Functional, Pasting and Sensory Properties of "Ogi" Enriched with Beetroot

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ABSTRACT: *This study examined the effects of graded levels of beetroot (Beta vulgaris L.) flour substitution (0–20%) on the properties of ogi made from provitamin A biofortified maize to create an enriched cereal product. Composite flour formulations were made and analyzed for proximate composition, functional properties, RVA pasting properties, dietary fiber fractions, Vitamin C content, antioxidant activities, instrumental color, and sensory properties. The proximate composition was significantly affected by the addition of beetroot with varying results for moisture (9.68–13.08%), crude fat (8.59–15.16%), crude fiber (0.53–0.95%), ash (1.37–1.73%), and carbohydrates (56.03–67.40%) for the different formulations. The protein and vitamin C content increased with increasing levels of beetroot, making it a more nutrient dense product. The functional properties also became improved with the addition of the beetroot flour with the water absorption capacity (1.06–1.71 g/g), oil absorption capacity (0.64–0.71 g/g), and swelling power (5.55–6.41 g/g) all increased, suggesting a more effective and better hydrated, and binder of the product. The Rapid Visco Analyzer showed peak viscosities between 1677.50 and 2095.50 RVU. The paste with the higher level of beetroot had improved peak, trough, and final viscosities demonstrating the increased strength of the paste but also higher breakdown values demonstrating a reduction in thermal stability with increased levels of beetroot substitution. Antioxidant activity significantly increased with the addition of beetroot flour, beneficial due to the low level of antioxidants typically found in provitamin A maize. Higher levels of beetroot caused a reduction in the soluble dietary fiber content of the pastes. Sensory analysis showed that up to 10% beetroot substitution retained desirable color, taste, aroma, and overall acceptability, yet higher levels of substitution in samples caused decreased acceptability. The findings demonstrate that a balance between product composition and nutrient density can be found within an acceptable level for consumers with a biofortified plant-functional cereal product.*

Keywords: *Nutritional Composition, Enrichment, Ogi, Beetroot, composite flour, functional food*



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INTRODUCTION

"Ogi" is a cereal-based fermented food that is consumed in Nigeria as a breakfast and staple item for households. Ogi is traditionally produced from maize (Zea mays L.), sorghum or millet, resulting in products of different colours depending on which cereal was used. While "Ogi" is an accepted traditional food and often celebrated for its cultural value, its conventional formulation is essentially a carbohydrate-based food with little micronutrient or

functional bioactive component value. This situation is most pronounced in sub-Saharan Africa, where the public health relevance of micronutrient deficiencies has not yet been eradicated (FAO, 2023).

Recently, biofortified maize, specifically provitamin A maize high in β-carotene, has been promoted to combat vitamin A deficiency using food-based fortification (Bouis & Saltzman, 2017; Palmer et al., 2016). Provitamin A maize has a raised carotenoid content that acts as a precursor to vitamin A and holds other health value as an antioxidant (Gannon et al., 2023). Biofortified maize is an excellent option for food-based fortification, specifically for traditional formulations of the food, to improve the nutritional value of the food without affecting the consumption customs associated with it. Biofortification, however, targets specific micronutrients only and does not address improving the functional and phytochemical properties of cereal-based foods.

Current trends in the area of food innovations consider various plant-based fortification strategies of integrating vegetables high in bioactive compounds into cereal-based foods to increase their antioxidant effects, functional processing performance and, thereby, their health value to the consumer (Tolve, 2024). Beetroot (Beta vulgaris L.) emerges as a strong candidate in the scientific literature, considering its impressive betalain, phenolic, nitrate, dietary fibre and vitamin C content that boasts antioxidant effects and cardiometabolic health benefits (Chen et al., 2021). Beyond its nutritional content, beetroot also exhibits natural colourant properties and alters the hydration, pasting and textural properties of cereal-based food systems (Dai et al., 2022). However, despite the growing popularity of vegetable-based cereal products, little work has been done to investigate the joint effects of beetroot fortification on the nutritional composition, functional properties, pasting properties, antioxidant activities, colour and sensory acceptability of "Ogi" made from biofortified maize; more importantly, the nutritional enhancement and sensory acceptability of the end product has not been documented. Thus, the objective of this study is to assess the effect of replacing graded levels of beetroot flour (0–20%) on the proximate composition, functional properties, Rapid Visco Analyzer (RVA) pasting properties, fibre fractions, antioxidant activities, colour and sensory properties of ogi made from provitamin A biofortified maize. By bridging the gap between micronutrient biofortification and vegetable-based functional fortification, this study represents progress towards the long-sought goal of developing cereal-based products with increased nutritional value and bioactive properties.

MATERIALS AND METHODS

Sources of materials

Pro-Vitamin A maize was sourced from an accredited and recommended IITA farmer in Ibadan and the beetroots, were sourced at Mile 12 market in Lagos State. The food processing of the sample was performed in the Food Processing Laboratory of the Department of Food Science and Technology, Yaba College of Technology. Every reagent in the research was of analytical laboratory quality.

Processing of *Ogi* Powder

The grains of maize were cleaned and sorted to eliminate grains that were unwholesome as shown in (Figure 1). The kernels of maize were then steeped at ambient temperature (72 h). The steep water was then decanted after fermentation so that the fermented grains could be washed with the portable water. The process of wet-milling fermented grains performed on an attrition mill that was locally produced was obtained by grinding to obtain a slurry. The mixture is allowed to ferment in 24 h. The slurry was dried in a convective hot air cabinet dryer at 50 °C and milled using Laboratory hammer mill (Fritsch, D-55743, Idar-oberstein-Germany). The fermented maize flour was sieved to a mesh size to get a uniform particle (630 µm) and put in air-tight containers before analysis as stated in the method by Oluwabukola and Victor (2016).

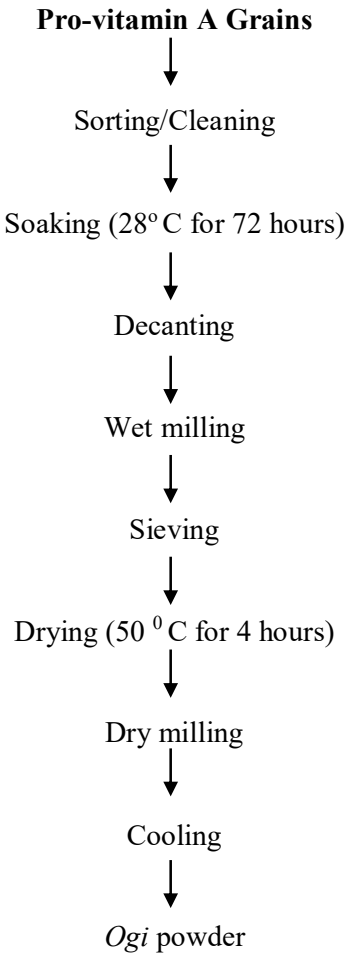


Figure 1: Flowchart for the Production of "Ogi powder" Source: Oluwabukola and Victor (2016)

Beetroot Powder Processing Preparation

Fresh beetroot (*Beta vulgaris* L.) roots were processed into powder following a standardized dehydration and milling procedure as shown in (Figure 2). The beetroots were first sorted to remove damaged and diseased samples and thoroughly washed under running potable water to eliminate adhering soil and extraneous materials. The cleaned roots were manually peeled using a stainless-steel vegetable peeler and subsequently sliced into thin sections (approximately 2–3 mm thickness) using a stainless-steel slicer to ensure uniform drying. The sliced beetroot samples were dehydrated using a hot-air drying oven (Memmert Universal Oven, Model UN55, Memmert GmbH, Germany) at 40 ± 2 °C for 36 hours, until a constant weight was achieved and the slices became crisp. After drying, the beetroot slices were allowed to cool to room temperature and then milled into a fine powder using a laboratory grinder (Retsch Grindomix GM 200, Retsch GmbH, Germany). The resulting powder was sieved through a 250 µm stainless-steel mesh sieve to obtain uniform particle size. The beetroot powder was immediately packed in airtight, food-grade polyethylene containers and stored at ambient temperature in a dry and dark environment until further use.

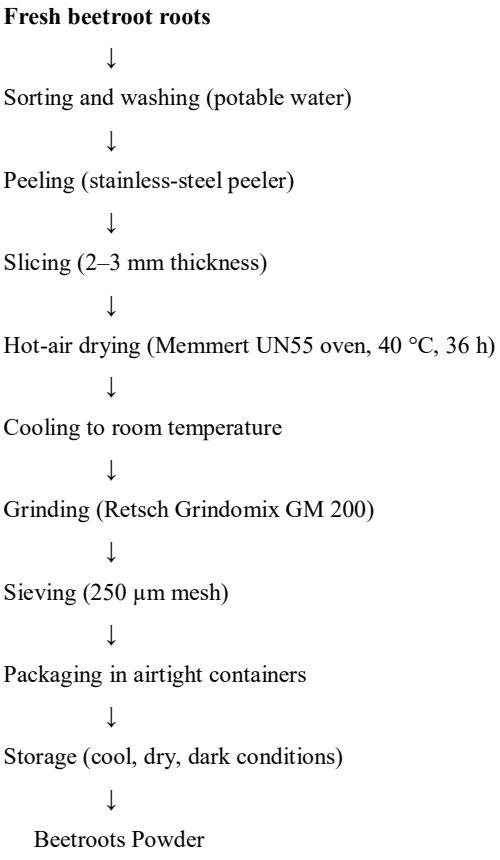


Figure 2: Flowchart for the production of Beetroot Powder**. Source:** Stintzing and Carle (2004).

Proximate composition

The content of Moisture was determined by the method described by AOAC (2015) was used to measure moisture content with the help of the hot-air oven method. Two grams (2 g) of sample (C) were weighed to dried dishes (A) and put in an oven that was controlled to set temperatures at 105 ℃ and dried in 2 hours. The dishes were dried then weighed in a desiccator to cool down. This process was carried on until the drying, cooling, and weighing were performed until a consistent weight was reached. The weight of sample (B) and the dish were used in the computation of the moisture content; this was the weight of the sample (B) added with the dish. The moisture content of the samples was determined by taking the percentage of moisture by the formula:

$$\%\text{Moisture content} = \frac{A-B}{C} \times 100$$

Where;
C = Sample weight in g
A = Weight of dish **+** sample before drying
B = Weight of dish + sample after drying
A – B = Loss in weight of the sample after drying

Ash content was determined by incineration in an oven to a gray ash at 550°C. The method was taken to determine the content of ash according to AOAC (2015). Each sample (2g) was weighed in a silica dish after being cleaned and heated to a temperature of approximately 600 ºC and cooled in a desiccator followed by weighing the samples using a digital weighing balance. A muffle furnace was heated to approximately 525°C and the silica dish together with the sample was heated in it over a period of 2 h. This was allowed to be heated until one gets whitish-grey colored ash, which suggests that all the organic matter in the sample has been destroyed. The contents along with its dish was taken away, allowed to cool in a desiccator and weighed in a digital balance. The ash content was determined and indicated as a percentage as follows:

$$\%\ \text{Ash content} = \frac{Weigh\ \ of\ ash + Crucible - Weight\ of\ Crucible}{Original\ Weight\ of\ Sample} \times 100$$

The method of AOAC (2015) was applied in determining crude fibre. The entire sample shall be defatted with N-Hexane followed by drying, the sample being weighed (W_1) to 250 ml beaker, boiled with 100 ml H_2SO_4 and then filtered using filter paper. The residue was washed in boiling water till it stopped being acidic. The residue was boiled further after 30 minutes in the presence of 100 ml of 0.02 M NaOH solution, filtered and washed by using hot water in 3 minutes. The residue was added to a previously heated, cooled down, and weighted crucible and dried in an oven during an hour. The digital weighing balance was used to weigh the crucible and the contents in it in a desiccator. The sample will be cooled followed by igniting

in a muffle furnace at 525 o C temperature after 3 hours after which the sample will be cooled and weighing (W3) on a digital balance. Calculation of percentage of crude fibre was done using expression:

$$\% \text{ Crude Fibre} = \frac{W2-W3}{W1} \times 100$$

Where W_1 = Initial weight of sample
W_2 = Weight of sample + crucible
W_3 = Weight of sample + crucible after drying

The amount of crude fat was ascertained through the Soxhlet extraction method AOAC, 2015). The sample weighing 2 grams (2 g) was placed in a digital balance and a cellulose thimble. The pasteion tube of Soxhlet apparatus was loaded with the thimble and its content. The petroleum ether (boiling point = 40 -60°C) was weighed into the flask with a round bottom to approximately three-quarters (3/4) of its volume and attached to the pasteion tube and placed on the heating mantle. The samples were left to reflux between 6 - 8 hrs and then the solvent (N-Hexane) was collected and the pasteion oil in the flask dried in the oven at 80°C in 30 min to eliminate traces of the solvents. This will then be cooled on a desiccator and then weighed on a digital balance. The fat amount was indicated as percentage of raw material. The weights of the empty flask and the flask containing oil will indicate the difference in weight; this difference will be taken as the oil content which was determined as:

$$\% \text{ Fat} = \frac{Weight\ of\ Paste + Crucible - Weigh\ \ of\ Crucible}{Weight\ of\ Original\ Sample} \times 100$$

Micro-Kjeldahl crude protein content method by described was used to determine the crude protein content. AOAC (2015). All the samples (1.0g) were weighed into Kjeldahl flasks, 3.0g of hydrated cupric sulphate (catalyst) was added to the flask, 20 ml of anhydrous sodium sulphate and 1.0 ml of concentrated sulphuric acid ($H2SO_4$) were placed in the flask. The solution in the flask was clamped and heated until it turned colourless. Five (5ml) of the digest was warmed and distilled to a volume of 100 ml in the flask used in the distillation with 10 (10ml) of 40% NaOH solution and then distilled, which was titrated with 0.1 ml of hydrochloric acid (HCl). Titre value or colour endpoint where the change of colour occurred, that is, from green to pink was recorded. The expression applied to the calculation of the crude protein was:

$$\% \text{ Crude protein} = \frac{14.01 \times 6.25 \times 25 \times t}{W \times 10} \times 100$$

Where:
W = Weight of sample digested
T = Titre value
6.25 = Conversion factor
100 = Total volume of the digest
10 = Aliquot volume distilled
N = Normality of HCl, in moles/1000 ml (0.1N)

The difference between the carbohydrate content of each sample was obtained. The amount of the total proximate component is deducted with 100. The balance was presupposed as carbohydrate. Carbohydrate =100-percent protein, fat, fibre, ash and moisture.

Functional Properties of Samples

Determination of Bulk Density

The technique outlined in the article by Aderonke *et al*. (2019) was employed. A sample of flour (50g) was placed in the measuring cylinder after which it was tapped until a constant volume of the powdered sample was collected and measured. Bulk density (g/cm^3) will then be calculated using the formula:

$$\text{Bulk Density} = \frac{\text{Weight of the sample}}{\text{Volume of sample after tapping}} \times 100$$

Determination of Water Absorption Capacity (WAC)

The technique outlined in the article by Aderonke *et al*. (2019) was employed. A one-gram sample of the well-mixed sample was put in a beaker. The weight was noted and 10ml of water was added and it was vigorously mixed with it during 5 mins. The content was compared in already weighed centrifuge tubes (the weight was noted as W1). The mixture was centrifuged at its highest force (3500rpm) during 30mins. The supernatant was decanted and the adhering water was washed off in the tube. A weight of the residue was calculated and noted as W2.

$$\% \text{ WAC} = \frac{W2\ (W2 - W1)}{W0} \times 100$$

Solubility

The sample of 1g was weighed in a centrifuge tube and 10ml of distilled water was added. It was adequately stirred and boiled in a water bath at 80°C in 30 mins. It was taken out of water bath, dried and left to cool. It was centrifuged at 2200rpm within 15mins. The supernatant was decanted into a weigh dish that had been weighed before and labelled W_1. Evaporation and drying of the petri dish was done in an oven. It was re-weighed and measured as W_2 (Orisa and Udofia 2020).

$$\% \text{ Solubility} = \frac{W2 - W1}{\text{Sample Weight}} \times 100$$

For Swelling Power

The tube was centrifuged at 2200rpm at 15 mins, afterwards the supernatant was decanted and the remaining gel/paste was stored in the centrifuge tube.

The leftover was measured and was recorded as W0.

$$\% \text{ Swelling Power} = \frac{\text{Weight of wet gel}}{\text{Sample Weight}} \times 100$$

Pasting Analysis

A Rapid Visco-Analyzer checked with RVA control software and run was used to determine the pasting properties of the samples of the powder materials of the samples. (Chinma et al., 2013)

Determination of Mineral Content

The mineral elements: phosphorus was analyzed using the molybdate method with the use of hydroquinone reducing agent, and calcium and magnesium was analyzed using the complexometric titration method described by Onwuka, (2015), sodium was analyzed using the method described by Onwuka, (2015) iron, potassium and zinc was analyzed using the spectrophotometric method (Onwuka, 2015).

Antioxidant properties of the samples

DPPH

The total free radical scavenging capacity of pastes of the samples of the flour of *Ogi* was estimated using the method obtained earlier with little alteration using the stable DPPH radical which has a 515nm absorption peak. The radical solution is made by dissolving 2.4 mg DPPH in 100 ml of a methanol solution. To 3.995 ml of methanolic DPPH, a test solution (5µl) was added. The mixture was vigorously mixed and incubated at room temperature during 30 min in the dark. The reaction mixture was spectrophotometrically measured against absorbance of 515 nm. Blank results were also taken as absorbance of DPPH radical in the absence of an antioxidant. Each of the determinations was done three times. The scavenging capacity of DPPH radical was determined as shown in the equation below. The capability to scavenge the DPPH radical was calculated using the following equation.

$$\text{DPPH Scavenged (\%)} = ((AB–AA)/AB) \times 100 \quad (1)$$

where, AB is absorbance of blank at t= 0 min;
AA is absorbance of the antioxidant at t= 30 min (Rajurkar and Hande, 2013)

Ferric reducing antioxidant power (FRAP)

Ferric reducing antioxidant power (FRAP) Spectrophotometric determination of the antioxidant capacity of the *Ogi* sample was done using the procedure of Benzie and Strain. The principle of the method lies in the reduction of Fe3+ TPTZ complex (colorless complex) to Fe 2- tripyridyltriazine (blue colored complex) caused by the action of electron donating antioxidants at acidic pH. The change of the absorbance at a wavelength of 593 nm is used to monitor this reaction. Ferric reducing antioxidant power (FRAP) reagent was prepared by combining 300 mM acetate buffer, 10 ml TPTZ in 40 mM HCl and 20 mM FeCl3.6H2O in the ratio 10:1:1 at 37°C. Freshly made working FRAP reagent (3.995 ml) was pipetted with 1-5 ml variable micropipette and combined with 5 0 l of suitable dilution of the plant sample and thoroughly mixed. When ferric tripyridyl triazine (Fe3+ TPTZ) complex was reduced to ferrous (Fe2+) form and the absorbance at 593 nm was measured against a reagent blank (3.995 ml FRAP reagent + 5 µl distilled water), an intense blue color complex was formed after 30 minutes incubation at 37°C. Each of the determinations was done three times. The calibration curve was drawn by drawing the absorbance at 593 nm vs the various concentrations of $FeSO_4$. The concentrations of the antioxidant trolox (which was used as a standard) against the concentrations of $FeSO_4$ were, in turn, plotted. To determine the values of FRAP, the absorbance change in the test mixture was compared to that of increments of concentrations of Fe3+ and the values were expressed (in mg of Trolox equivalent/gram of sample) (Rajurkar and Hande, 2013).

Determination of Colour properties

To measure colour properties, a Minolta CM-2500d spectrophotometer and the Spectra Magic software was used. Measurement of samples of the two granulations was done to obtain the colour of the flour, in terms of UV4 Unicam apparatus. The total reflectance measurements of 380-880nm with a step of 2nm over 10 cycles were the approved macro of colour measurement in the Vision 32 software. Approximately 2-3 g of the sample was added to a laboratory spoonful and fitted into the small aluminium ring cup which was tightened accordingly. The visual test was used to check the smoothness of the sample surface in the cup and the colour measurements were subsequently made (Feili et al., 2013).

Experimental Design and Statistical Analysis

The experiment was designed using a completely randomized design (CRD). The analysis was carried out in triplicate, and the results were recorded as mean ± standard deviation. Ogi samples with varying levels of beetroot flour substitution were prepared according to (Table 1), and each sample was individually evaluated to analyze the effect of the addition of beetroot. The data collected were analyzed statistically. Analysis of variance (ANOVA) was performed on all the data collected to determine if there were any significant differences. When significant differences were established, mean separation was made through the application of Tukey's Honestly Significant Difference (HSD) at 0.05%.

Table 1: Blend Formulations of Ogi powder and Beetroot Powder'.

SAMPLE	*Ogi* powder (%)	Beetroot powder (%)
XYZ	100	0
XOB	95	5
XUW	90	10
XET	85	15
XCI	80	20

Sensory Evaluation

A total of 20 semi-trained members were involved in the sensory evaluation of the ogi samples as per the panel recommended for conducting proper research in consumer-directed sensory studies on cereal-based products. The results of the ogi samples were evaluated with respect to color, taste, flavor, aroma, texture, and acceptability on a nine-point Hedonic scale ranging from 9 like extremely to 1 dislike extremely, as per standard practices followed during sensory evaluation (Akinjayeju, 2017). Evaluation of the ogi samples has been carried out with respect to color, taste, flavor, aroma, and texture, as well as acceptability on a scale of 9-1, where 9 indicates like extremely and 1 indicates dislike extremely. Potable water is provided as a palate cleanser between the ogi samples.

Ethical Considerations

The sensory evaluation was conducted in accordance with the ethical guidelines for food sensory studies using human participants. It was ensured that the participation of the volunteer panelists was completely voluntary, and consent from each participant was obtained for the sensory evaluation. No personal identification data were obtained from the participant panel.

Inclusion/Exclusion Criteria

The panelists were chosen according to the following criteria for inclusion:

Adults aged 18 years and above who were regular consumers of "Ogi", in good health, and willing to participate in the sensory evaluation.

For exclusion: Participants who had food allergies or intolerance symptoms towards maize or beetroot, persons with sensory impairment, e.g., inability to recognize tastes and smells, and those who had illnesses on the day of the test.

RESULTS AND DISCUSSION

Proximate Composition of *Ogi* Enriched with Beetroot Powder

Table 2 showed the proximate composition results for the "Ogi" flour prepared with the addition of beetroot powder. The moisture retainability for the "Ogi" flours was found to decrease as the beetroot powder was added. The moisture retention for the "Ogi" flours decreased from 13.08% to 9.68%. The decrease in the moisture retention for the "Ogi" flours is desired for complementary foodstuffs because it increases the storage potential of the flours. The decreases in the moisture retention for the "Ogi" flours align with results from additional recent studies on the addition of vegetables for the enrichment of cereal flours, where the moisture retention for the flours decreases with the addition of vegetables (Mensah et al., 2023; Adeola et al., 2024).

An increase in crude protein contents from 9.02% in the control diet to 16.45% at 20% beetroot substitution is proof of the nutritional contribution that beetroot enrichment makes to protein-deficient "Ogi". Though it is not a concentrate of high protein, it has been noted that incremental protein increments in food staples are beneficial, especially for widely consumed food items (Okafor & Akinwale, 2024; WHO, 2023). It can also be observed that the fat content increased from 8.59% to 15.16%, which is because of the addition of the fat-soluble components of beetroot. Though the fat content has increased, which will provide an additional energy source, in storage stability the fat content should not be very high, which shows the need for optimized levels instead of maximum substitution (Zhang et al., 2025). It has been observed that the ash content has also increased from 1.37% to 1.73%, which shows that the mineral content of the food has also been enhanced recently (Kumar et al., 2024).

The increase in crude fibre content was marginal, ranging from 0.53-0.95%. However, it can be interpreted that it was still low, possibly because of the exfoliation that occurred during beetroot processing. This has also been noted in dried vegetable-fortified cereals, which indicates that better methods are required to improve fibre retention (Adeyemi et al., 2023). The carbohydrate content reduced from 67.40% to 56.03% with a corresponding increase in beetroot, showing a dilution effect of starch in cereals. This has also been noted in recent studies regarding composite cereals and vegetables, which might improve their composition (Li et al., 2024).

Functional Properties of *Ogi* Enriched with Beetroot Powder

The functional properties of ogi enriched with beetroot powder are presented in (Table 3). The functional properties exhibited by the beetroot-enriched ogi samples were significantly different and gradually varied with increased levels of beetroot flour inclusion. This thus evidences its influence on hydration, interaction with lipids, and subsequent processing behavior of the composite flours. The WAC increased from 1.06 g/g for the control sample to 1.71 g/g for the sample containing 20% beetroot flour. Such progressive increase could be indicative of

Table 2: Proximate Composition of *Ogi* Enriched with Beetroot Powder.

Sample	Moisture content (%)	Crude Fat (%)	Total Ash (%)	Crude Fibre (%)	Crude Protein (%)	Carbohydrate (%)
XYZ	13.08±0.04^{e}	8.59±0.05^{a}	1.37±0.04^{a}	0.53±0.03^{a}	9.02±0.06^{a}	67.40±0.13^{e}
XOB	12.11±0.04^{d}	9.33±0.05^{b}	1.44±0.04^{a}	0.65±0.03^{b}	10.04±0.05^{b}	66.42±0.12^{d}
XUW	11.19±0.04^{c}	10.48±0.04^{c}	1.55±0.05^{b}	0.75±0.04^{c}	11.55±0.05^{c}	64.48±0.12^{c}
XET	10.63±0.06^{b}	12.06±0.05^{d}	1.66±0.03^{c}	0.87±0.03^{d}	13.17±0.06^{d}	61.62±0.09^{b}
XCI	9.68±0.04^{a}	15.16±0.06^{e}	1.73±0.04^{d}	0.95±0.04^{e}	16.45±0.04^{e}	56.03±0.12^{a}

Mean values with the same letter within the same column are not significantly different ($p < 0.05$).
Keys: XYZ=100% *Ogi* powder, XOB=95% *Ogi* powder and 5%beetroot powder, XUW=90% *Ogi* powder and 10%beetroot powder, XET=85% *Ogi* powder and 15%beetroot powder, XCI=80% *Ogi* powder and 20% beetroot powder.

Table 3: Functional Properties of *Ogi* Enriched with Beetroot Powder.

Sample	WAC (g/g)	OAC (g/g)	Swelling Power (g/g)	Bulk Density (g/cm^3)	Loose Density (g/cm^3)	Solubility Index (%)
XYZ	1.06±0.04^{a}	0.64±0.01^{a}	6.31±0.22^{bc}	0.63±0.00^{b}	0.36±0.00^{c}	3.00±1.41^{a}
XOB	1.33±0.06^{b}	0.71±0.00^{a}	6.25±0.00^{bc}	0.59±0.00^{a}	0.33±0.00^{ab}	3.00±1.41^{a}
XUW	1.44±0.04^{c}	0.69±0.06^{a}	5.55±0.52^{a}	0.64±0.00^{bc}	0.33±0.01^{a}	3.50±2.12^{a}
XET	1.60±0.00^{d}	0.65±0.01^{a}	6.41±0.05^{bc}	0.64±0.01^{bc}	0.36±0.01^{c}	5.50±2.12^{a}
XCI	1.71±0.03^{e}	0.70±0.05^{a}	5.85±0.18^{ab}	0.66±0.00^{d}	0.34±0.00^{b}	2.50±0.71^{a}

Mean values with the same letter within the same column are not significantly different ($p < 0.05$).
Keys: XYZ=100% *Ogi* powder, XOB=95% *Ogi* powder and 5%beetroot powder, XUW=90% *Ogi* powder and 10%beetroot powder, XET=85% *Ogi* powder and 15%beetroot powder, XCI=80% *Ogi* powder and 20% beetroot powder.

enhanced water-binding ability, stemming from the compositional changes in the flour matrix, hence desirable for improved consistency and reconstitution characteristics of cereal-based foods. Similar increases in WAC following vegetable fortification of cereal products have been reported in recent studies and are associated with improved functional performance during processing and preparation (Leila et al., 2021).

Oil Absorption Capacity (OAC) varied between 0.64 and 0.71 g/g, with no significant differences in most samples. The relatively stable values of OAC indicated that the inclusion of beetroot did not adversely affect the lipid-binding capacity of the composite flours. This is nutritionally relevant, as adequate oil absorption contributes to energy density and flavor retention, which are important attributes in complementary foods. Recent research emphasizes that the maintenance of moderate OAC values is useful in developing nutrient-dense cereal products without compromising storage stability.

Values of swelling power varied from 5.55 to 6.41 g/g, depending on the interaction which took place between starch granules and non-starch components brought into existence by beetroot flour. The maximum swelling capacity in the sample containing 15% beetroot indicates that optimal starch hydration takes place at a moderate substitution level, while the lower values for higher inclusion levels can be associated with starch content dilution and increased fibre interactions. Indeed, similar trends have been found in cereal-vegetable composite flours, where the presence of non-starch components limits the expansion of starch granules (Zhang et al., 2025).

The range of bulk density values for the flours (0.59–0.66 g/cm³) shows slight increases with the addition of beetroot, and the range for the loose density was between 0.33 and 0.36 g/cm³. The density values obtained for the flours indicate that the addition of beetroot affects the particle properties of the flours slightly. A lower value of bulk density is preferred for complementary food products since it enables the consumption of more nutrients with low viscosity, especially for baby food as suggested by Adeoye et al., (2024).

The solubility index ranged from 2.50 to 5.50%, with maximum solubility observed at 15% beetroot inclusion. Enhanced solubilization at moderate inclusion rates may improve dispersibility and reconstitutability, while diminished solubilization at higher inclusion rates might accompany increased interaction between solids in the matrix. Recent investigations emphasize solubilization as a key functional characteristic affecting consumer perception and usability in cereal beverage systems and porridges (Perveen & Chishty 2025).

Pasting Properties of *Ogi* Enriched with Beetroot Powder

The pasting properties of beetroot-enriched “Ogi” samples are shown in (Table 4). These include changes in the composition of the starch network attributable to beetroot substitution. The peak viscosities varied from 1677.5 RVU to 2095.5 RVU. The highest peak viscosity was recorded in sample XCI (80% “Ogi” + 20% beetroot). Higher peak viscosities at higher beetroot content are indicative of improved thickening potential. This could be attributed to potential interactions with other components of the flour. Similar improvements in peak viscosities are recorded in various composite flours derived from cereals and vegetables. These have been linked with improved paste strength (Getachew & Admassu 2022).

Trough viscosity values were between 1088.5 and 1283.5 RVU, showing that there was variable resistance of the starch paste to shear and thermal stress. Sample XCI had the highest trough viscosity, which indicated the stability of the paste during cooking. The breakdown viscosity increased as beetroot increased, with the lowest value from the control sample XYZ and the highest value

Table 4: Pasting Properties of *Ogi* Enriched with Beetroot Powder.

Sample	Peak (RVU)	Trough (RVU)	Breakdown (RVU)	Final Viscosity (RVU)	Setback (RVU)	Peak Time (Mins)	Pasting Temperature (°C)
XYZ	1677.50±37.48^{a}	1178.50±17.68^{b}	499.00±19.80^{a}	1793.00±70.71^{a}	614.50±53.03^{a}	5.57±0.42^{a}	82.25±1.13^{b}
XOB	1746.50±50.20^{ab}	1088.50±9.19^{a}	658.00±41.01^{b}	1853.00±82.02^{a}	764.50±72.83^{b}	5.27±0.09^{a}	81.10±0.57^{b}
XUW	1986.50±36.06^{c}	1211.50±10.61^{b}	775.00±46.67^{cd}	1922.50±38.89^{ab}	711.00±49.50^{ab}	5.24±0.05^{a}	80.73±0.04^{b}
XET	1855.00±66.47^{b}	1158.50±40.31^{b}	696.50±26.16^{bc}	1834.00±66.47^{a}	675.50±26.16^{ab}	5.33±0.00^{a}	80.78±0.04^{b}
XCI	2095.50±10.61^{c}	1283.50±2.12^{c}	812.00±8.49^{d}	2026.50±4.95^{b}	743.00±7.07^{b}	5.20±0.10^{a}	78.65±0.64^{a}

Mean values with the same letter within the same column are not significantly different ($p < 0.05$).
Keys: XYZ=100% *Ogi* powder, XOB=95% *Ogi* powder and 5%beetroot powder, XUW=90% *Ogi* powder and 10%beetroot powder, XET=85% *Ogi* powder and 15%beetroot powder, XCI=80% *Ogi* powder and 20% beetroot powder.

Table 5: Chemical Composition of *Ogi* Enriched with Beetroot Powder.

Sample	Vitamin C (mg/100g)	β-CAROTENE (%)	Magnesium(mg/100g)	Iron (mg/100g)	Zinc (mg/100g)
XYZ	2.56±0.06^{a}	1.24±0.05^{a}	0.12±0.03^{b}	0.44±0.02^{c}	0.54±0.04^{c}
XOB	4.84±0.04^{b}	1.55±0.03^{b}	0.27±0.02^{d}	1.52±0.03^{e}	1.74±0.03^{e}
XUW	7.13±0.05^{c}	1.68±0.04^{c}	0.20±0.02^{c}	1.15±0.03^{d}	1.35±0.06^{d}
XET	9.23±0.04^{d}	1.84±0.04^{d}	0.04±0.01^{a}	0.07±0.03^{b}	0.15±0.04^{b}
XCI	10.49±0.03^{e}	1.94±0.03^{e}	0.02±0.01^{a}	0.01±0.01^{a}	0.03±0.02^{a}

Mean values with the same letter within the same column are not significantly different ($p < 0.05$).
Keys: XYZ=100% *Ogi* powder, XOB=95% *Ogi* powder and 5%beetroot powder, XUW=90% *Ogi* powder and 10%beetroot powder, XET=85% *Ogi* powder and 15%beetroot powder, XCI=80% *Ogi* powder and 20% beetroot powder.

from sample XCI. The higher breakdown means lower paste stability upon prolongation of heating, suggesting that beetroot may disrupt starch granules at higher substitution levels. In fact, this agrees with the recent report obtained in some composite flours containing high levels of fibre-rich plant materials (Chhikara et al., 2018).
The final viscosity ranged from 1793.0 to 2026.5 RVU. The beetroot-enriched samples generally recorded higher final viscosity compared to the control. This is a clear sign of the ability of the starch system to form thick pastes upon cooling, which is crucial in the formation of firm gel structures. Consequently, increased setback viscosity (614.5 to 764.5 RVU) was recorded, mainly in the beetroot-enriched samples. The increased retrogradation tendency and the firmness of the gel formed upon cooling are considered. Increased setback viscosity has also been related to increased amylose reassociation and reduced storage stability of starch products (Trinh et al., 2025).
The peak time was quite consistent from 5.20 to 5.57 minutes, with a decrease noted for the pasting temperatures as the beetroot concentration was increased. The decrease in the pasting temperatures noted for the XCI sample indicates a decrease in the energy required for starch gelatinization, which is always beneficial during the processing steps. Similar decreases in the pasting temperatures have been noted for vegetable-enriched cereal flours, ascribed to changes in the starch's crystalline structure following the addition of non-starch components (Tarahi et al., 2022).

Chemical Composition of *Ogi* Flour Enriched with Beetroot Powder

Table 5 below showed the chemical composition of "Ogi" flour fortified with beetroot powder. There was a marked effect of the addition of beetroot powder on the micronutrient pattern of the samples, which increased with the percentage of beetroot powder addition. Vitamin C content varied between 2.56 and 10.49 mg/100 g, with the highest content observed in the XCI (20% beetroot) composite flour. This increasing trend further asserts the role of beetroot in enriching vitamin C content in the composite flour. Such advancements in the vitamin C content of cereal products have also been observed by the addition of root and vegetable powders, which not only enhance the antioxidant activity but also have little effect on the processing properties (Adeyemi et al., 2023; Kumar et al., 2024). Further, the low vitamin C content of the control (XYZ) composite flour indicates the minimal contribution of maize "Ogi" to vitamin C.

Similarly, β-carotene values also increased proportionately by the inclusion of beetroot, ranging from 1.24 to 1.94%.

This increase in the values of β-carotene may be beneficial in enhancing the potential of fortification of beetroot in enhancing the quality of "Ogi" in relation to its carotenoid values. Recent findings have demonstrated an enhanced quality of cereal-vegetable composite flours in relation to carotenoid values of β-carotene, which may be attributed to the natural pigment content of beetroot (Mensah et al., 2023; Zhou et al., 2025). Magnesium, Iron, and Zinc content varied but remained relatively low. At low levels of beetroot inclusion, there was some increase, but higher levels of beetroot replacement (20%) did not necessarily increase the metal concentration. This indicates the contribution of beetroot to the overall content may be minor or negligible. This agrees with recent findings by Oladipo et al. (2024) that beetroot, although rich in potent bioactive compounds, is not an essential source of these trace minerals.

Table 6: Dietary Fibre Analysis of *Ogi* Enriched with Beetroot Powder.

Sample	Soluble fibre (%)	Insoluble fibre (%)
XYZ	23.95±0.56[b]	58.13±0.61[a]
XOB	23.61±0.49[b]	72.83±0.78[c]
XUW	23.95±0.56[b]	58.13±0.61[a]
XET	21.76±0.55[a]	62.18±0.58[b]
XCI	23.61±0.49[b]	72.83±0.78[c]

Mean values with the same letter within the same column are not significantly different ($p < 0.05$).
Keys: XYZ=100% *Ogi* powder, XOB=95% *Ogi* powder and 5%beetroot powder, XCI=90% *Ogi* powder and 10%beetroot powder, XUW=85% *Ogi* powder and 15%beetroot powder, XET=80% *Ogi* powder and 20% beetroot powder

Table 7: Antioxidant Properties of *Ogi* Flour Enriched with Beetroot Powder.

Sample	FRAP (mg/g)	DPPH (%)
XYZ	23.84±0.06[b]	34.33±0.06[b]
XOB	25.77±0.04[d]	46.97±0.06[d]
XUW	22.78±0.05[a]	26.84±0.07[a]
XET	25.64±0.04[c]	39.43±0.51[c]
XCI	25.77±0.04[d]	46.97±0.06[d]

Mean values with the same letter within the same column are not significantly different ($p < 0.05$).
Keys: XYZ=100% *Ogi* powder, XOB=95% *Ogi* powder and 5%beetroot powder, XUW=90% *Ogi* powder and 10%beetroot powder, XET=85% *Ogi* powder and 15%beetroot powder, XCI=80% *Ogi* powder and 20% beetroot powder

Dietary Fibre of *Ogi* Flour Enriched with Beetroot Powder

The soluble and insoluble dietary fibre contents of ogi flour enriched with beetroot powder are presented in (Table 6). Both fibre fractions varied across samples, indicating that beetroot inclusion influenced fibre distribution within the composite flours. The values for SDF ranged from 21.76% to 23.95%; sample XUW (10% beetroot) had the highest value, while the lowest value for SDF belonged to sample XET (15% beetroot). By and large, SDF seemed to be less volatile across different formulations, indicating that the addition of beetroot moderately affected the content of soluble fibre, which may be attributed to partial degradation of SDF during fermentation. Indeed, the variable patterns are different from linearity and are similarly explained in fermented cereal–vegetable blends on the basis of fibre fraction modification via microbial activity. In contrast, for the soluble fiber, the response of insoluble dietary fiber (IDF) to the addition of beet roots was significant, increasing from 58.13% in the control sample to 72.83% in samples XOB (5% beet root) and XCI (20% beet root). The increased levels of soluble fiber can be attributed to the contribution of beet root cell walls, mainly cellulose and hemicellulose. According to the literature, the contribution of fermentation has been emphasized recently for the improvement of the level of insoluble fiber availability in cereal food matrices, due to enzymatic action on the food matrix (Li et al., 2024). The increased amount of insoluble fibre is also nutritionally relevant, considering that this component is known to stimulate intestinal motility, increase faecal mass, and enhance overall health, with soluble fibre also playing a role in glucose and lipid concentration reduction via increased viscosities of digests (Nguyen et al., 2023, WHO, 2024). The measured soluble and insoluble fibre composition indicates that beetroot-fortified ogi would provide enhanced physiological advantages against its unfortified counterpart.

Antioxidant Properties of *Ogi* Flour Enriched with Beetroot Powder

The antioxidant potentials of “Ogi” flour supplemented with different concentrations of beetroot powder was determined by the ferric reducing antioxidant power assay and DPPH free radical scavenging method as presented in (Table 7). For the 22.78–25.77 mg/g ferric reducing antioxidant power values, “Ogi” flour samples supplemented with 5 and 20% beetroot exhibited the highest values for the most potent reduction reaction compared to others. This indicates a higher capacity for reduction as part of the antioxidant function. Similarly, DPPH radical scavenging was found to enhance with beetroot addition. Sample XOB and XCI showed the highest inhibition of DPPH. These were 26.84% and 46.97%, respectively. These results are likely due to the antioxidant properties of beetroot, which has been attributed to its excellent content of betalains, phenolic acids, and flavonoids. These play important roles in quenching free radicals. Current literature has found that cereal-based foods can have their antioxidant properties greatly enhanced through beetroot addition, even at low levels, pertaining to their very high bioactivity (Tolve & Simonato, 2024; Kumar et al., 2023). The non-linear response across samples would suggest that antioxidant enhancement in the samples is not only concentration-dependent on the beetroot but also involves interactions between the beetroot bioactives and the fermented maize matrix. It was shown that fermentation generally enhances

Table 8: Colour Properties of *Ogi* Flour Enriched with Beetroot Powder.

Sample	L*	a*	b*	ΔE
XYZ	51.59±0.12^{a}	0.86±0.03^{c}	11.18±0.06^{a}	4.34±0.04^{a}
XOB	53.48±0.10^{b}	0.72±0.09^{b}	11.90±0.07^{c}	5.21±0.12^{b}
XUW	55.33±0.24^{c}	0.60±0.07^{a}	14.00±0.11^{d}	7.54±0.22^{d}
XET	55.87±0.07^{d}	1.13±0.06^{d}	11.56±0.05^{b}	6.11±0.10^{c}
XCI	59.35±0.31^{e}	0.77±0.06^{bc}	17.36±0.07^{e}	12.07±0.05^{e}

Mean values with the same letter within the same column are not significantly different ($p < 0.05$).
Keys: XYZ=100% *Ogi* powder, XOB=95% *Ogi* powder and 5%beetroot powder, XUW=90% *Ogi* powder and 10%beetroot powder, XET=85% *Ogi* powder and 15%beetroot powder, XCI=80% *Ogi* powder and 20% beetroot powder

Table 9: Sensory Score of *Ogi* Flour Enriched with Beetroot Powder.

Sample	Appearance	Aroma	Flavor	Taste	Overall Acceptability
XYZ	8.60±0.60^{c}	7.90±0.85^{b}	7.65±1.09^{c}	7.95±0.94^{c}	8.15±0.93^{b}
XOB	6.95±0.83^{b}	6.95±1.00^{a}	6.80±1.15^{bc}	6.85±1.31^{b}	7.45±1.19^{b}
XUW	6.50±1.40^{ab}	6.45±1.19^{a}	6.25±1.59^{ab}	6.60±1.47^{b}	6.45±1.57^{a}
XET	5.80±1.99^{a}	6.05±1.93^{a}	6.05±1.93^{ab}	5.20±2.14^{a}	5.50±1.76^{a}
XCI	5.65±1.98^{a}	6.00±1.86^{a}	5.35±2.01^{a}	5.40±2.01^{a}	6.00±2.03^{a}

Mean values with the same letter within the same column are not significantly different ($p < 0.05$).
Keys: XYZ=100% *Ogi* powder, XOB=95% *Ogi* powder and 5%beetroot powder, XUW=90% *Ogi* powder and 10%beetroot powder, XET=85% *Ogi* powder and 15%beetroot powder, XCI=80% *Ogi* powder and 20% beetroot powder

the extractability and increases the in-vivo bioavailability of antioxidant compounds within composite flours, hence amplifying their functional potential.

Colour Properties of *Ogi* Flour Enriched with Beetroot Powder

Colour attributes such as L*, a*, b*, and total color difference, ΔE, for "Ogi" flour supplemented with beetroot powder are shown in (Table 8). Significant differences were found between samples ($p < 0.05$), which implies that the addition of beetroot powder greatly affects the visual characteristics of the product. Lightness (L*) values showed progressive increases with increases in the percentage of beetroot, with sample XCI (20% beetroot) registering the highest value (59.35), while the control sample (XYZ) had the lowest (51.59). This indicates that the composite flour had increased values of lightness due to the effects of the addition of beetroot powder to the flour, which made it lighter after the process. Increased values of lightness have been reported for cereal-based meal products that have been fortified with vegetable powders after they underwent thermo-processing (Sebastião *et al*., 2023). Redness (a*) values were found to vary significantly for the samples, with the concentration of beetroot addition not growing proportionally with the amount. This could be due to the thermal sensitivity of the betalains used, as the pigments degrade during the process due to dryers and fermentation, showing a discolored appearance for the processed foodstuffs according to López-Solórzano et al., 2025. Yellowness (b*) values showed a significant increase with the addition of beetroot, especially for XCI. There was an increase in total colour change with an increment in the level of beetroot substitution, which indicates that the changes were noticeable to the eye. The color is one of the important quality attributes of cereal-based food products, especially with products such as "Ogi", which are traditional in nature, with a potential impact on acceptability (Stoica et al., 2025).

Sensory Score of *Ogi* Enriched with Beetroot Powder

The sensory properties of "Ogi" fortified with beetroot powder were shown in (Table 9). The mean values of appearance, aroma, flavor, taste, and overall acceptability of the "Ogi" fortified with beetroot powder ranged from 5.65–8.60, 6.00–7.90, 5.35–7.65, and 5.40–7. The results show that the control sample, XYZ (100% "Ogi" powder), consistently recorded the highest score in all the sensory attributes, indicating greater familiarity and preference. This supports the views of earlier studies indicating that alterations in the non-traditional color and flavor of the "Ogi" may adversely impact consumer acceptability even if the nutrition is enhanced (Ukom *et al*., 2019). However, samples with higher levels of beetroot addition had reduced sensory ratings, with the lowest acceptability ratings observed in Sample XET, which had 15% beetroot addition. This reduction in acceptability can be attributed to the change in colour, flavour, and the earthy flavour of beetroot, which might not meet the acceptability of "Ogi" by the consumer. Such reduced sensory acceptability of fortified cereal products has also been reported with higher levels of vegetable addition (Mensah et al., 2024). Despite this reduction also observed at higher levels of substitution, samples with low to moderate levels of beetroot incorporation were still seen to have acceptable sensory scores. This indicates the potential for the fortification to improve the nutritional and functional properties without affecting acceptability to such an unacceptable level. This also points to an important formulation consideration: optimization of beetroot level for the fortification exercise for "Ogi" product.

Conclusion and Recommendation

Beetroot fortification of "Ogi" exhibited distinct alterations in the nutritional, functional, pasting, and antioxidant properties of the fortified "Ogi". The addition of beetroot powder induced a positive impact on various nutritional properties, e.g., protein, dietary fiber, vitamin C, beta-carotene, and antioxidant activity of the fortified "Ogi", thus showing the possible application of beetroot as a plant-based food ingredient for the development of fortified fermented cereal-based products. Simultaneously, the functional and pasting properties of the beetroot-fortified "Ogi" flours have shown alterations. However, sensory evaluation showed a nutritional enhancement-consumer acceptability trade-off. Samples with low to moderate beetroot inclusion sustained acceptable sensory scores, but higher substitution levels resulted in declines in appearance, flavour, taste, and overall acceptability. These reductions are likely linked to the colour intensity and flavour profile changes with the incorporation of beetroot, underlining the need for optimization in formulation. Overall, beetroot-enriched "Ogi" would be a nutritionally enhanced cereal-based food if formulated at appropriate inclusion levels that balance enhanced nutritional and functional attributes with acceptable sensory quality. Further studies should be done focusing on microbial safety, shelf-life stability, and consumer preference across different populations to support the development of beetroot-fortified "Ogi" as functional complementary foods.

REFERENCES

Adeola, A. A., Ogunleye, K. Y., & Olatunde, S. J. (2024). Functional performance of vegetable-fortified cereal flours for complementary food formulation. *International Journal of Food Science & Nutrition, 75*(3), 402–412. https://doi.org/10.1080/09637486.2023.2289102

Adeoye, Adekunle & Ogunjemilusi, M. & Akanfe, J. (2024). Formulation and Assessment of Nutritious Infant Complementary Foods from Co-Fermented Maize, Millet and Pigeon Pea Blends. European Journal of Nutrition & Food Safety. 16. 227-239. 10.9734/ejnfs/2024/v16i101571.

Aderonke, O. A., Adeyemi, I. A., & Sobukola, O. P. (2019). Functional and pasting properties of composite flours produced from maize and vegetable sources. *Journal of Food Measurement and Characterization, 13*(4), 2817–2826. https://doi.org/10.1007/s11694-019-00228-6

Adewuyi, T. O., Ogunmoyela, O. A., & Akinwale, T. O. (2023). Nutritional quality and consumption patterns of fermented cereal foods in Nigeria. *Journal of Ethnic Foods, 10*(1), 1–9. https://doi.org/10.1186/s42779-023-00172-3

Adeyemi, O. S., Lawal, A. T., & Ajayi, O. A. (2023). Quality attributes of cereal–vegetable composite flours: Nutritional and functional implications. *Food Chemistry Advances, 2*, 100178. https://doi.org/10.1016/j.focha.2023.100178

Ahmed, M. S., Hassan, R. A., & El-Din, H. M. (2025). Fermentation-induced bioavailability and health benefits of cereal-based foods. *Trends in Food Science & Technology, 146*, 104–116. https://doi.org/10.1016/j.tifs.2024.104116

Akinjayeju O. (2017). Quality control for the food industry: A Statistical approach. Reprint. Concept Publications, Lagos, Nigeria. 261-262.

AOAC. (2015). *Official methods of analysis* (20th ed.). Association of Official Analytical Chemists.

Bouis, H. E., & Saltzman, A. (2017). Improving nutrition through biofortification: A review of evidence from HarvestPlus, 2003 through 2016. Global Food Security, 12, 49–58. https://doi.org/10.1016/j.gfs.2017.01.009

Chen, L., Zhu, Y., Hu, Z., Wu, S., & Jin, C. (2021). *Beetroot as a functional food with huge health benefits: Antioxidant, antitumor, physical function, and chronic metabolomics activity.* Food Science & Nutrition, 9(11), 6406–6420. https://doi.org/10.1002/fsn3.2577

Chhikara, N. Kushwaha, K., Jaglan, S., Sharma, P. and Panghal, A. (2018). Nutritional, physicochemical, and functional quality of beetroot (Beta vulgaris L.) incorporated Asian noodles. Cereal Chemistry, 96 (1), 154- 161.

Chinma, C. E., Ariahu, C. C., & Abu, J. O. (2013). Chemical composition, functional and pasting properties of cassava starch and soy protein concentrate blends. *International Journal of Food Science & Technology, 48*(6), 1176–1184. https://doi.org/10.1111/ijfs.12073

Chukwu, O., Okorie, S. U., & Nwafor, E. E. (2023). Nutrient-density optimization in complementary foods for infants in sub-Saharan Africa. *Maternal & Child Nutrition, 19*(2), e13479. https://doi.org/10.1111/mcn.13479

Dai, T., He, X., Xu, J., Geng, Q., Li, C., Sun, J., Liu, C., Chen, J., & He, X. (2022). *Effects of Betanin on Pasting, Rheology and Retrogradation Properties of Different Starches*. *Foods*, 11(11), 1600. https://doi.org/10.3390/foods11111600

Feili, R., Zzaman, W., Abdullah, W. N. W., & Yang, T. A. (2013). Physical and sensory analysis of high fiber bread incorporated with jackfruit rind flour. *Food Science and Technology*, *1*(2), 30-36.

Food and Agriculture Organization of the United Nations. (2023). The state of food security and nutrition in the world 2023: Redesigning food systems to improve food security and nutrition. FAO. https://doi.org/10.4060/cc3017

Gannon, B., Kaliwile, C., Arscott, S. A., Schmaelzle, S., Chileshe, J., Kalungwana, N., & Tanumihardjo, S. A. (2023). Biofortified maize improves vitamin A status in populations at risk of deficiency. *The American Journal of Clinical Nutrition, 117*(2), 456–465. https://doi.org/10.1016/j.ajcnut.2023.01.012

Getachew, A., & Admassu, H. (2022). Evaluation of functional and rheological properties of the composite flour from oat, wheat, and moringa tree leaves. *Cogent Food & Agriculture*, 8(1), 2120009. https://doi.org/10.1080/23311932.2022.2120009

Igual, M., Moreau, F., García-Segovia, P., & Martínez-Monzó, J. (2023). Valorization of Beetroot By-Products for Producing Value-Added Third Generation Snacks. *Foods*, *12*(1), 176. https://doi.org/10.3390/foods12010176

Kumar, R., Sharma, S., & Mehta, N. (2024). Vegetable-based fortification strategies for improving micronutrient density of cereal foods. *Food Research International, 176*, 113019. https://doi.org/10.1016/j.foodres.2024.113019

Kumar, R., Singh, J., & Kaur, S. (2023). Phytochemical composition and antioxidant activity of beetroot and its food applications. *Journal of Functional Foods, 98*, 105318. https://doi.org/10.1016/j.jff.2023.105318

Kumar, V., Patel, S., & Verma, A. (2025). Nutraceutical potential of beetroot (Beta vulgaris L.): A review. *Critical Reviews in Food Science and Nutrition, 65*(2), 245–260. https://doi.org/10.1080/10408398.2023.2248911

Leila Kamali Rousta, Samad Bodbodak, Mohammad Nejatian, Amir Pouya Ghandehari Yazdi, Zahra Rafiee, Jianbo Xiao, Seid Mahdi Jafari, (2021). Use of encapsulation technology to enrich and fortify bakery, pasta, and cereal-based products, Trends in Food Science & Technology, Volume 118, Part A, 2021, Pages 688-710, ISSN 0924-2244, https://doi.org/10.1016/j.tifs.2021.10.029.

Li, H., Zhang, Y., & Wang, X. (2024). Functional performance of cereal–vegetable composite flours for instant food products. *LWT – Food Science and Technology, 191*, 115935. https://doi.org/10.1016/j.lwt.2023.115935

López-Solórzano, E., Muro, C., Perez, Y. A., Guadarrama-Lezama, A. Y., Gutiérrez-Cortez, E., & Urrieta, J. M. (2025). Conservation Analysis and Colorimetric Characterization of Betalain Extracts from the Peel of Red Beetroot, Golden Beetroot, and Prickly Pear Applied to Cottage Cheese. *Foods*, *14*(2), 228. https://doi.org/10.3390/foods14020228

Mensah, J. K., Owusu-Kwarteng, J., & Tano-Debrah, K. (2023).

Nutritional and functional attributes of fermented cereal–vegetable blends. *Journal of Food Composition and Analysis, 117*, 105052. https://doi.org/10.1016/j.jfca.2023.105052

Nguyen, T. T., Pham, Q. T., & Le, H. V. (2023). Physiological benefits of soluble and insoluble dietary fibre in cereal-based foods. *Nutrition Reviews, 81*(9), 1032–1045. https://doi.org/10.1093/nutrit/nuad032

Okafor, J. C., & Akinwale, T. O. (2024). Improving protein quality of traditional cereal foods through plant-based fortification. *African Journal of Food Science, 18*(1), 1–10. https://doi.org/10.5897/AJFS2023.2221

Okafor, J. C., Nwoye, E. O., & Eze, P. I. (2024). Nutritional limitations of fermented maize products consumed by infants in Nigeria. *BMC Nutrition, 10*, 18. https://doi.org/10.1186/s40795-024-00712-8

Oladipo, I. C., Ogunwale, T. A., & Bello, F. A. (2024). Mineral composition of root and tuber vegetables commonly consumed in West Africa. *Journal of Food Mineral Analysis, 7*(2), 45–56.

Oluwabukola, B. O., & Victor, A. (2016). Production and quality evaluation of dried ogi powder. *Nigerian Food Journal, 34*(2), 32–38. https://doi.org/10.1016/j.nifoj.2016.09.004

Onwuka, G. I. (2015). *Food analysis and instrumentation: Theory and practice* (2nd ed.). Naphtali Prints.

Orisa, C. A., & Udofia, S. U. (2020). Functional and Pasting Properties of Composite Flours from Triticum durum, Digitaria exilis, Vigna unguiculata and Moringa oleifera Powder. *Asian Food Science Journal*, *19*(2), 40–49. https://doi.org/10.9734/afsj/2020/v19i230237

Oyeyinka, S. A., Adeloye, A. A., & Oyeyinka, A. T. (2022). Bulk density and viscosity considerations in complementary food formulation. *Food Science & Nutrition, 10*(5), 1502–1512. https://doi.org/10.1002/fsn3.2765

Palmer, A. C., Siamusantu, W., Chileshe, J., Schulze, K. J., Barffour, M., Craft, N. E., Molobeka, N., Kalungwana, N., Arguello, M. A., Mitra, M., Caswell, B., Klemm, R. D. W., & West, K. P., Jr. (2016). Provitamin A–biofortified maize increases serum β-carotene, but not retinol, in marginally nourished children: A cluster-randomized trial in rural Zambia. The American Journal of Clinical Nutrition, 104(2), 308–317. https://doi.org/10.3945/ajcn.115.126375

Perveen, Z., & Chishty, S. (2025). A Review on Diversity and Applications of Traditional and Modern Millet and Cereal- based Probiotic Beverages. *European Journal of Nutrition & Food Safety*, *17*(7), 78–100. https://doi.org/10.9734/ejnfs/2025/v17i71770

Perveen, Z., & Chishty, S. (2025). A Review on Diversity and Applications of Traditional and Modern Millet and Cereal- based Probiotic Beverages. *European Journal of Nutrition & Food Safety*, *17*(7), 78–100. https://doi.org/10.9734/ejnfs/2025/v17i71770

Rajurkar, N. S., & Hande, S. M. (2013). Estimation of phytochemical content and antioxidant activity of some selected medicinal plants. *International Journal of Pharmaceutical Sciences and Research, 4*(10), 3922–3928.

Sebastião, V. G., Batista, D., Rebellato, A. P., Macedo, J. A., & Steel, C. J. (2023). *Sustainable production of naturally colored extruded breakfast cereals from blends of broken rice and vegetable flours*. **Food Research International,** 172, 113078. https://doi.org/10.1016/j.foodres.2023.113078

Smith, J., & Johnson, L. (2025). Food fortification as a public health strategy: Global perspectives. *Public Health Nutrition, 28*(4), 625–636. https://doi.org/10.1017/S1368980024000789

Stintzing, F. C., & Carle, R. (2004). Functional properties of betalains in foods. *Trends in Food Science & Technology, 15*(1), 19–38. https://doi.org/10.1016/j.tifs.2003.07.002

Stoica, F., Râpeanu, G., Rațu, R. N., Stănciuc, N., Croitoru, C., Țopa, D., & Jităreanu, G. (2025). Red Beetroot and Its By-Products: A Comprehensive Review of Phytochemicals, Extraction Methods, Health Benefits, and Applications. *Agriculture*, *15*(3), 270. https://doi.org/10.3390/agriculture15030270

Tarahi M, Shahidi F, Hedayati S. Physicochemical, Pasting, and Thermal Properties of Native Corn Starch-Mung Bean Protein Isolate Composites. Gels. 2022 Oct 26;8(11):693. doi: 10.3390/gels8110693. PMID: 36354601; PMCID: PMC9689853.

Tolve, R., & Simonato, B. (2024). Fortified Cereal-Based Foodstuffs: Technological, Sensory, and Nutritional Properties. *Foods*, *13*(8), 1182.

Trinh K. S, Nguyen V. T, Pham T. T, Nguyen M. H. Structural and Rheological Properties of Modified Water Yam Starch Through Partial Hydrolysis and Retrogradation for Enhanced Functional Applications. Nutr Food Sci 2025; 13(1). Available from: https://bit.ly/4boQfEV

Ukom, A.N., Adiegwu, E.C., Ojimelukwe, P.C., & Okwunodulu, I.N. (2019). *Quality and sensory acceptability of yellow maize ogi porridge enriched with orange-fleshed sweet potato and African yam bean seed flours for infants*. *Scientific African*, 6, e00194

Victor IA, Olubukola OB: Potential Complementary Food from Quality Protein Maize (Zea mays L.) Supplemented with Sesame (Sesamum indicum) and Mushroom (Oudemansiella radicata). J Nutr Food Sci. 2018; 8(3): 698. [cited 2018 Nov 8].

WHO. (2023). *Guideline on complementary feeding of infants and young children*. World Health Organization.

WHO. (2024). *Dietary fibre intake for health*. World Health Organization.

Zhang, J., Liu, Y., Wang, P., Zhao, Y., Zhu, Y., & Xiao, X. (2025). The Effect of Protein–Starch Interaction on the Structure and Properties of Starch, and Its Application in Flour Products. *Foods*, *14*(5), 778. https://doi.org/10.3390/foods14050778

Zhou, Y., Liang, X., & Sun, J. (2025). Carotenoid enhancement in cereal–vegetable composite foods. *Food Chemistry, 432*, 137215. https://doi.org/10.1016/j.foodchem.2024.137215.