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Full Length Research

Proximate, Functional and Sensory Properties of Doughnut Developed from Local Rice and White Maize Flour Blends

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ABSTRACT

Nigeria's rising cost and import dependence on wheat flour have driven the search for sustainable, locally sourced alternatives in bakery products. This study assessed the proximate, functional, and sensory properties of doughnuts developed from composite flours comprising local rice (*Oryza glaberrima*), white maize (*Zea mays*), and wheat flour, formulated in varying ratios. Five blends were analyzed, comprising of 70% ARF: 30% WCF (sample A), 30% ARF: 70% WCF (sample B), 50% ARF: 50% WCF (sample C), 20% WF: 20% ARF: 60% WCF (sample D) and 100% WF (sample E). Standard procedures were adopted in determining the proximate and functional properties of the composite flours. Likewise, the sensory evaluations of the developed doughnuts were carried out by panelists using structured 9-point hedonic scale. The composite blends (Samples B and C) had lower moisture and fat content but higher fibre and carbohydrate content than the control (100% wheat), enhancing their nutritional profile. They also showed higher water absorption (55.14 g/mL and 60.49 g/mL), and good swelling capacity (4.75 g/mL and 4.78 g/mL for Samples B and D) was observed, making them suitable for dough development. Sample E (control) showed the highest acceptability in terms of taste (7.47), texture (7.40), aroma (7.50), appearance (7.33), and general acceptability (8.00). Doughnuts produced from sample B (30% ARF: 70% WCF) recorded encouraging scores in all the parameters- taste (5.80), texture (5.97), aroma (6.23), appearance (6.17), and general acceptability (6.20) evaluated. The study revealed that composite flour blends comprising maize and rice flour (samples B and C) compared favorably with the control sample (100% wheat) in moisture, fat, fiber, and carbohydrate compositions. Therefore, demonstrating that maize and African rice flour blends can successfully reduce wheat dominance in doughnut production while maintaining nutritional quality and other desirable quality attributes.

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INTRODUCTION

The consumption of snacks is rising due to urbanization, and the food sector can capitalize on this trend by creating innovative snack products using locally produced flours. Doughnuts are leavened and fried confections produced by deep-frying dough composed of flour, water, egg, oil, sugar, and milk (Ugwuona et al., 2021). According to Paku et al. (2025), doughnuts are characterized by their golden-brown appearance and crispy interior that looks more like a baked composite rather than fried dish. They could be fried without yeast (cake type) or with yeast (risen type).

Rice, botanically known as *Oryza sativa* is a crop of significant relevance in both developed and developing nations. It contains a lot of nutritional qualities, including carbohydrates (starch), minerals like riboflavin, niacin and thiamine, minerals and marginal amount of fats and protein (Balogun et al., 2024). Rice flour is a vital component in Nigeria food industry considering its nutritional benefits, availability and economic relevance. Recent studies have indicated that rice flour is gluten-free and a viable substitute to wheat (Marques et al., 2023). The presence of high-quality protein in rice with optimal amino acid profile makes it an effective dietary choice for various demographics, especially the elderly, who may be susceptible to protein-energy malnutrition (Andrey, 2023; Tumenova & Myktabayeva, 2023).

Maize, or corn, is a member of the Poaceae family, scientifically designated as *Zea mays* L. Maize is among the most prevalent cereal crops utilized for food, fodder, and medicinal applications globally. According to Onyeka & Okwume (2023), about 3,500 corn product applications have been identified. Maize products are a significant source of vitamins A, B, and E and many minerals. It has decreased hypertension and averted neural tube abnormalities during delivery. Lawrence (2022) asserted that

humanity has consistently employed crops for its advancement and sustenance, deriving their nutritional, economic, industrial, and scientific benefits. Due to its significant economic importance, maize is one of humanity's three most extensively cultivated food crops, alongside rice and wheat. White maize is nutritionally abundant in carbohydrates, offering roughly 72 to 75 grams per 100 grams of dry weight, therefore serving as a dependable dietary energy source, especially in low-income contexts (Agwu et al., 2025; FAO, 2020).

The increasing reliance on wheat flour for doughnuts in Nigeria presents non-ignorable limitations in forms of import dependence, unfavourable economic stretch and general food insecurity. Despite the presence of cereals like white maize and rice in Nigeria, billions of dollars are spent each year on wheat imports (Agwu et al., 2025; Babatunde et al., 2021). Though composite flour production has been recommended as an effective alternative to wheat, most studies have concentrated on millet, legumes and sorghum with little concentration on rice and maize mixtures. Also, little research has been carried out on rice and maize composite adoption in the production of food such as doughnuts and this has created a knowledge gap in the innovation of functional food while utilizing indigenous crops (Ugwuona et al., 2021).

While several studies have assessed composite flours' nutritional and sensory characteristics for bakery and snack purposes, limited research has focused on their incorporation into doughnut compositions. Folorunso et al. (2016) examined doughnuts made from broken rice flour; however, their study was deficient in thoroughly evaluating functional properties and did not incorporate white maize blends. Onyeka & Okwume (2023) similarly examined the functional qualities of composite flours comprising maize and pearl millet for stiff dough products; however, their study did not encompass fried food matrices such as doughnuts. This gap indicates that Nigerian food science research has not adequately recorded the proximate, functional, and sensory attributes of rice-white maize mixes for doughnut applications.

Furthermore, the lack of empirical sensory evaluations of doughnuts made from rice and maize composite flours hinders the creation of acceptable, wheat-free alternatives that satisfy consumer expectations. Although research on alternative flour types has recorded moderate to high acceptability in comparable goods, no benchmarks exist for doughnuts made from rice/maize mixes. The absence of such studies restricts innovation in fried snack manufacture utilizing local staples and hinders the development of nutritionally balanced, economically feasible alternatives to wheat-based products. Bridging this gap will enhance the scientific comprehension and practical application of locally produced cereal-based flour within Nigeria's food system.

MATERIALS AND METHODS

Materials

Local rice (*Oryza glaberrima*), white maize (*Zea mays*) and wheat (*Triticum aestivum*) were purchased from commercial food retailers in Market Square, Ekpoma, Esan West Local Government Area, Edo State, Nigeria. They were subsequently conveyed to the Human Nutrition and Dietetics Laboratory for analysis.

Facilities/Equipment

Food Laboratory

The samples were processed in the Food Laboratory located in the department of Human Nutrition and Dietetics, Ambrose Alli University, Ekpoma, Edo State. The food laboratory is a specialized facility specifically designed for the preparation, formulation and evaluation of new food products. Food processing equipment present in the laboratory including; sieves, frying pan, measuring scales, mixing bowls, cutters, cooking thermometer, spatulas and tongs, blender, measuring cups, mixer, frying pan and sieve.

Chemical Laboratory

Chemical laboratory equipment used include, Kjeldahl digestion apparatus, test tubes, centrifuge, analytical balance, petri-dishes, muffle furnace, Soxhlet extractor, reflux condenser, filter paper, viscometer, pipettes, measuring cylinders, water bath, thermometer, beakers, glass rods, distilled water.

Chemicals and Reagents

Distilled water, hydrochloric acid, sodium hydroxide, sulfuric acid, n-hexane, boric acid, mixed indicator, petroleum ether and ethanol. All chemicals and reagents used for the analysis were of analytical grade.

Sample Processing

Production of Rice Flour

One (1kg) of rice grains was sorted, washed severally and drained out using a sieve, it was spread on an ankom filter nylon and dried for 96 hours at room temperature (60^0C) in the Human Nutrition and Dietetics Food Laboratory, Faculty of Life Sciences. Dry grains were ground using a commercial Retsch mill and sieved to obtain the flour, stored in an air-tight container for further use.

Production of Maize Flour

Maize grains (1kg) were sorted to remove dirt, washed with clean water, and sun-dried for 48 hours. It was later milled into flour using a commercial Retsch mill, sieved to obtain smooth flour, and packaged in an airtight container for further use

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Table 1: Composite Flour samples

Samples	WF (%)	ARF (%)	WMF (%)
A	0	70	30
B	0	30	70
C	0	50	50
D	20	20	60
E	100	0	0

Keys: WF - Wheat flour; ARF – African rice flour; WCF – White maize flour

Chemical Analysis

Proximate Properties

The proximate analyses of the formulated samples were investigated using the following standard methods:

Determination of Moisture Content

The AOAC (2006) method was used. Two-gram portions of each flour blend sample were weighed into previously weighed dry crucibles. The crucibles with samples were dried in an oven at 105^0C, cooled in desiccators for ten minutes, reweighed, and returned to the oven until a constant weight was attained.

$$\% \text{ Moisture content} = \frac{\text{Weight } \mathbf{loss}}{\text{Weight of sample}} \times 100$$

Determination of Ash Content

The ash content was assessed using the AOAC (2006) method as modified by Uzoukwu et al. (2020). Two grams of the samples were measured in triplicate into pre-weighed silica crucibles. The samples within the crucibles were incinerated on a heater within a fume cabinet to eliminate the majority of the smoke. The crucibles containing the materials were placed in a muffle furnace and heated for approximately four hours at 550 °C. They were subjected to cooling in a desiccator and subsequently weighed. The heating was conducted repeatedly until the samples became grayish white and reached a stable weight.

$$\% \text{ Ash} = \frac{\textbf{Weight of ash}}{\text{Weight of sample taken}} \times 100$$

Determination of Crude Proteins

Crude protein was determined using the micro-Kjeldahl apparatus as outlined by AOAC (2006). Two grams of the sample were placed in a Kjeldahl flask, and 30 mL of concentrated H_2SO_4 acid was added. Ten g of potassium sulphate and copper sulphate (1 g) were further added to the mixture. The mixture was heated gently until frothing ceased. The digest was allowed to cool and diluted with distilled water (washing the digestion flask) up to 100 ml. Ten milliliters (10 ml) of the dilute digest was pipetted into a distillation flask and 10 ml of 40% (w/v) sodium hydroxide added. The mixture was distilled, and the liberated ammonia was collected in 10 ml of 2% boric acid containing an indicator. This was titrated with 0.01 N hydrochloric acid to a colored endpoint. A blank was also prepared without a sample and treated as above. The amount of crude protein was then calculated by multiplying the percentage nitrogen in the digest by the conversion factor (6.25).

$$\% \text{ N} = \frac{(\mathbf{a}-\mathbf{b})\, x\ \mathbf{0.01}\ x\ \mathbf{14}\ x\ v}{\text{W x C}} \quad \text{x } 100$$

Where: a is the digested sample's titre value; b is the blank sample's titre value; V is the volume after dilution; W is the dried sample's weight (mg); C = Sample's aliquot while 14 = Atomic weight of Nitrogen

Crude protein = 6.25 x % N

Determination of Crude Fibre

AOAC (2006) methods were employed. Two grams of the flour samples were measured in duplicate into a 600 ml long Pyrex beaker, to which 200 ml of a 1.25% H_2SO_4 solution was added. The beaker was sealed with a watch glass, and the contents were slowly heated on a hot plate for 30 minutes. The acid was eliminated by filtration through muslin fabric using a Buchner funnel, and the sample was rinsed three times with 50 ml of boiling water to remove any residual acid before returning it to the beaker. Subsequently, 200 ml of 1.25% NaOH solution was introduced to the residue in the beaker, which was covered with a watch glass, gently heated on a hot plate for 30 minutes, and subsequently filtered. The residue was transferred into a pre-weighed No. 2 sintered glass crucible using 50 ml of hot water and subsequently cleaned twice with 30 ml of petroleum spirit. The crucible was subjected to drying in an oven at 80^0C until a consistent weight was achieved, followed by ignition in a muffle furnace at 60^0C until a light gray ash was produced. The crucible and content were cooled to ambient temperature in a desiccator and then weighed.

$$\% \text{ Crude fibre} = \frac{\textbf{Loss in weight on ignition}}{\text{Weight of sample}} \text{ x } 100$$

Determination of Fat Content

The total fat content of the samples was assessed utilizing the AOAC (2006) Soxhlet fat extraction technique. Five grams of the material were measured into a pre-weighed fat-free extraction thimble securely sealed with cotton wool. The thimble was positioned in the Soxhlet extractor equipped with a reflux condenser, all linked to a boiling flask with 200 ml of petroleum ether (boiling point 60 ^{0}C) on a heating mantle. After heating the flask and petroleum ether, the solvent evaporated and condensed in the thimble, extracting oil from the sample and refluxing it back into the boiling flask with the extracted oil. This was conducted for four hours. After extraction, the solvent (petroleum ether) was evaporated by heating to 70 ^{0}C on a hot plate, resulting in the lipid extract remaining in the flask. The flask containing its contents was positioned in an oven, subjected to drying at 110^{0}C for one hour, then chilled in a desiccator, and reweighed.

$$\% \text{ Fat content} = \frac{\text{Weight of oil}}{Weight\ of\ sample} \times 100$$

Determination of Carbohydrates

The carbohydrate content was obtained by different means, according to Onwuka (2005).

% Carbohydrate = (100% - % Moisture - % Crude protein - % Fat - % Ash- % Crude fibre)

Functional Properties

The functional properties of the formulated samples were determined using the following standard methods:

Determination of Viscosity

This was determined using the method by Onwuka (2005), the falling number (FN) formula. Twenty (20) g of flour in water suspension in a measuring cylinder was immersed in a boiling water bath and stirred for 60 seconds. A plunger (7g mass) was then allowed to fall at a fixed distance in the measuring cylinder, and the falling time is the time in seconds for the plunger to fall at the fixed distance.

FN = FT + 60

Where, FN = Falling number; FT = Falling time; 60 = a constant added to FT to obtain FN

Wettability

The AOAC (2006) was adopted in examining the wettability of the samples. One gram of flour was deposited in a graduated 25 ml test tube with a diameter of 1 cm. A finger was positioned over the specimen's aperture to prevent the sample from spilling when inverted. The finger closing the specimen was placed 10 cm above the surface of a 25 ml beaker containing 250 ml of distilled water. The digit was excised, and the specimen was transferred into the beaker. Wettability refers to the duration required for the sample to achieve total saturation.

Bulk Density

Bulk density was determined as described by Onwuka (2005). 2.5g of the sample was filled into a 10mL graduated cylinder, and its bottom was tapped on the laboratory bench until the sample volume did not decrease. The volume was recorded.

$$\text{Bulk density (g/mL)} = \frac{\text{Weight of sample (g)}}{\text{Volume of sample (mL)}}$$

Oil Absorption Capacity

Oil absorption capacity was determined using a method described by Onwuka (2005). 1 g of each sample was weighed in a conical flask, and 5 mL of oil was added. The flask was shaken thoroughly and allowed to stand for 30 minutes at room temperature (30 ± 20 °C). It was then transferred into a graduated centrifuge tube and centrifuged at 3500 rpm for 30 min.

$$\text{OAC} = \frac{\text{Density of oil x volume absorbed}}{\text{weight of sample}}$$

Water Absorption Capacity

Water absorption capacity was determined using a method described by Onwuka (2005). 1 g of each sample was weighed in a conical flask, and 5 ml of distilled water was added. The flask was shaken thoroughly and allowed to stand for 30 minutes at room temperature (30 ± 20 °C). It was then transferred into a graduated centrifuge tube, which was then centrifuged at 3500 rpm for 30 min.

$$\text{WAC} = \frac{\text{Density of water x volume absorbed}}{\text{weight of sample}}$$

Foam capacity

The foaming capacity of the flour samples was determined according to the AOAC (2006) method. Two grams of the flour sample were blended with 100 ml of distilled water using a warming blender. The suspension was whipped at 1600 rpm (revolutions per minute) for 5 minutes. The mixture was then poured into a 100 ml measuring cylinder, and its volume was recorded after 30 seconds.

Foam capacity (%) =

$$\frac{\text{Volume after whipping} - \text{volume after whipping}}{\text{Volume before whipping}} \times 100$$

Swelling Capacity

The swelling capacity was evaluated according to the methods described by Onwuka (2005). Ten grams of the substance were introduced into a graduated cylinder, and the dry bulk volume was measured. Subsequently, 100 ml of heated water was precisely mixed with the sample in the cylinder. The volume was measured after 10 minutes, and the swelling index was calculated as:

Swelling index (mL/g)=

$$\frac{\text{Change in volume of Sample (mL)}}{\text{Original weight of sample (g)}}$$

Least Gelation Property

This property was determined using the method described by Onwuka (2005) where 2% to w/v was dispersed in 5 mL distilled water in a test tube. The sample was thoroughly mixed to obtain a uniform suspension. The test tubes were heated in a boiling water bath for 1 hour. After heating, the tubes were rapidly cooled under running tap water and refrigerated at 4°C for 2 hours to allow gel formation. After the cooling period, the test tubes were inverted to observe whether the sample had formed a firm gel that did not slip or fall under gravity. The least concentration at which the sample does not fall or slip upon inversion was recorded as the Least Gelation Property (LGP).

Sensory Evaluation

The sensory qualities of the doughnuts produced were evaluated using a multiple comparison test. The samples were coded and presented on clean dishes to the sensory panel members. The acceptability of the products in terms of taste, texture, aroma, appearance and general acceptability was assessed by 30 untrained test panel members comprising of students and staff of the Department of Human Nutrition and Dietetics, Ambrose Alli University, Ekpoma, Edo State. This was done based on a 9-point hedonic preference scale (1 = dislike immensely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like nor dislike, 6 = like slightly, 7 = like moderately, 8 = like very much and 9 = like extremely). Drinking water was provided for the panelists to rinse their mouths after evaluating each sample.

STATISTICAL ANALYSIS

The triplicate data obtained from the chemical analysis were subjected to statistical analysis using the Statistical Package for the Social Sciences (SPSS), version 28. The analysis of variance (ANOVA) was used to determine a significant difference between the means ($p<0.05$), while the means were separated using Duncan Multiple Range Test (DMRT).

RESULTS

Table 2 presents the proximate analysis result of composite flour samples. Moisture content ranged from 2.81% - 4.52%, with sample A (70% ARF: 30% WCF) significantly ($p<0.05$) lower. Sample B (30% ARF: 70% WCF) showed the highest ash content value of 13.81% while sample D (20% WF: 20% ARF: 60% WCF) showed the least at 10.68% ($p>0.05$). Sample E (control) showed the highest fat content at 4.89% while sample C (50% ARF: 50% WCF) showed the least at 4.27%. The crude fibre samples ranged from 2.53 % to 3.86% protein content ranged from 6.30% to 11.20%. The proximate composition showed significant ($p<0.05$) differences in three (3) parameters, moisture, protein and carbohydrate content of flour samples.

Table 2: Proximate Analysis of Composite Flour Samples

Samples	Moisture (%)	Ash (%)	Fat (%)	Fibre (%)	Protein (%)	Carbohydrates (%)
A	2.81 ±0.67^{ab}	13.16 ±0.39^{a}	4.50^{a} ±0.46^{a}	2.99 ±1.07^{b}	6.30 ±0.49^{b}	70.24 ±2.89^{a}
B	4.09 ±0.11^{b}	13.81±0.06^{a}	4.70±1.49^{a}	3.08±0.28^{a}	7.88±0.74^{bc}	66.44±1.78^{b}
C	4.35±0.07^{b}	12.64±1.54^{a}	4.27±0.006^{b}	3.86±0.15^{a}	10.68±0.74^{a}	64.20±1.01^{ab}
D	4.52±0.317^{a}	10.68±0.63^{b}	4.68±0.11^{a}	3.07 ±0.27^{a}	9.28±0.25^{b}	67.77±0.91^{b}
E	4.52±0.80^{a}	12.67±3.05^{a}	4.89±1.11^{a}	2.53±0.35^{ab}	11.20±0.50^{a}	64.19±5.80^{ab}

Values are means ± standard deviations of triplicate scores. Means with different superscripts in the same column differed significantly ($p<0.05$). A - 70% African rice flour (ARF): 30% white maize flour (WMF); B - 30% ARF: 70% WMF; C - 50% ARF: 50% WMF; D - 20% WF: 20% ARF: 60% WMF; E - 100% WF (control)

Table 3 presents the results on the functional properties of the composite flour samples. Sample B (30% ARF: 70% WMF) showed the highest bulk density value at 0.89 g/mL while sample C (50% ARF: 50% WMF) showed the least. The water absorption capacity result also shows that sample C had the highest value while sample D (20% WF: 20% ARF) showed the least and the samples were significantly different ($p<0.05$). The swelling capacity demonstrated a range of 3.86 to 4.78 mL/g., Least gelation (2.50%) property was observed in sample A, while sample E showed the highest value of 5.50%. The oil absorption capacity result revealed a ranged value of 48.40 g/mL to 52.55g/mL and the samples were significantly different ($p<0.05$). Sample B showed the least viscosity value at 209.34Nsm^{-2} while sample D had the highest value at 351.00 Nsm^{-2}. The flour blends showed a ranged wettability values of 12.65s – 34.45s and were significantly different ($p<0.05$).

Table 3: Functional Properties of Composite Flour Samples

Samples	Bulk Density	WAC (g/mL)	Swelling capacity	Foam capacity	Least gelation	OAC (g/mL)	Viscosity (Nsm^{-2})	Wettability (s)

	(g/mL)		(mL/g)	(%)	(%)			
A	0.81± 0.001[a]	49.11± 8.07[ab]	3.86± 0.11[a]	24.99± 1.14[a]	2.50± 0.71[a]	50.92± 1.40[ab]	259.40± 4.03[b]	12.65 ± 0.33[a]
B	0.89± 0.0007[d]	55.14± 0.28[ab]	4.75 ± 0.15[a]	23.39 ± 5.70[a]	3.50± 0.71[a]	52.55± 1.45[b]	209.34 ± 7.23[a]	23.76± 0.76[b]
C	0.63± 0.0007[e]	60.49± 4.36[b]	4.19± 0.09[a]	26.61 ± 1.14[a]	4.50± 0.71[ab]	49.64± 1.52[ab]	221.15± 2.62[a]	26.70± 1.56[c]
D	0.86± 0.009[c]	45.66± 3.63[a]	4.78± 0.129[b]	33.87± 2.28[bc]	4.00± 1.4[ab]	49.51± 0.83[a]	351.00± 7.54[c]	30.75± 0.49[d]
E	0.85± 0.0021[b]	48.15± 1.63[a]	4.76 ± 0.23[b]	40.32± 0.00 [c]	5.50± 0.71[b]	48.40± 0.53[a]	342.40± 5.54[c]	34.45± 1.34[e]

Values are means ± standard deviations of triplicate scores. Means with different superscripts in the same column differed significantly ($p<0.05$). A - 70% African rice flour (ARF): 30% white maize flour (WMF); B - 30% ARF: 70% WMF; C - 50% ARF: 50% WMF; D - 20% WF: 20% ARF: 60% WMF; E - 100% WF (control)

Table 4 presents the results of the sensory evaluation of doughnut samples. Sample E (100% WF) ranked highest across the parameters, though not significant ($p<0.05$), while sample D (20% WF: 20% ARF: 60% WMF) ranked the lowest across the parameters.

Table 4: Sensory Evaluation of Doughnut Samples

Samples	Taste	Texture	Aroma	Appearance	General acceptability
A	5.30±1.32[a]	5.40±1.59[a]	5.57±1.62[a]	6.00±0.88[a]	6.13±1.20[a]
B	5.80±1.65[a]	5.97±1.61[a]	6.23±1.28[a]	6.17±1.24[ab]	6.20±1.33[a]
C	4.60±1.78[a]	4.97±1.65[ab]	4.90±1.89[a]	5.20±1.69[ab]	5.17±1.37[b]
D	4.03±1.96[a]	4.53±1.91[ab]	4.03±1.91[a]	5.87±1.93[b]	4.93±1.66[b]
E	7.47±1.28[b]	7.40±1.17[a]	7.50±1.31[b]	7.33±1.19[b]	8.00±1.21[ab]

Values are means ± standard deviations of triplicate scores. Means with different superscripts in the same column differed significantly ($p<0.05$). A - 70% African rice flour (ARF): 30% white maize flour (WMF); B - 30% ARF: 70% WMF; C - 50% ARF: 50% WMF; D - 20% WF: 20% ARF: 60% WMF; E - 100% WF (control)

DISCUSSION

Proximate Analysis of Doughnut Samples

The proximate analysis of composite flour formulated from five flour blends (A-E) as shown in table 2 revealed clear, vibrant trends in their moisture, ash, fat, crude fibre, crude protein, and carbohydrate contents. The study revealed low moisture content ranging from 2.81% to 4.52% in rice-maize composite samples. According to Adebayo (2025), composite blends with higher moisture content tends to retain more water. The result shows that as the substitution level of rice blends increased, the moisture content reduces. This result is lower than the value reported in Composite flour, formulated from wheat, acha, and date fruit (Ijemi et al., 2025). These findings suggest that flour blends could have low spoilage microbial proliferation potentials, which suggest a longer shelf stability and suitability for pastries. The findings of the current study disagree with the study of Lawrence (2022), who reported higher moisture content of 12.75 – 16.62 % for millet, maize, and rice flour. The flour blends exhibited high ash content (0.68 – 13.81%), no significant difference was detected among the samples. However, research by Batuhan & Huri (2024) showed that composite flour frequently disrupts mineral content. Hence, blending African rice and maize (rich in dietary fiber) into doughnut flour improved the ash value relative to wheat alone. The result of crude fibre showed a more pronounced value with the blend composition. Sample C (50% ARF: 50% WCF) showed the highest crude fibre of 3.86 ± 0.15 %. No significant difference was recorded among the composite flours. These findings agree with the proven fact that wheat flour has little fibre while wholegrain or legumes possess increased dietary fibre. Adding rice and maize (because of their bran content) can significantly boost the fibre content of foods (Peter-Ikechukwu et al., 2020).

The crude protein compositions of the blends were significantly different. Sample E (100% WF) and C (50% ARF, 50% WCF) had the highest protein content of 11.20±0.50 % and 10.68±0.74 % respectively. The protein value of the samples increased with the introduction of rice and maize, which correlates with relevant studies (Yusufu & Alexander, 2022) that flour tends to increase in protein content with the addition of rice and maize. Also, the research of Batuhan and Huri (2024) further strengthens the position that adding flour rich in protein (e.g., millet, corn, and rice) immensely increases the protein content of baked products.

Functional Properties of Doughnut Samples

The functional properties of flour blends are essential in assessing their suitability for specific food applications, especially in doughnuts, where texture, water interaction, and oil retention profoundly affect quality. The bulk density of the samples varied from 0.63±0.0007 g/mL in sample C (50% ARF: 50% WCF) to 0.89±0.0007 g/mL in sample B (30% ARF: 70% WCF). The result, however, is lower than the bulk density values of whole wheat, sweet potatoes and rice bran discovered by Chiedu et al. (2023). The result also indicated a notable disparity among all the blends. Elevated bulk density is often associated with improved packaging and handling attributes, especially for baked goods (Ibrahim & Stephen, 2022). The increased values (0.89±0.0007 g/mL) of Sample B and 0.86±0.009 g/mL of D, suggest superior compatibility, which may influence product texture. The reduced value (0.63±0.0007g/mL) obtained in Sample C indicates a more aerated flour composition, which aids in the production of softer doughnuts. The water absorption capacity (WAC) exhibited considerable variation among samples, with Sample C demonstrating the most outstanding value at 60.49±4.36 g/mL, while sample D recorded the lowest at 45.66±3.63 g/mL. A high WAC signifies the flour's capacity to hold moisture, which is essential for dough development and the sensory quality of the end product (Peter-Ikechukw et al., 2020). The increased WAC of Sample A suggests improved hydration properties. This is likely due to the significant quantity of native starch granules in African rice, which may exhibit a more porous structure compared to maize or wheat (Ijemi et al., 2025).

Swelling capacity is the capacity of starch granules to absorb water and expand, which directly influences dough consistency and the volume of the finished product (Ijeme et al., 2025). The swelling capacity was maximal in sample D and Sample E which recorded 4.78±0.129 mL/g and 4.76±0.23 mL/g respectively, while sample A

3.86±0.11 mL/g had the lowest. The increase in swelling index as evident in sample D and sample E, highlights the water-retention capacity of African rice starch, indicating its potential to provide doughnuts with superior crumb structure and moisture preservation. The foaming capacity which is crucial for aeration and texture in doughnuts, was high in Sample D (33.87±2.28 %) and Sample E (40.32±0.00 %), whereas samples A (24.99±1.14 %) and B (23.39±5.70 %) exhibited lower values.

Foaming capacity is often attributed to protein which enhances air bubbles throughout the mixing process (Chukwu et al., 2018). The reduction in the foaming capacity of Sample A correlates with its lower protein level, as demonstrated by the proximate analysis. The outstanding performance of wheat-based blends (D and E) in foaming capacity confirms the recognized functional advantage of wheat gluten in baking applications (Al-Shahib & Marshall, 2023). The least gelation concentration (LGC) which signifies the minimum amount of protein required to form a gel, was lowest in sample A (2.50±0.71 %) and highest in Sample E (5.05±0.71 %). Reduced LGC values signify enhanced gelation capacity, indicating a superior ability to establish a stable gel at reduced concentrations (Patience & Miracle, 2023). This is advantageous for manufacturing structured pastry items such as doughnuts. The enhanced gelling capacity of rice-based blends can be ascribed to their starch composition and interaction with trace proteins (Msugh et al., 2024). The oil absorption capacity (OAC), which enhances flavour and improves mouthfeel, varied from 48.40±0.53 g/mL in the control Sample to 52.55±1.45 g/mL in Sample B. Sample B demonstrated the highest oil absorption capacity of 52.55±1.45 g/mL. Increased oil absorption values are beneficial in deep-fried items as they improve flavor retention and moisture (Zainol et al., 2020).

The viscosity which reflects the flour's resistance to flow was examined. Sample D had the highest value of 351.00±7.54 Ns·m², followed closely by sample E (342.40±5.54 Ns·m²). This characteristic is intricately associated with the interplay between starch and protein, signifying the mixture's capacity to generate viscous pastes or batters (Anon et al., 2021). The reduced viscosity observed in rice-corn blends (sample B with 209.34±7.23 Nsm²) may lead to less cohesive batters, affecting doughnut formation. Wettability which is the time required for flour to absorb water and achieve complete saturation, was lowest in sample A (12.65 ±0.33 s) and highest in sample E (34.45±1.34 s). Improved wettability accelerates hydration during mixing (Agwu et al., 2025). The diminished wetness seen in the control sample may be attributed to increased surface tension and grain density, hindering water absorption (Paku et al., 2025).

Sensory Evaluation of Doughnut Samples

The sensory evaluations of doughnut samples showed significant variation across different flour blends. Sample E attained the highest Taste score (7.47 ± 1.28), significantly ($p<0.05$) above other composite blends; sample B received the second-highest score (5.80 ± 1.65), while sample C registered the lowest taste score (4.60 ± 1.78). This preference could be attributed to the respondents' familiarity with doughnuts made from wheat flour (Nwadili, 2021). The control sample had the highest rating of 7.40 ± 1.17 while Sample C showed the lowest ratings of 4.97 ± 1.64. The gluten component in wheat flour imparts chewiness and flexibility to fried dough, a quality absent in composite flours, especially those with elevated rice or corn proportions, leading to denser or crumblier textures (Nzenwata et al., 2025).

Aroma ratings were highest for sample E, followed by Sample B. This suggests that wheat imparts volatile chemicals that enhance the desirability of fried scent (Nwabali et al., 2019). In composite flour studies, the aromatic profile is frequently associated with the flour's source; the incorporation of legumes or tubers can impart beany or earthy flavours unless adequately treated (e.g., through roasting or fermentation) to reduce undesirable odours (Paku et al., 2025). Appearance exhibited a comparable pattern where sample E got the highest ratings of 7.33 ± 1.19, significantly ($p<0.05$) surpassing the other blends. Samples C and D had the mean ratings of 5.20±1.69 and 5.87±1.93 respectively. Studies on composite pastries suggested that replacing wheat with alternative grains may negatively impact visual aesthetics unless blending proportions are meticulously controlled (Awotadeju & Olapade, 2020). The general acceptability of the doughnuts sample showed that sample E had the highest rating of 8.00±1.21 while sample D showed the lowest rating of 4.93±1.66. These patterns correspond with empirical evidence indicating that the sensory acceptability of composite snacks significantly decreases when wheat is excluded or substituted beyond certain threshold levels (Udo et al., 2021).

CONCLUSION

Substituting wheat with African rice–maize blends significantly improved the protein, ash and fiber content of the doughnut composition. The composite doughnuts were typically less moist and drier than the whole wheat flour, exhibiting notably reduced moisture levels (suggesting an extended shelf life) and much decreased fat content. The elevated carbohydrate content indicates that the blended doughnuts are energy-dense snacks, serving as substantial fuel sources. Also, the local-grain mixtures (sample B) showed good absorption of water and exhibited increased swelling, indicating their higher fibre and protein content. Sample B and C retained more water and exhibited reduced bulk density, resulting in lighter dough. Also, the blends were denser and formed well-risen, tender doughnuts, demonstrating satisfactory functional performance. Sensory evaluation indicated that sample E was the most favoured; however, samples A and Sample B were deemed acceptable. Sample B achieved an overall acceptability score roughly equivalent to the control and was the most favorable among alternatives.

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