International Journal of Biotechnology and Microbiology
www.biotechnologyjournals.com
Online ISSN: 2664-7680
Received: 02-12-2025, Accepted: 01-01-2026, Published: 16-01-2026
Volume 8, Issue 1, 2026, Page No. 10-15

Mycological quality of packaged and unpackaged plantain flour

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Abstract
Plantain flour, derived from *Musa paradisiaca*, serves as a vital staple in West African diets, offering rich nutritional benefits such as high carbohydrates, dietary fiber, and potassium. However, its production and storage are prone to fungal contamination, leading to spoilage, nutrient degradation, and health risks from mycotoxins. This study investigated the mycological quality of packaged and unpackaged plantain flour samples sourced from Swali Market in Yenagoa, Bayelsa State, Nigeria, to assess the impact of packaging on fungal proliferation and diversity. Samples were collected and analyzed in the microbiology laboratory at Niger Delta University using standard protocols, including serial dilution, pour plate techniques for enumeration on nutrient media (e.g., Nutrient agar, Potato Dextrose Agar implied for fungi), and biochemical/morphological identification of isolates. Fungal populations were enumerated as colony-forming units per gram (CFU/g), with statistical comparisons via t-tests or ANOVA to determine significance ($P < 0.05$). Results indicated significantly higher fungal loads in unpackaged samples, ranging from $0.32 \pm 0.04 \times 10^2$ CFU/g (Sample C) to $0.41 \pm 0.06 \times 10^2$ CFU/g (Sample A), compared to packaged samples at $0.24 \pm 0.07 \times 10^2$ CFU/g (Sample C) to $0.34 \pm 0.04 \times 10^2$ CFU/g (Sample A), reflecting elevated contamination risks from environmental exposure. Seven fungal genera were identified: *Aspergillus* sp., *Penicillium* sp., *Rhizopus* sp., *Fusarium* sp., Rhodotorula sp., Alternaria sp., and Yeast sp., with unpackaged samples exhibiting greater diversity and higher isolation frequencies (e.g., Yeast at 32 occurrences, *Penicillium* at 12) versus packaged samples (Yeast at 20, *Rhizopus* at 16). These disparities underscore packaging's role in mitigating airborne spores, humidity, and handling-induced contamination, potentially reducing mycotoxin production by toxigenic species like *Aspergillus* and *Fusarium*. The findings align with ICMSF standards, emphasizing the need for improved hygiene, moisture-resistant packaging, and regular microbial monitoring to enhance shelf life and public health safety in tropical markets. Future research should quantify mycotoxins and evaluate advanced preservation methods.

Keywords: Plantain flour, mycological quality, fungal contamination, packaging effects, *Aspergillus*, *Penicillium*, *Rhizopus*, mycotoxins, food safety, West Africa

Introduction

Plantain flour, derived from the starchy fruit of the plantain plant (*Musa paradisiaca*), is a staple food product in many tropical regions, particularly in West Africa, where it is used to prepare dishes like fufu, amala, or baked goods (Oku & Oyadougha, 2024) [10]. The production process typically involves peeling, slicing, drying, and milling unripe or semi-ripe plantains into a fine powder (Honfo *et al*., 2022) [5]. This flour is valued for its nutritional content, including high levels of carbohydrates, dietary fiber, and minerals like potassium, but its shelf life and safety can be compromised by microbial contamination, especially from fungi (Oku & Oyadougha, 2024) [10].

Mycological quality refers to the assessment of fungal presence, growth, and associated risks in a food product. Fungi, including molds and yeasts, are ubiquitous in the environment and can contaminate flour during harvesting, processing, drying, storage, or retailing (Deligeorgakis *et al*., 2023) [3]. Key concerns include spoilage, which affects sensory properties like color, texture, and flavor, and the production of mycotoxins—toxic secondary metabolites that pose health risks such as immunosuppression, carcinogenicity, and acute poisoning (Maduka & Ugbogu, 2024) [6]. Common fungal genera in flours include *Aspergillus*, *Penicillium*, *Rhizopus*, and *Fusarium*, which thrive in warm, humid conditions typical of plantain-producing areas (Deligeorgakis *et al*., 2023) [3].

The mycological quality of plantain flour is critical for food safety and public health. Uncontrolled fungal growth can lead to reduced nutritional value, as molds degrade proteins, fats, and carbohydrates, and introduce allergens or pathogens (Oku & Oyadougha, 2024) [10]. In regions like Nigeria, where plantain flour is commonly sold in open markets, contamination is exacerbated by poor hygiene, insect vectors, dust, and improper handling (Aruwa & Ogundare, 2017) [1]. Regulatory standards, such as those from the International Commission on Microbiological Specifications for Foods (ICMSF), recommend fungal counts below 10^3 CFU/g for safe consumption, but many samples exceed this, highlighting the need for better processing and storage practices (Odu *et al*., 2019) [8].

A key factor influencing mycological quality is packaging. Packaged plantain flour, often sealed in polyethylene bags or aluminum foil, provides a barrier against environmental contaminants, moisture, and oxygen, which can inhibit fungal proliferation (Honfo *et al*., 2022) [5]. In contrast, unpackaged (exposed) flour, displayed openly in markets, is more susceptible to airborne spores, handling by vendors, and humidity fluctuations, leading to higher fungal loads (Mbata *et al*., 2022) [7]. Studies consistently show that exposure increases contamination risks, potentially rendering the product unsafe (Odu *et al*., 2019) [8].

Empirical findings underscore these differences. For instance, in a study from Port Harcourt, Nigeria, exposed plantain flour exhibited mean heterotrophic microbial counts (including fungi) of 7.2 × 10^5 CFU/g, compared to 0.36 × 10^5 CFU/g in packaged samples (Odu *et al*., 2019) [8]. Fungal isolates identified included *Aspergillus* sp. and

Microsporum sp., with higher prevalence in exposed flour due to unhygienic retailing (Odu *et al*., 2019) [8]. Another analysis reported total fungal counts (TFC) ranging from 2.30-3.10 $\log_{10}$ CFU/g in packaged plantain flour, while exposed samples showed elevated levels, often exceeding safe thresholds (Odu *et al*., 2019) [8]. Cited fungal species in plantain flour include *Rhizopus oryzae* (38.5%) and *Aspergillus niger* (61.5%), with potential for aflatoxin production (Aruwa & Ogundare, 2017) [1]. Additional research on market-sold plantain flour found fungal counts up to 3.1 × 10^4 SFU/ml, with dominant species like *Penicillium crustosum*, *Penicillium chrysogenum*, *Rhizopus oryzae*, and *Aspergillus niger*, though direct packaging comparisons were limited (Aruwa & Ogundare, 2017) [1]. Bacterial studies, while not purely mycological, corroborate that unpackaged flour has higher overall microbial loads (e.g., 6.01 × 10^2 CFU/g vs. 4.52 × 10^2 CFU/g in packaged), implying similar trends for fungi (Oku & Oyadougha, 2024) [10].

Mycotoxins add another layer of concern. Fungi like *Aspergillus* can produce aflatoxins, which are hepatotoxic and carcinogenic, with higher risks in humid storage conditions common for unpackaged flour (Maduka & Ugbogu, 2024; Okafor & Eni, 2018) [6, 9]. Reviews of swallow meals (including plantain-based products) highlight mycotoxin prevalence, emphasizing the need for moisture control and proper packaging to mitigate risks (Maduka & Ugbogu, 2024) [6].

In summary, while plantain flour offers nutritional benefits, its mycological quality is heavily influenced by packaging. Packaged flour generally maintains lower fungal contamination, extending shelf life and reducing health risks, whereas unpackaged flour's exposure leads to elevated fungal growth and potential toxin accumulation (Honfo *et al*., 2022) [5]. Recommendations include adopting good manufacturing practices, using moisture-resistant packaging, and regular microbial testing to ensure safety (Mbata *et al*., 2022) [7]. Further research is needed on mycotoxin levels specific to plantain flour varieties and storage conditions (Deligeorgakis *et al*., 2023) [3].

Materials and Methods

Sample Area

This study was based on plantain flour samples collected from Swali Market (Yenagoa, Bayelsa State. The flour samples were analysed and processed in the microbiology laboratory at Niger Delta University's Wilberforce Island, Southern Ijaw Local Government Area, Bayelsa State.

Sterilization/Disinfection of Materials

During the bacteriological investigation of the samples, the instruments and materials used in this study were sterilized to detect contamination. The autoclave was used for sterilization. Glassware, nutritional medium, and cotton wool are all included in this category. They were autoclaved at 121^{0}C for 15 minutes at 15 PSI. Droppers and glass rods that couldn't be autoclaved were disinfected with 70% ethanol. The bench was cleaned both before and after each shift using 70% ethanol.

Preparation of Nutrient Media

Autoclaving was utilized to sterilize the nutritional medium in this investigation. The bacterial population of the samples was cultured and counted using Nutrient agar, Cetrimide agar, and MacConkey agar, while faecal and total coliform bacteria were estimated using MacConkey broth. Kliger iron agar was employed to identify lactose and glucose fermentation, gas generation, and hydrogen sulfide formation during biochemical testing of the isolates. Citrate utilization as a carbon source were performed using Simmon citrate agar, Indole production was detected using tryptone water. It was done according to the manufacturer's instructions to dissolve the powder medium in distilled water. The containers were covered by loosened lid with aluminium foil for 15 minutes at 121^{o}C to autoclave the dissolved medium.

Bacteriological Analysis

Standard operating protocols such as determining the data, cleaning the data, etc were used to conduct the quantitative and qualitative investigation of the bacteria found in the flour samples. There were strict guidelines in place for the usage of the chemicals, nutrients, and other equipment.

Enumeration of total heterotrophic bacteria

Nutrient agar was used to estimate the population of the heterotrophic bacteria present in the flour samples. Before plating the flour samples, they were serially diluted. Transferring 5 grams of flour into a test tube filled with 10 ml of 0.85 percent normal saline, the stock culture was created. After a thorough shaking, the stock culture was ready to use. One millilitre of the stock culture was then diluted 1:10 with 9 millilitres of sterile water. A third dilution tube was used for the samples (1:1000). The pour plate technique was used after the third dilution (1ml of the sample was poured into the plates aseptically). It was then poured onto the petri dishes with the help of 20ml of the ready-made molten agar. The dishes were allowed to cool before dispensing (solidify). A 24-hour incubation period at 37^{0}C followed the plates being inverted.

Enumeration of Coliform Bacteria

The coliform count was tallied using a modified version of the most probable number (MPN) approach developed by Ginigaddarage *et al*., (2018) [4]. MacConkey agar was used to count the number of coliform bacteria. 3.4.1 describes the plating procedure that made advantage of the third dilution of the material. The mixture was incubated at 37^0 C for 24 hours.

Enumeration of Pseudomonads

In order to count the Pseudomonas species, the experiment was carried out on a Cetrimide agar. It took 48 hours to incubate the plates at 37^0 Fahrenheit. The reduced growth time of Pseudomonads on Cetrimide agar necessitated a longer incubation period.

Enumeration of total and Faecal Coliform

Following a modified Ginigaddarage *et al*. technique, the third (3rd) dilution was utilized to count faecal and total coliforms (2018). There were three tubes with 10ml each of double strength MacConkey broth, single strength MacConkey broth, and inoculum inoculation, and each tube had 10ml of dilution added to it. The inoculum was then divided into three and added to 10ml each of the three different concentrations. There was a total of nine tubes in each sample. For faecal and total coliform, two sets of tubes

were utilized for each. The faecal and total coliform cultures were maintained at 36^0C and 44^0C, respectively, during the broth cultures. The test tubes were incubated for 48 hours. The Durham tubes were inspected at the conclusion of the incubation time for gas generation and fermentation. An MPN index was used to analyse the outcomes of the positive and negative tubes.

Isolation of Pure Cultures of Bacteria

After the agar plates had been incubated, a random sample of colonies were chosen and removed using a sterile wire loop. Sub-cultured colonies on new nutritional agar plates were produced by streaking the colonies over the agar surface. Purified isolates were obtained by flipping the plates and incubating them at 37^0C in an aerobic environment.

Biochemical characterization and identification of bacterial isolates

Gram Staining Technique

Colonies from several pure culture plates were emulsified on a slide with a drop of distilled water. A drop of the suspended culture was transferred with an inoculation loop to ta microscope slide, and the culture spread on the slides to an even thin film over a circle of 15mm in diameter. The slide was then air-dried. Crystal violet stain was applied to the fixed culture for 60 seconds, the stain was poured off, and the excess stain rinsed with water. Lugol's iodine solution was used to cover the smear for 60 seconds. The iodine solution was poured off, and the slide was rinsed with running water. Excess water from the surface was shaken off. After being decoloured with alcohol, the slide was quickly rinsed with water in 5 seconds. The smear was counter stained with basic fuchsin solution for 60 seconds. The fuchsin solution was washed off with water, and slide air-dried after shaking off the excess water. The slide was examined under a microscope with x40 and x100 objective.

Oxidase Test

Three milliliters (3ml) of hydrogen peroxide were added to three sterile test tubes, and the colony of the pure culture was chosen and dipped into one of these test tubes, and the bubbles were observed. (Cheesbrough, 2010) [2].

Indole Test

Tubes containing 10 millilitres of tryptophan broth were made. Test organisms were placed on a wire loop and cultured for 48 hours. The medium was then treated with five drops of Kovac reagent, after which the bubbles were observed for the presence or absence of cherry-red ring (Cheesbrough, 2010) [2].

Kliger Iron Agar Slant Test

Test tubes containing 10ml of Kliger Iron Agar were used to prepare the slants. With an inoculating needle, pick the centre of well-isolated colonies obtained from solid culture media. The test tubes were initially injected with the bacteria by stabbing the centre of the medium, inoculating needle, into the deep of the tube to within 3-5mm from the bottom. The inoculating needle was withdrawn and streaked on the surface of the slant. The tubes were incubated at 37^0C for 24 hours, with cotton wool covering the openings. Colour changes, darkening, and cracking of the media after incubation were observed and recorded (Cheesbrough, 2010) [2].

Citrate Utilization Test

Ten milliliters of Simmon citrate slants were prepared in test tubes. The media slope was inoculated with the test isolate using a wire loop. The tubes were then incubated at 37^0C for 24 hours, and the colour change in the medium was observed (Cheesbrough, 2010) [2].

Catalase Test

Three milliliters (3ml) of hydrogen peroxide were added to three sterile test tubes, and the colony of the pure culture was chosen and dipped into one of these test tubes, and the bubbles were then observed (Cheesbrough, 2010) [2].

Methyl Red Test

A new Methyl red medium was infected with a bacterial isolate and incubated at 37^0C for 24 hours. Five drops of methyl red were added after the incubation period. If it turns red, then it is a positive test; if it is yellow, then it is a negative test.

Results

Assessment of the Mycological Quality of Flour Samples

The results for the population of fungal species associated with packaged and unpackaged flour sample are presented in table 1 below. The fungal population in the packaged plantain samples ranged from $0.34 \pm 0.04 \times 10^2$ cfu/g in plantain flour A to $0.24 \pm 0.07 \times 10^2$ cfu/g in plantain flour C, while the unpackaged plantain flour samples recorded mean values ranging from $0.41 \pm 0.06 \times 10^2$ cfu/g in plantain flour A to $0.32 \pm 0.04 \times 10^2$ cfu/g in plantain flour C. However, relatively increased levels of fungal contamination were recorded in the unpackaged samples, compared to the packaged. The percentage increase in fungal contamination recorded for the unpackaged plantain flour C, respectively were higher than those for the respective flour samples A and B.

Table 1: Enumeration of Fungal Population

Samples	Packaged (10^2 cfu/g)	Unpackaged (10^2 cfu/g)	Difference (%)
Plantain flour A	0.34 ± 0.04	0.41 ± 0.06	20.59
Plantain flour B	0.26 ± 0.04	0.32 ± 0.04	23.07
Plantain flour C	0.24 ± 0.07	0.34 ± 0.05	41.47

Table 2 below presents the comparison between the fungal load in the packaged and unpackaged samples. The plantain flour unpackaged had significantly ($P<0.05$) higher fungal count than the packaged. In all, the counts of the unpackaged samples were apparently higher than that of the packaged.

Table 2: Fungal Comparison

Flour Samples	Sample Class	Mean
Plantain Flour	Packaged	84.0 ± 15.00^a
	Unpackage	107 ± 13.00^a

Occurrence of Fungal Isolates in Packaged and Unpackaged Flour Samples

The frequency of isolation of the fungal species associated with the packaged flour samples is presented in figure 1 below. *Yeast* species were isolated 20 times, *Aspergillus* species 10, *Rhizopus* species 16, and the least *Fusarium* species, 6.

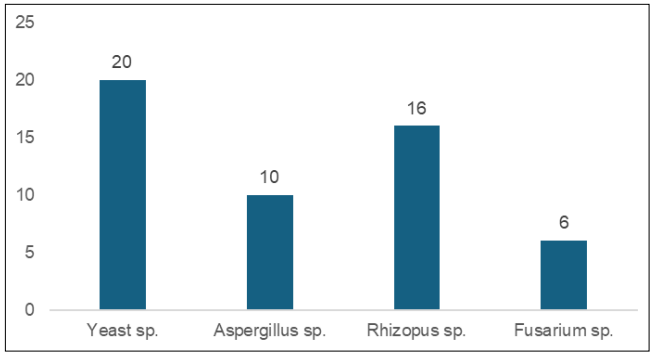

Fig 1: Frequency of Occurrence of Fungal Isolates in Packaged Samples

Figure 2 below presents the results for the frequency of occurrence of the fungal species I the unpackaged flour samples. The data shows *Yeast* species were predominant, with value of 32, *Penicillium* species were isolated 12 times, *Aspergillus* species 8, *Rhizopus* 5, *Alternaria* 3 and the least *Rhodotorula* species 2.

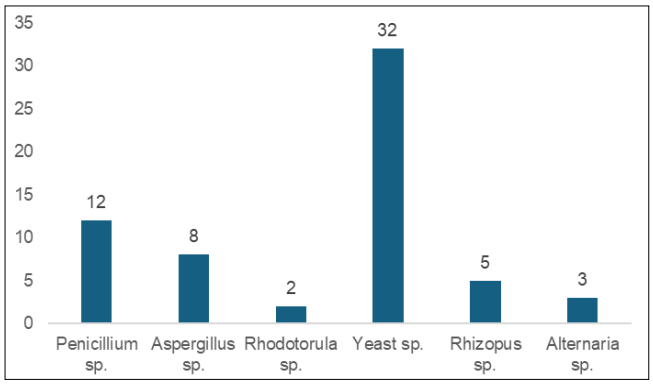

Fig 2: Frequency of Occurrence of Fungal Isolates in Unpackaged Samples

Identification of Fungal species associated with Packaged and Unpackaged Plantain Flour Samples

Seven different fungal genera were identified in this study. The isolates were identified on the basis of their macroscopic and microscopic features. The fungal isolates identified includes; *Aspergillus* sp, *Penicillium* sp., *Rhizopus* sp., *Fusarium* sp., *Rhodotorula* sp., *Alternaria* sp., and *Yeast* sp.

Table 3: Identification of Fungal Isolates

S/N	Fungal Isolates	Macroscopic Features	Microscopic Features
1	*Aspergillus* sp.	Colonies appear white	Flask shaped conidiophores
2	*Penicillium* sp.	Wooly green colony	Hyphae septate, branched conidiophores
3	*Rhizopus* sp.	White cotton like colony	Non-septate broad hyphae
4	*Fusarium* sp.	Cream cottony colony	Hyaline septate hyphae and conidiophores present
5	*Rhodotorula* sp.	Yellow, rough, mucoid colony	No hyphae
6	*Alternaria* sp.	Colonies are suede-like and black	Branched conidia
7	*Yeast* sp.	Flat, smooth, glistering cream colony	Blastoconidia present. Hyphae are absent

Discussion of Research Findings

The results from this study on the mycological quality of plantain flour samples collected from Swali Market in Yenagoa, Bayelsa State, Nigeria, provide valuable insights into the impact of packaging on fungal contamination. By comparing packaged and unpackaged samples, the findings highlight significant differences in fungal populations, species diversity, and occurrence frequencies, underscoring the role of environmental exposure in compromising food safety. These outcomes align with broader literature on microbial contamination in tropical food products, while also revealing specific patterns in fungal ecology that have implications for public health, storage practices, and regulatory standards.

Fungal Population and Load Comparison

The enumeration of fungal populations (Table 1) demonstrates a clear disparity between packaged and unpackaged plantain flour samples. Packaged samples exhibited lower fungal counts, ranging from $0.24 \pm 0.07 \times 10^2$ CFU/g (Sample C) to $0.34 \pm 0.04 \times 10^2$ CFU/g (Sample A), whereas unpackaged samples showed higher levels, from $0.32 \pm 0.04 \times 10^2$ CFU/g (Sample C) to $0.41 \pm 0.06 \times 10^2$ CFU/g (Sample A). This translates to a relative increase in fungal contamination in unpackaged samples, particularly pronounced in Sample C, where the percentage increase was notably higher compared to Samples A and B.

Statistical analysis (Table 2) further confirms that unpackaged samples had significantly higher fungal loads ($P < 0.05$) than their packaged counterparts. This difference can be attributed to the protective barrier provided by packaging materials, such as polyethylene bags or aluminum foil, which limit exposure to airborne spores, moisture ingress, and physical handling—factors known to promote fungal proliferation (Honfo *et al*., 2022) [5]. In contrast, unpackaged flour, often displayed openly in markets, is vulnerable to environmental contaminants like dust, insect vectors, and humidity fluctuations, which are prevalent in tropical settings like Bayelsa State (Aruwa & Ogundare, 2017) [1].

These fungal counts, while not exceeding extreme thresholds reported in some studies (e.g., up to 7.2×10^5 CFU/g in exposed samples from Port Harcourt; Odu *et al*., 2019) [8], still indicate a risk of spoilage and reduced shelf life. The ICMSF recommends fungal counts below 10^3 CFU/g for safe consumption (Odu *et al*., 2019) [8], and although the values here are in the 10^2 range, the elevated levels in unpackaged samples suggest they may approach or surpass safe limits under prolonged storage or suboptimal conditions. This reinforces the introduction's emphasis on how uncontrolled fungal growth can degrade nutritional components, such as carbohydrates and proteins, leading to diminished product quality (Oku & Oyadougha, 2024) [10].

Frequency of Fungal Isolates

The occurrence frequencies of fungal isolates (Figures 1 and 2) reveal distinct microbial profiles between the two sample types, reflecting differences in contamination sources and growth conditions. In packaged samples (Figure 1), *Yeast* species dominated with 20 isolations, followed by *Rhizopus* (16), *Aspergillus* (10), and *Fusarium* (6). This suggests that even in protected environments, endogenous fungi from the plantain itself or minimal post-processing contamination can persist, with yeasts thriving in low-oxygen or sealed conditions where they may outcompete molds.

Unpackaged samples (Figure 2), however, showed a broader diversity and higher frequencies: *Yeast* remained predominant (32 isolations), but *Penicillium* (12), *Aspergillus* (8), *Rhizopus* (5), *Alternaria* (3), and *Rhodotorula* (2) were also present. The increased yeast isolations in unpackaged samples indicate rapid opportunistic growth facilitated by exposure, while the emergence of additional genera like *Penicillium*, *Alternaria*, and *Rhodotorula* points to external contamination from market environments, such as soil, air, or handling (Deligeorgakis *et al*., 2023) [3]. Notably, the lower frequency of *Rhizopus* and *Aspergillus* in unpackaged samples compared to their relative presence in packaged ones might suggest competitive exclusion among species in open conditions, where faster-growing molds like Penicillium could dominate.

This diversity aligns with prior research identifying *Aspergillus*, *Penicillium*, *Rhizopus*, and *Fusarium* as common contaminants in flours from humid regions (Aruwa & Ogundare, 2017; Mbata *et al*., 2022) [1, 7]. The higher overall isolations in unpackaged samples (totaling 62 across genera vs. 52 in packaged) emphasize how exposure amplifies contamination risks, potentially leading to synergistic interactions among fungi that exacerbate spoilage.

Identification of Fungal Species and Health Implications

The identification of seven fungal genera *Aspergillus* sp., *Penicillium* sp., *Rhizopus* sp., *Fusarium* sp., *Rhodotorula* sp., *Alternaria* sp., and *Yeast* sp. (Table 3) based on macroscopic and microscopic features corroborates the ecological patterns observed. *Aspergillus* and *Penicillium*, prevalent in both sample types but more so in unpackaged, are notorious mycotoxin producers; *Aspergillus* niger, for instance, can generate aflatoxins, which are hepatotoxic and carcinogenic, posing severe health risks in regions with high dietary reliance on plantain flour (Maduka & Ugbogu, 2024; Okafor & Eni, 2018) [6, 9]. *Rhizopus oryzae*, dominant in packaged samples, is associated with mucormycosis in immunocompromised individuals and can cause rapid spoilage through enzymatic degradation.

The presence of *Fusarium* and *Alternaria*, though less frequent, is concerning due to their production of fumonisins and alternariol toxins, respectively, which can lead to immunosuppression and chronic toxicity (Deligeorgakis *et al*., 2023) [3]. *Yeasts*, while generally less toxigenic, can contribute to off-flavors, fermentation issues, and allergic reactions. *Rhodotorula*, appearing only in unpackaged samples, is an emerging opportunistic pathogen linked to environmental exposure.

These findings echo literature on Nigerian market flours, where *Aspergillus* niger (61.5%) and *Rhizopus oryzae* (38.5%) predominate, often exceeding safe fungal counts (Aruwa & Ogundare, 2017) [1]. The higher diversity in unpackaged samples suggests a greater potential for mycotoxin accumulation, especially under the warm, humid conditions of Bayelsa State, which favor toxin production (Maduka & Ugbogu, 2024) [6]. Although the study did not quantify mycotoxins, the identified genera imply a need for such assessments, as even low fungal loads can produce harmful levels if conditions allow.

Broader Implications and Recommendations

Overall, the results affirm that packaging significantly mitigates fungal contamination in plantain flour, extending shelf-life and enhancing safety (Honfo *et al*., 2022) [5]. The elevated fungal loads and diversity in unpackaged samples highlight vulnerabilities in open-market retailing, where poor hygiene and environmental factors amplify risks (Odu *et al*., 2019) [8]. This has public health implications in West Africa, where plantain flour is a dietary staple, potentially contributing to foodborne illnesses, nutritional losses, and economic burdens from spoilage.

Limitations include the focus on a single market, which may not generalize to other regions, and the absence of mycotoxin quantification or long-term storage simulations. Future research could explore mycotoxin profiles, the efficacy of alternative packaging (e.g., vacuum-sealing), and interventions like UV treatment or antifungal additives.

Conclusion

In conclusion, these findings advocate for improved practices: mandatory packaging, hygiene training for vendors, and routine microbial testing to align with ICMSF standards (Mbata *et al*., 2022) [7]. By addressing these, the nutritional benefits of plantain flour can be preserved while minimizing health risks.

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