

Assessment of Nutritional Quality and Mineral Composition of Fortified Gari from Provitamin A Cassava, Bambara Nut, Dates, and Baobab Pulp during Storage

David T. Ishola¹, Mathew K. Bolade², Oluwole S. Ijarotimi³, Lateef O. Sanni¹, Damilola T. Ogundele⁴, and Opemipo T. Ishola⁵

¹Durable Crop Research Department, Nigerian Stored Products Research Institute Headquarters, Ilorin, Kwara State, Nigeria.

²Food Science and Technology Department, Federal University of Technology (FUTA), Akure, Ondo State, Nigeria.

³Nutrition and Dietetics Department, Federal University of Technology (FUTA), Akure, Ondo State, Nigeria.

⁴Department of Chemistry and Industrial Chemistry, Kwara State University, Malete, Ilorin, Nigeria

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CORRESPONDING AUTHOR

David T. Ishola

Durable Crop Research Department,
Nigerian Stored Products Research
Institute, Ilorin, Kwara State, Nigeria.
td.ishola21@gmail.com;
isholadt@nspri.gov.ng
+2348135445333

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Abstract

This study evaluated the nutritional impact of fortifying gari, a widely consumed cassava-based staple in West Africa, using Provitamin A-dense cassava (TMS-IKN130010) and nutrient-dense ingredients, Bambara nut flour, date powder, and baobab pulp flour. Fortified gari samples (FG1–FG6) were formulated in varying proportions, with FG7 serving as the control (100% cassava). Proximate and mineral compositions were analysed over a 3-month storage period to assess nutrient retention and stability. Results revealed that fortification significantly enhanced protein (11.55 g/100 g in FG3), crude fibre (12.38 g/100 g in FG5), and ash content (3.00 g/100 g in FG3) compared to the control. FG3 and FG6 exhibited superior mineral profiles, with elevated levels of phosphorus, potassium, calcium, and magnesium. Critical mineral-to-mineral ratios (Zn/Cu, Ca/Mg, Na/K, Fe/Zn) across all fortified samples remained within recommended thresholds for diabetes and cardiovascular risk management. Notably, FG4 and FG5 exhibited the most favourable ratios required for mitigating oxidative stress and enhancing insulin sensitivity. Storage trials demonstrated minimal degradation of protein and fat, with slight increases in energy content attributed to moisture loss and compositional concentration. These findings highlight the potential of nutrient fortification in transforming gari into a functional food that can address micronutrient deficiencies and metabolic health risks in sub-Saharan Africa. Further research into bioavailability, sensory attributes, and consumer acceptability is recommended to support large-scale adoption.

Keywords:

Cassava, Fortification, Functional food, Gari, Micronutrients

Introduction

Gari, a fermented and roasted granular flour derived from cassava (*Manihot esculenta* Crantz), is a staple food across West Africa, valued for its high carbohydrate content and energy yield. However, its limited protein, fibre, and micronutrient composition increases the risk of deficiencies among populations that depend heavily on it (Anyaiwe et al., 2024). Bio-fortification with nutrient-rich, locally available food sources has therefore emerged as a sustainable approach to enhance its nutritional quality (Hillocks et al., 2002). The introduction of provitamin A biofortified cassava, such as TMS-IKN130010, provides a foundation for addressing vitamin A deficiency (Ilona et al., 2017). Complementary fortificants, including Bambara nut (*Vigna subterranea*), baobab pulp flour (*Adansonia digitata*), and date powder, contribute protein, minerals, fibre, antioxidants, and bioactive compounds, alongside improved sensory attributes (Maphosa & Jideani, 2016; Kazeem et al., 2020; Baliga et al., 2011). This study examined the proximate composition, mineral content, mineral ratios, and storage stability of fortified gari, with implications for managing nutrition-related disorders, including diabetes and hypertension.

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Materials and Methods

Source of food materials and Authentication

Yellow flesh, provitamin-A laden-(IITA-TMS-IKN130010) Cassava tubers (*Manihot esculentus Crantz*) were identified, authenticated and purchased from International Institute of Tropical Agriculture (IITA), Ibadan. Bambara groundnut (*Vigna subterranea* (L.) Verdc.) was procured from Minna, Niger State, and processed into flour. Dried baobab fruit pulp (*Adansonia digitata* L.) was procured from Minna, Niger State and processed into flour. Dates fruit pulp (*Phoenix dactylifera* L.) was obtained from Yankaba market in Kano, Kano State, Nigeria. All other materials authentication was done at the

Department of Crop, Soil, and Pest Management, Federal University of Technology, Akure, Nigeria.

Sample Preparation

Cassava (TMS-IKN130010) was processed into gari using standard fermentation and roasting techniques, as described by Udoro et al. (2014) and Awoyale et al. (2021), with slight modifications. Fortified samples (FG1–FG6) were produced by introducing cooked oven-dried Bambara nut flour (BNF), baobab pulp flour (BPF), and dried date powder (DDP) in specified ratios into the cassava frying process at the point of garification. FG7 (100% cassava) served as the control. Figure 1 and Table 1.

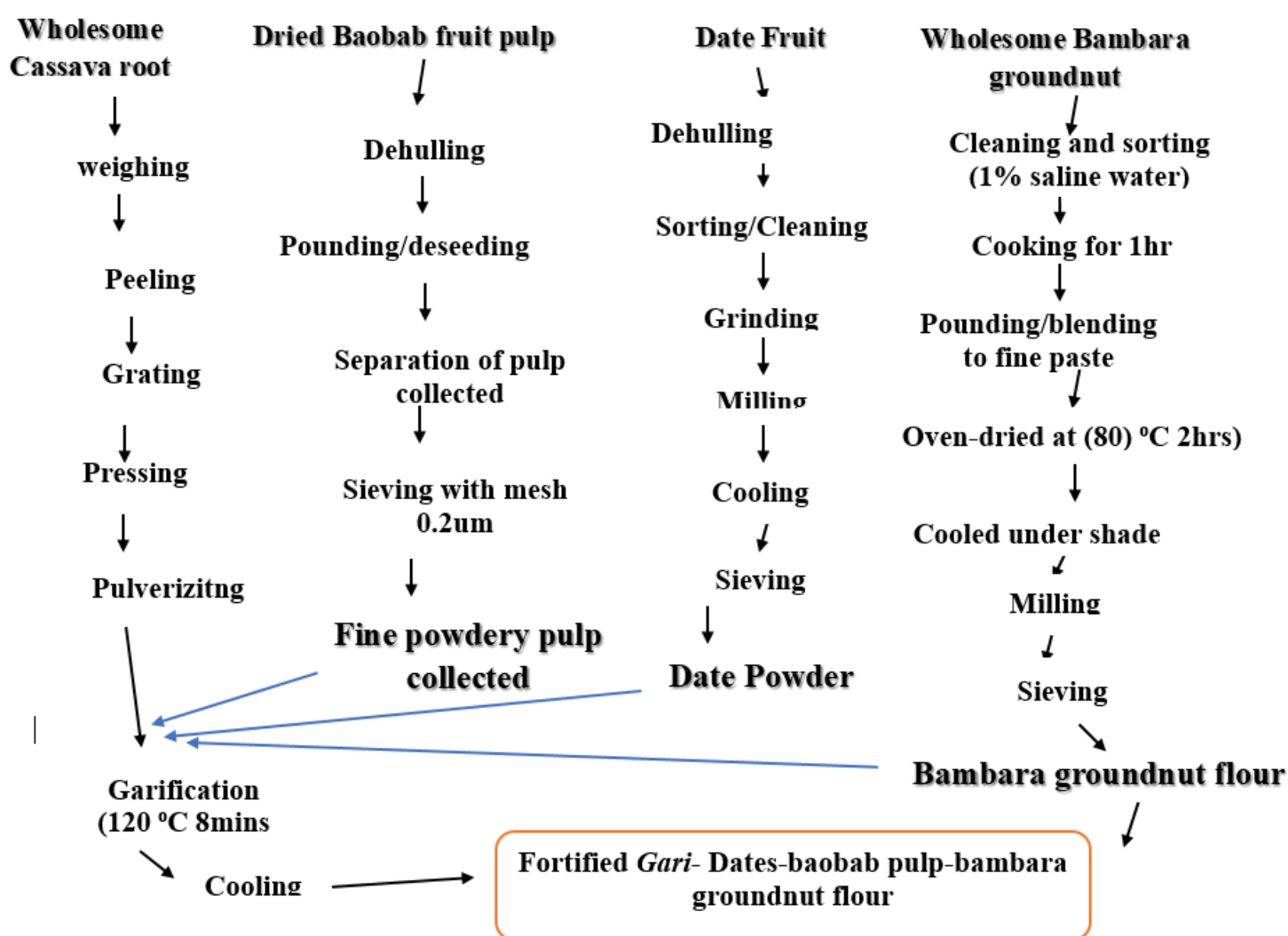


Figure 1: Flow chart for the production of Gari from Provitamin A-cassava-bambara groundnut -date powder-Baobab Pulp flour

Source: Udoro et al. (2014) and Awoyale et al. (2021) with slight modification

Table 1: The sample formulation of fortified *Gari* from provitamin A-dense (IITA-TMS-IKN130010) cassava, cooked oven-dried Bambara nut, Baobab pulp flour and Date powder for physical and chemical tests (blend ratios by weight).

SAMPLE	IITA-TMS-IKN130010 Cassava (KNCG)	Cooked Oven-dried Bambara Nut Flour (BNF)	Baobab Pulp Flour (BPF)	Dried Date powder (DDP)	TOTAL (%)
DDF	----	----	----	100	100
BNF	----	100	----	----	100
BPF	----	----	100	----	100
FG7	100	----	----	----	100
FG1	80.96	9.52	4.76	4.76	100
FG2	72	16.67	6.67	4.66	100
FG3	41.67	33.33	16.67	8.33	100
FG4	38.46	23.12	23.04	15.38	100
FG5	60.85	10.86	8.20	20.09	100
FG6	58.44	20.23	5.67	15.67	100

FG7-ITIKNCG-IITA-TMS-IKN130010 Cassava Gari (100%); BNF-Cooked Oven-dried Bambara Nut Flour (100%); BPF-Baobab Pulp Flour (100%); DDP-Dried Date powder (100%); FG1-Fortified Gari from ITIKNC, BNF, BPF, DDP at varying ratio of (80.96:9.52:4.76:4.76); FG2-Fortified Gari from ITIKNC, BNF, BPF, DDP at varying ratio of (72:16.67:6.67:4.66); FG3-Fortified Gari from ITIKNC, CODBNF, BPF, DDP at varying ratio of (41.67:33.33:16.67:8.33); FG4-Fortified Gari from ITIKNC, CODBNF, BPF, DDP at varying ratio of (38.46: 23.12: 23.12:23.04:15.34); FG5-Fortified Gari from ITIKNC, CODBNF, BPF, DDP at varying ratio of (60.85:10.86:8.20:20.09); FG6-Fortified Gari from ITIKNC, CODBNF, BPF, DDP at varying ratio of (58.44:20.23:5.67:15.67)

Methods

Proximate analysis

The proximate composition of the samples, including moisture, ash, crude protein, crude fibre, fat, and carbohydrate, was determined following standard procedures outlined by AOAC (2019). The energy content was subsequently calculated using the Atwater conversion factors. Carbohydrate content was estimated by difference, whereby the sum of the percentages of moisture, protein, ash, and fibre was subtracted from 100 to obtain the percentage of total carbohydrate.

$$\% \text{ Carbohydrate} = 100 - (\% \text{ protein} + \% \text{ fat} + \% \text{ fibre} + \% \text{ ash} + \% \text{ moisture})$$

Mineral analysis

The mineral contents were determined using atomic absorption spectrophotometry, as described in the AOAC (2019) method. Mineral content (P, K, Na, Ca, Mg, Cu, Fe, Se, Zn) was determined. Mineral-to-mineral molar ratios (Zn/Cu, Ca/Mg, Na/K, Fe/Zn) were calculated to evaluate health implications.

Storage study

The samples were packaged in LIP GLOSS anti-static re-sealable food storage bags and stored under ambient conditions, with temperatures ranging between 36.2 and 38 °C and relative humidity maintained at 65–67% for a period of three months. During this storage

period, the proximate composition (i.e., crude protein, ash, fat, moisture, and carbohydrate), energy value, and mineral content variations were systematically monitored to assess the compositional stability of the products.

Statistical analysis

Data were subjected to analysis of variance using SPSS (IBM version 20.0, SPSS Inc., Quarry Bay, and Hong Kong) and presented as means (\pm SD). Comparisons between different groups were done using Pearson correlation and New Duncan's Multiple Range F-Test (DMRT). Values of $p < 0.05$ were considered statistically significant as described by Yalta & Talha (2008).

Results and Discussion

Proximate composition and energy value of fortified gari

The proximate composition (g/100g) and energy value of *gari* fortified with Bambara Nut, Date Powder and Baobab Pulp Flour (wet weight basis) are presented in Table 2 and Table 3. The proximate parameters considered include moisture content, ash, protein, crude fibre, crude fat, and carbohydrate. The moisture content of the samples ranged from 5.53% (FG4) to 9.09% (FG3). The highest moisture content was observed in FG3 (9.09 %), while the lowest was recorded in FG4 (5.53%). The relatively high moisture

content of FG3 may be attributed to the presence of Bambara Nut, which tends to retain moisture. The moisture content of all the samples was below the recommended limit of 12% for safe storage of gari (SON, 2004; Codex Alimentarius, 2013), indicating their potential stability during storage. Ash content is an indicator of the total mineral content present in food products. The ash content of the samples varied from 1.49% (FG5) to 2.87% (FG4). The highest ash content recorded in FG4 (2.87 %) suggests a higher mineral contribution from the Baobab Pulp Flour. The lowest ash content in FG5 (1.49%) might be attributed to the reduced level of mineral-rich components in its formulation. The control sample (FG7) had an ash content of 2.3%, which was moderately higher compared to most of the other fortified samples, except FG4. This may be due to the matrix of pure cassava, which may lead to better combustion residue during proximate analysis, yielding slightly higher ash values compared to mixed matrices of fortified samples (Akinwande & Oyekan, 2021). Protein content ranged from 1.17% (FG7) to 11.48% (FG3). As expected, FG7 (the control sample made from 100% TMS-IKN130010 cassava) exhibited the lowest protein content (1.17%), while FG3, containing a higher proportion of Bambara Nut flour, displayed the highest protein content (11.48%). Bambara Nut is known for its high protein content, thereby significantly enhancing the protein levels of the fortified gari samples. The protein content of most fortified samples (FG1-FG6) was considerably higher than that of the

control, indicating the nutritional enhancement achieved by the inclusion of Bambara Nut (Olawuni & Ogunbanwo, 2023). Crude fibre content ranged from 3.69% (FG7) to 12.31% (FG5). FG5 had the highest crude fibre content (12.31%), likely due to the contribution of Baobab Pulp Flour, which is rich in dietary fibre. The low fibre content in FG7 (3.69%) is consistent with the fact that it is the control sample made solely from cassava. The increased crude fibre in fortified samples suggests their potential health benefits, particularly in improving bowel function and reducing the risk of certain chronic diseases (Slavin, 2013). The elevated fibre content observed in FG5 could be attributed to the inherently high fibre levels of the fortifying agents incorporated into the blend (Osman, 2011). The significant variation ($p < 0.05$) in fibre content across the samples indicates that fortification has a marked influence on the crude fibre composition of the final products. In terms of crude fat, the samples exhibited values ranging from 0.22% in FG6 to 0.67% in FG7. Notably, FG2 presented the highest crude fat concentration (2.02%), whereas FG6 contained the lowest (0.22%). The comparatively higher crude fat content in FG2 is likely a reflection of the natural oil contributions from the fortifying materials. The relatively low fat content in fortified samples (FG1-FG6) indicates their suitability for low-fat dietary formulations. The carbohydrate content of the samples ranged from 65.35% (FG3) to 79.75% (FG6). FG6 exhibited the highest carbohydrate content

Table 2: Proximate composition (g/100 g) of fortified gari from provitamin A-Dense (TMS-IKN130010) cassava with bambara nut, date powder and baobab pulp flour

Sample	Moisture	Ash	Protein	Crude fibre	Crude fat	Carbohydrate	Energy value (Kcal)
FG1	7.86 ± 0.24 ^c	2.46 ± 0.06 ^{de}	5.63 ± 0.01 ^e	9.93 ± 0.01 ^e	2.01 ± 0.09 ^f	72.11 ± 0.23 ^{bcd}	321.09 ± 0.70 ^a
FG2	6.23 ± 0.10 ^{def}	2.5 ± 0.03 ^d	9.46 ± 0.03 ^c	10.17 ± 0.03 ^d	2.02 ± 0.01 ^f	69.62 ± 0.09 ^{cde}	325.94 ± 1.23 ^c
FG3	9.09 ± 0.14 ^b	2.8 ± 0.08 ^c	11.48 ± 0.24 ^b	9.7 ± 0.01 ^f	1.58 ± 0.01 ^g	65.35 ± 0.36 ^e	318.94 ± 0.27 ^b
FG4	5.53 ± 0.04 ^f	2.87 ± 0.04 ^c	6.71 ± 0.01 ^d	10.7 ± 0.06 ^c	0.43 ± 0.01 ^h	73.86 ± 0.06 ^{abc}	320.53 ± 0.43 ^e
FG5	6.99 ± 0.05 ^d	1.49 ± 0.01 ^g	4.54 ± 0.01 ^g	12.31 ± 0.05 ^b	0.55 ± 0.03 ^b	68.13 ± 0.12 ^{cde}	336.06 ± 0.57 ^f
FG6	5.76 ± 0.03 ^f	1.81 ± 0.01 ^f	3.36 ± 0.01 ^h	9.1 ± 0.01 ^g	0.22 ± 0.01 ^h	79.75 ± 0.012 ^a	328.18 ± 0.22 ^g
FG7(Control)	6.85 ± 0.22 ^{de}	2.3 ± 0.047 ^{de}	1.17 ± 0.01 ⁱ	3.69 ± 0.01 ^j	0.67 ± 0.03 ^a	78.33 ± 0.175 ^{ab}	346.22 ± 0.19 ^{de}

¹Results are mean values of triplicate determination ± standard deviation. Mean values within the same column, denoted by the same letter, are not significantly different at $P < 0.05$. Keys: FG7-ITIKNCG-IITA-TMS-IKN130010 Cassava Gari (100%); BNF-Cooked Oven-dried Bambara Nut Flour (100%); BPF-Baobab Pulp Flour (100%); DDP-Dried Date powder (100%); FG1-Fortified Gari from ITIKNC, CODBNF, BPF, DDP at varying ratio of (80.96:9.52:4.76:4.76); FG2-Fortified Gari from ITIKNC, CODBNF, BPF, DDP at varying ratio of (72:16.67:6.67:4.66); FG3-Fortified Gari from ITIKNC, CODBNF, BPF, DDP at varying ratio of (41.67:33.33:16.67:8.33); FG4-Fortified Gari from ITIKNC, CODBNF, BPF, DDP at varying ratio of (38.46: 23.12; 23.12:23:04:15.34); FG5-Fortified Gari from ITIKNC, CODBNF, BPF, DDP at varying ratio of (60.85:10.86:8.20:20.09); FG6-Fortified Gari from ITIKNC, CODBNF, BPF, DDP at varying ratio of (58.44:20.23:5.67:15.67)

(79.75 ± 0.019%), while FG3 had the lowest (65.35 ± 0.358%). The higher carbohydrate content of FG6 suggests that the blend is predominantly composed of cassava, with minimal incorporation of other food materials used for the fortification process.

In contrast, FG3, with the highest protein content, had the lowest carbohydrate content, suggesting that protein-rich components, such as Bambara Nut, displace carbohydrates in the blend. The significant difference ($p < 0.05$) in carbohydrate content can be attributed to the varying proportions of protein, fibre, and fat contributed by the fortifying agents. FG6, which contained more Baobab Pulp Flour, had the highest carbohydrate content, possibly due to the high carbohydrate content of Baobab fruit pulp (Chadare et al., 2009). Protein content was negatively correlated with carbohydrate content ($r = -0.87$, $p < 0.05$), indicating that samples with higher protein content had lower carbohydrate values. Additionally, ash content showed a positive correlation with crude fibre ($r = 0.78$, $p < 0.05$), suggesting that mineral-rich samples also exhibited higher fibre content. Overall, the results indicate that fortification with Bambara Nut, Date Powder, and Baobab Pulp Flour significantly improved the nutritional quality of gari in terms of protein, ash, and fibre content while moderately affecting fat and carbohydrate levels. The findings agree with previous studies that fortification of staple foods with nutrient-rich sources enhances their

nutritional value (Chadare et al., 2009; Osman, 2011; Al-Jasass & Al-Jasser, 2012). The results of this study demonstrate that fortification of TMS-IKN130010 cassava with Bambara Nut, Date Powder, and Baobab Pulp Flours for the production of functional gari significantly improves the nutritional quality of the product. Notably, the addition of Bambara Nut flour contributed significantly to the protein content, while Baobab Pulp Flour enhanced the ash and crude fibre contents. The varying levels of moisture, crude fat, and carbohydrate content across the samples suggest that formulation adjustments can be tailored to achieve desired nutritional profiles. The control sample (FG7) consistently recorded the lowest values for protein and crude fibre, underscoring the benefits of fortification.

Effects of storage (90 days) on the proximate composition of fortified gari

The moisture content of the samples remained relatively stable over the storage period, with minimal variations. For instance, FG1 increased slightly from 7.86% to 7.88%, while FG3 and FG6 showed negligible changes. However, slight reductions were observed in FG2 (from 6.23% to 6.24%) and FG4 (from 5.53% to 5.55%). The stability of moisture content suggests that storage conditions were relatively controlled, which is crucial in preventing microbial growth and spoilage (Adepoju & Aworh, 2023).

Table 3: Proximate composition and energy value of Fortified Gari from Provitamin A-Dense (TMS-IKN130010) Cassava with Bambara Nut, Date Powder and Baobab Pulp Flour

Sample	Moisture	Ash	Protein	Crude fibre	Crude fat	Carbohydrate	Energy value (Kcal)
FG1	7.88 ± 0.24 ^c	2.50 ± 0.05 ^{de}	5.78 ± 0.01 ^e	9.97 ± 0.01 ^e	1.98 ± 0.08 ^f	71.89 ± 0.23 ^{bcd}	328.50 ± 0.70 ^a
FG2	6.24 ± 0.10 ^{def}	2.70 ± 0.04 ^d	9.44 ± 0.04 ^c	10.30 ± 0.03 ^d	1.99 ± 0.02 ^{ef}	69.33 ± 0.08 ^{cd}	332.99 ± 1.23 ^c
FG3	9.10 ± 0.14 ^b	3.00 ± 0.08 ^c	11.55 ± 0.24 ^b	9.83 ± 0.01 ^f	1.50 ± 0.01 ^g	65.02 ± 0.41 ^e	319.78 ± 0.27 ^b
FG4	5.55 ± 0.04 ^f	2.95 ± 0.04 ^c	6.70 ± 0.01 ^d	10.90 ± 0.06 ^c	0.42 ± 0.01 ^h	73.48 ± 0.05 ^{ac}	325.50 ± 0.43 ^e
FG5	7.00 ± 0.05 ^d	1.51 ± 0.01 ^g	4.30 ± 0.01 ^g	12.38 ± 0.05 ^b	0.50 ± 0.03 ^b	68.31 ± 0.16 ^{de}	348.94 ± 0.57 ^f
FG6	5.77 ± 0.03 ^f	1.80 ± 0.01 ^f	3.34 ± 0.01 ^h	9.44 ± 0.01 ^g	0.28 ± 0.01 ^h	79.35 ± 0.02 ^a	333.28 ± 0.22 ^g
FG7	6.85 ± 0.22 ^{de}	2.3 ± 0.047 ^{de}	1.17 ± 0.01 ⁱ	3.69 ± 0.01 ^j	0.67 ± 0.03 ^a	78.33 ± 0.18 ^{ab}	387.03 ± 0.19 ^{de}

¹Results are mean values of triplicate determination ± standard deviation. Mean values within the same column having the same letter are not significantly different at $P < 0.05$. Keys:- FG7-ITIKNCG-IITA-TMS-IKN130010 Cassava Gari (100%); BNF-Cooked Oven-dried Bambara Nut Flour (100%); BPF-Baobab Pulp Flour (100%); DDP-Dried Date powder (100%); FG1-Fortified Gari from ITIKNC, CODBNF, BPF, DDP at varying ratio of (80.96:9.52:4.76:4.76); FG2-Fortified Gari from ITIKNC, CODBNF, BPF, DDP at varying ratio of (72:16.67:6.67:4.66); FG3-Fortified Gari from ITIKNC, CODBNF, BPF, DDP at varying ratio of (41.67:33.33:16.67:8.33); FG4-Fortified Gari from ITIKNC, CODBNF, BPF, DDP at varying ratio of (38.46: 23.12; 23.12:23:04:15.34); FG5-Fortified Gari from ITIKNC, CODBNF, BPF, DDP at varying ratio of (60.85:10.86:8.20:20.09); FG6-Fortified Gari from ITIKNC, CODBNF, BPF, DDP at varying ratio of (58.44:20.23:5.67:15.67)

The overall stability of protein content suggests that protein degradation was not significant during storage. Crude fibre content exhibited slight increases in most samples, likely due to changes in structural carbohydrate integrity. For instance, FG1 increased from 9.93% to 9.97%, FG2 from 10.17% to 10.30%, and FG4 from 10.70% to 10.90%. These changes may be attributed to moisture loss, resulting in a relative concentration effect or minor modifications in fibre components (Abiodun et al., 2024). The crude fat content generally decreased slightly across most samples. FG1 reduced from 2.01% to 1.98%, FG3 from 1.58% to 1.50%, and FG6 from 0.22% to 0.22%. This reduction could indicate lipid oxidation, a common issue during storage, especially in products with unsaturated fats (Eke-Ejiofor & Fubara, 2023). However, FG7 remained stable at 0.67%, suggesting potential lipid stability in that formulation. A slight decrease in carbohydrate content was observed in some samples. For example, FG1 decreased from 72.11% to 71.89%, FG3 from 65.35% to 65.02%, and FG4 from 73.86% to 73.48%. These reductions may be linked to slight enzymatic activity or non-enzymatic browning reactions, such as Maillard reactions, that occur during storage (Oyetoro et al., 2024). The energy values of most samples increased slightly over the storage period. Notably, FG1 increased from 321.09 kcal to 328.50 kcal, FG5 from 336.06 kcal to 348.94 kcal, and FG7 from 346.22 kcal to 387.03 kcal. This increase may be due to relative compositional adjustments, moisture loss, and concentration effects (Amankwah et al., 2023). By implication, the Nutrient Stability during Storage postulates that the employed packaging material used for storing these products performed appreciably in enhancing moisture control and shelf life, as the stability of moisture content observed in all the formulated samples suggests minimal water absorption, which is beneficial in preventing microbial spoilage. These slight changes in moisture content could impact the textural properties of the fortified gari over time (Akande et al., 2024). Notably, the observed stability of protein and fat is also evident, as indicated by the minor reduction in protein content in the formulated samples, particularly in FG5, which suggests possible enzymatic degradation but is not severe. This is corroborated by the observed decrease in fat content, which also suggests lipid oxidation, which can impact sensory quality (rancidity) and nutrient retention (Eke-Ejiofor & Fubara, 2023). The observed carbohydrate and energy Stability was also impressive. Still, it is pertinent to note that the slight decrease in carbohydrate content indicates potential

enzymatic breakdown or Maillard reactions, and the observed increase in energy value suggests a possible concentration effect due to moisture loss (Oyetoro et al., 2024). Lastly, it's worth mentioning that the observed increase in ash content indicates good mineral retention, with possible minor concentration effects (Idowu et al., 2022). Overall, the proximate composition of the fortified gari samples remained relatively stable over three months of storage. While minor reductions in fat and protein content were observed, the increase in ash and energy values suggests good nutrient retention (Amarteifio et al., 2006). However, extended storage may lead to more pronounced oxidative and enzymatic changes, which should be monitored for long-term quality assurance (Amankwah et al., 2023). Hence, fortification significantly improved protein (1.17–11.55 g/100 g), crude fibre (3.69–12.38 g/100 g), and ash (1.49–3.00 g/100 g). FG3 had the highest protein and ash content, likely due to its higher Bambara nut content, while FG5 recorded the highest fibre content, likely due to the baobab pulp. In a nutshell, regarding the proximate composition evaluation, it is pertinent to note that storage Stability, evaluated and monitored for all the fortified Gari, revealed that minor nutrient shifts occurred during storage. Moisture remained below 12%, preserving shelf life. Slight increases in crude fibre and energy content were attributed to the loss of moisture. Minimal protein and fat degradation (lipid oxidation) was observed, with FG7 showing the highest lipid stability.

Mineral composition (mg/100 g) of fortified gari from provitamin A-Dense (TMS-IKN130010) cassava with Bambara nut, date powder and baobab pulp flour

The phosphorus content of the fortified gari samples ranged from 23.88 ± 0.26 mg/100 g (FG7) to 39.52 ± 0.42 mg/100 g (FG3) (Table 4). Phosphorus plays a critical role in bone mineralisation, energy metabolism, and cellular signalling (Haug et al., 2023). FG3 exhibited the highest phosphorus content, making it a valuable source for ATP synthesis and cellular functions. Adejumo et al. (2024) emphasised that phosphorus deficiency in cassava-based diets can contribute to impaired growth and metabolic disorders, suggesting that fortified gari variants, such as FG3 and FG6, could help improve phosphorus intake in local diets. Potassium is essential for maintaining electrolyte balance, muscle contractions, and blood pressure regulation. Hu et al. (2024) emphasised that potassium-rich diets reduce the risk of hypertension

Table 4: Effects of Bambara nut, baobab pulp and date flours on mineral composition (mg/100 g) of fortified gari

Sample	P	K	Na	Ca	Mg	Cu	Fe	Se	Zn
FG1	31.95 ± 0.34 ^c	1.77 ± 0.01 ^g	1.21 ± 0.10 ^f	1.88 ± 0.01 ^c	0.93 ± 0.00 ^d	0.06 ± 0.03 ^f	0.08 ± 0.02 ^f	0.01 ± 0.04 ^e	0.25 ± 0.02 ^c
FG2	31.20 ± 0.33 ^c	4.00 ± 0.01 ^b	2.82 ± 0.06 ^b	1.23 ± 0.02 ^d	0.73 ± 0.02 ^e	0.08 ± 0.02 ^c	0.11 ± 0.03 ^c	0.01 ± 0.30 ^c	0.28 ± 0.03 ^b
FG3	39.52 ± 0.42 ^a	4.23 ± 0.02 ^a	2.97 ± 0.03 ^a	2.61 ± 0.03 ^a	1.13 ± 0.02 ^b	0.05 ± 0.03 ^g	0.13 ± 0.03 ^a	0.01 ± 0.20 ^d	0.20 ± 0.01 ^d
FG4	35.23 ± 0.38 ^b	2.90 ± 0.01 ^e	1.96 ± 0.04 ^d	1.07 ± 0.06 ^e	0.68 ± 0.01 ^e	0.07 ± 0.01 ^e	0.07 ± 0.03 ^g	0.01 ± 0.40 ^b	0.30 ± 0.04 ^a
FG5	34.22 ± 0.37 ^b	2.51 ± 0.01 ^f	1.74 ± 0.06 ^e	1.10 ± 0.04 ^e	0.69 ± 0.01 ^e	0.09 ± 0.03 ^b	0.09 ± 0.04 ^d	0.01 ± 0.30 ^a	0.18 ± 0.02 ^e
FG6	32.21 ± 0.35 ^c	3.95 ± 0.03 ^c	2.68 ± 0.08 ^b	2.43 ± 0.02 ^b	1.23 ± 0.02 ^a	0.10 ± 0.04 ^a	0.11 ± 0.02 ^b	0.01 ± 0.30 ^b	0.26 ± 0.03 ^c
FG7	23.88 ± 0.26 ^d	3.31 ± 0.06 ^d	2.38 ± 0.02 ^c	1.91 ± 0.03 ^c	0.99 ± 0.01 ^c	0.08 ± 0.00 ^d	0.09 ± 0.03 ^e	0.01 ± 0.50 ^a	0.21 ± 0.04 ^d

¹Results are mean values of triplicate determination ± standard deviation. Mean values within the same column having the same letter are not significantly different at P < 0.05.

Keys: FG7-ITIKNCG-IITA-TMS-IKN130010 Cassava Gari (100%); BNF-Cooked Oven-dried Bambara Nut Flour (100%); BPF-Baobab Pulp Flour (100%); DDP-Dried Date powder (100%); FG1-Fortified Gari from ITIKNC, CODBNF, BPF, DDP at varying ratio of (80.96:9.52:4.76:4.76); FG2-Fortified Gari from ITIKNC, CODBNF, BPF, DDP at varying ratio of (72:16.67:6.67:4.66); FG3-Fortified Gari from ITIKNC, CODBNF, BPF, DDP at varying ratio of (41.67:33.33:16.67:8.33); FG4-Fortified Gari from ITIKNC, CODBNF, BPF, DDP at varying ratio of (38.46: 23.12; 23.12:23:04:15.34); FG5-Fortified Gari from ITIKNC, CODBNF, BPF, DDP at varying ratio of (60.85:10.86:8.20:20.09); FG6-Fortified Gari from ITIKNC, CODBNF, BPF, DDP at varying ratio of (58.44:20.23:5.67:15.67)

and improve insulin sensitivity. The potassium content in the fortified gari samples ranged from 1.77 ± 0.01 mg/100 g (FG1) to 4.23 ± 0.02 mg/100 g (FG3). FG3 and FG2 were the most potassium-rich samples, suggesting their potential benefits in reducing the risk of hypertension and cardiovascular diseases. A recent Nigerian study (Ogunmola & Adebayo, 2024) on traditional cassava-based diets emphasised the importance of potassium fortification in mitigating salt-induced hypertension, thereby further supporting the potential benefits of FG3 and FG2 in local dietary practices. Excess sodium intake is associated with an increased risk of hypertension and cardiovascular disease (Whelton et al., 2023). The sodium content varied across samples, with FG3 (2.97 ± 0.03 mg/100g) having the highest and FG5 (1.74 ± 0.06 mg/100g) the lowest. A lower Na/K ratio is recommended to enhance cardiovascular health (Hu et al., 2024). FG1 had the lowest K content (1.77 mg/100g) and a relatively high Na content (1.21 mg/100 g), indicating a less favourable Na/K balance. Conversely, FG3 had a higher K level, supporting a better Na/K ratio. A recent study in southwestern Nigeria (Afolayan et al., 2024) found that reducing the Na/K ratio in cassava-based meals significantly improved blood pressure levels in hypertensive patients, reinforcing

the potential health benefits of potassium-rich gari formulations, such as FG3. Calcium is essential for maintaining bone strength, neuromuscular function, and enzymatic activity. The highest calcium content was observed in FG3 (2.61 ± 0.03 mg/100g), followed by FG6 (2.43 ± 0.02 mg/100 g). The lowest values were found in FG4 (1.07 ± 0.06 mg/100g) and FG5 (1.10 ± 0.04 mg/100 g). The calcium levels in these fortified gari samples may help in preventing osteoporosis, particularly in populations with low dairy consumption (Rodriguez-Morán et al., 2024). Local research by Eze et al. (2024) confirmed that calcium fortification in traditional cassava-based foods significantly improved bone density in middle-aged women, supporting the benefits of calcium-rich gari variants such as FG3 and FG6. Magnesium is essential for glucose metabolism and insulin sensitivity (Volpe, 2023). Magnesium deficiency has been linked to an increased risk of type 2 diabetes. The magnesium content in the fortified gari samples ranged from 0.68 ± 0.006 mg/100g (FG4) to 1.23 ± 0.017 mg/100 g (FG6). FG6 and FG3, with the highest magnesium levels, may offer better support for glycemic control in diabetic patients. A recent study by Onuoha et al. (2024) highlighted that magnesium supplementation in traditional Nigerian diets significantly improved

glycemic control in diabetic patients, indicating that magnesium-rich gari variants may have similar benefits. Copper is a cofactor for antioxidant enzymes and plays a role in iron metabolism (Linder, 2024). FG6 (0.10 ± 0.04 mg/100 g) had the highest copper content, while FG3 (0.05 ± 0.03 mg/100 g) had the lowest. Copper deficiency has been linked to anaemia and oxidative stress (Adeyemi et al., 2024), suggesting that gari samples with higher copper levels may help enhance antioxidant activity and prevent oxidative stress-related diseases. Iron is a critical micronutrient involved in oxygen transport and the formation of haemoglobin. The iron content ranged from 0.07 ± 0.03 mg/100 g (FG4) to 0.13 ± 0.03 mg/100 g (FG3). FG3 had the highest iron content, suggesting a potential role in reducing iron deficiency anaemia, particularly in populations with high anaemia prevalence (WHO, 2023). Research conducted in Nigeria (Nwankwo et al., 2024) found that cassava-based iron fortification programs improved haemoglobin levels in anaemic children, reinforcing the nutritional value of iron-rich, fortified gari, such as FG3. Selenium is an essential trace element involved in immune function and antioxidant defence. The selenium content was relatively low across all samples but varied slightly, with FG7 (0.01 ± 0.50 mg/100 g) having the highest concentration. Selenium's antioxidant properties may contribute to reducing inflammation and metabolic disorders (Rayman et al., 2024). Zinc is essential for immune function, wound healing, and insulin metabolism. FG4 (0.30 ± 0.04 mg/100 g) contained the highest zinc level, while FG5 had the lowest (0.18 ± 0.02 mg/100 g). Adequate zinc

intake is essential for maintaining insulin function and reducing the risk of infections in individuals with diabetes (Prasad, 2023). A Nigerian study (Chukwuma & Adediran, 2024) found that zinc supplementation in cassava-based diets enhanced immune responses in malnourished children, reinforcing the benefits of zinc-rich, fortified gari formulations. The mineral composition of fortified gari samples (FG1–FG7) demonstrates significant variability, with FG3 and FG6 exhibiting the highest overall mineral content. These samples may be beneficial for individuals who require an enhanced mineral intake, particularly for managing hypertension, diabetes, osteoporosis, and anaemia. Recent local studies affirm that fortification strategies in cassava-based diets have improved micronutrient intake and health outcomes, making these fortified gari an important viable dietary intervention alternative.

Mineral to mineral ratios of fortified gari and their implications for diabetes and obesity management

Mineral-to-mineral ratio evaluation is a crucial aspect of nutritional and biomedical research, particularly in the management of chronic diseases. Certain mineral ratios play a crucial role in glucose metabolism, insulin function, and the regulation of oxidative stress. Below are the most commonly evaluated mineral ratios and their implications for diabetes: These mineral-to-mineral ratios are critical indicators of metabolic health, and maintaining optimal Zn: Cu, Ca: Mg, Na: K, Fe: Zn, and Cu: Mn ratios helps improve insulin sensitivity, glucose metabolism, and oxidative stress response (Table 5).

Table 5: Effects of Bambara Nut, Baobab Pulp and Date Flours on Mineral to Mineral Molar Ratio Indicators on the potency of the fortified Gari Samples

Sample	Zn/Cu	Ca/Mg	Na/K	Fe/Zn
FG1	4.20 ± 0.30^c	2.02 ± 0.02^a	0.68 ± 0.12^b	0.32 ± 0.01^c
FG2	3.50 ± 0.18^c	1.68 ± 0.01^b	0.71 ± 0.06^b	0.39 ± 0.02^d
FG3	4.00 ± 0.22^a	2.31 ± 0.02^a	0.70 ± 0.04^a	0.65 ± 0.03^a
FG4	4.29 ± 0.27^b	1.57 ± 0.03^d	0.68 ± 0.04^d	0.23 ± 0.06^e
FG5	2.00 ± 0.19^b	1.59 ± 0.03^f	0.69 ± 0.06^e	0.50 ± 0.04^e
FG6	2.60 ± 0.24^c	1.98 ± 0.04^c	0.68 ± 0.07^f	0.42 ± 0.02^b
FG7	2.63 ± 0.23^d	1.93 ± 0.06^d	0.72 ± 0.02^c	0.43 ± 0.03^c
Ref	>1	≤ 2.5	< 1	< 2.5

Means (\pm SD) with different superscripts in the same column are significantly different ($P < 0.05$). Keys: FG7-ITIKNCG-IITA-TMS-IKN130010 Cassava Gari (100%); BNF-Cooked Oven-dried Bambara Nut Flour (100%); BPF-Baobab Pulp Flour (100%); DDP-Dried Date powder (100%); FG1-Fortified Gari from ITIKNC, CODBNF, BPF, DDP at varying ratio of (80.96:9.52:4.76:4.76); FG2-Fortified Gari from ITIKNC, CODBNF, BPF, DDP at varying ratio of (72:16.67:6.67:4.66); FG3-Fortified Gari from ITIKNC, CODBNF, BPF, DDP at varying ratio of (41.67:33.33:16.67:8.33); FG4-Fortified Gari from ITIKNC, CODBNF, BPF, DDP at varying ratio of (38.46: 23.12; 23.12:23:04:15.34); FG5-Fortified Gari from ITIKNC, CODBNF, BPF, DDP at varying ratio of (60.85:10.86:8.20:20.09); FG6-Fortified Gari from ITIKNC, CODBNF, BPF, DDP at varying ratio of (58.44:20.23:5.67:15.67) Note: [$Ca/Mg \leq 2.5$ (Rodriguez-Morán et al. (2024))]; [$Zn/Cu > 1$ (Prasad (2023))]; [$Na/K < 1$ (Hu et al. (2024))]; [$Fe:Zn < 2.5$ (Fernández-Real et al. (2023))]

Zinc-to-copper (Zn/Cu) ratio

The Zn/Cu ratio plays a crucial role in regulating oxidative stress and immune function. According to Prasad (2023), people with diabetes often exhibit a Zn/Cu ratio of less than 1, which contributes to increased oxidative stress and worsened glycemic control. The reference value for an adequate Zn/Cu ratio is greater than 1. In the present study, as revealed in Table 5, all fortified gari samples (FG1–FG7) exhibited Zn/Cu ratios significantly above the reference threshold of >1 , ranging from 2.00 ± 0.19 (FG5) to 4.29 ± 0.27 (FG4). This suggests that these samples provide a favourable Zn/Cu balance for mitigating oxidative stress in diabetic patients. Specifically, FG4 (4.29 ± 0.27) and FG1 (4.20 ± 0.30) had the highest Zn/Cu values, which could be particularly beneficial in preventing oxidative damage and enhancing antioxidant enzyme activity.

Calcium-to-magnesium (Ca/Mg) ratio

The Ca/Mg ratio is crucial in glucose metabolism and insulin sensitivity. Rodriguez-Morán et al. (2024) reported that a Ca/Mg ratio exceeding three is associated with a higher risk of type 2 diabetes. The reference range for an optimal Ca/Mg ratio is ≤ 2.5 . In this study, all fortified gari samples had Ca/Mg ratios within the recommended range (≤ 2.5), except FG3 (2.31 ± 0.02) and FG1 (2.02 ± 0.02), which were at the upper limit but still within the acceptable threshold (Table 5). The lowest Ca/Mg values were observed in FG4 (1.57 ± 0.03) and FG5 (1.59 ± 0.03), suggesting that these samples may offer better magnesium availability, which could improve insulin sensitivity and reduce the risk of diabetes.

Sodium-to-potassium (Na/K) ratio

The Na/K ratio is a critical factor in blood pressure regulation, insulin sensitivity, and overall cardiovascular health. According to Hu et al. (2024), lowering the Na/K ratio below 0.9 improves insulin sensitivity and reduces the risk of hypertension in diabetic patients. The reference threshold for a healthy Na/K ratio is <1 . All fortified gari samples in this study exhibited Na/K ratios well below the reference threshold (<1), ranging from 0.68 ± 0.04 (FG4) to 0.72 ± 0.02 (FG7). This suggests that these formulations are suitable for individuals with diabetes and hypertension, as they promote a favourable balance of sodium and potassium to support blood pressure control and glucose metabolism.

Iron-to-zinc (Fe/Zn) ratio

The Fe/Zn ratio is crucial for managing oxidative stress and maintaining glycemic control. Fernández-Real et al. (2023) found that individuals with diabetes often have Fe/Zn ratios exceeding 3, contributing to oxidative stress and worsening metabolic outcomes. The recommended reference value is <2.5 . All fortified gari samples had Fe/Zn ratios well below the critical threshold (<2.5), with values ranging from 0.23 ± 0.06 (FG4) to 0.65 ± 0.03 (FG3). FG4 had the lowest Fe/Zn ratio, suggesting a reduced risk of oxidative stress-related complications in diabetic individuals. FG3 (0.65 ± 0.03) had the highest Fe/Zn value among the samples, but it was still well within the recommended range, indicating suitability for consumption. Based on a comparative analysis of mineral-to-mineral molar ratios, the fortified gari samples (FG1–FG7) meet or exceed the recommended thresholds for managing diabetes and obesity. The Zn/Cu and Fe/Zn ratios indicate a reduced risk of oxidative stress, while the Ca/Mg and Na/K ratios support insulin sensitivity and cardiovascular health (Table 5). FG4 and FG5 demonstrated the most favourable mineral balance for diabetic patients, due to their optimal Ca/Mg and Fe/Zn ratios. FG1 and FG3 also performed well but were at the upper limits of some thresholds. These findings suggest that the fortified gari samples are suitable for inclusion in dietary management strategies for individuals with diabetes and obesity, promoting metabolic health and reducing the risk of associated complications. Notably, fortification was observed to significantly increase the levels of key minerals. FG3 and FG6 were richest in phosphorus, calcium, potassium, and magnesium. All samples exhibited favourable Zn/Cu (>1), Ca/Mg (≤ 2.5), Na/K (<1), and Fe/Zn (<2.5) ratios, critical for managing oxidative stress, insulin resistance, and blood pressure. FG4 and FG5 demonstrated the most balanced mineral profiles, indicating potential for effective management of diabetes and obesity.

Conclusion

The fortification of *gari* with Bambara nut, date powder, and baobab pulp flour effectively enhances its nutritional value, particularly in terms of protein, crude fibre, and essential minerals, while maintaining a low fat content and stable storage characteristics. Mineral-to-mineral ratios revealed the potential application of fortified *gari* as a functional food for managing metabolic disorders, such as diabetes and hypertension. FG3 and FG5, in particular, show promise as therapeutic dietary alternatives. These

findings highlight the potential of nutrient fortification in transforming gari into a functional food that can address micronutrient deficiencies and metabolic health risks in sub-Saharan Africa.

Recommendation

Further research into bioavailability, sensory attributes, long-term health impacts, and consumer acceptability is recommended to support large-scale adoption.

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