

Nutritional Analysis of Modified and Unmodified Resistant Starches of African Yam Beans and Pearl Millet and Their Sensory Properties



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ABSTRACT

This study investigated the nutritional composition of modified and unmodified resistant starches of African yam bean (AYB) and pearl millet (PM), alongside the sensory attributes of pearl millet bread supplemented with varying proportions of AYB flour. Proximate analysis revealed significant compositional shifts following modification. In AYB, modification reduced moisture (6.10% vs. 10.20%), fat (0.90% vs. 9.50%), crude fiber (0.20% vs. 1.90%), protein (8.00% vs. 21.40%), and ash (1.20% vs. 2.30%), while markedly increasing carbohydrate content (83.60% vs. 54.80%). Similar but less drastic trends were observed in PM, where modification lowered moisture (6.33% vs. 8.50%), fat (1.33% vs. 1.67%), crude fiber (2.83% vs. 3.50%), protein (8.75% vs. 13.12%), and ash (1.17% vs. 2.50%), with carbohydrates increasing to 63.52% from 57.83%. These results suggest that while modification enhances carbohydrate enrichment and potential industrial applications (e.g., bioethanol, starch-based products), it compromises nutritional quality by reducing proteins, minerals, and dietary fiber. Sensory evaluation of pearl millet bread showed that the control bread (100% PM) had superior acceptability across color, aroma, taste, and overall preference. Supplementation with low levels of AYB (5–10%) produced acceptable breads with improved texture and moderate consumer approval. However, higher inclusion levels ($\geq 15\%$) negatively impacted sensory properties, with bitterness, dense texture, and undesirable aftertaste lowering overall acceptability. The optimal formulation was achieved at 5–10% AYB substitution, balancing improved protein and fiber contributions with sensory acceptability. In conclusion, modification of resistant starches in AYB and PM alters their proximate composition toward carbohydrate dominance but at the cost of protein and mineral losses. For food applications, moderate AYB incorporation into pearl millet bread ($\leq 10\%$) is recommended to enhance nutritional quality without compromising consumer preference, while higher substitution levels or extensive modifications may be more suitable for industrial rather than direct dietary use.

Keywords: African Yam Bean, Pearl millet, resistant starch, Sensory properties.

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1. Introduction

The global food system is currently experiencing rapid changes driven by population growth, evolving dietary habits, and greater recognition of the link between nutrition and overall wellbeing [1]. These changes have emphasized the need to identify new and sustainable sources of nutrients that can improve food security, enhance diet quality, and widen staple food options. Among such nutrients, resistant starch (RS) has gained much scientific and industrial attention because of its distinctive nutritional, functional, and health-promoting attributes [2].

Starch is the primary source of carbohydrates in the human diet and occurs in a variety of plant structures such as seeds, tubers, rhizomes, fruits, and roots. It is composed of two polymers—amylose and amylopectin whose proportions affect both digestibility and functional behavior [3].

Based on digestion patterns, starch is grouped into rapidly digestible starch (RDS), slowly digestible starch (SDS), and resistant starch (RS). RS differs from other fractions because it escapes digestion in the small intestine and is instead fermented in the colon, where it produces short-chain fatty acids that support gut health [4]. This property enables RS to function much like dietary fiber, offering several physiological advantages, including improved glucose regulation, cholesterol reduction, decreased colon cancer risks, better mineral absorption, and beneficial effects on gut microbiota [5].

Resistant starch is further classified according to its resistance mechanism: RS1 (physically inaccessible starch), RS2 (native granular starch), RS3 (retrograded starch), and RS4 (chemically modified starch) [2]. Factors such as the amylose-to-amylopectin ratio, granule crystallinity, and processing methods strongly influence RS formation and digestibility. To improve RS yield and performance, various modification techniques including hydrothermal treatments, retrogradation, acetylation, cross-linking, and enzymatic hydrolysis are often employed [6]. However, the use of native starch in food processing is restricted due to its tendency to form undesirable gels and pastes, which makes modification necessary for broader industrial applications [7].

Underutilized cereals and legumes provide promising sources of RS, yet their potential remains underexplored. African yam beans, a legume known for its high protein and dietary fiber content, and pearl millet, a drought-tolerant cereal rich in energy and micronutrients, are especially significant in sub-Saharan Africa but are still largely overlooked in research and development [10]. African yam beans offer advantages such as a low glycemic index and gluten-free applications, while pearl millet plays a vital role in food security due to its adaptability to harsh environments. Despite these benefits, limited studies have investigated the nutritional and functional properties of resistant starches from these crops, especially within Nigeria [11].

Another important aspect is consumer acceptance, which influences the success of RS-based food products. Sensory attributes such as flavor, texture, and overall acceptability are key determinants in their integration into daily diets [8]. Therefore, evaluating the sensory qualities of pearl millet-based foods, alongside analyzing the nutritional composition of modified and unmodified resistant starches from African yam beans and pearl millet, is critical for understanding their application in food systems [9].

In this context, the present study aims to analyze the nutritional composition of modified and unmodified resistant starches obtained from African yam beans and pearl millet, while also assessing the sensory characteristics of pearl millet-based products.

2. Materials and Methods

2.1 Sample Collection and Preparation of Resistant Starch of Modified and Unmodified African Yam Beans and Pearl Millet

The African yam bean and pearl millet, were purchased from a nearby market in Jalingo, Taraba State. The beans and grains went through a screening procedure to get rid of any damaged goods and dust particles in order to guarantee the quality of the samples. The samples have their seed coats physically removed after the first screening. Two groups, one for each sample modified and one for the unmodified were produced. A blender was used to grind the altered samples.

The modified portion was ground, then mixed with sodium sulphite and dried in an oven at 45 °C. The unaltered samples undergo parallel oven drying at the same 45 °C following grinding. Until they are ready for use, the modified and unmodified flour samples were kept apart in polythene bags and kept in a refrigerator at 4 °C.

2.2 Proximate Analysis (AOAC, 2000)

2.2.1 Determination of Moisture Content

2.0 grams of the sample were accurately weighed into a previously cleaned, dried and weighed crucible. The crucible with its content was put into a Gallenkamp drying oven at 105 °C for 3 hours. The sample was then cooled in desiccators and weighed. The process was repeated until a constant weight was obtained. The loss in weight expressed as a percentage of the initial weight of the sample gave the percent moisture.

$$\% \text{Moisture} = \frac{(\text{weight of wet sample} - \text{weight of dry sample}) \times 100}{\text{Weight of wet sample}}$$

2.2.2 Determination of Ash Content

1 gram of the samples was weighed into a clean dried and cooled crucible. It was incinerated in a furnace at 550 to 600 °C for 3 hours. It was removed and allowed to cool in desiccators and weighed again. The percentage ash content was calculated as:

$$\% \text{Ash content} = \frac{\text{weight of ash (g)} \times 100}{\text{weight of original sample}}$$

2.2.3 Crude Protein Content Determination

2.0 g of the sample was weighed into a digestion flask containing 0.5 g of selenium catalyst. 25 cm³ of concentrated H₂SO₄ was added and the contents were thoroughly mixed. The flask was heated on a digestion burner for 8 hours until the solution was green and clear. The solution was transferred into a 100 cm³ volumetric flask and made up to the mark with distilled water. 25 cm³ of 2% boric acid was pipette into a 250 cm³ conical flask and 2 drops of mixed indicator (20 cm³ of bromocresol green and 4 cm³ of methyl red) solution were added. 10 cm³ of the digested sample solution was then introduced into a Kjeldahl flask, the condenser tip of the distillation apparatus containing 15 cm³ of 40% NaOH was dipped into the boric acid contained in the conical flask. The ammonia in the sample solution was distilled into the boric acid until it became bluish green. The distillate was titrated with 0.1M HCl solution colorless end point. The percent total nitrogen and crude protein were calculated.

$$\% \text{Total nitrogen} = \frac{(100 \times (VA - VB) \times M \times 0.01401)}{10W} \times 100$$

Where:

VA = volume (cm³) of HCl used in the sample titration

VB = volume (cm³) of HCl used in the blank titration

M = Molarity of HCl

W = weight of sample (g)

% Crude protein = % nitrogen x 6.25

2.2.4 Crude Fiber Content Determination

2.0 g of the defatted sample (from crude fat determination) was transferred into a 250 cm³ Erlenmeyer flask and 2.5 cm³ of 1.25% H₂SO₄ was added. The content of the flask was boiled under reflux and digested for 30 minutes. At the end of the 30 minutes, the content was filtered and subsequently washed with boiling water until the washings were no longer acidic using blue litmus paper.

The sample was washed back into the flask with 200 cm³ boiling 1.25% NaOH solution and boiled for 30 minutes. It was then be filtered and thoroughly washed with boiling water until the washings was no longer be alkaline using red litmus paper. The crucible with its content was dried in an oven at 105 °C overnight and cooled in desiccators and weighed. The crucible with its content was ignited in a furnace at 600 °C for 30minutes, cooled and weighed. The loss in weight was expressed as a percentage of the initial weight of the sample.

$$\text{Crude fiber (\%)} = \frac{(\text{Wt. of crucible + sample before ignition}) - (\text{weight of crucible + ash}) \times 100}{\text{Weight of fresh sample}}$$

2.2.5 Determination of Crude Lipid Content

5 g of the sample was weighed into the extraction thimble, and about 50 cm³ of petroleum ether (40 – 60 °C) was added to the extraction flask. A condenser was fixed at the top of the extractor. The flask was fitted into the extraction unity and refluxed to about 60 °C for 6 hours. The ether extract was evaporated on an evaporating bath until the lipid will be solvent-free. This was dried in an oven at 100 °C for 1 hour, cooled in a desiccator and weighed. The lipid was stored in plastic containers for further analysis.

$$\% \text{Total nitrogen} = \frac{(\text{weight of beaker + lipid}) - (\text{weight of beaker}) \times 100}{\text{Sample weight}}$$

2.2.6 Carbohydrate Content Determination

Total percentage carbohydrate (Nitrogen Free Extract) was determined by the difference method as reported by Oyeyinka *et al.*, [2]. This method involves adding the total values of crude protein, crude fat, crude fiber, moisture and ash constituents of the sample and subtracting it from 100. The value obtained was the percentage carbohydrate.

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

2.2.7 Sensory Properties Evaluation

Sensory evaluation was carried out using a 10-man untrained panellist to access the organoleptic attributes of the prepared samples. The organoleptic attributes assessed were; taste, aroma, appearance, after taste, texture, and general acceptability. The panellists were selected randomly from the students of Taraba State University, Jalingo. The sensitivity evaluation was conducted using a 9-point hedonic scale, where the scoring scale ranged from 9 = liked extremely and to 1 = disliked extremely.

3. Results and Discussion

3.1 Nutritional Analysis of Modified and Unmodified Resistant Starch of African Yam Bean (AYB)

As seen in Table 1 and Figure 2, the nutritional profiles of modified and unmodified resistant starch of African Yam Beans (AYB) change significantly based on their proximate makeup. Modified AYB has a moisture content of 6.14%, whereas the unmodified RS of AYB contains 10.2%. Modified AYB's reduced moisture content points to the need for processing techniques such as acetylation treatments to increase shelf stability. Microbial growth is inhibited by reduced moisture, which is consistent with methods for prolonging storage life in modified legumes.

However, research on heat-treated Bambara groundnuts has shown that excessive drying might degrade texture [13]. Modified RS of AYB has a fat content of 0.93±0.03%, whereas unmodified RS of AYB has a fat value of 9.5±0.29%. Modification activities are probably the cause of the modified AYB's sharp 90% reduction in fat content. Similar patterns may be seen in defatted cowpea and soybean flours, where the removal of fat improves the concentration of carbohydrates for particular culinary uses. However, as has been shown in lipid-reduced legume products, this reduces energy density and the preservation of fat-soluble vitamins [14].

Modified and unmodified resistant starch of AYB have crude fiber contents of 0.23±0.03% and 1.9±0.05%, respectively. The significant decrease in fiber (about 88% reduction) suggests that fibrous components were removed, maybe by milling or dehulling. This increases palatability and digestibility but decreases the advantages of dietary fiber, including its ability to promote gut health. Similar fiber loss was noted in recent studies on modified pigeon pea, indicating a general disadvantage of rigorous processing [12].

Modified and unmodified resistant starch of AYB have protein contents of 8.03±0.09% and 21.4±0.63%, respectively. The protein decrease of 73% is remarkable and unusual for the majority of alteration techniques. This implies severe processes that denature or leach proteins, such as high heat or alkaline hydrolysis. This extreme is uncommon in the literature on fermented or extruded legumes, which usually find modest protein losses (10–30%) [15].

Modified and unmodified AYB have ash contents of 1.2±0.02% and 2.3±0.08%, respectively. Modified RS of AYB's reduced ash percentage suggests that minerals were lost during processing, maybe as a result of leaching or washing. Ash reduction is consistent with research on polished grains, where the outer layers rich in minerals are removed during milling. This lowers the nutritional value, especially for iron and zinc, which are essential for diets based on legumes [16].

Modified RS of AYB has 83.6±0.1% carbs, whereas unmodified AYB contains 54.8±0.89%. Modified RS of AYB has a greater carbohydrate content since it has less fat, protein, and fiber. This is consistent with changes aimed at starch enrichment for uses such as the manufacturing of bioethanol or gluten-free flours. However, compared to conventional modified legumes, which have more balanced macronutrient profiles, the significant carbohydrate dominance (83.6%) stands out. Modified RS of AYB has a significantly changed proximate composition, with significant decreases in protein, fat, fiber, and ash and increased carbohydrate content (83.6%). This profile restricts its nutritional value for direct food consumption, even if it could be appropriate for industrial purposes (such as biofuels or starch-based adhesives) [17].

Table 1: Nutritional Analysis of Modified and Unmodified Resistant Starch of African Yam Bean

% Content	Modified AYB	Unmodified AYB
Moisture content	6.10 ^a ± 0.03	10.20 ^b ± 0.26
Fat content	0.90 ^c ± 0.03	9.50 ^b ± 0.29
Crude fibre	0.20 ^c ± 0.03	1.90 ^c ± 0.05
Protein content	8.00 ^a ± 0.09	21.40 ^b ± 0.63
Ash content	1.20 ^a ± 0.02	2.30 ^b ± 0.08
Carbohydrates	83.60 ^c ± 0.1	54.80 ^d ± 0.89

Data are mean ± standard deviation of triplicate determinations.

Source: Author's Field Work, 2025

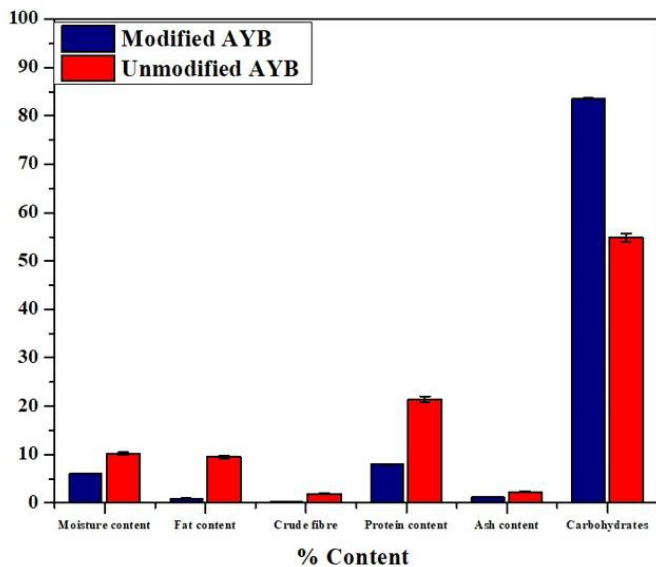


Figure 1: Nutritional Analysis of Modified and Unmodified Resistant Starch of African Yam Bean

Source: Author's Field Work, 2025

3.2 Nutritional Analysis of Modified and Unmodified Resistant Starch of Pearl Millet (PM)

Table 2 and Figure 2 shows the proximate composition of modified and unmodified RS of Pearl Millet (PM). Modified and unmodified resistant starch of PM have respective moisture contents of $6.33 \pm 0.41\%$ and $8.50 \pm 0.35\%$. Modified PM's reduced moisture content points to the need for thermal treatments to improve shelf stability. Similar patterns have been noted in heat-treated millet, where a decrease in moisture prolongs storage life and prevents microbiological growth. Modified and unmodified PM have fat contents of $1.33 \pm 0.41\%$ and $1.67 \pm 0.41\%$, respectively. Mild processing, such as milling, which partially eliminates lipid-rich germ layers, may be the cause of the minor fat decrease. This is consistent with research that shows a little reduction in fat in millet that has been mechanically processed [18].

Modified and unmodified resistant starch of PM have crude fiber contents of $2.83 \pm 0.53\%$ and $3.50 \pm 0.35\%$, respectively. The elimination of bran during refining is shown by the 19% fiber reduction. Modified and unmodified PM have ash contents of $1.17 \pm 0.18\%$ and $2.50 \pm 0.35\%$, respectively. The 53% drop in ash indicates a loss of minerals, most likely as a result of the removal of iron, zinc, and magnesium-rich bran and germ layers. The decreases in fiber and ash are consistent with research on polished millet, where refining improves texture and digestibility at the expense of nutrients [18].

Modified and unmodified resistant starch of PM have protein contents of $8.75 \pm 0.03\%$ and $13.12 \pm 0.25\%$, respectively. Aggressive techniques like alkaline hydrolysis or high heat may denature proteins, as shown in overcooked millet products, but extrusion or fermentation normally maintains protein (da Rosa, 2008). This implies that carbohydrate enrichment takes precedence over protein retention during the modification process.

Modified and unmodified resistant starch of PM have carbohydrate contents of $63.52 \pm 0.56\%$ and $57.83 \pm 0.52\%$, respectively. As other components are gradually reduced, Modified PM has a greater carbohydrate content. This is consistent with starch-focused changes for uses such as industrial starch extraction or gluten-free flours. The higher carbohydrate content is consistent with post-processing patterns in maize and modified sorghum, where starch takes

over as the predominant component [11]. Moisture, fat, fiber, protein, and ash are all lower in modified PM, whereas carbs are up to 63.5%. Although this profile could be appropriate for industrial applications (such as starch-based goods), its usefulness for direct human consumption is limited by the nutritional trade-offs, particularly the loss of protein and minerals.

Table 2: Nutritional Analysis of Modified and Unmodified Resistant Starch of Pearl Millet

% Content	Modified PM	Unmodified PM
Moisture content	6.33± 0.41	8.50± 0.35
Fat content	1.33± 0.41	1.67± 0.41
Crude fibre	2.83± 0.53	3.50± 0.35
Protein content	8.75± 0.03	13.12± 0.25
Ash content	1.17± 0.18	2.50± 0.35
Carbohydrates	63.52± 0.56	57.83± 0.52

Data are mean ± standard deviation of triplicate determinations.

Source: Author's Field Work, 2025

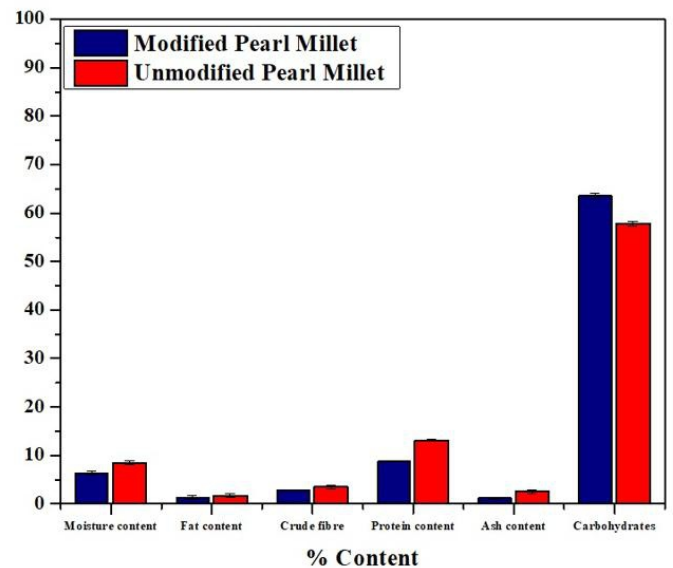


Figure 2: Proximate Composition of Modified and Unmodified Resistant Starch of Pearl Millet

Source: Author's Field Work, 2025

3.3 Sensory Attributes of Pearl Millet Bread

The sensory evaluation of control bread (100% pearl millet flour, T0) and bread supplemented with 5%–100% African yam bean (AYB) flour (T1–T5) is shown in Table 4.28. The attributes evaluated are color, aroma, taste, aftertaste, texture, and overall acceptability, and they are rated on a Likert scale (likely 1–7, where higher scores indicate better acceptability). The bread darkened as the AYB content increased, probably due to Maillard reactions and natural pigments in legumes. The aroma showed that T0 (5.66) had the strongest aroma, while T3–T5 (≤ 3.22) declined sharply. Pearl millet has a distinct nutty aroma, whereas AYB may introduce beany or earthy notes, which are less preferred by consumers.

According to the taste test, T0 (5.48) was the most favored and T5 (2.08, 100% AYB) was the least favored. At greater doses, AYB's bitter or astringent taste (caused by polyphenols and saponins) probably decreased palatability. T0 (5.40) had the strongest aftertaste, but T4–T5 (≤ 2.00) had persistently unpleasant aftertastes. Anti-nutritional elements included in legumes, such as tannins, can make food taste bitter or dry after eating. According to the texture, T5 (2.68) had the worst texture, while T1 (5.82, 5% AYB) had the nicest. Because of protein-water interactions, low AYB (5–10%) may make the crumb softer, but high AYB ($\geq 15\%$) increases fiber and produces denser, drier textures.

According to a study, adding more than 10% of bean flour increases hardness and decreases loaf volume. In terms of overall acceptability, T0 (5.68) is greater than T1–T2 (~5.20–5.28) and T3–T5 (≤ 3.62). At $\geq 15\%$ AYB, acceptability sharply declined (T3). The ideal AYB level of 5–10% (T1–T2) improved nutritional value while preserving tolerable sensory qualities. Although AYB flour increases the amount of protein and fiber, its sensory impact restricts its acceptability to less than 10% to 15%. To boost adoption, consumers should be educated about the nutritional advantages. Table 3: Sensory Attributes of Pearl Millet and African Yam Beans Bread

Table 3: Sensory Attributes of Pearl Millet and African Yam Beans Bread

Parameters	T0	T1	T2	T3	T4	T5
Colour	5.14 $\pm$ 0.66 ^{cd}	5.60 $\pm$ 0.82 ^d	4.68 $\pm$ 0.75 ^c	4.92 $\pm$ 0.86 ^c	3.72 $\pm$ 1.02 ^b	3.00 $\pm$ 0.71 ^a
Aroma	5.66 $\pm$ 0.77 ^c	4.80 $\pm$ 0.82 ^{bc}	4.74 $\pm$ 0.99 ^b	3.22 $\pm$ 1.17 ^a	2.48 $\pm$ 0.87 ^a	2.78 $\pm$ 1.07 ^a
Taste	5.48 $\pm$ 0.92 ^c	5.04 $\pm$ 0.84 ^c	4.84 $\pm$ 0.80 ^c	3.32 $\pm$ 0.90 ^b	2.56 $\pm$ 0.96 ^a	2.08 $\pm$ 0.95 ^a
Aftertaste	5.40 $\pm$ 0.96 ^c	4.10 $\pm$ 0.87 ^b	4.30 $\pm$ 1.15 ^b	2.60 $\pm$ 1.04 ^a	2.00 $\pm$ 1.08 ^a	1.92 $\pm$ 0.95 ^a
Texture	5.12 $\pm$ 1.17 ^{bc}	5.82 $\pm$ 0.89 ^c	5.06 $\pm$ 0.98 ^{bc}	4.48 $\pm$ 1.08 ^b	3.32 $\pm$ 1.25 ^a	2.68 $\pm$ 1.11 ^a
Overall Acceptability	5.68 $\pm$ 0.56 ^d	5.20 $\pm$ 0.41 ^d	5.28 $\pm$ 0.54 ^d	3.64 $\pm$ 0.81 ^c	2.76 $\pm$ 0.72 ^b	2.12 $\pm$ 0.60 ^a

T0: Control bread prepared by using pearl millet flour only (100%); T1: bread supplemented with 5% of African yam beans (legume) flour; T2: bread supplemented with 10% of African yam beans (legume) flour; T3: bread supplemented with 15% of African yam beans (legume) flour; T4: bread supplemented with 20% of African yam beans (legume) flour; T5: with 100% of African yam beans (legume) flour.

Values are mean $\pm$ standard deviation ($n=30$). Means with different superscript letters within the same row differ significantly ($P < 0.05$).

Source: Author's Field Work, 2025

Conclusion

The findings of this study demonstrate that modification of resistant starches in African yam bean (AYB) and pearl millet (PM) significantly alters their nutritional composition, with clear trade-offs between carbohydrate enrichment and the loss of other essential nutrients. In both AYB and PM, modification consistently reduced moisture, fat, crude fiber, protein, and ash contents, while carbohydrate content increased substantially. This trend reflects the effectiveness of modification processes such as acetylation, hydrolysis, or heat treatment in producing starch-enriched fractions suitable for industrial applications, including starch-based adhesives, bioethanol production, and gluten-free formulations. However, the considerable reductions in protein, dietary fiber, and minerals highlight a major limitation for their direct use as balanced food ingredients, since these nutrients are critical for supporting human health, particularly in populations that rely heavily on legumes and cereals as staple foods.

In terms of food application, the sensory evaluation of pearl millet bread supplemented with AYB flour revealed that consumer acceptability is highly dependent on the level of substitution. Low inclusion levels (5–10%) of AYB improved nutritional value by contributing additional protein and fiber, while maintaining acceptable sensory qualities such as color, texture, and overall palatability. At higher substitution levels ($\geq 15\%$), however, the bread suffered from darker coloration, bitter or astringent flavors, unpleasant aftertaste, and dense texture, which significantly reduced consumer preference. These outcomes suggest that while AYB has strong nutritional potential, its sensory limitations constrain its use in high proportions in composite food products.

Generally, the study concludes that the modification of resistant starches from AYB and PM enhances their carbohydrate concentration, making them valuable for industrial purposes, but reduces their suitability as direct dietary sources due to nutrient losses. For food product development, particularly in bakery applications, AYB can be incorporated into pearl millet-based products at low levels (5–10%) to achieve a balance between improved nutritional quality and consumer acceptability. Future research should focus on optimizing modification techniques that retain higher levels of protein, fiber, and minerals, while also exploring strategies such as

fermentation, enzyme treatments, or blending with other grains to improve sensory qualities and expand the utilization of these underutilized crops in functional and staple foods.

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