

Comparative Quality Evaluation of Plain, Turmeric- and Palm Oil - Enriched Garri Produced

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ABSTRACT

This study comparatively evaluated the nutritional and anti-nutritional composition of conventional garri and garri enriched with palm oil and turmeric powder. Garri samples were formulated as plain garri (GUS), garri enriched with 3% palm oil (GFP), and garri enriched with 3% turmeric powder (GFT). The samples were evaluated for proximate composition, cyanide content, functional properties, antioxidant activity, starch composition, carotenoid content, physicochemical properties, heavy metals, sensory characteristics, colour, anti-nutritional factors and mineral composition. Results showed that GFT recorded higher ash (2.08%), protein (1.82%), fibre (2.14%), antioxidant activity, total phenolic content (72.46 mg GAE/100 g), total flavonoid content (34.84 mg QE/100 g), vitamin C (12.68 mg/100 g) and resistant starch (2.64%) than GUS. GFT also exhibited improved water absorption, swelling capacity, dispersibility and mineral composition. GFP recorded the highest fat (3.84%), energy value (368.64 kcal/100 g) and overall sensory acceptability (8.36). Turmeric enrichment also enhanced the colour characteristics and antioxidant potential of garri while reducing phytate and oxalate contents. Overall, turmeric enrichment demonstrated considerable potential for improving the nutritional, functional and bioactive properties of garri while maintaining good sensory acceptability.

Keywords: Garri, turmeric, nutritional composition, antioxidant activity, anti-nutritional factors, functional properties.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is an important tropical root crop and a major source of dietary energy in many developing countries. Its high starch content, adaptability to diverse agroecological conditions, relatively low production requirements and ability to withstand periods of drought have contributed to its importance in food systems, particularly in sub-Saharan Africa (El-Sharkawy, 2004; Burns et al., 2010). Cassava roots are processed into a wide range of traditional foods, including flour, fufu, starch and garri. However, the high carbohydrate content of cassava, coupled with its comparatively low protein and micronutrient content, means that cassava-based staples may provide substantial dietary energy without necessarily supplying a balanced nutrient profile when consumed as major components of the diet (Montagnac et al., 2009).

Garri is among the most extensively consumed cassava products in Nigeria and other parts of West Africa. It is produced through a sequence of processing operations involving peeling, washing, grating, fermentation, pressing, pulverization, sieving and roasting. These operations contribute to the characteristic physicochemical and sensory properties of garri, improve its storability and, importantly, reduce cyanogenic compounds naturally occurring in cassava (Adewusi & Akindahunsi, 1994; Kemdirim et al., 1995). Garri may be

consumed directly after soaking in water or processed into eba, a stiff dough commonly served with soups and stews. Its relatively long shelf life, convenience, affordability and cultural acceptability have made it an important component of household diets in Nigeria.

Notwithstanding its importance, conventional garri is predominantly an energy-dense, starch-based food. Consequently, dependence on garri as a major dietary staple may contribute to inadequate intake of protein, selected micronutrients and other bioactive food components when the overall diet lacks sufficient diversity. This nutritional limitation has stimulated interest in the modification or enrichment of traditional cassava products with locally available ingredients capable of improving their nutritional and functional characteristics. Food enrichment provides an opportunity to improve the composition of commonly consumed staple foods without necessarily changing their basic form or traditional method of consumption (Montagnac et al., 2009).

Turmeric (*Curcuma longa* L.), a member of the Zingiberaceae family, is an important rhizomatous spice that has received considerable scientific interest because of its characteristic yellow-orange colour and its content of biologically active compounds. Curcuminoids, particularly curcumin, represent the principal bioactive constituents associated with turmeric and have been extensively investigated for their antioxidant and anti-inflammatory activities (Hewlings & Kalman, 2017; Prasad et al., 2014). In addition to its use as a spice and natural colourant, turmeric has potential application as a functional food ingredient. Incorporating turmeric into commonly consumed staple foods may therefore provide an approach for increasing the intake of phytochemicals while simultaneously modifying selected nutritional and sensory characteristics of the food.

The incorporation of turmeric into garri, however, may produce effects extending beyond nutritional enhancement. The addition of a plant-derived ingredient can alter the proximate composition, mineral profile, colour, functional properties and sensory characteristics of the resulting product. The extent of these changes is dependent on the proportion of turmeric incorporated, the characteristics of the base food and the processing conditions employed. Therefore, the nutritional benefit of an enriched product cannot be established solely from the presence of a potentially beneficial ingredient; the resulting product must be analytically evaluated to determine the magnitude and direction of compositional changes.

Another important consideration in the development of enriched plant-based foods is the presence of anti-nutritional factors. Phytates, oxalates, tannins, saponins and other naturally occurring phytochemicals may influence nutrient utilization and mineral bioavailability depending on their concentration and the overall dietary context. Cassava processing can also influence cyanogenic compounds, making assessment of cyanide levels particularly relevant when evaluating cassava-based food products. Consequently, simultaneous assessment of nutritional and anti-nutritional characteristics provides a more comprehensive basis for determining the quality and potential dietary implications of an enriched cassava product. Studies have demonstrated that cassava processing methods such as fermentation, dewatering and roasting can substantially reduce cyanogenic compounds in cassava products (Westby, 2002; Cardoso et al., 2005).

Although turmeric has been investigated extensively as a functional ingredient in several food systems, comparatively limited information is available on the nutritional and anti-nutritional implications of incorporating turmeric powder directly into garri, particularly in relation to conventionally produced garri. Establishing whether turmeric enrichment produces measurable improvements in proximate and mineral composition while maintaining acceptable levels of anti-nutritional constituents is therefore important for the scientific evaluation of the product. Such information may contribute to the development of value-added cassava foods and provide a basis for further investigation of turmeric-enriched traditional staples.

The present study therefore evaluated plain garri and turmeric-enriched garri produced from cassava roots, with particular emphasis on their nutritional and anti-nutritional composition. The study provides comparative information on the effect of turmeric incorporation on the composition of garri and contributes to the growing body of research on the nutritional improvement of traditional staple foods through the incorporation of plant-based functional ingredients.

Aim of the Study

The aim of this study was to comparatively evaluate the nutritional and anti-nutritional composition of conventional garri and turmeric-enriched garri produced from cassava (*Manihot esculenta* Crantz) roots.

Objectives of the Study

The specific objectives of the study were to:

1. Produce turmeric-enriched garri from cassava (*Manihot esculenta* Crantz) roots.
2. Determine the proximate composition of conventional and turmeric-enriched garri.
3. Determine the anti-nutritional composition of conventional and turmeric-enriched garri.
4. Compare the nutritional and anti-nutritional characteristics of conventional garri with those of turmeric-enriched garri.

MATERIALS AND METHODS

Sources of Materials

Fresh cassava (*Manihot esculenta* Crantz) roots used for the production of garri were obtained from a local farm in Ogere, Remo, Ogun State, Nigeria. Fresh turmeric (*Curcuma longa* L.) rhizomes and food-grade red palm oil were purchased from Ogere Market, Remo, Ogun State, Nigeria. All raw materials were selected based on freshness, maturity, uniformity and absence of visible physical damage, mould growth, pest infestation and other defects.

The chemicals, reagents and solvents used for the proximate, anti-nutritional, mineral and other physicochemical analyses were of analytical grade and obtained from the Food Science and Technology Laboratory. Distilled water was used throughout the analytical procedures.

Preparation of Raw Materials

Production of Garri

Fresh cassava roots were manually sorted to remove rotten, diseased, bruised and damaged roots. The selected roots were washed thoroughly with clean water to remove adhering soil and other extraneous materials. The roots were manually peeled using stainless-steel knives and washed again to remove residual peel and contaminants.

The peeled roots were grated using a mechanical cassava grater to obtain a fine cassava mash. The mash was packed into clean polypropylene sacks and subjected to fermentation and dewatering simultaneously using a hydraulic press for 72 h. Following fermentation and pressing, the compacted cassava cake was loosened manually and pulverized into smaller particles. The pulverized mash was sieved using a clean woven sieve to obtain relatively uniform granules.

The sieved cassava granules were roasted in a clean stainless-steel frying pan over moderate heat with continuous stirring to ensure uniform heating and prevent burning. Roasting continued until the product attained the characteristic dry, crisp and free-flowing texture of garri. The roasted garri was allowed to cool to room temperature and subsequently packaged in clean, airtight polyethylene bags until required for formulation and laboratory analyses.

Flow chart for the production of garri:

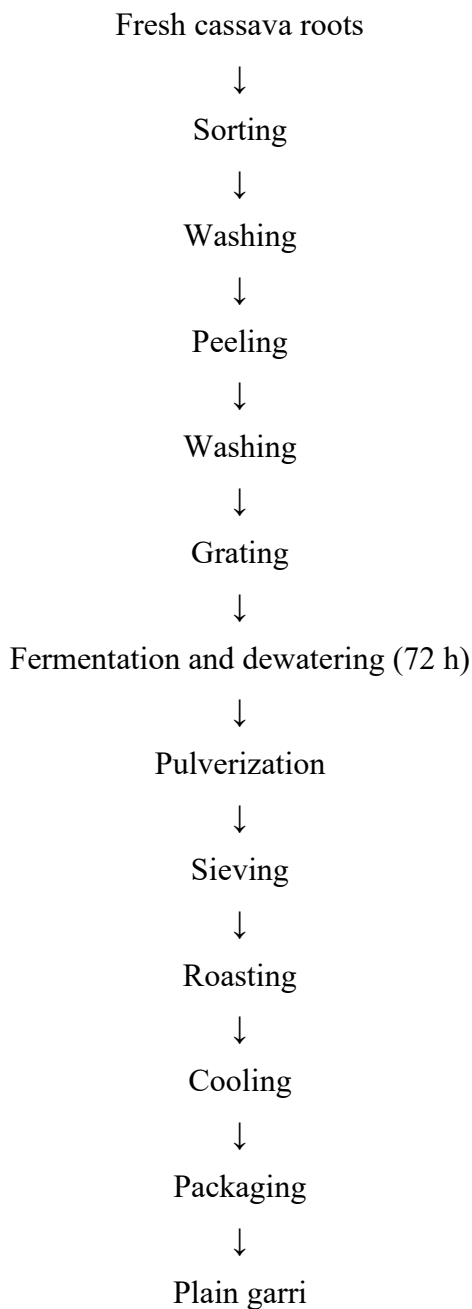


Figure 3.1: Flow chart for the production of plain garri

Preparation of Turmeric Powder

Fresh turmeric rhizomes were manually sorted to remove mouldy, bruised, damaged and deteriorated portions. The selected rhizomes were washed thoroughly under running potable water to remove adhering soil and other foreign materials. The rhizomes were peeled using clean stainless-steel knives and subsequently sliced into thin, relatively uniform pieces to facilitate efficient drying.

The turmeric slices were spread in a single layer on clean drying trays and dried in a hot-air oven at $60 \pm 2^{\circ}\text{C}$ until constant weight was achieved. The dried slices were removed from the oven and cooled to room temperature in a clean, dry environment. They were subsequently milled into fine powder using a laboratory hammer mill. The resulting powder was passed through a 250- μm mesh sieve to obtain relatively uniform particle size.

The turmeric powder was transferred into clean, airtight polyethylene containers and stored in a cool, dry environment protected from direct sunlight until required for garri enrichment.

Flow chart for the preparation of turmeric powder:

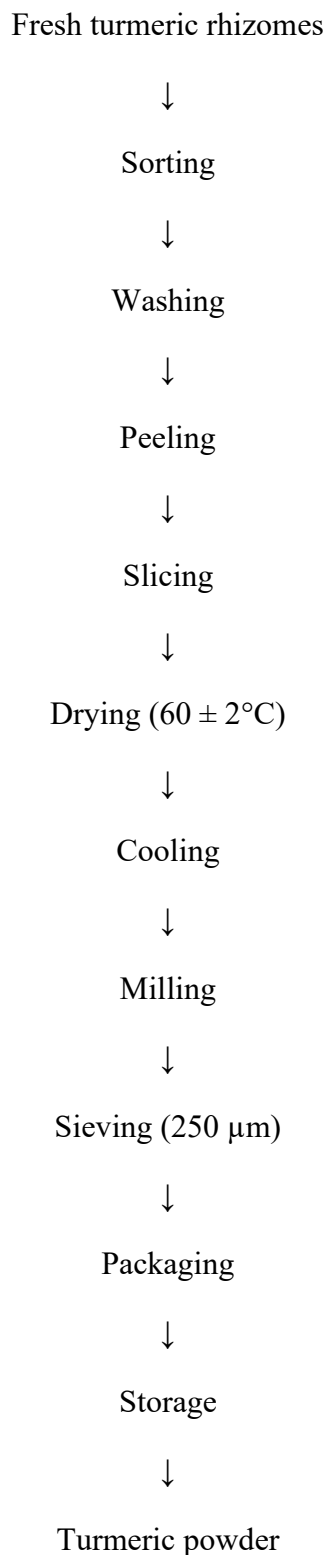


Figure 3.2: Flow chart for the preparation of turmeric powder

Preparation of Palm Oil

Food-grade red palm oil was filtered through a clean muslin cloth to remove suspended impurities, fibre particles and other visible extraneous materials. The filtered palm oil was transferred into clean, dry, amber-

coloured containers, tightly covered and stored at room temperature until required for formulation of the enriched garri.

Flow chart for the preparation of palm oil:

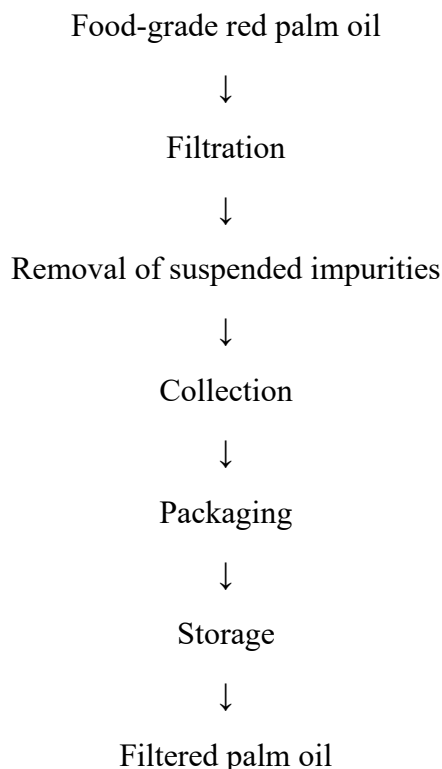


Figure 3.3: Flow chart for the preparation of palm oil

Formulation of Plain, Palm Oil- and Turmeric-Enriched Garri

Three garri formulations were produced. Plain garri served as the control, while the experimental samples were enriched with either red palm oil or turmeric powder. The formulations were prepared on a weight-by-weight basis as presented in Table 3.1.

Table 3.1: Formulation of plain, palm oil- and turmeric-enriched garri

Sample Code	Formulation
GUS	100% plain garri (control)
GFP	97% plain garri + 3% red palm oil
GFT	97% plain garri + 3% turmeric powder

Where applicable, the quantities of garri and enrichment materials were weighed using a calibrated electronic weighing balance to ensure accuracy and reproducibility.

Preparation of Enriched Garri Samples

The control sample (GUS) consisted entirely of plain garri without the addition of any enrichment material. For the palm oil-enriched sample (GFP), 97% plain garri was weighed and thoroughly mixed with 3% food-grade red palm oil. Mixing was performed manually in a clean, dry stainless-steel bowl until the oil was uniformly distributed over the garri granules. The mixture was allowed to stand for approximately 30 min at ambient temperature to facilitate uniform distribution and absorption of the oil.

For the turmeric-enriched sample (GFT), 97% plain garri was weighed and blended with 3% turmeric powder in a clean stainless-steel bowl. The mixture was thoroughly stirred and manually homogenized until the turmeric powder was uniformly distributed throughout the garri granules.

Each formulated sample was packaged separately in clean, airtight polyethylene bags, properly labelled and stored under ambient laboratory conditions until required for analysis.

Flow chart for the preparation of enriched garri:

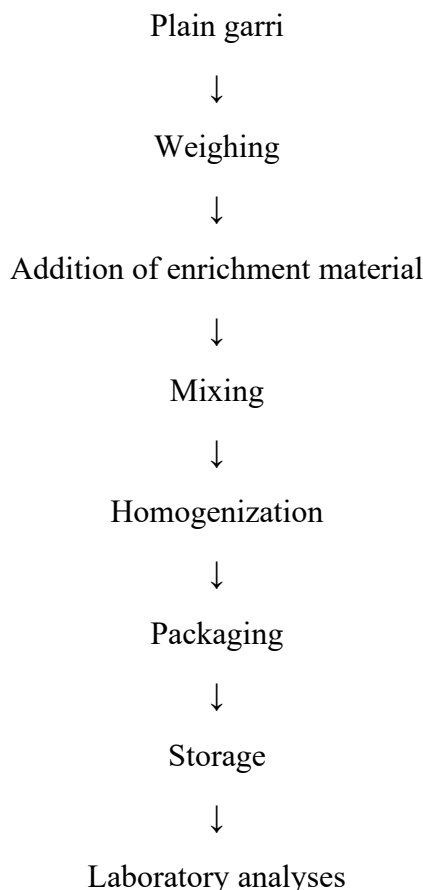


Figure 3.4: Flow chart for the preparation of enriched garri

Analytical Determinations

The formulated garri samples were analysed for proximate composition, anti-nutritional factors, mineral composition, cyanide content, functional properties, starch composition, physicochemical characteristics, colour attributes and sensory properties using established standard analytical procedures. Unless otherwise stated, laboratory analyses were conducted in triplicate to improve analytical precision and reproducibility.

Determination of Proximate Composition

The proximate composition of the garri samples was determined using standard procedures of the Association of Official Analytical Chemists (AOAC). Moisture, ash, crude protein, crude fat and crude fibre contents were determined experimentally, while carbohydrate content was calculated by difference.

Moisture Content

Moisture content was determined using the hot-air oven method (AOAC Method 925.10). Approximately 5 g of each homogenized sample was accurately weighed into a previously dried and weighed moisture dish. The samples were dried in a hot-air oven at 105°C until constant weight was obtained. The dishes containing the dried samples were transferred into a desiccator, cooled to room temperature and reweighed.

Moisture content was calculated as follows:

$$\text{Moisture (\%)} = [(\text{Weight of sample before drying} - \text{Weight of sample after drying}) / \text{Weight of sample before drying}] \times 100$$

Ash Content

Ash content was determined using the dry ashing method (AOAC Method 923.03). Approximately 2 g of each sample was weighed into a previously dried and weighed porcelain crucible. The sample was initially charred gently over a low flame and subsequently transferred into a muffle furnace maintained at 550°C. Incineration was continued until a light-grey or whitish ash was obtained.

The crucibles were cooled in a desiccator and weighed. Ash content was calculated as:

$$\text{Ash (\%)} = (\text{Weight of ash} / \text{Weight of sample}) \times 100$$

Crude Protein

Crude protein content was determined using the Kjeldahl method (AOAC Method 979.09). Approximately 1 g of each sample was subjected to digestion with concentrated sulphuric acid in the presence of an appropriate catalyst mixture until a clear digest was obtained. The digest was diluted with distilled water and made alkaline with sodium hydroxide. The liberated ammonia was steam-distilled into boric acid solution and titrated against standardized hydrochloric acid.

The nitrogen content was calculated from the titre value and converted to crude protein using a nitrogen-to-protein conversion factor of 6.25:

$$\text{Crude protein (\%)} = \text{Nitrogen (\%)} \times 6.25$$

Crude Fat

Crude fat was determined using the Soxhlet extraction method (AOAC Method 920.39). Approximately 2 g of dried sample was accurately weighed into an extraction thimble and continuously extracted with petroleum ether with a boiling range of approximately 40–60°C for about 6 h.

Following extraction, the solvent was recovered and the extraction flask containing the extracted lipid was dried to constant weight. Crude fat was expressed as a percentage of the original sample weight.

$$\text{Crude fat (\%)} = (\text{Weight of extracted fat} / \text{Weight of sample}) \times 100$$

Crude Fibre

Crude fibre was determined using the standard AOAC method (Method 962.09). The sample was subjected to sequential digestion with dilute sulphuric acid and dilute sodium hydroxide under controlled heating conditions. The resulting residue was filtered, washed thoroughly with distilled water and dried to constant weight.

The dried residue was weighed and subsequently incinerated in a muffle furnace. The difference between the weight of the dried residue and the weight of the ash obtained after incineration represented the crude fibre content.

Carbohydrate Content

Carbohydrate content was calculated by difference using the following equation:

$$\text{Carbohydrate (\%)} = 100 - [\text{Moisture (\%)} + \text{Ash (\%)} + \text{Crude protein (\%)} + \text{Crude fat (\%)} + \text{Crude fibre (\%)}]$$

The calculated carbohydrate value was expressed as percentage of the sample.

Determination of Cyanide Content

The cyanide content of the garri samples was determined using an appropriate standard titrimetric or spectrophotometric procedure following extraction of cyanogenic compounds from the samples. A representative quantity of each finely milled sample was weighed and extracted with distilled water under controlled conditions. The extract was subjected to the appropriate analytical procedure, and cyanide concentration was calculated from the analytical response obtained using a standard calibration or titration procedure.

Results were expressed as milligrams of hydrogen cyanide equivalent per kilogram of sample (mg HCN/kg).

Determination of Anti-Nutritional Factors

The anti-nutritional constituents of the garri samples were determined using established analytical procedures. The anti-nutrients evaluated included phytate, oxalate, tannin, saponin, alkaloids and flavonoids.

Phytate was determined following acid extraction and subsequent quantitative determination using a suitable colourimetric procedure. Oxalate was determined following acid extraction and precipitation/titrimetric determination. Tannin was determined using the Folin–Denis spectrophotometric method.

Saponin content was determined following solvent extraction and gravimetric quantification, while alkaloid content was determined by acid extraction, precipitation and gravimetric measurement. Total flavonoid content was determined using an appropriate spectrophotometric assay based on aluminium chloride complex formation.

The concentrations of the anti-nutritional factors were calculated from the respective calibration curves or analytical equations and expressed as mg/100 g of sample.

Determination of Mineral Composition

The mineral composition of the garri samples was determined following wet-acid digestion. Approximately 2 g of each finely milled sample was weighed into a digestion flask and treated with an appropriate mixture of concentrated nitric acid and perchloric acid. Digestion was continued under controlled heating until a clear digest was obtained.

The digest was cooled, filtered through Whatman No. 1 filter paper and diluted to a known volume with distilled water. Calcium, magnesium, iron, zinc, copper and manganese were quantified using Atomic Absorption Spectrophotometry (AAS), while potassium and sodium were determined using an appropriate flame-emission technique. Phosphorus was determined colorimetrically using a UV–Visible spectrophotometer.

Appropriate reagent blanks, standards and calibration curves were used during mineral determination. The mineral concentrations were expressed as mg/100 g of sample.

Determination of Functional Properties

The functional properties of the garri samples were evaluated using standard food science analytical procedures. Properties assessed included bulk density, water absorption capacity, oil absorption capacity, swelling capacity and solubility, where applicable.

For bulk density, a known quantity of each sample was gently transferred into a graduated measuring cylinder of known volume without compacting and the volume occupied was recorded. Bulk density was calculated as the ratio of sample weight to occupied volume.

Water absorption capacity was determined by dispersing a known weight of sample in a measured quantity of distilled water, allowing the mixture to equilibrate and centrifuging or filtering where applicable. The amount of water retained by the sample was calculated and expressed as grams of water absorbed per gram of sample.

Determination of Starch Composition

The starch characteristics of the garri samples were determined using established enzymatic or spectrophotometric procedures. Total starch was quantified following enzymatic hydrolysis of the starch fraction to glucose and subsequent measurement of the released glucose.

Where applicable, amylose and amylopectin contents were determined using a suitable iodine-binding spectrophotometric method. Results were expressed as percentage of the sample on the appropriate moisture basis.

Determination of Physicochemical Properties

Selected physicochemical properties of the garri samples were determined using standard laboratory procedures. The parameters evaluated included pH, titratable acidity and other relevant quality characteristics.

For pH determination, a known quantity of the sample was dispersed in distilled water and homogenized. The pH of the resulting suspension was measured using a previously calibrated digital pH meter. Calibration was performed using appropriate standard buffer solutions before sample measurement.

Titratable acidity was determined by titration of an aqueous sample extract against standardized sodium hydroxide using an appropriate indicator. The result was calculated and expressed as percentage acidity.

Determination of Colour Characteristics

The colour characteristics of the garri samples were evaluated using a calibrated colourimeter or spectrophotometer based on the CIE colour system. The colour parameters L^* , a^* and b^* were recorded, where L^* represents lightness, a^* represents redness/greenness and b^* represents yellowness/blueness.

Measurements were taken at appropriate points on each sample, and mean values were calculated for each formulation. The colour differences among the samples were used to assess the effect of palm oil and turmeric enrichment on the visual characteristics of garri.

Sensory Evaluation

Sensory evaluation was conducted to determine the acceptability of the plain and enriched garri samples. Twenty-five (25) semi-trained panelists who were familiar with garri consumption participated in the evaluation. Panelists were selected based on their willingness to participate and familiarity with the sensory attributes of garri.

The samples were coded using three-digit random numbers and presented to the panelists in randomized order to minimize order and positional bias. Drinking water was provided for mouth rinsing between samples.

The samples were evaluated for colour, appearance, aroma, taste, texture when prepared as eba, mouthfeel, crispness when consumed as dry garri, and overall acceptability. A nine-point hedonic scale was used, ranging from 9 = "like extremely" to 1 = "dislike extremely", with 5 representing "neither like nor dislike" (Stone and Sidel, 2004).

Sensory evaluation was conducted under suitable conditions with minimal distractions. Panelists were informed about the nature of the evaluation and instructed to assess each sample independently.

Experimental Design and Replication

The study employed a completely randomized design (CRD) comprising three garri formulations: plain garri (GUS), palm oil-enriched garri (GFP) and turmeric-enriched garri (GFT). Each laboratory determination was conducted in triplicate, and the replicate values were used to obtain the mean and standard deviation for each parameter.

Statistical Analysis

Data generated from the laboratory analyses were subjected to statistical analysis using IBM Statistical

Package for the Social Sciences (SPSS), Version 25.0, or an equivalent statistical software package. Results were expressed as mean $\pm$ standard deviation (SD).

One-way Analysis of Variance (ANOVA) was used to determine whether significant differences existed among the mean values of the three garri formulations. Where significant differences were observed, Duncan's Multiple Range Test (DMRT) was used for mean separation. Statistical significance was accepted at $p < 0.05$.

For sensory data, mean hedonic scores were similarly subjected to appropriate statistical analysis to determine significant differences in consumer acceptability among the formulations.

Quality Assurance and Control

To ensure reliability and reproducibility of the analytical results, all glassware and laboratory equipment were properly cleaned before use. Analytical balances, pH meters, spectrophotometers and other instruments were appropriately calibrated before measurements were taken. Analytical-grade reagents and distilled water were used throughout the analyses.

Samples were properly labelled, stored in airtight containers and analysed under controlled laboratory conditions. Laboratory analyses were conducted in triplicate, and reagent blanks and appropriate standards were included where applicable. Results were reported as mean values with corresponding standard deviations.

Ethical Consideration for Sensory Evaluation

Participation in the sensory evaluation was voluntary. Panelists were informed about the purpose and nature of the evaluation before participation, and informed consent was obtained. Participants were allowed to withdraw from the evaluation at any time without penalty. Only samples intended for normal food consumption were presented during the sensory assessment.

Note: The analytical procedures should be matched to the exact laboratory methods and equipment actually used. In particular, the cyanide, anti-nutrient, mineral, starch and functional-property methods should not be reported as performed by a technique that was not actually used in the laboratory

RESULTS

TABLE 1: FORMULATION

SAMPLE	FORMULATION
GUS	100 % Garri Plain (Control)
GFP	Garri Enriched with Palm Oil (97% Garri+3% Palm Oil)
GFT	Garri Enriched with Turmeric (97% Garri+3% Turmeric Powder)

GUS 100 % Garri Plain (Control), GFP Garri Enriched with Palm Oil (97% Garri+3% Palm Oil), GFT Garri Enriched with Turmeric (97% Garri+3% Turmeric Powder. Values are mean $\pm$ SD of triplicate determinations. Means with different superscript letters within the same column are significantly different ($p < 0.05$).

Table 2: Proximate Analysis

Parameters	Gus	Gfp	Gft
Moisture	10.84 $\pm$ 0.18 ^a	10.26 $\pm$ 0.16 ^b	10.42 $\pm$ 0.17 ^b

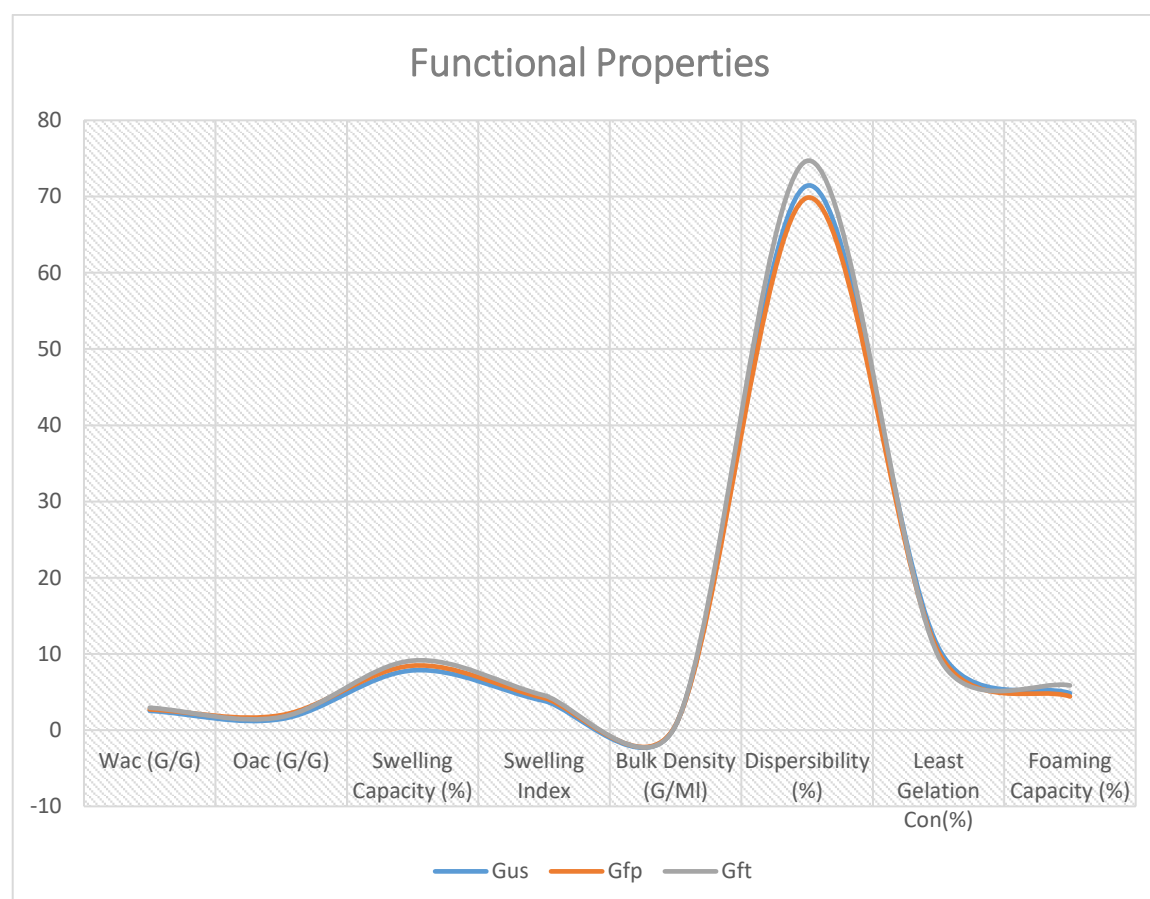
Ash	1.62±0.05 ^c	1.86±0.05 ^b	2.08±0.06 ^a
Crude Protein	1.48±0.04 ^c	1.56±0.04 ^b	1.82±0.05 ^a
Crude Fat	0.82±0.03 ^c	3.84±0.08 ^b	1.18±0.04 ^a
Crude Fibre	1.46±0.04 ^c	1.62±0.05 ^b	2.14±0.06 ^a
Carbohydrate	83.78±0.62 ^a	80.86±0.58 ^c	82.36±0.60 ^b
Energy (Kcal/100g)	346.82±2.84 ^c	368.64±0.312 ^a	350.42±2.96 ^b

GUS 100 % Garri Plain (Control), GFP Garri Enriched with Palm Oil (97% Garri+3% Palm Oil), GFT Garri Enriched with Turmeric (97% Garri+3% Turmeric Powder). Values are mean ± SD of triplicate determinations. Means with different superscript letters within the same column are significantly different ($p < 0.05$).

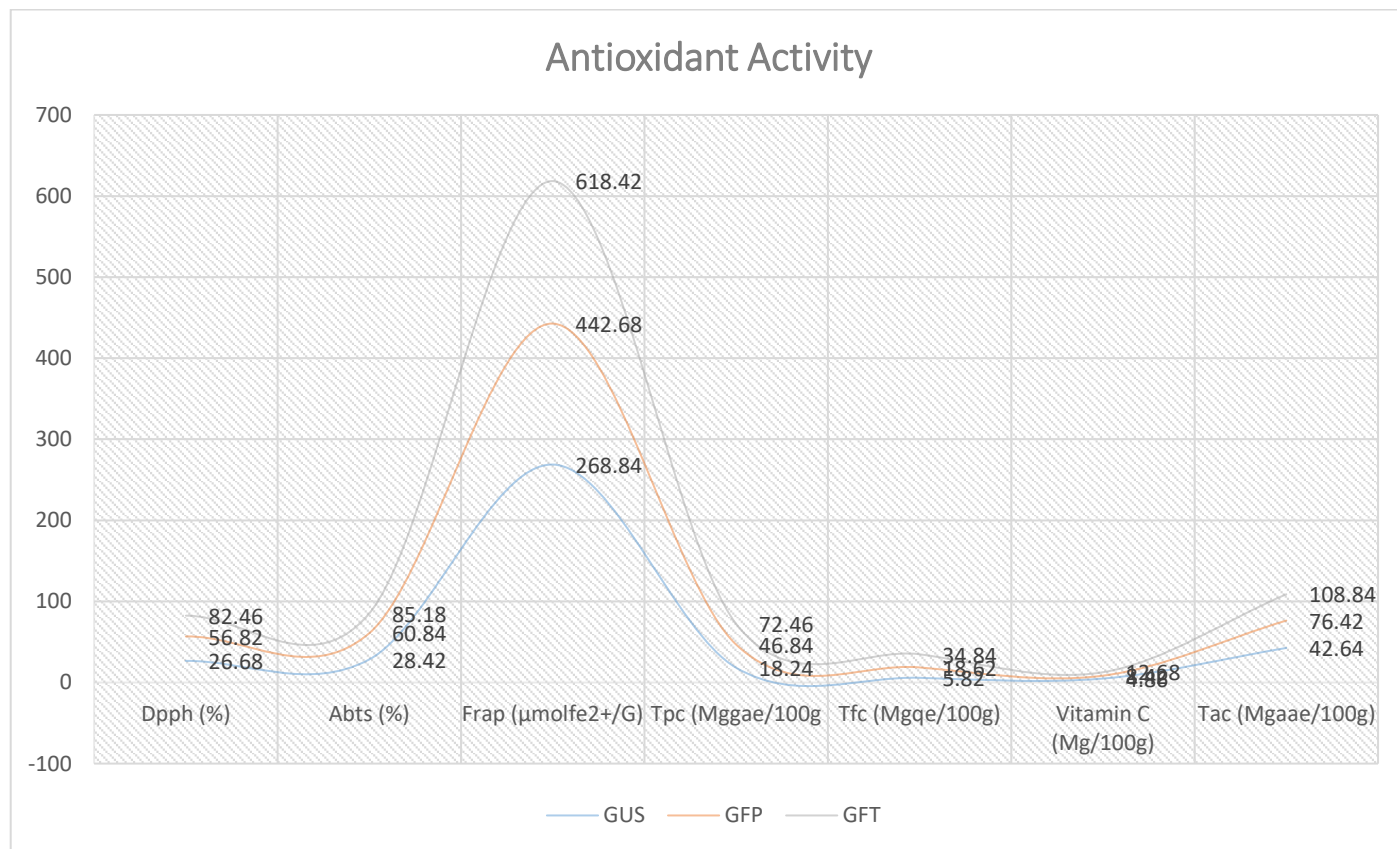
Table 3: Cyanide Content

Parameters Mg/100g	Gus	Gfp	Gft
Total Hydrogen Cyanide	0.32±0.02 ^c	7.84±0.12 ^a	5.26±0.10 ^b
Hydrogen Cyanide	5.84±0.18 ^a	5.42±0.16 ^b	4.96±0.15 ^c

GUS 100 % Garri Plain (Control), GFP Garri Enriched with Palm Oil (97% Garri+3% Palm Oil), GFT Garri Enriched with Turmeric (97% Garri+3% Turmeric Powder). Values are mean ± SD of triplicate determinations. Means with different superscript letters within the same column are significantly different ($p < 0.05$).



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Table 6: Starch Composition

PARAMETERS	GUS	GFP	GFT
Total Starch	78.84 $\pm$ 0.62 ^a	77.46 $\pm$ 0.58 ^b	75.82 $\pm$ 0.56 ^c
Amylose	22.82 $\pm$ 0.32 ^a	22.16 $\pm$ 0.30 ^b	21.48 $\pm$ 0.28 ^c
Amylopectin	56.00 $\pm$ 0.54 ^a	55.30 $\pm$ 0.52 ^b	54.34 $\pm$ 0.05 ^c
Resistant Starch	1.84 $\pm$ 0.08 ^c	2.16 $\pm$ 0.09 ^b	2.64 $\pm$ 0.10 ^a

GUS 100 % Garri Plain (Control), GFP Garri Enriched with Palm Oil (97% Garri+3% Palm Oil), GFT Garri Enriched with Turmeric (97% Garri+3% Turmeric Powder). Values are mean $\pm$ SD of triplicate determinations. Means with different superscript letters within the same column are significantly different ($p < 0.05$).

Table 7: Carotene Content (Mg/100g)

PARAMETERS	GUS	GFP	GFT
Total Carotene	0.32 $\pm$ 0.02 ^c	7.84 $\pm$ 0.12 ^a	5.26 $\pm$ 0.10 ^c
B-Carotene	0.18 $\pm$ 0.02 ^c	4.86 $\pm$ 0.08 ^a	2.64 $\pm$ 0.06 ^b

GUS 100 % Garri Plain (Control), GFP Garri Enriched with Palm Oil (97% Garri+3% Palm Oil), GFT Garri Enriched with Turmeric (97% Garri+3% Turmeric Powder). Values are mean $\pm$ SD of triplicate determinations. Means with different superscript letters within the same column are significantly different ($p < 0.05$).

Table 8: Physicochemical Properties

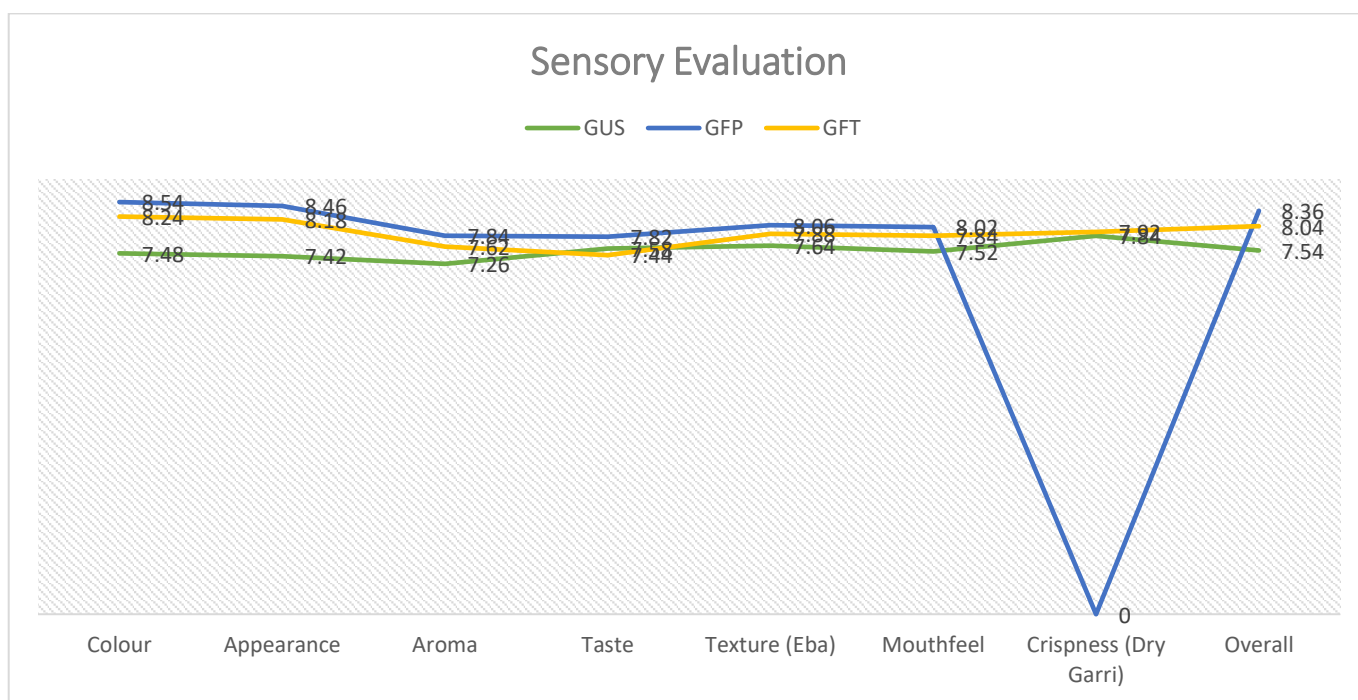
PARAMETERS	GUS	GFP	GFT
Ph	4.68±0.03 ^a	4.54±0.03 ^b	4.46±0.02 ^c
Tta (%)	0.52±0.02 ^c	0.56±0.02 ^b	0.61±0.02 ^a
Tss (°Brix)	3.24±0.08 ^a	3.12±0.07 ^b	3.06±0.07 ^c
Water Activity (Aw)	0.48±0.01 ^a	0.45±0.01 ^b	0.04±0.01 ^b

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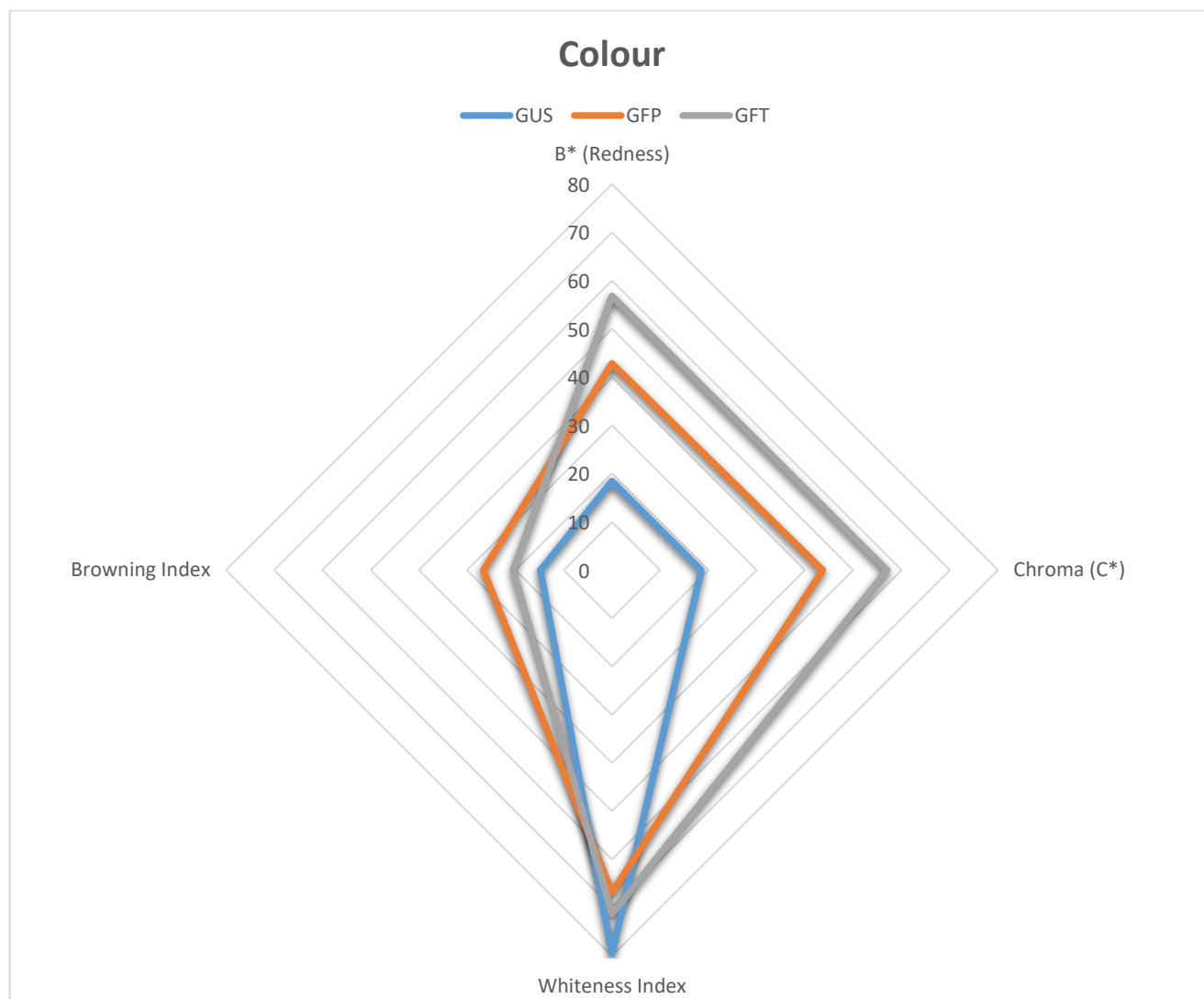
Table 9: Heavy Metal Composition

PARAMETERS	GUS	GFP	GFT
Lead(Pb)	0.021±0.002 ^a	0.018±0.001 ^b	0.016±0.001 ^c
Cadmium (Cd)	0.004±0.001 ^a	0.003±0.001 ^b	0.016±0.001 ^c
Arsenic(As)	Nd	Nd	Nd
Mercury (Hg)	Nd	Nd	Nd
Chromium (Cr)	0.042±0.003 ^a	0.038±0.002 ^b	0.034±0.002 ^c
Nickel(Ni)	0.056±0.004 ^a	0.048±0.003 ^b	0.044±0.003 ^c
Copper (Cu)	0.24±0.02 ^b	0.28±0.02 ^a	0.26±0.02 ^{ab}
Zinc (Zn)	0.86±0.04 ^b	0.94±0.04 ^b	1.08±0.05 ^a

GUS 100 % Garri Plain (Control), GFP Garri Enriched with Palm Oil (97% Garri+3% Palm Oil), GFT Garri Enriched with Turmeric (97% Garri+3% Turmeric Powder). Values are mean ± SD of triplicate determinations. Means with different superscript letters within the same column are significantly different ($p < 0.05$).



GUS 100 % Garri Plain (Control), GFP Garri Enriched with Palm Oil (97% Garri+3% Palm Oil), GFT Garri Enriched with Turmeric (97% Garri+3% Turmeric Powder). Values are mean $\pm$ SD of triplicate determinations. Means with different superscript letters within the same column are significantly different ($p < 0.05$)

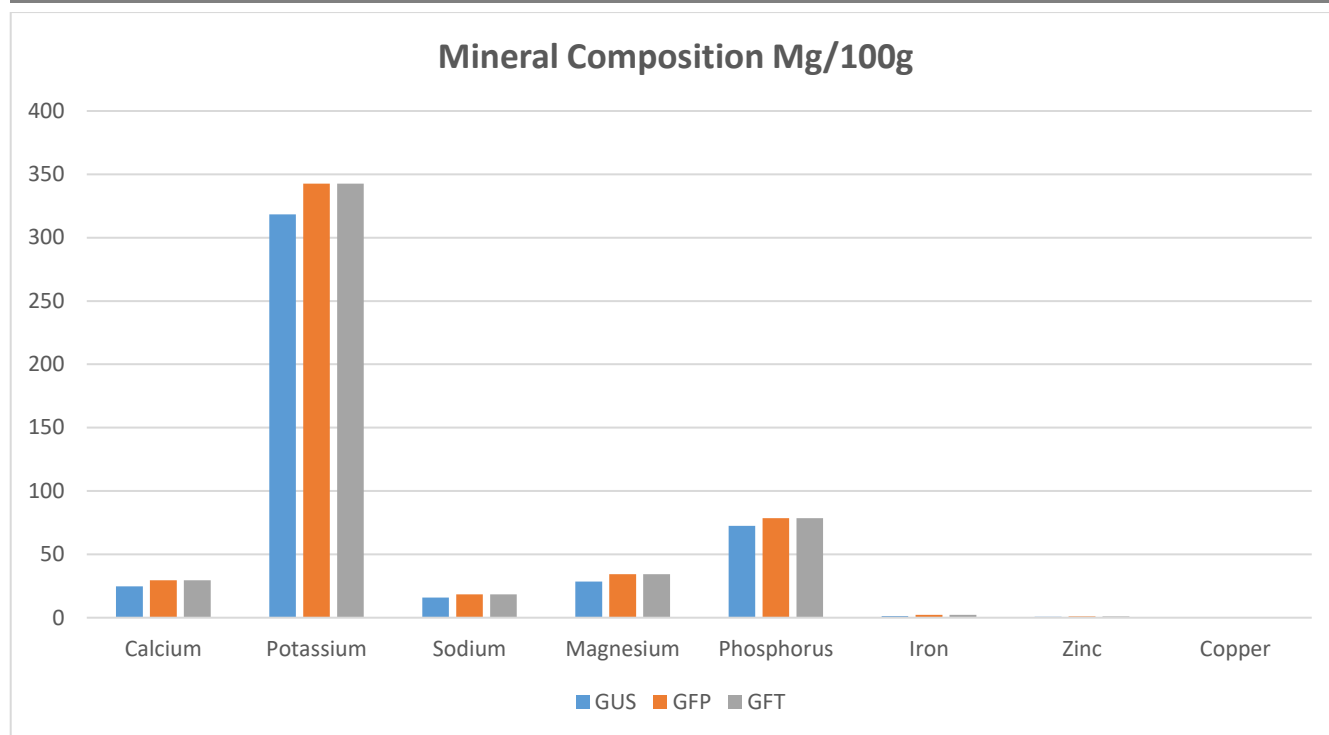


GUS 100 % Garri Plain (Control), GFP Garri Enriched with Palm Oil (97% Garri+3% Palm Oil), GFT Garri Enriched with Turmeric (97% Garri+3% Turmeric Powder). Values are mean $\pm$ SD of triplicate determinations. Means with different superscript letters within the same column are significantly different ($p < 0.05$).

Table 12: Anti-nutritional

PARAMETERS	GUS	GFP	GFT
Phytate	18.46 $\pm$ 0.42 ^a	16.84 $\pm$ 0.38 ^b	15.62 $\pm$ 0.36 ^c
Oxalate	7.84 $\pm$ 0.20 ^a	7.12 $\pm$ 0.18 ^b	6.48 $\pm$ 0.16 ^c
Tannin	2.24 $\pm$ 0.08 ^c	2.86 $\pm$ 0.09 ^b	3.84 $\pm$ 0.10 ^a
Saponin	Nd	0.84 $\pm$ 0.04 ^b	1.42 $\pm$ 0.05 ^a
Alkaloid	Nd	0.18 $\pm$ 0.28 ^b	0.32 $\pm$ 0.02 ^a
Flavonoid	6.24 $\pm$ 0.18 ^c	14.86 $\pm$ 0.28 ^b	26.48 $\pm$ 0.36 ^a

GUS 100 % Garri Plain (Control), GFP Garri Enriched with Palm Oil (97% Garri+3% Palm Oil), GFT Garri Enriched with Turmeric (97% Garri+3% Turmeric Powder). Values are mean $\pm$ SD of triplicate determinations. Means with different superscript letters within the same column are significantly different ($p < 0.05$).



GUS 100 % Garri Plain (Control), GFP Garri Enriched with Palm Oil (97% Garri+3% Palm Oil), GFT Garri Enriched with Turmeric (97% Garri+3% Turmeric Powder). Values are mean $\pm$ SD of triplicate determinations. Means with different superscript letters within the same column are significantly different ($p < 0.05$).

DISCUSSION

Table 1 presents the formulations used for the production of the garri samples. GUS served as the plain garri control, while GFP and GFT were enriched with 3% palm oil and 3% turmeric powder, respectively. The use of turmeric as an enrichment ingredient is relevant because turmeric contains bioactive compounds, particularly curcuminoids, which have been associated with antioxidant activity and food applications.

The results showed significant differences ($p < 0.05$) among the samples for all proximate parameters. GFT recorded the highest ash (2.08 g/100 g), protein (1.82 g/100 g) and fibre (2.14 g/100 g), indicating an improvement in these components following turmeric enrichment. GFP had the highest fat (3.84 g/100 g) and energy value (368.64 kcal/100 g), attributable to the added palm oil, whereas GUS had the highest carbohydrate content (83.78 g/100 g). The findings are consistent with reports that gari is predominantly carbohydrate-rich and relatively low in protein and fat.

The cyanide results showed variations among the samples. GUS recorded the lowest reported total hydrogen cyanide value, while GFP and GFT showed higher values; however, free hydrogen cyanide decreased progressively from GUS (5.84 mg/100 g) to GFP (5.42 mg/100 g) and GFT (4.96 mg/100 g). Cassava processing, particularly fermentation, pressing and roasting, is known to substantially reduce cyanogenic compounds, although the final cyanide level depends on the cassava variety and processing conditions.

Significant variations were observed in the functional properties of the samples. GFT generally showed higher water absorption capacity (2.94 g/g), swelling capacity (9.12%) and swelling index (4.56), as well as the highest dispersibility (74.68%), suggesting improved interaction with water and better hydration characteristics. The variations may be associated with the incorporation of turmeric and changes in the composition of the cassava matrix; functional properties are important determinants of the preparation and handling characteristics of gari and related products.

GFT demonstrated markedly higher antioxidant activity than GUS and GFP, recording DPPH inhibition of 82.46%, ABTS inhibition of 85.18% and FRAP of 618.42 $\mu\text{mol Fe}^{2+}/\text{g}$. It also had the highest total phenolic content (72.46 mg GAE/100 g), total flavonoid content (34.84 mg QE/100 g), vitamin C (12.68 mg/100 g) and

total antioxidant capacity (108.84 mg AAE/100 g). This improvement is attributable to the bioactive constituents of turmeric, particularly curcuminoids and other phenolic compounds known for their antioxidant properties.

Significant differences were observed in starch characteristics among the samples. GUS had the highest total starch (78.84%), amylose (22.82%) and amylopectin (56.00%), while GFT recorded the lowest values. Conversely, resistant starch increased from 1.84% in GUS to 2.64% in GFT. The reduction in total starch following turmeric enrichment may be related to the dilution effect of incorporating the non-starch turmeric powder, while the increase in resistant starch may be nutritionally beneficial because resistant starch is less readily digested in the small intestine.

Carotenoid content was substantially increased by enrichment. GFP recorded the highest total carotene (7.84 mg/100 g) and β -carotene (4.86 mg/100 g), while GUS had the lowest values. GFT also showed increased β -carotene (2.64 mg/100 g) compared with GUS (0.18 mg/100 g). The elevated carotenoid content in the enriched samples indicates that incorporation of plant-derived ingredients can improve the bioactive pigment profile of gari.

The samples differed significantly in pH, titratable acidity and total soluble solids. GUS had the highest pH (4.68), whereas GFT had the lowest (4.46), indicating a slight increase in acidity with turmeric incorporation. Titratable acidity increased from 0.52% in GUS to 0.61% in GFT, while total soluble solids decreased slightly from 3.24 to 3.06 °Brix. These changes indicate that turmeric incorporation influenced the physicochemical characteristics of the product.

The heavy-metal results showed variations among the samples. GFT had the lowest lead (0.016 mg/100 g), chromium (0.034 mg/100 g) and nickel (0.044 mg/100 g), while zinc was highest in GFT (1.08 mg/100 g). Arsenic and mercury were not detected in any sample. Overall, the absence of detectable arsenic and mercury and the relatively low concentrations of the detected metals indicate no substantial heavy-metal accumulation based on the parameters measured; however, interpretation should ultimately be made against applicable food-safety limits.

All samples were generally well accepted, with mean scores above 7.0 on the 9-point hedonic scale. GFP recorded the highest overall acceptability (8.36), followed by GFT (8.04), while GUS had the lowest score (7.54). GFP also obtained the highest scores for colour, appearance, aroma, texture, mouthfeel and crispness, suggesting that palm-oil enrichment produced particularly favourable sensory characteristics, whereas turmeric enrichment maintained good overall acceptability.

Significant differences ($p < 0.05$) were observed in all colour parameters. GUS had the highest lightness ($L^* = 82.64$) and whiteness index (79.46), while GFP and GFT showed greater colour intensity, particularly in b^* and chroma values. GFT recorded the highest b^* value (56.82) and chroma (57.01), reflecting the characteristic yellow-orange pigmentation associated with turmeric and its curcuminoid pigments.

The results showed that GUS had the highest phytate (18.46) and oxalate (7.84), whereas GFT had the lowest values of phytate (15.62) and oxalate (6.48). Conversely, tannin, saponin, alkaloid and flavonoid contents increased with turmeric enrichment, with GFT recording the highest values. The reduction in phytate and oxalate may favour mineral availability, although the increased levels of other phytochemicals indicate the need to consider both beneficial and potentially antinutritional effects when evaluating the enriched product. Processing is known to influence antinutritional factors in cassava products.

GFP and GFT generally recorded higher mineral values than GUS, with calcium increasing from 24.82 to 29.46 mg/100 g, potassium from 318.46 to 342.68 mg/100 g and iron from 1.26 to 2.18 mg/100 g. GFT also recorded the highest zinc value (1.04 mg/100 g as reported), indicating that enrichment may improve the mineral contribution of gari. These findings support the potential of plant-based enrichment as an approach for improving the nutritional quality of cassava-based staples.

Overall, the findings demonstrate that enrichment significantly modified the nutritional, functional, antioxidant, physicochemical, mineral and sensory characteristics of garri. GFT showed particular advantages in protein, fibre, ash, antioxidant activity, phytochemical content, resistant starch and several functional properties, while GFP achieved the highest fat, energy and overall sensory scores. The results therefore indicate that turmeric enrichment has considerable potential for producing a nutritionally and functionally improved garri while maintaining good consumer acceptability. This is consistent with the established potential of turmeric as a functional food ingredient and with evidence that processing and formulation strongly influence gari quality.

CONCLUSION

The study demonstrated that incorporation of 3% turmeric powder significantly influenced the nutritional, functional, antioxidant, physicochemical and sensory characteristics of garri. Turmeric-enriched garri (GFT) showed improved protein, ash, crude fibre, resistant starch, antioxidant activity, phenolic and flavonoid contents, as well as favourable mineral and functional properties compared with conventional garri. Palm-oil-enriched garri (GFP), however, recorded the highest fat and energy values and achieved the highest overall sensory acceptability. The findings therefore indicate that turmeric can serve as a promising functional ingredient for value addition and nutritional improvement of garri. Overall, turmeric-enriched garri provides a potential alternative to conventional garri with enhanced nutritional and bioactive characteristics while retaining acceptable sensory quality.

REFERENCES

1. Adewusi, S. R. A., & Akindahunsi, A. A. (1994). Cassava processing, consumption, and cyanide toxicity. *Journal of Toxicology and Environmental Health*, 43(1), 13–23. <https://doi.org/10.1080/15287399409531900>. (PubMed)
2. Burns, A., Gleadow, R., Cliff, J., Zacarias, A., & Cavagnaro, T. (2010). Cassava: The drought, war and famine crop in a changing world. *Sustainability*, 2(11), 3572–3607.
3. Cardoso, A. P., Mirione, E., Ernesto, M., Massaza, F., Cliff, J., Haque, M. R., & Bradbury, J. H. (2005). Processing of cassava roots to remove cyanogens. *Journal of Food Composition and Analysis*, 18(5), 451–460.
4. El-Sharkawy, M. A. (2004). Cassava biology and physiology. *Plant Molecular Biology*, 56, 481–501.
5. Hewlings, S. J., & Kalman, D. S. (2017). Curcumin: A review of its effects on human health. *Foods*, 6(10), 92. <https://doi.org/10.3390/foods6100092>.
6. Kemdirim, O. C., Chukwu, O. A., & Achinewhu, S. C. (1995). Effect of traditional processing of cassava on the cyanide content of gari and cassava flour. *Plant Foods for Human Nutrition*, 48(4), 335–339. <https://doi.org/10.1007/BF01088492>.
7. Montagnac, J. A., Davis, C. R., & Tanumihardjo, S. A. (2009). Nutritional value of cassava for use as a staple food and recent advances for improvement. *Comprehensive Reviews in Food Science and Food Safety*, 8(3), 181–194.
8. Prasad, S., Gupta, S. C., Tyagi, A. K., & Aggarwal, B. B. (2014). Curcumin, a component of golden spice: From bedside to bench and back. *Biotechnology Advances*, 32(6), 1053–1064.
9. Westby, C. A. (2002). Cassava utilization, storage and small-scale processing. Natural Resources Institute, University of Greenwich.
10. Momtazi-Borojeni, A. A., Abdollahi, E., Nikfar, B., Chaichian, S., & Ekhlesi-Hundrieser, M. (2023). Antioxidant and anti-inflammatory effects of curcumin/turmeric supplementation in adults: A GRADE-assessed systematic review and dose-response meta-analysis of randomized controlled trials. *Cytokine*, 166, 156144. <https://doi.org/10.1016/j.cyto.2023.156144>.