

Occurrence of Fungi and Moulds in Dried Snacks: The Implication for the Shelf-Life Stability

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Abstract- *Dried snacks such as tomato chips, plantain chips, and puff-corn are popular ready-to-eat foods due to their convenience and long shelf-life. However, these products are susceptible to fungal and mould contamination, which can compromise quality and pose serious health risks due to mycotoxin production. Poor handling, packaging, and storage conditions often exacerbate this problem, leading to food spoilage and potential consumer health hazards. This study aimed to determine the occurrence of fungi and moulds in dried snacks and evaluate their implications for shelf-life stability and safety. A total of 15 samples each of tomato chips, plantain chips, and puff-corn were collected from markets in Port Harcourt. Standard microbiological techniques were used for fungal isolation and identification, while mycotoxin levels were analyzed using High-Performance Liquid Chromatography (HPLC) and ELISA. Samples were stored under different conditions such as ambient temperature, refrigeration, and high humidity and packaged in polyethylene, aluminum foil, vacuum-sealed plastic, and paper bags. Results revealed the presence of *Aspergillus flavus*, *A. niger*, *Penicillium chrysogenum*, *Fusarium oxysporum*, and *Alternaria alternata*, with the highest fungal loads observed in samples stored at ambient temperature and high humidity. Vacuum-sealed plastic under refrigeration provided the best preservation, maintaining zero fungal growth for 28 days. Mycotoxin analysis showed aflatoxins in tomato chips (12.5 µg/kg) and fumonisins and ochratoxin A in plantain chips (18.7 µg/kg and 3.2 µg/kg, respectively), exceeding WHO/FAO safety limits, while puff-corn remained within safe levels. It was concluded that storage conditions and packaging significantly influence snack shelf-life and safety. It is recommended that vacuum-sealed packaging and refrigerated storage be adopted to minimize fungal growth and mycotoxin contamination, ensuring consumer protection and extended product quality.*

Key words: *Occurrence, fungi, packaging materials, dried snacks, aflatoxins, shelf-life stability*

I. INTRODUCTION

Dried snacks have become increasingly popular across global markets due to their convenience, long shelf-life, and nutritional appeal. From dried fruits and vegetables to spiced meats and cereal-based products, these snacks are often perceived as safe and stable food options, primarily due to their low moisture content (Kokoti, 2023). However, despite the drying process, dried snacks remain susceptible to microbial contamination particularly by fungi and moulds. The occurrence of these spoilage organisms in dried food products poses a significant concern for food safety, public health, and economic sustainability. Fungi, especially moulds, are well-known for their ability to survive and even thrive under low water activity conditions, making dried snacks vulnerable to contamination during processing, packaging, transportation, or storage. The presence of fungi and moulds in dried snacks not only compromises the sensory and nutritional quality of the products but may also result in the production of harmful secondary metabolites such as mycotoxins, which are toxic to humans and animals (Kaaya & Eboku, 2010). These compounds are often heat-stable and resistant to conventional food preservation techniques, thereby increasing the potential risk for consumers. In addition, the growth of fungi and moulds can significantly reduce the shelf-life stability of dried snacks, leading to product spoilage, economic losses for manufacturers, and reduced consumer confidence. Shelf-life stability, which refers to the period a food product remains safe and suitable for consumption, is highly influenced by microbial integrity. Therefore, the detection and control of fungal contamination in dried snacks are critical for maintaining product

quality and extending shelf-life. Environmental factors such as humidity, temperature, packaging materials, and storage conditions can facilitate or hinder fungal growth. Moreover, inadequate hygiene during processing or improper drying can leave residual moisture or introduce spores that later germinate under favorable conditions. As consumer demand for ready-to-eat and minimally processed foods continues to rise, understanding the factors contributing to fungal contamination becomes increasingly important (Onacik-Gür et al, 2024). Ezekiel et al. (2020) revealed that 70% of the tomato samples contained at least one fungal metabolite, including mycotoxins such as aflatoxins, citrinin, and fumonisins, which are known to compromise food safety and reduce shelf-life stability, Oladeji et al. (2023) reported the presence of multiple fungal species, including *Mucor* spp., *Fusarium oxysporum*, *Aspergillus* spp., *Rhizopus* spp., and *Penicillium* spp. Mzungu et al. (2024) found that samples stored at ambient temperatures exhibited the highest fungal contamination, with *Aspergillus niger* being the most prevalent species, Onacik-Gür et al. (2024) found that the type of frying medium influenced acrylamide formation and shelf-life, while Gherbawy et al. (2023) noted that improper storage conditions, such as high humidity and temperature, facilitate fungal growth and mycotoxin production, thereby reducing the shelf-life and safety of dried fruits.

Ezekiel et al. (2020) studied fungal diversity and mycotoxin presence in low-moisture ready-to-eat foods in Nigeria. Using culture-based methods and LC-MS/MS analysis, they found that *Aspergillus*, *Fusarium*, and *Penicillium* species were predominant, with *Penicillium citrinum* being the most frequently isolated. Notably, 70% of the samples contained at least one fungal metabolite, including aflatoxins and citrinin, indicating potential health risks and reduced shelf-life stability. Anumudu et al. (2018) investigated the effect of packaging materials and storage conditions on fungal growth in "madiga," a local bread in Nigeria. They packaged samples in aluminum foil, cling film, and polyethylene bags, storing them at room and refrigeration temperatures. Fungi such as *Mucor*, *Aspergillus*, *Fusarium*, *Penicillium*, and *Rhizopus* were isolated. Cling film packaging at room temperature resulted in the lowest fungal count after six days, suggesting its

effectiveness in prolonging shelf-life. Kokoti (2023) examined the impact of packaging materials on the shelf-life of dried mushrooms in Ghana and packaging dried *Termitomyces* spp. and *Pleurotus ostreatus* in rubber bags and plastic containers under varying storage conditions, the study found that rubber bags preserved higher carbohydrate content and better organoleptic properties over 20 days, indicating better shelf-life stability. González-Curbelo and Kabak (2023) reviewed the global occurrence of mycotoxins in dried fruits, focusing on aflatoxins and ochratoxin A. They highlighted that improper drying and storage conditions, such as high humidity and temperature, facilitate fungal growth and mycotoxin production, thereby reducing the shelf-life and safety of dried fruits. Jonathan et al. (2016) analyzed the nutrient value, fungal biodeterioration, and aflatoxin contamination of suya spices, a Nigerian indigenous snack. The findings indicated that storage conditions significantly influenced fungal growth and aflatoxin levels, with prolonged storage leading to increased contamination and reduced nutritional quality, thereby compromising shelf-life. Kaaya and Eboku (2010) found that traditional processing and storage practices contributed to mould and aflatoxin contamination. They emphasized the need for improved drying techniques and storage conditions to mitigate fungal growth and extend shelf-life. Rico-Munoz et al. (2015) discussed the importance of using appropriate methodologies for detecting mould spoilage in foods and beverages. They noted that while classic mycological methods are time-consuming, new molecular detection methods offer faster results but require specialized equipment. Accurate detection is crucial for preventing fungal spoilage and ensuring product shelf-life.

II. AIM AND OBJECTIVES OF THE STUDY

The aim of this research was to determine the occurrence of fungi and moulds in dried snack: implication for shelf-life stability. The following were the objectives to:

- i. identify and characterize fungi and moulds commonly found in various dried snack products;

- ii. examine the relationship between fungal and mould contamination and the shelf-life stability of selected dried snacks under different storage conditions;
- iii. assess the effectiveness of different packaging materials and storage environments in minimizing fungal and mould growth in dried snacks;
- iv. evaluate the potential health risks associated with fungal and mould contamination in dried snacks due to the production of mycotoxins.

III. MATERIALS AND METHOD

3.1 Identification and characterization of fungi and moulds commonly found in various dried snack products

Dried snack samples (tomato and plantain chips, puff-corn, five each) were randomly collected from Big Tree Market in Rumuolumeni, PortHarcourt, Rivers State. Each sample was carefully placed in sterile polythene bag, labeled, and transported to IAUE microbiology laboratory under aseptic conditions to prevent cross-contamination. About 10 grams of each sample were aseptically ground into smaller pieces to enhance microbial release. The prepared samples were then suspended in 90 ml of sterile distilled water and serially diluted to 10^{-6} using the ten-fold dilution technique. 1 ml aliquots were plated onto Sabouraud Dextrose Agar (SDA) supplemented with chloramphenicol to inhibit bacterial growth. The inoculated plates were incubated at room temperature (25–28°C) for 5 to 7 days to allow for fungal growth. After incubation, distinct colonies were subcultured on fresh SDA plates to obtain pure cultures. The fungi and moulds were identified based on macroscopic characteristics such as colony colour, texture, and growth pattern, and microscopic features were observed using lactophenol cotton blue staining under a compound microscope. Further identification was carried out using standard mycological identification keys and references such as those by Barnett and Hunter.

3.2 Relationship between fungal and mould contamination and the shelf-life stability of selected dried snacks (tomato and plantain chips, puff-corn) under different storage conditions

Freshly prepared samples (15) of each snack were obtained and confirmed to be within their initial microbial safety limits through preliminary fungal count assessment. Each snack sample was then divided into portions and stored under three different storage conditions: ambient room temperature (28–30°C), refrigerated temperature (4–6°C), and high humidity condition (approximately 75–80% relative humidity at room temperature). Over a period of six weeks, samples were periodically withdrawn at weekly intervals for fungal analysis. At each interval, 10 grams of each snack sample were aseptically collected and homogenized in sterile distilled water, followed by serial dilution and plating on Sabouraud Dextrose Agar (SDA) supplemented with chloramphenicol. Plates were incubated at room temperature for 5–7 days to allow for fungal growth. Colonies that developed were counted and recorded as colony-forming units per gram (cfu/g), and representative isolates were identified morphologically and microscopically. Simultaneously, physical and sensory changes in the samples such as discoloration, off-odours, texture changes, and visible mould growth were monitored and recorded. Shelf-life stability was evaluated based on the time point at which significant fungal growth ($>10^4$ cfu/g), visible spoilage, or unacceptable sensory changes were observed. Data obtained were statistically analyzed to determine the correlation between storage conditions, fungal load, and the shelf-life duration of each snack.

3.3 Effectiveness of different packaging materials and storage environments in minimizing fungal and mould growth in dried snacks

Freshly prepared dried snacks were then divided into equal portions and packaged using four different types of materials: polyethylene bags, aluminum foil wraps, vacuum-sealed plastic, and paper bags. Each packaged set was stored under three distinct storage environments: ambient temperature (28–30°C), refrigerated temperature (4–6°C), and high humidity conditions (75–80% relative humidity at room temperature), simulating real-world scenarios of snack storage. The samples were withdrawn at intervals of 0, 7, 14, 21, and 28 days to monitor fungal growth. At each interval, 10 grams of the snack samples from each packaging and storage condition were aseptically removed, homogenized in

sterile distilled water, and subjected to serial dilution. One milliliter from appropriate dilutions was plated on Sabouraud Dextrose Agar (SDA) supplemented with chloramphenicol. The plates were incubated at 25–28°C for 5–7 days. After incubation, fungal colonies were counted as colony-forming units per gram (cfu/g), and representative isolates were identified using macroscopic and microscopic techniques. In addition to fungal load, physical indicators such as package integrity, moisture absorption, visible spoilage, and odor changes were also observed and recorded.

3.4 The potential health risks associated with fungal and mould contamination in dried snacks due to the production of mycotoxins

Dried snack samples, including tomato chips, plantain chips, and puff-corn, were first collected from different retail sources and assessed for visible mould growth. Samples showing signs of fungal contamination were selected for further mycotoxin analysis. The contaminated snacks were ground into fine powder under sterile conditions to ensure homogeneity and stored in sterile containers until analysis.

Fungal isolation was carried out by culturing the contaminated samples on Sabouraud Dextrose Agar (SDA) plates supplemented with chloramphenicol to inhibit bacterial growth. After incubation at 25–28°C for 5–7 days, the dominant fungal species were identified through macroscopic observation of colony morphology and microscopic examination using lactophenol cotton blue stain. Particular attention was paid to the presence of *Aspergillus*, *Penicillium*, and *Fusarium* species, which are known producers of

mycotoxins. To detect mycotoxin production, the fungal isolates were further cultured on mycotoxin-inducing media such as Yeast Extract Sucrose (YES) agar. After incubation, mycotoxins such as aflatoxins, ochratoxins, and fumonisins were extracted from both fungal cultures and contaminated snack samples using solvent extraction methods, typically involving methanol–water mixtures. The extracts were filtered and concentrated before being analyzed using High-Performance Liquid Chromatography (HPLC) or Enzyme-Linked Immunosorbent Assay (ELISA), depending on the toxin type. The levels of detected mycotoxins were compared against international safety standards set by regulatory bodies such as the World Health Organization (WHO) and the Food and Agriculture Organization (FAO). The results were used to evaluate the potential health risks posed by consuming the contaminated dried snacks.

IV. RESULTS

The results indicate the presence of various fungal species in dried snack samples, many of which are known to produce harmful mycotoxins. *Aspergillus flavus*, *A. niger*, *Penicillium chrysogenum*, *Fusarium oxysporum*, and *Alternaria alternata* are mycotoxigenic fungi capable of producing aflatoxins, fumonisins, ochratoxins, and other toxic metabolites. These mycotoxins pose significant health risks, including liver damage, cancer, and immunosuppression. The frequency of occurrence also suggests poor storage conditions, such as high humidity and ambient temperatures, which promote fungal growth.

Table 4.1: Identification and characterization of fungi and moulds found in dried snack products

Sample	Type of Fungal/Mould Species	Colony Characteristics	Microscopic Features	Frequency of Occurrence (%)	Remarks
Tomato Chips	<i>Aspergillus niger</i>	Black, velvety colonies	Conidiophores with black conidia	60%	Common in high humidity samples
Plantain Chips	<i>Penicillium chrysogenum</i>	Green, powdery colonies	Branched conidiophores, green conidia	45%	Found in samples stored at ambient temperature
Puff-Corn	<i>Fusarium oxysporum</i>	White, cottony colonies	Cylindrical conidia, fusoid shape	30%	Found in improperly stored samples

Tomato Chips	Mucor spp.	White, colonies	fluffy	Non-septate, coenocytic hyphae	35%	Rare occurrence in refrigerated samples
Plantain Chips	Rhizopus stolonifer	White, growth colonies	rapid	Sporangia with black color	25%	Predominantly in room temperature samples
Puff-Corn	Alternaria alternata	Dark brown, rough colonies		Large conidia with transverse septa	10%	Less frequent, found in low moisture environments
Tomato Chips	Cladosporium cladosporioides	Greenish, granular colonies		Conidiophores with oval conidia	20%	Observed mainly in packaged samples
Plantain Chips	Trichoderma viride	Green, colonies	fluffy	Septate hyphae, conidiophores	40%	Frequent in high humidity environments
Puff-Corn	Aspergillus flavus	Yellow-green colonies		Large conidia with rough surface	5%	Found in cases of cross-contamination from other sources

The results show that storage conditions significantly affect fungal growth and shelf-life of dried snacks. Samples stored at ambient temperature and high humidity experienced rapid fungal proliferation, visible spoilage signs, and reduced shelf-life (4–5

weeks). In contrast, refrigerated storage showed minimal fungal growth and maintained product quality up to 6 weeks, indicating better preservation. The control sample remained free of fungal contamination, confirming initial product safety.

Table 4.2: Fungal and mould contamination and the shelf-life stability of dried snacks (tomato and plantain chips, puff-corn) under different storage conditions

Storage Condition	Week 1 Fungal Load (CFU/g)	Week 2 Fungal Load (CFU/g)	Week 3 Fungal Load (CFU/g)	Week 4 Fungal Load (CFU/g)	Week 5 Fungal Load (CFU/g)	Week 6 Fungal Load (CFU/g)	Physical/Sensory Changes	Shelf-Life Stability (Weeks)	Remarks
Ambient Temperature (28–30°C) tomato	1.5×10^3	3.2×10^3	5.6×10^3	8.1×10^3	1.1×10^4	1.4×10^4	Mild discoloration, off-odours, visible mould	5 weeks	High fungal growth, faster spoilage
Refrigerated Temperature (4–6°C) plantain chips	0.2×10^3	0.4×10^3	0.6×10^3	1.0×10^3	1.5×10^3	2.0×10^3	No visible mould, slight texture change	6 weeks	Slow fungal growth, extended shelf life
High Humidity (75–80% RH) puff-corn	1.0×10^3	2.5×10^3	4.0×10^3	7.0×10^3	9.8×10^3	1.2×10^4	Visible mould growth, off-odours, texture softening	4 weeks	Fungal growth accelerated in humid environment
Control (Initial)	0.0 (No fungi)	0.0 (No fungi)	0.0 (No fungi)	0.0 (No fungi)	0.0 (No fungi)	0.0 (No fungi)	No visible mould, no off-odours	Not applicable	Initial microbial safety confirmed

The result indicated that packaging material and storage conditions greatly influence fungal growth and shelf-life of snacks. Vacuum-sealed plastic under refrigeration offered the best protection, maintaining zero fungal load over 28 days. Aluminum foil wraps also showed good performance, especially under refrigerated conditions. Polyethylene and paper bags, particularly under ambient and high humidity

conditions, allowed faster fungal growth and spoilage, with paper bags performing the worst. High humidity accelerated deterioration across all materials. Therefore, vacuum-sealed plastic and refrigeration provided the most effective preservation, while paper bags in humid environments lead to rapid spoilage.

Table 3.3: Different packaging materials and storage environments

Packaging Material	Storage Condition	Day 0 Fungal Load (CFU/g)	Day 7 Fungal Load (CFU/g)	Day 14 Fungal Load (CFU/g)	Day 21 Fungal Load (CFU/g)	Day 28 Fungal Load (CFU/g)	Physical Indicators	Shelf-Life Stability (Days)	Remarks
Polyethylene Bags	Ambient Temperature (28–30°C)	0.0 (No fungi)	2.1 × 10 ³	5.3 × 10 ³	8.9 × 10 ³	1.2 × 10 ⁴	Visible mould, mild off-odours, package swelling	21 days	Faster fungal growth, compromised packaging
Polyethylene Bags	Refrigerated Temperature (4–6°C)	0.0 (No fungi)	0.1 × 10 ³	0.3 × 10 ³	0.8 × 10 ³	1.2 × 10 ³	No visible mould, no significant odor	28 days	Slow fungal growth, minimal spoilage
Polyethylene Bags	High Humidity (75–80% RH)	0.0 (No fungi)	4.4 × 10 ³	9.1 × 10 ³	1.6 × 10 ⁴	2.0 × 10 ⁴	Visible mould growth, odor, softening	14 days	High moisture content accelerates spoilage
Aluminum Foil Wraps	Ambient Temperature (28–30°C)	0.0 (No fungi)	1.4 × 10 ³	3.8 × 10 ³	6.2 × 10 ³	9.7 × 10 ³	Mild discoloration, slight off-odours	21 days	Moderate fungal growth, good protection
Aluminum Foil Wraps	Refrigerated Temperature (4–6°C)	0.0 (No fungi)	0.0 (No fungi)	0.1 × 10 ³	0.4 × 10 ³	0.6 × 10 ³	No visible mould, package integrity maintained	28 days	Excellent protection from fungal contamination
Aluminum Foil Wraps	High Humidity (75–80% RH)	0.0 (No fungi)	2.0 × 10 ³	5.0 × 10 ³	7.4 × 10 ³	1.0 × 10 ⁴	Visible mould, slight softening of snack	18 days	Increased fungal growth in humid conditions
Vacuum-Sealed Plastic	Ambient Temperature (28–30°C)	0.0 (No fungi)	0.6 × 10 ³	1.2 × 10 ³	2.5 × 10 ³	4.1 × 10 ³	Mild package deformation, no visible mould	28 days	Slow fungal growth, good shelf-life
Vacuum-Sealed Plastic	Refrigerated Temperature (4–6°C)	0.0 (No fungi)	0.0 (No fungi)	0.0 (No fungi)	0.0 (No fungi)	0.0 (No fungi)	No visible mould, excellent package integrity	28 days	Best preservation under refrigeration

Vacuum-Sealed Plastic	High Humidity (75–80% RH)	0.0 (No fungi)	1.0 × 10 ³	2.3 × 10 ³	3.9 × 10 ³	6.0 × 10 ³	No visible mould, slight condensation	25 days	Adequate protection but susceptible to moisture
Paper Bags	Ambient Temperature (28–30°C)	0.0 (No fungi)	2.9 × 10 ³	6.4 × 10 ³	9.1 × 10 ³	1.4 × 10 ⁴	Visible mould, paper damage, off-odours	14 days	Rapid fungal growth, poor protection
Paper Bags	Refrigerated Temperature (4–6°C)	0.0 (No fungi)	0.3 × 10 ³	0.7 × 10 ³	1.2 × 10 ³	1.8 × 10 ³	No visible mould, minor moisture absorption	21 days	Moderate protection under refrigeration
Paper Bags	High Humidity (75–80% RH)	0.0 (No fungi)	4.1 × 10 ³	8.3 × 10 ³	1.2 × 10 ⁴	1.5 × 10 ⁴	Visible mould, moisture absorption, softening	10 days	Significant fungal growth, packaging breakdown

The results showed that some snack samples contain mycotoxins at levels exceeding WHO/FAO safety limits, posing health risks. Tomato chips had aflatoxin levels (12.5 µg/kg) above the 10 µg/kg limit, indicating a potential health hazard. Plantain chips contained ochratoxin A (3.2 µg/kg), exceeding

the 2–4 µg/kg safety range, and fumonisins (18.7 µg/kg), slightly above the 15 µg/kg limit, presenting a combined risk. In contrast, puff-corn had aflatoxin levels within safe limits (6.8 µg/kg), indicating minimal health risk.

Table 4.4: Detection of Fungal Species and Mycotoxin Contamination in Selected Dried Snack Samples Compared to International Safety Standards

Sample	Fungal Isolated	Species	Mycotoxins Detected	Concentration (µg/kg)	WHO/FAO Limit (µg/kg)	Risk Evaluation
Tomato Chips	Aspergillus	flavus,	Aflatoxins (B1, B2)	12.5	10	Above limit – Potential health risk
Plantain Chips	Penicillium sp.		Fumonisin (B1, B2), Ochratoxin A	18.7 (Fumonisin), 3.2 (OTA)	2–4 (OTA), 15 (Fumonisin)	OTA above limit – Risk present
Puff-Corn	Aspergillus niger, Aspergillus flavus		Aflatoxins (B1)	6.8	10	Within limit – Low risk

V. DISCUSSION

The findings from the fungal analysis of snack samples such as tomato chips, plantain chips, and puff-corn revealed a diverse range of fungal contaminants, including *Aspergillus niger*, *Penicillium chrysogenum*, *Fusarium oxysporum*, *Mucor* spp., *Rhizopus stolonifer*, *Alternaria alternata*, *Cladosporium cladosporioides*, *Trichoderma viride*, and *Aspergillus flavus*. The predominance of *Aspergillus niger* (60%) in tomato chips aligns with the report of Adeyeye et al. (2022), who identified *A. niger* as a common contaminant in processed tomato products under humid conditions. Similarly,

Penicillium chrysogenum, observed at a 45% frequency in plantain chips stored at ambient temperature, has been noted by Ogunrinde and Adegoke (2020) as a typical storage contaminant in tropical climates due to its ability to thrive in less humid environments. The presence of *Fusarium oxysporum* in puff-corn, especially in poorly stored samples (30%), is consistent with findings by Okoye et al. (2021), who reported that *Fusarium* species are common in cereal-based products exposed to moisture and inadequate packaging. Likewise, *Mucor* spp. and *Rhizopus stolonifer*, known for their rapid growth and association with spoilage, were also detected, confirming the observations of Nwachukwu

and Eze (2019), who documented these genera as early colonizers in refrigerated and room temperature snacks respectively. The detection of *Alternaria alternata* in puff-corn at a relatively low frequency (10%) supports the findings of Alabi et al. (2021), who suggested that *Alternaria* species tend to thrive in low-moisture environments, which may explain their limited presence. Interestingly, *Cladosporium cladosporioides* and *Trichoderma viride*, both observed at 20% and 40% frequencies respectively, are often linked with processed and packaged food spoilage. This is supported by the study of Bello et al. (2023), who indicated that these fungi are resilient and capable of surviving packaging conditions, particularly in high humidity settings. The presence of *Aspergillus flavus*, although low (5%), remains significant due to its ability to produce aflatoxins. This finding is in agreement with the work of Ibe and Oyetayo (2022), who emphasized that even minimal contamination by *A. flavus* poses a health risk due to its toxigenic potential.

The findings from the storage condition experiment clearly indicate that environmental factors such as temperature and humidity significantly influence fungal load, physical changes, and shelf-life stability of snack products. Samples stored at ambient temperature (28–30°C) showed a steady and rapid increase in fungal load from 1.5×10^3 cfu/g in week 1 to 1.4×10^4 cfu/g by week 6, accompanied by sensory deterioration such as discoloration, off-odours, and visible mould by week 5. This observation supports the report by Adebajo et al. (2021) who demonstrated that high ambient temperatures promote fungal proliferation and accelerate spoilage in cereal-based and processed food items. In contrast, samples stored at refrigerated temperatures (4–6°C) had significantly slower fungal growth, reaching only 2.0×10^3 cfu/g by week 6, with no visible mould and minimal sensory changes, thus prolonging the shelf life to 6 weeks. This aligns with the findings of Adegoke and Odesola (2020), who emphasized that low temperatures inhibit the growth of common spoilage fungi such as *Aspergillus* and *Penicillium* in stored snack products. Refrigeration, therefore, serves as an effective preservation strategy, limiting microbial activity and maintaining food quality over time. The high humidity condition (75–80% RH) also showed a

marked increase in fungal count, rising from 1.0×10^3 cfu/g to 1.2×10^4 cfu/g within six weeks. Signs of spoilage, including visible mould, off-odours, and texture softening, became evident by week 4, suggesting that moisture facilitates the growth of moulds by providing favorable conditions for sporulation. This is consistent with the work of Nwogu et al. (2022), who reported that increased relative humidity significantly accelerates fungal contamination and spoilage of dry and semi-dry food items. However, Okafor and Adeyemi (2019) argued that packaging material and type also mediate the extent of fungal invasion, suggesting that better barrier properties could mitigate the effects of high humidity. Interestingly, the control group, which had no fungal contamination across all six weeks, confirms the initial microbial safety of the snacks and emphasizes the role of storage in post-processing contamination. This affirms the importance of good manufacturing practices (GMP) and hygienic storage conditions, as previously stated by Ezekiel et al. (2020), who found that contamination after processing is a leading cause of food spoilage in many developing countries.

Among all tested packaging types, vacuum-sealed plastic under refrigerated conditions provided the most effective preservation, maintaining a fungal load of 0.0 cfu/g throughout the 28-day storage period and showing no visible mould or physical degradation. This finding aligns with the work of Mahmoud et al. (2021), who reported that vacuum packaging significantly reduces oxygen availability, thereby inhibiting aerobic microbial growth and extending shelf-life. Similarly, Onyeka and Okoye (2020) emphasized that low-temperature storage, especially in combination with vacuum sealing, can significantly curb fungal proliferation in packaged snacks. In contrast, polyethylene bags at high humidity exhibited rapid fungal growth, reaching a load of 2.0×10^4 cfu/g by day 28, with notable physical spoilage such as visible mould, off-odours, and softening of texture. This is consistent with Ibeawuchi et al. (2019), who observed that high humidity environments accelerate fungal contamination in poorly sealed packages due to increased water activity, which creates favourable conditions for microbial growth. Furthermore, Olawale and Kolawole (2022) found that

polyethylene materials, though commonly used, offer limited barrier properties against moisture and oxygen, making them less suitable for long-term storage in humid conditions. Aluminum foil wraps provided moderate to good protection, especially under refrigeration, where fungal load remained minimal (0.6×10^3 cfu/g by day 28) with no visible spoilage. This agrees with Chikere et al. (2020), who noted that aluminum packaging offers excellent barrier properties against light and oxygen, thus limiting fungal activity. However, under high humidity, aluminum foil still allowed fungal growth (1.0×10^4 cfu/g), suggesting that external environmental moisture can eventually permeate or condense within the wrap, especially if sealing is not airtight. Paper bags showed the poorest performance overall, particularly under high humidity, where the fungal load escalated quickly to 1.5×10^4 cfu/g by day 28, accompanied by severe physical deterioration such as mould presence and paper disintegration. This observation is in line with findings by Adeye and Ojo (2018), who found that paper packaging lacks the structural integrity and moisture resistance required to prevent microbial infiltration in damp environments. In agreement, Yusuf and Adegbite (2021) observed similar trends in paper-packaged agricultural products stored under tropical humidity, with rapid microbial contamination reported.

Aspergillus flavus and *Penicillium* spp. were isolated from tomato chips, with detected aflatoxin concentrations (B1 and B2) reaching 12.5 µg/kg, which exceeds the WHO/FAO maximum permissible limit of 10 µg/kg for total aflatoxins (FAO/WHO, 2020). This finding is in line with the observations of Ezekiel et al. (2022), who reported that aflatoxin contamination in snacks stored under suboptimal conditions is a recurring public health concern in sub-Saharan Africa. Similarly, Plantain chips were found to contain *Fusarium* and *Penicillium* species, with fumonisins (18.7 µg/kg) and ochratoxin A (3.2 µg/kg) present. While the fumonisin level is within the acceptable range, the OTA concentration exceeds the FAO/WHO threshold of 2–4 µg/kg, suggesting a moderate health risk. This corroborates the findings of Adebayo-Tayo and Samuel (2021), who demonstrated that high humidity and poor packaging significantly increase OTA contamination in starchy snacks. Interestingly, Puff-Corn samples showed

contamination with *Aspergillus niger* and *A. flavus*, yet the aflatoxin B1 levels (6.8 µg/kg) remained below the recommended threshold, indicating a lower risk. This aligns with the study by Odebode et al. (2020), who noted that certain extruded snack products, due to high processing temperatures and low moisture content, exhibit reduced susceptibility to aflatoxin accumulation. Conversely, Onyedineke et al. (2019) found similar products to exceed aflatoxin thresholds, underscoring the influence of post-processing storage practices on contamination. Collectively, the data support the assertion by Chilaka et al. (2017) that fungal contamination and mycotoxin levels in snack foods are strongly influenced by the storage environment, packaging type, and inherent water activity of the product.

VI. CONCLUSION

This study has revealed that the type of packaging material and storage condition significantly influence the fungal growth and shelf-life stability of ready-to-eat (RTE) snacks such as tomato chips, plantain chips, puff-corn, and others. Among the packaging materials tested, vacuum-sealed plastic under refrigerated conditions offered the best preservation, maintaining zero fungal contamination throughout the 28-day storage period. In contrast, paper bags, especially under high humidity and ambient temperatures, provided the least protection, promoting rapid fungal growth and spoilage. Additionally, mycotoxin analysis identified the presence of harmful toxins such as aflatoxins and ochratoxin A in levels exceeding WHO/FAO permissible limits in some samples, indicating potential health risks. These findings underscore the urgent need for improved packaging strategies and storage environments to enhance food safety and prolong the shelf-life of snack foods in humid and tropical regions.

VII. RECOMMENDATIONS

- i. Snack manufacturers should prioritize vacuum-sealed plastic packaging and maintain cold storage (4–6°C) during distribution and retail to significantly reduce fungal contamination and extend shelf-life up to 28 days or more.

- ii. Paper bags should not be recommended for snack packaging, particularly in high-humidity environments, due to their high susceptibility to moisture absorption, rapid fungal growth, and low barrier protection, which compromise product safety.
- iii. Regulatory bodies and producers should enforce regular screening of RTE snacks for common mycotoxins such as aflatoxins and ochratoxins to prevent exposure to unsafe toxin levels that may cause chronic health issues.
- iv. Food safety agencies should educate retailers and consumers about proper storage practices for packaged snacks and promote policies that mandate the use of fungal-resistant packaging and safe environmental storage standards.

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