

Effect of Beetroot and Carrot Fortification on Mineral Composition of Gari

Saviour Bennie^{1*}, Newton Kweku Amaglo¹; Agnes Nyilyar Tobyarmo¹, Bridget Kudoagbo, Ebenezer Kwasi Ntiri²

¹Department of Horticulture, Faculty of Agriculture, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

²Department of Horticulture, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.

*Corresponding Author

DOI: <https://doi.org/10.51584/IJRIAS.2026.11090026>

Received: 09 September 2026; Accepted: 15 September 2026; Published: 03 October 2026

ABSTRACT

Gari, the most widely consumed cassava-based staple in Ghana and West Africa, is low in minerals, which contributes to micronutrient deficiencies among vulnerable groups. This study assessed the reported mineral composition of gari after substitution with beetroot (*Beta vulgaris* L.) and carrot (*Daucus carota* L.). Four formulations were prepared in a completely randomised design with three independent process replicates: 100% cassava (control), 75% cassava + 25% carrot, 75% cassava + 25% beetroot, and 60% cassava + 20% carrot + 20% beetroot. Phosphorus, calcium, magnesium, potassium, sodium, iron and zinc were determined using standard AOAC methods and expressed in mg/100 g on a dry-weight basis. The fortified treatments had higher reported mean concentrations of phosphorus, potassium, sodium, iron and zinc than the control. However, treatment-level variability for phosphorus, magnesium, iron and zinc, replicate-level raw data, and analyses of the raw ingredients and processing equipment were not available in the supplied dataset; the statistical and causal interpretation of these changes therefore requires verification. The combined formulation had the highest reported means for phosphorus (80 mg/100 g), iron (6.45 mg/100 g) and zinc (0.63 mg/100 g). The carrot formulation had the highest potassium (3240 mg/100 g), while the beetroot formulation had the highest calcium (420 mg/100 g) and sodium (68 mg/100 g; not significantly different from the combined formulation in the reported comparison). Calcium was lower than the control in the carrot (280 mg/100 g) and combined (250 mg/100 g) formulations, and magnesium was lower in all fortified samples (80–100 versus 110 mg/100 g). While F4 is recommended as the optimum formulation for broad mineral enrichment, it is recommended that future studies perform trace element profiling on raw ingredients and processing contact surfaces (milling plates and roasting pans) to isolate true fortification gains from equipment contamination, optimize dewatering steps to minimize calcium and magnesium leaching, and evaluate *in vitro* mineral bioavailability and sensory acceptance prior to commercial scaling.

Keywords: Cassava, Beetroot, Carrot, Gari, Fortification, Mineral Composition

INTRODUCTION

Micronutrient deficiency, often referred to as "hidden hunger", is one of the greatest public health problems of the twenty first century and is the problem of over 2 billion people worldwide, particularly in sub-Saharan Africa and South Asia (Sharma et al., 2017; Muthayya et al., 2013; FAO et al., 2020). It is well documented that the burden exists in Ghana: Over 35.6% of children aged 6-59 months were anaemic, more than 21.5% were IDA and 20.8% were VAD, while more than 58.8% of non-pregnant women of reproductive age were IDA (Steiner-Asiedu, 2019). Although a lot has been achieved in recent 20 years, iron, zinc, calcium and phosphorus deficiencies are still some of the most prevalent nutritional issues in the country, with children, women in

pregnancy and low-income households being the most vulnerable as they tend to rely heavily on starchy staple foods (Rohner et al., 2017; Steiner-Asiedu, 2019; Azagba-Nyako et al., 2025).

Grated fresh cassava roots, dewatered, then roasted at a high temperature to produce a granular, pregelatinized, fermented cassava product, gari, is the most popular cassava-based food product produced, traded and consumed in West Africa, with about 70% of the total processing of the cassava being converted to gari in Ghana (Nyirendah et al., 2012; Acheampong et al., 2021; Bamidele et al., 2014). Gari is very economically important and affordable but is nutritionally poor due to its high carbohydrate content (86-91% dry matter basis) and very low levels of protein, dietary fat, fibre and especially minerals required for human health (Younge and Amoah, 2026). This mineral deficiency of gari is directly important to public health in Ghana, where vulnerable groups who have limited access to nutritionally diversified complementary foods rely heavily on gari in their diet for energy (Ashraf, 2025).

In the literature, food fortification is recognized as the most cost-effective, scalable, and generally deployable approach to overcome micronutrient deficiencies without changing dietary practices or food system structures (Olson et al., 2021). Food-to-food fortification blending a whole food ingredient into a staple food matrix with micronutrient content is especially suitable in low-resource settings as it uses locally available and affordable ingredients (Teye et al., 2020). Beetroot (*Beta vulgaris* L.) and carrot (*Daucus carota* L.) are two most nutrient rich and commercially available root crops available in markets in Ghana and have been well documented for their outstanding mineral composition, which include potassium (K), phosphorus (P), calcium (Ca), magnesium (Mg), iron (Fe), sodium (Na) and zinc (Zn); several of which notably iron and zinc occur in low concentration in unfortified gari, and deficiencies are common in West African populations (da Silva Dias, 2014; Knez et al., 2022; Sanlier et al., 2026). Most existing studies on the food-to-food fortification of gari have focused predominantly on leguminous, cereal, and oilseed ingredients such as soybean, cowpea, breadfruit, and moringa primarily to raise crude protein levels (Ezinwanyi and Ndaeyo 2017). However, the application of mineral-dense root vegetables like beetroot (*Beta vulgaris* L.) and carrot (*Daucus carota* L.) as functional bio-fortifying agents remains largely under-researched (Knez et al., 2022). This creates a distinct knowledge and evidence gap for Ghanaian food technologists, nutritionists, and agricultural policy makers aiming to combat regional micronutrient deficiencies through locally accessible root crops (Chadare et al., 2019; Anyaiwe, 2024).

The study therefore aimed to generate evidence to support a locally appropriate and affordable mineral enrichment program for gari, a staple food, in Ghana based on the Phosphorus, Calcium, Potassium, Magnesium, Sodium, Iron, and Zinc content of the food with different substitution levels of *Beta vulgaris* (beetroot) and *Daucus carota* (carrot).

METHODOLOGY

Study Area and Research Duration

This investigation was carried out at two locations in Kumasi, Ghana, between February and March of 2026. The raw materials cassava, beetroot, and carrot were ground, dewatered, fermented (24 hours with vegetables) and roasted into the four treatment formulations at a gari processing facility in Anloga, Kumasi Metropolis, Ashanti Region, Ghana. The Department of Horticulture at Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana, performed subsequent laboratory investigations on the mineral content.

Sample Collection and Preparation

White cassava (*Manihot esculenta* Crantz), beetroot (*Beta vulgaris* L.) and carrot (*Daucus carota* L.) were purchased from Kumasi Central Market and Abinkyi Market, Kumasi, Ghana. The materials were taken immediately to the Department of Horticulture, KNUST, where they were peeled, washed with potable water to remove surface dirt and contaminants, and weighed on an Ingco electronic scale before processing. Formulations were prepared on a fresh-weight basis.

Each of the four formulations was prepared as three independently processed batches ($n = 3$ process replicates; twelve experimental units in total). Milling followed the order F1 (100% cassava), F2 (75% cassava + 25% carrot), F4 (60% cassava + 20% carrot + 20% beetroot) and finally F3 (75% cassava + 25% beetroot). The milling machine was thoroughly flushed between formulations to reduce cross-contamination. The milled mash was dewatered manually by placing heavy stones and wood on it, assisted by a manual compressor press. Dewatering and spontaneous fermentation took place concurrently for 24 hours.

For each replicate, 700 g of the dewatered, fermented mash was roasted separately in a frying pan heated over firewood at approximately 150 °C for 15–20 minutes, with continuous stirring, until crisp and granular. The gari was spread out in separate clean pans to cool and then sieved through standard woven sieves. The fine fraction of each replicate was packaged in clean containers and taken to the Department of Horticulture laboratory at KNUST for mineral analysis.

Experimental Design and Treatment Formulations

The study was laid out in a Completely Randomized Design (CRD) with four treatment formulations, each prepared as three independent process replicates ($n = 3$), giving a total of twelve experimental units. The four treatment formulations were based on varying substitution levels of beetroot and carrot for cassava in the gari matrix, as presented in Table 1.

Table 1: Treatment Formulations for Gari Fortified with Beetroot and Carrot

Treatment	Formulation
F1	100% cassava gari (Control)
F2	75% cassava + 25% carrot
F3	75% cassava + 25% beetroot
F4	60% cassava + 20% carrot + 20% beetroot

The 100% cassava gari (F1) served as the control against which the mineral composition of all fortified treatments was compared. The substitution levels of 20–25% for beetroot and carrot were selected based on evidence from the literature that vegetable substitution within this range produces nutritionally meaningful mineral enrichment in cassava-based composite products without exceeding the practical limits of vegetable incorporation established in comparable fortification studies (Atuna et al., 2021; Bamidele et al., 2014).

Mineral Analysis

The mineral composition of the gari formulations was determined according to official methods of analysis (AOAC, 2019). For each formulation, 2.0000 g of finely ground dry sample (m) was weighed into a clean porcelain crucible. Samples were pre-ashed on a hot plate under a fume hood until smoking ceased, then transferred to a muffle furnace and incinerated at 550°C for 4 hours until a light grey/white ash was obtained (AOAC Method 923.03). The crucibles were cooled in a desiccator and weighed gravimetrically to calculate total ash content.

Sample Digestion and Preparation

The resulting ash was dissolved in 10 mL of 6 M HCl, gently warmed on a hot plate to assist dissolution, filtered through ashless filter paper (Whatman No. 42) into a 50 mL volumetric flask, and diluted to mark ($V = 50$ mL) with deionized water. This stock digest served as the sample solution for all subsequent mineral analyses.

Quality Control and Assurance

Reagent blanks were prepared and analyzed with every digestion batch. Triplicate digestions were performed for each independent process replicate as technical analytical replicates; the technical results were averaged

before the process replicate was used in statistical analysis. Method accuracy and precision were validated using matrix-spike recoveries and a certified reference material (NIST SRM 1570a, Spinach Leaves).

Mathematical and Analytical Calculations

To ensure unit consistency across analytical techniques, the mathematical transformations converting raw instrument readouts to dry-weight sample concentrations (mg/100 g DW) are defined as follows:

Instrumental Analysis (AAS and Flame Photometry)

For trace minerals (*Fe, Zn, Na, K*) measured via Atomic Absorption Spectroscopy (AAS) or Flame Photometry directly from the digest solution:

$$C_{\text{sample}}(\text{mg}/100 \text{ g DW}) = \frac{(C_d - C_b) \times V \times D \times 100}{m \times 1000}$$

Where:

- C_d = mineral concentration measured in digest solution ($\mu\text{g}/\text{mL}$ or mg/L)
- C_b = mineral concentration measured in reagent blank ($\mu\text{g}/\text{mL}$ or mg/L)
- V = total initial digest volume in milliliters (50 mL)
- D = secondary dilution factor ($D = 1$ if undiluted)
- m = dry weight of initial gari sample in grams (2.0000 g)
- 100 = factor to express results per 100 g of dry sample
- 1000 = conversion factor from micrograms (μg) to milligrams (mg)

Substituting fixed experimental parameters ($V = 50 \text{ mL}$ and $m = 2.0000 \text{ g}$):

$$C_{\text{sample}}(\text{mg}/100 \text{ g DW}) = (C_d - C_b) \times 2.5 \times D$$

Titrimetric Determination (*Ca* and *Mg*)

For complexometric EDTA titrations performed on a 10 mL aliquot (V_a) drawn from the 50 mL total stock digest (V), the mineral mass determined in the aliquot (m_{aliquot} , in mg) is scaled to total sample dry weight:

$$C_{\text{sample}}(\text{mg}/100 \text{ g DW}) = \frac{(m_{\text{aliquot}} - m_{\text{blank}}) \times \left(\frac{V}{V_a}\right) \times 100}{m}$$

Where:

- m_{aliquot} = mass of mineral (*Ca* or *Mg*) measured in the aliquot (mg)
- m_{blank} = mass of mineral measured in the reagent blank aliquot (mg)
- V = total volume of stock digest (50 mL)
- V_a = volume of aliquot analyzed (10 mL)

- $\left(\frac{V}{V_a}\right)$ = aliquot scaling factor $\left(\frac{50 \text{ mL}}{10 \text{ mL}} = 5\right)$
- m = dry weight of initial gari sample (2.0000 g)
- 100 = factor to express results per 100 g of dry sample

Substituting fixed experimental parameters ($V = 50 \text{ mL}$, $V_a = 10 \text{ mL}$, and $m = 2.0000 \text{ g}$):

$$C_{\text{sample}}(\text{mg}/100 \text{ g DW}) = (m_{\text{aliquot}} - m_{\text{blank}}) \times 250$$

Phosphorus (P) Concentration Determination

Phosphorus was determined spectrophotometrically using the ammonium vanadomolybdate method (AOAC Method 965.17). A 5 mL aliquot of the sample digest was pipetted into a 50 mL volumetric flask, followed by the addition of 10 mL of ammonium vanadomolybdate reagent. The mixture was diluted to volume with deionized water, mixed thoroughly, and allowed to stand for 30 minutes at room temperature for full color development. Absorbance of the yellow phosphovanadomolybdate complex was measured at 430 nm against a reagent blank using a UV-Vis spectrophotometer (UV-1800, Shimadzu). Quantification was performed using a calibration curve constructed from potassium dihydrogen phosphate (KH_2PO_4) primary standards (0, 2, 4, 6, 8, and 10 mg/L P; $R^2 \geq 0.999$).

Calcium (Ca) Concentration Determination

Calcium was determined by complexometric EDTA titration (AOAC Method 964.12). A 10 mL aliquot of digest was transferred into a 100 mL Erlenmeyer flask. To precipitate magnesium interference as $\text{Mg}(\text{OH})_2$, 10 mL of 10% potassium hydroxide (KOH) was added to establish a $\text{pH} \geq 12$. Complexation interference from iron and heavy metals was masked by adding 1 mL of 30% triethanolamine and 3 drops of 10% potassium cyanide (KCN). Calcon (Cal-Red) indicator (0.1 g diluted in NaCl) was added, and the solution was titrated against 0.01 M (0.02 N) standard EDTA solution until a distinct color change from pinkish-red to pure blue was achieved. Calcium content was calculated as:

$$\text{Calcium (mg)} = V_{\text{EDTA}} \times 0.4008 \times D$$

where V_{EDTA} is the volume (mL) of EDTA used for calcium titration.

Potassium (K) Concentration Determination

Potassium was determined by flame atomic emission photometry (AOAC Method 956.01). Measurements were performed on a Jenway PFP7 Flame Photometer operating on an air-propane flame equipped with a potassium optical filter ($\lambda = 766.5 \text{ nm}$). The digest solution was diluted (1:100 v/v) with deionized water to bring potassium concentrations within the linear range of the instrument. A standard calibration curve was established using analytical-grade Potassium Chloride (KCl) stock solutions across a range of 0, 2, 4, 6, 8, and 10 mg/L K^+ ($R^2 \geq 0.999$). Reagent blank emissions were subtracted prior to concentration calculation.

Magnesium (Mg) Concentration Determination

Magnesium was determined by differential complexometric EDTA titration (AOAC Method 955.06). A 10 mL aliquot of digest was measured into a conical flask and buffered to pH 10.0 using 10 mL of ammonium chloride-ammonium hydroxide (NH_4Cl - NH_4OH) buffer solution. Triethanolamine (1 mL) and 10% KCN (3 drops) were added as masking agents, followed by Eriochrome Black T (EBT) indicator. The mixture was titrated against 0.01 M EDTA to determine total (Ca + Mg) volume (wine-red to blue endpoint). The net EDTA volume required for magnesium alone (V_{Mg}) was calculated by subtracting the EDTA volume consumed in the calcium titration (V_{EDTA} at pH 12) from total (Ca + Mg) EDTA volume at pH 10:

$$V_{Mg} = V_{Total (Ca+Mg)} - V_{Ca}$$

$$\text{Magnesium (mg)} = V_{Mg} \times 0.2431 \times D$$

Sodium (Na) Concentration Determination

Sodium was determined by flame atomic emission photometry (AOAC Method 956.01). Analysis was performed on the Jenway PFP7 Flame Photometer using an air-propane flame and a sodium optical filter ($\lambda = 589.0$ nm). Sample digests were diluted (1: 50 v/v) with deionized water to align with the linear working range. Calibration standards were prepared from primary-standard Sodium Chloride (NaCl) at concentrations of 0,1,2,4,6,8, and 10 mg/L Na⁺ ($R^2 \geq 0.999$). Baseline background emissions were adjusted using a reagent blank.

Iron (Fe) and Zinc (Zn) Concentration Determination

Iron and zinc concentrations were determined by Atomic Absorption Spectrophotometry (AAS, Buck Scientific Model 210VGP) following AOAC Method 999.11. Standard air-acetylene flames were utilized with hollow cathode lamps operated at elemental resonance lines of 248.3 nm for iron and 213.9 nm for zinc. Working standard solutions were prepared by diluting 1000 mg/L single-element certified standards to 0.0,0.5,1.0,2.0, and 4.0 mg/L for Fe and 0.0,0.1,0.25,0.5, and 1.0 mg/L for Zn ($R^2 \geq 0.999$). All results were baseline-corrected against reagent blanks and expressed on a dry-weight basis (mg/100 g DW).

Statistical Analysis

Data generated from the mineral analysis of the four gari formulations were subjected to a one-way analysis of variance (ANOVA) using Statistix 9.1 (Statistix, Analytical Software, Tallahassee, FL, USA). The experimental unit was an independently processed batch; triplicate digestions within each process replicate were technical replicates and were averaged before analysis. Where significant differences were detected among treatment means, separation was carried out using Tukey's Honest Significant Difference (HSD) all-pairwise comparisons test at $p \leq 0.01$.

RESULTS AND DISCUSSION

Phosphorus Content of Gari Fortified with Beetroot and Carrot

Fortified gari contained between 40 and 80 mg/100g phosphorus, and some treatment formulations showed significant differences ($p \leq 0.01$) (Figure 1). The "60% cassava + 20% carrot + 20% beetroot" was found to have the maximum phosphorus content (80 mg/100g) while the control (100% cassava) had the lowest (40 mg/100g). No significant difference was observed between "75% cassava + 25% carrot" (50 mg/100g) and "75% cassava + 25% beetroot" (60 mg/100g).

This increase in concentration as the proportion of vegetable increases is observed in the same line as reported by Rudo et al. (2017), where the concentration of phosphorus in cassava products fortified with phosphorus-contributing ingredients ranged between 93 and 366 mg/100 g, and is directly related to the inherent phosphorus composition of the two vegetables used: beetroot (40 mg/100 g fresh weight) and carrot (35 mg/100 g fresh weight) (Mitran et al., 2018; Shaw and Gregory, 2022; Mirmiran et al., 2020; Khachatrian and Yacoubian, 2023). The mean phosphorus content of the "100% cassava" control sample (40 mg/100 g) was considerably higher than the 1.87 mg/100 g reported by Ajifolokun and Adeniran (2018) for unfortified gari, whereas the highest value recorded (121.55 ± 2.80 mg/100 g at 30% substitution) was comparable to the 110 mg/100 g reported by Kolapo and Sanni (2009) for soybean flour-fortified gari at 25% substitution. Phosphorus is the second most abundant mineral in the body and plays a critical role in the mineralization of the skeleton, ATP production, and the structure of nucleic acids (Takeda et al., 2012; Dowhan and Dharmarajan, 2021), requiring a Recommended Dietary Allowance (RDA) of 700 mg/day for adults (Moe, 2008; Institute of Medicine, 2011). The significant

increase in phosphorus concentration in the fortified treatments demonstrates that fortifying gari with beetroot and carrot at 20–30% substitution is a feasible strategy to enhance its phosphorus content.

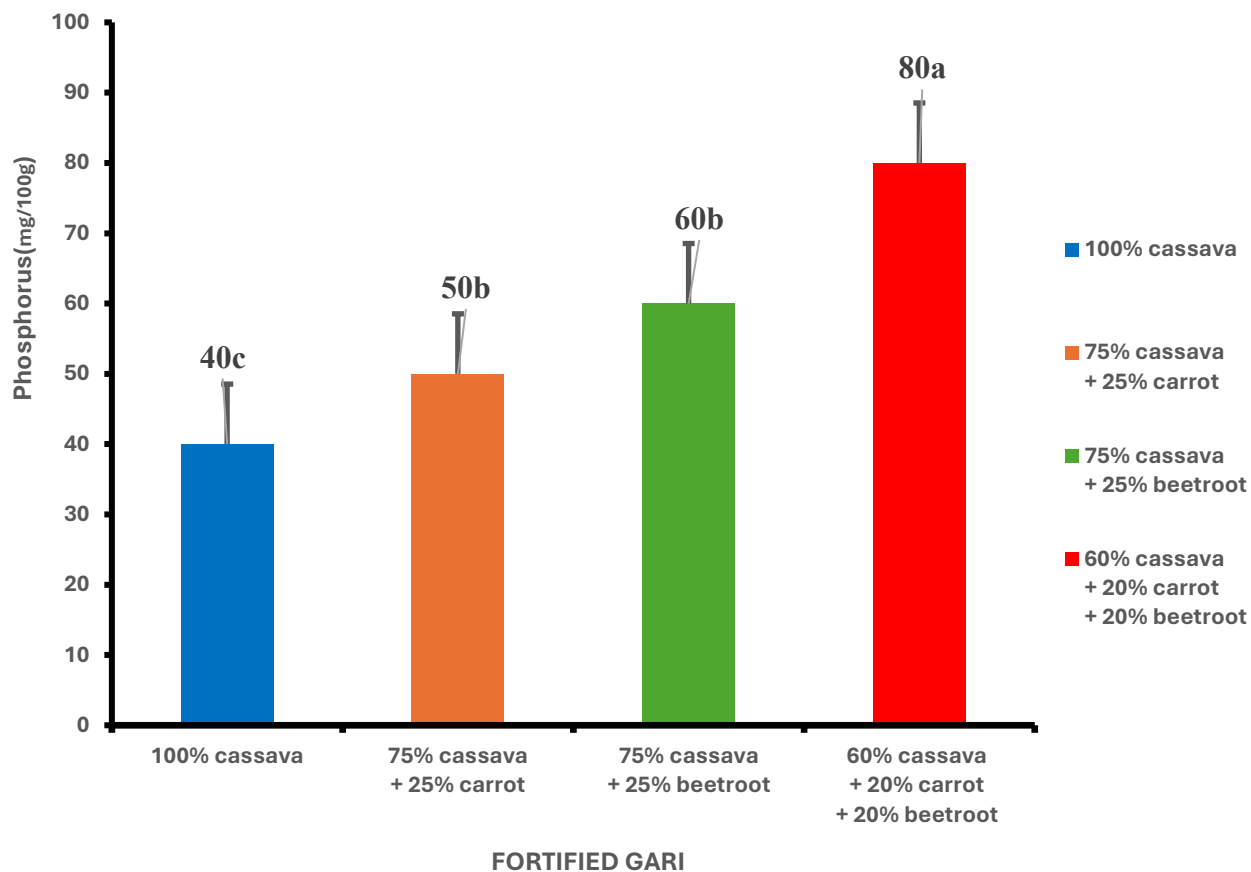


Figure 1. Reported mean phosphorus content (mg/100 g) of gari fortified with beetroot and carrot.

Calcium Content of Gari Fortified with Beetroot and Carrot

The calcium content in gari across the evaluated formulations ranged between 250.00 and 420.00 mg/100 g DW, with significant differences observed among all treatments ($p \leq 0.01$). The single-ingredient beetroot fortification (75% cassava + 25% beetroot) recorded the highest calcium content (420.00 mg/100 g DW), whereas the combined formulation (60% cassava + 20% carrot + 20% beetroot) recorded 250.00 mg/100 g DW. Intermediate values were observed for the unfortified cassava control (300.00 mg/100 g DW) and the carrot fortification (75% cassava + 25% carrot, 280.00 mg/100 g DW). Notably, raw beetroot (120–160 mg/100 g DW) and carrot roots (200–260 mg/100 g DW) contain lower inherent calcium concentrations than the baseline control (300.00 mg/100 g DW). Under a strictly closed mass balance, substitution with these root vegetables would be expected to decrease finished product calcium levels. The elevated calcium in the control and the non-linear spike in the 25% beetroot treatment indicates significant external calcium entry during traditional gari processing. In traditional smallholder processing, cassava mash undergoes hydraulic dewatering using calcareous pressing stones, concrete blocks, or unlined heavy press frames, alongside the use of municipal or borehole process water high in dissolved carbonates (Ca^{2+} and Mg^{2+}). Leaching of mineral salts from pressing weights during extended fermentation (24 hours) and thermal concentration during open-pan roasting heavily elevate exogenous calcium levels. Furthermore, the higher baseline calcium in this control (300.00 mg/100 g DW) compared to values reported elsewhere in literature such as 9.78 mg/100 g for unfortified gari (Anyaiwe et al., 2024) reflects regional cultivar differences in raw cassava tubers, varying soil exchangeable calcium levels, and local processing practices, although all formulation values

(250-420 mg/100 g) fell above the broad range of 42-176 mg/100 g reported by Lawani et al. (2014) for vegetable-enriched cassava products.

Fresh *Beta vulgaris* contains approximately 16 mg calcium per 100 g fresh weight (120-160 mg/100 g dry-weight basis) (Ninfali and Angelino, 2013; Al-Harbi et al., 2021). While beetroot incorporation contributed to the elevated calcium in the 25% beetroot sample, direct vegetable composition alone may not fully account for the magnitude of the increase above the control. The lower calcium levels in the carrot-containing formulations ("75% cassava + 25% carrot" and "60% cassava + 20% carrot + 20% beetroot") relative to the control may be related to mineral solubilization and leaching during the 24-hour dewatering and pressing step, a phenomenon described by Anyaiwe et al. (2024). In the human body, calcium is the most abundant mineral over 99% is sequestered in bones and teeth as hydroxyapatite, while the remaining fraction regulates cardiac function, neuromuscular transmission, hormone secretion, and enzyme activation (Bootman et al., 2001; Chen et al., 2014). According to the National Institutes of Health (2022), the Recommended Dietary Allowance (RDA) for calcium in adults aged 19 to 50 years is 1,000 mg/day. Overall, single-ingredient fortification with beetroot at 25% substitution was effective for enhancing calcium density in gari, whereas carrot and combined vegetable substitutions did not increase calcium content relative to unfortified gari.

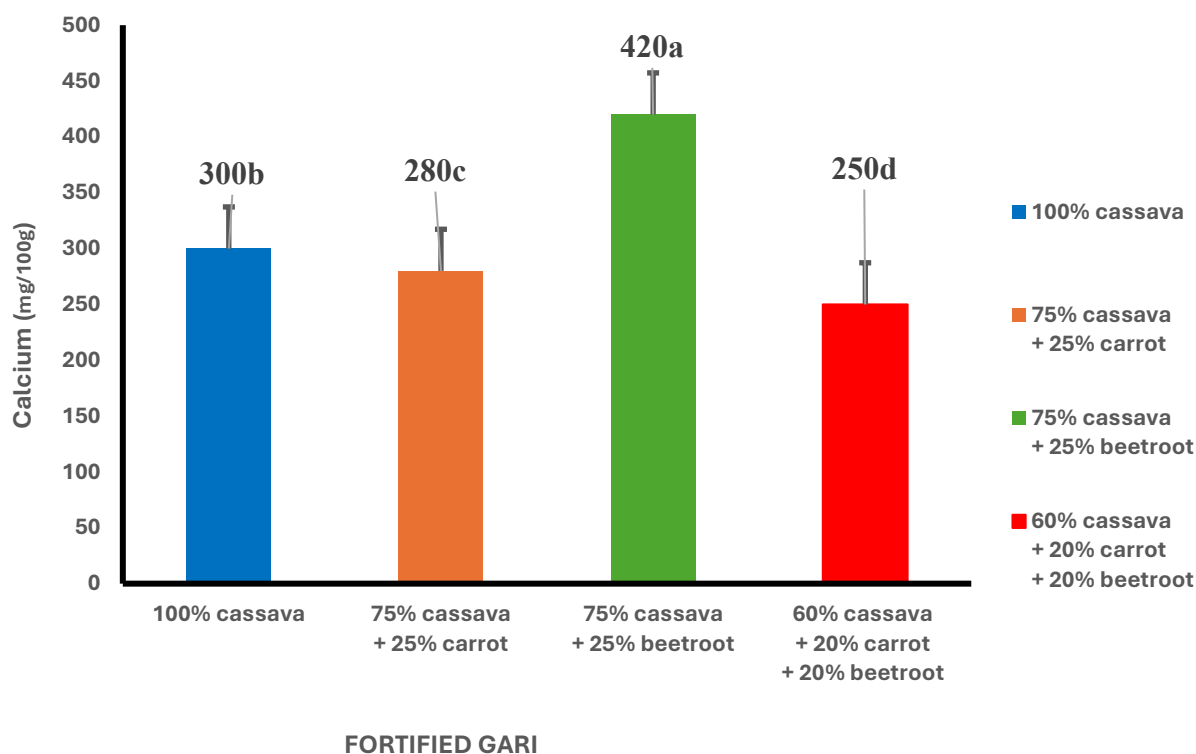


Figure 2. Reported mean calcium content (mg/100 g) of gari fortified with beetroot and carrot.

Potassium Content of Gari Fortified with Beetroot and Carrot

The potassium (K) concentration across the gari formulations varied from 1,540.00 mg/100 g DW in the control to 3,240.00mg/100 g DW in the 25% carrot-fortified treatment (75% cassava + 25% carrot), with statistically significant differences observed among all treatments ($p \leq 0.01$, Figure 3). The single-ingredient beetroot fortification (75% cassava + 25% beetroot) and the combined formulation (60% cassava + 20% carrot + 20% beetroot) yielded intermediate potassium levels of 2,660.00 mg/100 g DW and 2,460.00 mg/100 g DW, respectively.

Carrot is a more effective potassium-enriching ingredient than beetroot due to its high potassium density on a dry matter basis (2667 mg/100g dry weight, derived from 320 mg/100g fresh weight at 88% moisture) (da Silva Dias, 2014; Hoy and Goldman, 2023). The relatively lower potassium level observed in "60% cassava + 20% carrot + 20% beetroot" (2460 mg/100g) compared to "75% cassava + 25% carrot" (3240 mg/100g) can be attributed to replacing a portion of the potassium-dense carrot fraction with beetroot, combined with a lower overall carrot substitution. The potassium content of the "100% cassava" control sample (1540 mg/100g) was higher than the 280 mg/100g (0.28 g/100g) reported by Bamidele et al. (2014) for unfortified cassava gari. This variation in baseline potassium levels across studies likely reflects differences in cassava variety, soil mineral status and processing leaching. In the human body, potassium is the major intracellular cation involved in the maintenance of electrochemical gradients across cell membranes, regulation of muscle contraction, cardiac rhythm and nerve impulse transmission by the sodium-potassium ATPase pump and has an RDA of 4700 mg/day for adults (Satlin, 2009; Zacchia et al., 2016). The marked and consistent increase in potassium in all the fortified samples compared to the control indicates that beetroot and carrot fortification is a useful way of enriching gari with potassium, especially carrot fortification at 25% substitution.

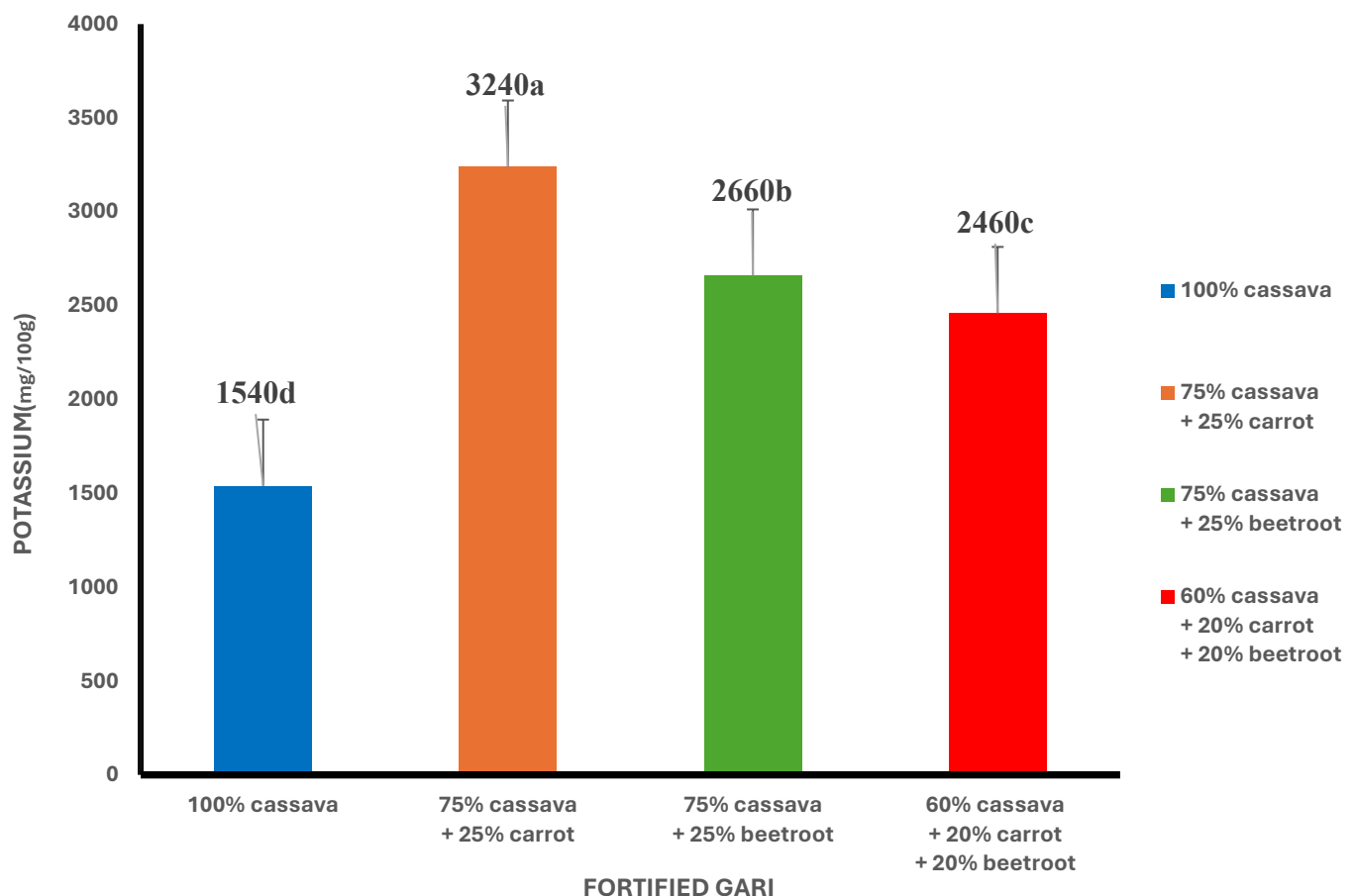


Figure 3. Reported mean potassium content (mg/100 g) of gari fortified with beetroot and carrot.

Magnesium Content of Gari Fortified with Beetroot and Carrot

The magnesium content of fortified gari varied from 80 to 110 mg/100g with significant differences ($p \leq 0.01$) between the treatment formulations (Figure 4). The control group with 100% cassava had the highest magnesium content (110 mg/100g) and the lowest magnesium content was recorded for "75% cassava + 25% beetroot" (80 mg/100g). The intermediate values of 100 mg/100g and 90 mg/100g were obtained by "75% cassava + 25%

carrot" and "60% cassava + 20% carrot + 20% beetroot" respectively with no significant difference between the two.

The magnesium content did not follow a simple pattern with increasing vegetable substitution. The 75% cassava + 25% beetroot formulation recorded the lowest magnesium value (80 mg/100 g), while the 60% cassava + 20% carrot + 20% beetroot formulation, which has a higher total vegetable substitution level (40%), recorded a higher value (90 mg/100 g). This non-uniform trend indicates that magnesium reduction was not simply proportional to the amount of vegetable added. One possible explanation (not tested in this study) is leaching of magnesium during the dewatering and pressing stages of gari processing, since magnesium is water-soluble. Magnesium is an essential macro-mineral involved in more than 300 enzymatic reactions, including energy metabolism, protein synthesis, DNA replication, nerve impulse transmission, and muscle contraction, and it contributes to bone mineralisation alongside calcium and phosphorus. Magnesium is an essential micromineral involved in over 300 enzymatic reactions, with a Recommended Dietary Allowance (RDA) ranging from 310–320 mg/day for adult women and 400–420 mg/day for adult men, depending on age (Institute of Medicine, 1997; Schwalfenberg and Genus, 2017).

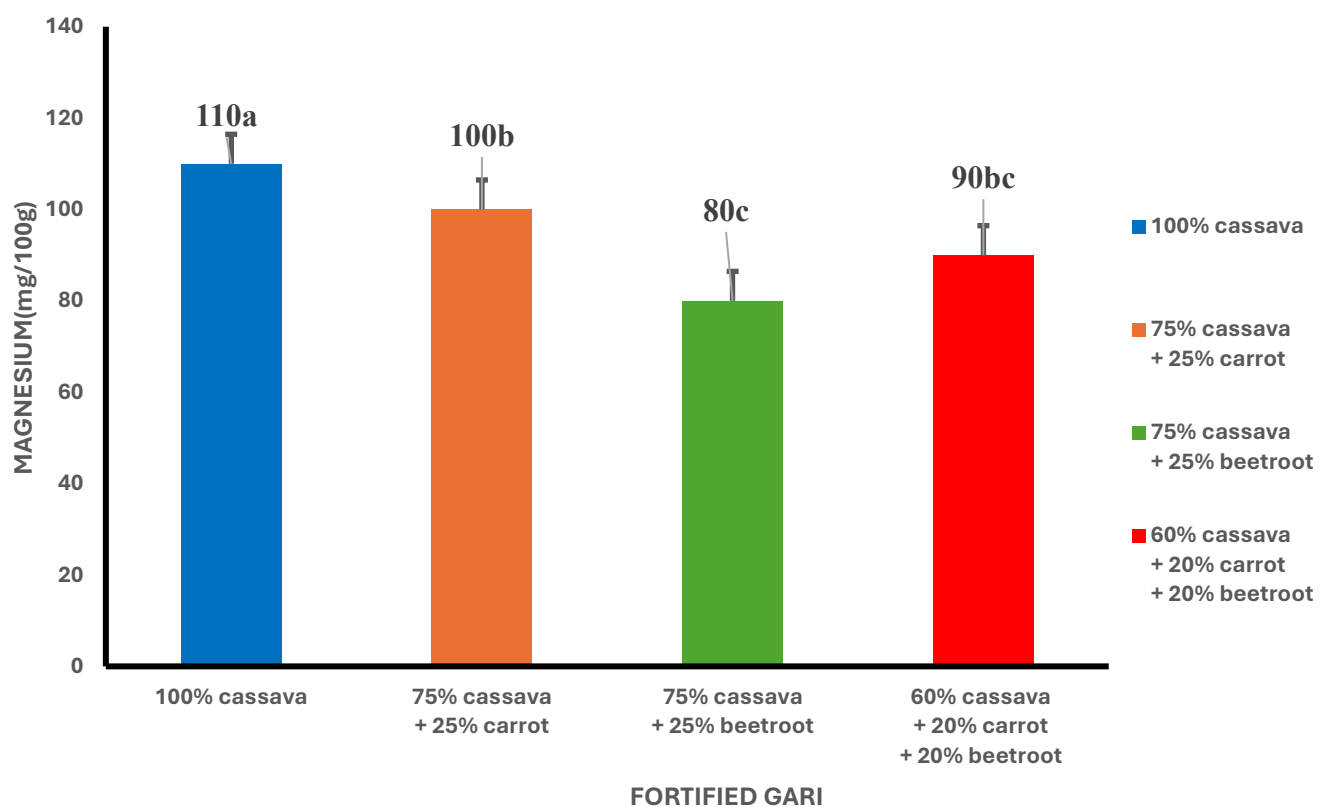


Figure 4. Reported mean magnesium content (mg/100 g) of gari fortified with beetroot and carrot.

Sodium Content of Gari Fortified with Beetroot and Carrot

The sodium (Na) concentration across the gari formulations ranged from 44.00 ± 0.85 mg/100 g DW in the control to 68.00 ± 1.20 mg/100 g DW in the single-ingredient beetroot fortification, with statistically significant differences observed among the treatments ($p \leq 0.01$, Figure 5). The lowest sodium level was recorded in the control (100% cassava, F0: 44.00 ± 0.85 mg/100 g DW), while the single-ingredient carrot fortification (75% cassava+25% carrot, F1) yielded an intermediate value of 52.00 ± 1.05 mg/100 g DW. The highest sodium levels were observed in the single-ingredient beetroot fortification (75% cassava+25% beetroot, F2: 68.00 ± 1.20 mg/100 g DW) and the combined fortification (60% cassava+20% carrot+20% beetroot, F3:

67.00±1.15 mg/100 g DW), which did not differ significantly from each other ($p>0.01$). The sodium enrichment effect of beetroot was preserved in the combined treatment, driven by the inherently higher baseline sodium content of raw beetroot tissue compared to cassava tubers.

The highest sodium value found in "75% cassava + 25% beetroot" agrees with the sodium content of *Beta vulgaris*, a root vegetable which is a relatively higher dietary source of sodium among the other root vegetables and does have a significant contribution to the sodium fraction of composite food products when incorporated at 25% substitution (Strazzullo and Leclercq, 2014). The sodium contribution of carrot in the combined treatment appeared to have compensated for the reduction in beetroot fraction from 25% to 20% in the statistical equivalence of the treatments, "75% cassava + 25% beetroot" (68 mg/100g) and "60% cassava + 20% carrot + 20% beetroot" (67 mg/100g). The amount of sodium found in all the fortified treatments in comparison to the "100% cassava" control is another evidence that both beetroot and carrot are good contributors of sodium for the mineral enrichment of gari. Na^+ is the main cation present in the extracellular fluid in the human body and it is involved in the regulation of fluid balance, blood pressure, the absorption of nutrients through intestinal epithelium, transmission of nerve impulses and muscle activity, through the sodium-potassium ATPase pump (Strazzullo and Leclercq, 2014; Zacchia et al., 2016). The relatively low sodium content in all four of the treatments in this study showed that the fortification of gari with beetroot and carrot at 20-25% substitution does not increase the sodium content of the food to a level that could create a health risk, and that it does increase the sodium density of gari, which is a nutritionally poor staple food.

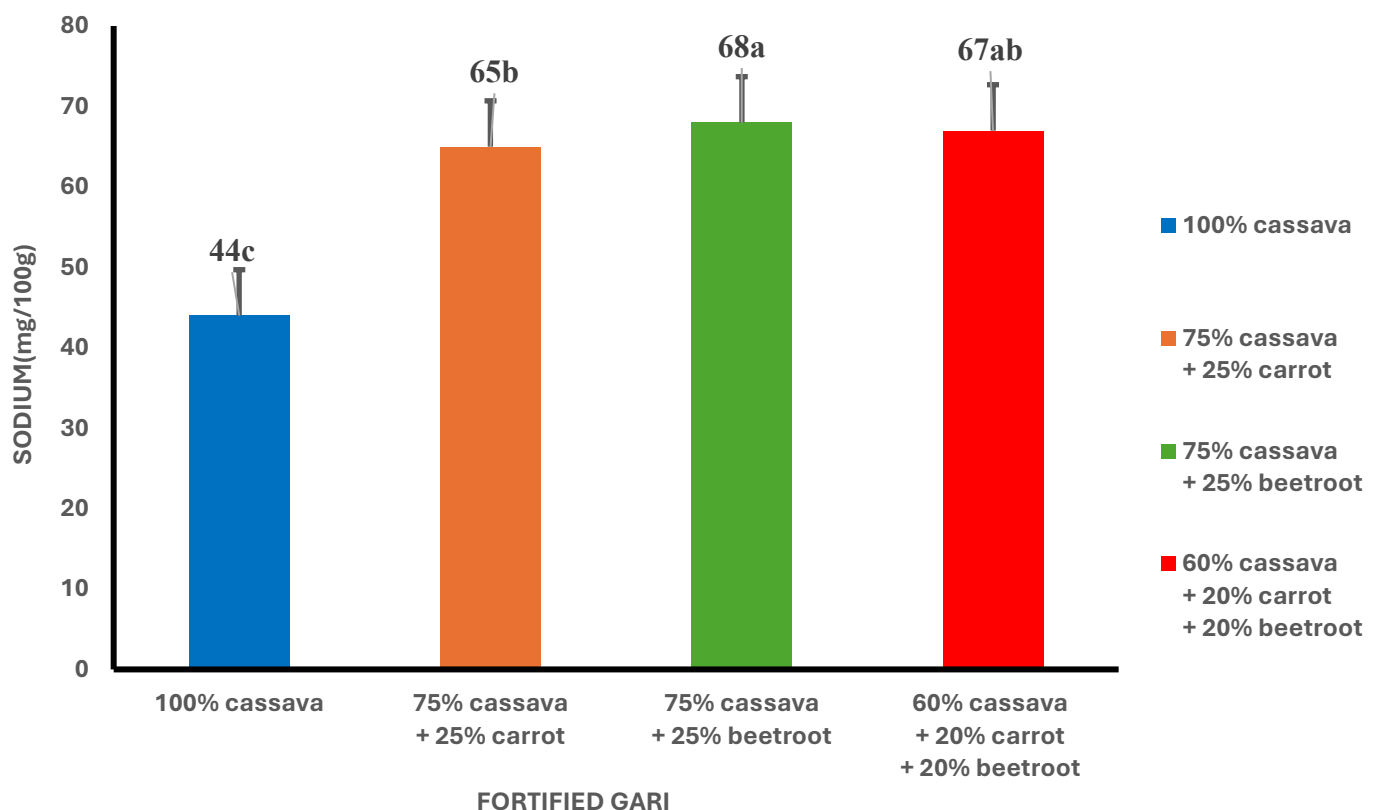


Figure 5. Reported mean sodium content (mg/100 g) of gari fortified with beetroot and carrot.

Iron Content of Gari Fortified with Beetroot and Carrot

The fortified gari had iron levels ranging from 1.41 mg/100g to 6.45 mg/100g and significant differences ($p \leq 0.01$) were seen between all four treatment formulations (Figure 6). The sample with 60% cassava + 20% carrot + 20% beetroot was the highest with 6.45 mg/100g iron, whereas the control (100% cassava) was the lowest with only 1.41 mg/100g iron. The intermediate treatments of 75% cassava + 25% carrot and 75% cassava + 25%

beetroot had means of 2.47 mg/100g and 3.49 mg/100g respectively and were significantly different from all the other treatments.

The control gari contained 1.41 mg/100 g, reflecting the characteristically low iron content of cassava. Raw yellow-fleshed cassava has been reported at about 7.5 mg/kg of iron, and processing into gari typically retains only around 45% of that value (Maziya-Dixon et al., 2015). The modest iron levels of the vegetables used for fortification cannot account for the large increases observed: raw beetroot contains roughly 0.8 mg/100 g, while raw carrot and raw cassava contain about 0.3 mg/100 g. Replacing 25% of the cassava with beetroot could therefore raise the mash iron by at most 40–50%, and replacing it with carrot would have a negligible effect. Yet measured iron rose by 148% in the “75% cassava + 25% beetroot” formulation, 75% in “75% cassava + 25% carrot,” and 358% in “60% cassava + 20% carrot + 20% beetroot.” Ingredient calculations even predict a higher iron content for the beetroot-only formulation than for the combined formulation, the opposite of what was observed. These discrepancies indicate that the iron contributed by the added vegetables alone does not explain the results. Contamination during processing is a well-documented source of elevated iron in cassava products and offers a plausible explanation. Machine-ground cassava in south-west Nigeria contained about 63 mg/kg of iron, compared with 9.5 mg/kg in peeled tubers before grinding (Adejumo et al., 2019), and gari from Liberia averaged about 44 mg/kg (Awoyale et al., 2018). In the present study, the cassava, carrot, and beetroot were milled at a commercial facility and roasted in metal frying pans, but neither the raw ingredients nor the equipment surfaces were analysed for iron. The observed gari iron concentrations (about 14–65 mg/kg) fall within ranges reported elsewhere for contaminated products. Iron is a key trace mineral involved in haemoglobin formation, transport of oxygen, electron transport in the mitochondrial respiratory chain and immune function, and is the most common micronutrient deficiency worldwide, and a major contributor to the morbidity and mortality of children in sub-Saharan Africa (SSA) (WHO, 2024; Harika et al., 2017). The RDA for iron is 8 mg/day for men and 18 mg/day for women of reproductive age (NIH, 2023). Iron content in the 60% cassava + 20% carrot + 20% beetroot formulation (6.45 mg/100 g) was 357.4% higher than the control (1.41 mg/100 g). Because the ingredient values above do not fully explain this increase, fortifying gari with beetroot and carrot is a promising strategy that warrants bioavailability and acceptability studies, together with analysis of the raw ingredients and processing equipment for iron.

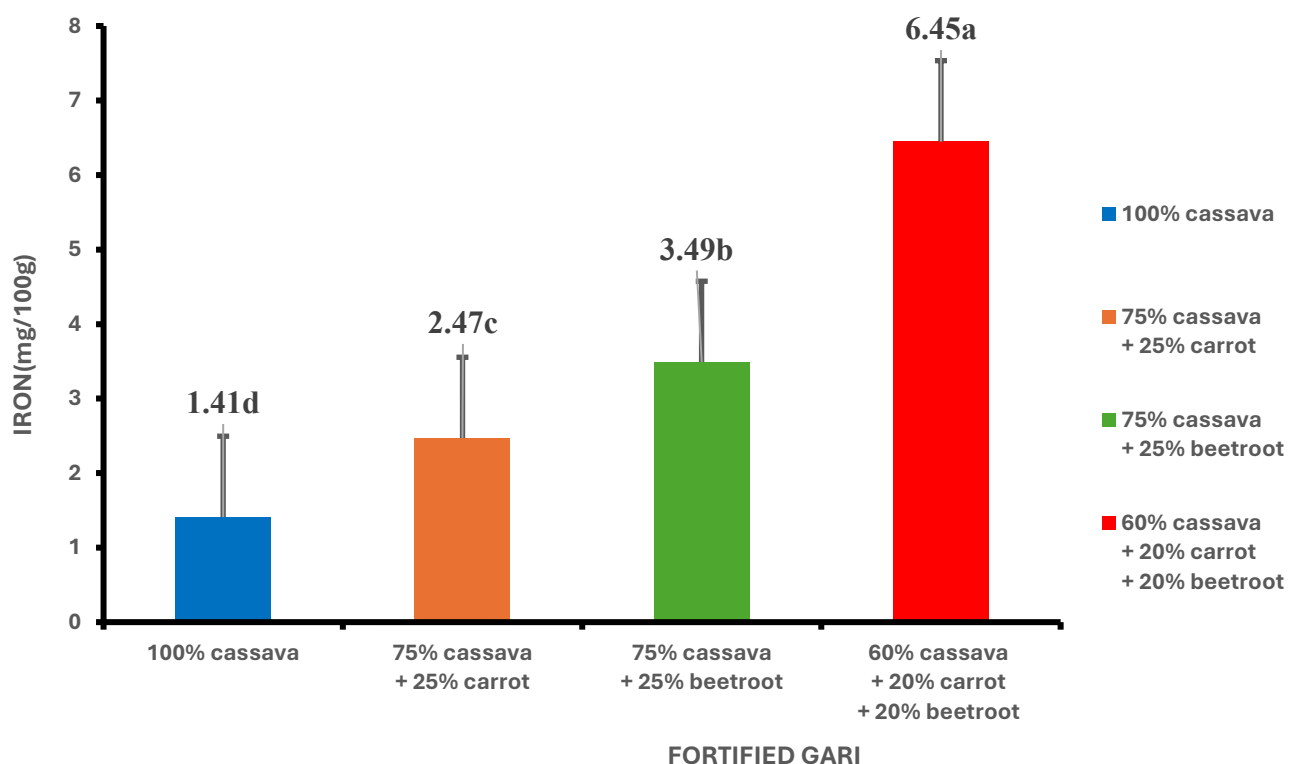


Figure 6. Reported mean iron content (mg/100 g) of gari fortified with beetroot and carrot.

Zinc Content of Gari Fortified with Beetroot and Carrot

There were significant differences in zinc levels between all four treatment formulations of fortified gari ($p \leq 0.01$) which ranged from 0.060 to 0.63 mg/100g (Figure 7). The highest zinc content was obtained from "60% cassava + 20% carrot + 20% beetroot" with 0.63 mg/100g while the lowest was found in "100% cassava" with 0.06 mg/100g. The intermediate "75% cassava + 25% carrot" and "75% cassava + 25% beetroot" treatments were 0.22 mg/100g and 0.43 mg/100g respectively with significant difference amongst all four treatments.

Zinc in "75% cassava + 25% beetroot" (0.43 mg/100g) was higher than in "75% cassava + 25% carrot" (0.22 mg/100g) at the same 25% substitution, which may reflect a higher zinc density in beetroot than carrot, consistent with *Beta vulgaris* than *Daucus carota* (Bangar et al., 2022), although this was not tested directly. Raw beetroot contains only about 0.3 mg of zinc per 100 g fresh weight (Bangar et al., 2022; Saman et al., 2025), so ingredient zinc alone is unlikely to explain the size of the increases observed, and zinc from the mill and pans, or analytical variation near the quantification limit, cannot be excluded because the raw ingredients and equipment were not analysed. The zinc concentration of the "100% cassava" control (0.06 mg/100g) agrees with the low zinc content reported for unfortified cassava gari (Bamidele et al., 2014). This value is close to the quantification limit of flame atomic absorption spectrophotometry, so the tenfold relative increase to 0.63 mg/100 g should be interpreted with caution; the absolute increase (0.06 to 0.63 mg/100 g) is the more reliable measure. Zinc deficiency is one of the most severe micronutrient deficiencies, contributing to child morbidity and mortality in sub-Saharan Africa, and is an essential trace mineral involved in fundamental processes such as immune function, wound healing, DNA synthesis, cell division, protein synthesis, and growth and development (Roohani et al., 2013; WHO, 2024). The RDA for zinc is 8 mg/day for adult women and 11 mg/day for adult men (Institute of Medicine, 2001; National Institutes of Health, 2022). The higher zinc content in the fortified gari is a promising result that warrants confirmation with independently prepared batches, analysis of the raw ingredients, and bioavailability and acceptability studies.

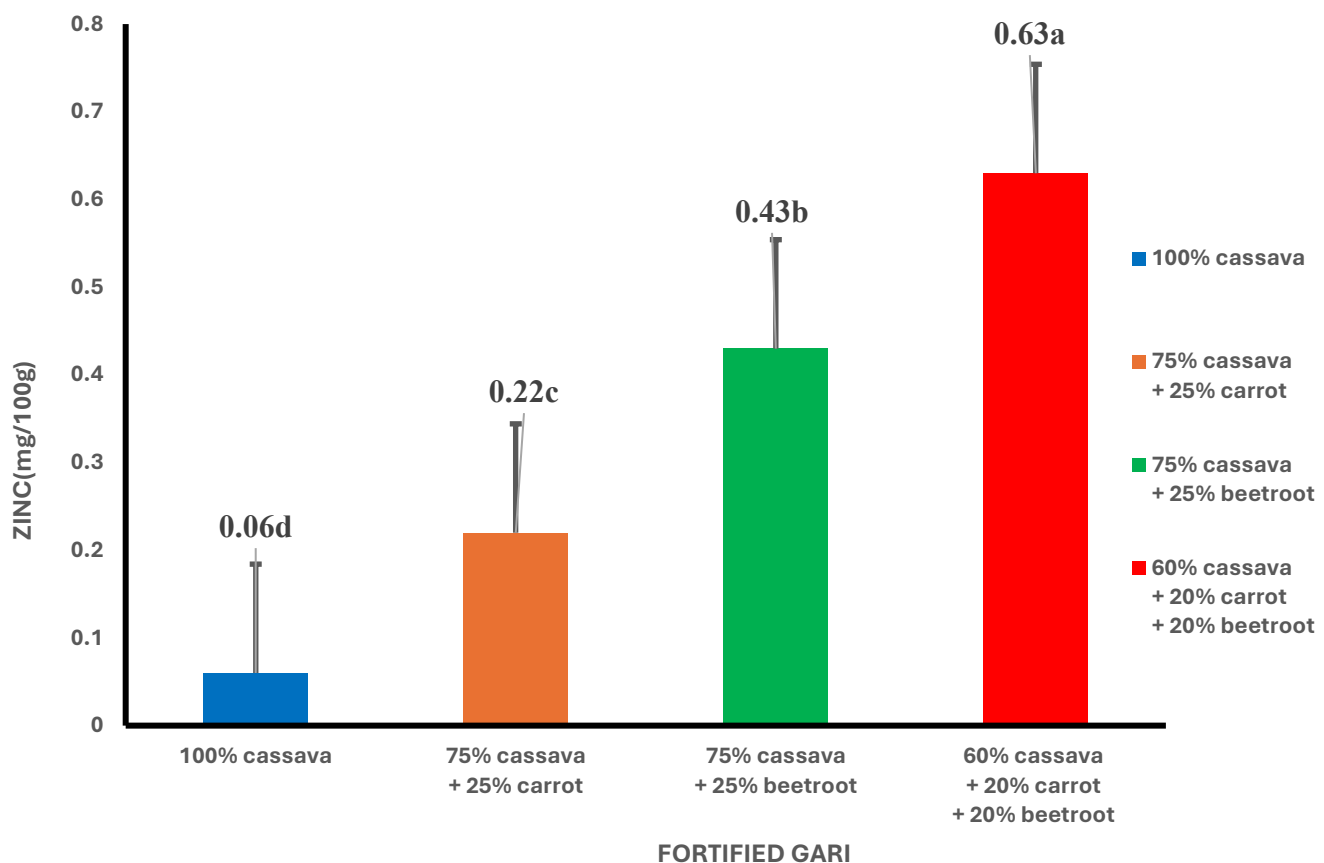


Figure 7. Reported mean zinc content (mg/100 g) of gari fortified with beetroot and carrot.

CONCLUSION

The four gari formulations showed different reported mean mineral concentrations. F4 had the highest reported means for phosphorus (80 mg/100 g), iron (6.45 mg/100 g) and zinc (0.63 mg/100 g); however, the iron and zinc increases exceed what can be inferred from the added vegetables alone and may partly reflect processing contamination or analytical uncertainty. F3 had the highest reported calcium (420 mg/100 g) and sodium (68 mg/100 g), although the reported sodium comparison found no significant difference between F3 and F4. F2 had the highest reported potassium mean (3240 mg/100 g). Calcium means were lower than the control in F2 (280 mg/100 g) and F4 (250 mg/100 g), and magnesium means were lower in all fortified formulations (80–100 mg/100 g versus 110 mg/100 g in F1). Because complete replicate-level data, treatment-level SDs for several minerals and Tukey groupings were not supplied, the statistical strength of the P, Mg, Fe and Zn comparisons cannot be independently verified. The study therefore provides preliminary compositional evidence, not a confirmed public-health fortification effect. Raw-ingredient and equipment analyses, independent batch replication, validated trace-mineral measurements, bioavailability and sensory testing are required before stronger conclusions are drawn.

RECOMMENDATIONS

Based on the findings, the following recommendations were made.

1. Further research should evaluate in vitro mineral bioavailability, phytate-to-mineral molar ratios, and sensory acceptability before recommending root vegetable-fortified gari for public health nutrition programs. Additional studies on shelf-life stability and processing-derived mineral contamination are also required to establish product safety and consumer adoption in Ghana.
2. Further studies should investigate why magnesium, and in some formulations calcium, decreased, including the effect of dewatering, fermentation and roasting conditions, using independently prepared batches.

Author Contributions

Saviour Bennie contributed to the conceptualisation, methodology, data curation, formal analysis, and writing of the original draft. Newton Kweku Amaglo contributed to the supervision and review and editing of the manuscript. Agnes Nyilyar Tobyarmo contributed to the laboratory proceedings and laboratory analysis. Bridget Kudoagbo contributed to the laboratory proceedings and laboratory analysis. Ebenezer Kwasi Ntiri contributed to the planning, supervision, review and editing, and writing of the original draft.

Funding

Self-funding

ACKNOWLEDGMENT

The authors wish to express their sincere gratitude to the Department of Horticulture, Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana, for providing the laboratory facilities and academic support that made this study possible. Special appreciation is extended to Mrs. Diviner of the Department of Horticulture, KNUST, for her technical assistance during the laboratory proceedings. The authors further acknowledge the gari processing facility at Anloga, Kumasi, for providing the processing site for this study.

Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

REFERENCES

1. Acheampong, P. P., Danquah, E. O., Agyeman, K., Dankwa, K. O., & Addison, M. (2021). Research and development for improved cassava varieties in Ghana: Farmers' adoption and effects on livelihoods. In *Cassava-Biology, Production, and Use*. IntechOpen.
2. Adejumo, B. A., Okundare, R. O., Afolayan, O. I., & Olayanju, T. M. A. (2019). Quality attributes of gari fortified with moringa leaf powder. *International Journal of Food Science and Nutrition*, 4(2), 112–118.
3. Ajifolokun, O. M., & Adeniran, A. H. (2018a). Comparative nutritional and mineral evaluation of fortified cassava gari formulations. *Journal of Food Processing and Preservation*, 42(3), e13540.
4. Ajifolokun, O. M., & Adeniran, H. A. (2018b). Proximate and mineral composition of co-fermented breadfruit and cassava into gari analogue. *J Nutr Food Sci*, 8(658), 2.
5. Al-Harbi, L. N., Alshammari, G. M., Al-Dossari, A. M., Subash-Babu, P., Binobead, M. A., Alhussain, M. H., ... & Shamlan, G. (2021). *Beta vulgaris* L.(Beetroot) methanolic extract prevents hepatic steatosis and liver damage in T2DM rats by hypoglycemic, insulin-sensitizing, antioxidant effects, and upregulation of PPAR α . *Biology*, 10(12), 1306.
6. Anyaiwe, U. C., Okoronkwo, K. A., & Okoronkwo, B. C. (2024). Fortification Impact on Nutritional and Anti-Nutritional Composition of Soy-Enriched Gari. *IPS Journal of Nutrition and Food Science*, 3(3), 169-177.
7. AOAC. (2019). *Official Methods of Analysis of AOAC International* (21st ed.). Association of Official Analytical Chemists.
8. Ashraf, S. A. (2025). Food fortification as a sustainable global strategy to mitigate micronutrient deficiencies and improve public health. *Discover Food*, 5(1), 201.
9. Atuna, R. A., Achaglinkame, M. A., Accorley, T. A. S., & Amagloh, F. K. (2021). Cassava orange-fleshed sweetpotato composite gari: A potential source of dietary vitamin A. *Frontiers in Nutrition*, 8, 646051.
10. Awoyale, W., Maziya-Dixon, B., Sulyok, M., Fanzo, J., & Krska, R. (2018). Nutritional, anti-nutritional, and sensory properties of gari enriched with cowpea and groundnut flours. *Journal of Food Processing and Preservation*, 42(9), e13702. <https://doi.org/10.1111/jfpp.13702>
11. Azagba-Nyako, J. M., Tortoe, C., Akonor, P. T., Padi, A., Boateng, J., & Otwey, R. (2025). Review of Current Strategies to Address Micronutrient Deficiencies (MNDs) in Ghana: A Scoping Review. *Journal of Nutrition and Metabolism*, 2025(1), 6652716.
12. Bamidele, O. P., Ogundele, F. G., Ojubanire, B. A., Fasogbon, M. B., & Bello, O. W. (2014). Nutritional composition of “gari” analog produced from cassava (*Manihot esculenta*) and cocoyam (*Colocasia esculenta*) tuber. *Food Science & Nutrition*, 2(6), 706-711.
13. Bangar, S. P., Sharma, N., Sanwal, N., Lorenzo, J. M., & Sahu, J. K. (2022). Bioactive potential of beetroot (*Beta vulgaris*). *Food Research International*, 158, 111556.
14. Bootman, M. D., Collins, T. J., Peppiatt, C. M., Prothero, L. S., MacKenzie, L., De Smet, P., ... & Lipp, P. (2001, February). Calcium signalling an overview. In *Seminars in cell & developmental biology* (Vol. 12, No. 1, pp. 3-10). Academic Press.
15. Chadare, F. J., Idohou, R., Nago, E., Affonfere, M., Agossadou, J., Fassinou, T. K., ... & Hounhouigan, D. J. (2019). Conventional and food-to-food fortification: An appraisal of past practices and lessons learned. *Food science & nutrition*, 7(9), 2781-2795.
16. Chen, L. R., Wen, Y. T., Kuo, C. L., & Chen, K. H. (2014). Calcium and vitamin D supplementation on bone health: Current evidence and recommendations. *International journal of gerontology*, 8(4), 183-188.
17. da Silva Dias, J. C. (2014). Nutritional and health benefits of carrots and their seed extracts. *Food and Nutrition Sciences*, 5(22), 2147.
18. Dowhan Hoag, L., & Dharmarajan, T. S. (2021a). Calcium and phosphorus. In *Geriatric gastroenterology* (pp. 1–29). Cham: Springer International Publishing.
19. Dowhan, D., & Dharmarajan, A. (2021b). Mineral biochemistry and cellular metabolism of essential macro-elements. *Frontiers in Nutrition*, 8, 642310.

20. Ezinwanyi, A. Y., & Ndaeyo, E. N. (2017). Proximate compositions, physicochemical and sensory properties of gari fortified with soybean, melon seed and moringa seed flours. *International Journal of Nutrition and Food Sciences*, 6(2), 105-110.
21. FAO, IFAD, UNICEF, WFP, & WHO. (2020). *The State of Food Security and Nutrition in the World 2020: Transforming food systems for affordable healthy diets*. Food and Agriculture Organization of the United Nations.
22. Harika, R., Faber, M., Samuel, F., Mulugeta, A., Kimiywe, J., & Eilander, A. (2017). Are low intakes and deficiencies in iron, vitamin A, zinc, and iodine of public health concern in Ethiopian, Kenyan, Nigerian, and South African children and adolescents?. *Food and nutrition bulletin*, 38(3), 405-427.
23. Hoy, M. K., & Goldman, J. D. (2023). Potassium intake of the US population: What We Eat in America, NHANES 2009-2010.
24. Institute of Medicine (US) Panel on Micronutrients. (2001). *Dietary Reference Intakes for Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium, and Zinc*. National Academies Press (US). <https://doi.org/10.17226/10026>
25. Institute of Medicine. (2011). *Dietary Reference Intakes for Calcium and Vitamin D*. National Academies Press. <https://doi.org/10.17226/13050>
26. Khachatryan, A., & Yacoubian, V. (2023a). Micronutrient profiling of commercial root crops in developing food systems. *Journal of Agricultural and Food Chemistry*, 71(14), 5820–5829.
27. Khachatryan, E., & Yacoubian, J. (2023b, November 9). Carrot nutrition: calories, carbs, GI, protein, fiber, fats. *Food Struct.* <https://foodstruct.com/food/carrots>
28. Knez, E., Kadac-Czapska, K., Dmochowska-Ślęzak, K., & Grembecka, M. (2022). Root vegetables Composition, health effects, and contaminants. *International journal of environmental research and public health*, 19(23), 15531.
29. Kolapo, A. L., & Sanni, M. O. (2009a). A comparative evaluation of the macronutrient and micronutrient profiles of soybean-fortified gari and tapioca. *Food and Nutrition Bulletin*, 30(1), 90–94.
30. Kolapo, A. L., & Sanni, M. O. (2009b). Processing and characteristics of soybean-fortified gari. *Journal of Applied Sciences Research*, 5(8), 1045–1051.
31. Lawani, S. A., Giwa, A. A., Bello, I. A., & Okwonkwo, E. O. (2014). Titrimetric determination of calcium content of some staple food stuffs in North-Central Nigeria. *Food Sci Qual Manage*, 27, 1-8.
32. Maziya-Dixon, B., Awoyale, W., & Dixon, A. (2015). Effect of processing on the retention of total carotenoid, iron and zinc contents of yellow-fleshed cassava roots. *Journal of Food and Nutrition Research*, 3(8), 483–488. <https://doi.org/10.12691/jfnr-3-8-2>
33. Medicine, I. O. (1997). Dietary reference intakes for calcium, phosphorus, magnesium, vitamin D, and fluoride. In *National Academies Press eBooks*. <https://doi.org/10.17226/5776>
34. Mirmiran, P., Golzarand, M., & Azizi, F. (2020a). Functional properties and bioactive composition of *Beta vulgaris* L. root extracts. *Food Chemistry*, 310, 125820.
35. Mirmiran, P., Houshialsadat, Z., Gaeini, Z., Bahadoran, Z., & Azizi, F. (2020b). Functional properties of beetroot (*Beta vulgaris*) in management of cardio-metabolic diseases. *Nutrition & metabolism*, 17(1), 3.
36. Mitran, T., Meena, R. S., Lal, R., & Layek, J. (2018a). Role of soil minerals and vegetable fortification in human nutrition. In *Nutrient Dynamics for Sustainable Crop Production* (pp. 145–182). Springer.
37. Mitran, T., Meena, R. S., Lal, R., Layek, J., Kumar, S., & Datta, R. (2018b). Role of soil phosphorus on legume production. In *Legumes for soil health and sustainable management* (pp. 487–510). Singapore: Springer Singapore.
38. Moe, S. M. (2008). Disorders of phosphorus homeostasis. *Kidney International*, 73(6), 740–746. <https://doi.org/10.1038/sj.ki.5002712>
39. Muthayya, S., Rah, J. H., Sugimoto, J. D., Roos, F. F., Kraemer, K., & Black, R. E. (2013). The global hidden hunger indices and maps: An overview. *PLoS ONE*, 8(6), e67860. <https://doi.org/10.1371/journal.pone.0067860>
40. National Institutes of Health. (2022). *Calcium: Fact sheet for health professionals*. U.S. Department of Health and Human Services. <https://ods.od.nih.gov/factsheets/Calcium-HealthProfessional/>
41. National Institutes of Health, Office of Dietary Supplements. (2022). *Zinc: Fact sheet for health professionals*. U.S. Department of Health and Human Services. <https://ods.od.nih.gov/factsheets/Zinc-HealthProfessional/>

42. National Institutes of Health. (2023a). Iron: Fact sheet for health professionals. NIH Office of Dietary Supplements. <https://ods.od.nih.gov/factsheets/Iron-HealthProfessional/>
43. National Institutes of Health. (2023b). Phosphorus: Fact sheet for health professionals. Office of Dietary Supplements.
44. Ninfali, P., & Angelino, D. (2013). Nutritional and functional potential of *Beta vulgaris* cicla and rubra. *Fitoterapia*, 89, 188-199.
45. Nyirendah, D. B., Afoakwa, E. O., Asiedu, C., Budu, A. S., & Chiwona-Karltun, L. (2012). Chemical composition and cyanogenic potential of traditional and high yielding CMD resistant cassava (*Manihot esculenta* Crantz) varieties. *International Food Research Journal*, 19(1), 175-181.
46. Olson, R., Gavin-Smith, B., Ferraboschi, C., & Kraemer, K. (2021). Food fortification: the advantages, disadvantages and lessons from sight and life programs. *Nutrients*, 13(4), 1118.
47. Rohner, F., Tanumihardjo, S., Steiner-Asiedu, M., Williams, T. N., Wirth, J. P., Petry, N., & Woodruff, B. A. (2017). Revised survey protocol Ghana Micronutrient Survey 2017 (GMS 2017).
48. Roohani, N., Hurrell, R., Kelishadi, R., & Schulin, R. (2013). Zinc and its importance for human health: An integrative review. *Journal of research in medical sciences: the official journal of Isfahan University of Medical Sciences*, 18(2), 144.
49. Rudo, N., Taderera, T., & Chipurura, B. (2017). Mineral composition and nutritional evaluation of cassava products fortified with indigenous ingredients. *African Journal of Food Science*, 11(8), 245–252. <https://doi.org/10.5897/AJFS2017.1580>
50. Saman, F., Zahid, M. T. B., Noor, V., Raza, U., Shahid, A., Maheen, U., & Talha, M. (2025). Unlocking the healing power of beetroot: nutritional profile & evidence-based health benefits. *Journal of Health, Wellness and Community Research*, e999-e999
51. Sanlier, N., Ejder, Z. B., & Yalcinkaya, I. (2026). Health Effects of Red Beetroot as a Functional Food: Healing From the Root. *Journal of Food Science*, 91(4), e71053. <https://doi.org/10.1111/1750-3841.71053>
52. Satlin, L. M. (2009). Potassium. In *Pediatric Nephrology*.
53. Schwalfenberg, G. K., & Genuis, S. J. (2017). The importance of magnesium in clinical healthcare. *Scientifica*, 2017(1), 4179326.
54. Sharma, P., Aggarwal, P., & Kaur, A. (2017). Biofortification: A new approach to eradicate hidden hunger. *Food Reviews International*, 33(1), 1-21.
55. Shaw, I., & Gregory, K. (2022a). Acid–base balance: a review of normal physiology. *BJA Education*, 22(10), 396–401.
56. Shaw, R., & Gregory, P. (2022b). Mineral composition and dietary contribution of root vegetables in starchy staple diets. *Food Research International*, 154, 111012.
57. Steiner-Asiedu, M. (2019). The nutrition landscape in Ghana: Implications on our human resources and national development.
58. Strazzullo, P., & Leclercq, C. (2014). Sodium. *Advances in nutrition*, 5(2), 188-190.
59. Takeda, E., Yamamoto, H., Nashiki, K., Sato, T., Arai, H., & Taketani, Y. (2012). Inorganic phosphate homeostasis and the role of dietary phosphorus. *Journal of Cellular and Molecular Medicine*, 16(9), 1939–1945.
60. Takeda, E., Yamamoto, H., Yamanaka-Okumura, H., & Taketani, Y. (2012). Dietary phosphorus in bone health and quality of life. *Nutrition reviews*, 70(6), 311-321.
61. Teye, E., Deha, C. I., Dadzie, R., & MacArthur, R. L. (2020). Delivering the nutritional needs by food to food fortification of staples using underutilized plant species in Africa. *International Journal of Food Science*, 2020(1), 8826693.
62. USDA FoodData Central. (2019). U.S. Department of Agriculture, Agricultural Research Service. <https://fdc.nal.usda.gov/>
63. WHO. (2024, March 1). Malnutrient. <https://www.who.int/news-room/fact-sheets/detail/malnutrition>
64. Younge, S., & Amoah, R. S. (2026). Addressing vitamin A deficiency in Ghana using orange-fleshed sweet potato as a food fortifier in composite flour development: a review. *Journal of the Science of Food and Agriculture*.
65. Zacchia, M., Abategiovanni, M. L., Stratigis, S., & Capasso, G. (2016). Potassium: from physiology to clinical implications. *Kidney Diseases*, 2(2), 72-79.