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DOI: https://doi.org/10.64388/IREV10I2-1722655

Effect of Okra Mucilage Incorporation on the Physico-Chemical and Baking Properties of Wheat–Bambara Groundnut Composite Flour and Bread Quality

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Abstract-** The over-dependence of the Nigerian baking industry on imported wheat, together with the limited nutritional density of refined-wheat bread, has intensified interest in composite flour technologies that combine wheat with indigenous, protein-rich legumes. This study evaluated the effect of partial replacement of wheat flour with Bambara groundnut (Vigna subterranea) flour, together with graded levels of okra (Abelmoschus esculentus) mucilage, on the functional properties of composite flours and on the physical, proximate and sensory qualities of the resulting bread. Composite flours were formulated at wheat:Bambara groundnut ratios of 100:0, 70:30 and 50:50, each incorporated with okra mucilage at 0, 5, 10 and 15%, giving twelve formulations arranged in a 3 × 4 factorial design. Bambara groundnut flour and okra mucilage were produced separately and blended with wheat flour prior to bread making; all data were analysed by one-way ANOVA ($P \leq 0.05$). Bambara groundnut and okra mucilage inclusion significantly ($P < 0.05$) improved the functional indices of the composite flour: swelling capacity rose from 9.52 to 11.09%, water absorption capacity from 164.80 to 186.73%, and oil absorption capacity from 108.0 to 158.0%, while bulk density fell from 0.62 to 0.40 g/mL. Loaf weight increased with Bambara groundnut level (111.11–125.90 g), whereas loaf volume and specific volume were generally reduced by gluten dilution, although the 40:50:10 (wheat:Bambara groundnut:okra mucilage) blend produced the highest loaf volume (618.53 cm³). Proximate analysis showed increases in protein (9.04–11.20%), ash (1.57–2.18%) and crude fibre (2.92–4.21%) content, accompanied by a corresponding fall in carbohydrate content (61.19–51.59%). Sensory evaluation, however, showed that acceptability declined once okra mucilage exceeded 5%, owing to a beany flavour and darker colour; the 50:50:0 and 95:0:5 samples were the most preferred among the composites, while the 100% wheat control remained the reference standard. Overall, moderate substitution (up to 50% Bambara groundnut flour with ≤5% okra mucilage) offers a technologically feasible and nutritionally superior alternative to conventional wheat bread, supporting the utilisation of underexploited indigenous crops to reduce wheat importation and mitigate protein–energy malnutrition in Nigeria.

***Keywords:** Bambara groundnut, okra mucilage, composite flour, bread quality and hydrocolloid*

I. INTRODUCTION

Bread is one of the most widely consumed fermented bakery products globally, conventionally prepared from wheat (Triticum aestivum) flour, water, yeast and salt through mixing, fermentation and thermal processing (Sivam et al., 2022). As a staple food, it supplies a substantial share of the daily carbohydrate, protein and mineral intake of populations in both developed and developing countries (He et al., 2021), and in Nigeria it has moved from an occasional luxury to a daily necessity owing to its convenience and affordability (Ocheme et al., 2020).

The functionality of wheat in bread making is underpinned by its glutenin and gliadin fractions, which associate to form a viscoelastic gluten network capable of retaining the carbon dioxide generated during fermentation and thereby producing an aerated crumb (Shewry and Hey, 2021). Nigeria, however, is not agro-ecologically suited to large-scale wheat cultivation, so virtually all wheat used in the domestic baking industry is imported, exposing the sector to foreign-exchange volatility and supply-chain risk (Nwadike et al., 2021). In addition, the extensive refining that wheat undergoes strips much of the grain's fibre and phytonutrients, so that a food consumed daily by millions of Nigerians is comparatively nutrient-poor (Bordoloi et al., 2022). These pressures, reinforced by the growing prevalence of gluten-related disorders (Catassi et al., 2022), have directed research attention toward composite-flour technology, in which part of the wheat flour is replaced with flour from indigenous, non-wheat crops.

Bambara groundnut (Vigna subterranea (L.) Verdc.) is a drought-tolerant, climate-resilient indigenous legume valued for its balanced amino acid profile, notably lysine and methionine, and its appreciable iron and zinc content (Oyeyinka and Singh, 2021). Its incorporation into wheat-based products has repeatedly been shown to raise protein, fibre and mineral density (Mubaiwa et al., 2018). However, because Bambara groundnut flour is gluten-free, its inclusion dilutes the wheat gluten network, weakening dough elasticity and gas-retention capacity, and typically reducing loaf volume once substitution exceeds about 30% (Tufaro et al., 2022; Onimawo et al., 2016).

Plant-derived hydrocolloids offer one route to offset this loss of functionality. Okra (Abelmoschus esculentus) pods contain an abundant, easily extractable polysaccharide mucilage (Sengkhamparn et al., 2021) that, when incorporated into gluten-reduced or composite dough systems, can mimic some gluten functions by increasing water-binding capacity, stabilising gas cells during proofing and slowing staling (Rosell et al., 2009; Aman and Williamson, 2010; Tufaro et al., 2022). As a widely cultivated, low-cost Nigerian vegetable, okra mucilage represents a locally sourced alternative to synthetic hydrocolloids such as xanthan gum or carboxymethylcellulose. Nevertheless, the combined effect of graded Bambara groundnut substitution and okra mucilage addition on the full spectrum of functional, physical, proximate and sensory attributes of composite bread has not been comprehensively documented for Nigerian raw materials and processing conditions. The present study therefore quantified the effect of wheat replacement with Bambara groundnut flour (0, 30 and 50%) combined with okra mucilage (0, 5, 10 and 15%) on the functional properties of the resulting composite flour and on the physico-chemical, nutritional and sensory quality of the bread produced from it, with a view to identifying formulations that balance nutritional enhancement with consumer acceptability.

II. MATERIALS AND METHODS

2.1 Source of raw materials

Wheat flour, Bambara groundnut (Vigna subterranea) seed and okra (Abelmoschus esculentus) pods, together with granulated sugar, baker's yeast, margarine, milk, nutmeg and vanilla flavour, were purchased from Eke Awka market, Awka, Anambra State, Nigeria.

2.2 Preparation of Bambara groundnut flour

Bambara groundnut seeds (2 kg) were sorted, washed, boiled at 100 °C for 5 min to inactivate anti-nutritional factors, dehulled, oven-dried at 60 °C, milled with an attrition mill (Model 594), sieved through a 180 µm mesh, and packaged as Bambara groundnut flour.

2.3 Preparation of okra mucilage flour

Fresh okra pods were washed, topped and sliced to 2 mm thickness, then soaked in water at a pod-to-water ratio of 1:3 (w/v) for 12 h to extract the mucilage. The aqueous mucilage extract was blended with 5% corn starch (w/v), oven-dried at 60 °C for 6 h, and the dried okra–starch blend was pulverised to a particle size of 0.2 mm to give okra mucilage flour.

2.4 Formulation of composite flour

A 3 × 4 factorial design was used to formulate the composite flours, combining three wheat:Bambara groundnut flour ratios (100:0, 70:30 and 50:50) with four levels of okra mucilage (0, 5, 10 and 15%), giving twelve treatments (Table 1).

Table 1. Flour-blend formulations

Sample code	Wheat (%)	Bambara groundnut (%)	Okra mucilage (%)
WBO_0 (control)	100	0	0
WBO_1	95	0	5

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DOI: https://doi.org/10.64388/IREV10I2-1722655

Sample code	Wheat (%)	Bambara groundnut (%)	Okra mucilage (%)
WBO_2	90	0	10
WBO_3	85	0	15
WB_1O	70	30	0
WB_2O	65	30	5
WB_3O	60	30	10
WB_4O	55	30	15
W_1BO	50	50	0
W_2BO	45	50	5
W_3BO	40	50	10
W_4BO	35	50	15

2.5 Bread production

Bread was produced following the straight-dough method of Olusanya (2008), with slight modification. Composite flour (600 g) was combined with okra mucilage (0–15%, as per formulation), sugar (100 g), margarine (120 g), egg (50 g), salt (0.5 g), instant baker's yeast (2 g), vanilla flavour (2 g) and water (250 mL). Ingredients were mixed to a homogeneous dough, moulded, panned and proofed at 32 °C, then baked at 180 °C for 40 min in an electric oven (Astell Hearson, England, Model 648). Loaves were depanned, cooled at ambient temperature (26 °C) and packaged for analysis.

2.6 Functional properties of composite flour

Bulk density, water absorption capacity (WAC), oil absorption capacity (OAC) and swelling capacity were determined by the methods of Onwuka (2005).

2.7 Physical properties of bread

Loaf weight was determined by weighing balance; loaf volume was determined by rapeseed/millet-seed displacement, and specific loaf volume was calculated as the ratio of loaf volume to loaf weight.

2.8 Proximate composition

Moisture, ash, crude fat, crude fibre and crude protein ($N \times 6.25$) were determined according to AOAC (2010) standard methods, and carbohydrate was calculated by difference.

2.9 Sensory evaluation

Thirty semi-trained panellists drawn from staff and students of the Department of Food Science and Technology, Nnamdi Azikiwe University, Awka, evaluated coded bread samples for appearance, mouthfeel, taste, aroma, texture and general acceptability using a 9-point hedonic scale (1 = dislike extremely, 9 = like extremely), with water provided for palate cleansing between samples (Iwe et al., 2014).

2.10 Statistical analysis

Data were analysed by one-way analysis of variance (ANOVA) using SPSS version 23. Significant means were separated using Least Significant Difference (LSD) at the 5% probability level ($P \leq 0.05$). All determinations were conducted in triplicate (sensory data: n = 30) and results are reported as mean ± standard deviation.

III. RESULTS AND DISCUSSION

3.1 Functional properties of the composite flour

The functional properties of the wheat–Bambara groundnut–okra mucilage composite flours are presented in Table 2. Bulk density decreased significantly ($P < 0.05$) from 0.62 g/mL in the 100% wheat control to as low as 0.40 g/mL in the 45:50:5 blend, reflecting the looser, less compact packing typical of legume-enriched flours; this has implications for packaging and transport, since a lower bulk density means a greater volume is required to package an equivalent mass of product. Swelling capacity rose progressively with Bambara groundnut and okra mucilage inclusion, from 9.52% in the control to 11.09% in the 35:50:15 blend, consistent with the higher starch–protein interaction reported for legume-fortified flours (Aprianita et al., 2009). Water absorption capacity increased from 164.80% (control) to a maximum of 186.73% in the 50:50:0 blend, an improvement attributable to the

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DOI: https://doi.org/10.64388/IREV10I2-1722655

greater density of hydrophilic protein and polysaccharide groups contributed by Bambara groundnut and okra mucilage (Oladipo and Nwokocha, 2011); values obtained here exceeded those previously reported for cassava–Bambara groundnut flour blends (Olapade et al., 2014). Oil absorption capacity likewise rose significantly, from 108.0% in the control to a peak of 158.0% in the 45:50:5 blend, consistent with the greater proportion of non-polar amino-acid side chains available for lipid binding as Bambara groundnut protein content increased (Leach et al., 2019).

Table 2. Functional properties of wheat–Bambara groundnut–okra mucilage composite flour

Sample	W:B:O	Bulk density (g/mL)	Swelling (%)	WAC (%)	OAC (%)
WBO_0	100:0:0	0.62 ± 0.03	9.52 ± 0.08	164.80 ± 2.40	108.00 ± 0.40
WBO_1	95:0:5	0.54 ± 0.01	9.52 ± 0.49	173.10 ± 1.31	115.50 ± 0.44
WBO_2	90:0:10	0.54 ± 0.02	9.95 ± 0.08	172.46 ± 0.34	117.71 ± 0.10
WBO_3	85:0:15	0.57 ± 0.00	9.93 ± 0.12	166.00 ± 2.00	112.40 ± 0.04
WB_1O	70:30:0	0.45 ± 0.00	10.70 ± 0.00	170.23 ± 0.40	142.90 ± 0.11
WB_2O	65:30:5	0.46 ± 0.00	10.73 ± 0.04	170.90 ± 0.14	144.10 ± 0.23
WB_3O	60:30:10	0.47 ± 0.00	10.00 ± 0.00	168.75 ± 4.12	112.60 ± 0.12
WB_4O	55:30:15	0.44 ± 0.00	10.71 ± 0.01	170.66 ± 1.15	142.80 ± 0.05
W_1BO	50:50:0	0.44 ± 0.02	11.03 ± 0.15	186.73 ± 0.46	154.30 ± 0.37
W_2BO	45:50:5	0.40 ± 0.01	10.92 ± 0.01	181.11 ± 0.63	158.00 ± 0.90
W_3BO	40:50:10	0.45 ± 0.00	11.06 ± 0.06	186.00 ± 1.73	152.80 ± 0.01
W_4BO	35:50:15	0.45 ± 0.01	11.09 ± 0.11	181.39 ± 2.25	154.50 ± 0.10

Values are means ± SD of triplicate determinations ($P < 0.05$). W:B:O = wheat:Bambara groundnut:okra mucilage.

3.2 Physical properties of the bread

Loaf weight, loaf volume and specific loaf volume are presented in Table 3. Loaf weight increased significantly ($P < 0.05$) with Bambara groundnut inclusion, from 111.11 g in the control to 125.90 g in the 35:50:15 blend, consistent with greater water retention and reduced gas retention in the more heavily substituted doughs, which yields a heavier, denser loaf (Shittu et al., 2007). Loaf volume and specific loaf volume, in contrast, generally declined as Bambara groundnut substitution rose from 30 to 50%, reflecting progressive dilution of the wheat gluten network and consequent loss of gas-holding capacity during proofing and oven-rise (Mepba et al., 2007); nonetheless, the 40:50:10 formulation produced the single highest loaf volume recorded (618.53 cm³), suggesting that okra mucilage at the 10% level can partially restore gas-cell stability even at high legume substitution.

Table 3. Physical properties of wheat–Bambara groundnut–okra mucilage bread

Sample	W:B:O	Weight (g)	Loaf volume (cm³)	Specific loaf volume (cm³/g)
WBO_0	100:0:0	111.11 ± 0.11	469.03 ± 0.04	4.47 ± 0.03
WBO_1	95:0:5	114.03 ± 0.95	544.37 ± 0.03	4.77 ± 0.25
WBO_2	90:0:10	114.50 ± 0.50	530.76 ± 0.05	4.64 ± 0.01
WBO_3	85:0:15	112.17 ± 0.29	578.03 ± 0.04	5.15 ± 0.06
WB_1O	70:30:0	113.90 ± 0.10	521.18 ± 0.17	4.58 ± 0.05
WB_2O	65:30:5	116.90 ± 0.10	575.97 ± 0.03	4.93 ± 0.59
WB_3O	60:30:10	114.50 ± 0.10	544.34 ± 0.05	4.75 ± 0.02
WB_4O	55:30:15	114.27 ± 0.23	544.37 ± 0.01	4.76 ± 0.06
W_1BO	50:50:0	122.07 ± 0.06	575.25 ± 0.04	4.71 ± 0.01
W_2BO	45:50:5	125.00 ± 1.00	544.40 ± 0.07	4.33 ± 0.02

Sample	W:B:O	Weight (g)	Loaf volume (cm³)	Specific loaf volume (cm³/g)
W_3BO	40:50:10	125.70 ± 0.20	618.53 ± 0.05	4.92 ± 0.02
W_4BO	35:50:15	125.90 ± 0.20	575.97 ± 0.02	4.57 ± 0.10

Values are means ± SD of triplicate determinations ($P < 0.05$).

3.3 Proximate composition of the bread

The proximate composition of the composite breads is shown in Table 4. Moisture content rose from 24.03% in the control to 30.19% in the 35:50:15 sample, reflecting the higher water-binding capacity conferred by Bambara groundnut and okra mucilage; this is a factor that will need to be balanced against shelf-life considerations, given the established relationship between moisture content and microbial spoilage risk (Basman and Köksel, 2023). Ash content, an index of the mineral density of the flour, increased from 1.57% to 2.18% with increasing composite substitution, corroborating the higher inherent mineral content of Bambara groundnut and okra mucilage relative to wheat flour. Crude fat content rose from 1.10% in the control to a maximum of 1.56% in the most heavily substituted samples, consistent with reports that Bambara groundnut supplementation raises the fat content of baked products (Ndife et al., 2018). Crude fibre increased from 2.92% to 4.21%, values that place the composite breads within the range recognised as beneficial for digestive health and glycaemic control (Slavin, 2017; Trinidad et al., 2015). Crude protein rose from 9.04% in the control to a peak of 11.20% in the 40:50:10 formulation, an improvement of practical significance in a country such as Nigeria where protein–energy malnutrition remains prevalent (Okpala and Okoli, 2011), and broadly consistent with the 8.75–24.65% protein increases reported for wheat–Bambara composite breads by Ndife et al. (2016). As expected from the dilution of the starch-dense wheat fraction, carbohydrate content fell from 61.19% in the control to 51.59% in the most heavily substituted sample, although residual carbohydrate levels remained sufficient to support the “protein-sparing” role of dietary energy (Butt and Batool, 2020).

Table 4. Proximate composition (%) of wheat–Bambara groundnut–okra mucilage bread

Sample	W:B:O	Moisture	Ash	Fat	Fibre	Protein	Carbohydrate
WBO_0	100:0:0	24.03 ± 0.06	1.57 ± 0.04	1.10 ± 0.00	2.92 ± 0.03	9.04 ± 0.03	61.19 ± 0.02
WBO_1	95:0:5	24.23 ± 0.05	1.90 ± 0.03	1.24 ± 0.04	3.08 ± 0.08	9.62 ± 0.14	60.28 ± 0.28
WBO_2	90:0:10	24.36 ± 0.43	1.92 ± 0.02	1.15 ± 0.16	3.33 ± 0.25	9.57 ± 0.11	60.42 ± 0.70
WBO_3	85:0:15	24.05 ± 0.16	1.90 ± 0.03	1.27 ± 0.07	3.03 ± 0.06	9.62 ± 0.11	60.41 ± 0.70
WB_1O	70:30:0	28.20 ± 0.19	2.24 ± 0.21	1.52 ± 0.03	3.91 ± 0.02	10.20 ± 0.09	52.47 ± 0.03
WB_2O	65:30:5	28.29 ± 0.40	1.76 ± 0.14	1.43 ± 0.08	2.89 ± 0.06	11.10 ± 0.07	54.98 ± 0.55
WB_3O	60:30:10	28.72 ± 0.19	1.95 ± 0.01	1.49 ± 0.03	3.08 ± 0.05	10.20 ± 0.24	54.70 ± 0.28
WB_4O	55:30:15	28.71 ± 0.20	1.96 ± 0.01	1.50 ± 0.02	3.05 ± 0.06	10.10 ± 0.18	57.71 ± 0.36
W_1BO	50:50:0	29.17 ± 0.21	1.64 ± 0.03	1.56 ± 0.03	2.97 ± 0.03	11.10 ± 0.13	59.09 ± 0.61
W_2BO	45:50:5	29.93 ± 0.10	2.08 ± 0.04	1.51 ± 0.02	4.17 ± 0.07	10.30 ± 0.06	52.44 ± 0.50
W_3BO	40:50:10	29.38 ± 0.11	1.69 ± 0.02	1.52 ± 0.02	2.95 ± 0.01	11.20 ± 0.10	53.29 ± 0.03
W_4BO	35:50:15	30.19 ± 0.17	2.18 ± 0.02	1.56 ± 0.03	4.21 ± 0.05	10.26 ± 0.06	51.59 ± 0.26

Values are means ± SD of triplicate determinations ($P < 0.05$).

3.6 Sensory properties of the bread

Sensory scores for appearance, mouthfeel, taste, aroma, texture and general acceptability are presented in Table 7. All sensory attributes differed significantly ($P < 0.05$) among samples. The 50:50:0 sample (W_1BO) recorded the highest general acceptability score (6.55), followed by the 95:0:5 sample (WBO_1, 6.35); the 100% wheat control scored 5.85. Bambara groundnut substitution up to 50%, in the absence of okra mucilage, therefore produced

DOI: https://doi.org/10.64388/IREV10I2-1722655

bread that was at least as acceptable as the control, but increasing okra mucilage beyond 5% consistently depressed taste, aroma and general-acceptability scores, with the 15%-mucilage samples (WBO_3, WB_4O and W_4BO) recording the lowest scores. This decline is attributable to the characteristic mucilaginous mouthfeel and mild beany flavour that intensify at higher inclusion levels, a pattern consistent with the findings of Arise et al. (2022) for Bambara groundnut–okra composite breads.

Table 7. Sensory scores (9-point hedonic scale) of wheat–Bambara groundnut–okra mucilage bread

Sample	W:B:O	Appearance	Mouthfeel	Taste	Aroma	Texture	General acceptability
WBO_0	100:0:0	6.40 ± 1.27	6.35 ± 1.22	5.40 ± 1.69	5.65 ± 1.49	6.30 ± 1.17	5.85 ± 1.66
WBO_1	95:0:5	6.75 ± 1.25	6.75 ± 1.25	5.85 ± 1.95	5.65 ± 1.81	6.40 ± 1.09	6.35 ± 1.69
WBO_2	90:0:10	6.20 ± 1.50	5.95 ± 1.60	5.10 ± 1.25	5.35 ± 1.13	6.45 ± 0.99	5.65 ± 1.42
WBO_3	85:0:15	6.45 ± 1.76	6.45 ± 1.79	3.85 ± 0.75	5.25 ± 1.91	5.60 ± 1.78	4.75 ± 1.80
WB_1O	70:30:0	6.15 ± 1.30	6.15 ± 1.30	4.15 ± 1.84	5.05 ± 1.53	5.65 ± 1.53	4.90 ± 1.65
WB_2O	65:30:5	6.85 ± 1.08	6.85 ± 1.08	4.10 ± 1.65	4.70 ± 1.41	6.55 ± 1.09	5.25 ± 1.20
WB_3O	60:30:10	6.75 ± 1.25	6.75 ± 1.25	5.90 ± 1.94	5.60 ± 1.84	5.50 ± 1.43	6.15 ± 1.63
WB_4O	55:30:15	6.75 ± 1.25	6.75 ± 1.25	5.85 ± 1.95	5.65 ± 1.81	6.40 ± 1.09	6.10 ± 1.65
W_1BO	50:50:0	6.85 ± 1.08	6.85 ± 1.08	6.05 ± 1.50	5.60 ± 1.84	5.75 ± 1.25	6.55 ± 1.09
W_2BO	45:50:5	6.75 ± 1.25	6.75 ± 1.25	5.85 ± 1.95	5.65 ± 1.81	6.85 ± 1.13	6.10 ± 1.65
W_3BO	40:50:10	6.25 ± 1.29	6.25 ± 1.29	5.40 ± 1.75	5.10 ± 1.74	6.10 ± 1.07	5.75 ± 1.51
W_4BO	35:50:15	6.15 ± 1.26	6.15 ± 1.26	4.60 ± 1.39	4.65 ± 1.22	5.50 ± 1.47	5.05 ± 1.23

Values are mean scores ± SD of 30 panellists ($P < 0.05$).

IV. CONCLUSION

Partial replacement of wheat flour with Bambara groundnut flour, combined with graded addition of okra mucilage, significantly improved the functional, nutritional quality of composite bread relative to the 100% wheat control. Composite substitution increased protein, ash, fibre content of the bread, while functional indices of the flour (swelling capacity, water and oil absorption capacity) were likewise enhanced, reflecting the greater hydrophilicity and hydrophobicity contributed by legume protein and okra polysaccharides, respectively. Loaf volume and specific volume were reduced by gluten dilution at higher Bambara groundnut levels, although okra mucilage at 10% partially restored loaf volume in the 40:50:10 formulation, indicating a functional, hydrocolloid-mediated compensation for lost gluten structure. Sensory evaluation confirmed that consumer acceptability is optimal at moderate substitution — up to 50% Bambara groundnut flour in the absence of mucilage, or up to 5% okra mucilage with lower Bambara groundnut levels — beyond which the characteristic beany flavour and mucilaginous texture of the raw materials become organoleptically limiting. These findings support wheat–Bambara groundnut–okra mucilage composite bread as a technologically viable, nutritionally enhanced alternative capable of reducing Nigeria's dependence on imported wheat while contributing to the alleviation of protein–energy malnutrition. Further work should explore process optimisation (e.g., dough conditioners, fermentation time) to improve loaf volume at high legume-substitution levels, alongside consumer studies across broader demographic groups and shelf-life/microbiological evaluation of the enriched bread.

ACKNOWLEDGEMENTS
The authors acknowledge the technical support of the staff of the Department of Food Science and Technology, Nnamdi Azikiwe University, Awka, Nigeria.

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