicochemical and techno-functional properties of the 6 investigated flour samples, statistical analysis was carried out. Considering that the type of ingredient was the only factor examined in the current study, one-factor Completely Randomized Design (CRD) was applied for all experimental trials. The 6 levels of the independent variable were sorghum flour, finger millet flour, Bengal gram flour, carrot powder, turnip powder, and bathua powder, while the physicochemical and functional properties were the dependent response variable. Triplicate independent experiments (n = 3) were conducted for all experimental observations under the same experimental conditions. Mean±Standard deviation (SD) values of experimental results were calculated. The use of replicates allowed for reduction of random analytical errors, enhancement of the precision of measurement, and better reliability of the experimental outcomes.

$$Y_{ij} = \mu + \tau_i + \varepsilon_{ij}$$

Where

- Y_{ij} = Observed response

- μ = Overall experimental mean
- τ_i = Effect of the i th ingredient
- ε_{ij} = Random experimental error

The statistical significance of each model was evaluated using the F-test.

$$F = \frac{\text{Mean Square of Treatment}}{\text{Mean Square Error}}$$

Higher F-values together with lower p-values indicate stronger statistical evidence that ingredient type significantly influenced the measured response.

2.6.1 Model Adequacy Evaluation

The quality and fit of each model were assessed by several indicators provided by Design-Expert® software following the analysis of variance, i.e.:

- Coefficient of determination (R^2)
- Adjusted coefficient of determination (Adj R^2)
- Predicted coefficient of determination (Pred R^2)
- Coefficient of variation (CV, %)
- Adequacy precision

- Prediction error sum of squares (PRESS)
- Akaike Information Criterion (AICc)
- Bayesian Information Criterion (BIC)

The coefficient of determination (R^2) measures the percent variation in the response explained by the regression model.

$$R^2 = 1 - \frac{SS_E}{SS_T}$$

Where

- SS_E = Error Sum of Squares
- SS_T = Total Sum of Squares

Higher R^2 values approaching unity indicate excellent agreement between experimental observations and model predictions. Adjusted R^2 was employed to compensate for the influence of model complexity by considering the number of predictor variables.

$$\text{Adjusted } R^2 = 1 - \left(\frac{SS_E/(n - p - 1)}{SS_T/(n - 1)} \right)$$

where

- n = Number of observations
- p = Number of model parameters

Predicted R^2 was used to estimate the predictive capability of the developed regression model for new experimental observations.

The coefficient of variation (CV%) was calculated as

$$CV(\%) = \frac{SD}{Mean} \times 100$$

Lower CV values indicate greater experimental precision and improved repeatability.

Adequate Precision measures the signal-to-noise ratio generated by the regression model. A value greater than 4.0 indicates that the model possesses sufficient discrimination capability for reliable prediction.

Table 3: Statistical design adopted in the study

Factor	Description
Experimental Design	Completely Randomized Design (CRD)
Independent Variable	Flour ingredient type
Number of Treatments	6
Number of Replications	3
Total Experimental Units	18
Statistical Software	Design-Expert®
Statistical Test	One-way ANOVA
Significance Level	$p < 0.05$

Table 4: Statistical criteria used for model evaluation

Statistical Parameter	Purpose	Acceptance Criterion
Model F-value	Determines overall model significance	Larger F-value preferred
p-value	Determines statistical significance	$p < 0.05$
R^2	Goodness of fit	Close to 1
Adjusted R^2	Model explanatory power	Close to R^2
Predicted R^2	Prediction capability	Difference from Adjusted $R^2 < 0.20$
CV (%)	Experimental precision	Lower value preferred
Adeq Precision	Signal-to-noise ratio	> 4
PRESS	Prediction error	Lower value preferred
AICc	Model comparison	Lower value preferred
BIC	Model comparison	Lower value preferred

2.6.2 Regression Model Development

Design-Expert® produced coded-factor and actual-factor equations for every response looked into. Because the factor coefficients are standardized, the coded equations were useful in determining the contribution of each ingredient to each response variable. On the other hand, the actual-factor equations, which gave the responses in terms of the initial ingredient levels, were used for prediction.

The coded regression model used in this study is described as follows:

$$Y = \beta_0 + \sum_{i=1}^n \beta_i X_i$$

Where

- Y = Predicted response
- β_0 = Model intercept
- β_i = Regression coefficient
- X_i = Ingredient factor

Based on the analysis, it was observed that highly significant regression model fits were produced by the Design-Expert® software for all of the functional characteristics being explored.

The coded and actual mathematical equations for the functional properties of water absorption capacity, oil absorption capacity, water absorption index, water solubility index, foaming capacity, foaming stability, and emulsion activity are given below.

3. Results and Discussion

3.1 Physicochemical Characterization of Individual Flour Samples

Assessing the potential of cereals, legumes, and vegetables-based flours as a base for nutritionally enhanced flour formulations begins with physicochemical characterization. These physicochemical properties are critical, as they determine flour flow, packaging, shipment, storage characteristics, and process performance and also affect hydration characteristics and the food quality of the product derived from them. These differences are associated with the variations in their botanical origin, chemical composition, shape and size of starch granules, and particle

size, along with differences in their content of dietary fiber and minerals.

Six types of flour such as sorghum flour, finger millet flour, Bengal gram flour, carrot powder, turnip powder, and bathua powder were used in this study, and the physicochemical properties of these flours were evaluated.

The result reveals significant differences among all studied ingredients, which confirms that the differences in the composition of raw material may cause variations in their physicochemical properties, and these values provide a reference for later studies of functional properties of water adsorption, oil absorption, emulsion, and foaming capacity.

Table 5: Physicochemical properties of the investigated flour samples

Flour Sample	Bulk Density (g/mL)	Tapped Density (g/mL)	Moisture (%)	Ash (%)
Sorghum Flour	0.541	0.986	7.292±0.052	1.977±0.388
Bengal Gram Flour	0.521	0.705	9.002±0.235	2.909±0.111
Finger Millet Flour	0.540	0.896	7.648±0.122	2.062±0.662
Turnip Powder	0.490	0.658	5.216±0.359	6.413±0.011
Carrot Powder	0.455	0.641	5.976±0.472	5.860±0.328
Bathua Powder	0.568	0.715	7.412±0.333	16.861±0.481

3.1.1 Bulk Density and Tapped Density

It seems that relatively higher bulk density of bathua powder was due to its relatively fine particle size and compact fibrous matrix of tissue which allows efficient particle packing. Relatively higher bulk density observed in sorghum and finger millet may be due to the presence of starch in the endosperm and less porous particle. Table 5 shows the results of bulk density of investigated flours, it can be observed that they were not same, values ranged from 0.455 g/ml to 0.568 g/ml. Among them carrot powder possesses lowest bulk density due to its cellular matrix, which dehydrated to become porous and has large volume

per mass unit. These low-density vegetable powders may have good hydration and swelling capacity during food making. From the industrial point of view, ingredients with higher bulk density can minimize packaging volume, transportation cost, and storage volume. While ingredients with low bulk density can improve texture, hydration and swelling property of flour-based bakery products and instant food items. So, if high density cereal flour is combined with low density vegetable powder, then composite flour should possess a good blend between processing efficiency and functionally active properties.

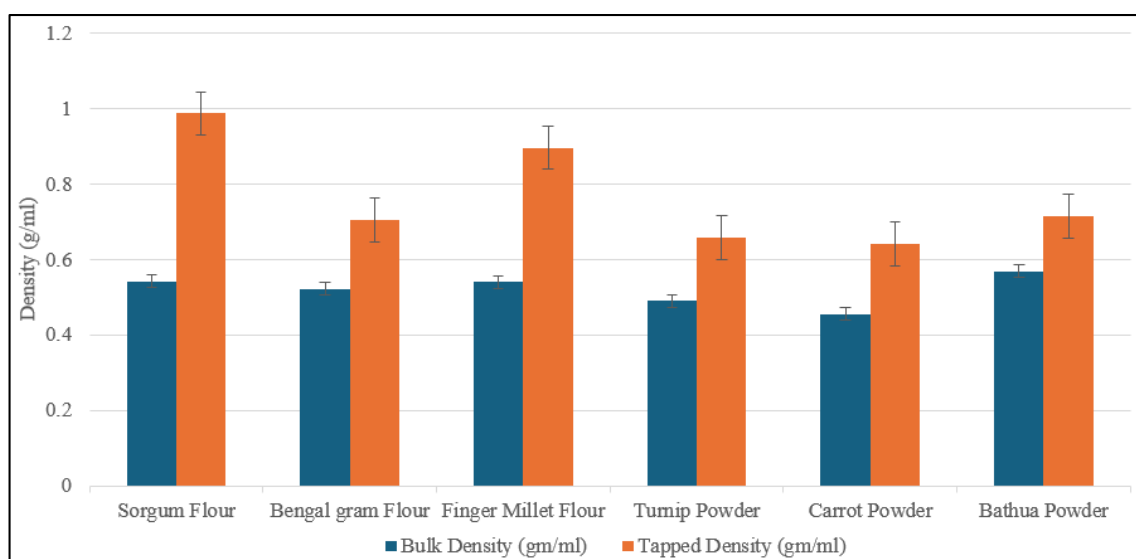


Fig 1: Bar Graph presentation of Bulk & Tapped of all flour samples

Tapped density is a measure of the highest packing achieved following mechanical compaction and is often correlated with the compressibility, storage and handling of powders in the industry. A large difference in the bulk and tapped density indicates greater compressibility and inter-particle empty space.

3.1.2 Moisture Content

Moisture content is among the primary quality factors affecting the storage stability, microbial safety, enzyme activity, and shelf life. A lower moisture content improves the quality of the product and prevents microbial activity and chemical breakdown of food products. The moisture contents of the different flours were found to be in the range of 5.216 to 9.002% (Table 5). The flour sample from Bengal

gram contained the maximum (9.002±0.235%) moisture, and the flour sample from turnip contained the minimum moisture content (5.216±0.359%). Carrot flour also showed the minimum moisture content (5.976±0.472), and sorghum, finger millet, and bathua flour contained a moderate moisture content in comparison to the above. The lower moisture content of flour powder may be due to efficient drying during powder processing. Such flours are preferred, and their low moisture content results in high shelf life, a low rate of microbial growth, and good storage quality. However, Bengal gram flour had the highest moisture content, indicating its storage quality could be improved. All the studied samples showed acceptable values of moisture content required for commercial flour storage, indicating the suitability of raw materials used for composite flour.

3.1.3 Ash Content

Ash content is the major criterion of food ingredients that indicates the total amount of inorganic matter left when food ingredients are completely incinerated. It is the most common indicator of mineral content such as calcium, potassium, magnesium, phosphorus, and iron in the ingredients. Ingredients having high ash content are of higher nutritional value.

High ash content of bathua flour shows that the ingredient is very rich in mineral content and has a high potential to

increase mineral content while making composite flour products. It is also seen that vegetables like turnip and carrot have much higher mineral contents than cereals because of naturally occurring micronutrient contents. However, sorghum and finger millet showed low ash values because minerals are generally low in cereal grains as compared to vegetables. Thus, bathua flour and other vegetable flour samples showed high mineral contents and high potential to increase mineral contents and increase nutritional values of composite flour.

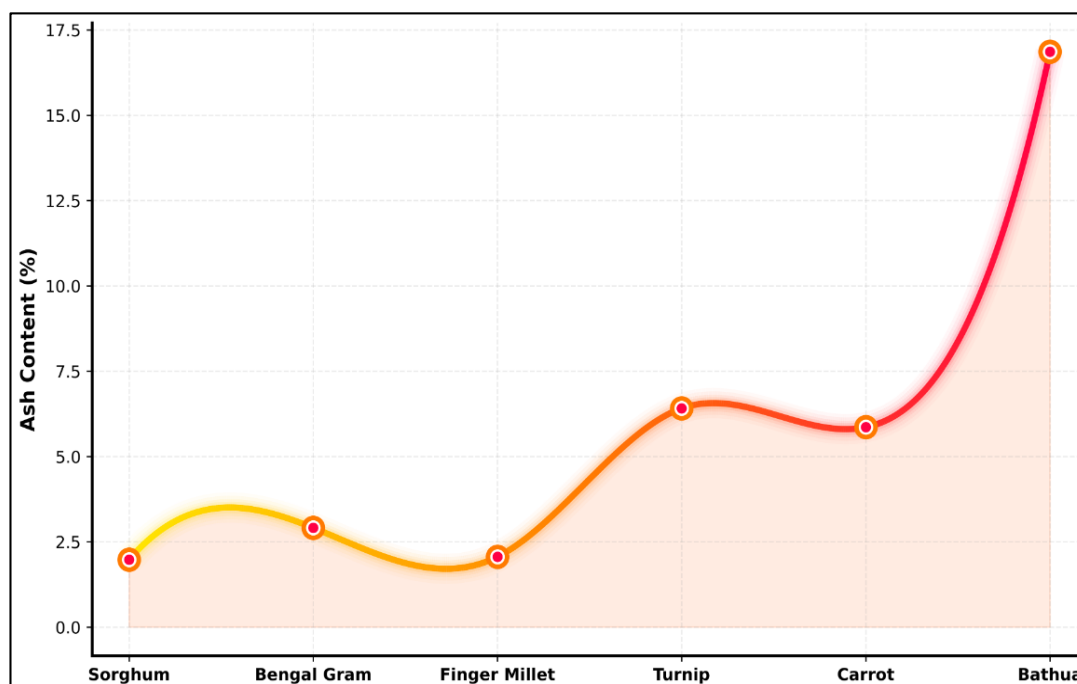


Fig 2: Multi-color spline graph showing variation in ash content among different flour samples.

3.2 Techno-Functional Properties of Flour Samples

The techno-functional characteristics of flours play a crucial role in food processing; they significantly affect final product quality by influencing properties such as texture, moisture content, emulsification, and foaming, as well as consumer acceptability. These characteristics are

significantly influenced by the chemical composition of starch, protein, dietary fiber, lipids, and native polysaccharides. As the present investigation involved cereal, legume, and vegetable powders with differing compositions, diverse functional properties were anticipated.

Table 6: Functional Properties of the investigated flour samples

Ingredients	Functional Properties						
	WSI (%)	WAI (g/g)	WAC (%)	OAC (%)	FC (%)	FS (%)	EA (%)
Sorghum	6.987	3.391	108.460	91.270	5.556	2.381	16.5
Carrot	30.863	4.241	296.942	110.037	4.724	2.362	6.0
Ragi	7.904	2.979	128.357	82.470	4.918	1.639	10.5
Bathua	16.614	4.174	316.331	100.817	7.377	4.098	7.5
Turnip	16.861	4.473	284.565	54.854	8.696	6.087	5.5
Bengal Gram	23.279	2.027	187.525	81.360	6.897	5.172	39.5

3.2.1 Water Solubility Index (WSI)

The Water Solubility Index (WSI) of the extrudates was significantly influenced by the type of ingredient incorporated ($F(5,12) = 9.95$, $p = 0.0006$), as revealed by one-way ANOVA. The model explained 80.57% of the total variation in WSI ($R^2 = 0.8057$), with an adjusted R^2 of 0.7248 and a predicted R^2 of 0.5629, the close agreement between which confirmed the adequacy and predictive reliability of the model. An adequate precision ratio of 8.271 (>4) further validated an acceptable signal-to-noise ratio for navigating the design space. Among the ingredients evaluated, Carrot-incorporated samples exhibited the highest

WSI (30.86%), followed by Bengal Gram (23.28%), Turnip (16.86%), and Bathua (16.61%), while Ragi (7.90%) and Sorghum (6.99%) recorded the lowest WSI values. The higher WSI observed in Carrot and Bengal Gram-based formulations may be attributed to greater starch degradation, dextrinization, and gelatinization during extrusion, leading to the formation of smaller, more soluble molecules, whereas the lower WSI in Sorghum and Ragi could be associated with their comparatively lower starch and higher fiber content, which limit water-soluble fragment formation during processing.

3.2.2 Water Absorption Index (WAI)

The effect of ingredient type on water absorption index (WAI) was evaluated using a one-factor ANOVA. The model was highly significant ($F = 1175.35$, $p < 0.0001$), indicating that ingredient type had a statistically significant effect on WAI, with only a 0.01% probability that this variation arose from noise. The model accounted for 99.80% of the total variability ($R^2 = 0.9980$), and the close agreement between the Adjusted R^2 (0.9971) and Predicted R^2 (0.9954) — a difference well under 0.2 — confirmed the model's strong predictive reliability. A low coefficient of variation (C.V. = 1.35%) indicated high reproducibility across replicates, and an Adequate Precision ratio of 84.76 (far exceeding the minimum desirable threshold of 4) confirmed an adequate signal-to-noise ratio for the model to be used to navigate the design space. Among the ingredients, Turnip exhibited the highest WAI (4.473%), followed closely by Carrot (4.241%), while Bengal Gram recorded the lowest WAI (2.026%). Bathua, Ragi and Sorghum showed intermediate values of 4.174%, 2.979% and 3.391%, respectively. These results suggest that Turnip, Sorghum, and Carrot possess a greater capacity to bind water within their matrix, likely attributable to differences in their polysaccharide, fiber, and protein composition relative to Bengal Gram flour.

3.2.3 Water Absorption Capacity (WAC)

There was a considerable difference in the WAC of different flour types examined in the present study. Bathua flour displayed the highest value (316.33%), followed by carrot flour (296.942%), turnip flour (284.56%), Bengal gram flour, finger millet flour (128.36%), and sorghum flour (108.46%). Bathua flour exhibited high WAC, which can be attributed to its high dietary fibre content; the presence of pores inside the cells could also provide a large surface area that enables numerous interactions with water molecules through hydrophilic binding. Carrot and Turnip powder demonstrated high absorption due to the presence of pectin and soluble polysaccharides. Compared with vegetable powder samples, cereal flours showed lower values, as starches possess lesser hydrophilic groups than dietary fibers found in vegetable flours. The analysis of variance (ANOVA) showed a highly significant difference among the samples, where the F-value was found to be high (2194.88) and the p-level 0.0001 ($p < 0.0001$), R^2 was found to be 0.9989. The high value of R^2 confirmed that the proposed model fitted the data well.

3.2.4 Oil Absorption Capacity (OAC)

Oil absorption capacity is a quality characteristic that reflects the ability of flour to absorb or retain lipids when incorporated into food formulations during food processing. High oil absorption capacity increases flavor retention, sensory attributes and the tenderness of the processed foods. The higher oil absorption in carrot and bathua powders could be due to the porous fibrous structure and the ability of hydrophobic protein domains to trap the oil molecules. However, lower oil binding capacity was recorded in turnip powder indicating lesser interactions between oil and the

powder. A highly significant model F-value of 43.81, $p < 0.0001$, and R^2 of 0.9481 suggested that ingredient was highly significant for oil absorption capacity.

3.2.5 Emulsion Activity (EA)

The emulsion activity of the flour samples was significantly influenced by ingredient type ($F(5,12) = 477.75$, $p < 0.0001$), as revealed by one-way ANOVA. The model explained 99.50% of the total variation in EA ($R^2 = 0.9950$), with an adjusted R^2 of 0.9929 and a predicted R^2 of 0.9888, the close agreement between which confirmed excellent model adequacy and predictive reliability. An adequate precision ratio of 55.426 (>4) further validated a very strong signal-to-noise ratio. Among the ingredients evaluated, Bengal Gram incorporated samples exhibited a markedly higher EA (39.50%) than all other formulations, followed by Sorghum (16.50%), Ragi (10.50%), Bathua (7.50%), Carrot, (6.00%) and Turnip which recorded the lowest EA (5.5%). The pronounced emulsifying activity of is likely attributable to a higher proportion of soluble, surface-active proteins capable of adsorbing at the oil-water interface, whereas the carbohydrate/pectin-dominant composition of turnip and carrot limited its capacity to stabilize an emulsion.

3.2.6 Foaming Capacity (FC)

Ingredient type had a statistically significant effect on foaming capacity ($F(5,12) = 29.23$, $p < 0.0001$). The model accounted for 92.41% of the variability in FC ($R^2 = 0.9241$), with an adjusted R^2 of 0.8925 and a predicted R^2 of 0.8293, indicating reasonable agreement and adequate predictive capability of the model. The adequate precision ratio of 13.757 confirmed a sufficient signal-to-noise ratio for reliable use of the model. Turnip exhibited the highest foaming capacity (8.70%), followed by Bathua (7.38%) and Bengal Gram (6.90%), while Carrot showed the lowest value (4.72%), closely followed by Ragi (4.92%) and Sorghum (5.56%). The superior foaming capacity of Turnip suggests a favorable proportion of flexible, soluble proteins able to rapidly unfold and lower interfacial tension at the air-water boundary, promoting greater incorporation of air during whipping.

3.2.7 Foaming Stability (FS)

One-way ANOVA revealed a highly significant effect of ingredient type on foaming stability ($F(5,12) = 105.10$, $p < 0.0001$). The model explained 97.77% of the total variation in FS ($R^2 = 0.9777$), with an adjusted R^2 of 0.9684 and a predicted R^2 of 0.9498, demonstrating strong model adequacy and predictive reliability. The adequate precision ratio of 25.678 confirmed an excellent signal-to-noise ratio. Turnip again showed the highest foaming stability (6.09%), followed by Bengal Gram (5.17%) and Bathua (4.10%), while Ragi recorded the lowest value (1.64%), followed closely by Carrot (2.36%) and Sorghum (2.38%). The greater foam stability of Turnip is consistent with its high foaming capacity, indicating that its protein fraction forms a more cohesive, viscoelastic interfacial film capable of resisting bubble drainage and coalescence over time.

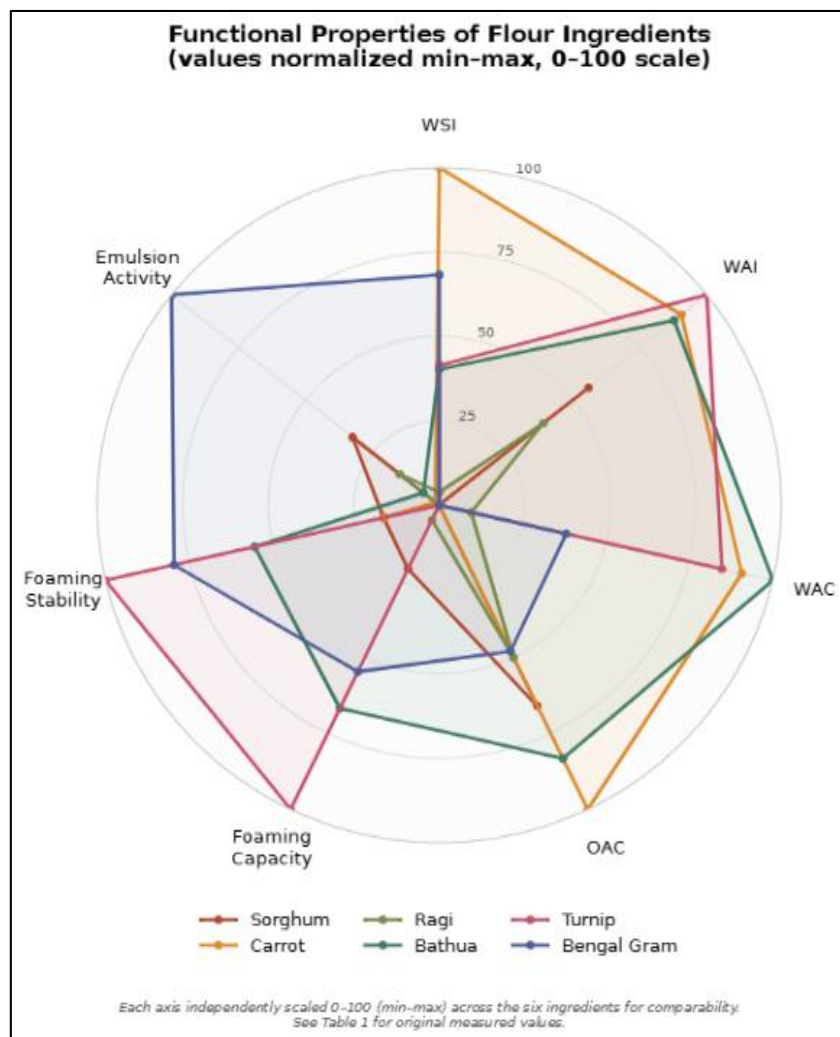


Fig 3: Radar Chart presentation of functional properties of flours

4. Conclusion

This study successfully developed and characterized a novel cereal-legume-vegetable composite flour from sorghum, finger millet, Bengal gram, carrot, turnip, and bathua, formulated for the development of edible spoons as a sustainable alternative to single-use plastic cutlery. Significant variation was observed across ingredients in physicochemical and techno-functional properties, with bathua showing the highest water absorption capacity and carrot the highest oil absorption capacity — properties directly relevant to dough cohesion, mould-ability, and structural rigidity required for edible cutlery. These findings demonstrate that strategic ingredient selection can tailor composite flour functionality to produce a firm, food-safe, and biodegradable spoon, offering a nutrient-dense and environmentally responsible alternative to conventional plastic and single-ingredient edible cutlery.

5. References

1. Olcay HS, Ozulku G. Improvement of storage stability of barley, buckwheat and lupin composite flour by microwave treatment and its influence on functional properties of bread. *Food Chem.* 2025;463(Pt 1):141123. doi:10.1016/j.foodchem.2026.150359.
2. Poojara RH, Sreekumar SP, Somarajan N, *et al.* The development of a nutritionally enhanced composite flour: nutritional, functional, and sensory properties. *World Nutr J.* 2026;10(1):45-58. doi:10.1016/j.foodchem.2026.150359.
3. Akinwotu KO, Taiwo KA, *et al.* Advancements in composite flours: applications, nutritional benefits and processing techniques. *Asian Food Sci J.* 2025;24(6):24-36. doi:10.1016/j.foodchem.2026.150359.
4. Fan H, Qiao W, Zhu D, Yang L, Jiang S, Liu H. Polysaccharide-modified quinoa-wheat composite flour: optimization of functional properties and flavor profiles in steamed buns. *Food Chem.* 2026;525:150359.
5. Babatunde T, Adegoke A, Omohimi C, *et al.* Valorizing underutilized cereals and legumes: optimizing functional properties of composite flour and nutritional composition of extruded puffed snack from fonio and legumes. *Legume Sci.* 2026;8(1):70086. doi:10.1002/leg3.70086.
6. Moin A, Hosseini E, Smaoui S, Varzakas T. Research progress on lentil-based composite flours: physicochemical, techno-functional properties, and high-performance food applications. *Qual Assur Saf Crops Foods.* 2025;17(2):232-250.
7. Ehis-Eriakha CB, Oleghe PO, Akharaiyi FC. Enhancing food security and nutrition through indigenous agro-product-based functional foods: a case study on composite flour development. *Proceedings.* 2025;112(1):42. doi:10.3390/proceedings2025112042.
8. Alija D, Olędzki R, Nikolovska Nedelkoska D, *et al.* The addition of pumpkin flour impacts the functional

- and bioactive properties of soft wheat composite flour blends. *Foods*. 2025;14(3):412.
doi:10.3390/foods14030412.
9. Oresanya T, Adebawale AR, Adegoke A, *et al*. Nutritional, techno-functional and pasting properties of orange-fleshed sweet potato, Bambara groundnut and date seed composite flour. *Cogent Food Agric*. 2026;12(1):2310921.
doi:10.1080/23311932.2025.2310921.
 10. Ersedo TL, Tekla TA, Forsido SF, *et al*. Enrichment of Ethiopian roasted corn bread (Dabo Kolo) with ginger powder: effect on composite flour functionality, physicochemical properties, and antioxidant activity. *Future Postharvest Food*. 2025;2(1):45.
doi:10.1002/fpf2.45.
 11. Mshayisa VV, Biyela TB, Netsianda P, Mayekiso L, *et al*. Nutritional, structural, physicochemical and techno-functional properties of wheat-cricket (*Acheta domestica*) composite flours. *Discover Food*. 2026;6(1):12. doi:10.1007/s44187-025-00211-1.
 12. Nangobi P. Consumer acceptability and functional properties of instant porridge made from popcorn-maize-chickpeas composite flour. *Int J Food Sci Nutr*. 2025;10(1):89-96.
doi:10.22271/food.2025.v10.i1b.1105.
 13. Anderson RA, Conway HF, Pfeifer VF, Griffin EL. Gelatinization of corn grits by roll cooking, extrusion cooking and steaming. *Cereal Sci Today*. 1969;14(1):4-11.
 14. Eleazu CO, Ironua C. Physicochemical composition and antioxidant properties of a sweetpotato variety (*Ipomoea batatas* L.) commercially sold in South Eastern Nigeria. *Afr J Biotechnol*. 2013;12(11):1232-1238.
 15. Kaur M, Sandhu KS, Ahlawat AK. Physicochemical, thermal and pasting properties of starches separated from different chickpea cultivars. *J Food Eng*. 2005;69(1):111-120.
 16. Association of Official Analytical Chemists. Official methods of analysis of AOAC International. 19th ed. Gaithersburg, MD: AOAC International; 2012.
 17. Okaka JC, Potter NN. Physico-chemical and functional properties of cowpea powders processed to reduce beany flavor. *J Food Sci*. 1979;44(4):1235-1240.
 18. Jamal S, Qazi IM, Ahmed I. Comparative studies on flour proximate compositions and functional properties of selected Pakistani rice varieties. *J Anim Plant Sci*. 2016;26(6):1748-1756.
 19. Anderson AK, Sefa-Dedeh S. Effects of fermentation and species on the functional properties of Bambara groundnut (*Vigna subterranea*) flours. *J Food Sci Technol*. 2001;38(5):476-482.
 20. Narayana K, Narasinga Rao MS. Functional properties of raw and heat processed winged bean (*Psophocarpus tetragonolobus*) flour. *J Food Sci*. 1982;47(5):1534-1538.