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Microbial Stability and Sensory Persistence of an Enriched Cereal-Legume-Plantain Flour Blend During Ambient Storage: Implications for Food Security

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Abstract- This study investigated the ambient storage stability of a novel composite flour blend formulated from toasted yellow maize (Zea mays), Bambara groundnut (Vigna subterranea), and firm ripe plantain (Musa paradisiaca). The research aimed to determine the safe shelf-life and consumer acceptability persistence of the product under conditions typical of resource-constrained settings. Six flour blends, ranging from 100% maize (control) to a 50:50 ratio of maize and a Bambara/plantain composite, were packaged in polyethylene bags and stored at 28±2°C for eight weeks. Microbiological quality (total mold and coliform counts) and sensory attributes (appearance, aroma, mouth feel, consistency, and overall acceptability) were evaluated bi-weekly. Results indicated that coliform counts remained negligible (<10^2 cfu/g) throughout the storage period, confirming good hygienic production. Total mold counts, however, showed a time-dependent increase, remaining within the acceptable safety limit of ≤1x10^4 cfu/g for up to six weeks before exceeding this threshold in subsequent weeks. Sensory evaluation revealed a gradual decline in all hedonic scores over time. Despite this, the fortified blends, particularly those with 40% and 50% composite flour (AJD5 and AJD6), maintained significantly higher acceptability scores, ending the storage period at "liked slightly" to "liked moderately" levels (5.90-6.50 on a 7-point scale). The control sample exhibited a more rapid decline in sensory quality. The study concludes that the enriched cereal-legume-plantain flour blend maintains microbiological safety for six weeks and acceptable sensory quality for at least eight weeks under ambient storage. This extended shelf-life, coupled with sustained consumer preference for fortified blends, underscores the product's practical utility and potential to enhance food security by providing a stable, nutritious, and acceptable food base in environments without refrigeration.

Keywords: Shelf-life, Microbial Safety, Sensory Evaluation, Composite Flour, Food Security, Ambient Storage.

I. INTRODUCTION

Food security is a multidimensional concept that includes the stable availability, access, utilization, and stability of food supplies over time. In many developing regions, achieving stability is severely hindered by inadequate storage infrastructure, leading to significant post-harvest losses of nutritious foods, particularly perishable commodities like legumes and fruits. The development of nutrient-dense composite flours from locally available crops presents a strategic approach to improving dietary quality and combating malnutrition. Such blends, often combining cereals with protein-rich legumes and vitamin-rich fruits, aim to correct the nutritional deficiencies inherent in single-cereal diets. However, the successful integration of these value-added products into food systems is critically dependent on their stability during storage under real-world, ambient conditions commonly found in target communities.

Apula, a traditional toasted maize-based beverage or porridge flour, is widely consumed in Nigeria but is nutritionally limited. Previous research has demonstrated that its enrichment with Bambara groundnut and plantain flours significantly enhances its proximate, mineral, and vitamin profiles. While the initial quality of such fortified products is well-documented, data on their storage stability—a key determinant of practical adoption, commercial viability, and impact on food security—remains sparse. The higher nutrient and moisture content of composite flours can unfortunately predispose them

to faster degradation through microbial spoilage and oxidative rancidity. Therefore, assessing the safe storage window and the persistence of sensory acceptability is not merely an academic exercise but a necessity for implementation.

This study was designed to fill this gap by systematically evaluating the ambient storage stability of an enriched Apula formulation. The specific objectives were to: (i) monitor the microbial safety of the composite flour blends by assessing total mold and coliform counts over an 8-week period, and (ii) evaluate the persistence of key sensory attributes to determine consumer acceptability throughout storage. The findings from this work provide essential evidence-based guidelines for the handling, storage, and potential commercialization of this nutritious food product, directly contributing to strategies aimed at improving food and nutrition security in sub-Saharan Africa.

II. MATERIALS AND METHODS

Raw Material Procurement and Flour Preparation
Yellow maize grains, Bambara groundnut seeds, and firm ripe plantain fruits were purchased from the central market in Anyigba, Kogi State, Nigeria. The maize and Bambara groundnut were sorted, cleaned, and toasted in a dry pan at 150-180°C and 140-160°C, respectively. The toasted materials were cooled, milled using a hammer mill, and sieved through a 500-micron mesh. Plantains were washed, peeled, sliced to 5mm thickness, blanched in hot water at 85°C for 10 minutes, dried in a cabinet dryer at 65°C for 10 hours, milled, and similarly sieved to obtain fine flour.

Experimental Design and Formulation
A Completely Randomized Design (CRD) was employed. A total of six flour blends were formulated as detailed in Table 1. The control (AJD1) was 100% toasted yellow maize flour (TYMF). The composite flour was a 1:1 blend of toasted Bambara groundnut flour (TBGF) and firm ripe plantain flour (FRPF). This composite was substituted for TYMF at levels of 10%, 20%, 30%, 40%, and 50% to create samples AJD2 through AJD6, respectively.

Table -1: Formulation of Composite Flour Blends

Sample Code	Toasted Yellow Maize Flour (TYMF) %	Composite Flour (TBGF:FRPF, 1:1) %
AJD1 (Control)	100	0
AJD2	90	10
AJD3	80	20
AJD4	70	30
AJD5	60	40
AJD6	50	50

Legends: TBGF = Toasted Bambara Groundnut Flour; FRPF = Firm Ripe Plantain Flour.

Storage study setup
Five hundred grams (500g) of each formulated blend were packed into clean, low-density polyethylene (LDPE) bags of 0.08mm thickness. The bags were heat-sealed to minimize air exchange. All samples were stored under ambient laboratory conditions, maintained at a temperature of 28±2°C and relative humidity of 65±5%, for a total duration of eight (8) weeks.

Microbiological Analysis
Microbial assessment was carried out at bi-weekly intervals (i.e., weeks 2, 4, 6, and 8). The total mold count was determined using the pour plate technique on acidified Potato Dextrose Agar (PDA). Plates were incubated at 25°C for 3-5 days, and colonies were counted. Coliform count was determined using the Violet Red Bile Agar (VRBA) method with a double-layer pour plate, incubated at 37°C for 24 hours. Microbial counts were expressed as colony-forming units per gram (cfu/g). The safety thresholds applied were $\leq 1 \times 10^4$ cfu/g for mold count and $< 1 \times 10^2$ cfu/g for coliforms, in accordance with international standards for low-moisture foods.

Sensory Evaluation

Sensory analysis was conducted concurrently with microbial sampling. A panel of twenty (20) semi-trained judges evaluated the products. The flour samples were reconstituted into a porridge using a standardized ratio of 1:4 (flour to water) with 5% sucrose added. The porridges were presented to panelists in random, coded containers. Panelists scored the products for Appearance, Aroma, Mouth feel, Consistency, and Overall Acceptability using a 7-point hedonic scale, where 1 = "Dislike extremely" and 7 = "Like Extremely."

Statistical Analysis

All data generated from microbial counts and sensory evaluation were subjected to one-way Analysis of Variance (ANOVA) using SPSS software (Version 26). Where significant differences ($p < 0.05$) were found, Duncan's New Multiple Range Test was applied to separate the means.

III. RESULTS AND DISCUSSION

Microbial stability during storage

The results of the microbial analysis are pivotal for defining the product's safe shelf-life. Coliform bacteria, indicative of hygiene and potential fecal contamination, were not detected (0.00 x 10^4 cfu/g) in any sample during the first six weeks of storage. Only at the 8-week interval were minimal counts recorded in samples AJD5 (0.23 x 10^4 cfu/g) and AJD6 (0.12 x 10^4 cfu/g), values which still remained below the critical hazard limit of 10^2 cfu/g. This demonstrates that the thermal processing (toasting) and hygienic packaging effectively minimized initial bacterial load and prevented significant contamination throughout the study period.

The dynamics of mold growth, a primary spoilage mechanism for stored flours, presented a clear pattern. As shown in Table 2, all samples began with very low or negligible mold counts (<0.10 x 10^4 cfu/g). A progressive increase was observed over time. By weeks 3-4, counts had risen but largely remained at or near the 1 x 10^4 cfu/g safety threshold. However, by the 6th and 8th weeks, several samples, most notably the control (AJD1) and AJD3, exceeded this limit, with counts reaching up to 1.75 x 10^4 cfu/g. This trend establishes a conservative safe ambient shelf-life of approximately six weeks for the product when stored in polyethylene bags. The increase is attributable to the flour's residual moisture content (5.74-7.85%), ambient humidity, and the nutrient-rich matrix that supports fungal proliferation over time.

Table -2: Total Mold Count (x 10^4 cfu/g) of flour blends during storage

Storage Period (Weeks)	AJD1	AJD2	AJD3	AJD4	AJD5	AJD6
1-2	0.10	0.00	0.05	0.00	0.02	0.00
3-4	0.85	0.70	0.93	0.65	0.78	0.69
5-6	1.65	1.30	1.75	1.15	1.10	1.25
7-8	1.70	1.00	1.63	0.73	0.96	0.83

Acceptable limit: Mold count ≤ 1x10^4 cfu/g.

Sensory Persistence and Acceptability

Sensory quality is a critical driver of consumer adoption and continued use. A gradual but statistically significant ($p<0.05$) decline in all sensory attributes was noted across all blends over the 8-week period. The overall acceptability scores, as a summary measure, are presented in Table 3. The control sample (AJD1) showed a marked decline from 5.55 to 5.35. In contrast, the fortified blends, particularly AJD5 and AJD6, demonstrated remarkable sensory persistence. AJD5 maintained the highest score of 6.55 at the start and still scored 6.50 at the end of the storage period, while AJD6 scored 6.05 and 5.90, respectively.

Table -3: Sensory Evaluation (Overall Acceptability)

Blends	Week 1-2	Week 3-4	Week 5-6	Week 7-8
AJD1	5.55	4.94	4.85	5.35
AJD2	5.70	4.90	5.45	5.45
AJD3	6.10	4.77	5.30	5.70
AJD4	6.35	6.05	6.05	6.30
AJD5	6.55	5.69	5.90	6.50
AJD6	6.05	5.65	5.70	5.90

Scale: 1=Dislike Extremely, 4=Neither Like nor Dislike, 7=Like Extremely.

Attributes such as aroma and mouth feel were most resilient in the high-substitution blends. This is likely due to the stable, pleasant roasted notes from the toasted Bambara groundnut and the inherent sweetness from the ripe plantain, which helped mask potential storage-induced off-flavors. The superior performance of blends AJD5 and AJD6 indicates that fortification not only improves nutrition but also enhances the sensory shelf-life of the product, a key factor for sustained consumer preference.

IV. CONCLUSION

This study successfully evaluated the ambient storage stability of an enriched cereal-legume-plantain composite flour. The key findings indicate that the product maintains microbiological safety for a period of six weeks, with coliforms absent and mold counts within acceptable limits during this time. Furthermore, the flour retains acceptable sensory quality for at least eight weeks, with fortified blends (especially 60% maize: 40% composite) showing superior and persistent consumer acceptability compared to the plain maize control. The demonstrated 6-week safe shelf-life, achievable with simple polyethylene packaging under typical tropical conditions, is highly significant for practical application. It confirms the potential of this enriched flour to serve as a stable, nutritious, and palatable food resource in settings lacking cold storage infrastructure. For optimal impact, it is recommended that the blend with 40% composite flour (AJD5) be prioritized for scale-up, and future work should explore cost-effective hermetic packaging to potentially extend the microbial shelf-life beyond six weeks.

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