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Antidiabetic Physical and Sensory Properties of Bread Produced from Wheat, Acha, Plantain, and Aerial Yam Flours

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ABSTRACT

This study evaluated the antidiabetic, physical and sensory properties of bread produced from wheat, acha, plantain and aerial yam composite flours. Six formulations were prepared using wheat, acha, plantain and aerial yam flours in the following proportions (g): 100:0:0:0, 80:7.5:7.5:5, 70:15:7.5:7.5, 60:17.5:12.5:10, 50:20:17.5:12.5 and 40:25:20:15, designated as 101,202,303,404,505 and 606, respectively. Physical properties were assessed using loaf weight, height, volume and specific volume, while sensory quality was assessed by 20 panelists using a nine-point hedonic scale. For the antidiabetic assessment, 25 alloxan-induced diabetic Wistar rats were allocated to five groups receiving three selected composite bread formulations (303, 404 and 505), plantain–tapioca or metformin treatment. Blood glucose was monitored during 28 days of feeding. Increasing substitution generally reduced loaf dimensions. Loaf weight decreased from 238.70 g in the wheat control to 215.50 g in sample F, while loaf volume declined from 201.00 to 151.00 cm^3. Blood glucose reductions were 72.33%, 72.58% and 74.82% for formulations 303, 404 and 505, respectively, compared with 59.80% for plantain–tapioca and 64.92% for metformin. Formulation 505 produced the greatest proportional reduction and lowest final mean blood glucose concentration (103 mg/dL). Sensory acceptability declined with increasing non-wheat flour incorporation. The wheat control had the highest overall acceptability score (7.35), while sample B scored highest among composite breads (7.05). The study demonstrated that incorporating acha, unripe plantain and aerial yam flours into wheat-based bread influenced its physical and sensory characteristics while producing appreciable blood glucose reductions in diabetic Wistar rats. Formulation 505 exhibited the greatest glucose-lowering response, whereas sample B maintained the most favourable sensory acceptability among the composite breads. These findings establish the potential of the selected flour blends for developing functional bread products with desirable glycemic properties.

KEYWORDS: Composite bread; Acha flour; Aerial yam; Blood glucose reduction; Wistar rats.

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INTRODUCTION

Bread is a widely consumed cereal-based food whose quality depends largely on flour composition, dough development and baking conditions. Wheat flour remains the principal ingredient in conventional bread production because its gluten-forming proteins contribute to dough elasticity, gas retention and loaf expansion. However, reliance on wheat flour also presents opportunities for incorporating alternative crops into bakery products to diversify raw materials and modify their nutritional and functional characteristics. Composite flour technology provides one approach to achieving these objectives, although the incorporation of non-wheat ingredients can alter loaf volume, crumb structure and consumer acceptance. Chikpah *et al*. (2023) demonstrated that blending wheat flour with orange-fleshed sweet potato and pumpkin flours influenced dough behaviour and bread quality, indicating that flour composition must be carefully considered when developing composite bread.

Acha (*Digitaria exilis*), plantain (*Musa spp*.) and aerial yam (*Dioscorea bulbifera*) are potential ingredients for composite bread production because they provide alternative sources of starch and other food constituents. Acha is an indigenous African cereal that can be processed into flour for bakery applications, while plantain and aerial yam offer additional opportunities for utilising locally available crops. Their incorporation into wheat flour may influence water absorption, starch behaviour and the physical

characteristics of bread. Onuegbu *et al*. (2021) investigated wheat–acha composite bread and reported changes in loaf volume, specific volume and sensory properties following acha incorporation. Their findings showed that replacing wheat flour with alternative ingredients requires consideration of both technological performance and product acceptability. Nevertheless, the combined effects of acha, plantain and aerial yam flours cannot be inferred directly from studies involving acha alone.

Beyond physical quality, the glycemic characteristics of bread are relevant to the development of carbohydrate-based foods with desirable physiological properties. Glycemic index describes the relative blood glucose response to available carbohydrate in a food compared with a reference food under standardised testing conditions (FAO/WHO, 1998). Carbohydrate digestion also involves α-amylase and α-glucosidase, enzymes responsible for the breakdown of starch and related carbohydrates into absorbable sugars. Consequently, examining glucose-lowering activities can provide complementary information about the functional characteristics of composite bread. Oguntuase *et al*. (2022) evaluated wheat bread containing Bambara groundnut flour and reported lower glycemic index values, greater α-amylase and α-glucosidase inhibitory activities, and reduced sensory ratings in some composite formulations. Their findings illustrate the potential trade-off between glycemic properties and consumer acceptance in functional bread development.

Despite these advances, developing composite bread with desirable physical characteristics, glucose-lowering activities and sensory acceptability remains a formulation challenge. Increasing the quantity of alternative flours may modify starch digestibility and enzyme inhibitory activity, but it may also weaken the gluten network, reduce loaf expansion and affect flavour and texture. Previous studies have examined wheat–acha bread, wheat–Bambara groundnut bread and wheat-based formulations containing sweet potato and pumpkin flours (Onuegbu *et al*., 2021; Oguntuase *et al*., 2022; Chikpah *et al*., 2023). However, these studies do not establish how the combined incorporation of acha, plantain and aerial yam flours affects the physical, antidiabetic-related and sensory properties of bread. This represents a specific formulation gap, particularly because improvements in one quality attribute may be accompanied by deterioration in another.

The present study therefore investigated bread produced from wheat, acha, plantain and aerial yam composite flours using six formulations containing 40–100 g of wheat flour and varying quantities of the three alternative flours. Specifically, the study evaluated loaf weight, height, volume and specific volume; determined glycemic index using Wistar rats and assessed glucose-lowering activities; and examined crumb colour, aroma, taste, texture and overall acceptability. By evaluating these properties together, the study sought to identify formulations with favourable glycemic characteristics while retaining acceptable physical and sensory quality. The findings are intended to provide experimental evidence for the development of composite bread using acha, plantain and aerial yam flours, without assuming that results obtained in Wistar rats establish equivalent glycemic effects in humans.

MATERIAL AND METHODS

Raw materials

Market branded wheat flour (*Triticum aestivum*), mature unripe plantain (horn-type) and all other baking ingredients including granulated sugar (Dangote Group Nigeria), baking fat (topper margarine), instant dry yeast (STK Royal brand) and salt (Dangote Group, Nigeria) were procured from Swali market Yenagoa, Bayelsa State, while acha grains was obtained Dawanau market, Kano State, while aerial yam was obtained Ugbawka community in Nkanu-East LGA of Enugu State, Nigeria.

PREPARATION OF SAMPLE FLOURS

Preparation of Acha flour

Acha flour was prepared according to the procedure reported by Olagunju *et al*. (2020) with slight modification. The Acha grains were washed with tap water to separate stones and sand, then, they were dried in the cabinet dryer at 50 ^{0}C for 6 hours. The resultant dried Acha was milled and sieved into flour using the hammer mill with 0.5 mm screen size.

Production of Plantain flour

The unripe plantain flour was prepared according to the method of Chinmah *et al*. (2004). Five kilograms (5kg) of matured unripe plantain fruits was thoroughly cleaned and peeled manually with a kitchen knife. The peeled plantain fruits were cut into smaller sizes with a knife. The slices were rinsed, placed in a stainless pot and blanched with 3 liters of potable water at 85 ^{0}C for 20 min on a hot plate. The blanched slices were drained, rinsed and spread on the trays and dried in a hot air oven (Model DHG 9101 ISA) at 60 ^{0}C for 10 h with occasional stirring of slices at intervals of 30 min to ensure uniform drying. The dried slices were milled in the attrition mill and sieved through a 40µm mesh sieve. The flour produced was packaged in an airtight plastic container, labeled and kept in a refrigerator until needed for further use.

Preparation of Raw Aerial Yam Flour

Raw aerial yam flour was prepared using the method described by Okechukwu *et al*. (2025). One kilogram (1 Kg) of the aerial yams which were free from dirt and other extraneous materials were weighed, cleaned, peeled and sliced into chips manually (using knife) and rewashed using tap water. The chips were rinsed and dried in a hot air oven (Model DHG 9101 ISA) at 60 ^{0}C for 24 h with

occasional stirring of the chips at intervals of 30 min to ensure uniform drying. The dried chips were milled into flour using the attrition mill and sieved using a China-made mechanical sieve shaker with 500micron mesh sieve. The flour produced was packaged in an airtight plastic container, labeled and kept in a refrigerator until needed for analysis.

Formulation of flour blends

The wheat, acha, plantain and aerial yam flours were blended to fit into the experimental design as shown in Table 1. The flours were thoroughly mixed at predetermined ratios; 101= (100:0:0:0), 202 = (80:7.5:7.5:5), 303 = (70:15:7.5:7.5), 404 = (60:17.5:12.5:10), 505 = (50:20:17.5:12.5) and 606 = (40:25:20:15) to give samples A-F using a Panasonic MX-AC 2105 blending machine to obtain homogenous blends. The composite flour blends produced were separately packaged in lidded plastic containers labeled and stored in a refrigerator until needed for analysis. The whole wheat flour without any substitution (Sample A) served as control.

Table 1: Composition of the different formulations based on experimental design.

Experimental Run	Wheat flour	Acha flour	Plantain flour	Aerial yam flour
101	100	0	0	0
202	80	7.5	7.5	5
303	70	15	7.5	7.5
404	60	17.5	12.5	10
505	50	20	17.5	12.5
606	40	25	20	15

Physical Properties of Bread Loaves

The physical properties of bread loaves were determined by the method of AACC (2000). Bread loaves were weighed after baking using the electronic weighing balance and the loaf weights were recorded in grams. The bread loaf height was measured by using a measuring ruler. The loaf volume was determined using the Rape seed displacement method. The specific volume was calculated as loaf volume divided by loaf weight (cm^3/g).

Experimental Protocol

The study protocol was approved by the Health Research Ethics Committee of University of Nigeria Teaching Hospital Ituku-Ozalla, Enugu State, Nigeria (UNTH/HREC/2026/04/4031). The experiments on animals were conducted in accordance with the force laws and regulations as regards care and use of laboratory animals. Twenty-five Wistar Albino rats of body weights between 150-175 g were purchased from animal unit of Veterinary Medicine Department of University of Nigeria Enugu Campus. The animals were randomly group and housed in plastic cages in a climate-controlled environment with free access to free access to feed and water.

Induction of diabetes mellitus on Wistar rats

The method described by Odebode *et al*. (2017) was adopted for the study. After 7 days of acclimatization to the new environment, the initial baseline blood glucose levels of the animals were taken; the Wistar albino rats were fasted overnight and induced for diabetes mellitus by single intraperitoneal injection of freshly prepared solution of alloxan monohydrate (150 mg/kg body weight, recommended for testing drugs for use in noninsulin-dependent diabetes mellitus [Etuk, 2010]) dissolved in physiological saline as previously described by Famakin *et al*. (2016). Hypoglycemic effect of the drug was prevented by making 5% glucose solution available to the animals. The blood glucose levels were measured 72 hr after the administration of alloxan through tail tipping using glucometer (Accu-Chek Active, Roche Diagnostics, IN) and diabetic animal with fasting serum glucose level of ≥250 mg/dL were selected for further study. The diabetic rats were divided into five groups with five rats in each group. Three groups were fed with the experimental diets (303, 404, and 505), another group was treated with metformin hydrochloride (antidiabetic drug) and saline solution and fed with commercially available animal feeds, and the last group was fed with unripe-plantain *tapioka* (a control flour sample commonly recommended for diabetic patient in Southern-Ijaw). The animals were fed for 28 days and the blood glucose levels of the animals were measured early in the morning at 7 days interval through tail tipping using glucometer.

Sensory Evaluation

The bread samples were presented to a 20-member panel of Judges that comprised of the students and staff of the Federal Polytechnic Ekowe, Ekowe town, Southern Ijaw, Bayelsa State, Nigeria. The samples were assessed for crust appearance, crumb colour, crumb texture, aroma, and overall acceptability using a nine-point hedonic scale, where 9 indicated ―liked extremely and 1 indicated ―dislike extremely according to Ihekoronye and Ngody (1985).

Statistical Analysis

The data generated will be subjected to one-way analysis of variance (ANOVA) using Special Package for Social Science (SPSS

Version 20) software. Duncan's New multiple range test will be used to separate significant difference at $p<0.05$.

RESULTS AND DISCUSSION

Physical Properties of Bread Produced from Wheat, Acha, Unripe plantain and Aerial Yam Composite Flours

Table 2: Physical Properties of Bread Produced from Wheat, Acha, Unripe plantain and Aerial Yam Composite Flours

Sample	Loaf weight (g)	Loaf height (cm)	Loaf volume (cm^3)	Specific volume (cm^3/g)
101	$238.70^a \pm 0.04$	$6.46^a \pm 0.04$	$201.00^a \pm 0.02$	$0.82^b \pm 0.00$
202	$236.20^b \pm 0.04$	$4.25^c \pm 0.07$	$198.00^b \pm 0.07$	$0.83^a \pm 0.02$
303	$232.50^c \pm 0.07$	$4.50^b \pm 0.02$	$182.00^c \pm 0.04$	$0.76^c \pm 0.01$
404	$230.10^d \pm 0.05$	$3.35^d \pm 0.05$	$172.00^d \pm 0.00$	$0.73^d \pm 0.02$
505	$225.30^e \pm 0.07$	$3.22^e \pm 0.02$	$164.00^e \pm 0.02$	$0.71^e \pm 0.01$
606	$215.50^f \pm 0.07$	$3.13^f \pm 0.02$	$151.00^f \pm 0.02$	$0.70^f \pm 0.03$

Values are expressed as mean ± standard deviation. Different superscripts indicate significant differences ($p < 0.05$). Formulation key: 303 = 70g wheat flour, 15g acha flour, 7.5g plantain flour, 7.5g aerial yam flour; 404 = 60g wheat flour, 17.5g acha flour, 12.5g plantain flour, 10g aerial yam flour; 505 = 50g wheat flour, 20g acha flour, 17.5g plantain flour, 12.5g aerial yam flour; Plantain-tapioka = locally produced fufu for diabetic people; MET = metformin.

Physical Properties

The physical properties of bread produced from wheat, acha, unripe plantain and aerial yam composite flours are presented in Table 2. Loaf weight ranged from 215.50 to 238.70 g, with the highest value recorded in sample 101 (238.70 g) and the lowest in sample 606 (215.50 g). A progressive reduction in loaf weight was observed as the combined quantity of acha, unripe plantain and aerial yam flours increased. Sample 202, containing 80 g wheat, 7.5 g acha, 7.5 g unripe plantain and 5 g aerial yam flours, recorded a loaf weight of 236.20 g, while samples 303, 404 and 505 recorded 232.50, 230.10 and 225.30 g, respectively. The reduction may be associated with differences in water absorption, moisture retention and the structural properties of the composite flour blends. Replacing wheat flour with alternative starch-rich ingredients can influence dough development and moisture behaviour during baking. Chikpah *et al*. (2023) demonstrated that flour blending proportions and baking conditions affected the physical characteristics of wheat-based composite bread. The present findings suggest that the incorporation of acha, unripe plantain and aerial yam flours influenced loaf mass, although moisture measurements would be required to establish the factors responsible for the observed reduction. Loaf height ranged from 3.13 to 6.46 cm, with the highest value recorded in sample 101 (6.46 cm), followed by sample 303 (4.50 cm) and sample 202 (4.25 cm). Samples 404, 505 and 606 recorded heights of 3.35, 3.22 and 3.13 cm, respectively. The findings indicate that increasing the combined quantity of non-wheat flours generally reduced loaf height, although sample 303 recorded a slightly higher value than sample 202. This variation suggests that the different proportions of acha, unripe plantain and aerial yam flours may have influenced dough expansion differently. The reduction in loaf height may be attributed partly to dilution of the gluten-forming proteins in wheat flour. Gluten contributes to the formation of a viscoelastic network that retains fermentation gases and supports dough expansion during baking. Onuegbu *et al*. (2021) investigated wheat–acha composite bread and reported that flour composition influenced physical bread characteristics. The findings of the present study are consistent with the structural changes expected when gluten-containing wheat flour is progressively replaced with non-gluten-forming ingredients. Loaf volume ranged from 151.00 to 201.00 cm^3. The control sample (101) recorded the highest volume (201.00 cm^3), followed by sample 202 (198.00 cm^3), while sample 606 had the lowest value (151.00 cm^3). The progressive reduction in loaf volume indicates that increasing the combined quantity of acha, unripe plantain and aerial yam flours was associated with reduced dough expansion. Compared with the control, sample F exhibited a reduction of approximately 24.88% in loaf volume. This reduction may reflect the weakening of the gluten network as wheat flour was replaced by alternative flours. Although these ingredients contribute starch and other food constituents, they do not provide the same gluten-forming properties as wheat. Chikpah *et al*. (2023) similarly observed that increasing the incorporation of orange-fleshed sweet potato and pumpkin flours influenced loaf expansion and other bread quality characteristics. Onuegbu *et al*. (2021) also reported changes in loaf volume following the incorporation of acha flour into wheat bread. The present results therefore suggest that higher quantities of the alternative flours reduced the capacity of the bread dough to maintain expansion during baking. The reported specific volume values ranged from 0.70 to 0.83 cm^3/g. Sample 202 recorded the highest value (0.83 cm^3/g), followed by the control sample (0.82 cm^3/g), while sample 606 had the lowest value (0.70 cm^3/g). From sample C onwards, specific volume declined progressively as the combined quantity of alternative flours increased. Specific volume expresses the relationship between loaf volume and weight and is commonly used to assess bread expansion and structural quality. Chikpah *et al*. (2023) identified specific volume as an important physical parameter in evaluating composite bread, while Onuegbu *et al*. (2021) demonstrated that changes in wheat–acha flour composition affected

loaf volume and specific volume. The relatively high reported specific volume of sample B suggests that the incorporation of 7.5 g acha, 7.5 g unripe plantain and 5 g aerial yam flours may have maintained favourable loaf expansion compared with formulations containing larger quantities of alternative flours. However, the specific volume values should be recalculated from the original replicate measurements before definitive interpretation.

Blood Glucose Reduction and Blood Glucose Concentrations of Wistar Rats Fed Experimental and Control Diets

The table 3 provides the blood glucose concentrations before and after feeding, together with the percentage reduction and statistical groupings.

Table 3: Blood Glucose Levels and Percentage Reduction in Wistar Rats Fed Experimental and Control Diets

Sample	Blood glucose before feeding (mg/dL)	Blood glucose after feeding (mg/dL)	Blood glucose reduction (%)
303	430 ± 12	119 ± 21	72.33^{c}
404	383 ± 37	105 ± 17	72.58^{b}
505	409 ± 41	103 ± 12	74.82^{a}
Plantain-tapioka	296 ± 18	119 ± 19	59.80^{e}
MET	419 ± 44	147 ± 11	64.92^{d}

Values are presented as mean ± SEM. Different superscripts indicate significant differences ($p < 0.05$). Formulation key: 303 = 70g wheat flour, 15g acha flour, 7.5g plantain flour, 7.5g aerial yam flour; 404 = 60g wheat flour, 17.5g acha flour, 12.5g plantain flour, 10g aerial yam flour; 505 = 50g wheat flour, 20g acha flour, 17.5g plantain flour, 12.5g aerial yam flour; Plantain-tapioka = locally produced fufu for diabetic people; MET = metformin.

Blood Glucose Reduction and Blood Glucose Concentrations of Wistar Rats Fed Experimental and Control Diets

Table 3 presents the blood glucose concentrations of Wistar rats before and after administration of bread produced from wheat, acha, plantain and aerial yam composite flours, alongside the plantain–tapioca and metformin control treatments. The initial blood glucose concentrations ranged from 296 ± 18 to 430 ± 12 mg/dL, while the final concentrations ranged from 103 ± 12 to 147 ± 11 mg/dL. All treatment groups exhibited reductions in blood glucose concentrations, although the magnitude varied among the formulations. Sample 505, containing 50 g wheat, 20 g acha, 17.5 g plantain and 12.5 g aerial yam flours, recorded the highest percentage reduction (74.82%), followed by sample 404 (72.58%) and sample 303 (72.33%). The metformin group recorded a reduction of 64.92%, while the plantain–tapioca group exhibited the lowest reduction (59.80%). These findings indicate that the three composite bread formulations were associated with greater proportional reductions in blood glucose than the two comparison treatments under the experimental conditions. Although sample 303 exhibited the greatest absolute decrease in blood glucose concentration, sample 505 recorded the greatest proportional reduction and the lowest final mean blood glucose concentration.

The findings suggest that the incorporation of acha, plantain and aerial yam flours may have influenced the glucose-lowering properties of the composite bread. Across samples 303, 404 and 505, the combined quantity of alternative flours increased from 30 to 50 g, while the quantity of wheat flour decreased from 70 to 50 g. This formulation sequence corresponded with an increase in blood glucose reduction from 72.33% to 74.82%. The difference between the highest and lowest experimental reductions was 2.49 percentage points, indicating a relatively modest numerical variation among the three composite bread formulations. Nevertheless, the observed pattern suggests that the composition of the flour blends may have contributed to differences in the glycemic responses of the experimental animals.

The comparison with metformin provides an additional indication of the glucose-lowering responses associated with the experimental bread formulations. The metformin-treated rats exhibited a reduction from 419 ± 44 to 147 ± 11 mg/dL, corresponding to 64.92%. In comparison, samples 303, 404 and 505 produced reductions of 72.33%, 72.58% and 74.82%, respectively. These values exceeded the metformin group's reduction by 7.41, 7.66 and 9.90 percentage points. The final mean glucose concentrations of the three composite bread groups were also lower than that of the metformin group. The findings are evidence that the experimental formulations exhibited substantial glucose-lowering activity within the Wistar rat model.

The findings are in agreement with the report of Oguntuase *et al*. (2026), who investigated functional bread containing Bambara groundnut and orange peel in rats with high-fat diet/streptozotocin-induced type 2 diabetes. Their study demonstrated that dietary administration of the composite bread over 14 days reduced elevated blood glucose concentrations, with formulations containing larger quantities of Bambara groundnut producing stronger glucose-lowering responses. The authors also observed improvements in pancreatic antioxidant defence and reductions in carbohydrate-hydrolysing enzyme activities. Although their formulations differed from the wheat–acha–plantain–aerial yam bread evaluated in the present study, the findings provide recent experimental evidence that composite bread formulations can influence glucose regulation in diabetic rats.

The potential contribution of plantain to the observed blood glucose reductions deserves consideration because plantain starch

composition can vary with maturity and processing. Unripe plantain is recognised as a potential source of resistant starch, which is less readily digested in the small intestine than rapidly digestible starch. A recent experimental investigation published in 2025, entitled Dietary Intervention with Resistant Starch-Rich Unripe Plantain Flour Restores Gut Microbiome-Metabolome Axis and Ameliorates Type 2 Diabetes in Rats, reported that unripe plantain flour influenced intestinal microbial composition and metabolic characteristics in a diabetic rat model. The study identified changes in beneficial bacterial populations and metabolites associated with carbohydrate metabolism. The results shows a possible biological proof for the potential contribution of plantain-based ingredients to glycemic regulation. Xiong *et al*. (2021), in a systematic review and meta-analysis of 19 randomised controlled trials, reported that resistant starch consumption was associated with modest improvements in fasting plasma glucose and insulin resistance. The authors found that the effects varied according to intervention duration and resistant starch intake. The plantain–tapioca group recorded a reduction in blood glucose concentration from 296 ± 18 to 119 ± 19 mg/dL, corresponding to 59.80%, the lowest percentage reduction among the five treatments. Although its final glucose concentration was similar to that of sample 303, its lower initial concentration contributed to the smaller proportional decrease. This finding indicates that the locally produced plantain–tapioca meal was associated with a measurable reduction in blood glucose but did not achieve the same proportional response as the experimental composite bread formulations. The difference may reflect variations in the carbohydrate composition, starch structure, fibre content and processing characteristics of the products. However, these explanations remain tentative because the present table does not provide compositional measurements for the plantain–tapioca meal or establish the specific mechanisms responsible for its glycemic response.

The findings also correspond with the experimental report of Famakin *et al*. (2016), who developed plantain-based functional dough meals incorporating soybean cake and cassava fibre and evaluated their nutritional characteristics, glycemic properties and antidiabetic potential in Wistar rats.

Sensory Properties of Bread Produced from Wheat, Acha, Unripe plantain and Aerial Yam Composite Flours

Table 4: Sensory Properties of Bread Produced from Wheat, Acha, Unripe plantain and Aerial Yam Composite Flours

Sample	Crumb colour	Aroma	Taste	Texture	Overall acceptability
A	$7.90^{a} \pm 0.10$	$8.05^{a} \pm 0.30$	$7.80^{a} \pm 0.30$	$7.30^{a} \pm 0.10$	$7.35^{a} \pm 0.30$
B	$7.65^{b} \pm 0.20$	$7.45^{b} \pm 0.10$	$7.20^{b} \pm 0.40$	$7.10^{b} \pm 0.10$	$7.05^{b} \pm 0.30$
C	$6.40^{c} \pm 0.20$	$6.25^{c} \pm 0.30$	$6.10^{c} \pm 0.20$	$6.05^{c} \pm 0.40$	$6.20^{c} \pm 0.07$
D	$6.10^{d} \pm 0.20$	$6.00^{d} \pm 0.20$	$5.90^{d} \pm 0.30$	$5.65^{d} \pm 0.40$	$5.50^{d} \pm 0.10$
E	$6.05^{e} \pm 0.07$	$5.90^{e} \pm 0.30$	$5.55^{e} \pm 0.20$	$5.50^{e} \pm 0.40$	$5.40^{e} \pm 0.40$
F	$6.00^{f} \pm 0.05$	$5.60^{f} \pm 0.40$	$5.40^{f} \pm 0.20$	$5.35^{f} \pm 0.40$	$5.30^{f} \pm 0.20$

Values are expressed as mean ± standard deviation of the scores provided for 20 panelists. Different superscripts indicate significant differences ($p < 0.05$). Formulation key: 303 = 70g wheat flour, 15g acha flour, 7.5g plantain flour, 7.5g aerial yam flour; 404 = 60g wheat flour, 17.5g acha flour, 12.5g plantain flour, 10g aerial yam flour; 505 = 50g wheat flour, 20g acha flour, 17.5g plantain flour, 12.5g aerial yam flour; Plantain-tapioka = locally produced fufu for diabetic people; MET = metformin.

Sensory Properties

The sensory properties of bread produced from wheat, acha, unripe plantain and aerial yam composite flours are presented in Table 4. The attributes evaluated included crumb colour, aroma, taste, texture and overall acceptability. The crumb colour scores ranged from 6.00 to 7.90, with sample A recording the highest value (7.90), followed by sample B (7.65), while sample F had the lowest score (6.00). Samples C, D and E recorded scores of 6.40, 6.10 and 6.05, respectively. The progressive decline in colour preference suggests that increasing the quantities of acha, unripe plantain and aerial yam flours altered the appearance of the bread crumb. Differences in the natural colour of the flour constituents and their behaviour during baking may have contributed to these changes. Bread colour is influenced by ingredient composition, processing conditions and reactions occurring during baking. Chikpah *et al*. (2023) reported that incorporating alternative flours into wheat-based bread influenced colour characteristics. The relatively high colour score recorded for sample B suggests that incorporating 7.5 g acha, 7.5 g unripe plantain and 5 g aerial yam flours maintained a crumb appearance that was comparatively well accepted by the sensory panelists.

Aroma scores ranged from 5.60 to 8.05, with the control sample recording the highest value (8.05) and sample F the lowest (5.60). Sample B received an aroma score of 7.45, while samples C, D and E recorded 6.25, 6.00 and 5.90, respectively. The decline in aroma scores with increasing quantities of alternative flours suggests that the composite formulations produced aromatic characteristics that differed from those of conventional wheat bread. Aroma development in bread is influenced by volatile compounds originating from the raw ingredients and those formed during fermentation and baking. Differences in flour composition may therefore alter the aromatic profile of the final product. The findings indicate that the panelists preferred the aroma of the wheat bread control and the formulation containing the lowest combined quantity of alternative flours. This agrees with the broader

observation of Onuegbu *et al*. (2021) that increasing acha incorporation can reduce sensory ratings in wheat-based composite bread. Taste scores varied from 5.40 to 7.80. Sample A recorded the highest score (7.80), followed by sample B (7.20), while sample F had the lowest value (5.40). Samples C, D and E recorded scores of 6.10, 5.90 and 5.55, respectively. The progressive reduction in taste preference indicates that increasing the combined quantity of acha, unripe plantain and aerial yam flours influenced the perceived flavour of the bread. The higher preference for the control sample may reflect familiarity with conventional wheat bread and differences in the flavour characteristics of the alternative ingredients. The findings are comparable to those of Onuegbu *et al*. (2021), who observed lower sensory ratings in wheat–acha composite bread containing greater quantities of acha flour. The relatively favourable taste score obtained for sample B suggests that incorporating 20 g of combined alternative flours into a 100 g flour blend maintained a taste profile that was reasonably acceptable to the panelists.

Texture scores ranged from 5.35 to 7.30, with the control sample recording the highest value (7.30), followed by sample B (7.10). Samples C, D, E and F recorded scores of 6.05, 5.65, 5.50 and 5.35, respectively. The progressive decline suggests that increasing the quantities of acha, unripe plantain and aerial yam flours reduced the panelists' preference for bread texture. This observation is consistent with the reduction in loaf volume and height recorded in Table 1. The replacement of wheat flour with non-gluten-forming ingredients may weaken the dough structure, reduce gas retention and produce a denser crumb. Differences in starch gelatinisation, water absorption and moisture distribution may also contribute to the resulting texture. Chikpah *et al*. (2023) reported that the incorporation of alternative flours influenced bread texture and related quality characteristics. The comparatively high texture score recorded for sample B suggests that lower quantities of acha, unripe plantain and aerial yam flours may be incorporated without substantially reducing the perceived textural quality of the bread.

Overall acceptability scores ranged from 5.30 to 7.35. Sample A recorded the highest score (7.35), followed by sample B (7.05), while sample F had the lowest value (5.30). Samples C, D and E recorded overall acceptability scores of 6.20, 5.50 and 5.40, respectively. The findings indicate that the control sample remained the most preferred formulation, although sample B demonstrated comparatively favourable sensory acceptance among the composite bread samples. The decline in overall acceptability with increasing quantities of alternative flours is consistent with the reductions observed in crumb colour, aroma, taste and texture. Oguntuase *et al*. (2022) similarly reported lower organoleptic ratings for experimental Bambara groundnut-substituted bread than for control bread, despite improvements in certain nutritional and functional properties. The present findings suggest that the formulation containing 80 g wheat, 7.5 g acha, 7.5 g unripe plantain and 5 g aerial yam flours offered the most favourable sensory performance among the composite formulations.

CONCLUSION

The study revealed that incorporating acha, plantain and aerial yam flours into wheat-based bread influenced its physical properties, with increasing quantities of the alternative flours generally reducing loaf weight, height, volume and specific volume. Sample B, containing 80 g wheat, 7.5 g acha, 7.5 g plantain and 5 g aerial yam flours, exhibited relatively favourable physical characteristics among the composite bread formulations. The antidiabetic assessment showed that the composite bread formulations were associated with substantial reductions in blood glucose concentrations in Wistar rats. Sample 505 exhibited the most favourable numerical response, recording a 74.82% reduction and the lowest final mean blood glucose concentration (103 ± 12 mg/dL). The sensory evaluation revealed that increasing the quantities of alternative flours generally reduced the panelists' preference for crumb colour, aroma, taste, texture and overall acceptability. However, sample B recorded the highest overall acceptability score (7.05) among the composite formulations, indicating that incorporating 20 g of combined acha, plantain and aerial yam flours into a 100 g flour blend produced bread with comparatively acceptable sensory characteristics.

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