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EVALUATION OF PHYT EXPONENT® CONCENTRATIONS AS NATURAL SPRAY PRESERVATIVE FOR EXTENDING THE SHELF-LIFE OF TOMATOES (*SOLANUM LYCOPERSICUM*).

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A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS OF THE BACHELOR OF AGRICULTURAL SCIENCE HONOURS DEGREE IN CROP SCIENCE.

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2026

DECLARATION

I, Prince Sawunyama (B223441B) do hereby declare to the Senate of Bindura University of Science Education that this research dissertation entitled 'Evaluation of Phyt Exponent® as a spray preservative for extending the shelf life of tomatoes (*Solanum lycopersicum)'* is a result of my original research work. It has neither been submitted nor been concurrently submitted to any other institution. All sources of information from other researchers have been duly acknowledged and cited.

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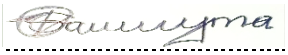
Signature: 

Date: 21 June 2026

I have supervised the above-mentioned research project and I am convinced that the research project can be submitted.

Project supervisor: Dr. N. Mgocheki.

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Date: 21 June 2026

Chairman Mr. Mutsengi

Signature .....

Date .....

DEDICATION

This dissertation is dedicated to my loving parents (J and J Sawunyama) for their endless support, encouragement, sacrifices and prayers throughout my academic journey. It is also dedicated to my family and friends for their motivations and beliefs that inspired me to continue and complete this study successfully

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ABSTRACT

Tomatoes (*Solanum lycopersicum)* are highly perishable crops that experience postharvest losses due to microbial spoilage, moisture loss and rapid physiological deterioration during storage. The increasing concerns associated with synthetic chemical preservatives have created a need for safer and environmentally friendly natural alternatives. This study therefore evaluated the effectiveness of Phyt Exponent® as a natural spray preservative for extending the shelf-life of tomatoes under normal storage conditions. A Completely Randomized Design (CRD) consisting of four treatments was used to conduct the experiment with the treatments named T0 (control-0%), T1 (1%), T2 (3%) and T3 (5%) Phyt Exponent® concentrations. These treatments were replicated five times. The tomatoes were assessed over a 14-day storage period for physical attributes including weight loss, firmness and colour change. The chemical attributes of tomatoes were also assessed and these were pH and total soluble solids (TSS). In addition, antimicrobial activity was determined through the measurement of zone of microbial inhibition against two spoilage microorganisms (fungi and bacteria). The results showed that Phyt Exponent® significantly reduced weight loss and maintained fruit's firmness compared to untreated control ($p < 0.05$). The best preservation effect was produced with the 5% concentration throughout the storage period. Significant differences in pH and TSS were also observed from day 7 onwards for the physical attributes. The tomato fruits which were treated have maintained lower pH and slowed increase in TSS respectively as compared to the control. However, in colour change there were no significant differences that were observed among all the treatments. Moreover, the spray preservative demonstrated a concentration-dependent antimicrobial activity against spoilage microorganisms (*Erwinia carotovora* and *Botrytis cinerea*) producing measurable zones of inhibition ranging from 8 mm at 1% to 17 mm at 5% with no inhibition observed in the untreated control ($F = 261.90$; $p \leq 0.001$). This study contributes to the field of postharvest technology and food preservation by providing evidence on the effectiveness of Phyt Exponent® as a natural spray preservative for tomatoes (*S. lycopersicum)* especially to smallholder farmers. Based on these findings, the study recommends the application of Phyt Exponent® at the 5% concentration for the effective postharvest preservation of tomatoes, particularly among smallholder farmers lacking cold-chain infrastructure.

Key words: Phyt Exponent®, tomato, natural preservative, shelf-life, postharvest, microbial spoilage, zone of inhibition, antimicrobial activity.

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LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of Variance.
CFU	Colony Forming Units.
CRD	Complete Randomized Design.
LSD	Least Significant Difference.
MBC	Minimum Bactericidal Concentration.
MFC	Minimum Fungicidal Concentration.
MIC	Minimum Inhibitory Concentration.
NA	Nutrient Agar.
NIR	Near Infrared Radiation.
PDA	Potato Dextrose Agar.
PGI	Protected Geographical Indication.
TA	Titratable Acidity.
TSS	Total Soluble Solids.
ZOI	Zone of Inhibition.

CHAPTER 1

INTRODUCTION

1.1 Background of the study

Globally, tomatoes are considered as one of the most vital horticultural crops to be grown. The crop is valued for its nutritional content that contributes mainly to human health (Abebe *et al*., 2017). The tomato fruits are highly perishable despite their significant dietary and economic values and they mainly affected with postharvest losses. Their postharvest losses are estimated at approximately 25.80% globally annually. The losses are mainly caused by factors like increased respiration, transpiration and microbial spoilage during storage and transportation (Akotowanou & Sènan, 2023). These substantial losses are prevalent in developing countries where there is inadequate infrastructure which necessitates effective postharvest preservation strategies which are efficient and consumer-safe (Meena *et al*., 2020).

There are conventional methods of preserving the postharvest produce which are used and they include the use of synthetic fungicides and chemical treatments. These methods despite their efficacy in restricting spoilage, raise several concerns regarding potential health implications and environmental persistence (Lisboa *et al*., 2024). Due to these concerns, there is a growing imperative to investigate natural alternatives. These natural alternatives are mainly plant derived. (Nizamani, Khaskheli, Khaskheli *et al*., 2021; Fagundes *et al*., 2014).

In particular, fungal pathogens contribute significant to the postharvest losses as they cause fruit decay leading to considerable monetary losses and rendering fruits incompetent for market (Slathia *et al*., 2021). For example, fruit rot is caused by pathogens like *Fusarium oxysporum* (commonly known as Fusarium rot), which significantly diminishes the market value of tomato produce and also shortens their shelf-life (Torres-Rodriguez *et al*., 2024). This therefore, underscores the need for sustainable and biologically caring interventions that can extend the shelf-life of postharvest produce thereby ensuring food security and reducing economic detriment.

In view of these challenges, the present study was aimed to evaluate Phyt Exponent® as a natural spray preservative for its efficacy in extending the shelf-life of tomatoes by mitigating microbial spoilage and preserving fruit quality. The composition and plant-derived source of Phyt Exponent® are detailed in Section 2.5.

1.2 Problem statement

Post-harvest loses of tomatoes remain alarmingly high in several regions lacking cold-chain infrastructures, with microbial spoilage constituting the major causal factor. In the real-world synthetic fungicides and bactericides are being used to cater for these postharvest loses. They are highly effective but are increasingly restricted by regulatory authorities and are met with growing consumer resistance owing to residue safety concerns.

Although a considerable body of available literature supports the antimicrobial potential of individual herbal constituents found in Phyt Exponent®, no published studies have evaluated the commercial Phyt Exponent® formulation as a spray-applied postharvest preservative for tomatoes. Its efficacy has also not been validated through standardized microbiological assays like the zone of inhibition assay.

This available gap represents both a scientific and a practical deficiency. With the absence of validated antimicrobial data, any claims of preservative efficacy of Phyt Exponent® remain untrustworthy. The absence of validated data keeps its adoption by farmers, vendors or regulatory bodies unjustified scientifically. This present study will therefore be designed to provide experimental evidence necessary for the evaluation of Phyt Exponent® legitimacy as a natural postharvest spray preservative.

1.3 Justification

Postharvest tomato losses in developing countries are high and they represent a severe and persistent threat to food security and smallholder livelihoods. Existing preservation solutions are either prohibitively expensive, increasingly restricted due to residue safety concerns or impractical in low resource settings. This creates an urgent need for inexpensive, reachable and scientifically validated natural alternative.

Phyt Exponent® represents a convincing candidate as its ingredients independently characterized phytochemical arsenal which may deliver synergistic protection against spoilages in tomatoes. Despite this strong phytochemical basis, Phyt Exponent® has never been subjected to rigorous postharvest evaluation and no published data exists on its effects on physical and chemical attributes of tomatoes. There exists no published data also on its effect on zone of microbial inhibition against spoilage microorganisms associated with tomatoes (*Erwinia carotovora* and *Botrytis cinerea).*

This study therefore fills a particular gap as it will be the first microbiologically validated assessment of Phyt Exponent® as a postharvest applied spray preservative. The study will

integrate mechanistic antimicrobial data with applied shelf-life results under ambient storage conditions relevant to smallholder contexts. The interventions of this study only require a commercially available product and a spray bottle. This enables immediate feasible adoption without infrastructure investments. The research therefore straddles herbal medicine and food preservation science, with direct implications for reducing postharvest losses, supporting farmer incomes and reducing dependence on synthetic agrochemicals.

1.4 Objectives

1.4.1 Main objective

To evaluate the effectiveness of Phyt Exponent® spray in extending the shelf-life of tomatoes and inhibiting spoilage microorganisms.

1.4.2 Specific objectives

1. To assess the effect of Phyt Exponent® spray concentration on physical attributes (weight loss, colour change and firmness) of tomatoes over a 14-day storage period.
2. To assess the effect of different concentrations of Phyt Exponent® on the chemical quality attributes (pH and total soluble solids) of tomatoes during storage.
3. To evaluate the zone of microbial inhibition of Phyt Exponent® at varying concentrations against spoilage microorganisms associated with tomatoes (*B. cinerea* and *E. carotovora).*

1.5 Hypotheses

- There is no significant effect of different concentrations of Phyt Exponent® spray on the physical quality attributes (weight loss, colour change, and firmness) of tomatoes over a 14-day storage period.
- There is no significant effect of different concentrations of Phyt Exponent® on chemical quality attributes (pH and total soluble solids) of tomatoes during storage.
- Different concentrations of Phyt Exponent® produce no significant zone of microbial inhibition against common postharvest spoilage microorganisms associated with tomatoes (*B. cinerea* and *E. carotovora).*

CHAPTER 2

LITERATURE REVIEW

2.1 Botanical classification and characteristics of tomatoes (*Solanum lycopersicum)*

Tomato is a common cultivated crop scientifically known as *S. lycopersicum.* It is a member of the *Solanaceae* family commonly referred to as the nightshade family (Akotowanou & Sènan, 2023). The *Solanaceae* family is one of the largest groups of flowering plants that encompasses approximately 2 700 species across 94 genera. Many of them are economically significant which includes potatoes, papers and eggplants. The crop is within the genus *Solanum* and is considered as one of the major genera that are found in the kingdom *Plantae*. The genus is further categorized into several subgenera, *S. lycopersicum* belongs to the subgenus *Lycopersicon* which is exclusively comprised of tomato and its wild relatives (Kimura & Sinha, 2008).

The fruit plant originates from western South America. It was domesticated in Central America where it evolved into one of the most important vegetable crops worldwide (Kimura & Sinha, 2008). It is cultivated in an area of approximately 5 million hectares and yields an annual produce exceeding 171 million tons. Countries like China and India contribute significantly to its annual production (Delarue *et al*., 2024). Tomatoes worldwide cultivation and consumption rank it second only to potatoes in global horticultural output by weight (Ullah *et al*., 2022). The crops are grown all over the world across diverse climatic conditions which range from open fields to controlled environments. Sophisticated techniques like artificial lightning and fertigation can be used in controlled environments to enhance yields and quality of the tomato fruit (Cyrille *et al*., 2022).

It is botanically classified as a berry and is characterized by sympodial growth habit, a complex inflorescence structure and diverse for morphologies that have been extensively shaped by domestication and selective breeding. Tomato is an herbaceous plant that typically ranges to heights of 1-3 meters. It is characterized by weak woody stem and botanically classified as fruits despite its common culinary categorized as vegetable (Nizamani, Khaskheli, Khaskheli, *et al*., 2021). It is also characterized by determinant and indeterminate growth patterns and these influences stem elongation, the arrangement of leaves and development of reproductive organs which ultimately define fruit set and yield (Kurmi *et al*., 2022). Its morphological structure included the fibrous root system, a primary stem that can be either erect or decumbent. The leaves are arranged in a spiral character that is typically

pinnately compound (Liu *et al*., 2022). The reproductive morphology is conversely characterized by cymes which often exhibit dichasial branching which bears perfect flowers leading to fruit formation (Cyrille *et al*., 2022)

2.1.1 Nutritional and economic importance of tomatoes (*S. lycopersicum)*

Globally Tomato is a significant crop that ranks seventh in worldwide production with harvested yields of approximately 160 million tons produced annually from an area of about 4.8 million hectares (Hnatuszko-Konka, 2015). According to Ahmed et al., (2017), tomatoes have a global production value exceeding $50 billion and this positions them as the fourth important commercial crop grown worldwide. As a second-most important vegetable globally after potatoes, tomatoes contribute significantly to food security. It is used in forming ingredient in numerous processed foods like soups, juices, purees and sauces (Antoniou, 2022). In 2020, 186 million tons of tomatoes were produced across 144 countries and these further underscores the widespread cultivation and dietary integration (Delarue *et al*., 2024; Khatib *et al*., 2023).

In additions to their economic importance, tomatoes are an important nutritional powerhouse. The crop provides important vitamins such as retinol, ascorbic acid and vitamin K along with carotenoids such as alpha- and beta-carotenoids and lycopene as well as phenolic compounds (Cyrille *et al*., 2022). The above-mentioned phytochemicals present in a tomato significantly contributes significantly to human health offering antioxidant properties and mitigating risks of chronic diseases like cancer and cardiovascular disorders (Karki & Dawadi, 2022; Fedeli *et al*., 2023). Tomatoes are a major source of dietary minerals like iron and calcium as well as wide array of health promoting metabolites. These health-promoting metabolites include flavonoid pigments that contribute to their diverse coloration (Seymour & Rose, 2022).

Primarily tomatoes are made up of 93-95% of water with dry matter making up the rest of the contents which includes soluble sugars. These soluble sugars include glucose and fructose (approximately 55% of dry matter), organic acids such as citric and malic acids (12%), minerals (7%) and insoluble components like cellulose and pectin (21%) (Eloff *et al*., 2022). All these constituents contribute to the fruit's nutritional profile, flavor and postharvest stability where carbohydrates dominate at around 70-75 g/100g dry weight, alongside proteins (10-25 g/100g), lipids (3-5g /100g) and vitamins including ascorbic acids and β-carotene (Dawad & Karki, 2022; Isack & Monica, 2013). The chemical makeup in tomatoes evolves during the ripening process with an increase in sugars and acids peaking at the

breaker stage of ripening before declining which therefore affects texture, color and microbial resistance (Isack & Monica, 2013).

2.1.2 Major postharvest losses of tomatoes (*S. lycopersicum)*

Postharvest losses in tomatoes are one of the major global challenges which results in economic disadvantages to producers and reduces food availability for consumers (Ahmed *et al*., 2017). The global postharvest losses are as high as 40%. These are both quantitative reductions in marketable yield and qualitative degradation affecting consumer acceptability and nutritional value (Tilahun *et al*., 2017). These losses are typical in developing countries where the lack of storage facilities and the inefficiency transportation exacerbate spoilage of the produce (Meena *et al*., 2020). Physiological processes like ripening and senescence are the major factors contributing to postharvest deterioration in tomatoes. Also, postharvest losses were due to mechanical damage sustained during harvesting and biotic factors predominantly microbial spoilage by fungi, virus and bacteria (Slathia *et al*., 2021).

Losses recorded specifically attributable to fungal infections are substantial, ranging from 17% to 26% of the wider 40% global postharvest loss figure cited above, and are linked in particular to *Fusarium spp.* Furthermore, these not only shorten the postharvest life but also drastically reduce market value of the tomato produce (Torres-Rodriguez *et al*., 2024). According to Flores et al., (2024), physiological processes like respiration and transpiration also significantly contributes to postharvest losses. These processes lead to senescence, chlorophyll degradation and ultimately undesirable fruit deterioration and weight loss. The climacteric nature of tomatoes characterized by rapid increase in the respiration processes and the production of ethylene during ripening further accelerates their perishability (Salas-Méndez *et al*., 2019). The natural vulnerability to quick senescence and the chance of pathogen invasion leads to postharvest losses estimated to 25.8% in fresh tomato fruit (Akotowanou & Sènan, 2023).

Moreover, environmental parameters like inappropriate storage temperatures, particularly chilling injury below 12℃ can cause substantial irreversible physiological damage to the tomatoes. This is manifested as surface lesions, discoloration together with accelerated softening which further compromises postharvest quality and shelf-life of tomatoes (Albornoz *et al*., 2019). In fact, bad postharvest practices account for approximately 50% of tomato production loss with developing countries losing 20% to 50% due to weak infrastructure and inadequate marketing facilities (El-Beltagi *et al*., 2023; Tiwari *et al*.,

2020). Poor harvesting techniques such as inadequate pre-cooling further compound these losses and unsanitary storage conditions compound these losses and they cumulatively reduce marketable yields and compromise fruit quality (Karki & Dawadi, 2022).

2.2 Microbial spoilage of tomatoes (*S. lycopersicum)*

Microorganisms, particularly fungi and bacteria represent a primary cause of postharvest deterioration in tomatoes, leading to significant economic losses globally (Ahmed *et al*., 2017). The spoilage can be seen as rots, textural change and undesirable odours from the spoiled tomato fruits. The spoilages significantly diminish fruit quantity, quality and marketability (Slathia *et al*., 2021). Tomatoes exhibit an amplified susceptibility to microorganisms throughout their ripening stage. This is where there are elevated respiration and metabolic activities which offers ideal substrate for pathogen growth. Micro-environments which are conducive for microbial colonization and spread can be brought about by the accelerated senescence of the fruit due to the above-mentioned processes. (Akotowanou & Sènan, 2023; Nendissa *et al*., 2020).

2.2.1 Common post-harvest microbial pathogens affecting tomatoes (*S. lycopersicum)*

Tomato is a fruit that is highly susceptible to a wide range of fungal and bacterial pathogens which inflict significant postharvest losses due to decay (Ahmed *et al*., 2017; Slathia *et al*., 2021). Fungal pathogens like the *Fusarium spp.* are particularly problematic as they cause rots that shortens the shelf-life of the fruit and reduces its market value (Nizamani, Khaskheli, Jiskani, *et al*., 2021; Torres-Rodriguez *et al*., 2024). According to Salas-Méndez et al. (2019), high moisture content and nutrient rich composition of tomatoes further create an environment for rapid microbial proliferation which often leads to rapid decay. In tomatoes, the key fungal species that frequently infect the harvested fruits includes *Alternaria alternata, Alternaria solani, Geotrichum candidum and B. cinerea* (Pobiega, 2020).

There are also bacterial pathogens that are of importance in harvested tomatoes and they include *E. carotovora* which significantly contribute to postharvest losses (Pobiega, 2020; Taha *et al*., 2023). *A. alternata* and *B. cinerea* are the main prevalent fungus in tomatoes and they cause black spots and gray molds respectively. These two are recognized as saprophytic pathogens found in cherry tomatoes (Fagundes *et al*., 2014). Other prevalent fungal genera that are also significant in tomatoes are *Penicillium, Aspergillus, Colletotrichum, Phytophthora, Pythium* and *Rhizopus*. These frequently infect tomatoes' postharvest but

among these *Rhizopus stolonifera, B. cinerea* and *A. alternata* are recognized as the primary causal agents of postharvest black rot in tomatoes (Koka *et al*., 2017).

Bacterial pathogens like *E. carotovora, Clavibacter spp., Xantomonas campestris* and *Pseudomonas aeruginosa* have been isolated from infected tomatoes with the *X. campestris* frequently exhibiting the highest occurrence. Moreover, species like *Culvularia spp.* have been recognized as the causative agents for tomato decay (Abdel-Ghany & Bakri, 2019). Microorganisms in tomatoes are also notable of producing mycotoxins which includes alternariol, tenuazonic acid and alternariol monomethyl ether. These mycotoxins pose significant food safety concerns and health risks to consumers (Asim *et al*., 2023; Bellotti *et al*., 2020). The pervasive microbial contaminations are a major factor in the considerable postharvest losses of tomatoes and these losses can reach up to 16% of global production annually (Tripathi & Tiwari, n.d.).

2.2.2 Mechanism of microbial spoilage in tomatoes

The microbial spoilage begins with enzymatic degradation of pectin and cellulose in cell walls by microbial exoenzymes. This process compromises the epidermal barrier and facilitates the entrance of pathogens in the tomato fruit (Pinto, 2024). The microorganisms then enzymatically degrade the tissues causing them to soften and leak their cellular contents, creating a substrate that is ideal for the growth and further microbial proliferation, which accelerating decay (Odinita & Osas, 2023). Generally, the first to cause the spoilage process are *A. alternata* and *B. cinerea*. They can penetrate the skin of the fruit and perform their metabolic activities within a fruit. Inside the fruit, they metabolize the fruit's internal sugars and organic acids (Quarantine *et al*., 2016).

Outside fungal pathogens, bacterial species also such as *Erwinia* and *Pseudomonas* are of paramount status in spoilage of tomato fruits. These bacterial pathogens have a tendency to yield extracellular enzymes that softens the tissues of host fruit leading to soft rots and further compromise fruit integrity (Odinita & Osas, 2023). Tomato's high-water activity and nutrient content make them susceptible to the diverse microbial pathogens (Wang & Wu, 2025).

Fruit injuries and physiological disorders are also entry points for pathogens causing pathogen deterioration. More than 90% of losses during harvesting and marketing are attributed to the pathogen decay alone (Taha *et al*., 2023). The extent and development of postharvest tomato spoilage depend on the complex interplay of host susceptibility, environmental conditions during storage and the virulence of the pathogen (Abdel-Ghany &

Bakri, 2019; Bist & Bist, 2021; Ahmed *et al*., 2017). For example, the fungus *R. stolonifer* secretes pectolytic enzymes involved in the degradation of the cellulose cell walls. This brings optimum temperatures and relative humidity, discoloration and liquefaction (Ahmed *et al*., 2017). High environmental temperatures and humidity are conducive to bacterial growth for pathogens like *E. carotovora.* The pathogen causes soft rots by macerating tissues of the host (Slama *et al*., 2022).

2.2.3 Factors influencing microbial growth on tomatoes

Intrinsic fruit characteristics such as pH and water activity in combination strongly influence the growth of microorganisms on harvested tomatoes. Temperature, relative humidity and atmospheric composition are also key external environmental factors that influence the microbial growth on tomatoes (Makau *et al*., 2023). Improper management of temperature during harvest and storage may lead to drastically reduction of value for tomatoes by encouraging microbial growth and speeding senescence (Cyrille *et al*., 2022). High humidity in storage facilities can create a microclimate on the fruit surface favoring the germination of fungal spores and subsequent penetration of the hyphae. Poor ventilation can also build up the ethylene further hastening the ripening and decaying processes (Akotowanou & Sènan, 2023; Flores-Lopéz *et al*., 2024).

Additionally, these problems can be aggravated by poor harvesting handling practices like careless harvesting, bulk packaging and inadequate transportation to distant markets. Such physical damages provide entry points for pathogens and also help moisture to condense, which favors microbial proliferation (Sciences *et al*., 2021). The losses from poor harvesting handling are estimated to be a third of the yield being lost before reaching the market (Nya *et al*., 2023). Physical damage to the fruits during harvesting also reduces the fruits' natural defense against pathogens. This creates entry points for latent pathogens that can proliferate rapidly as the fruits' constitutive defense decline (Kehinde et al., 2026).

2.3 Conventional postharvest preservation methods

These are traditional methods of preservation involving chemical treatment, controlled atmosphere storage and refrigeration. Each method has its own advantages and limitations in extending the shelf-life of tomatoes while maintaining quality (Lucera *et al*., 2012). For small scale farmers these methods can be too expensive or may raise concerns about chemical residues and environmental impact.

2.3.1 Chemical preservatives and their limitations

Chemical treatment is a traditional postharvest preservation method that has been designed to inhibit microbial growth and delays senescence in tomatoes (Mahajan *et al*., 2014). Chemicals like chlorine are used to wash the surface of the tomatoes so as to reduce surface microbial loads. Chlorine has a widespread use in food industry but it demonstrated limited efficacy in reducing microbial loads due to inactivation by organic matter and pH dependence. It can form unhealthy byproducts like trihalomethanes which are no good for consumers' health (Laurentiis, 2019; Linares-Morales et al., 2018).

Other disinfectants like ozone and hydrogen peroxide are also used in postharvest tomatoes to try to eradicate pathogens from the tomato fruit. However, these disinfectants have shown that they cannot entirely eliminate microorganism on fresh produce and can have potential toxicity and side effects on the sensorial properties of the products (Patrignani *et al*., 2015). The efficiency of chemical is often limited and their long-term environmental impacts is a significant concern in the world realm. For instance, the use of chlorinated water as disinfectant in tomatoes is increasingly scrutinized due to the potential formation of carcinogenic byproducts and its limited effectiveness against embedded pathogens (Vukić *et al*., 2016). Furthermore, the use of chemical compounds like diphenylamine in postharvest management of tomatoes has been linked to considerable environmental pollution. They also promote adverse health effects which includes but not limited to tissue dysfunction and impaired endocrine function (Niu *et al*., 2025). Regulatory bodies like the European Union have mandated the substantial reduction in the application of these chemicals for postharvest treatment of tomatoes due their significant environmental persistence in air, soil and water alongside the alarming expansion of pathogen resistance (Cabral *et al*., 2013).

2.3.2 Physical methods for preserving tomatoes

The physical methods of preserving tomatoes tries to precisely regulate the levels of oxygen, carbon dioxide and nitrogen so as to slow down respiration and ripening processes. They also lower the metabolic activities of micro-organisms and their enzymatic reactions and these retards tomato fruit spoilage (Arah *et al*., 2016). There are several packaging technologies that can be employed to further enhance preservation as they create an optimized micro-environment around the fruit and this may include modified atmosphere packaging and active packaging incorporating antimicrobial agents (Kusstatscher *et al*., 2021). Thermal treatments like blanching or pasteurization are also used in the inactivation of microorganism's spoilage and enzymes. The application of this thermal treatment in fresh tomatoes is much limited due

to potential adverse effects on texture and flavor. Irradiation is one other method that can be used as it uses ionizing radiation to reduce microbial loads on tomato surfaces and delay senescence but it's wide use is much limited as consumer acceptance and regulatory concerns often restricts its use (Lisboa *et al*., 2024).

Refrigeration is one other method that can be employed in preserving tomatoes. Refrigeration is not universally applicable as tomatoes are highly susceptible to chilling injury which in turn compromises their quality (Vukić *et al*., 2016). Therefore, alternative physical treatments combined with modified atmosphere packaging have shown improved efficacy in preserving fruit quality and delaying ripening in tomatoes. Modified atmosphere packaging has proved to be effective in reducing weight loss and delaying ripening even though the precise benefits depend heavily on factors such as fruit cultivar, storage conditions and the specific gas porousness of the wrapping material in use (Akbudak et al., n.d.; Wilson et al., 2019).

Physical methods collectively aim to minimize microbial proliferation and enzymatic degradation thereby maintaining the sensory and nutritional attributes of tomatoes for extended periods. However, some of the methods like chlorine disinfection led to undesirable alterations in physical parameters like increased oxygen consumption and the production of carbon dioxide which therefore results in accelerated ripening (Workneh *et al*., 2011).

2.4 Herbal and plant-based preservatives

Due to concerns regarding chemical residues, consumers are demanding natural based products and this has intensified researches based on plant-derived compounds which can be used in preserving horticultural products for postharvest preservations. These plant-based preservatives include essential oils and various plant extracts which have antimicrobial effects and they present a promising alternative to conventional synthetic pesticides (Din *et al*., 2023). According to Rizzo, (2025), these preservatives are safer for consumption and they exhibit a reduced tendency of inducing pathogen resistance as compared to synthetic chemicals. They offer both antimicrobial and antioxidant properties and these two are crucial for inhibiting microbial growth, maintaining color stability, reducing oxidative degradation and preventing off-flavors (Chen *et al*., 2025). Plant-derived antimicrobial compounds like bacteriocins, chitosan and other various plant extracts are growing into viable alternatives to the synthetic preservatives and are safeguarding food safety and extend product longevity (McClements *et al*., 2021). They can be applied in different ways which includes fumigation, dipping, spraying or integrating them into composite coatings (Wang *et al*., 2022).

2.4.1 Natural antimicrobial compounds from plants

Antimicrobial compounds derived from plants have gained ground due to demand from consumers for negligibly processed and chemical free produce (Wang *et al*., 2025). These natural antimicrobials are the secondary metabolites from plants and they pose diverse mechanisms of action against microbial pathogens. They offer multi-target inhibition which avoid resistance development associated with single target inhibition synthetic agents and these secondary metabolites includes phenolics, terpenes and alkaloids (Carmello *et al*., 2025). A lot of the plant extracts have demonstrated efficacy against key pathogens that affects tomatoes like *A. alternata* and *B. cinerea.* These disrupts microbial cell membranes or inhibit enzymatic processes which are critical for pathogen survival (Slathia *et al*., 2021).

These compounds can be extracted as essential oils or crude plant extracts (Kehinde *et al*., 2026). The medicinal plants used in the extraction of essential oils and various extracts include *Annona muricata* and *Moringa oleifera*. These plants were found to reduce the incidence of tomato postharvest losses caused by pathogens like *A. solani* (Slathia *et al*., 2021). Moreover, *invitro* studies have demonstrated that aqueous extracts derived from cinnamon and clove can inhibit the growth of *A. alternata* in tomatoes (Carmello *et al*., 2025).

The readily used locally available plant-based preservatives can significantly increase tomato shelf-life by inhibiting the growth of rot-inducing fungi like *Alternaria spp.* thereby offering a safer alternative to conventional chemical treatments (Carmello *et al*., 2025; Nizamani, Khaskheli, Jiskani *et al*., 2021). The plant secondary metabolites are crucial in plant defense against pathogens and when applied to postharvest produce they disrupt ergosterol synthesis or causing cell membrane lysis (Din *et al*., 2023; Scherer & Sassoni, 2016).

2.4.2 Efficacy and safety considerations of herbal preservatives

Some natural plant extracts obtained from lemongrass or mulan magnolia have demonstrated antifungal activities against a wide spectrum of postharvest pathogens which includes *B. cinerea* and *Colletotrichum coccudes* in which they inhibit the germination of spores and generation of germ tube (Salas-Méndez *et al*., 2019). In the same aspect, garlic extracts have proved to reduce mycotoxins in *Alternaria* and have demonstrated broad applicability of botanical compounds in mitigating postharvest spoilage (Asim *et al*., 2023). According to Siroli et al. (2015), some plant derivative compounds exhibit indirect defensive properties on plants as they enhance the plant's natural defense mechanisms despite their direct antimicrobial properties.

Researchers have increased their researches on the utilization of essential oils and other plant derived extracts as promising biological substitutes for the synthetic fungicides in postharvest phytopathogen control. This is due to their biodegradability, non-phytotoxicity and diverse mechanisms of action (Deresa & Diriba, 2023). Most of the substances containing these antimicrobial activities have been identified in plant-based edible materials which are able to protect themselves from invading pathogens (McClements *et al*., 2021).

2.5 Phyt Exponent® ingredient profiles

Phyt Exponent® is a branded preparation or formulation that integrates a blend of plant derived compounds which have been selected for their synergistic antimicrobial and antioxidant properties. This aims to deliver a vibrant and natural solution to extending the shelf-life of perishable produce and it comprises of phytochemicals like polyphenols, flavonoids, tannins and terpenoids (Oz & Kafkas, n.d.).

2.5.1 Active phytochemical components of Phyt Exponent®

Phyt Exponent® is formulated from different alcoholic extracts of several plant derived compounds. It comprises of the *Allium sativum, Triticum repens, Echinacea purpurea, Viola tricolor* and *Matricaria chamomilla,* all solubilized in 63% v/v ethanol. The 63% v/v ethanol potentiates extraction of these lipophilic secondary metabolites while exerting its own preservative action by denaturing microbial proteins and enhancing shelf-life stability (Aziz *et al*., 2020; Scherer *et al*., 2023). *A. sativum* commonly known as garlic is rich in allicin and organosulfur compounds which have disruption effects on the cell membranes of pathogens. These compounds have shown to be active antifungally against postharvest tomato pathogens like *Alternaria* spp. and *B. cinerea* (Aziz *et al*., 2020).

Couch grass scientifically know as *T. repens* is another compound of the Phyt Exponent® and it comprises of polysaccharides and phenolic acids. These polysaccharides and phenolic acids have potential biofilm-disrupting properties which are effective in controlling and managing postharvest pathogens. It also features *E. purpurea* regularly recognized as purple coneflower. This component has alkamides, caffeic acid derivatives and polysaccharides which are known for enhancing immune modulation and inhibit fungal growth (Aziz *et al*., 2020). Moreover, *V. tricolor (*purple coneflower) is abundant in flavonoids, saponins and sesquiterpenes like the bisabolol oxides which have got broad-spectrum antimicrobial effects (Karnwal & Malik, 2024). Lastly, Phyt Exponent® contains the *M. chamomilla* known as

chamomile and this compound provides bisabolol, flavonoids and coumarins which have anti-inflammatory and antifungal attributes (Scherer *et al*., 2023).

The interactions among the diverse phytochemicals of the Phyt Exponent® coupled with the ethanol solvent are hypothesized to confer a comprehensive antimicrobial spectrum against a wide array of spoilage microorganisms (Gurjar *et al*., 2012). Specifically, the presence of various phytochemicals like essential oils, flavonoids, phenolics and polyphenolics contributes much to the broad-spectrum antimicrobial properties of such plant derived formulations. The natural compounds present in the derivatives interfere with the microbial growth and survival of the pathogens through various mechanisms which includes cell membrane disruption, enzyme inhibition and nucleic acid damage (Aziz *et al*., 2020; Scherer *et al*., 2023).

2.6 Chemical attributes of tomatoes

2.6.1 pH of tomatoes

The tomato has a pH value that varies from 3.9 to 4.9 with ordinary cultivars falling between 4.0 and 4.7 which are mostly determined by organic acid content like citric acid (Tigist *et al*., 2013; Wilkerson *et al*., n.d.). The acidity level of tomatoes inhibits microbial proliferation below pH 4.5 and enhancing shelf-life even though the values tend to increase during storage. The values tend to increase due to acid metabolism into sugars and pectin breakdown (Tigist *et al*., 2013; Tolesa & Workneh, 2017). The pH is significantly influenced by maturity, rising from 4.8 (green) to around 5.0 (pink/red) with storage at controlled temperatures accelerating this shift (Tadesse *et al*., 2022; Vinha *et al*., 2013). Elevated pH of tomatoes during senescence associates with reduced titratable acidity. This impacts the flavor balance and spoilage risk as riper fruits like those harvested at red stage exhibit pH up to 4.93 (Oliveira *et al*., 2016). The pH also directly influences the enzymatic activities within the fruit, impacting cell wall degradation and pigment synthesis, thereby dictating overall textural integrity and color development (Tigist *et al*., 2013). Monitoring these pH values is crucial for the assessment of postharvest quality and preservative efficacy in extending tomato viability.

2.6.2 Total soluble solids (TSS) of tomatoes

TSS are the dissolved substances present in the tomato juice and they mainly include sugars but sometimes can also include small amounts of acids, vitamins, proteins and minerals. TSS are measured in ˚Brix via refractometry and its values ranges from 4.0 to 6.0 in tomatoes with sugars primarily ranges from 65-70% glucose/fructose, associating with sweetness and

maturity (Okiror *et al*., 2017; Quamruzzaman *et al*., 2022). The breaker and red stages in tomatoes yields the highest TSS of 5.4-6.0 ˚Brix, optimal for market while turning stage is lowest with a value of about 4.0 ˚Brix but this usually increases due to respiration (Kanski *et al*., 2020; Quamruzzaman *et al*., 2022). Tomato cultivar and handling can also impact TSS with non-PGI tomatoes show higher values linked to ripeness (Panebianco *et al*., 2023). Higher TSS signals consumer appeal about spoilage risks, where portable NIR sensors predict it alongside firmness for quality grading. Preservatives targets TSS stability to extent shelf life without altering sensory profiles (Igarashi-Mafra *et al*., 2022).

2.7 Zone of microbial inhibition

2.7.1 Concept of zone of inhibition (ZOI)

The zone of inhibition (ZOI) is a clear range around an antimicrobial agent on agar plates where microbial growth is absent. It is formed by radial diffusion creating a concentration gradient exceeding the minimum inhibitory concentration (Wiegand *et al*., 2015). In diffusion assays, standardized inoculum (0.5 McFarland) on Mueller-Hinton agar allows agent diffusion post-incubation with ZOI diameter inversely proportional to MIC and interpreted per CLSI guidelines. Larger ZOI indicates higher efficacy though dependent on diffusion rates (Maliha *et al*., 2022; Wiegand *et al*., 2015).

2.7.2 Factors affecting zone of inhibition

The size of ZOI depends on agent concentration, diffusion rate, inoculum density, agar thickness, pH, temperature and medium composition (Eloff, 2019; Wiegand *et al*., 2015). Higher temperatures and concentrations enhance diffusion while thick agar or high inoculum reduces ZOI and particle size also affects solubility. For plant extracts, extraction method and molecular charge modulates efficacy (Wiegand *et al*., 2015). Standardization ensures comparability in postharvest preservative tests. This highlights the critical need for meticulous control over experimental parameters when evaluating novel natural preservatives for tomato shelf-life extension.

2.7.3 Significance of zone of inhibition in postharvest studies

The ZOI is a measurement of antimicrobial potential and is useful in the selection of preservatives to prolong the shelf life and is inversely proportional to the MIC (Wiegand *et al*., 2015). It evaluates natural agents in tomatoes against spoilers like *Rhizopus* and predicts their efficacy in the field (Eloff, 2019; Gonelimali *et al*., 2018). Larger ZOI means strong inhibition, which is helping in biopesticide development. Postharvest applications of

extracts/coatings to validate against fungicide resistance bridges *in-vitro* to *in-vivo*, optimizing sprays like Phyt Exponent® for tomato preservation. This methodology allows for a rapid preliminary assessment of various natural compounds' inhibitory effects against target spoilages thereby streamlining the selection of promising candidates for subsequent in-situ evaluation (Gonelimali *et al*., 2018).

CHAPTER 3

METHODOLOGY

3.1 Study site

The project was carried out at Astra Biological Sciences Laboratory at Bindura University of Science Education. The laboratory is located in Mashonaland Central, Bindura, about 87 km North-East of Harare, Zimbabwe 1041 Masembura Road off, Trojan Road, Bindura, GPS coordinates 17.3167˚S, 31.3228˚E. The laboratory provided a controlled indoor environment shielded from direct sunlight and precipitation, with tomatoes stored at ambient room temperature (25 ± 2℃) and away from sources of ethylene contamination or mechanical disturbance, thereby minimizing extraneous environmental variation across the storage period.

3.2 Experimental design

A Completely Randomized Design (CRD) with four treatments and five replications was employed and a total of 20 experimental units were obtained. The structure of the treatments is shown in Table 3.2.

Table 3.2: Structure and details of the treatments

Treatment	Concentration	Number of replicates	Description
T0	0% (Control)	5	Distilled water only
T1	1%	5	1 mL Phyt Exponent® plus 99 mL water
T2	3%	5	3 mL Phyt Exponent® plus 97 mL water
T3	5%	5	5 mL Phyt Exponent® plus 95 mL water

3.3 Materials and methodology

Materials and equipment used in this study, including Phyt Exponent® herbal formulation, sterile distilled water, nutrient agar (NA), potato dextrose agar (PDA), an analytical balance, digital vernier caliper, penetrometer, incubator, laminar flow cabinet, autoclave, spray bottles and a standard colour chart, are described in context within the relevant procedures below where and how each was used.

3.4 Preparation of Phyt Exponent® concentrations

The Phyt Exponent solution was diluted with sterile distilled water to prepare working concentrations as follows:

- 0% (control): 100 mL sterile distilled water.
- 1% (T1): 1 mL Phyt Exponent® + 99 mL sterile distilled water.
- 3% (T2): 3 mL Phyt Exponent® + 97 mL sterile distilled water.
- 5% (T3): 5 mL Phyt Exponent® + 95 mL sterile distilled water.

Each solution was prepared freshly in a sterile glass vessel, mixed thoroughly by inversion and then transferred to sterile spray bottles. The solutions were used immediately to prevent degradation of the phytochemicals particularly allicin and essential oil monoterpenes.

3.5 Tomato selection and treatment

Commercially mature tomatoes of the Tengeru variety were obtained from a single batch at a local market to ensure homogeneity. The tomatoes were individually inspected and those free of wounds, blemishes, slit skins, or evidence of pre-existing disease were selected. Those selected ones were weighed independently before surface sterilization.

Surface sterilization was performed by wiping each and every tomato surface with sterile cotton wool which was lightly moistened with 70% ethanol. It was then followed by rinsing with sterile distilled water and air drying on sterile absorbent paper for 15 minutes under laminar flow cabinet. This was done as to reduce initial epiphytic microbial loads to baseline levels comparable across all treatment groups, minimizing confounding variability.

Each tomato was inoculated uniformly with 10^{-6} CFU *Botrytis cinerea* before being sprayed with its designated treatment solution using calibrated spray bottles (five sprays per tomato, rotating the fruit to achieve complete surface coverage). Tomatoes were allowed to air-dry afterwards for 30 minutes under normal conditions before being arranged in their designated

treatment boxes. The fruits were stored at normal room temperatures (25°C ± 2°C) throughout the 14-day period.

3.6 Data collection

Tomato quality parameters were assessed on days 0, 2, 4, 7, 10, 12 and 14 respectively except for colour change which was recorded up to day 12. Each treatment was represented by five replicate tomatoes (one tomato per replicate unit), giving 20 tomatoes in total across the four treatments. All tomatoes were harvested at the pink stage of ripening (colour score 4, Table 4.2) prior to treatment application. The following parameters were recorded:

3.6.1 Weight loss

Every tomato was weighed on a calibrated analytical balance at each assessment day. The percentage weight loss of each tomato was calculated using the formula:

- $\textbf{Weight loss} = \frac{\textbf{Initial weight-Current weight}}{\textbf{Initial weight}} \textbf{ x 100}$

3.6.2 Firmness

Fruit firmness was measured using a digital penetrometer with a flat-tipped probe (5mm diameter) applied to the equatorial region of each fruit at three positions. Results were expressed in Newtons (N) as the mean of three readings per fruit.

3.6.3 Colour change

Colour changes of tomato fruits were assessed visually against the USDA tomato colour chart (1 = green; 2 = breaker; 3 = turning; 4 = pink; 5 = light red and 6 = red).

3.7 Chemical quality attributes

Chemical parameters were measured at day 0, 7 and 14 respectively alongside the physical parameters.

3.7.1 pH

The pH of the extracted tomato juice was determined using calibrated digital pH meter. Prior to each measurement session, the pH meter was standardized using buffer solution of pH 4.0 and 7.0 to ensure accuracy and reliability of readings. 20 mL of freshly extracted tomato juice from each experimental unit was poured into a clean beaker and the pH electrode was immersed into the juice and allowed to stabilize before readings were recorded. Three readings were taken per sample and then averaged. The electrode was rinsed with distilled water and blotted dry between samples to avoid cross-contamination.

3.7.2 Total Soluble Solids (TSS)

TSS content which primarily reflects the sugar content of the tomato juice was measured using a hand-held refractometer calibrated with distilled water at room temperature before each use. A few drops of freshly extracted tomato juice were placed on the prism of the refractometer and the cover plate was gently closed. The readings from the refractometer were taken by looking through the eyepiece towards a light source. The point where the boundary between the light and the dark fields intersected the scale was recorded as the TSS value expressed in degrees Brix (˚Brix). The prism was cleaned with a damp cloth and dried between each sample measurement to prevent carryover errors. TSS measurements were taken in triplicate and the average was recorded.

3.8 Zone of microbial inhibition assessment

The antimicrobial activity of Phyt Exponent® at varying concentrations was determined using the agar well diffusion method. One bacterial (*E. carotovora)* and one fungal *(B. cinerea)* spoilage microorganisms associated with tomatoes were isolated and used as test organisms. Nutrient agar (NA) plates were inoculated with a standardized suspension of *E. carotovora* (bacteria) and Potato Dextrose Agar (PDA) plates were inoculated with the standardized suspension of *B. cinerea* (fungi), both prepared at 0.5 McFarland standard. Wells of 6mm diameter were bored into the NA and PDA plates using a sterile cork-borer. Each well was filled with 100 µL of respective Phyt Exponent® concentrations (T0, T1, T2 and T3). The plates were incubated at 37℃ for 24 hours for bacteria and 25℃ for 72 hours for the fungi. The zone of inhibition (ZOI) was measured in millimeters (mm) using a vernier caliper and recorded.

3.9 Data analysis

Data collected were subjected to Analysis of Variance (ANOVA) using GenStat statistical software (18th Edition) at a 5% level of significant variance ($p \leq 0.05$). Where significant differences were detected among treatments, Least Significant Difference (LSD) test was used for mean separation and comparison. Results were presented as mean ± standard deviation in tables and figures.

CHAPTER 4

RESULTS

4.1 The effect of Phyt Exponent® spray on weight loss of tomatoes (14-day period)

There was no significant difference in mean tomato weight among treatments at day 0 of storage ($p > 0.05$), confirming that all treatment groups began with comparable initial fruit weight. A significant treatment effect emerged from day 2 onwards and became progressively more pronounced through days 4, 7, 12 and 14 ($p \leq 0.05$). Fruit weight declined steadily in all treatments over the 14-day storage period, but at a markedly slower rate in tomatoes treated with Phyt Exponent®. By day 14, the untreated control (0%) had lost 16.4% of its initial weight (359.4 g to 300.4 g), compared with 9.4% in the 1% treatment (375.8 g to 340.4 g), 10.2% in the 3% treatment (394.2 g to 354.0 g), and only 3.9% in the 5% treatment (374.0 g to 359.4 g). The 5% concentration therefore retained the greatest proportion of fruit weight throughout storage, followed by the 1% and 3% treatments, while the untreated control lost weight most rapidly, as summarized in Table 4.1.

Table 4.1: The effect of Phyt Exponent® spray on weight loss of tomatoes (14-day period)

Treatments	Weight (g) at day 0	Weight (g) at day 2	Weight (g) at day 4	Weight (g) at day 7	Weight (g) at day 12	Weight (g) at day 14
T0	359.4	352.4^{b}	341.2^{b}	334.8^{b}	315.2^{b}	300.4$^{\mathbf{b}}$
T1	375.8	371.4^{ab}	366.6^{ab}	360.2^{ab}	348.6^{a}	340.4^{a}
T2	394.2	388.4^{a}	382.8^{a}	377.6^{a}	364.8^{a}	354.0^{a}
T3	374.0	389.0^{a}	383.2^{a}	376.6^{a}	363.8^{a}	359.4^{a}
Grand Mean	375.9	375.3	368.4	362.3	348.1	338.6
P-value	0.221	0.029	0.020	0.017	0.011	0.006

SED	15.78	12.40	13.33	13.20	14.41	15.34
LSD	33.46	26.29	28.25	27.98	14.41	32.52
CV %	6.6	5.2	5.7	5.8	6.5	7.2

At $p \leq 0.05$, means sharing the same letter within a column are not significantly different.

Letter groupings are omitted at day 0, where no significant differences were detected among treatments.

4.2 The effect of Phyt Exponent® spray on colour change of tomatoes (12-day period)

There were no significant differences of Phyt Exponent® observed on colour change of tomato fruits ($p > 0.05$). Colour development progressed predictably across all treatments from pink (score 4) to full red (score 6) (Table 4.2).

Table 4.2: Effect of Phyt Exponent® spray on colour change of tomatoes (12-day period)

Treatment	Colour change at day 0	Colour change at day 2	Colour change at day 4	Colour change at day 7	Colour change at day 12
T0	4.00	4.60	5.200	5.80	6.000
T1	4.00	4.20	5.000	5.40	6.000
T2	4.00	4.40	5.000	5.60	5.800
T3	4.00	4.20	5.000	5.00	5.800
Grand mean	4.00	4.35	5.050	5.45	5.900
P-value		0.547	0.418	0.066	0.585
SED	0.00	0.316	0.1414	0.283	0.2000
LSD	0.000	0.670	0.1414	0.600	0.4240
CV %	0.0	11.5	4.4	8.2	5.4

At $p \leq 0.05$, means sharing the same letter within a column are not significantly different. Letter groupings are omitted throughout, as no significant differences were detected among treatments at any assessment day.

4.3 The effect of Phyt Exponent® spray on firmness of tomatoes (14-day storage)

There was no significant effect of Phyt Exponent® observed on firmness of tomato fruits among treatments at day 0 and day 2 ($p > 0.05$), confirming that all treatment groups began with comparable initial fruit firmness. A significant treatment effect emerged from day 4 ($p \leq$

0.05) and became highly significant by days 7, 12 and 14 ($p \leq 0.001$, Table 4.3). By day 4, the 5% and 1% treatments had begun to separate from the untreated control, recording 45.6 N and 44.8 N respectively against 40.8 N in the control. This divergence widened sharply by day 7, when the 5% treatment retained the highest firmness (43.2 N) followed by the 1% treatment (40.2 N), while the 3% treatment and the untreated control had both declined to 32.4 N. By day 12 and day 14, firmness in the untreated control had fallen most steeply, to 16.4 N and 13.6 N respectively, whereas the 5% treatment retained the highest firmness at both time points (35.4 N and 30.8 N), followed by the 1% (32.2 N and 29.0 N) and 3% (30.0 N and 28.0 N) treatments. Firmness therefore declined progressively in all treatments over the storage period, consistent with normal ripening, but Phyt Exponent®-treated tomatoes, particularly at 5%, retained significantly greater firmness than the untreated control from day 4 onwards.

Table 4.3: The effect of Phyt Exponent® spray on firmness of tomatoes (14-day storage)

Treatment	Firmness at day 0	Firmness at day 2	Firmness at day 4	Firmness at day 7	Firmness at day 12	Firmness at day 14
T0	50.40^{a}	48.00^{a}	40.80^{b}	32.40^{c}	16.40^{c}	13.60^{b}
T1	52.00^{a}	49.80^{a}	44.80^{a}	40.20^{b}	32.20^{ab}	29.00^{a}
T2	50.60^{a}	48.20^{a}	43.20^{ab}	32.40^{c}	30.00^{b}	28.00^{a}
T3	50.20^{a}	47.80^{a}	45.60^{a}	43.20^{a}	35.40^{a}	30.80^{a}
Grand mean	50.80	48.45	43.60	38.55	28.50	25.35
P-value	0.448	0.485	0.016	0.001	0.001	0.001
SED	1.196	1.400	1.393	1.360	2.045	1.871
LSD	2.535	2.968	2.953	2.883	4.334	3.966
CV%	3.7	4.6	5.1	5.6	11.3	11.7

At $p \leq 0.05$, means sharing the same letter within a column are not significantly different.

4.4 The effect of different concentrations of Phyt Exponent® on pH of tomatoes

There was no significant effect of Phyt Exponent® observed on pH at day 0 ($p > 0.05$), with all means clustering narrowly between 4.08 and 4.11, confirming comparable initial fruit acidity across all treatment groups. Significant differences emerged by day 7 ($p \leq 0.05$) and became highly significant by day 14 ($p \leq 0.001$). By day 7, the untreated control (0%) recorded the highest pH (5.046), while the 5% treatment maintained the lowest (4.418), with the 1% (4.758) and 3% (4.546) treatments intermediate. This pattern persisted to day 14,

when pH in the control had risen further to 5.080, compared with 4.782, 4.720 and 4.640 in the 1%, 3% and 5% treatments respectively. LSD groupings at day 14 confirmed that the 5% treatment maintained the lowest and most stable pH throughout storage, followed by the 3% and 1% treatments, while the untreated control showed the greatest rise in pH over the storage period (Table 4.4).

Table 4.4: The effect of different concentrations of Phyt Exponent® on pH of tomatoes

Treatments	pH at day 0	pH at day 7	pH at day 14
T0	4.0820[a]	5.046[a]	5.080[a]
T1	4.0960[a]	4.758[ab]	4.782[b]
T2	4.1020[a]	4.546[b]	4.720[bc]
T3	4.1080[a]	4.418[b]	4.640[c]
Grand mean	4.0970	4.692	4.806
P-value	0.662	0.004	0.001
SED	0.1488	0.1488	0.0644
LSD	0.3155	0.3155	0.1365
CV%	0.8	5.0	2.1

At $p \leq 0.05$, means sharing the same letter within a column are not significantly different.

4.5 The effect of different concentrations of Phyt Exponent® on the total soluble solids (TSS) of tomatoes during storage

At day 0, there was no significant difference in TSS among treatments ($p > 0.05$), with means ranging narrowly from 3.920 to 3.936 ˚Brix, confirming comparable initial sugar content across all fruit. By day 7, treatments had diverged significantly ($p \leq 0.05$), with the untreated control (0%) recording the highest TSS (4.680 ˚Brix) and the 5% treatment the lowest (4.408 ˚Brix), with the 1% (4.576) and 3% (4.476) treatments intermediate. The difference was highly significant by day 14 ($p \leq 0.001$), with LSD groupings confirming that all four treatments differed significantly from one another: TSS rose progressively from 4.506 ˚Brix in the 5% treatment, to 4.624 in the 3% treatment, 4.740 in the 1% treatment and 4.950 in the untreated control (Table 4.5).

Table 4.5: The effect of different concentrations of Phyt Exponent® on the total soluble solids (TSS) of tomatoes during storage

Treatments	TSS at day 0	TSS at day 7	TSS at day 14
T0	3.9220[a]	4.680[a]	4.950[a]
T1	3.9360[a]	4.576[ab]	4.740[b]
T2	3.9200[a]	4.476[b]	4.624[c]
T3	3.9320[a]	4.408[b]	4.506[d]
Grand mean	3.9275	4.535	4.705
P-value	0.822	0.005	0.001
SED	0.01980	0.0668	0.0302
LSD	0.04197	0.1416	0.0640
CV%	0.8	2.3	1.0

At $p \leq 0.05$, means sharing the same letter within a column are not significantly different.

4.6 The zone of microbial inhibition of Phyt Exponent® at varying concentrations against bacteria and fungi spoilage (*E. carotovora* and *B. cinerea)*

There was highly significant effect on ZOI for both bacterial and fungal test organisms (*E. carotovora* and *B. cinerea)* ($p \leq 0.001$) (Figure 4.1). The 0% Phyt Exponent® control treatment produced no ZOI on either plate. All three Phyt Exponent® concentrations produced clear measurable zones on both media increasing in a concentration dependent manner and these are demonstrated in the figures below. They were all different from each other as confirmed by the LSD groupings.



Figure 4.1: Plates showing ZOI for bacteria (*E. carotovora)* (left) and fungi (*B. cinerea)* (right)

4.6.1 The zone of microbial inhibition of Phyt Exponent® at varying concentrations against *Erwinia carotovora* bacteria (Figure 4.3)

The zone of microbial inhibition of Phyt Exponent® at different concentrations against *E. carotovora* showed a highly significant concentration-dependent response ($p \leq 0.001$). The untreated control (0%) produced no inhibition while the 1%, 3% and 5% concentrations produced progressively larger zones of inhibition of 8 mm, 12 mm and 17 mm. All the values were significantly different from each other as confirmed by the LSD groupings (Figure 4.2).

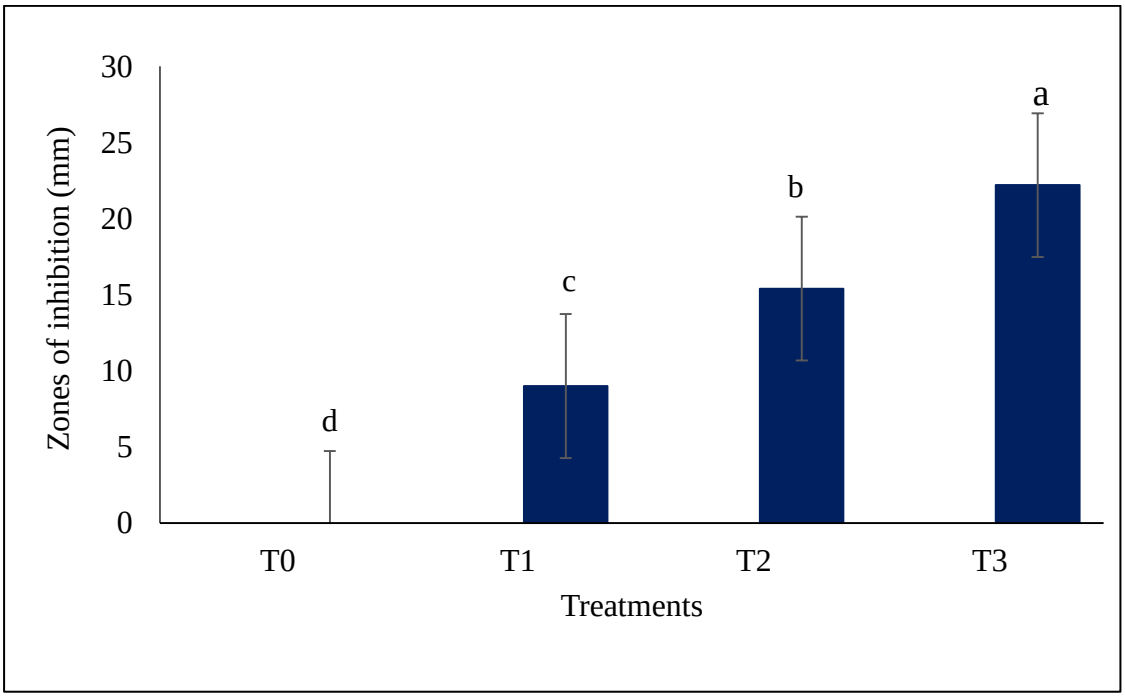

Figure 4.2: The zone of microbial inhibition of Phyt Exponent® at varying concentrations against bacterial spoilage (*Erwinia carotovora)*

4.6.2 The zone of microbial inhibition of Phyt Exponent® at varying concentrations against *B. cinerea* indicated (Figure 4.3)

The zone of microbial inhibition of Phyt Exponent® at varying concentrations against *B. cinerea* was also highly significant ($p \leq 0.001$). As with bacteria the untreated control produced no inhibition with the 1%, 3% and 5% concentrations producing progressively larger zones of inhibition. All the zones produced were significantly different from each other as confirmed by the LSD groupings.

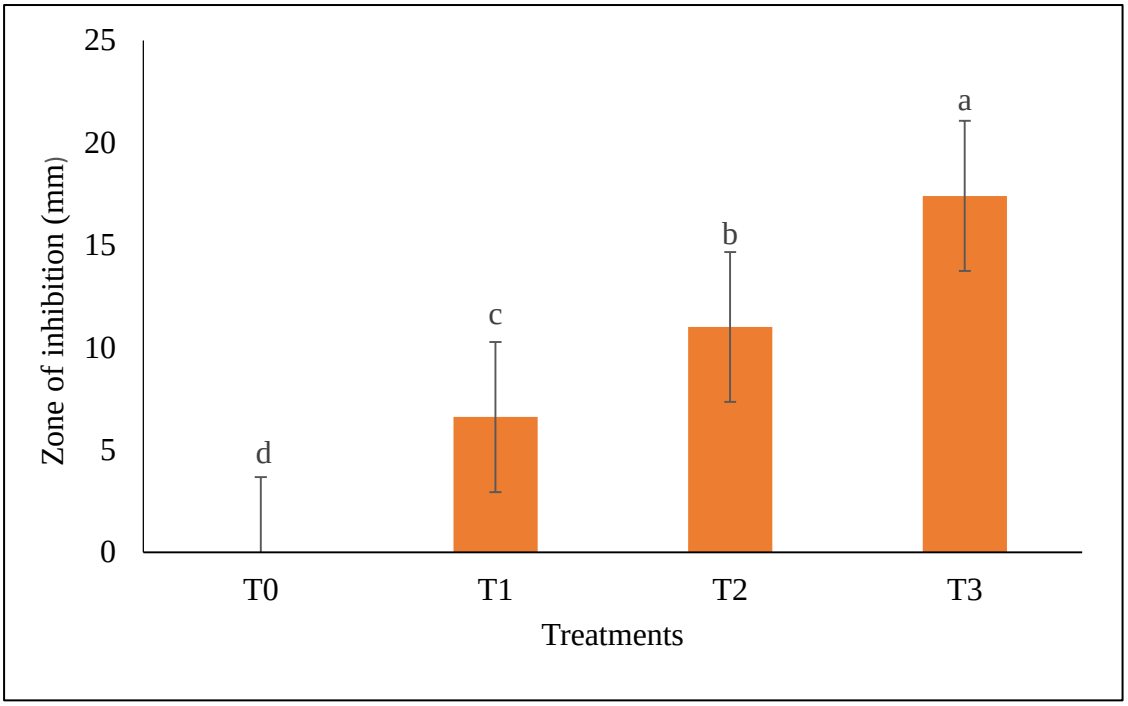

Figure 4.3: The zone of microbial inhibition of Phyt Exponent® at varying concentrations against fungi spoilage (*Botrytis cinerea).*

CHAPTER 5

DISCUSSION

5.1 Effects of Phyt Exponent® spray on weight loss of tomatoes

The results of this study demonstrated that there was no significant effect of Phyt Exponent® spray on the weight of tomatoes at day 0. This was expected as all tomatoes were selected from the same batch and were uniformly allocated across treatments prior to any spray application. This uniformity confirms that the experimental units were comparable and any successive differences in weight loss were attributable to the treatments rather than initial variation. This is consistent in with the standard expectations in postharvest studies where initial weight homogeneity across treatments is a prerequisite for valid comparison (Isack & Monica, 2013).

Weight loss was significantly lower from day 2 onwards in all Phyt Exponent® treated tomatoes compared to the untreated control. Differences became more progressively announced throughout the 14-day storage period. By day 14, 5% Phyt Exponent® concentration recorded the highest retained weight compared to untreated control. This significant suppression of weight loss in treated tomatoes is consistent with the known capacity of phytochemical preservatives. These phytochemical preservatives have the ability to retard the rate of transpiration and microbially induced epidermal degradation (Kehinde *et al*., 2026). The phytochemical constituents of Phyt Exponent® particularly allicin from *Allium sativum* and flavonoids from *Matricaria chamomilla* are known to disrupt microbial cell membranes and inhibit enzymatic activity. This reduces microbial colonization of the fruit surface which could otherwise accelerate moisture loss through epidermal damage (Aziz *et al*., 2020).

Ethanol solvent base (63% v/v) (food grade) used in Phyt Exponent® also independently contributed to surface sterilization at the point of application by denaturing surface-resident microbial proteins. This may have hampered the initial microbial colonization that initiates cuticle degradation (Scherer *et al*., 2023). The concentration dependent pattern of weight retention (5% > 3% > 1% > 0% Phyt Exponent®), suggestive of dose-response relationship with higher concentrations providing stronger protection. These results are in line with those of Salas-Méndez et al. (2019) who reported an appreciable reduction in weight loss of tomatoes coated with edible nanolaminates containing plant-derived antimicrobial extracts. Meena et al. (2020) also mentioned that chitosan nanoparticle treatments significantly reduced weight loss in tomatoes.

5.2 Effect of Phyt Exponent® spray on colour change of tomatoes

No significant treatment effects on colour change were observed at any of the assessment days. This indicates that Phyt Exponent® did not have meaningful interference with the natural ripening-associated colour development in tomatoes. All treatments demonstrated a predictable progression from pink at day 0 to full red by day 12. This agrees with natural lycopene accumulation dependent on ethylene, which is characteristic of ripening in climacteric tomato (Flores-López *et al*., 2024). This is an important observation from a food quality and consumer acceptability point of view as it confirms that the application of Phyt Exponent® does not compromise the natural maturation process of the fruit.

The slightly slower colour advancement observed for the 5% Phyt Exponent® treatment at day 7 was not statistically significant and is therefore not interpreted as a treatment effect; it is reported here only because a broadly similar non-significant delay in colour progression has been noted for other antimicrobial coatings, for example in Pobiega's (2020) study of a pullulan-based propolis coating on cherry tomatoes, which did not significantly alter the overall colour progression trajectory. This supports the conclusion that Phyt Exponent® preserves fruit shelf-life without adversely altering the natural ripening-associated pigmentation that consumers associate with tomato quality.

5.3 Effect of Phyt Exponent® spray on firmness of tomatoes

The progressive decline in fruit firmness observed across all treatments in consistent with the well-documented climacteric ripening physiology of tomatoes. This involves the increased ethylene production and the concurrent enzymatic hydrolysis of pectin and hemicellulose in cell wall matrix (Flores-López *et al*., 2024). The non-significant differences at day 0 and day

2 confirms that all treatments began with comparable fruit firmness thereby validating the experimental allocation.

Significantly treatment effects emerged from day 4 and became highly significant by day 7, 12 and 14 respectively. Phyt Exponent® treated fruits consistently retained significantly greater firmness than the control. By day 14, the untreated control (0% Phyt Exponent®) had declined further while 1%, 3% and 5% Phyt Exponent® treatments maintained significantly higher firmness values respectively. This marked difference is attributable to the antimicrobial suppression of pectolytic microorganisms by Phyt Exponent® (Ahmed *et al*., 2017). The suppression of these microorganisms by Phyt Exponent® indirectly retarded enzymatic cell wall degradation resulting in significantly higher firmness retention in treated fruits.

The firmness LSD groupings at day 7 revels that all treatments were significantly different from each other. This demonstrates a clear concentration-dependent firmness retention effect. These findings are supported by Carmello et al. (2025) who demonstrated that aqueous extracts of cinnamon and clove, significantly maintained firmness in tomatoes. They confirmed that these two acts by suppressing *A. alternata,* a key pectolytic pathogen that secretes cell wall degrading enzymes responsible for accelerated tissue softening both in vitro and under postharvest storage conditions.

5.4 Effect of Phyt Exponent® on the pH of tomatoes

No significant differences in pH were observed at day 0 across all treatments, confirming comparable initial fruit acidity across all experimental units. This is consistent with the expected pH range of commercially mature tomatoes typically between 4.0 and 4.7 (Tigist *et al*., 2013). The non-significant pH confirms that the surface spray application did not immediately alter the internal chemical environment of the fruit.

By day 7, significant treatment differences were observed with the control treatment (0 % Phyt Exponent® recording a markedly elevated pH while the 5% Phyt Exponent® treatment maintained the lowest pH. The control treatment (0% Phyt Exponent®) pH has risen by day 14 compared to 1%, 3% and 5% respectively. Observed rise in pH in the untreated control is consistent with the well-documented process of organic acid degradation during tomato senescence. This is where citric and malic acids are metabolized through the Krebs cycle and concurrently consumed by microbial metabolic activity, producing alkalizing metabolites such as ammonia and basic fermentation by-products (Tigist *et al*., 2013). The significantly

lower and more stable pH in treated fruits is thus attributable to the antimicrobial suppression of acid-consuming microorganisms by Phyt Exponent®.

From a food safety perspective, the retention of pH below 4.7 in treated tomatoes is significant, as this inhibits the growth of most pathogenic bacteria which require pH above 4.5 for proliferation (Tigist *et al*., 2013). The acidic components of Phyt Exponent® itself, particularly organic acids derived from *E. purpurea* and *M. chamomilla*, may also have contributed directly to the maintenance of lower internal pH in treated fruits. These findings are consistent with those of Tolesa & Workneh, (2017) who demonstrated that postharvest disinfection treatments that reduce surface microbial loads on tomatoes concurrently retard pH elevation during storage. This confirms the link between antimicrobial efficacy and pH stability.

5.5 Effect of Phyt Exponent® on the Total Soluble Solids (TSS) of tomatoes

No significant differences were observed in TSS at day 0. This confirms that all treatments started with comparable initial sugar content. The non-significant differences confirm that Phyt Exponent® did not alter the initial biochemical composition of the fruit as expected from a surface spray application.

Treatments had diverged significantly by day 7 with the control treatment recording the highest TSS and the 5% Phyt Exponent® treatment with the lowest. The difference was highly significant by day 14. All the four treatments were significantly different from each other at day 14 as confirmed by the LSD groupings. The significantly higher TSS accumulation in the untreated control is consistent with accelerated senescence characterized by increased hydrolysis of cell wall polysaccharides and starch into simple sugars (Isack & Monica, 2013).

The inverse relationship between Phyt Exponent® concentrations and TSS accumulation suggests that the formulation retarded the overall senescence process. Higher TSS in the control group indicates advanced sugar availability which further promotes microbial proliferation and creates a self-accelerating spoilage cycle (Isack & Monica, 2013). The ability of Phyt Exponent® to moderate TSS accumulation reflects its role in retarding both microbial spoilage and endogenous senescence. The results are in agreement with Meena et al., (2020) who reported the effect of chitosan nanoparticle on modulating TSS accumulation in tomatoes by reducing respiratory enzyme activity. They are further supported by (Tolesa &

Workneh, 2017) who demonstrated that surface disinfection treatments consistently reduced TSS accumulation rates in ambient-stored tomatoes.

5.6 Zone of microbial inhibition of Phyt Exponent®

The agar well diffusion assay confirmed that Phyt Exponent® possesses highly significant and concentration dependent antimicrobial activity against both bacterial and fungal pathogens (*E. carotovora* and *B. cinerea*). The absence of ZOI on either plate in T0 indicates that neither the solvent nor the well contributed to any observed inhibitory effect, validating the specificity of antimicrobial response to Phyt Exponent®. The progressively larger ZOI in 1%, 3% and 5% Phyt Exponent® concentrations on each agar demonstrates a strong and consistent dose-response relationship as they are all significantly different from each other. This directly mirrors the concentration-dependent shelf-life improvements observed in the physical and chemical quality parameters.

The broad-spectrum antimicrobial activity demonstrated by Phyt Exponent® on both agar is consistent with the known multi-target mechanisms of its constituent phytochemicals. Allicin from *A. sativum* disrupts sulfhydryl enzyme systems and lipid bilayer integrity in both fungal and bacterial cells (Aziz *et al.,* 2020). *E. purpurea* components inhibits fungal cell membrane integrity while flavonoids, bisabol and coumarins from *M. chamomilla* and saponins and sesquiterpenes from *V. tricolor* all contributes to broad-spectrum antibacterial and antifungal effects (Karnwal & Malik, 2024; Scherer *et al.,* 2023). The synergistic interaction among these diverse phytochemical classes confers a multi-target mechanism of inhibition that is less susceptible to resistance development compared to single-compound synthetic fungicides (McClements *et al.,* 2021). The 63% v/v ethanol solvent further potentiates the antimicrobial effect by denaturing microbial surface proteins at the point of application (Aziz *et al.,* 2020).

The ZOI values recorded in this study fall within the ranges reported in published literature for individual Phyt Exponent® constituents. Rahman et al. *(*2022) reported ZOI values of 8-18 mm for ethanolic garlic extracts against bacterial pathogens while Yazdanian et al. *(*2022) reported ZOI values of 14-20mm for ethanolic *E. purpurea* extracts against both fungal and bacterial organisms. The ZOI of 17.0mm produced by 5% Phyt Exponent® in the present study is consistent with these published ranges and is expected to exceed values reported for individual constituents. Gurjar et al. (2021) demonstrated that multi-component plant extracts consistently produce larger zones of inhibition than single extract treatments. This was further reinforced by Nizamani et al. (2021) as he reported clear ZOI against tomato rot fungi using locally available plant-based preservatives applied via agar well diffusion. Collectively,

the ZOI data provide mechanistic *invitro* validation for in situ shelf-life improvements observed across all physical and chemical quality parameters measured in this study.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This study evaluated the efficacy of Phyt Exponent®, a commercially available plat-derived herbal formulation as a spray-applied postharvest preservative for extending shelf-life of tomatoes (*Solanum lycopersicum)* under normal storage conditions over a 14-day period. Based on the experimental findings, the following conclusions are drawn:

- Phyt Exponent® spray significantly extended the shelf life of tomatoes compared to the untreated control across all measured physical quality parameters. Treated tomatoes retained significantly more weight, great firmness and distinctly lower visible spoilage incidence from day 2 and 4 onwards respectively. The highest concentration of 5% Phyt Exponent® consistently produced superior results across all parameters. The null hypothesis that Phyt Exponent® has no significant effect on the physical quality of tomatoes was therefore rejected for weight loss and firmness from day 4 onwards.
- Secondly, colour development was not significantly affected by Phyt Exponent® treatment at any assessment day ($p > 0.05$). All the treatments progressed naturally from pink (score 4) to full red (score 6) within a 14-day period. This confirms that the formulation preserves fruit quality without adversely altering natural ripening-associated pigmentation. This is a critical criterion for consumer acceptability and market suitability of treated produce.
- Thirdly, Phyt Exponent® significantly improved the chemical quality attributes of stored tomatoes. Treated tomato fruits retained significantly lower pH values and lower Total Soluble Solids (TSS) relative to the control from day 7 onwards ($p \leq 0.05$

and $p \leq 0.001$ respectively). It was consistent with retarded senescence, preserved organic acid content and suppressed respiratory conversion of polysaccharides to simple sugars. The null hypothesis of no significant effect on chemical quality attributes was therefore rejected.

- Fourthly, Phyt Exponent® demonstrated clear concentration-dependent antimicrobial activity against both bacterial (*Erwinia carotovora)* and fungal (*Botrytis cinerea*) tomato postharvest pathogens *invitro*. This is evidenced by measurable progressively larger zones of inhibition at 1%, 3% and 5% concentrations on both Nutrient Agar and Potato Dextrose Agar. The null hypothesis of no significant zone of microbial inhibition therefore was rejected. This *invitro* antimicrobial activity provides automatic justification for the observed shelf-life improvements.
- Overall, Phyt Exponent® is a scientifically valid natural alternative to synthetic chemical preservatives for postharvest tomato preservation, particularly in low-resource settings lacking cold chain infrastructure. Its simple spray application protocol and commercial availability make it readily adoptable by smallholder farmers without infrastructure investment.

6.2 Recommendations

Based on the findings and limitations of the present study, the following recommendations are provided for future research and practical implications:

- Farmers, particularly smallholder farmers lacking access to cold-chain infrastructure, are recommended to adopt the 5% Phyt Exponent® concentration as a practical, low-cost spray treatment for extending the postharvest shelf-life and quality of tomatoes.
- Future studies should have larger sample size and longer storage duration beyond the 14-day storage. This may better characterize the potential for extending the shelf-life of Phyt Exponent® and determine how long each concentration maintains effective preservation. This would also result in increased statistical power and reduce the impact of natural variation in fruit ripeness at harvest.
- The zone of inhibition assay should be extended to test a broader panel of representative tomato postharvest pathogens. Standardized inoculum concentrations should be used in accordance with internationally recognized antimicrobial testing protocols like the Clinical and Laboratory Standards Institute (CLSI). MIC and

MBC/MFC determinations should be conducted to provide instinctively rigorous data supporting the preservative claims.

- Titratable acidity (TA) and lycopene content should be quantified in future trials as they are critical nutritional and flavor quality indicators in tomatoes. TA provides a more sensitive and quantitative measure of organic acid content than pH alone. Lycopene quantification on the other hand would allow assessment of whether Phyt Exponent® treatment affects the accumulation of this important health-promoting carotenoid during ripening.
- An economic cost-benefit analysis of Phyt Exponent® application at farm level should be conducted to evaluate its viability relative to conventional chemical preservatives and alternative treatments. Such analysis should account for the cost of the product, application labour, reduction in postharvest losses and market price differentials for better quality produce. This information would be critical for informing adoption recommendations targeted at smallholder farmers in Zimbabwe and similar developing countries.
- Given the significant preservation efficacy observed at 5%, future dose-response trials should evaluate concentrations above 5%. This is to determine whether further concentration increases yield proportionally greater benefits or whether diminishing returns are observed. This may facilitate the identification of the optimal application rate for maximum efficacy without phytotoxic effects on fruit quality.

REFERENCES

Abdel-Ghany, T.M. and Bakri, M.M., 2019. Effectiveness of a biological agent (Trichoderma harzianum and its culture filtrate) and a fungicide (methyl benzimacold-2-ylcarbamate) on the tomato rotting activity (growth, celluloytic, and pectinolytic activities) of Alternaria solani. *Bio Resources*, 14(1), p.1591-1602.

Abebe, Z., Tola, Y. B., & Mohammed, A. (2017). Effects of edible coating materials and stages of maturity at harvest on storage life and quality of tomato (Lycopersicon Esculentum Mill.) fruits. *African Journal of Agricultural Research 12*(8), p.550-565. https://doi.org/10.5897/AJAR2016.11648

Ahmed, F. A., Sipes, B. S., & Alvarez, A. M. (2017). Postharvest diseases of tomato and natural products for disease management. *African Journal of Agricultural research 12*(9), p.684-691. https://doi.org/10.5897/AJAR2017.12139

Akbudak, B., Akbudak, N., Seniz, V., & Eris, A. (n.d.). Sequential treatments of hot water and modified atmosphere packaging in cherry tomatoes. *Journal of Food Quality 30*(2007), p.896-910.

Akotowanou, O. C. A., & Sènan, E. (2023). Antifungal Properties of Pimenta racemosa (Mill.) and Mentha x piperita (L.) Essential Oils against Fusarium oxysporum Causing Tomato Fruit Rot. *Journal of Advances in Biology and Biotechnology 26*(11), p.50-59. https://doi.org/10.9734/JABB/2023/v26i11666

Albornoz, K., Cantwell, M. I., Zhang, L., & Beckles, D. M. (2019). Integrative analysis of postharvest chilling injury in cherry tomato fruit reveals contrapuntal spatio- temporal

responses to ripening and cold stress. *Scientific Reports*, (January), p. 1-14. https://doi.org/10.1038/s41598-019-38877-0

Antoniou, C., Loannou, A., Balestrini, R., Fotopoulos, V. and Gedeon, S., 2022. Application of biostimulants in tomato plants (Solanum lycopersicum) to enhance plant growth and salt stress tolerance. *Plants*, 11(22), p.3082.

Arah, I.K., Ahorbo, G.K., Anku, E.K., Kumah, E.K. and Amaglo, H., 2016. Postharvest handling practices and treatment methods for tomato handlers in developing countries: A mini review. *Advances in Agriculture*, 2016(1), p.6436945.

Asim, S., Bacha, S., Li, Y., Nie, J., & Xu, G. (2023). Comprehensive review on patulin and Alternaria toxins in fruit and derived products. *Frontie*rs *in Plant Science*, 14, p. 1139757. https://doi.org/10.3389/fpls.2023.1139757

Aziz, M., Karboune, S., August, J.-, Mugao, L. G., Erturk, A. G., Erturk, O., Ayvaz, M. Ç., Erturk, E. Y., Calefi, G. G., Silva, N. B. S., Alhatlani, B. Y., Abdallah, E. M., Martins, C. H. G., Amiri, S., Moghanjougi, Z. M., Bari, M. R., Khaneghah, A. M., Fierascu, R. C., Fierascu, I., … Igarashi, I. (2020). Bioactivity of essential oils: A review on their interaction with food components. *Frontiers in Microbiology*, *6*(1), p.1-7. https://doi.org/10.3389/fmicb.2015.00076

Bellotti, G., Guerrieri, M.C., Giorni, P., Bulla, G., Fiorini, A., Bertuzzi, T., Antinori, M.E. and Puglisi, E., 2023. Enhancing plant defense using rhizobacteria in processing tomatoes: a bioprospecting approach to overcoming Early Blight and Alternaria toxins. *Frontiers in Microbiology*, 14, p.1221633.

Bist, N. S., & Bist, P. (2021). Sustainability in Food and Agriculture (SFNA) Role of microorganisms in post-harvest loss of agricultural products : A Review. *Sustainability in Food and Agriculture 2*(1), p.1-4. https://doi.org/10.26480/sfna.01.2021.01.04

Cabral, C., Pinto, V. F., & Patriarca, A. (2013). International Journal of Food Microbiology Application of plant derived compounds to control fungal spoilage and mycotoxin production in foods. International Journal of Food Microbiology *166*, p.1-14.

Carmello, C. R., Maria, M., Magri, R., & Cardoso, J. C. (2025). Cinnamon and clove aqueous extracts promote invitro and postharvest control of Alternaria alternata in tomato fruit. *European Journal of Plant Pathology, 172(2), p.*1-21.

Chen, D., Liu, L., Gao, Z., Zhao, J., Yang, Y., & Shen, Z. (2025). Preservation of Fruit Quality at Postharvest Through Plant-Based Extracts and Elicitors. Horticulturae, 11(10), p.1186

Cyrille, O., Akotowanou, A., Adjou, E. S., Olubi, A. B., Daton, S., Ahoussi, E. D., & Sohounhloué, D. C. K. (2022). The tomato (S. lycopersicum L .) in community development : An overview focused on nutritional properties , agronomic constraints , recent achievements and future prospective. International Journal of Frontier in Biology and Pharmacy Research, 3(2), p.008-016

Dawad, E., & Karki, A. (2022). A review on post-harvest handling practices of tomato (lycopersicum esculentum). *Food and Agri Economics Review*, *2*(2), p.100-103. https://doi.org/10.26480/faer.02.2022.100.103

Delarue, M., Behnamed, M., & Fragkostefanakis, S. (2024). The role of epigenetics in tomato stress adaptation. Jo u rn a l P of. *New Crops*, 100044. https://doi.org/10.1016/j.ncrops.2024.100044

Deresa, E. M., & Diriba, T. F. (2023). Heliyon Phytochemicals as alternative fungicides for controlling plant diseases : A comprehensive review of their efficacy , commercial representatives , advantages , challenges for adoption , and possible solutions. *Heliyon*, *9*(3), p.13810. https://doi.org/10.1016/j.heliyon.2023.e13810

Din, A., Mihaescu, C., Stegarus, D. I. P., Vilcoci, D., Cirstea, G., Sardarescu, I., Vizitiu, D. E., Paunescu, A., Mitrea, I., & Mitrea, R. (2023). Ecological control of mycotic pathogens in tomato crops - alternatives to synthetic pesticides. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, 51(4), p.13492-13492. https://doi.org/10.15835/nbha51413492

El-beltagi, H. S., Parmar, A., Chen, T., & El-mogy, M. M. (2023). *Editorial : Advances in pre- and postharvest applications to reduce qualitative and quantitative food loss and waste*. (February), p.1–3. https://doi.org/10.3389/fpls.2023.1149358

Eloff, J. N. (2019). Avoiding pitfalls in determining antimicrobial activity of plant extracts and publishing the results. In *BMC Complementary and Alternative Medicine* (Vol. 19, Number 1). BioMed Central Ltd. https://doi.org/10.1186/s12906-019-2519-3

Eloff, J. N., Igarashi-mafra, L., Slathia, S., Sharma, Y. P., Hakla, H. R., Urfan, M., Abebe, Z., Tola, Y. B., Mohammed, A., Pobiega, K., Sinha, S. R., Singha, A., Faruquee, M., Jiku, A. S., Rahaman, A., Karki, A., Dawadi, E., Ahmed, F. A., Sipes, B. S., Raie, W. Y. (2022).

Application of natural antimicrobials for food preservation. *Journal of Food Science and Technology*, *5*(2), p.1-9. https://doi.org/10.1504/ijpti.2022.125902

Fagundes, C., Palou, L., Monteiro, A.R. and Pérez-Gago, M.B., 2014. Effect of antifungal hydroxypropyl methylcellulose-beeswax edible coatings on gray mold development and quality attributes of cold-stored cherry tomato fruit. *Postharvest Biology and Technology*, 92, p.1-8.

Fedeli, R., Carullo, G., Butini, S., Campiani, G., Frattaruolo, L., Panti, A., Fusi, F., Saponara, S., Gemma, S., Cappello, A. R., Vannini, A., & Loppi, S. (2023). Nutritionally enriched tomatoes (S. lycopersicum L .) grown with wood distillate : chemical and biological characterization for quality assessment. *Journal of Food Science*, 88(12), p.5324-5338. https://doi.org/10.1111/1750-3841.16829

Flores-López, L., Vieira, J. M., Rocha, C. M. R., Lagar, M., Cerqueira, M. A., Jasso, D., Rodr, D., & Vicente, A. (2024). Postharvest Quality Improvement of Tomato (S. lycopersicum L .) Fruit Using a Nanomultilayer Coating Containing Aloe vera. *Foods*, 13(1), p.83.

Flores-López, M. L., Vieira, J. M., Rocha, C. M. R., Lagarón, J. M., Cerqueira, M. A., Jasso de Rodríguez, D., & Vicente, A. A. (2024). Postharvest Quality Improvement of Tomato (*S. lycopersicum* L.) Fruit Using a Nanomultilayer Coating Containing Aloe vera. *Foods*, *13*(1). https://doi.org/10.3390/foods13010083

Gonelimali, F. D., Lin, J., Miao, W., Xuan, J., Charles, F., Chen, M., & Hatab, S. R. (2018). Antimicrobial Properties and Mechanism of Action of Some Plant Extracts Against Food Pathogens and Spoilage Microorganisms. *9*(July), Frontiers in microbiology 9 (2018): 1639. https://doi.org/10.3389/fmicb.2018.01639

Gurjar, M. S., Ali, S., Akhtar, M., & Singh, K. S. (2012). Efficacy of plant extracts in plant disease management. *Agricultural Sciences*, *03*(03), p.425-433. https://doi.org/10.4236/as.2012.33050

Hnatuszko-Konka, A. G. K. (2015). Tomato (S. lycopersicum L.) in the service of biotechnology. Plant Cell, Tissue and Organ Culture (PCTOC), 120(3), p.881-902. https://doi.org/10.1007/s11240-014-0664-4

Igarashi-Mafra, L., de Souza, P. G., Toci, A., Amaral, W. do, Mafra, M. R., & Farias, F. O. (2022). Natural extracts from Eugenia brasiliensis Lam leaves to improve the shelf-life of fresh tomatoes. https://doi.org/10.21203/rs.3.rs-1498652/v1

Isack, M. E., & Monica, L. (2013). Effect of post-harvest handling practices on physico-chemical composition of tomato. In *Journal of Agricultural Technology* (Vol. 9, Number 6). http://www.ijat-aatsea.com

Kanski, L., Naumann, M., & Pawelzik, E. (2020). Flavor-Related Quality Attributes of Ripe Tomatoes Are Not Significantly Affected Under Two Common Household Conditions. *Frontiers in Plant Science*, *11*. https://doi.org/10.3389/fpls.2020.00472

Karki, A. and Dawadi, E., 2022. A review on post-harvest handling practices of tomato (Lycopersicum esculentum). Energy (kcal/100 g), 34(18.74), p.18-00. https://doi.org/10.26480/faer.02.2022.100.103

Karnwal, A., & Malik, T. (2024). Exploring the untapped potential of naturally occurring antimicrobial compounds : novel advancements in food preservation for enhanced safety and sustainability. *Frontiers in Sustainable Food Systems*, 8, p.1307210. https://doi.org/10.3389/fsufs.2024.1307210

Kehinde, E., Oladipo, B., Victor, T., & James, O. (2026a). Postharvest losses of tomato : Causes , spoilage mechanisms , and advances in conventional and emerging technologies for preservation. *Food Research International*, *227*(August 2025), 118247. https://doi.org/10.1016/j.foodres.2025.118247

Kehinde, E., Oladipo, B., Victor, T., & James, O. (2026b). Postharvest losses of tomato : Causes , spoilage mechanisms , and advances in conventional and emerging technologies for preservation. *Food Research International*, *227*(August 2025), 118247. https://doi.org/10.1016/j.foodres.2025.118247

Khatib, M., Cecchi, L., Bellumori, M., & Zonfrillo, B. (2023). Polysaccharides and Phenolic Compounds Recovered from Red Bell Pepper, Tomato and Basil By-Products Using a Green Extraction by Extractor Timatic ®. *International journal of molecular sciences*, 24(23), p.16653.

Kimura, S., & Sinha, N. (2008). Tomato (*S. lycopersicum*): A model fruit-bearing crop. *Cold Spring Harbor Protocols*, *3*(11). https://doi.org/10.1101/pdb.emo105

Koka, J. A., Wani, A. H., Bhat, M. Y., & Parveen, S. (2017). Antagonistic Activity of Trichoderma spp Against Some Fungi Causing Fungal Rot Disease of Brinjal. Trends in Biosciences, *10*(16), p.2844-2846.

Kurmi, B. N., Tiwari, K. H., Roy, N. K., Sigdel, B., & Pokharel, P. (2022). Sustainability in Food and Agriculture (SFNA) Effective management practices of tomato leafminer- Tuta absoluta (LEPIDOPTERA : GELECHIIDAE): A review. *3*(2), p.58–61. https://doi.org/10.26480/sfna.02.2022.

Kusstatscher, P., Cernava, T., Abdelfattah, A., Gokul, J., Korsten, L., & Berg, G. (2021). Microbiome approaches provide the key to biologically control postharvest pathogens and storability of fruits and vegetables. *FEMS Microbiology Ecology*, *96*(7), p.1-11. https://doi.org/10.1093/FEMSEC/FIAA119

Laurentiis, D. (2019). Effects of Biopreservatives Combined with Modi fi ed Atmosphere. *Journal of Food and Nutrition Science*, *69*(3), p.289-296. https://doi.org/10.31883/pjfns/110564

Linares-morales, J. R., Gutiérrez-méndez, N., & Rivera-chavira, B. E. (2018). *Biocontrol Processes in Fruits and Fresh Produce , the Use of Lactic Acid Bacteria as a Sustainable Option*.2. *Frontiers in Sustainable Food Systems, 2, p.50.* https://doi.org/10.3389/fsufs.2018.00050

Lisboa, H. M., Pasquali, M. B., dos Anjos, A. I., Sarinho, A. M., de Melo, E. D., Andrade, R., Batista, L., Lima, J., Diniz, Y., & Barros, A. (2024). Innovative and Sustainable Food Preservation Techniques: Enhancing Food Quality, Safety, and Environmental Sustainability. *Sustainability (Switzerland)*, *16*(18). https://doi.org/10.3390/su16188223

Liu, W., Liu, K., Chen, D., Zhang, Z., Li, B., El-Mogy, M. M., Tian, S., & Chen, T. (2022). *S. lycopersicum*, a Model Plant for the Studies in Developmental Biology, Stress Biology and Food Science. *Foods*, *11*(16), p.1-16. https://doi.org/10.3390/foods11162402

Lucera, A., Costa, C., Conte, A., & Del Nobile, M. A. (2012). Food applications of natural antimicrobial compounds. *Frontiers in Microbiology*, *3*(AUG), p.1-13. https://doi.org/10.3389/fmicb.2012.00287

Mahajan, P. V., Caleb, O. J., Singh, Z., Watkins, C. B., & Geyer, M. (2014). Postharvest treatments of fresh produce. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *372*(2017). https://doi.org/10.1098/rsta.2013.0309

Makau, S. M., Moumni, M., Landi, L., Pirozzi, D., Sannino, F., & Romanazzi, G. (2023). Invitro Evaluation of Chitosan Hydrochloride and COS Phytopathogenic Fungi and Escherichia coli. *Horticulturae*, 9(12), p.1275.

Maliha, M., Brammananth, R., Coppel, R. L., Werrett, M. V., Andrews, P. C., & Batchelor, W. (2022). The effect of pulp type on the performance of microfibrillar lignocellulosic bismuth-based active packaging material. *Cellulose*, *29*(8), p.4599-4611. https://doi.org/10.1007/s10570-022-04562-1

McClements, D. J., Das, A. K., Dhar, P., Nanda, P. K., & Chatterjee, N. (2021). Nanoemulsion-Based Technologies for Delivering Natural Plant-Based Antimicrobials in Foods. *Frontiers in Sustainable Food Systems*, *5*(February), p.1-23. https://doi.org/10.3389/fsufs.2021.643208

Meena, M., Pilania, S., Pal, A., Mandhania, S., Bhushan, B., Kumar, S., Gohari, G., & Saharan, V. (2020). Cu - chitosan nano - net improves keeping quality of tomato by modulating physio - biochemical responses. *Scientific Reports*, p.1-11. https://doi.org/10.1038/s41598-020-78924-9

Nendissa, S. J., Kembauw, E., & Nendissa, D. M. (2020). Kaffir lime leaf extract utilization as a natural. *XINAN JIAOTONG DAXUE XUEBAO*, 55(5), p.1-9.

Niu, J., Bao, H., Jiao, S., Han, H., & Wang, G. (2025). *Harnessing peptide hormones for postharvest preservation of horticultural produce*. (October), p.1-6. https://doi.org/10.3389/fpls.2025.1700360

Nizamani, S., Khaskheli, A. A., Jiskani, M. M., Nizamani, I. A., Khaskheli, A. J., Bahar, G., Khaskheli, S. A., Khaskheli, M. I., & Ibrahim, M. (2021). Invitro evaluation of different locally available preservatives against the fungus causing tomato fruit rot disease. *Journal of microbiology, biotechnology and food sciences*, 11(3), p.e3188-e3188.

Nizamani, S., Khaskheli, A. J., Khaskheli, A. A., & Jiskani, A. M. (2021). The Intensity of Tomato Post-Harvest Rot in the Surroundings of Tandojam. *Turkish Journal of Agriculture - Food Science and Technology*. *9*(2), p.288-295.

Nya, E., Peter, A., & Udofia, O. (2023). Profiling of fungi associated with Lycopersicum esculentum mill . spoilage in Nigeria using internal transcribed spacer (its) sequence of rDNA method. *ScienceOpen Preprints*. *6*(1), p.25-30. https://doi.org/10.15406/ijmboa.2023.06.00149

Odinita, A., & Osas, R. (2023). Phytochemical and Proximate Evaluation of Fresh and Spoilt Fruits of Tomatoes (S. lycopersicum L .) Sold in Five Major Markets in Benin City , Edo State , Nigeria. *24*(2), p.271-274.

Okiror, P., Lejju, J. B., Bahati, J., Rugunda, G. K., & Sebuuwufu, C. I. (2017). *African Journal of Agricultural Research Maturity indices for tomato (S. lycopersicum L.), cv. Ghalia 281 in Central Uganda*. *12*(14), p.1196-1203. https://doi.org/10.5897/AJAR2017.12150

Oz, A. T., & Kafkas, E. (n.d.). Phytochemicals in Fruits and Vegetables Phytochemicals in Fruits and Vegetables. Waisundara V. Superfood and functional food. London: *IntechOpen*, p.175-184.

Panebianco, S., van Wijk, E., Yan, Y., Cirvilleri, G., Continella, A., Modica, G., Musumarra, A., Pellegriti, M. G., & Scordino, A. (2023). Applications of Delayed Luminescence for tomato fruit quality assessment across varied Sicilian cultivation zones. *PLoS ONE*, 18(6), p.e0286383. https://doi.org/10.1371/journal.pone.0286383

Patrignani, F., Siroli, L., Serrazanetti, D. I., Gardini, F., & Lanciotti, R. (2015). Innovative strategies based on the use of essential oils and their components to improve safety, shelf-life and quality of minimally processed fruits and vegetables. *Trends in Food Science and Technology*, *46*(2), p.311-319. https://doi.org/10.1016/j.tifs.2015.03.009

Pinto, L. (2024). *Application of Plant Antimicrobials in the Food Sector : Where Do We Stand ? Foods*, 13(14), p.2222.

Pobiega, K. (2020). Prolonging the Shelf-life of Cherry Tomatoes by Pullulan Coating with Ethanol Extract of Propolis During Refrigerated Storage. *Food and Bioprocess Technology*, 13(8), p.1447-1461.

Quamruzzaman, A. K. M., Islam, F., Akter, L., & Mallick, S. R. (2022). Effect of Maturity Indices on Growth and Quality of High Value Vegetables. *American Journal of Plant Sciences*, *13*(07), p.1042-1062. https://doi.org/10.4236/ajps.2022.137069

Quarantine, E. P., Agric, F., & Agric, F. (2016). Impact of some plant essential oil treatments on controlling cherry tomatoes spoilage , improvement shelf-life and quality attributes during storage. *Fungal Isolates and Detection the Tested Fungi*. *43*(3), p.785–813.

Rizzo, V. (2025). *Sustainable Postharvest Innovations for Fruits and Vegetables : A Comprehensive Review*. *Foods*, 14(24), p.4334.

Salas-Méndez, E. D. J., Vicente, A., Cristina, A., Fernanda, L., Silva, P., Rodríguez-garcía, R., Hernández-castillo, F. D., Lourdes, M. De, Díaz-jiménez, V., Flores-López, M. L., Villarreal-quintanilla, J. Á., & Peña-ramos, F. M. (2019). Postharvest Biology and Technology Application of edible nanolaminate coatings with antimicrobial extract of Flourensia cernua to extend the shelf-life of tomato (S. lycopersicum L .) fruit. *Postharvest Biology and Technology*,*150*, p.19-27.

Salas-Méndez, E. de J., Vicente, A., Pinheiro, A. C., Ballesteros, L. F., Silva, P., Rodríguez-García, R., Hernández-Castillo, F. D., Díaz-Jiménez, M. de L. V., Flores-López, M. L., Villarreal-Quintanilla, J. Á., Peña-Ramos, F. M., Carrillo-Lomelí, D. A., & Jasso de Rodríguez, D. (2019). Application of edible nanolaminate coatings with antimicrobial extract of Flourensia cernua to extend the shelf-life of tomato (*S. lycopersicum* L.) fruit. *Postharvest Biology and Technology*, *150*, p.19-27. https://doi.org/10.1016/j.postharvbio.2018.12.008

Scherer, G. W., & Sassoni, E. (2016). Alma Mater Studiorum Università di Bologna Archivio istituzionale della ricerca *MINERAL CONSOLIDANTS*. (January), p.978-980.

Scherer, G. W., Sassoni, E., Castaldi, S., Zorrilla, J. G., Petrillo, C., Russo, M. T., Ambrosino, P., Masi, M., Cimmino, A., Isticato, R., Tenea, G. N., Angamarca, E., Cifuentes, V., Hidalgo, J., Kusstatscher, P., Cernava, T., Abdelfattah, A., Gokul, J., Korsten, L., Ullen, P. J. C. (2023). Nanoemulsion-Based Technologies for Delivering Natural Plant-Based Antimicrobials in Foods. *Frontiers in Microbiology*, *9*(1), p.1-11. https://doi.org/10.3389/fsufs.2021.643208

Sciences, P., Hussain, A., Khan, S. W., Ali, S., Faiz, F., Hussain, M., Ali, A., Rahman, S. U., & Qasim, S. (2021). Geostatistical analysis of tomato fruit rot and diversity of associated fungal species. *Journal of Animal and Plant Sciences*, *31*(4), p.1007-1014.

Seymour, G. B., & Rose, J. K. C. (2022). Tomato molecular biology special collection of papers for molecular horticulture. *Molecular Horticulture*, p.2-5. https://doi.org/10.1186/s43897-022-00042-z

Siroli, L., Patrignani, F., Serrazanetti, D. I., Gardini, F., & Lanciotti, R. (2015). Innovative strategies based on the use of bio-control agents to improve the safety, shelf life and quality of minimally processed fruits and vegetables. *Trends in Food Science and Technology*, *46*(2), p.302-310. https://doi.org/10.1016/j.tifs.2015.04.014

Slama, A., Mezni, F., Ayari, F., & Khaldi, A. (2022). Phytopathogenic / Mycotoxigenic Fungi Infecting S. lycopersicum Fruits (Market Storage Level). *European Journal of Biology and Biotechnology*, 3(5), p.17-19.

Slathia, S., Sharma, Y. P., Hakla, H. R., & Urfan, M. (2021). *Post-harvest management of alternaria induced rot in tomato fruits with essential oil of zanthoxylum armatum DC*. *5*(July), p.1-11. https://doi.org/10.3389/fsufs.2021.679830

Tadesse, E. E., Assaye, H., Delele, M. A., Fanta, S. W., Huluka, D. F., Alemayehu, M., Alemayehu, G., Adgo, E., Fanta, M. A., Huluka, S. W., Alemayehu, D. F., Alemayehu, M., & Adgo, G. (2022). Assessing tomato postharvest loss through the supply chain using load tracking technique in Northwest Ethiopia. In *Int. J. Postharvest Technology and Innovation* 8 (4), p.360-381.

Taha, N. A., Elsharkawy, M. M., Shoughy, A. A., El-kazzaz, M. K., & Khedr, A. A. (2023). Biological control of postharvest tomato fruit rots using Bacillus spp . and Pseudomonas. *Egyptian Journal of Biological Pest Control*, 33(1), p.106. https://doi.org/10.1186/s41938-023-00752-6

Tigist, M., Workneh, T. S., & Woldetsadik, K. (2013). Effects of variety on the quality of tomato stored under ambient conditions. *Journal of Food Science and Technology*, *50*(3), p.477-486. https://doi.org/10.1007/s13197-011-0378-0

Tilahun, S., Park, D. S., Seo, M. H., & Jeong, C. S. (2017). Review on factors affecting the quality and antioxidant properties of tomatoes. *African Journal of Biotechnology*. *16*(32), 1678-1687. https://doi.org/10.5897/AJB2017.16054

Tiwari, I., Shah, K. K., Tripathi, S., Modi, B., & Shrestha, J. (2020). Post-harvest practices and loss assessment in tomato (S. lycopersicum L .) in Kathmandu , Nepal. *Journal of Agriculture and Natural Resources*. *3*, p.335-352.

Tolesa, G. N., & Workneh, T. S. (2017). Influence of storage environment, maturity stage and pre-storage disinfection treatments on tomato fruit quality during winter in KwaZulu-Natal, South Africa. *Journal of Food Science and Technology*, *54*(10), p.3230-3242. https://doi.org/10.1007/s13197-017-2766-6

Torres-Rodriguez, J. A., Reyes-pérez, J. J., Carranza-patino, M. S., Gaibor-fernández, R. R., Rivas-garcía, T., & Rueda-puente, E. O. (2024). Chitosan : Biocontrol agent of Fusarium

oxysporum in tomato fruit (S. lycopersicum L.). *Emirates Journal of Food and Agriculture*, 36, p.1–9. https://doi.org/10.3897/ejfa.2024.122211

Tripathi, A. N., & Tiwari, S. K. (n.d.). Postharvest Diseases of Vegetable Crops and Their Management. Postharvest technology—Recent advances, new perspectives and applications.

Ullah, I., Hanif, M., Basit, A., Khattak, M. K., Shah, S. T., Ullah, A., Lodhi, K., Ullah, I., Ahmad, M., Ali, I., Ali, F., & Mohamed, H. I. (2022). Performance of two terms exponential model on the drying kinetics of solar-dried tomatoes (Lycopersicum esculentum L.) treated with and without chemical preservatives. *Egyptian Journal of Chemistry*, 65(3), p.455-464. https://doi.org/10.21608/ejchem.2021.93566.4414

Vinha, A. F., Barreira, S. V. P., Castro, A., Costa, A., & Oliveira, M. B. P. P (2013). Influence of the Storage Conditions on the Physicochemical Properties, Antioxidant Activity and Microbial Flora of Different Tomato (Lycopersicon esculentum L.) Cultivars. *Journal of Agricultural Science*, *5*(2). https://doi.org/10.5539/jas.v5n2p118

Vukić, M., Vujadinović, D., Gojković, V., & Grujić, R. (2016). Influence of Cold Plasma Treatment on Textural and Color Characteristics of Two Tomato Varieties. *Quality of Life (Banja Luka) - APEIRON*, *13*(1–2), p.12–16. https://doi.org/10.7251/qol1601012v

Wang, C., Li, M., Duan, X., Abu-izneid, T., Rauf, A., Mitra, S., Emran, T. Bin, Aljohani, A. S. M., Fahad, A., Thiruvengadam, M., Suleria, H. A. R., Wang, C., Li, M., Duan, X., Abu-izneid, T., & Rauf, A. (2022). Phytochemical and Nutritional Profiling of Tomatoes ; Impact of Processing on Bioavailability - A Comprehensive Review Phytochemical and Nutritional Profiling of Tomatoes ; Impact of Processing on Bioavailability - A Comprehensive Review. *Food Reviews International*, *00*(00), p.1–25. https://doi.org/10.1080/87559129.2022.2097692

Wang, Z., Wu, M., Liao, Q., Wang, Y., Sui, Y., & Gong, C. (2025). Current status and future trends of eco-friendly management of postharvest fungal decays in tomato fruit. *Npj Science of Food*, *9*(1). https://doi.org/10.1038/s41538-025-00477-w

Wiegand, C., Abel, M., Ruth, P., Elsner, P., & Hipler, U. C. (2015). Invitro assessment of the antimicrobial activity of wound dressings: influence of the test method selected and impact of the pH. *Journal of Materials Science: Materials in Medicine*, *26*(1). https://doi.org/10.1007/s10856-014-5343-9

Wilkerson, E. D., Rodriguez-Saona, L. E., Barringer, S. A., & Litchfield, J. (n.d.). Rapid Assessment of Quality Parameters in Processing Tomatoes Using Handheld and Bench-top Infrared Spectrometers and Multivariate Analysis. *Journal of agricultural and food chemistry*, 61(9), p.2088-2095.

Wilson, M. D., Stanley, R. A., Eyles, A., & Ross, T. (2019). Innovative processes and technologies for modified atmosphere packaging of fresh and fresh-cut fruits and vegetables. *Critical Reviews in Food Science and Nutrition*, *59*(3), p.411-422. https://doi.org/10.1080/10408398.2017.1375892

Workneh, T. S., Osthoff, G., & Steyn, M. S. (2011). Influence of preharvest and postharvest treatments on stored tomato quality. *Afr J Agric Res*, *6*(12), p.2725-2736.

APPENDIX

Appendix 1: Analysis of variance

Variate: Weight_at_D0_g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum					
Treatment	3	3053.8	1017.9	1.63	0.221
Residual	16	9964.8	622.8		
Total	19	13018.6			

Appendix 2: Analysis of variance

Variate: Weight_at_D2_g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum					
Treatment	3	4494.6	1498.2	3.90	0.029
Residual	16	6151.6	384.5		
Total	19	10646.2			

Appendix 3: Analysis of variance

Variate: Weight_at_D4_g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.

Replication stratum					
Treatment	3	5847.4	1949.1	4.39	0.020
Residual	16	7105.6	444.1		
Total	19	12953.0			

Appendix 4: Analysis of variance

Variate: Weight_at_D7_g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum					
Treatment	3	5996.2	1998.7	4.59	0.017
Residual	16	6966.0	435.4		
Total	19	12962.2			

Appendix 5: Analysis of variance

Variate: Weight_at_D12_g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum					
Treatment	3	8040.2	2680.1	5.17	0.011
Residual	16	8301.6	518.9		
Total	19	16341.8			

Appendix 6: Analysis of variance

Variate: Weight_at_D14_g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum					
Treatment	3	10661.4	3553.8	6.04	0.006
Residual	16	9413.6	588.4		
Total	19	20075.0			

Appendix 7: Analysis of variance

Variate: Colour_change_at_D0

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum					
Treatment	3	0.	0.		
Residual	16	0.	0.		
Total	19	0.			

Appendix 8: Analysis of variance

Variate: Colour_change_at_D2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum					
Treatment	3	0.5500	0.1833	0.73	0.547
Residual	16	4.0000	0.2500		
Total	19	4.5500			

Appendix 9: Analysis of variance

Variate: Colour_change_at_D4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum					
Treatment	3	0.15000	0.05000	1.00	0.418
Residual	16	0.80000	0.05000		
Total	19	0.95000			

Appendix 10: Analysis of variance

Variate: Colour_change_at_D7

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum					
Treatment	3	1.7500	0.5833	2.92	0.066
Residual	16	3.2000	0.2000		
Total	19	4.9500			

Appendix 11: Analysis of variance

Variate: Colour_change_at_D12

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum					
Treatment	3	0.2000	0.0667	0.67	0.585
Residual	16	1.6000	0.1000		
Total	19	1.8000			

Appendix 12: Analysis of variance

Variate: Firmness_at_D0_N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.

Replication stratum					
Treatment	3	10.000	3.333	0.93	0.448
Residual	16	57.200	3.575		
Total	19	67.200			

Appendix 13: Analysis of variance

Variate: Firmness_at_D2_N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum					
Treatment	3	12.550	4.183	0.85	0.485
Residual	16	78.400	4.900		
Total	19	90.950			

Appendix 14: Analysis of variance

Variate: Firmness_at_D4_N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum					
Treatment	3	67.200	22.400	4.62	0.016
Residual	16	77.600	4.850		
Total	19	144.800			

Appendix 15: Analysis of variance

Variate: Firmness_at_D7_N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum					
Treatment	3	310.950	103.650	22.41	<.001
Residual	16	74.000	4.625		
Total	19	384.950			

Appendix 16: Analysis of variance

Variate: Firmness_at_D12_N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum					
Treatment	3	1049.80	349.93	33.49	<.001
Residual	16	167.20	10.45		
Total	19	1217.00			

Appendix 17: Analysis of variance

Variate: Firmness_at_D14_N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum					
Treatment	3	940.550	313.517	35.83	<.001
Residual	16	140.000	8.750		
Total	19	1080.550			

Appendix 18: Analysis of variance

Variate: pH_at_D0

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum					
Treatment	3	0.001860	0.000620	0.54	0.662
Residual	16	0.018360	0.001148		
Total	19	0.020220			

Appendix 19: Analysis of variance

Variate: pH_at_D7

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum					
Treatment	3	1.13032	0.37677	6.81	0.004
Residual	16	0.88580	0.05536		
Total	19	2.01612			

Appendix 20: Analysis of variance

Variate: pH_at_D14

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum					
Treatment	3	0.55301	0.18434	17.78	<.001
Residual	16	0.16588	0.01037		
Total	19	0.71889			

Appendix 21: Analysis of variance

Variate: TSS_at_D0_UBrix

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.

Replication stratum					
Treatment	3	0.0008950	0.0002983	0.30	0.822
Residual	16	0.0156800	0.0009800		
Total	19	0.0165750			

Appendix 22: Analysis of variance

Variate: TSS_at_D7_UBrix

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum					
Treatment	3	0.21158	0.07053	6.32	0.005
Residual	16	0.17852	0.01116		
Total	19	0.39010			

Appendix 23: Analysis of variance

Variate: TSS_at_D14_UBrix

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum					
Treatment	3	0.537060	0.179020	78.60	<.001
Residual	16	0.036440	0.002278		
Total	19	0.573500			

Appendix 24: Analysis of variance

Variate: ZOI_for_fungus_mm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum					
Treatment	3	805.350	268.450	261.90	<.001
Residual	16	16.400	1.025		
Total	19	821.750			

Appendix 25: Analysis of variance

Variate: ZOI_for_fungus_mm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum					
Treatment	3	805.350	268.450	261.90	<.001
Residual	16	16.400	1.025		
Total	19	821.750			