

**FUNGI COMMUNITY ASSOCIATED WITH TOPSOIL IN SELECTED OPEN
MARKETS OF BENIN CITY**

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CERTIFICATION

This is to certify that this research titled **“FUNGI COMMUNITY ASSOCIATED WITH TOPSOIL IN SELECTED OPEN MARKETS OF BENIN CITY”** was carried out by **“IMAFIDON BENEDICTA ESOSA”** and presented to the Department of Environmental Management and Toxicology, Faculty of Life Sciences, University of Benin, Benin City; in partial fulfilment of the requirements for the award of Bachelor of Science (B.Sc) in Environmental Management and Toxicology. It was conducted under suitable conditions, was carefully supervised and subsequently approved as having met the requirements for the award of a Bachelor of Science degree in Environmental Management and Toxicology.

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DATE

PROF. (Mrs) E. T. AISIEN
(HEAD OF DEPARTMENT)

DATE

DECLARATION

I **“IMAFIDON BENEDICTA ESOSA)”** declare that **“FUNGI COMMUNITY ASSOCIATED WITH TOPSOIL IN SELECTED OPEN MARKETS OF BENIN CITY”** is my work and that all sources that I have used or quoted have been acknowledged using complete references and that this work has not been submitted before for any other degree at any other University.

IMAFIDON BENEDICTA ESOSA

DATE

DEDICATION

This report is dedicated to God Almighty, for his guidance and protection during this project. I also want to dedicate this report to my beloved parents Mr and Mrs Imafidon for their unwavering support, prayers, love and financial assistance throughout my academic journey.

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ABSTRACT

This study examined the fungal community associated with the topsoil of three major open markets in Benin City, Uselu, Kara, and Oluku, representing different environmental and sanitary conditions. The aim was to enumerate, identify, and compare the fungal species present in the topsoil, focusing on differences between the tomatoes (plant-based) and cattle/beef (animal-based) sections. Topsoil samples were collected aseptically from six locations and cultured on Potato Dextrose Agar using the pour plate technique. Fungal isolates were identified based on macroscopic and microscopic characteristics after staining with lactophenol cotton blue. The mean total heterotrophic fungal count ranged from $12.5 \pm 3.3 \times 10^3$ cfu/g in Uselu cattle/beef section to $28.5 \pm 3.7 \times 10^3$ cfu/g in Oluku cattle/beef section. Tomato sections of Uselu and Kara showed moderate counts ($15.7 \pm 2.9 \times 10^3$ and $16.2 \pm 4.7 \times 10^3$ cfu/g), while Oluku tomato soil had $27.7 \pm 6.5 \times 10^3$ cfu/g, indicating greater microbial activity. Ten fungal taxa were identified are *Aspergillus* species (*Aspergillus niger*, *Aspergillus flavus*, *Aspergillus parasiticus*), alongside *Rhizopus sp*, *Mucor sp*, *Penicillium sp*, *Fusarium*, *Trichoderma sp*, and *Alternaria sp*. Oluku Market exhibited the highest diversity, particularly in tomato sections, where potential aflatoxin producing fungi like; *Aspergillus flavus* were prevalent. The results of this reveal that market top soils in Benin City have diverse fungi. The frequent presence of toxin-producing *Aspergillus* species in the locations highlights the need for improved waste management and hygiene to reduce potential public health risks.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of study

Soil is a dynamic ecosystem teeming with microorganisms, among which fungi play a pivotal role in nutrient cycling, organic matter decomposition, and plant health (Frac *et al.*, 2018). In urban environments such as open markets, soil serves as a reservoir not only for beneficial fungi but also for pathogenic species due to constant human activity, waste accumulation, and exposure to diverse organic materials (Grishkan, 2024). The topsoil in these markets, often disturbed and enriched with organic residues, provides a unique niche for fungal colonization and proliferation (Enerijiofi *et al.*, 2019; Osazee *et al.*, 2013).

Open markets in Benin City, such as Oba, New Oluke, Kara, and Uselu, are characterized by high foot traffic, poor sanitation, and frequent dumping of organic and inorganic waste. These conditions create ideal microhabitats for fungi to thrive, particularly in the topsoil layer where moisture, nutrients, and oxygen are most abundant (Yang *et al.*, 2024). Fungal spores originate from multiple sources within market environments. Organic waste such as discarded food scraps, vegetable remains, and other biodegradable materials serves as a primary substrate for fungal growth, contributing to the rich fungal diversity observed in these environments (Ewekeye *et al.*, 2023). Additionally, fungal spores are introduced through airborne dispersal, human and animal activities, and the decomposition of plant and animal residues in the soil. These inputs contribute to a dynamic and heterogeneous fungal community in market soils.

Unhygienic market soils are particularly prone to harboring pathogenic fungi such as *Aspergillus flavus*, *Penicillium spp.*, and *Rhizopus stolonifer*, which have been isolated from stored maize and other food items sold in Benin City markets (Obatusin and Omonigho, 2017; Okobiebi and

Ezennia, 2021; Osazee *et al.*, 2013). These fungi not only degrade food quality but also pose serious health risks to consumers and vendors. Exposure to contaminated soil or food can lead to skin infections, respiratory issues, and mycotoxin-related illnesses (Grishkan, 2024; Baumgardner, 2012). For instance, aflatoxins produced by *A. flavus* are known carcinogens that can contaminate grains and cause liver damage upon ingestion (Niego *et al.*, 2023).

Several factors influence the diversity of soil fungi in market environments. These include soil pH, moisture content, organic matter availability, temperature, and anthropogenic disturbances such as tillage, waste disposal, and foot traffic (Baldrian *et al.*, 2022; Fraç *et al.*, 2018). Additionally, the type of produce sold, proximity to drainage systems, and seasonal variations can lead to shifts in fungal community composition. Studies have shown that fungal diversity tends to be higher in disturbed soils due to increased heterogeneity and nutrient inputs from decomposing materials (Yang *et al.*, 2024).

1.2 Statement of the Problem

Despite the ecological and economic significance of fungi in soil ecosystems, there is limited understanding of the fungal communities inhabiting topsoil in open market environments, particularly in tropical urban centers like Benin City. These markets experience frequent human activity, poor sanitation, and continuous deposition of organic waste, all of which can alter soil physicochemical properties and microbial dynamics. Yet, the specific composition, diversity, and health implications of fungi in these soils remain largely undocumented.

Previous studies have primarily focused on fungi in stored agricultural products or dumpsite soils, with few examining direct fungal colonization of topsoil in active market spaces. This gap in knowledge is concerning, as pathogenic fungi such as *Aspergillus flavus*, *Fusarium oxysporum*,

and *Penicillium spp.* are known to thrive in unhygienic soils and can contaminate food items or cause skin and respiratory infections upon contact or inhalation.

Moreover, the absence of baseline data on fungal diversity in market soils hinders efforts to assess public health risks, implement sanitation protocols, and develop sustainable soil management strategies. This study, therefore, seeks to determine the structure, diversity, and potential health impacts of fungal communities associated with topsoil in selected open markets of Benin City. By investigating the environmental factors influencing fungal proliferation and identifying dominant taxa, this research aims to fill a critical gap in urban soil microbiology and contribute to improved market hygiene and food safety practices.

1.3 Aim and objectives of the study

To investigate the fungal community associated with topsoil in selected open markets of Benin City.

Objectives:

1. To enumerate the fungi species present in the topsoil of selected open markets.
2. To identify the fungi species obtained from the soil samples.
3. To determine the differences in fungi population and fungi species among the three markets (Oluku, Urelu, and Kara markets).

1.4 Justification of the study

The investigation into the fungal community associated with topsoil in selected open markets of Benin City is both timely and essential. These markets experience high human traffic, accumulation of organic waste, and frequent environmental disturbances, all of which create favorable conditions for diverse fungal populations to thrive. Despite the ecological importance

and public health implications of these fungi, market soils remain largely understudied in microbial ecology, particularly in urban centers of developing countries.

Fungi in market topsoil can serve as both beneficial decomposers and harmful pathogens. Saprophytic fungi contribute to soil health through nutrient cycling, while pathogenic species such as *Aspergillus flavus*, *Fusarium oxysporum*, and *Penicillium spp.* can contaminate food, produce mycotoxins, and cause skin or respiratory infections in humans (Obatusin and Omonigho, 2017; Grishkan, 2024). These risks are heightened in unhygienic market environments where topsoil frequently comes into contact with fresh produce, thereby increasing the likelihood of contamination and disease transmission.

The diversity and structure of fungal communities in soil are influenced by various environmental and anthropogenic factors, including organic matter content, moisture, pH, temperature, and human activity (Frąc *et al.*, 2018; Baldrian *et al.*, 2022). In Benin City, open markets vary in sanitation and waste management practices, offering a natural setting to explore how such factors shape fungal ecology. Studying these soils will provide valuable insights into the environmental conditions that support or suppress different fungal groups.

Identifying potentially hazardous fungi in food-contact environments is a major public health concern, making this research especially significant. Documenting fungal diversity in urban tropical soils, a subject with limited data in West Africa, this study advances environmental microbiology. Furthermore, the findings can guide local authorities and policymakers in improving market hygiene and implementing more effective waste disposal strategies. Ultimately, this research will contribute to better urban environmental health, enhance sanitation practices in public spaces, and deepen our understanding of microbial ecology by characterizing the fungal communities present in market topsoil.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview of Soil Fungal Communities and Their Ecological Roles

Soil fungal communities represent one of the most diverse and functionally important groups of microorganisms in terrestrial ecosystems. These communities consist of various fungal taxa that differ in morphology, physiology, and ecological function. Their diversity is influenced by several factors, including soil type, vegetation cover, climatic conditions, and land use practices (Frąc *et al.*, 2018; Li *et al.*, 2022). Fungi colonize different soil layers, often exhibiting vertical stratification. Saprotrophic fungi typically dominate the litter layers, while mycorrhizal fungi are more common in deeper soil horizons (Li *et al.*, 2022).

Fungal communities are organized into ecological guilds such as saprotrophs, mycorrhizal fungi, endophytes, and pathogens. These groups interact with other soil organisms, forming complex networks that regulate nutrient cycling and maintain microbial balance (Frąc *et al.*, 2018). The structure and richness of these communities are affected by abiotic factors like pH, soil moisture, and temperature, as well as biotic interactions with plant roots and other microorganisms (Zeng *et al.*, 2023).

Fungi play critical roles in nutrient cycling, organic matter decomposition, and overall soil health. Saprophytic fungi release extracellular enzymes, including cellulases and ligninases, which break down complex organic materials and release essential nutrients such as carbon, nitrogen, and phosphorus back into the soil (Hale, 2024; Biology Insights, 2025). This decomposition process enhances humus formation and improves soil fertility.

Mycorrhizal fungi, including arbuscular mycorrhizae (AMF) and ectomycorrhizae (EMF), establish mutualistic associations with plant roots. They assist in the absorption of nutrients such

as phosphorus and nitrogen, while receiving carbohydrates from the host plant (Li *et al.*, 2022). These interactions not only support plant growth but also enhance soil structure by promoting aggregation and water retention.

In addition to their roles in nutrient dynamics, some fungi contribute to bioremediation. Certain fungal species are capable of immobilizing heavy metals and breaking down environmental pollutants, thus playing a role in soil detoxification and ecosystem restoration (Frąc *et al.*, 2018).

Several major fungal groups are commonly found in topsoil and are known for their distinct ecological roles. Ascomycota, the largest fungal phylum, includes saprotrophs, plant pathogens, and symbionts. Genera such as *Penicillium* and *Trichoderma* are notable for their decomposition abilities and use in biological control. Basidiomycota encompasses fungi such as *Agaricus* and *Polyporus*, which are essential for lignin degradation and nutrient cycling (LibreTexts, 2025). Zygomycota, characterized by coenocytic hyphae and zygospore production, includes species like *Rhizopus* that are involved in early stages of organic matter decomposition. Together, these fungi form a dynamic and ecologically vital component of soil systems, particularly in environments with high organic input and human activity, such as open markets.

2.2 Importance of Fungi in Soil Ecosystems

Fungi are indispensable components of soil ecosystems, playing crucial roles in nutrient cycling, organic matter decomposition, plant symbiosis, and overall soil health. Their ecological significance is best understood by examining their major functional groups, namely saprophytic, mycorrhizal, and pathogenic fungi, each of which interacts with the soil environment in unique ways (Frąc *et al.*, 2018; Biology Insights, 2025).

Saprophytic fungi function as primary decomposers within the soil. They are responsible for breaking down dead organic material and returning essential nutrients to the ecosystem. These fungi secrete a range of extracellular enzymes, including cellulases, ligninases, and proteases, which degrade complex compounds such as cellulose and lignin (Chaudhari and Sonawane, 2025; Hale, 2024). Through this activity, saprophytic fungi enhance carbon and nitrogen cycling, contribute to humus formation, and improve soil structure and fertility. Notable examples include *Trametes versicolor* and species of *Aspergillus*, which are well recognized for their ability to degrade lignin and other complex plant materials (Biology Insights, 2025).

Mycorrhizal fungi form mutualistic associations with the roots of most terrestrial plants. These symbiotic relationships significantly improve the plants' access to nutrients, particularly phosphorus and nitrogen, by extending the effective reach of their root systems (Bortolot *et al.*, 2024; Mycology Start, 2025). In addition to enhancing nutrient uptake, mycorrhizal fungi increase plant resilience to abiotic stresses such as drought and salinity, promote soil aggregation, improve water retention, and contribute to carbon sequestration via root exudates. Arbuscular mycorrhizae (AMF) are especially common in agricultural crops, while ectomycorrhizae (EMF) are more frequently found in forest ecosystems (Bone and Clarke, 2021).

Pathogenic fungi, although often considered harmful, also play an important role in ecosystem regulation. Species such as *Fusarium oxysporum* and *Puccinia graminis* infect plant tissues, leading to disease and sometimes death. However, the decomposition of infected plants releases nutrients back into the soil and alters plant community structure, which can increase overall biodiversity through natural selection and competitive displacement (Bone and Clarke, 2021; Biology Insights, 2025). In this way, pathogenic fungi act as ecological regulators in both natural and managed environments.

The combined actions of saprophytic, mycorrhizal, and pathogenic fungi are essential for maintaining soil health and ecological balance. Saprophytic fungi facilitate the breakdown and recycling of organic matter; mycorrhizal fungi optimize nutrient acquisition and support soil structure; and pathogenic fungi contribute to plant community dynamics and nutrient redistribution. Together, these groups form intricate networks with other soil organisms, helping to sustain ecosystem productivity, resilience, and long-term stability (Frąc *et al.*, 2018; Biology Insights, 2025).

2.3 Sources and Distribution of Soil Fungi in Urban Environments

Urban environments present a highly heterogeneous landscape with varying ecological conditions that influence the distribution, abundance, and composition of soil fungal communities. In contrast to more stable rural or forested ecosystems, urban soils are subjected to significant anthropogenic pressures such as land-use changes, pollution, compaction, and waste accumulation. These factors result in marked deviations in fungal ecology, affecting both the functional roles and diversity of soil fungi (Janowski and Leski, 2022).

Human activities including construction, industrialization, and rapid urban expansion disrupt natural soil processes and structure. Soil compaction and surface sealing reduce porosity and limit water infiltration and aeration, both of which are critical for fungal growth and survival (Whitehead *et al.*, 2022). Moreover, urban soils often accumulate heavy metals from vehicular emissions, industrial effluents, and waste disposal, which can suppress sensitive fungal species while favoring metal-tolerant taxa (Ramkat *et al.*, 2019). Fertilizer runoff and chemical inputs alter the soil's pH and nutrient content, further shaping fungal community composition and trophic dynamics (Janowski and Leski, 2022). These changes often lead to a reduction in ectomycorrhizal fungi, which are typically associated with trees and undisturbed soils, and a corresponding increase in

saprotrophic and pathogenic fungi more adapted to disturbed and nutrient-rich environments (Newbound *et al.*, 2010).

Urban open markets and dumpsites serve as concentrated sources of organic waste, creating favorable conditions for fungal colonization. The accumulation of decaying food items, plant debris, packaging materials, and animal waste provides an abundance of carbon-rich substrates that promote the growth of opportunistic fungi such as *Aspergillus*, *Penicillium*, and *Rhizopus* species (Ewekeye *et al.*, 2023). Runoff from animal waste further introduces spores and nutrients into topsoil, enhancing microbial activity and fungal diversity (Zhang *et al.*, 2019). Compost heaps and refuse piles also act as incubators for thermophilic and mycotoxigenic fungi, which may pose health risks to humans upon inhalation or contact (Grishkan, 2024). While such waste inputs boost fungal biomass and richness, they also contribute to the increased prevalence of potentially pathogenic species in urban soils.

Environmental disturbances common in cities, such as fluctuations in temperature, moisture, and vegetation cover, also affect fungal distribution. The urban heat island effect, for example, creates localized increases in temperature that can favor thermotolerant and fast-growing fungal species (Whitehead *et al.*, 2022). Green space fragmentation limits the connectivity of fungal populations and reduces the spread of certain symbiotic fungi (Newbound *et al.*, 2010). Seasonal variations in rainfall and organic matter input result in dynamic changes in fungal succession and community turnover (Zhang *et al.*, 2021). Additionally, dispersal mechanisms such as wind, rainwater runoff, and human movement contribute to the spread of fungal spores across urban landscapes, creating patchy and unpredictable distribution patterns (Janowski and Leski, 2022).

2.4 Fungal Biodiversity in Tropical Soil Ecosystems

Tropical and sub-tropical soil ecosystems are among the most biologically rich environments globally, characterized by high levels of biodiversity and complex ecological interactions. Fungi are key components of these systems, playing essential roles in nutrient cycling, decomposition of organic matter, and symbiotic associations with plants. The diversity of fungal communities in tropical soils is largely shaped by climatic variables such as temperature, precipitation, and humidity, as well as edaphic factors including soil pH, organic carbon content, and nutrient availability (Tedersoo *et al.*, 2014; Sheng *et al.*, 2025). Tropical rainforests, in particular, are noted for having the highest fungal richness worldwide, with many fungal taxa well adapted to warm, moist conditions and rapid turnover of organic materials (Tedersoo *et al.*, 2014; Yang *et al.*, 2024).

The dominant fungal phyla in tropical soils include *Ascomycota*, *Basidiomycota*, and *Glomeromycota*. These groups contain species that function as saprotrophs, mycorrhizal fungi, endophytes, and pathogens (Frag *et al.*, 2018). Collectively, they contribute to soil health and ecological balance by facilitating nutrient mobilization, improving soil structure, and influencing the composition and interactions of other soil microorganisms. The functional diversity of these fungal communities ensures their capacity to respond to environmental changes and sustain ecosystem productivity.

In the West African context, which encompasses diverse ecological zones such as the Guineo-Sudanian savannas and tropical rainforests, fungal biodiversity remains rich yet significantly underexplored. Despite the ecological and economic importance of fungi in agriculture, forestry, and food systems, systematic mycological research in the region is limited. A comprehensive survey by Piepenbring *et al.* (2020) recorded over 4,800 fungal species across various West

African countries; however, this figure represents only about 11 percent of the estimated fungal diversity, based on the widely accepted 6:1 fungus-to-plant species ratio proposed by Hawksworth. Recent advances in molecular techniques have enabled better characterization of fungal communities in tropical West Africa. For example, DNA metabarcoding analyses have identified diverse fungal taxa in cocoa agroforestry systems in Ghana and Côte d'Ivoire, with genera such as *Aspergillus*, *Phialophora*, and *Aureobasidium* being predominant (Kumah *et al.*, 2025). Similarly, soil samples collected from ectomycorrhizal-rich woodlands in Benin, Burkina Faso, and Mali have revealed high fungal richness, including species from the families *Russulaceae* and *Inocybaceae* (Meidl *et al.*, 2021). These findings demonstrate that both natural and managed ecosystems in West Africa support a wide range of fungal taxa, many of which have not been fully documented.

Environmental factors such as land use, organic matter inputs, and soil moisture availability significantly influence fungal diversity in these ecosystems. Unmanaged gallery forests, for instance, tend to harbor more diverse fungal communities than monoculture plantations, highlighting the importance of habitat complexity and organic inputs (Mishra *et al.*, 2024). In urban settings, however, anthropogenic disturbances, such as improper waste disposal and poor sanitation practices in open markets, can alter fungal community structure, often leading to a higher prevalence of pathogenic and mycotoxigenic species (Ewekeye *et al.*, 2023).

2.5 Environmental and Anthropogenic Factors Influencing Fungal Diversity in soil

The composition and diversity of soil fungal communities are governed by a complex interaction of environmental variables and anthropogenic influences. These factors determine not only the richness and distribution of fungal taxa but also their functional roles in ecosystem processes such

as organic matter decomposition, nutrient cycling, and plant-microbe interactions. In urban and market environments, where soils are often disturbed and enriched with waste, understanding these drivers is essential for assessing ecological balance and potential public health concerns (Yang *et al.*, 2024; Rousk *et al.*, 2009).

Soil pH is one of the most critical abiotic factors affecting fungal diversity and community composition. Acidic soils generally favor fungal proliferation over bacterial populations, resulting in a dominance of fungal species (Rousk *et al.*, 2009). A pH range that is neutral to slightly acidic supports a broader spectrum of fungal phyla, including members of Ascomycota and Basidiomycota (Yang *et al.*, 2024). Moreover, shifts in soil pH can influence the availability of nutrients and enzymatic activity, thereby altering fungal metabolic processes and species dominance (Lu *et al.*, 2022).

Temperature and moisture are also fundamental regulators of fungal metabolism and reproduction. Elevated temperatures may reduce overall fungal richness but tend to favor thermotolerant genera such as *Aspergillus* and *Rhizopus* (Fang *et al.*, 2025). In contrast, adequate soil moisture promotes spore germination, fungal colonization, and enzymatic activity, particularly in the upper soil layers that are rich in organic matter (Canini *et al.*, 2019). Seasonal fluctuations in temperature and humidity further contribute to shifts in fungal community dynamics, particularly in urban and peri-urban soils (Wei *et al.*, 2025).

The quantity and quality of organic matter within soil are essential determinants of fungal community structure. Soils rich in decomposing plant material, compost, and other organic residues tend to support diverse saprophytic fungal guilds, including species of *Trichoderma*, *Penicillium*, and *Mortierella* (Lin *et al.*, 2023). High organic carbon content is positively correlated with increased fungal biomass and enzymatic activity, which in turn enhances soil fertility and

ecosystem functioning (Yang *et al.*, 2024). Furthermore, the diversity of organic substrates, ranging from leaf litter to animal waste—affects fungal succession and the distribution of ecological niches within the soil (Yu *et al.*, 2024).

Anthropogenic activities, particularly in urban and market environments, significantly alter soil conditions and introduce various contaminants that influence fungal communities. Improper waste disposal practices lead to the accumulation of both organic and inorganic pollutants in the soil, enriching conditions for opportunistic fungal species such as *Candida*, *Fusarium*, and *Mucor* (Ewekeye *et al.*, 2023). Heavy metal contamination and chemical residues from industrial and agricultural sources can suppress sensitive fungi while promoting the proliferation of metal-tolerant species (Iram *et al.*, 2013). Additionally, urbanization and land-use changes result in soil compaction, reduced vegetation cover, and altered hydrology, all of which contribute to a decline in mutualistic mycorrhizal fungi and a rise in saprotrophic and pathogenic forms (Janowski and Leski, 2022).

2.6 Common Fungi Isolated from Unhygienic Soils

Unhygienic urban soils, particularly those located in open markets, waste dumps, and areas affected by industrial discharge, are known to harbor a wide variety of fungal genera. These fungi are well adapted to nutrient-rich, moist, and sometimes toxic environments created by poor sanitation, organic waste accumulation, and anthropogenic disturbances. The most frequently reported fungal genera in such soils include *Aspergillus*, *Penicillium*, *Fusarium*, and *Candida*. Each of these genera comprises species that play significant ecological roles and pose potential risks to public health (Iram *et al.*, 2013; Ewekeye *et al.*, 2023).

Species of the genus *Aspergillus* are particularly dominant in contaminated soils due to their high adaptability and resilience. Common species such as *A. flavus*, *A. niger*, *A. fumigatus*, and *A. terreus* have been isolated from market waste, sewage-contaminated soils, and dye-polluted areas (Sani *et al.*, 2022; Parveen *et al.*, 2012). These fungi are known producers of toxic secondary metabolites, notably aflatoxins and ochratoxins, which are harmful to human and animal health. In addition to their toxigenic potential, some *Aspergillus* species exhibit significant tolerance to heavy metals such as lead and chromium, making them relevant in the study of bioremediation (Iram *et al.*, 2013). Their widespread distribution in tropical and subtropical urban soils is attributed to their ability to withstand fluctuations in pH, temperature, and moisture levels (Ngum Nji *et al.*, 2023).

Penicillium species are also commonly found in unhygienic soil environments, particularly in decomposing organic matter and market refuse. According to Sani *et al.* (2022), *P. chrysogenum* and *P. digitatum* were isolated from soil samples collected from Bodija Market in Ibadan, and from spoiled fruits and vegetables, indicating that market refuse provides a favourable environment for fungal growth. These fungi are notable contributors to food spoilage and can produce secondary metabolites, including antimicrobial compounds and potential mycotoxins. Furthermore, some *Penicillium* species have been detected in soils polluted with industrial waste, indicating a level of resistance to heavy metals and chemical contaminants (Mohammadian *et al.*, 2020). Their rapid spore production and airborne dispersal capacity make them prominent fungal contaminants in urban settings.

Fusarium species, particularly *F. oxysporum* and *F. solani*, are known soil-borne pathogens that affect both plants and humans. These fungi are frequently isolated from agricultural and market soils, especially where organic waste is abundant (Parveen *et al.*, 2012; Sani *et al.*, 2022). In

agriculture, they cause serious diseases such as vascular wilts in crops, while in humans, they are capable of causing opportunistic infections, particularly in immunocompromised individuals or through open wounds. *Fusarium* species also produce harmful mycotoxins such as *fumonisin*, which pose food safety risks when they contaminate edible crops.

Although *Candida* species are typically associated with mucosal infections in clinical settings, several studies have reported their occurrence in contaminated urban soils. *Candida albicans* and *C. tetraginarum* have been isolated from soils polluted by dye effluents and abattoir waste (Sani *et al.*, 2022; Awari *et al.*, 2020). These yeasts survive in moist, nutrient-rich environments and may play a role in microbial succession within waste-impacted soils. Their ability to form biofilms and resist certain antifungal agents raises concerns about their persistence and potential for environmental transmission, particularly in densely populated urban areas.

2.7 Health Implications of Pathogenic Soil Fungi

Soil serves as a natural habitat for a wide range of fungal species, many of which are beneficial to ecological processes such as nutrient cycling and organic matter decomposition. However, certain soil fungi are pathogenic and pose significant risks to human health, particularly in urban and open-market environments where sanitation is inadequate and organic waste is prevalent (Grishkan, 2024). These pathogenic fungi can contaminate food, release airborne spores, and cause infections through dermal contact, ingestion, or inhalation.

One of the primary concerns associated with soil fungi in market environments is food contamination and subsequent mycotoxin exposure. Fungal genera such as *Aspergillus*, *Penicillium*, and *Fusarium* are notorious for colonizing food items and producing toxic secondary metabolites. *Aspergillus flavus* and *A. parasiticus*, for instance, are known producers of aflatoxins,

highly potent carcinogens that have been linked to liver cancer and immune system suppression (Magembe, 2025; Freire and Rocha, 2016). *Penicillium expansum* is responsible for the production of patulin, a mycotoxin commonly found in apples and apple-based products, with documented neurotoxic effects (Grishkan, 2024). Fusarium species, including *F. verticillioides* and *F. proliferatum*, produce fumonisins and trichothecenes, which are associated with esophageal cancer, neural tube defects, and gastrointestinal disorders (Milićević *et al.*, 2010). These mycotoxins are chemically stable and can persist through storage and food processing, making their control a significant challenge in food safety (Foodsafety Institute, 2024).

Beyond foodborne risks, pathogenic soil fungi can also cause direct health issues through skin contact and respiratory exposure. Dermatophytic infections such as ringworm (tinea) and athlete's foot are caused by fungi that invade the keratinized layers of the skin through minor abrasions or prolonged contact with contaminated soil (Baumgardner, 2012). Respiratory conditions are of particular concern in environments where fungal spores are aerosolized. *Aspergillus fumigatus* is known to cause allergic bronchopulmonary aspergillosis and invasive pulmonary aspergillosis, especially in individuals with compromised immune systems or chronic respiratory diseases (Grishkan, 2024; WHO, 2024). *Candida* species, although more commonly associated with mucosal infections, have been isolated from polluted soils and may cause opportunistic infections in individuals exposed through wounds or inhalation of aerosolized particles (Awari *et al.*, 2020). Airborne spores of these fungi can penetrate deep into the respiratory tract and, in some cases, result in chronic conditions such as asthma, sinusitis, or even central nervous system complications like brain granulomas (Grishkan, 2024).

The public health concerns posed by pathogenic soil fungi are further amplified in regions where environmental hygiene is poor and regulatory mechanisms are weak. Open markets and drainage

systems, often contaminated with decaying organic waste, act as persistent reservoirs for fungal growth and spore dissemination (Ogbonna, 2017). Additionally, contaminated soil has been linked to sick building syndrome, a condition in which occupants of poorly ventilated buildings suffer from respiratory and neurological symptoms due to exposure to indoor airborne fungal spores (Grishkan, 2024). In many developing countries, where food safety regulations and infrastructure for proper storage are lacking, the risk of mycotoxin exposure remains high, particularly among vulnerable populations (Freire and Rocha, 2016; Magembe, 2025).

2.8 Fungal Contamination in Market Environments

Open markets serve as essential hubs for food distribution, particularly in developing countries where a large proportion of fresh produce, grains, and processed foods are traded. However, these markets are often characterized by inadequate sanitation, poor infrastructure, and exposure to environmental contaminants. Such conditions create highly favorable environments for fungal colonization and proliferation on food surfaces, within the surrounding soil, and across accumulated organic waste. Fungal contamination in market settings is primarily driven by high humidity, improper food handling, unsanitary display methods, and insufficient storage facilities (Oyedele *et al.*, 2025; Yenew *et al.*, 2025).

Numerous studies have documented the presence of fungi on various food items sold in open markets. For instance, rice samples collected from Nigerian markets were found to contain *Aspergillus flavus*, *Fusarium*, *Penicillium*, and *Talaromyces*, with *aflatoxins* detected in approximately 18% of the samples examined (Oyedele *et al.*, 2025). Groundnut products in markets in Sokoto and Ibadan also showed contamination by *A. niger*, *A. flavus*, and *A. parasiticus*, with aflatoxin B1 confirmed using thin-layer chromatography (Musa *et al.*, 2025; Sangoyomi, 2016). In Ethiopian markets, fresh vegetables such as spinach and cabbage exhibited fungal

contamination above safe microbial limits, largely attributed to poor washing practices, exposure to unclean surfaces, and inadequate storage (Yenew *et al.*, 2025). These findings underscore the potential for significant mycotoxin exposure and foodborne illnesses through consumption of market-sourced produce.

In addition to food contamination, market soils and waste materials also serve as major reservoirs for fungal spores. Studies conducted on soil samples from dumpsites in Lagos revealed high fungal loads, including *Rhizopus*, *Mucor*, and *Aspergillus* species, reflecting the enrichment of fungal populations by organic waste inputs (Ewekeye *et al.*, 2023). Similarly, spoiled fruits collected from markets in Abuja were found to be heavily colonized by *A. niger*, *A. flavus*, *Rhizopus stolonifer*, and *Mucor mucedo*, with *A. niger* emerging as the most frequently isolated species (Mukhtar *et al.*, 2019). Smoke-dried fish from Makurdi markets also showed fungal contamination in approximately 74% of samples, with *Aspergillus*, *Penicillium*, and *Mucor* genera being predominant (Antiev, 2019). These studies suggest that market environments, particularly those lacking proper waste disposal and environmental sanitation measures, act as effective transmission points for fungal pathogens.

The public health implications of such contamination are profound. Mycotoxins produced by some fungi, including *aflatoxins*, *fumonisin*s, and *ochratoxin*s, have been linked to severe health conditions such as liver damage, immune system suppression, and various cancers (Oyedele *et al.*, 2025; Sangoyomi, 2016). Moreover, prolonged exposure to contaminated soil or airborne fungal spores may result in respiratory conditions and skin infections, especially among immunocompromised individuals (Grishkan, 2024). In addition to health concerns, fungal contamination also affects food quality and safety, leading to spoilage, loss of nutritional value, and economic hardship for vendors and consumers alike (Yenew *et al.*, 2025).

2.9 Effects of Soil Fungi on the Human Foot

Fungi commonly found in unhygienic soils, especially in open market environments, pose significant health risks to individuals who walk barefoot or wear open footwear. These fungi are responsible for various foot infections that are prevalent in tropical climates where poor sanitation and moisture retention create ideal conditions for fungal growth.

One of the most widespread infections is *Athlete's foot (Tinea pedis)*, caused by dermatophytes such as *Trichophyton rubrum*. This condition typically results in itching, peeling, and cracked skin between the toes (Cobb, 2025; Moyer, 2025). Another common condition is *Onychomycosis*, or toenail fungus, which often develops from untreated athlete's foot and leads to thickened, discolored, and brittle nails. Additionally, *Cutaneous candidiasis*, often caused by *Candida albicans*, can infect the skin folds between the toes, particularly in moist and warm environments (Chris, 2025).

Transmission of these infections typically occurs through direct contact with contaminated soil or surfaces. Fungi can enter the skin through tiny cuts or abrasions and thrive in the damp conditions created by enclosed footwear. Shared footwear or communal objects such as mats and weighing scales in market settings also increase the risk of transmission. Soil samples from markets have been found to contain fungal species like *Aspergillus*, *Candida*, and *Fusarium*, which are capable of causing opportunistic infections in humans (Chris, 2025; Infectioncycle, 2025).

These infections can result in skin irritation, inflammation, and discomfort, often leading to reduced mobility. In some cases, untreated fungal infections may result in secondary bacterial infections or develop into chronic conditions that are resistant to conventional treatment. For

immunocompromised individuals, the health consequences can be more severe, with the potential for systemic infections or respiratory complications if fungal spores are inhaled (Cobb, 2025; Moyer, 2025).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Area

This study was carried out in selected open markets within Benin City, Edo State, Nigeria. These markets are characterized by high human activity, the presence of organic waste, and varying sanitation conditions, which make them suitable sites for investigating fungal communities associated with topsoil.

Oluku Market is located in Oluku, a major gateway community that links Benin City to other parts of Edo State and neighboring states. It is a busy transit market, attracting traders, travelers, and commuters. The market is notable for the sale of foodstuffs such as yam, cassava, plantain, vegetables, and grains, alongside livestock and household goods. Due to its strategic location along a major road, the market experiences constant traffic and human activity. Waste disposal practices are often informal, with food residues, animal dung, and other organic wastes accumulating on the ground, creating favorable conditions for fungal proliferation in the soil.

Urelu Market is one of the largest and oldest open markets in Benin City. It serves as a central hub for wholesale and retail trading, particularly in food items such as cereals, tubers, vegetables, meat, and fish. The market is densely populated, with traders occupying permanent stalls, makeshift sheds, and open spaces. Sanitation challenges, including irregular waste collection and improper disposal of perishable items, are common. The accumulation of decaying organic matter, combined with heavy foot traffic, makes the soil in Urelu Market an important site for assessing fungal diversity and abundance.

Kara Market, located within Benin City, is a specialized livestock market known primarily for the sale of cattle, goats, sheep, and other domestic animals. In addition to livestock, the market features associated by-products such as hides, skins, and animal feed. The market environment is strongly influenced by animal droppings, feed remnants, and slaughter-related wastes, which are often left on the soil surface. These conditions create a unique microhabitat for fungal growth, distinct from those of the predominantly foodstuff-based markets.

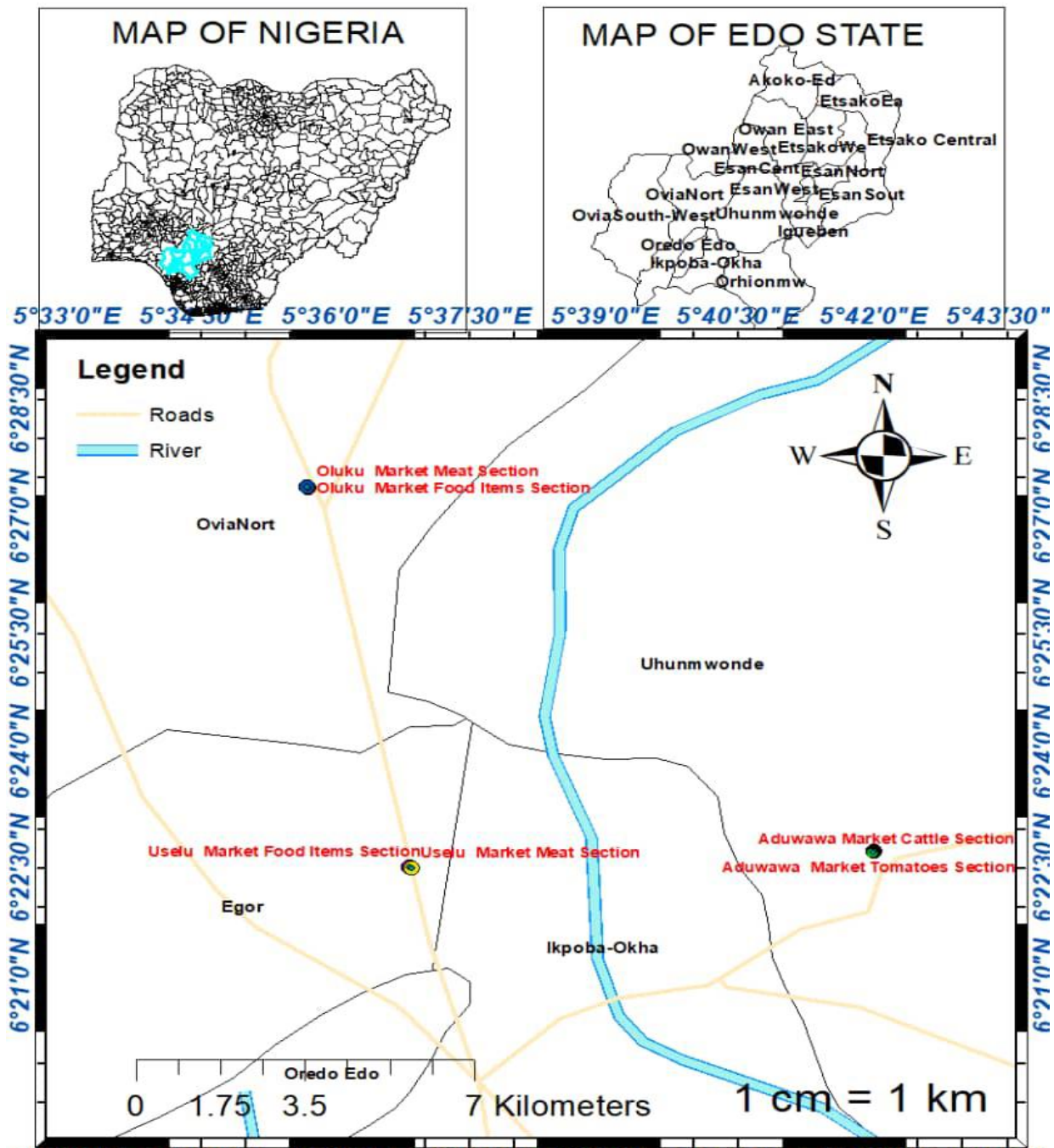


Figure 1: Map of study location

3.2 Sample Collection

Topsoil samples were collected from three major open markets in Benin City, Nigeria: Urelu Market, Kara Market, and Oluku Market. The sampling strategy was designed to capture areas within each market with the highest potential for fungal contamination, focusing on zones of intense organic waste accumulation and high human activity.

Site Selection and Sampling Strategy:

At each market, sampling was strategically carried out at two distinct locations to obtain a representative profile of the fungal community. These included the abattoir sections, where cattle are slaughtered and where blood, animal tissue, and cow dung are commonly present, and the tomato sales sections, which contain large concentrations of tomato vendors and are characterized by the accumulation of spoiled, damaged, and decaying tomatoes as well as other vegetable.

This approach was adopted because these sites represent significant and continuous sources of rich organic substrates (animal-based) in the abattoirs and (plant-based) in the tomato sections, which are known to support diverse and abundant fungal populations.

Sample Collection Procedure:

From each of the six designated locations (two per market), a composite soil sample was obtained.

Topsoil samples were aseptically collected using sterile hand trowel

from a depth of 0–15 cm from three randomly selected points, spaced approximately 5-10 meters apart. The three subsamples from each location were then thoroughly mixed in a sterile container to form a single, homogenous composite sample, representative of that specific point. This pooling method was employed to minimize the effect of small-scale heterogeneity and to obtain a more accurate representation of the average fungal load and diversity at each sampling point.

A total of twelve (12) composite samples were collected: four from Uselu Market (two from the Cattle slaughtering area and two from the tomato section), four from Kara Market (two from the cattle sales area and two from the tomato section), and four from Oluku Market (two from the Cattle slaughtering area and two from the tomato section).

Sample Handling and Preservation:

Immediately after collection, each composite sample was placed into a pre-labeled, sterile polyethylene bag. The samples were promptly placed in a cooler containing ice packs to maintain a cold chain and minimize microbial activity and growth during transport. Upon arrival at the laboratory, the soil samples were stored in a refrigerator at 4°C to preserve their microbiological integrity until processing, which was initiated within 24 hours of collection. This careful handling was crucial to prevent overgrowth of fast-growing microorganisms and to ensure an accurate analysis of the in-situ fungal community.

3.3 Preparation of Potato Dextrose Agar (PDA)

Thirty-nine (39) grams of Potato Dextrose Agar (PDA) powder was weighed and dissolved in 1 L of distilled water inside a conical flask covered with cotton wool and aluminium foil. The medium was mixed thoroughly and sterilized by autoclaving at 121 °C for 15 minutes. After sterilization, it was cooled to 45–50 °C and aseptically dispensed into sterile Petri dishes. The plates were allowed to solidify and incubated at room temperature (25 °C) for 72 hours to check for sterility before use.

3.4 Isolation of Fungi

One gram (1 g) of each soil sample was suspended in 9 mL of sterile distilled water and allowed to stand for 30 minutes to dislodge fungal spores. An aliquot was aseptically transferred to sterile Petri plates, and molten PDA was poured over the aliquot aseptically. The plates were incubated at room temperature (25 °C) for 72 hours.

After incubation, visible fungal colonies were counted using a colony counter. The number of colony-forming units per gram (CFU/g) of soil was calculated using the formula:

$$CFU/g = \frac{\text{Number of colonies}}{\text{Volume plated} \times \text{Dilution factor}}$$

3.5 Cultural Characteristics

The macroscopic (cultural) features of each fungal colony, such as size, texture, color, and reverse coloration, were examined and recorded.

3.6 Preparation of Pure Cultures

Distinct fungal colonies were picked and streaked as primary inocula on fresh PDA plates to obtain pure cultures. Once purity was confirmed, isolates were transferred to PDA slants and incubated at 25 °C for 72 hours. These pure cultures were maintained for further identification studies.

3.7 Lactophenol Cotton Blue Mounting of Fungi

Lactophenol cotton blue (LPCB) stain was used to prepare semi-permanent slides for microscopic observation of the fungi. This stain contains phenol (fungicidal agent), lactic acid (clearing agent), cotton blue (cytoplasmic stain), and glycerine (preservative to maintain semi-permanence).

The slides were examined under low-power ($\times 10$) and high-power ($\times 40$) objectives of a light microscope. The type of hyphae, conidiophores, conidia, and their arrangement were observed and described. Representative microscopic fields were sketched, and identification was carried out based on the morphological characteristics seen. The fungal cytoplasm appeared as a lightly stained blue region within the unstained cell wall of the hyphae, conidiophores, phialides, and conidia.

CHAPTER FOUR

RESULTS

This chapter presents the findings from the laboratory analysis of topsoil samples collected from three selected open markets in Benin City. The results encompass the enumeration of the total heterotrophic fungal population, the identification of the fungal isolates, and a comparative analysis of the fungal communities across the markets. Data are presented as the mean \pm standard deviation from replicate measurements.

4.1 Sample Collection

A total of twelve (12) topsoil samples were collected from three open markets in Benin City: Uselu Market (Us), Kara Market (Rg), and Oluku Market (Ol). Four samples were collected from each market, with two samples taken from the tomatoes section and two from the cattle holding/beef section. The sample codes are defined as follows:

Uselu Market Samples were labelled Us1 and Us2. Soil samples from the Kara Market Samples were labelled Rg1 and Rg2. While Oluku Market Sample were labelled O1 and O2. Tomatoes section and cattle/beef section were tagged 1 and 2 respectively.

4.2 Total Heterotrophic Fungal Count (Enumeration)

The total culturable fungal population in the soil samples was determined and expressed in colony-forming units per gram (cfu/g) of soil. The raw colony counts are presented in Table 1, while Table 1.1 shows the calculated mean counts for each sampling point, grouped by market and section.

Note on Sample Codes:

For clarity, abbreviated codes were used to represent each market and section combination. The letters indicate both the market name and the sampling section as follows:

- USMT – Uselu Market (Tomatoes section)
- USMB – Uselu Market (Beef section)
- KMT – Kara Market (Tomatoes section)
- KMC – Kara Market (Cattle section)
- OMT – Oluku Market (Tomatoes section)
- OMB – Oluku Market (Beef section)

Each abbreviation begins with the market initials followed by the section code: T for tomatoes and B (or C where applicable) for beef/cattle. This system was used consistently throughout the results and discussion to simplify data presentation and comparison among markets.

From Table 1; Mean Total Heterotrophic Fungal Counts in market top soils ($\times 10^3$ cfu/g)

Oluku is the clear hotspot, with the highest loads in both sections: 27.7 ± 6.5 in tomatoes and 28.5 ± 3.7 in beef. Compared with Uselu, Oluku's tomatoes are about 76 percent higher (27.7 vs 15.7), and Oluku's beef is about 128 percent higher (28.5 vs 12.5). Kara sits close to Uselu across sections, with tomatoes at 16.2 ± 4.7 and cattle at 12.8 ± 3.9 , reinforcing a two-tier pattern where Oluku is high and Uselu/Kara are moderate.

Within each market, section differences show a produce bias in Uselu and Kara. In Uselu, tomatoes exceed beef by 3.2×10^3 CFU/g, roughly 26 percent. In Kara, tomatoes exceed cattle by 3.4×10^3 CFU/g, about 27 percent. Oluku does not follow that pattern. Beef edges tomatoes slightly by 0.8×10^3 CFU/g, only about 3 percent, which suggests uniformly high contamination across activities in that market.

Variation, judged by the standard deviations, is moderate overall but relatively larger in Kara, especially in the cattle section (12.8 ± 3.9), pointing to uneven sanitation or intermittent waste accumulation. Oluku beef pairs the highest mean with the lowest relative spread among sections, indicating a steady, persistent fungal presence rather than sporadic spikes.

In practical terms, Oluku requires urgent hygiene and waste-management attention in both tomatoes and beef areas. For Uselu and Kara, interventions should start with the tomatoes sections, where loads are consistently higher than in cattle/beef. The patterns are consistent with greater organic matter and moisture supporting fungal proliferation, and they highlight specific zones where targeted cleaning, drainage improvement, and waste handling would likely reduce counts most effectively.

Table 1: Mean Total Heterotrophic Fungal Counts in market top soils ($\times 10^3$ cfu/g)

Market	Section	Fungal Count (Mean \pm SD, cfu/g)
USMT	Tomatoes	15.7 \pm 2.9
USMB	Beef	12.5 \pm 3.3
KMT	Tomatoes	16.2 \pm 4.7
KMC	Cattle	12.8 \pm 3.9
OMT	Tomatoes	27.7 \pm 6.5
OMB	Beef	28.5 \pm 3.7

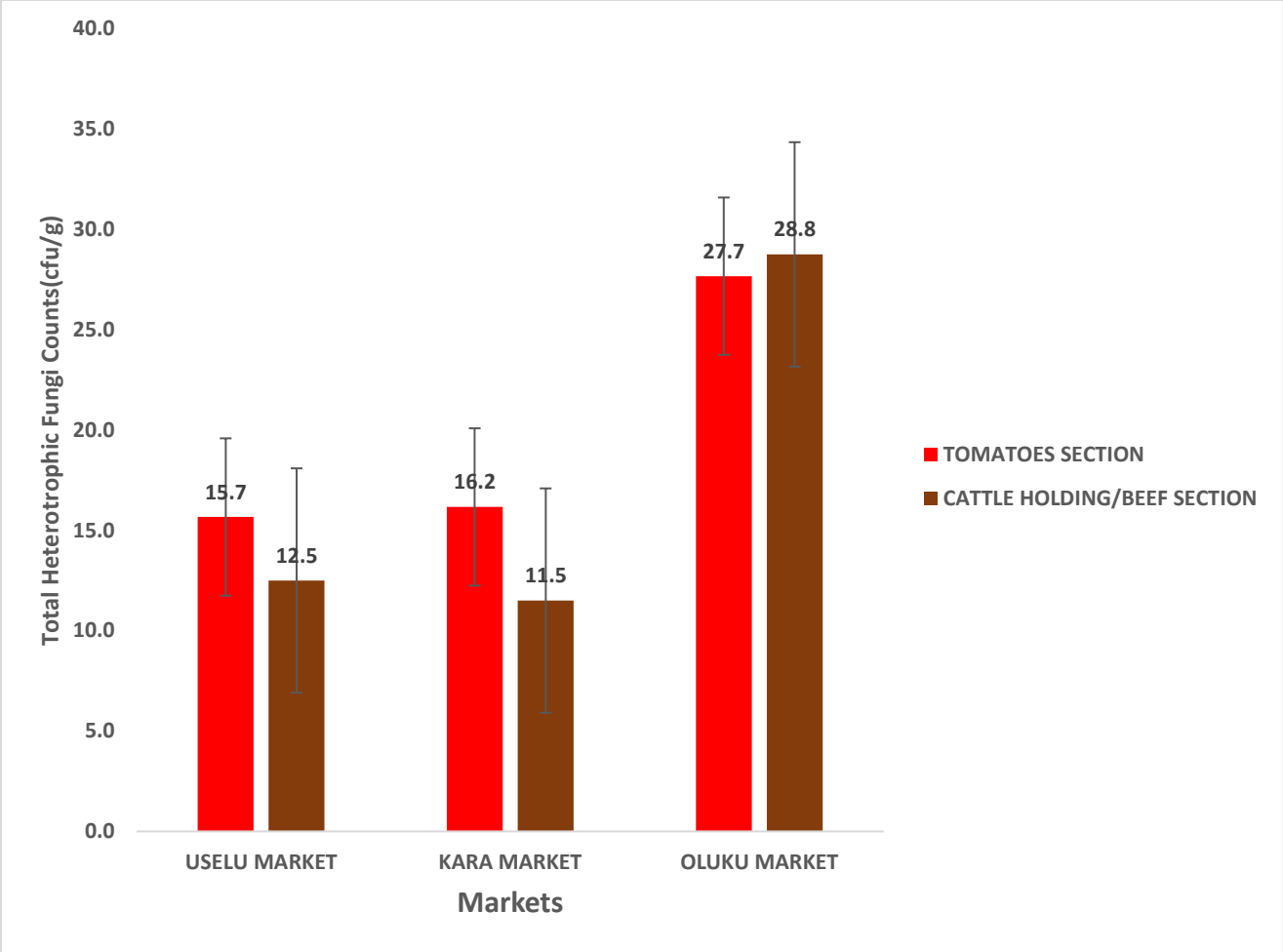


Figure 2: Mean Total Heterotrophic Fungal Counts (cfu/g) in Topsoil Samples from Selected Open Markets in Benin City

4.3 Distribution Pattern of Fungal Isolates in Soil Samples

A total of ten (10) distinct fungal taxa were identified across all the market topsoil samples. As shown in Table 2, members of the genus *Aspergillus* were the most prevalent and frequently observed, with three distinct species identified: *A. niger*, *A. flavus*, *A. parasiticus*. The other genera isolated were *Penicillium sp*, *Trichoderma, sp* *Rhizopus sp*, *Mucor sp*, *Fusarium sp*, and *Alternaria sp*.

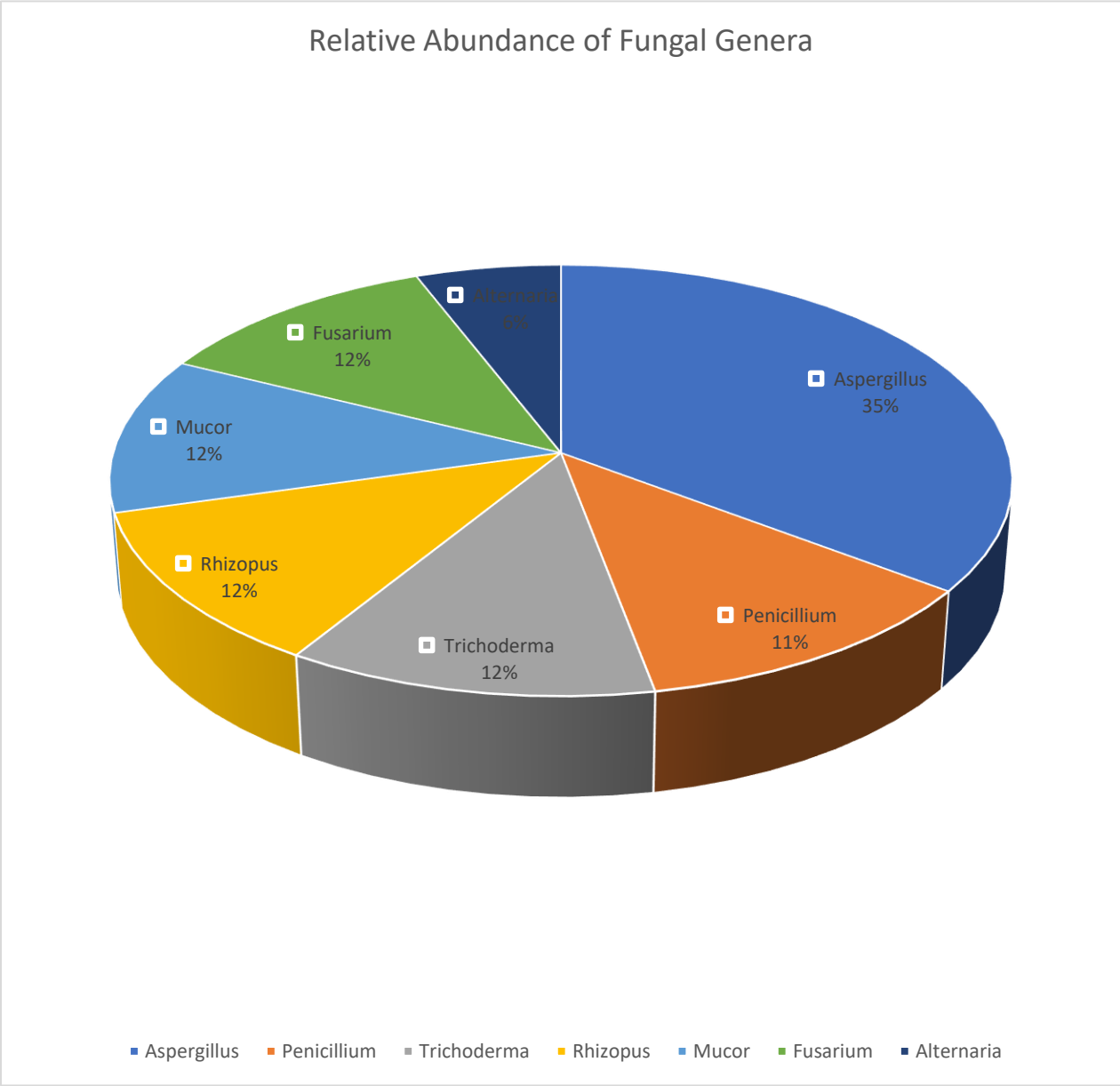


Figure 3: Relative Abundance of Fungal Genera Isolated from Market Topsoil

From Table 2, fungal species distribution varied between the Tomatoes and Cattle/Beef sections of each market:

Fungal species varied notably across the markets and sections. Oluku tomatoes (OMT) showed the highest diversity with six species, while Oluku beef (OMB) had the least with two. Uselu and Kara tomato sections each contained four species, slightly higher than their beef or cattle sections, which had three each.

The fungal community was dominated by *Aspergillus species*. *Aspergillus niger* and *Aspergillus parasiticus* occurred in about half of all sections, showing their wide distribution and strong adaptation to nutrient-rich market soils. Other frequently occurring genera included *Rhizopus* and *Trichoderma*, both typical of decomposing organic matter.

Pathogenic and toxin-producing fungi such as *Aspergillus flavus* were found in a few sections, indicating possible mycotoxin risks. Less common but still important species like *Alternaria*, *Fusarium*, *Mucor*, and *Penicillium* appeared in specific locations, mainly linked to plant residues or organic waste buildup.

Tomato sections in Uselu and Kara supported higher fungal diversity, while Oluku showed very high diversity in tomatoes but low in beef. The recurring presence of *A. flavus* and *A. parasiticus* highlights contamination risks, especially where waste management is poor. Improving sanitation, waste handling, and drainage in these market areas would help reduce fungal growth and health hazards.

Table 2: Distribution and Prevalence of Fungal Species in Market Soil Sections

Fungal Species	USMT	USMB	KMT	KMC	OMT	OMB	Frequency
<i>Aspergillus niger</i>	+	+	+				50%
<i>Aspergillus parasiticus</i>		+		+		+	50%
<i>Rhizopus sp.</i>		+		+	+		50%
<i>Trichoderma sp.</i>	+		+		+		50%
<i>Aspergillus sp.</i>		+	+		+	+	50%
<i>Aspergillus flavus</i>	+						33%
<i>Alternaria sp.</i>					+		16%
<i>Fusarium sp.</i>				+	+		33%
<i>Mucor sp.</i>			+				16%
<i>Penicillium sp.</i>					+		16%
Total Species per Section	3	4	4	3	6	2	

Key: “+” = Present

CHAPTER FIVE

5.0 DISCUSSION

The findings from this study show that fungal distribution and population varied significantly among the three sampled open markets (Urelu, Kara, and Oluku) and between the two sections (Tomatoes and Cattle/Beef) of each market. This variation in fungal counts and species diversity is largely linked to differences in waste accumulation, moisture content, and the type of organic matter present in each section, which are known ecological factors influencing fungal growth.

Among all locations, Oluku Market recorded the highest total heterotrophic fungal counts in both the Tomatoes (27.7 ± 6.5 cfu/g) and Cattle/Beef (28.5 ± 3.7 cfu/g) sections. This dominance indicates that the soil conditions in Oluku are more conducive to fungal proliferation. Factors such as high organic matter accumulation, moisture retention, and sub-optimal sanitation practices likely contribute to this elevated microbial activity (Musa *et al.*, 2024).

In contrast, Urelu and Kara Markets showed comparatively lower fungal counts, ranging between 11 – 16 cfu/g. These relatively smaller values may reflect more effective waste management systems or reduced organic deposition in those sections (Ewekeye *et al.*, 2023). Similar trends were reported in Lagos and Yola markets, where better drainage and periodic soil cleaning correlated with lower microbial loads (Abaka *et al.*, 2024).

Across all markets, clear sectional differences were observed in fungal counts. In Oluku Market, both sections exhibited high fungal populations, with the Cattle/Beef section slightly exceeding the Tomatoes section. This trend could be attributed to the accumulation of animal waste, blood residues, and other protein-rich organic materials that support rapid fungal metabolism and sporulation (Zakaria *et al.*, 2024). In Kara Market, the Tomatoes section recorded higher fungal

counts (16.2 ± 4.7 cfu/g) compared to the Cattle/Beef section (12.8 ± 3.9 cfu/g), likely due to the continuous deposition of decaying vegetable matter that favors the growth of saprophytic fungi such as *Aspergillus* and *Trichoderma*. A similar pattern was observed in Uselu Market, where the Tomatoes section (15.7 ± 2.9 cfu/g) surpassed the Cattle/Beef section (12.5 ± 3.3 cfu/g). The elevated fungal load in vegetable zones reflects the nutrient-rich conditions created by decomposing plant residues. These findings align with previous reports from southern Nigeria showing that vegetable-handling areas generally harbor greater fungal abundance than meat-handling zones because of their higher carbohydrate and cellulose content (Ewekeye *et al.*, 2023; Abaka *et al.*, 2024).

Across all three markets, members of the genus *Aspergillus* were the most prevalent, with *A. niger*, *A. flavus*, and *A. parasiticus* being the most frequently isolated. *A. parasiticus* appeared consistently in the Cattle/Beef sections of all markets, suggesting a strong ecological association with animal-derived organic waste. This finding aligns with previous studies in Lagos dumpsite soils, where *Aspergillus* species dominated because of their adaptability and ability to utilize complex protein substrates (Ewekeye *et al.*, 2023).

Across the Tomatoes and Cattle/Beef sections of all markets, notable differences in fungal diversity were observed. The Tomatoes sections consistently supported a wider range of fungal species than the Cattle/Beef sections. The Oluku Tomatoes samples exhibited the highest species richness, with six identified fungi, including toxin-producing species such as *Aspergillus flavus* and *Alternaria* sp., indicating a major contamination hotspot and potential aflatoxin risk. The Uselu Tomatoes section showed moderate diversity with three fungal species, among which *A. flavus* was predominant, a fungus widely recognized for aflatoxin production and its implications for food safety. Similarly, the Kara Tomatoes section demonstrated comparable diversity, with four

species isolated, notably *Trichoderma sp.* and *Rhizopus sp.*, which are important decomposers of plant residues. In contrast, the Cattle/Beef sections were generally less diverse, with the Oluku Cattle/Beef section showing the lowest diversity, containing only two fungal species. Nevertheless, *A. parasiticus* was consistently present across all Cattle/Beef samples, highlighting its ecological adaptation to protein-rich and animal waste environments. These observations are consistent with findings from Yola markets, where fungal diversity was highest in decomposing fruit and vegetable zones and lowest in meat-handling areas (Musa *et al.*, 2024).

Conclusion

The overall findings demonstrate that Oluku Market is the most biologically active and diverse, particularly within its Tomatoes section. *Aspergillus* species dominate the fungal flora across all markets, with *A. parasiticus* showing a strong association with Cattle/Beef sections and *A. flavus* commonly occurring in Tomatoes sections. Generally, Tomatoes sections supported greater fungal diversity due to the type and quantity of organic waste present.

These results emphasize the need for improved sanitation, waste management, and regular environmental monitoring in open markets, especially in vegetable and meat-handling areas. The detection of toxigenic species such as *A. flavus* and *A. parasiticus* raises public-health concerns, as both are known producers of aflatoxins and other mycotoxins. Strengthening hygiene protocols and promoting periodic soil treatment or turnover could help mitigate the risks associated with fungal contamination in open market environments.

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Appendix 1.

Table : Cultural Characteristics of Fungal Isolates on Potato Dextrose Agar (PDA)

Organism	Front Colour	Reverse Colour	Size	Texture
<i>Aspergillus niger</i>	Black	Green	Medium	Fluffy
<i>Aspergillus parasiticus</i>	Greenish black	Light yellow	Medium	-
<i>Rhizopus sp.</i>	Grey	Pale/Grey	Large	-
<i>Trichoderma sp.</i>	Light green	Green	Small	-
<i>Aspergillus sp.</i>	Black	Green	Medium	Velvet
<i>Aspergillus flavus</i>	Yellow	Yellow	Large	-
<i>Alternaria sp.</i>	Black	Black	Large	-
<i>Fusarium sp.</i>	White	Orange	Small	Velvet
<i>Mucor sp.</i>	Light brown	Brown	Small	Cotton
<i>Penicillium sp.</i>	Greenish blue	Pale	Medium	Fluffy

Appendix 2

Table: Morphological Characteristics of Fungal Isolates

Cultural Characteristics	Nature of Hyphae	Spore Type	Identified Organism
Fluffy colonies with black spores and pale reverse side	Septate	Conidiospore	<i>Aspergillus niger</i>
Dark green colonies with yellowish reverse side	Septate	Conidiospore	<i>Aspergillus parasiticus</i>
Fluffy grey colonies with dark spores at the air interface	Non-septate	Sporangiospore	<i>Rhizopus sp.</i>
Green colonies with pale reverse side & powdery texture	Septate	Conidiospore	<i>Trichoderma sp.</i>
Black fluffy colonies with pale reverse side	Septate	Conidiospore	<i>Aspergillus sp.</i>
Yellow fluffy colonies with a yellow reverse side	Septate	Conidiospore	<i>Aspergillus flavus</i>
Black fluffy colonies with a black reverse side	Septate	Conidiospore	<i>Alternaria sp.</i>
Wooly white colonies with orange spores	Septate	Chlamydospore	<i>Fusarium sp.</i>
Light brown fluffy colonies with brown reverse side	Non-septate	Sporangiospore	<i>Mucor sp.</i>

Green, dome-shaped colonies with dirty white reverse	Septate	Conidiospore	<i>Penicillium sp.</i>
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The distribution and occurrence of these identified fungal species across the various soil samples from the three markets are presented in Table 5

Appendix 3

Table: Distribution Pattern of Fungal Isolates in Soil Samples

Fungal Isolate	Us1	Us2	Rg1	Rg2	O11	O12
<i>Aspergillus niger</i>	+	+				+
<i>Aspergillus parasiticus</i>		+	+	+	+	+
<i>Rhizopus sp</i>		+		+		+
<i>Trichoderma sp</i>	+	+		+		+
<i>Aspergillus sp.</i>	+	+	+			
<i>Aspergillus Flavus</i>	+					+
<i>Alternaria sp.</i>		+				+
<i>Fusarium sp.</i>			+	+		
<i>Penicillium sp.</i>		+		+		

From Table 2, The distribution of fungal isolates revealed that the genus *Aspergillus* was the most prevalent, with *A. niger* occurring in both Tomatoes and Cattle/Beef sections of Uselu and Kara markets. *A. parasiticus* was exclusively found in Cattle/Beef sections across all three markets. *Trichoderma sp.* was present in Tomatoes sections of Uselu and Oluku, while *Rhizopus sp.* and *Fusarium sp.* were more frequent in Kara and Oluku. Notably, *A. flavus* was found in Uselu Tomatoes and Oluku Cattle/Beef sections. Oluku Market exhibited the highest fungal diversity, particularly in its Tomatoes section.

Appendix 4

Mean Total Heterotrophic Fungal Count (cfu/g) in Market Topsoil Samples

Sample Code	Market	Section	Fungal Count (Mean \pm SD, cfu/g)
Us1	Uselu	Tomatoes	14.0 \pm 1.73
Us2	Uselu	Tomatoes	17.3 \pm 3.06
Us3	Uselu	Cattle/Beef	10.0 \pm 3.00
Us4	Uselu	Cattle/Beef	15.0 \pm 0.00
Rg1	Kara	Tomatoes	20.0 \pm 2.00
Rg2	Kara	Tomatoes	12.3 \pm 2.52
Rg3	Kara	Cattle/Beef	9.0 \pm 1.41
Rg4	Kara	Cattle/Beef	15.3 \pm 2.31
Ol1	Oluku	Tomatoes	33.3 \pm 2.52
Ol2	Oluku	Tomatoes	22.0 \pm 2.00
Ol3	Oluku	Cattle/Beef	26.0 \pm 1.73
Ol4	Oluku	Cattle/Beef	31.0 \pm 3.61

Plating Method: Pour plating; Volume plated: 0.5 ml; Dilution: 10⁻²