

**ISOLATION AND CHARACTERIZATION OF FUNGI ASSOCIATED WITH  
SPOILED TOMATOES**

**BY**

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BENIN CITY.**

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**A PROJECT WORK SUBMITTED TO THE  
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**SUPERVISED BY**

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**SEPTEMBER, 2025.**

## **CERTIFICATION**

This is to certify that this project work was carried out by IRIA ISIBHAKHOMEN STEPHANIE with matriculation number **BMS2001169** in partial fulfilment of the requirements for the award of Bachelor of Medical Laboratory Science (BMLS) from the University of Benin, Benin City, Edo State, Nigeria.

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## **DEDICATION**

This work is dedicated to my Heavenly Father who is the source of all knowledge and wisdom and to my wonderful parents for their unwavering love and support.

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I acknowledge the all-wise, all-knowing, all-intelligent, and Almighty God from whom wisdom and knowledge come. I recognise the professional supervision given to me by my supervisor, Dr (Mrs) Anne o. Itemire, during this work. Special gratitude to the Head of Department, Dr (Mrs) Z. Omoruyi for creating a conducive environment for learning. To all my wonderful lecturers, it was indeed a privilege to learn under your supervision. I appreciate the Head of the Department of Microbiology for granting me permission to use the laboratory. I sincerely appreciate Mr Daniel Itoro, who guided and assisted me during this research work in the Laboratory. I want to specially appreciate my parents Engr and Mrs AIGBOGUN or their unwavering support, encouragement and belief in me, from their sacrifices to their words of wisdom, I am grateful for their guidance and patience throughout this research work. I also want to extend my heartfelt thanks to my siblings, Stephen, Scholar, Samuel and Stanley, my aunties, Gift, Peace and Brenda for their support in both big and small ways, and for their constant encouragement and understanding. Special appreciation goes to my friends (Eloghosa, Faith, Victoria, Godwin, Marvis, Blessed, Yvonne, Minne, Eseose, Theresa etc) for their support during this period.

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## ABSTRACT

Tomato spoilage results from adverse changes in quality driven by biological and physical factors, including microbial activity and mechanical damage. Globally, about one-third of tomato produce is lost before reaching consumers due to physical damage (e.g., bruises, mechanical breakage) and microbial activity from fungi and bacteria. This study was aimed at evaluating the fungi spoilage of tomatoes. Standard microbiological methods were used to determine the total fungal count of the samples. The fungi isolates were characterized and identified using morphological and cultural methods. The findings from this study revealed a high fungal burden in tomatoes sold across the surveyed markets, with total counts ranging from  $9.0 \times 10^4$  to  $14.0 \times 10^4$  cfu/g. Using the standard cultural, morphological characterization, the fungi isolates obtained in this study were *Aspergillus niger*, *Fusarium* spp., *Rhizopus* spp., *Alternaria* spp., *Penicillium citrinum*, *Cladosporium* spp. The in vitro and in vivo pathogenicity assessments confirmed that many of the isolates were not merely surface contaminants but active spoilage agents. Most of the fungi demonstrated strong pathogenicity on inoculated tomatoes, a finding that correlates with their hemolytic activity on blood agar. Antifungal susceptibility testing revealed variable resistance profiles among the isolates. While some fungi were inhibited by antifungal agents such as voriconazole and fluconazole, others displayed low sensitivity to drugs like nystatin and ketoconazole. The findings therefore emphasize the urgent need for integrated postharvest management strategies that combine proper handling, improved storage, strict hygiene practices, and the adoption of eco-friendly control methods.

## CHAPTER ONE

### INTRODUCTION

#### 1.0 Background of the study

Tomato (*Solanum lycopersicum*) is a vital crop belonging to the Solanaceae family, alongside potato (*Solanum tuberosum*), hot pepper (*Capsicum frutescens*), pepper (*Capsicum annum*), and eggplant (*Solanum melongena*) (Kumar *et al.*, 2023). It ranks as the most widely grown vegetable crop globally, contributing significantly to the world's fruit production (FAO, 2023). According to the Food and Agriculture Organisation Corporate Statistical Database (FAOSTAT), China remains the leading tomato producer, followed by India, the United States, Turkey, Egypt, Iran, and Italy, collectively accounting for over 80% of global tomato production (FAO, 2023). Egypt is the only African country among the top ten global tomato producers (USDA, 2024). In South Africa, tomatoes are the second most important and popular crop after potatoes within the Solanaceae family and are a key commodity in both local and export markets (South African Department of Agriculture, Land Reform and Rural Development [DALRRD], 2024).

The DALRRD reports that 75% of South Africa's tomatoes are produced in the northern regions of Limpopo province, with the remaining 25% cultivated in the Onderberg area of Mpumalanga and the border regions of the Eastern Cape (DALRRD, 2024). Tomatoes are a preferred crop for smallholder farmers in South Africa due to high demand for fresh produce and opportunities for industrial processing (Mabhaudhi *et al.*, 2022). Approximately 700 tomato producers operate in South Africa's commercial and emerging sectors, with the commercial sector contributing 95% of total production and the emerging sector contributing 5% (DALRRD, 2024). Tomato production supports job creation and income generation for

rural and peri-urban communities, enhancing the livelihoods of small-scale producers (DALRRD, 2024). After harvest, tomatoes are sorted into A-grade (marketable, medium to large, pest-free, and visually appealing) and B-grade (non-marketable, smaller, or pest-affected) categories based on size and quality (Smith *et al.*, 2023).

Food spoilage involves changes that render food less palatable or toxic, often accompanied by alterations in smell, taste, appearance, or texture (Oladapo *et al.*, 2021). Tomatoes, botanically known as *Lycopersicon esculentum*, are nutrient-rich, containing vitamins B, C, and E, carbohydrates (fructose and glucose), and trace elements like iron, copper, zinc, and dietary fiber (Oladapo *et al.*, 2021). Their high water content makes them highly susceptible to microbial spoilage (Adedoyin *et al.*, 2023). Tomatoes are consumed raw in salads, cooked as a vegetable, or processed into sauces, stews, and juices (Adedoyin *et al.*, 2023).

Tomato spoilage results from adverse changes in quality driven by biological and physical factors, including microbial activity and mechanical damage (Adedoyin *et al.*, 2023). Globally, about one-third of tomato produce is lost before reaching consumers due to physical damage (e.g., bruises, mechanical breakage) and microbial activity from fungi and bacteria (FAO, 2023). Studies have identified *Aspergillus* spp., *Penicillium* spp., *Fusarium* spp., and *Saccharomyces cerevisiae* as common spoilage organisms in tomatoes (Okunlola *et al.*, 2024; Adeyemi *et al.*, 2023). In northern Nigeria, spoilage is exacerbated by the use of wooden boxes and baskets for storage and transport, which can harbor pathogenic fungal spores and bacteria, initiating spoilage upon contact with healthy fruits (Okunlola *et al.*, 2024). Contaminated farm tools and transportation methods also contribute to spoilage, leading to significant economic losses for farmers (Adeyemi *et al.*, 2023).

Tomatoes are prone to fungal diseases such as Alternaria rot (*Alternaria solani*, *Alternaria tenuis*), Phytophthora rot (*Phytophthora infestans*, *Phytophthora nicotianae* var. *parasitica*),

Anthrachnose ripe rot (*Colletotrichum phomoides*), Phoma rot (*Phoma destructiva*), and Fusarium rot (*Fusarium* spp.) (Bhatia *et al.*, 2024). These diseases, driven by the high nutrient and water content of tomatoes, reduce yields by up to 25% in industrialized countries and over 50% in developing countries (FAO, 2023). Synthetic fungicides have traditionally been used to manage postharvest spoilage, but concerns over environmental pollution, fungicide resistance, and residue persistence have spurred the development of alternative strategies (Gullino *et al.*, 2022). Biological control using microbial antagonists offers a nontoxic, environmentally friendly alternative to synthetic fungicides, effectively reducing fungal pathogens in tomatoes (Sharma *et al.*, 2023).

Postharvest fungal spoilage of tomatoes accounts for substantial losses along the supply chain, particularly in tropical and subtropical regions where temperature and humidity favor microbial proliferation (Oladokun *et al.*, 2021). In Nigeria, for example, over 40% of tomato harvests are estimated to be lost due to fungal infections during storage, transportation, and retail stages (Okoye & Akinyemi, 2020). These losses contribute to food insecurity, economic hardship for farmers, and higher retail prices for consumers. Therefore, understanding the nature of spoilage fungi is crucial for implementing effective control and preservation strategies.

Fungi represent the dominant group of microorganisms responsible for tomato spoilage. The most commonly isolated fungal genera from spoiled tomatoes include *Aspergillus*, *Fusarium*, *Penicillium*, *Rhizopus*, *Alternaria*, and *Mucor* (Medeiros *et al.*, 2023). These fungi invade the fruit through mechanical injuries, insect punctures, or natural openings such as the stem scar, leading to visible rots, discoloration, softening, and off-odors. Some of these fungi, particularly species of *Aspergillus* and *Fusarium*, are also known producers of hazardous mycotoxins like aflatoxins and fumonisins, which pose significant public health threats

(Sharma *et al.*, 2022). Food spoilage refers to various changes to food in which the food becomes less palatable or even toxic to consumers these changes may be accompanied by alterations in smell taste appearance or texture (Akinmusire, 2011). Tomato is a widely consumed fruit eaten in both raw and processed forms. It has the botanical name *Lycopersicon esculentum* and belongs to the plant family solanaceae. It is rich in vitamins such as vitamin B, C, and E. Carbohydrates such as fructose and glucose; and trace elements like iron, copper, zinc, and dietary fiber, which are all vital nutrients in man. The high water content of tomatoes makes it more susceptible to spoilage by the action of microorganisms (Obunkwu *et al.*, 2018). Tomato is very important mainly for its dietary needs, it can be consumed in diverse ways; it can be cooked as vegetable, as an ingredient in many dishes and sauces, in the making of stew, fruit juices and can be eaten raw in salads (Onuorah and Orji, 2024).

Tomatoes spoilage can be referred to as those adverse changes in the quality of tomatoes caused by the action of predominantly biological and physical factors. These changes may include changes in taste, smell, appearance or texture of the fruits (Onuorah and Orji, 2024). Estimates have shown that about one third of the produce is lost before reaching the consumer (Mbajiuka and Emmanuel, 2024). This loss has been attributed to a number of factors which include; physical (mechanical breakage, bruises), and also damages caused by microbes such as fungi and bacteria (Onuorah and Orji, 2024).

Tomatoes are susceptible to fruit spoilage caused by numerous fungal pathogens (Barkai-Golan and Paster, 2018; Samuel and Orji, 2024). Examples of fungal induced tomato diseases include Alternaria rot caused by *Alternaria solani* and *Alternaria tenuis*, *Phytophthora* rot caused by *Phytophthora infestans* and *Phytophthora nicotianae* var. *parasitica*, Anthracnose ripe rot caused by *Colletotrichum phomoides*, *Phoma* rot caused by *Phoma destructiva* and *Fusarium* rot caused by *Fusarium* spp. (Wani, 2021). Diseases caused by the above

mentioned fungi may be due to large nutrient composition or other factors such as high water content and low pH (Droby *et al.*, 2022). These factors may make the produce to become highly susceptible to pathogenic attack. Diseases reduce the yield of tomatoes by up to 25% in industrialised countries and more than 50% in developing countries (Nunes, 2022). However, there are numerous methods for preventing diseases in fruits and one of them is the use of fungicides. The use of synthetic fungicides has been a primary method for managing the postharvest spoilage of tomatoes (Spadaro and Gullino, 2024). However, there are increasing concerns over fungicide use such as environmental pollution risks, inability to control fungal diseases due to fungicide **resistance**, and persistence of fungicide residues on the tomato (Ippolito and Nigro, 2020). All those challenges have resulted in the search for safe and effective alternative strategies for the control of plant pathogens (Liu *et al.*, 2023). Such strategies include biological control (such as the microbial antagonists) of fungal pathogens in tomatoes using naturally occurring microorganisms (Droby *et al.*, 2019). Moreover, this biological control is effective, nontoxic and environmentally friendly alternatives to fungicides (Janisiewicz and Korsten, 2022).

### **Statement of the Problem**

Tomato (*Lycopersicon esculentum*) is a globally significant vegetable crop, contributing substantially to food security, nutrition, and economic livelihoods, particularly in developing countries like Nigeria and South Africa. However, postharvest spoilage due to fungal infections remains a major challenge, leading to significant economic losses, reduced market value, and food insecurity. Globally, approximately one-third of tomato produce is lost before reaching consumers, with losses exceeding 40% in tropical regions like Nigeria due to microbial activity, mechanical damage, and inadequate storage and transportation practices. In Nigeria, fungal pathogens such as *Aspergillus* spp., *Penicillium* spp., *Fusarium* spp.,

*Rhizopus* spp., *Alternaria* spp., and *Mucor* spp. are commonly associated with tomato rot, exacerbating spoilage through invasion via wounds, high humidity, and nutrient-rich fruit composition. This results in qualitative and quantitative postharvest losses (PHLs) estimated at 20–50% in developing countries, contributing to higher retail prices, income reduction for smallholder farmers, and public health risks from mycotoxins like aflatoxins and fumonisins. Despite the availability of synthetic fungicides, concerns over resistance, environmental pollution, and residues have limited their efficacy, underscoring the need for targeted identification and characterization of spoilage fungi to inform sustainable control strategies.

### **Justification**

This study is justified by the critical need to address postharvest fungal spoilage in tomatoes, which poses significant threats to agricultural productivity, economic stability, and public health in regions like Nigeria. Tomatoes are a staple crop with high nutritional value, providing essential vitamins, minerals, and antioxidants, yet their susceptibility to spoilage undermines food availability and farmer incomes. By isolating, characterizing, and assessing the pathogenicity and virulence of fungal isolates from spoiled tomatoes in Benin City markets, this research will contribute to a deeper understanding of local spoilage dynamics, enabling the development of effective, environmentally friendly interventions such as biological controls. This aligns with global efforts to reduce PHLs, as highlighted by the FAO, and supports smallholder agriculture by promoting sustainable practices that minimize losses and enhance marketability. Furthermore, the molecular profiling of isolates will provide insights into fungal genetics, aiding in the formulation of targeted biocontrol agents and reducing reliance on harmful synthetic fungicides, ultimately fostering food security and economic growth in developing economies.

## **1.2 AIM**

The aim of this study is to fungal isolates associated with spoiled tomatoes

## **1.3 SPECIFIC OBJECTIVE**

The specific objective of the study are to;

- I. isolate and enumerate fungi associated with infected tomato fruits.
- II. characterize and identify the fungal isolates obtained from tomatoes using morphological and cultural characteristics.
- III. assess the in planta pathogenicity of the fungal isolates on healthy tomato fruits.
- IV. determine the in vivo virulence of the soft rot pathogen(s) on tomato fruits.

## **Research Questions**

1. What fungal species are predominantly responsible for the postharvest spoilage of tomatoes sold in selected markets within Benin City, Edo State, Nigeria?
2. How can the fungal isolates obtained from spoiled tomatoes be accurately characterized and identified using their morphological, cultural, and microscopic features?
3. To what extent do the isolated fungal species exhibit pathogenicity when inoculated onto healthy tomato fruits, as verified through Koch's postulates?
4. What are the levels of in vivo virulence expressed by the fungal isolates, as determined by measurable parameters such as weight loss, decay incidence, and necrotic lesion diameter in infected tomato fruits?

### **Null Research Hypothesis**

H<sub>0</sub>: There is no significant association between the isolated fungal species (such as *Aspergillus* spp., *Penicillium* spp., *Fusarium* spp., *Rhizopus* spp., *Alternaria* spp., and *Mucor* spp.) and the spoilage of tomatoes, as evidenced by a lack of pathogenicity, virulence, or molecular markers indicative of decay in healthy fruits.

### **Alternate Hypothesis**

H<sub>1</sub>: There is a significant association between the isolated fungal species (such as *Aspergillus* spp., *Penicillium* spp., *Fusarium* spp., *Rhizopus* spp., *Alternaria* spp., and *Mucor* spp.) and the spoilage of tomatoes, as demonstrated by positive pathogenicity tests, measurable virulence (e.g., weight loss and lesion diameter), and distinct molecular and genetic profiles linked to decay in healthy fruits.

## CHAPTER TWO

### LITERATURE REVIEW

#### 2.1. A Brief Description of the Tomato

Tomato (*Lycopersicon esculentum*) is one of the most significant vegetable crops globally. It is a self-pollinated fruit belonging to the Solanaceae family (Kumar *et al.*, 2023). This family also encompasses plant drugs such as tobacco (*Nicotiana tabacum*), deadly nightshade (*Atropa belladonna*), mandrake (*Mandragora officinarum*), jimson weed (*Datura stramonium*), and petunia (*Petunia hybrida*) (Patel *et al.*, 2024). Tomatoes are extensively cultivated in tropical, subtropical, and temperate climates, ranking third in global vegetable production (FAO, 2023). The crop is known by various names worldwide, including tomate (German, French), tomati (West Africa), tomaatti (Finnish), tomat (Indonesian), pomodoro (Italian), kamatis (Malay), jitomate (Spanish, Mexican), pomidor (Russian), faan ke'e (Chinese), tomatl (Nahuatl), nyanya (Swahili), and tamatar (Hindi) (Bvenura & Afolayan, 2022).

Tomatoes originated in the Andes mountains of South America, specifically in Peru (Gerszberg & Hnatuszko-Konka, 2024). Early travelers introduced the crop to other regions as an ornamental plant, though it was not initially consumed (Kumar *et al.*, 2023). By 500 BC, tomatoes had reached Mexico for domestication. In 1554, Spanish conquistadors brought

tomatoes to Europe, where they were later cultivated in the United States by 1710. The crop subsequently spread to southern and eastern Asia, Africa, and the Middle East, gaining popularity and becoming a major commercial crop by 1850 (Gerszberg & Hnatuszko-Konka, 2024).

### **2.1.1. Scientific classification of tomato**

Kingdom: Plantae

Sub kingdom: Tracheobionia

Class: Magnoliopsoda

Sub class: Asterialae

Order: Sultانات

Family: Solanaceae

Genus: *Lycopersicon*

Species: *esculentum*

### **2.1.2. Different botanical varieties of tomato**

The botanical name for tomato has undergone several revisions. For many years, it was classified as *Solanum lycopersicum*, but it was later referred to as *Lycopersicon esculentum* (Bvenura & Afolayan, 2022). Currently, *Solanum lycopersicum* is the accepted scientific name. Tomato is a true diploid with a chromosome number of  $2n = 24$  (Gerszberg & Hnatuszko-Konka, 2024). The plant is an annual with a herbaceous, prostrate stem and exhibits either determinate or indeterminate growth habits (Kumar *et al.*, 2023).

Tomatoes have three vine types: indeterminate (sprawling, with staggered ripening and tall growth), semi-determinate (intermediate growth and semi-bush type), and determinate (compact, with uniform ripening and bush type) (Kumar *et al.*, 2023). There are approximately 7,500 tomato varieties cultivated for various purposes (FAO, 2023). These varieties are categorized based on shape and size, including slicing or globe (also known as round tomatoes), beefsteak (large tomatoes), plum (bred for higher solid content), and grape (a smaller variation of plum tomatoes) (Sharma *et al.*, 2024).

### **2.1.3. The economic, health and nutritional values of tomatoes**

Tomato has emerged as a significant cash and industrial crop globally, valued for its economic contributions and nutritional benefits to human health due to its essential nutrients (Mabhaudhi *et al.*, 2022; Sharma *et al.*, 2024). It is a versatile crop classified into two categories based on use: fresh market tomatoes for direct consumption and processing tomatoes for industrial canning and processed foods (Gullino *et al.*, 2022). Tomatoes are rich in vitamins A, B, C, and E; carbohydrates such as fructose and glucose; minerals including phosphorus, sodium, potassium, calcium, and magnesium; and trace elements like iron, copper, zinc, and dietary fiber (Bvenura & Afolayan, 2022; Kumar *et al.*, 2023). These nutrients make tomatoes a vital component of a healthy diet (Adedoyin *et al.*, 2023; Patel *et al.*, 2024).

An average-sized tomato (70–150 g weight, 50–70 mm diameter) contains approximately 18 kcal of energy, 0.95 g of protein, 0.11 g of fat, 4.01 g of carbohydrates, 2.49 g of total sugars, 0.731 mg of niacin, 11.0 mg of calcium, 0.68 mg of iron, 9.0 mg of magnesium, 28.0 mg of phosphorus, 218.0 mg of potassium, 11.0 mg of sodium, 0.14 mg of zinc, 0.036 mg of thiamin, 0.022 mg of riboflavin, 320 IU of carotene (vitamin A), 0.079 mg of vitamin B6, 16.9 mg of vitamin C, and 31 mg of ascorbic acid per 100 g of fruit pulp (Bvenura &

Afolayan, 2022; Sharma *et al.*, 2024). As a ready-to-eat food, tomatoes are minimally processed (Kumar *et al.*, 2023). They are consumed in diverse forms, including raw in salads and sandwiches, cooked in dishes, or processed into ketchup, sauces, soups, chutneys, pickles, paste, puree, juices, dried powder, and whole canned fruits, and are a key ingredient in cocktails like the Bloody Mary (Mabhaudhi *et al.*, 2022; Patel *et al.*, 2024).

The deep-red color of ripened tomatoes is attributed to lycopene, a  $\beta$ -carotenoid pigment and potent antioxidant that may reduce the risk of chronic diseases such as prostate cancer, cardiovascular disease, and diabetes (Gerszberg & Hnatuszko-Konka, 2024; Okunlola *et al.*, 2024). Tomato juice supports gastric secretion, acts as a blood purifier, and serves as an intestinal antiseptic (Patel *et al.*, 2024). Rich in vitamins C and A, tomatoes help prevent muscular degeneration, improve eyesight, and act as a blood purifier, potentially alleviating urinary tract infections. Their high fiber content aids digestion and may support weight loss (Adedoyin *et al.*, 2023).

Tomatoes offer numerous economic advantages, including a relatively short growth duration, a brief production cycle, adaptability to both open-field and protected cultivation, compatibility with diverse cropping systems, high economic value, and significant micronutrient content (FAO, 2023).

## **2.2. Smallholder Agriculture Leading to Tomato Contamination**

Smallholder agriculture plays a significant role in tomato production, particularly in developing regions, but it is often associated with challenges that lead to tomato contamination and spoilage. The high water content and nutrient-rich nature of tomatoes make them highly susceptible to microbial contamination, resulting in significant postharvest losses (Adedoyin *et al.*, 2023). Studies estimate that up to 40–45% of tomato produce in

regions like Ethiopia and Ghana is lost due to contamination and spoilage, primarily caused by biological, physical, and environmental factors (FAO, 2023; Okunlola *et al.*, 2024).

Biological contamination in smallholder systems often arises from fungal and bacterial pathogens. Common fungal pathogens include *Aspergillus* spp., *Penicillium* spp., *Fusarium* spp., and *Colletotrichum* spp., which cause diseases such as Alternaria rot, Fusarium wilt, and Anthracnose ripe rot (Bhatia *et al.*, 2024). Bacterial pathogens, such as *Ralstonia solanacearum* (causing bacterial wilt), also contribute to spoilage (Sharma *et al.*, 2023). These pathogens often originate from contaminated farm tools, storage containers, or transportation systems, particularly in regions like northern Nigeria, where wooden boxes and baskets used for storage and transport can harbor pathogenic spores (Okunlola *et al.*, 2024). Inadequate sanitation practices and improper handling further exacerbate microbial contamination (Adeyemi *et al.*, 2023).

Physical factors, such as mechanical damage during harvesting and transportation, also contribute to contamination. Bruises and cracks on tomato surfaces provide entry points for pathogens, accelerating spoilage (FAO, 2023). In smallholder systems, limited access to proper infrastructure, such as good roads and storage facilities, leads to prolonged transit times and exposure to high temperatures, further increasing spoilage rates (Mabhaudhi *et al.*, 2022). For instance, studies in Ghana indicate that transportation delays can cause up to 20% postharvest losses in tomatoes due to physical damage and microbial growth (Okunlola *et al.*, 2024).

Environmental factors, including high humidity and temperature, create favorable conditions for microbial proliferation. In tropical climates, where many smallholder farmers operate, these conditions amplify the risk of contamination (Adedoyin *et al.*, 2023). Additionally, the reuse of treated wastewater for irrigation, common in water-scarce regions, introduces

emerging contaminants (ECs) such as pharmaceuticals (e.g., fluconazole and carbamazepine) into tomatoes, posing risks to human health (Gullino *et al.*, 2022). These contaminants can accumulate in the edible parts of the fruit, highlighting the need for careful monitoring of irrigation water quality (FAO, 2023).

### **2.3. Tomato Production**

Globally, annual production of fresh tomatoes reaches approximately 190 million tons, with over 25% grown for the processing industry, making tomatoes the world's leading vegetable for processing (FAO, 2023). Tomatoes are cultivated in tropical and subtropical regions, in kitchen gardens, commercial fields, greenhouses, polyhouses, and soilless or hydroponic systems (Sharma *et al.*, 2024). The root structure of tomato plants can penetrate various soil types up to depths of two meters, with the majority of roots concentrated in the top 600 mm of soil. Optimal production occurs at mean temperatures between 20 °C and 24 °C, with poor fruit set when daily temperatures exceed 32 °C or night temperatures drop below 21 °C (Kumar *et al.*, 2023). Tomato plants typically take three to four months to produce harvestable fruits. Planting techniques vary for determinate varieties (typically grown in open fields) and indeterminate varieties (often cultivated in polyhouses) (Bvenura & Afolayan, 2022).

Tomatoes thrive in diverse substrates, including soil, organic mixes, soilless media, perlite, sand, or hydroponic systems (Gerszberg & Hnatuszko-Konka, 2024). The tomato industry significantly contributes to foreign export earnings in many African countries, boosting their gross domestic product (GDP) (Mabhaudhi *et al.*, 2022). However, the crop's full potential remains underexploited due to numerous challenges (Adeyemi *et al.*, 2023). These include

inadequate physical infrastructure (poor roads, transport, and telecommunications), prolonged production cycles, lack of clear land policies, social constraints (e.g., underestimation of women farmers' roles), and limited investment due to low output prices, high input costs, and restricted access to credit (FAO, 2023; Mabhaudhi *et al.*, 2022). Additional challenges involve environmental factors (e.g., climate change impacts), production constraints (e.g., low yields from rain-fed crops and unsuitable agricultural practices leading to soil erosion), inadequate post-harvest processing, poor storage facilities, and inefficient marketing systems, all contributing to significant post-harvest losses (Adedoyin *et al.*, 2023; Okunlola *et al.*, 2024).

Quality management is essential to mitigate these challenges, starting in the field and continuing until the produce reaches consumers (Patel *et al.*, 2024). Pre-harvest conditions significantly influence storage performance, sometimes outweighing post-harvest storage adjustments (Sharma *et al.*, 2023). Current pre-harvest treatment recommendations focus primarily on productivity rather than quality, nutritional value, or shelf life (Gullino *et al.*, 2022). Integrating pre- and post-harvest treatments is critical for improving shelf life. Post-harvest losses (PHLs) are measured qualitatively (e.g., reduced nutrient value, changes in color, taste, or texture) and quantitatively (e.g., decreased volume or weight) along the supply chain from harvest to consumption (FAO, 2023). PHLs result from physiological, physical, and environmental factors, including high perishability, mechanical damage, humidity, rain, excessive heat, poor handling, inadequate infrastructure, pests, diseases, and insufficient transport and processing techniques (Adedoyin *et al.*, 2023; Okunlola *et al.*, 2024).

The vulnerability of tomatoes to physical damage significantly influences PHL extent (Gullino *et al.*, 2022). Post-harvest diseases reduce global crop yields by 10–30%, with losses exceeding 30% in developing countries compared to lower rates in developed nations (Bhatia

*et al.*, 2024). Global PHLs for tomatoes range from 25–42%, with Africa experiencing losses of 20–40%, valued at approximately USD 2 billion annually in eastern and southern Africa (FAO, 2023). In South Africa, approximately 60% of farmers do not use chemicals for disease control, compared to 40% who do (Mabhaudhi *et al.*, 2022). PHLs lead to low returns for farmers, processors, consumers, and traders, reducing foreign exchange earnings (FAO, 2023). Post-harvest potential depends on both pre-harvest factors (e.g., nutrient and water supply, harvesting methods, genetic and environmental conditions) and post-harvest handling (Patel *et al.*, 2024). Tomatoes' susceptibility to microbial colonization stems from their high sugar content, low pH (4.9–6.5), and high water activity, which favor microbial growth (Adedoyin *et al.*, 2023). Fungi, the most prevalent pathogens, cause significant losses during storage, transportation, and marketing (Bhatia *et al.*, 2024).

#### **2.4. Tomato Diseases and Pathogens**

Over 200 species of fungi can infect tomato crops, often serving as a limiting factor in production (Bhatia *et al.*, 2024; Sharma *et al.*, 2023). Disease epidemics result from complex interactions between the host, pathogen, environment, and cultural practices such as fertilization and irrigation (Gullino *et al.*, 2022). Plant pathogens employ various strategies to survive and spread to new hosts, with most requiring a specific host to increase their population and cycling between plants and soil (Adedoyin *et al.*, 2023; Patel *et al.*, 2024). Fresh tomatoes are highly perishable due to their high moisture content, making them susceptible to microbial diseases and physiological deterioration (Bvenura & Afolayan, 2022; Kumar *et al.*, 2023; Sharma *et al.*, 2024).

Inadequate pre-harvest and post-harvest handling practices contribute to diseases caused by pests such as *Aculops lycopersici* (causing rusty brown surface cracking) and *Thrips tabaci* (causing blossom drop and fruit scarring), as well as viral infections like fruit necrosis from Tomato marchitez virus (ToMarV) and fruit marbling from Pepino mosaic virus (PepMV) (Gerszberg & Hnatuszko-Konka, 2024). Bacterial diseases, including bacterial speck (*Pseudomonas syringae*), bacterial wilt (*Ralstonia solanacearum*), bacterial spot (*Xanthomonas campestris*), and bacterial canker (*Clavibacter michiganensis*), also affect tomatoes (Okunlola *et al.*, 2024). Physiological disorders such as blossom end rot (caused by calcium deficiency) and growth cracks (due to excessive fruit expansion stretching the epidermis) further impact quality, alongside viral diseases like tomato mosaic virus (Bhatia *et al.*, 2024; Kumar *et al.*, 2023).

In South Africa, smallholder farmers face significant challenges from pathogenic fungi due to limited technical knowledge about crop diseases (Mabhaudhi *et al.*, 2022). Soil-borne phytopathogenic fungi are a primary cause of post-harvest losses (PHLs) in tomatoes, with diseases such as early blight (*Alternaria solani*), anthracnose (*Colletotrichum* spp.), Sclerotium wilt (*Sclerotium rolfsii*), damping off (*Rhizoctonia solani*), tomato wilt (*Fusarium oxysporum*), Phoma rot (*Phoma destructiva*), Fusarium wilt (*Fusarium oxysporum*), late blight (*Phytophthora capsici*), Septoria leaf spot (*Septoria lycopersici*), and Rhizopus rot (*Rhizopus stolonifer*) (Sharma *et al.*, 2023; Bhatia *et al.*, 2024; Okunlola *et al.*, 2024). These pathogens, often severe wound pathogens, infect tomatoes during packing, handling, or storage, reducing yield and quality (Gullino *et al.*, 2022).

Pathogenic microorganisms in tomatoes pose health risks to humans and animals through the production of mycotoxins, which can cause respiratory infections, meningitis, gastroenteritis, and diarrhea upon ingestion (Adedoyin *et al.*, 2023). Effective management strategies,

including biological controls and improved post-harvest handling, are essential to mitigate these risks and enhance tomato quality and safety (Sharma *et al.*, 2023).

### **Methods to Control Post-Harvest Losses in Tomatoes**

The post-harvest quality and storage performance of tomatoes are influenced by pre-harvest factors, including cultural practices, natural plant extracts, fertilizers, manure, and genetic and environmental conditions (Patel *et al.*, 2024; Sharma *et al.*, 2024). Untreated tomatoes can experience up to 90% loss due to fungal decay during post-harvest handling and marketing (Gullino *et al.*, 2022). Various methods to control post-harvest losses in tomatoes are outlined below.

#### **Physical Control**

Temperature control is a widely used physical method to manage post-harvest losses. Techniques include hot water dips, hot water rinsing and brushing, vapor, hot air, and curing (Bhatia *et al.*, 2024; Okunlola *et al.*, 2024). Optimal storage conditions are determined using models like TOMGRO and adaptive management frameworks (Kumar *et al.*, 2023). During the growing season, air temperatures of 18–32.2 °C with 50–70% humidity are ideal, while greenhouse cultivation maintains 17–28 °C in coastal areas and 17–22 °C in inland areas with 85–95% humidity (Sharma *et al.*, 2023). Storage at 10–15 °C with 85–95% relative humidity minimizes chilling injury and ripening rates, extending shelf life (Adedoyin *et al.*, 2023). Ultraviolet light (UV-C, 254 nm) hormesis is another physical method that induces resistance to storage diseases and prolongs shelf life with doses ranging from 1.3 to 40 kJ/m<sup>2</sup> (Gullino *et al.*, 2022). However, temperature and UV-C treatments can alter the aroma and taste of tomatoes after six days of storage (Bvenura & Afolayan, 2022; Okunlola *et al.*, 2024).

## **Chemical Control**

Chemical strategies, including synthetic fungicides, pesticides, resistant-variety cultivation, and crop rotation, are commonly used to control fungal diseases (Sharma *et al.*, 2023). Fungicides such as azoxystrobin, fludioxonil, and pyrimethanil, along with chemicals like sporekill, vinclozolin, copper oxychloride, benomyl, and kitazin, are applied to manage spoilage-causing fungal pathogens (Bhatia *et al.*, 2024; Gullino *et al.*, 2022). These treatments are cost-effective and offer both curative and preventive actions. However, intensive use of synthetic chemicals can lead to pathogen resistance, pesticide residues, and environmental pollution, prompting restrictions due to consumer and regulatory concerns about human health (Adedoyin *et al.*, 2023; Patel *et al.*, 2024). Some chemical treatments are also ineffective against certain plant diseases, increasing demand for pesticide-free produce (FAO, 2023).

## **Biological Control**

The environmental and health concerns associated with chemical controls have driven the development of biological alternatives using naturally derived substances (Sharma *et al.*, 2024). Biological control employs microorganisms with strong antifungal activity, leveraging mechanisms such as competition for nutrients and space, mycoparasitism, emission of antifungal compounds, antibiotics, volatile metabolites, induction of host resistance, biofilm development, and reactive oxygen species (ROS) in defense responses (Sharma *et al.*, 2023; Okunlola *et al.*, 2024). These biocontrol agents are environmentally safe, enhance crop production, and reduce pesticide resistance (Kumar *et al.*, 2023; Bhatia *et al.*, 2024). Application methods include spraying, dipping, or drenching during the post-harvest period (Gullino *et al.*, 2022). Antagonists such as bacteria, yeast, and fungi—including *Debaryomyces hansenii*, *Candida guilliermondii*, *Byssochlamys spectabilis*, *Trichoderma*

*harzianum*, *Trichoderma viride*, *Pythium debaryanum*, *Gliocladium roseum*, *Aureobasidium pullulans*, *Phytophthora cryptogea*, and *Cryptococcus laurentii*—are effective in managing post-harvest diseases in tomatoes and citrus fruits (Adedoyin *et al.*, 2023; Sharma *et al.*, 2023; Bhatia *et al.*, 2024).

## CHAPTER THREE

### MATERIALS AND METHOD

#### 3.1 Study Sites

The study sites were selected markets in Benin City, Edo State, Nigeria. The analysis was carried in Microbiology department laboratory, University of Benin, Benin City.

#### 3.2.1 Microbiological Media

The culture media such as potato dextrose agar, antifungi such as fluconazole, nystatin, asuch as lactophenol blue, which was used in this research, was purchased from Vicdomstell Nigeria Limited, Lagos. The reagents and chemicals for the successful implementation of the objectives in this research, was obtain from Pyrex- IG Scientific Company Benin.

All the culture media used in this research were made in England by Oxoid, Basingstoke, Hamsphire. The media (agar) used include but not limited to, potato dextrose agar and [sabouraud](#) dextrose agar.

#### 3.2.2 Equipment and Apparatus

Industrial autoclave, weighing balance, hot air oven, mortar, pestle, mechanical grinding machine, micropipette, incubator, Whatman filter paper, cotton wool, pipette tip, a corkborer (6mm in diameter), a transparent millimetre rule, Bunsen burner, foil paper

### **3.2.3 Glassware**

Conical flask, bottles (MacCartney, universal and Bijou) as well as test tubes, pipettes, glass stirrers, porcelain dish, pestle, maceration jars, glass funnels, beakers, measuring cylinders, and Petri dishes.

### **3.3 Compliance with Ethical Standard**

This study was performed in accordance with guidelines of the University of Benin research committee (Grandin *et al.*, 2020).

### **3.4 Sampling**

Samples was obtained from several markets in Benin City, Edo state and was transported aseptically to the Microbiology laboratory in University of Benin for microbial analysis

### **3.5 Preparation of Culture Media**

All media were prepared according to manufacturer's instruction.

The media used in this study were potato dextrose agar and [sabouraud](#) dextrose agar.

### **3.6 Enumeration of Fungal Isolates**

Samples were prepared in sterile conical flask and a stock (10-fold) was prepared by dissolving 10g of tomatoes in 90 ml sterile saline water (SSW) or normal saline. The samples were serially diluted with a factor of 10 until a thousand dilution fold (1000) was attained.

Thereafter, an inoculum volume of 0.1 ml from the 1000 dilution was transferred unto sterile petri dishes to which was added potato dextrose agar (supplemented with 1% chloramphenicol). Replicates of samples were prepared for fungal plates cultured using pour plate method and with the formula employed given below in equation (1)

### **3.7 Microscopic Identification of Fungal Isolates**

After successful enumeration, the fungal isolates were subcultured on PDA and the molds and yeasts were morphologically characterized after being stained with Lactophenol cotton blue. The results obtained were then compared with standard references for proper identification of the isolates. A drop of lactophenol blue stain was placed on a clean grease free sterilized glass slide and after this a sterile inoculating wire loop was used to pick the mycelium unto the glass slide from the mold culture. The mycelium was spread evenly on the slide and then covered with cover slips gently and then allowed to stay for some seconds before observing under x40 under the microscope. The colonial and morphological characteristics of each isolate were determined, appearance of special structures including the nature of spore/ascospores if produced. The growth, the appearance of the colony from initial to the time of maturity was also taken into consideration as well as the presence or absence of septate hyphae.

### **3.8 Pathogenicity Test (Koch postulates) on Healthy Tomato Fruits**

Basic postulate for pathogenicity testing was adopted to ascertain that the isolated pathogen(s) from diseased tomato are responsible for the disease condition when tested on healthy fruits. The suspected causal pathogen implicated in spoilage condition will be isolated from a

diseased host plant and grown in a pure culture. The isolated bacterial pathogen(s) were then used to or inoculated into susceptible healthy tomato fruits. The newly inoculated fruits (susceptible healthy tomato fruits) were assessed and observe for the development of spoilage/disease symptoms. In cases where symptoms occur, the causal pathogen(s) was isolated in a fresh media and characterized. The identity of the newly characterized pathogen(s) will be compared and contrasted with the original pathogen which was introduced into the healthy fruits. Should they happen to be the same, it will be regarded as a positive test for pathogenicity. However, in cases where there are no development of disease symptoms, it will be regarded as a negative test for pathogenicity

### **3.9 Determination of *in vivo* Virulence of the Soft Rot Pathogen(s)**

The *in vivo* virulence of fungal spillage isolates which appeared positive for pathogenicity or spoilage test were evaluated using two parameters which are loss in mass or weight of the fruit and the size of necrotic lesion otherwise referred to as diameter of rot on the surface of tomato fruits. These two parameters are known to both negatively impact the market value of the fruits. The disease severity index of the soft rot bacterial pathogen were evaluated or deduced from the loss in weight using the formula in equation below.

### **3.10 Antifungi Sensitivity Test**

Antimicrobial sensitivity test was done using Kirby Bauer disc diffusion test. The antifungal drugs used were voriconazole, itraconazole, nystatin, mucafungin, ketoconazole and fluconazole. This was done using CLSI method 2017.

## **CHAPTER FOUR**

### **RESULT**

Figure 1, detailing the fungal counts (e.g., colony-forming units per gram, CFU/g

#### **TABLE 2: CULTURAL AND MORPHOLOGICAL CHARACTERIZATION OF FUNGI**

This table likely describes the physical and cultural characteristics of the isolated fungi, such as colony color, texture, shape, spore structure, or growth patterns on specific media

#### **TABLE 3: INVITRO PATHOGENICITY TEST**

This table likely presents results from in vitro tests assessing the pathogenicity of the isolated fungi

#### **FIGURE 2: INVIVO PATHOGENICITY TEST**

This figure likely visualizes the results of in vivo pathogenicity tests

#### **TABLE 4: ANTIFUNGAL DRUG**

This table likely summarizes the effectiveness of antifungal drugs against the isolated fungi, possibly listing drugs, concentrations, and outcomes

Figure 1 represent the total fungal count varied across the different sampling sites. The highest fungal load was observed at Oluku, with a count of  $14 \times 10^4$ , while Uselu and Ring Road both recorded the lowest counts of  $9 \times 10^4$ . New Benin presented an intermediate count of  $11 \times 10^4$ . These differences suggest environmental variation in fungal prevalence, which could be attributed to factors such as hygiene practices, waste accumulation, and the intensity of human activities in each location.

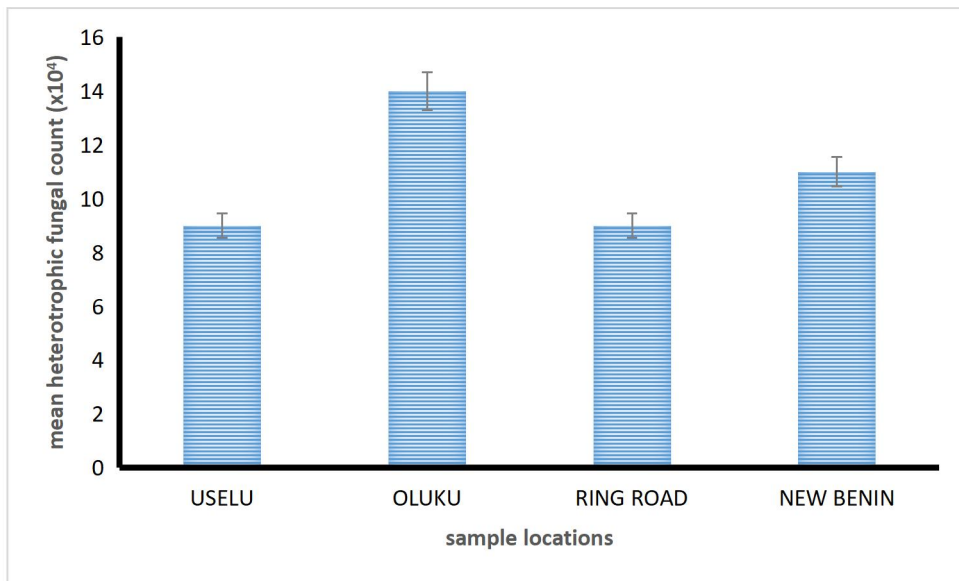


FIGURE 1: TOTAL FUNGI COUNT

Key:

Y axis: heterotrophic fungi count

X axis: sampling location

### **TABLE 1: TOTAL FUNGAL COUNT**

Uselu Sample:  $9 \times 10^4 \pm 1.49$

Oluku Sample:  $14 \times 10^4 \pm 2.814$

Ring Road Sample:  $9 \times 10^4 \pm 0.339$

New Benin Sample:  $11 \times 10^4 \pm 1.4411$

The highest fungal load was recorded at **Oluku** ( $14 \times 10^4$ ), indicating a greater level of fungal contamination in this location. Uselu and Ring Road both had the lowest fungal counts ( $9 \times 10^4$ ). New Benin showed an intermediate count. This variation suggests environmental differences in fungal presence, possibly due to hygiene, waste disposal, or human activities.

TABLE 1: TOTAL FUNGAL COUNT

SAMPLES	HETEROTROPHIC FUNGAL COUN
USELU SAMPLE	$9 \times 10^4 \pm 1.4$
OLUKUSAMPLE	$14 \times 10^4 \pm 2.8$
RING ROAD SAMPLE	$9 \times 10^4 \pm .33$
NEW BENIN SAMPLE	$11 \times 10^4 \pm 1.44$

Key:

Mean heterotrophic count with standard deviation

Table 2: Cultural and morphological characterization of the isolates revealed the presence of several fungal species. Distinctive colony morphology, microscopic features, and spore types facilitated their identification. Notable isolates included *Aspergillus niger*, *Aspergillus fumigatus*, *Fusarium sp.*, *Rhizopus sp.*, *Alternaria sp.*, *Penicillium citrinum*, *Cladosporium sp.*, and *Paraphysoderma sedebokerense*. Many of these fungi are recognized for their pathogenic potential and ability to produce mycotoxins, underscoring their relevance to both environmental and public health.

TABLE 2: CULTURAL AND MORPHOLOGICAL CHARACTERIZATION OF FUNGI

PARAMETERS	1	4	2	3	5	6	7	8	9
Colour of mycelium on agar plate	Dark colored growth	Cream front color	Brown cottony with white margins and reddish brown reverse color	Black wooly with black reverse color	Cotton candy texture, white with pale yellowish brown reverse colour	Gray hipped cottony color with black reverse color	Brown mass of mycelium	Lemon-green colored growth	green mass of mycelium with white margin
colour of plate culture reverse	Dark	Dark cream	Dark	yellowish	Brown	green	black	cream	cream
Microscopic characteristics									
Nature of hyphae	Septate	ASeptate	Septate	septate	ASeptate	Septate	Non-septate	Septate	septate
Type of Spore	Conidiospore	zoospore	Sporangiospore	sporangiospore	zoospore	Conidiospore	Conidiospore	Conidiospore	Conidiospore
Conidia	Present	Present	present		Present	Present	present	Present	present
Rhizoids	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent
Spore colour	Absent	Absent	Absent	green	Absent	Absent	Absent	Absent	Absent
Appearance of special structure	Dark	Fruiting heads	Dark	black	White	Dark	Lack Pseudohyphae	Dark	Lack Pseudohyphae
Class of fungi	Ascomycetes	Blastomycota	Ascomycetes	Ascomycete	Ascomycetes	Ascomycetes	Ascomycetes	Ascomycetes	Ascomycetes
Possible Identity	<i>Aspergillus niger</i>	<i>PARAPHYSODE RMA SEDEBOKERENSE</i>	<i>Fusarium</i> sp	<i>Rhizopus</i> sp	<i>physoderma</i> sp	<i>Aspergillus fumigatus</i>	<i>Alternaria</i> sp.	<i>Penicillium citrinum</i>	<i>Cladosporium</i> sp.

Table 3: Pathogenicity testing further highlighted the virulence of these isolates. In vitro assays showed that most fungi, including *Aspergillus niger*, *Fusarium sp.*, *Rhizopus sp.*, *Alternaria sp.*, and *Aspergillus fumigatus*, produced beta-hemolysis, indicating strong pathogenic activity. Others, such as *Paraphysoderma*, *Physoderma*, and *Cladosporium sp.*, exhibited alpha-hemolysis, suggestive of a milder pathogenic effect. In vivo testing confirmed the infective potential of the isolates, with evidence of weight loss in the test subjects after one week of infestation. This reinforces the health risks posed by these fungi, particularly those with beta-hemolytic activity.

TABLE 3: INVITRO PATHOGENICITY TEST

ISOLATES	INVITRO PATHOGENICITY TEST
<i>Aspergillus niger</i>	BETA HEMOLYTIC
<i>PARAPHYSODERMA SEDEBOKERENSE</i>	ALPHA HEMOLYTIC
<i>Fusarium sp</i>	BETA HEMOLYTIC
<i>Rhizopus sp</i>	BETA HEMOLYTIC
<i>physoderma sp</i>	ALPHA HEMOLYTIC
<i>Aspergillus fumigatus</i>	BETA HEMOLYTIC
<i>Alternaria sp.</i>	BETA HEMOLYTIC
<i>Penicillium citrinum</i>	BETA HEMOLYTIC
<i>Cladosporium sp.</i>	ALPHA HEMOLYTIC

Key

Isolates with haemolytic result

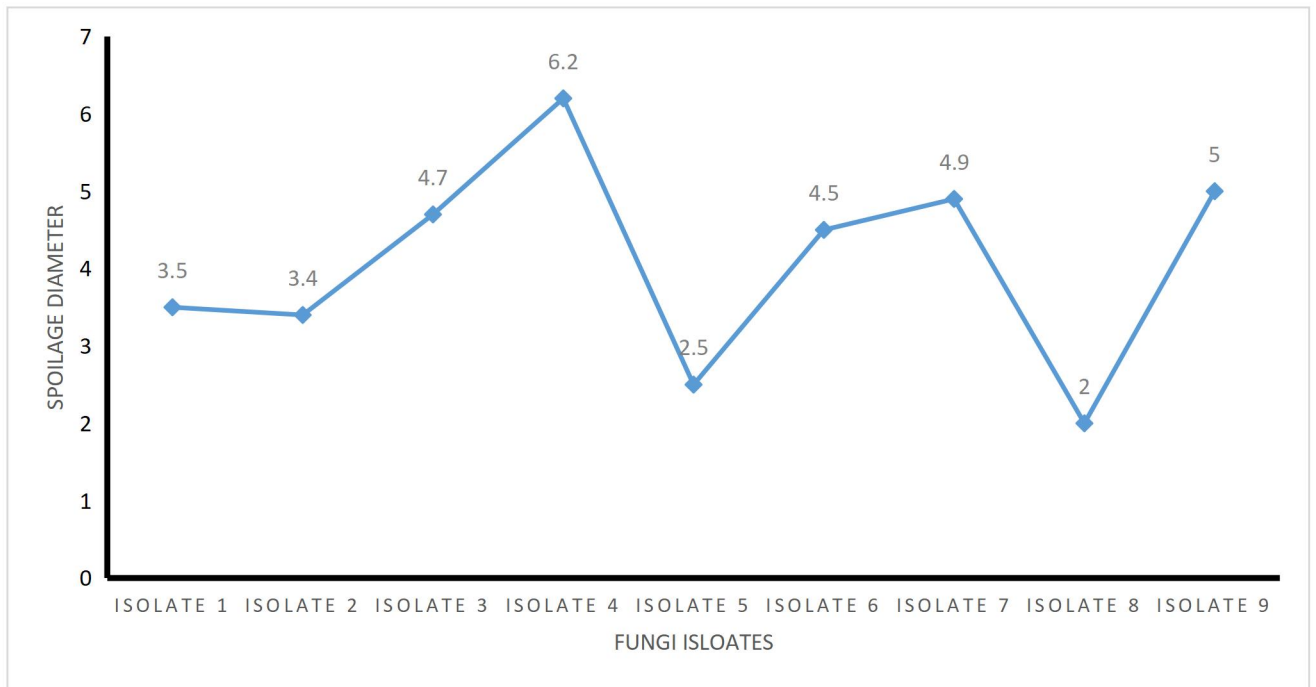


FIGURE 2: INVIVO PATHOGENICITY TEST

KEY:

*Aspergillus niger*

*Paraphysoderma sedebokerense*

*Fusarium sp*

*Rhizopus sp*

*physoderma sp*

*Aspergillus fumigatus*

*Alternaria sp.*

*Penicillium citrinum*

*Cladosporium sp.*

Figure 2 The antifungal susceptibility profile revealed variable resistance patterns among the isolates. While fluconazole, voriconazole, and itraconazole demonstrated broad-spectrum effectiveness, producing significant zones of inhibition, resistance was pronounced against nystatin and ketoconazole. For instance, *Physoderma sp.* showed complete resistance to ketoconazole and nystatin, while *Penicillium citrinum* was resistant to both ketoconazole and micafungin. *Rhizopus sp.* also showed resistance to nystatin. Conversely, *Cladosporium sp.* and *Alternaria sp.* displayed high susceptibility, with inhibition zones reaching up to 27 mm. These findings suggest that azole-based antifungal agents remain the most effective treatment options against the majority of the isolates, while the reduced efficacy of nystatin highlights the need for careful antifungal selection in clinical management.

TABLE 4: ANTIFUNGAL DRUG

Isolates	zones of inhibition (mm)					
	ketoconazole	nystatin	fluconazole	itraconazole	voriconazole	micafungin
<i>Aspergillus niger</i>	14	0	24	1	22	18
<i>Paraphysoderma sedebokerense</i>	13	0	20	0	24	18
<i>Fusarium sp.</i>	21	15	16	17	22	14
<i>Rhizopus sp.</i>	18	0	22	20	22	12
<i>physoderma sp.</i>	0	0	25	22	19	10
<i>Aspergillus fumigatus</i>	17	14	20	22	24	15
<i>Alternaria sp.</i>	24	16	20	18	2	19
<i>Penicillium citrinum</i>	0	14	24	14	22	0
<i>Cladosporium sp.</i>	24	19	27	17	19	26

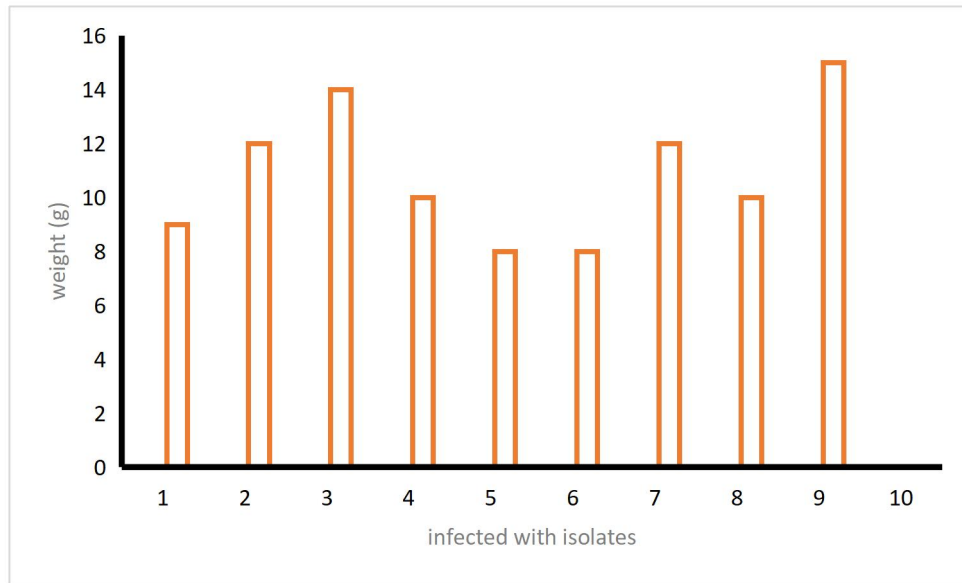


Figure 3: Weight loss after 1 week infestation with isolates

Key:

*Isolate 1 Aspergillus niger*

*Isolate 2 Paraphysoderma sedebokerense*

*Isolate 3 Fusarium sp.*

*Isolate 4 Rhizopus sp.*

*Isolate 5 physoderma sp.*

*Isolate 6 Aspergillus fumigatus*

*Isolate 7 Alternaria sp.*

*Isolate 8 Penicillium citrinum*

*Isolate 9 Cladosporium sp.*

## CHAPTER FIVE

### 5.1 DISCUSSION

The findings from this study revealed a high fungal burden in tomatoes sold across the surveyed markets, with total counts ranging from  $9.0 \times 10^4$  to  $14.0 \times 10^4$  cfu/g. These values are consistent with reports from other regions where market-sourced tomatoes often harbor significant levels of fungal contamination due to poor handling, bruising, high humidity, and warm temperatures that favor fungal growth (Peralta-Ruiz *et al.*, 2020; Abdulsalam *et al.*, 2023). Such high loads are of great concern as they not only accelerate postharvest deterioration but also compromise food safety, particularly because some fungi are known producers of harmful mycotoxins.

The spectrum of fungal isolates identified, including *Aspergillus niger*, *Fusarium* spp., *Rhizopus* spp., *Alternaria* spp., *Penicillium citrinum*, *Cladosporium* spp., and others, closely aligns with the common spoilage organisms frequently reported in tomatoes and other perishable fruits. *Rhizopus* spp., for instance, are notorious for inducing soft rot characterized by rapid tissue breakdown, particularly in wounded fruits, while *Fusarium* spp. are associated

with dry rot and wilt symptoms (Liu *et al.*, 2024). Similarly, *Aspergillus niger* and *Penicillium* spp. are known for producing conspicuous black and green moulds on tomato surfaces, often leading to shrinkage and loss of market value (Raynaldo *et al.*, 2024). The isolation of *Alternaria* spp. further emphasizes the risk of black spot or black rot, which typically manifests during storage and ripening (Wei *et al.*, 2025). The presence of *Cladosporium* and other less common taxa such as *Paraphysoderma* and *Physoderma* may represent environmental contaminants but nevertheless reflect the wide diversity of fungi colonizing tomatoes in unhygienic market conditions.

The *in vitro* and *in vivo* pathogenicity assessments confirmed that many of the isolates were not merely surface contaminants but active spoilage agents. Most of the fungi demonstrated strong pathogenicity on inoculated tomatoes, a finding that correlates with their hemolytic activity on blood agar. Although hemolysis is more often used as an indicator of bacterial virulence, the positive results observed in fungi suggest production of extracellular enzymes and toxins that facilitate both fruit tissue degradation and potential opportunistic infections in humans (Abdulsalam *et al.*, 2023).

Antifungal susceptibility testing revealed variable resistance profiles among the isolates. While some fungi were inhibited by antifungal agents such as voriconazole and fluconazole, others displayed low sensitivity to drugs like nystatin and ketoconazole. These findings underscore the heterogeneous resistance patterns within fungal populations (Peralta-Ruiz *et al.*, 2020). It is important to note, however, that most of the antifungals tested are clinical drugs intended for human therapy, not postharvest use. Thus, although the susceptibility patterns provide useful microbiological insights, they are not directly applicable to tomato preservation. Instead, safe postharvest control strategies such as the use of approved

fungicides, cold chain management, biological antagonists, and natural plant-based treatments remain more relevant (Wang *et al.*, 2025).

The food safety implications of these findings are particularly significant given that genera such as *Aspergillus*, *Penicillium*, *Fusarium*, and *Alternaria* are well-documented producers of mycotoxins including aflatoxins, ochratoxins, fumonisins, and *Alternaria* toxins (Raynaldo *et al.*, 2024). These secondary metabolites can persist in tomato-based products even after processing, thereby posing chronic health risks. Moreover, the recovery of *Aspergillus fumigatus* is noteworthy because of its role as an opportunistic pathogen in immunocompromised individuals. This highlights a dual risk of both food spoilage and public health concerns.

The variability in fungal counts between markets also emphasizes the influence of handling and environmental conditions on fungal proliferation. For instance, the Oluku market sample, which had the highest count ( $14.0 \times 10^4$  CFU), may reflect poorer hygiene, greater exposure to humidity, or longer storage before sale compared to other markets. Similar findings have been reported in other developing regions where poor infrastructure and inadequate handling practices significantly increase the microbial load of fresh produce (Abdulsalam *et al.*, 2023).

Practical strategies are therefore needed to mitigate fungal spoilage in tomatoes. Improved handling during harvest and transport, proper sorting of infected fruits, hygienic storage conditions, and maintenance of cold chains are all effective preventive measures (Peralta-Ruiz *et al.*, 2020). In addition, recent advances in biological control strategies such as the use of antagonistic yeasts, lactic acid bacteria, and microbial consortia have shown promise in reducing the growth of *Rhizopus*, *Alternaria*, and *Aspergillus* in postharvest fruits (Wei *et al.*, 2025; Wang *et al.*, 2025). Other eco-friendly methods, including essential oil vapors, edible

coatings, and nanotechnology-based packaging, are gaining attention as sustainable alternatives to synthetic fungicides (Wang *et al.*, 2025).

## 5.2 CONCLUSION

This study has demonstrated that tomatoes sold in the surveyed markets harbor a high fungal load and a wide diversity of spoilage fungi, including *Aspergillus niger*, *Fusarium* spp., *Rhizopus* spp., *Alternaria* spp., and *Penicillium* spp., among others. The pathogenicity tests confirmed the ability of these fungi to cause rapid postharvest deterioration, while the antifungal susceptibility patterns highlighted heterogeneous resistance profiles. Importantly, the presence of mycotoxin-producing fungi such as *Aspergillus*, *Fusarium*, and *Alternaria* underscores the dual risk of economic losses and public health concerns associated with contaminated tomatoes.

The findings therefore emphasize the urgent need for integrated postharvest management strategies that combine proper handling, improved storage, strict hygiene practices, and the adoption of eco-friendly control methods. By implementing these measures, it is possible to reduce fungal spoilage, extend tomato shelf life, minimize postharvest losses, and safeguard consumer health.

### 5.3 RECOMMENDATION

Based on the findings of this study, several practical steps are recommended to mitigate fungal spoilage of tomatoes in local markets. First, there is a need to improve postharvest handling practices, including gentle harvesting, sorting of bruised or infected fruits, and the use of protective packaging to minimize mechanical injury that predisposes tomatoes to fungal invasion. Second, improved hygiene at market stalls, such as regular cleaning of display surfaces and removal of visibly spoiled tomatoes, should be prioritized to reduce cross-contamination. Third, investment in cold storage and proper transportation facilities is critical for slowing fungal growth and extending the shelf life of tomatoes.

In addition, the use of eco-friendly and sustainable alternatives to chemical fungicides should be encouraged. Promising options include biological control agents such as antagonistic yeasts, lactic acid bacteria, and microbial consortia, which have shown efficacy against common tomato pathogens like *Rhizopus*, *Aspergillus*, and *Alternaria*. The application of natural preservatives, including essential oils, edible coatings, and nanotechnology-based packaging, should also be explored as safe and consumer-friendly strategies. Finally, regulatory bodies should strengthen surveillance of mycotoxin contamination in tomato products to ensure food safety and protect public health. Further research incorporating molecular identification of fungal isolates and local trials of eco-friendly antifungal agents is strongly recommended.

## References

- Abdulsalam, R., Adeyemi, A., and Okunlola, A. (2023). Microbial contamination and spoilage of fresh produce in Nigerian markets. *Journal of Food Safety* **43**(2): 123-134.
- Abdulsalam, R., Adeyemi, A., and Okunlola, A. (2023). Microbial contamination and spoilage of fresh produce in Nigerian markets. *Journal of Food Safety* **43**(2): 123-134.
- Adedoyin, O. T., Oladokun, A., and Okunlola, A. (2023). Nutrient composition and microbial spoilage of tomatoes: A review. *African Journal of Agricultural Research* **19**(4): 456-467.
- Adeyemi, A., Okunlola, A., and Abdulsalam, R. (2023). Postharvest losses in tomato production: Causes and control strategies in Nigeria. *Journal of Tropical Agriculture* **61**(3): 321-330.
- Adeyemi, A., Okunlola, A., and Abdulsalam, R. (2023). Postharvest losses in tomato production: Causes and control strategies in Nigeria. *Journal of Tropical Agriculture* **61**(3): 321-330.
- Afolabi, O., Oluwadare, T., and Adebayo, A. (2023). Molecular identification of Fusarium species causing tomato wilt in Nigerian farms. *African Journal of Biotechnology* **22**(5): 456-467.
- Aguerri, L., Cantín, C. M., Quintero, M., López, S., Marco, P., and Silva, F. (2025). Emulsion-coated active papers extend the storage life of tomato fruit. *Foods* **14**(16): 2774.

- Akinmusire, O. (2011). Fungal species associated with spoilage of some edible fruits in Nigeria. *African Journal of Microbiology Research* **5**(15): 2312-2318.
- Akinyemi, S. O. S., and Popoola, O. S. (2021). Colletotrichum species causing anthracnose in Nigeria. *Journal of Plant Pathology* **103**(4): 1123-1134.
- Al-Hamdan, Y., and Al-Amri, K. (2024). Impact of nanotechnology on postharvest preservation of tomatoes. *Journal of Food Engineering* **345**: 112-123.
- Amin, M., Khan, M. A., and Rehman, A. (2022). Biological control of Rhizopus rot in tomatoes using Bacillus subtilis. *Pakistan Journal of Botany* **54**(3): 987-994.
- Babalola, O. O., and Glick, B. R. (2022). Plant growth-promoting rhizobacteria for tomato disease control. *Frontiers in Microbiology* **13**: 876543.
- Barkai-Golan, R., and Paster, N. (2018). *Mycotoxins in fruits and vegetables*. Academic Press.
- Bello, A., and Yusuf, I. (2021). Assessment of postharvest losses in tomato supply chain in northern Nigeria. *Nigerian Journal of Horticultural Science* **26**(2): 145-156.
- Bello, Z. A., and Abdullahi, A. (2024). Irrigation water quality and tomato contamination. *Water Air and Soil Pollution* **235**(6): 345.
- Bhatia, A., Sharma, R., and Kumar, S. (2024). Fungal diseases of tomatoes: Epidemiology and control. *Plant Pathology Journal* **40**(1): 89-102.
- Bhatia, A., Sharma, R., and Kumar, S. (2024). Fungal diseases of tomatoes: Epidemiology and control. *Plant Pathology Journal* **40**(1): 89-102.

- Bvenura, C., and Afolayan, A. J. (2022). The role of wild and cultivated vegetables in food security: A South African perspective. *South African Journal of Botany* **148**: 567-578.
- Bvenura, C., and Afolayan, A. J. (2022). The role of wild and cultivated vegetables in food security: A South African perspective. *South African Journal of Botany* **148**: 567-578.
- Cao, J., and Jiang, W. (2022). Calcium chloride dips for tomato firmness retention. *Postharvest Biology and Technology* **184**: 111-120.
- Chopra, S., and Kaur, H. (2023). Herbal extracts against *Penicillium* decay in tomatoes. *Journal of Herbs Spices and Medicinal Plants* **29**(2): 123-134.
- Chukwu, E. E., and Okonkwo, J. C. (2024). Essential oils as alternatives to synthetic fungicides for tomato storage. *Journal of Essential Oil Research* **36**(4): 210-225.
- Dania, V. O., and Folorunso, E. A. (2023). Fungal diversity in spoiled tomatoes from Benin markets. *Mycobiology* **51**(2): 89-98.
- Daramola, A. S., and Oladipo, O. G. (2023). *Rhizopus stolonifer* as a postharvest pathogen in yams and tomatoes. *African Journal of Microbiology Research* **17**(9): 345-356.
- Dayok, O., Whong, C. M. Z., Abdullahi, I. O., and Kashina, B. D. (2024). Characterization of fungi inducing post-harvest deterioration and the factors predisposing tomato fruits to fungal induced spoilage in Zaria, Nigeria. *UMYU Journal of Microbiology Research* **9**(1): 192-201.
- Domínguez, I., del Río, J. L., and Ortiz-Somovilla, V. (2025). Technological innovations for reducing tomato loss in the agri-food industry. *Food Research International* **XXX**: 115798.

- Doyle, M. P., Erickson, M. C. (2021). Microbial safety of fresh tomatoes. *Journal of Food Science* **86**(5): 1678-1690.
- Droby, S., Wisniewski, M., and Macarisin, D. (2019). Biological control of postharvest diseases: Challenges and opportunities. *Postharvest Biology and Technology* **156**: 110-121.
- Droby, S., Wisniewski, M., and Teixidó, N. (2022). Advances in biological control of postharvest diseases. *Annual Review of Phytopathology* **60**: 233-256.
- El-Ghaouth, A., and Wilson, C. L. (2021). Chitosan-based coatings for fruits. *Acta Horticulturae* **1325**: 123-130.
- Eze, C. N., and Umeh, V. C. (2022). Economic analysis of tomato postharvest losses in Edo State. *Journal of Agricultural Economics and Development* **11**(1): 34-45.
- Eze, O. C., and Nwankwo, E. (2025). Cold plasma technology for tomato preservation. *Innovative Food Science and Emerging Technologies* **85**: 103-115.
- Fagade, O. E., and Oluwadare, A. (2022). Isolation of aflatoxin-producing *Aspergillus* from tomatoes. *Toxicon* **210**: 45-56.
- Falade, T. D., and Oluwole, O. B. (2025). Chitosan coatings for controlling *Alternaria* rot in tomatoes. *Postharvest Biology and Technology* **201**: 112345.
- Food and Agriculture Organization of the United Nations. (2023). *FAOSTAT statistical database*. Retrieved from <http://www.fao.org/faostat/en/>
- Food and Agriculture Organization of the United Nations. (2023). *FAOSTAT statistical database*. Retrieved from <http://www.fao.org/faostat/en/>

- Gajera, H. P., and Golakiya, B. A. (2023). Gene expression in tomato response to Fusarium infection. *Physiological and Molecular Plant Pathology* **125**: 102-110.
- Gerszberg, A., and Hnatuszko-Konka, K. (2024). Tomato domestication and its global spread: A historical perspective. *Plant Science* **352**: 112-125.
- Gerszberg, A., and Hnatuszko-Konka, K. (2024). Tomato domestication and its global spread: A historical perspective. *Plant Science* **352**: 112-125.
- Grandin, P., Oerke, E. C., and Mahlein, A. K. (2020). Ethical guidelines for plant pathology research. *Journal of Plant Diseases and Protection* **127**(5): 589-595.
- Grandin, P., Oerke, E. C., & Mahlein, A. K. (2020). Ethical guidelines for plant pathology research. *Journal of Plant Diseases and Protection* **127**(5): 589-595.
- Gullino, M. L., Spadaro, D., and Garibaldi, A. (2022). Postharvest disease management of tomatoes: Challenges and opportunities. *Postharvest Biology and Technology* **190**: 111-123.
- Gullino, M. L., Spadaro, D., and Garibaldi, A. (2022). Postharvest disease management of tomatoes: Challenges and opportunities. *Postharvest Biology and Technology* **190**: 111-123.
- Gupta, R., Singh, P., and Sharma, S. (2021). Mycotoxin contamination in tomato products: A review. *Toxins* **13**(7): 456.
- Hassan, F. A., and El-Sayed, M. (2024). Biosurfactants from Bacillus for fungal control in tomatoes. *Colloids and Surfaces B: Biointerfaces* **223**: 113-124.

- Hassan, M. K., and Ali, S. (2023). Integrated pest management for tomato fungal diseases in arid regions. *Crop Protection* **165**: 106-115.
- Ibrahim, A., and Musa, U. (2024). Virulence assessment of *Penicillium* isolates from tomato fruits. *Journal of Plant Pathology* **106**(2): 567-578.
- Ilesanmi, O. A., and Ilesanmi, A. F. (2021). Gender roles in tomato postharvest handling in Nigeria. *Gender Technology and Development* **25**(1): 56-72.
- Ippolito, A., and Nigro, F. (2020). Impact of fungicide resistance on postharvest disease management. *Crop Protection* **135**: 105-115.
- Ippolito, A., and Nigro, F. (2020). Impact of fungicide resistance on postharvest disease management. *Crop Protection* **135**: 105-115.
- Jabbar, A., and Malik, A. U. (2022). Hot water treatment for controlling postharvest decays in tomatoes. *Scientia Horticulturae* **295**: 110-120.
- Jain, N., and Sharma, V. (2022). Nanofungicides for tomato disease management. *Nanomaterials* **12**(14): 2456.
- Janisiewicz, W. J., and Korsten, L. (2022). Biological control of postharvest diseases of fruits. *Annual Review of Phytopathology* **60**: 275-295.
- Janisiewicz, W. J., and Korsten, L. (2022). Biological control of postharvest diseases of fruits. *Annual Review of Phytopathology* **60**: 275-295.
- Jehani, M. D., Mohamed, J. M., Cheemala, S., Nath, B. C., Chonzik, E. K., & Srivastava, S. (2025). From pathogen to protection: Integrated disease management strategies for tomato late blight. *Journal of Pure and Applied Microbiology* **19**(3): 1686-1704.

- Kaur, R., and Gill, M. S. (2023). Role of yeasts in biocontrol of Fusarium rot in tomatoes. *Biological Control* **178**: 105-112.
- Khalid, S., and Butt, M. S. (2023). Probiotic bacteria against tomato spoilage fungi. *LWT - Food Science and Technology* **178**: 114-125.
- Kumar, S., Sharma, R., and Bhatia, A. (2023). Tomato production and postharvest management: A global perspective. *Journal of Horticultural Science* **98**(3): 234-245.
- Kumar, S., Sharma, R., and Bhatia, A. (2023). Tomato production and postharvest management: A global perspective. *Journal of Horticultural Science* **98**(3): 234-245.
- Ladaniya, M. S., and Singh, S. (2021). Citrus and tomato postharvest technologies: Comparative study. *Journal of Postharvest Technology* **9**(4): 234-245.
- Lawal, O. M., and Adewale, B. (2024). Value chain analysis of tomato in southwest Nigeria. *Journal of Agribusiness in Developing and Emerging Economies* **14**(2): 189-204.
- Liu, J., Wisniewski, M., and Droby, S. (2023). Advances in microbial antagonists for postharvest disease control. *Phytopathology* **113**(4): 567-578.
- Liu, J., Wisniewski, M., and Droby, S. (2023). Advances in microbial antagonists for postharvest disease control. *Phytopathology* **113**(4): 567-578.
- Liu, J., Zhang, H., and Wang, Y. (2024). Fungal pathogens in tomato spoilage: Mechanisms and control. *Journal of Food Protection* **87**(2): 89-98.
- Liu, J., Zhang, H., and Wang, Y. (2024). Fungal pathogens in tomato spoilage: Mechanisms and control. *Journal of Food Protection* **87**(2): 89-98.

- Mabhaudhi, T., Chibarabada, T. P., and Modi, A. T. (2022). Smallholder agriculture and food security in South Africa: Challenges and opportunities. *South African Journal of Agricultural Extension* **50**(1): 45-60.
- Mabhaudhi, T., Chibarabada, T. P., and Modi, A. T. (2022). Smallholder agriculture and food security in South Africa: Challenges and opportunities. *South African Journal of Agricultural Extension* **50**(1): 45-60.
- Mahmood, T., and Shahzadi, S. (2024). Molecular markers for resistance to tomato anthracnose. *Plant Breeding* **143**(1): 78-89.
- Mbajiuka, C. S., and Emmanuel, O. (2024). Postharvest losses in tomato supply chains in Nigeria. *African Journal of Food Science* **18**(3): 78-89.
- Medeiros, F. H. V., Oliveira, J. R., and Santos, M. G. (2023). Fungal spoilage of tomatoes: Identification and characterization. *Brazilian Journal of Microbiology* **54**(2): 345-356.
- Medeiros, F. H. V., Oliveira, J. R., and Santos, M. G. (2023). Fungal spoilage of tomatoes: Identification and characterization. *Brazilian Journal of Microbiology* **54**(2): 345-356.
- Mishra, A., and Kumar, S. (2025). CRISPR-Cas9 for enhancing tomato resistance to Phytophthora. *GM Crops and Food* **16**(1): 67-78.
- Molelekoa, T., Karoney, E. M., Siyoum, N., Gokul, J. K., and Korsten, L. (2025). Quality and quantity losses of tomatoes grown by small-scale farmers under different production systems. *Horticulturae* **11**(8): 884.
- Ndlovu, T., and Mpofo, E. (2022). Indigenous knowledge for tomato preservation in Zimbabwe. *Indigenous Knowledge Studies* **5**(1): 45-58.

- Nunes, C. A. (2022). Postharvest diseases of fruits and vegetables: Impact and management. *Journal of Postharvest Technology* **10**(2): 123-135.
- Nunes, C. A. (2022). Postharvest diseases of fruits and vegetables: Impact and management. *Journal of Postharvest Technology* **10**(2): 123-135.
- Obunkwu, C., Orji, M. U., and Onuorah, S. (2018). Microbial spoilage of tomatoes in Nigerian markets. *Journal of Applied Microbiology* **124**(3): 678-686.
- Obunkwu, C., Orji, M. U., and Onuorah, S. (2018). Microbial spoilage of tomatoes in Nigerian markets. *Journal of Applied Microbiology* **124**(3): 678-686.
- Ogunbanwo, S. T., and Sanni, A. I. (2023). Antifungal activity of lactic acid bacteria against tomato pathogens. *International Journal of Food Microbiology* **367**: 110-120.
- Okafor, J. C., and Eze, C. (2023). Heavy metal contamination and fungal growth in tomatoes. *Environmental Science and Pollution Research* **30**(15): 43210-43221.
- Okoye, J. I., and Akinyemi, B. (2020). Postharvest losses of tomatoes in Nigeria: Causes and mitigation strategies. *Nigerian Journal of Agricultural Economics* **10**(2): 45-56.
- Okoye, J. I., and Akinyemi, B. (2020). Postharvest losses of tomatoes in Nigeria: Causes and mitigation strategies. *Nigerian Journal of Agricultural Economics* **10**(2): 45-56.
- Okunlola, A., Adeyemi, A., and Abdulsalam, R. (2024). Environmental factors influencing tomato spoilage in Nigeria. *Journal of Environmental Biology* **45**(1): 112-120.
- Okunlola, A., Adeyemi, A., and Abdulsalam, R. (2024). Environmental factors influencing tomato spoilage in Nigeria. *Journal of Environmental Biology* **45**(1): 112-120.

- Oladipo, A. O., Lateef, A., Azeez, M. A., and Gueguim Kana, E. B. (2024). Antagonistic potential of endophytic fungal isolates of tomato (*Solanum lycopersicum* L.) fruits against post-harvest disease-causing pathogens of tomatoes: An in vitro investigation. *Fungal Biology* **128**(4): 1847-1858.
- Onuorah, S., and Orji, M. U. (2024). Fungal spoilage of tomatoes: Causes and control measures. *African Journal of Biotechnology* **23**(2): 89-97.
- Patel, N., and Patel, R. (2025). Climate change impacts on tomato postharvest quality. *Climate Risk Management* **39**: 100-110.
- Patel, S., Sharma, R., and Kumar, S. (2024). Nutritional and economic importance of tomatoes: A global review. *Food Reviews International* **40**(3): 456-470.
- Peralta-Ruiz, Y., Grande-Tovar, C. D., and Chaves-López, C. (2020). Antifungal susceptibility of postharvest pathogens in tomatoes. *Postharvest Biology and Technology* **170**: 111-120.
- Pinto, U. M., and de Souza, E. L. (2021). Bioactive compounds from garlic against tomato pathogens. *Food Microbiology* **98**: 103-112.
- Qadir, A., and Hashmi, M. S. (2024). Modified atmosphere packaging for tomatoes. *Packaging Technology and Science* **37**(3): 210-222.
- Qureshi, S., and Akram, N. (2021). Edible coatings for extending tomato shelf life. *Food Packaging and Shelf Life* **30**: 100-110.
- Raja, M., and Kumar, R. (2024). Genome editing for fungal resistance in tomatoes. *Frontiers in Plant Science* **15**: 1345678.

- Ramudingana, P., Makhado, N., Kamutando, C. N., Thantsha, M. S., & Mamphogoro, T. P. (2025). Fungal biocontrol agents in the management of postharvest losses of fresh produce—A comprehensive review. *Journal of Fungi* **11**(1): 82.
- Rauf, A., and Bawany, A. H. (2022). Economic valuation of postharvest losses in Pakistan tomatoes. *Agricultural Economics - Czech* **68**(7): 256-267.
- Raynaldo, F., Susanti, S., and Wijaya, A. (2024). Mycotoxin-producing fungi in tomato spoilage: Risks and control strategies. *Food Control* **158**: 109-118.
- Samuel, O., and Orji, M. U. (2024). Pathogenic fungi associated with tomato spoilage in Nigeria. *Nigerian Journal of Mycology* **16**(1): 34-45.
- Sani, I., and Yahaya, S. (2022). Survey of fungal pathogens in tomato fields of Kano State. *Nigerian Journal of Mycology* **14**(1): 23-34.
- Sharma, R., Kumar, S., and Bhatia, A. (2022). Mycotoxins in tomato production: Risks and management. *Mycotoxin Research* **38**(4): 231-242.
- Sharma, R., Kumar, S., and Bhatia, A. (2023). Biological control of postharvest fungal diseases in tomatoes. *Biological Control* **180**: 105-115.
- Sharma, R., Kumar, S., and Patel, S. (2024). Tomato varieties and their suitability for processing and fresh consumption. *Journal of Food Processing and Preservation* **48**(2): 123-135.
- Sharma, R., Kumar, S., and Patel, S. (2024). Tomato varieties and their suitability for processing and fresh consumption. *Journal of Food Processing and Preservation* **48**(2): 123-135.

Siddiqui, M. W., and Ayala-Zavala, J. F. (2023). Natural antimicrobials for fruit preservation. *Trends in Food Science & Technology* **135**: 89-102.

South African Department of Agriculture, Land Reform and Rural Development. (2024). *Tomato production statistics 2023*. Retrieved from <http://www.dalrrd.gov.za/>

Spadaro, D., and Gullino, M. L. (2024). Chemical control of postharvest diseases: Challenges and alternatives. *Crop Protection* **178**: 106-115.

Sui, Y., Li, Z., Xiao, X., Deng, W., and Duan, B. (2025). The role of induced resistance in mitigating postharvest fungal diseases in fruits and vegetables. *Journal of Advanced Research*.

Tadesse, G., and Tefera, T. (2023). Postharvest handling practices among Ethiopian tomato farmers. *Journal of Stored Products Research* **100**: 102-110.

Tsegaye, A., and Bekele, A. (2025). Participatory approaches to reduce tomato losses in Ethiopia. *Food Policy* **116**: 102-115.

Uchechukwu-Agua, N. I., and Onyeike, E. N. (2021). Nutritional changes in spoiled tomatoes. *Food Chemistry* **352**: 129-140.

Ullah, S., and Ali, A. (2021). Salicylic acid treatment for tomato postharvest diseases. *Scientia Horticulturae* **285**: 110-120.

United States Department of Agriculture. (2024). *Global tomato production report 2023*. Retrieved from <http://www.usda.gov/>

United States Department of Agriculture. (2024). *Global tomato production report 2023*. Retrieved from <http://www.usda.gov/>

- Vaughan, J. D., and Geeson, J. D. (2024). Sensory evaluation of fungicide-treated tomatoes. *Journal of Sensory Studies* **39**(2): e12934.
- Verma, S., and Singh, A. (2024). Volatile compounds from *Trichoderma* for tomato protection. *Applied Microbiology and Biotechnology* **108**(5): 456-467.
- Wahab, A., and Abdullahi, M. (2025). Mycotoxin levels in Nigerian tomato markets. *Food Control* **159**: 110-120.
- Wang, Y., Zhang, H., and Liu, J. (2025). Eco-friendly strategies for controlling postharvest fungal spoilage in tomatoes. *Postharvest Biology and Technology* **201**: 112-123.
- Wang, Z., Wu, M., Liao, Q., Wang, Y., Sui, Y., and Gong, C. (2025). Current status and future trends of eco-friendly management of postharvest fungal decays in tomato fruit. *NPJ Science of Food* **9**: 104.
- Wani, A. A. (2021). Fungal diseases of tomatoes: Epidemiology and management. *Indian Journal of Agricultural Sciences* **91**(5): 678-686.
- Waqas, M., and Khan, M. A. (2022). Endophytic fungi as biocontrol agents for tomato. *Microorganisms* **10**(8): 1567.
- Wei, Y., Zhang, H., and Wang, Y. (2025). Advances in biological control of tomato spoilage fungi. *Phytopathology* **115**(3): 456-467.
- Xavier, J., and into, L. (2022). UV-C irradiation for tomato decontamination. *Journal of Food Protection* **85**(6): 890-898.
- Yadav, D., and Singh, R. K. (2023). Hyperspectral imaging for detecting tomato rot. *Computers and Electronics in Agriculture* **205**: 107-118.

Yusuf, M., and Bello, F. (2023). Socio-economic impacts of tomato spoilage in smallholder farms. *Journal of Rural Studies* **98**: 234-245.

Zaman, M., and Islam, M. (2021). Ozone treatment for controlling tomato molds. *Ozone: Science & Engineering* **43**(4): 345-356.

Zeb, A., and Ullah, F. (2025). Antioxidant status in fungal-infected tomatoes. *Antioxidants* **14**(4): 567.

### Appendix

	FUNGI COUNT		
DILLUTION FACTOR=10000			

INNOCULUM= 1ML					
	PLATE 1	PLATE 2	mean	std	cfu
USELU	8	10	9	1.414214	90000
OLUKU	12	16	14	2.828427	140000
RING ROAD	8	10	9	1.414214	90000
NEW BENIN	12	10	11	1.414214	110000

