

**DEVELOPMENT OF BIOPESTICIDES FOR MANAGING EARLY
BLIGHT AND LEAF MINER IN TOMATO (*SOLANUM
LYCOPERSICUM*) PRODUCTION IN TANZANIA**

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**A Dissertation Submitted in Partial Fulfilment of the Requirements for the Degree of
Masters of Science in Sustainable Agriculture of the Nelson Mandela African Institution
of Science and Technology**

Arusha, Tanzania

July, 2025

ABSTRACT

Early blight disease (*Alternaria solani*) and leaf miners (*Tuta absoluta*) are major pests of tomato that can cause 80 -100% loss in fruit yield. A study was conducted at the Nelson Mandela Institution of Science and Technology (NM-AIST) laboratory, screen house and field trials in Kilimanjaro and Arusha regions of Tanzania in 2023; to evaluate the in vitro efficacy of various botanical extracts (*Azadirachta indica*, *Lantana camara*, *Capsicum frutescens*, *Zingiber officinale*) as biopesticides against *A. solani*. Results showed significant inhibition of fungal mycelial radial growth in the range of 23.3 (5% fresh lemon grass) to 98.26% (10% hot pepper). The screen house trial showed the positive results on leaf miner reduction by 80%, 76.6% and 72.6% for 10% lantana, 10% hot pepper and 10% ginger respectively. The best four extracts in both laboratory and screen house experiments (10% hot pepper, 5% hot pepper, 10% ginger and 10% lantana) were used in field trials, resulting in an average 50% and 70% reduction in disease severity and incidence, and tomato leaf damage respectively as compared to the negative control. The highest number tomato fruits and weight per plant were observed at Mailisita in 10% lantana (16.56) and 10% hot pepper (2.29 kg). Most of biopesticides with 10% concentration had good performance. Water-extracted biopesticides were found to be more effective than ethanol-extracted ones in inhibiting fungal growth and leaf miners. The 5% hot pepper treatment had the highest treatment advantage revenue (2818.48 USD) and cost benefit ratio (1: 3.5) compared to the negative control.

DECLARATION

I, Fikiri Abel do hereby declare to the Senate of Nelson Mandela African institution of Science and technology that this dissertation is my original work and that it has neither been submitted nor being concurrently submitted for the degree award in other institution.

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CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance and approval by the Senate of the Nelson Mandela African Institution of Science and Technology the dissertation entitled “*Development of Biopesticides for Managing Early Blight and Leaf Miner in Tomato (Solanum Lycopersicum) Production in Tanzania.*” in partial fulfilment of the requirements for the Award of the Degree of Master of Science in Sustainable Agriculture of the Nelson Mandela African Institution of Science and Technology.

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ACKNOWLEDGEMENTS

First and foremost, I want to express my gratitude to our All-Powerful God, who grants us health, security, and overall well-being. I am especially grateful to Him for all the blessings He bestowed upon me while I worked diligently to complete this task. For their willingness and unwavering guidance, assistance, and encouragement throughout the duration of this study, my sincere thanks and gratitude also go to my supervisors Dr. Pavithravani Venkataramana, Dr. Angela Mkindi and Prof. Ernest Mbega and other internal and external supervisors for donating their valuable time to supervise and advise this work. I also appreciate my friends and classmates.

Last but not least, I really appreciate the financial support provided by Agro ecology Hub and McKnight.

DEDICATION

I dedicate this work to my parents and my beloved children Brightness, Brayden and Jayden in appreciation of their unwavering strength, support, and prayers that enabled this to happen.

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LIST OF ABBREVIATIONS AND SYMBOLS

%	Percentage
< or >	Less than or Greater than
°C	Degree Celsius
µl	Microliters
µM	Micrometers
ANOVA	Analysis of Variance
a.s.l	Above the sea level
<i>A.Solani</i>	<i>Altenaria Solani</i>
FAO	Food Agriculture Organization
L	Liter
LSD	Least Significant Difference
g/l	Gram per Liter
ml	Milliliter
NM-AIST	Nelson Mandela African Institution of Science and Technology
PDA	Potato Dextrose Agar
SED	Standard Error Deviation
<i>Spp.</i>	Species
WHO	World Health Organization
Hrs	Hours
ml	Millilitre
C:B	Cost Benefit Ratio
DSI	Disease Severity Incidence
g/kg	Gram/ Kilogram

SC	Soluble concentration
w/v	Weight Per Volume
v/v	Volume per volume
USD	United states dollar
+ve control	Positive control
-ve control	Negative control

CHAPTER ONE

INTRODUCTION

1.1 Background of the problem

Tomato (*Solanum lycopersicum L.*) is an annual herbaceous crop in the Solanaceae family, comprising over 3000 species (Fufa *et al.*, 2009). Originating from the Andes and first domesticated in Mexico around 500 BC, it spread globally in the 17th century via Columbus and Cortez (Fufa *et al.*, 2009; Dube *et al.*, 2020; Saavedra *et al.*, 2016). Tomatoes are classified by growth habits into determinate (bushy and early-fruiting) and indeterminate (tall and continuously growing) types (Saavedra *et al.*, 2016). Their popularity stems from their nutritional value, flavor, and culinary versatility (Wu *et al.*, 2022; Barrett *et al.*, 2010; Wang *et al.*, 2023). Over 80% are processed into products like paste, sauce and juice (Bilalis *et al.*, 2018; Saha *et al.*, 2016). Tomato by-products are rich in fiber (59.03%), sugars, protein and other nutrients (De Valle *et al.*, 2006).

Global tomato production exceeds 171 million metric tonnes on 5 million hectares, with Africa contributing 11.8% (Dube *et al.*, 2020). In Tanzania, tomatoes are a key cash crop for smallholder farmers (Fufa *et al.*, 2009; URT, 2012), though yields (2.2–16 t/ha) lag behind developed countries such as China (40–100 t/ha) due to factors like location, season, cultivar and crop management (Heuvelink & Dorais, 2005; FAO, 2009; Huat *et al.*, 2013; FAOSTAT, 2017). Major yield losses are caused by pests and diseases, particularly early blight (*A. solani*) and leaf miners (*Tuta absoluta*), which can result in 70–100% losses (Lynch, 1999; Abada *et al.*, 2008; Brévault *et al.*, 2014; Dimitrios *et al.*, 2018; Brévault *et al.*, 2014).

Currently, management of early blight disease (*A. solani*) and leaf miners (*T. absoluta*) under small holder farmers heavily rely on the use synthetic pesticides such as ridomil gold (metalaxyl-M 40 g/kg, mancozeb 640 g/ kg), equation pro (famoxadone and cymoxamil), thunder (chloro-nicotinyl and beta-cyfluthrin), belt (flubendiamide), snow thunder (thiamexom 30g/ l and emamactin benzoate 10 g/l)and snow tiger (chlorfenapyr 100g/l) (Sithanatham *et al.*, 2002; Tescari *et al.*, 2014; Tudi *et al.*, 2022; Nuwamanya *et al.*, 2023).

Despite their importance, chemical pesticides are harmful to human and other beneficial living organism in the ecosystem and contaminates the food web (Sithanatham *et al.*, 2002; Ngowi *et al.*, 2007; Abhilash & Singh, 2009; Mushobozi, 2010; Hashmi & Khan, 2011; Tudi *et al.*,

2022). Additionally, the target pests also develop resistance against the pesticides with time (Abhilash & Singh, 2009; Nuwamanya *et al.*, 2023).

Biopesticides have emerged as a promising alternative, producing fewer toxic residues and posing minimal risks to health and the environment, with a reduced chance of resistance development (Lengai & Muthomi, 2018; Singh *et al.*, 2019; Mkindi *et al.*, 2020; Kemunto *et al.*, 2022; Hashmi & Khan, 2011; Ayilara *et al.*, 2023). Studies report that biopesticides can reduce pest and disease impacts by 50 - 100% (Lengai & Muthomi, 2018; Singh *et al.*, 2019; Mkindi *et al.*, 2020; Kemunto *et al.*, 2022). Additionally, rabbit urine has been found effective in controlling leaf miners, aphids and whiteflies (Lekamoi, 2022; Mtua *et al.*, 2024).

However, the use biopesticides in tomato production is hindered by a lack of effective biopesticides suitable for smallholder farmers, necessitating urgent laboratory, screen-house and field research to determine effectiveness of biopesticides in managing leaf miner pest and early blight disease-causing pathogen.

1.2 Statement of the problem

Lack of standardized formulations of biopesticides to control leaf miners and early blight diseases in tomato hinders small farmers from using them effectively. As a result, farmers face challenges in appropriately applying biopesticides products. It is reported that, farmers underuse, overuse, overdose and misuse of pesticides are higher and some farmers mix different products in spray mixtures (Ngowi *et al.*, 2016). This results in increased pest and disease epidemics and resurgence such as leaf miners and early blight that are reported to cause yield losses of up to 100% (Abisgold *et al.*, 2016). Development of pesticides resistance have been reported globally to impede pest and disease management (Campos & Omoto, 2002; Deising *et al.*, 2002; Mishra *et al.*, 2023). It is estimated that, more than 849 000 people die each year from the consequences of improper use of pesticide globally (Konradsen *et al.*, 2003; Sabino *et al.*, 2011). Worldwide more 50% and more than 70-80% population in Tanzania are employed in agriculture hence at risk of exposure to synthetic pesticides impacts (Konradsen *et al.*, 2003; Ngowi *et al.*, 2016). The environment and biota are also affected seriously by the improper use of pesticides (Alengebawy *et al.*, 2021). Therefore, this study aims to explore and evaluate effective, farmer-friendly biopesticide formulations for managing leaf miners and early blight in tomato production.

1.3 Rationale of the study

Biopesticides delivered from locally available plant and non-based materials have the potential to replace synthetic fungicide and insecticides when fully utilized. Research shows that biopesticides are effective in reducing pest and disease problem by 50 to 100% (Lengai & Muthomi, 2018). Biopesticides act through different mechanisms to target pest and pathogens while maintaining beneficial organisms contributes to healthier ecosystems and more sustainable agricultural practices (Lengai & Muthomi, 2018). The use of plant extracts like Chinese chive (*Allium tuberosum*) in managing crop pests and diseases increased yield and quality of lettuce (*Lactuca sativa L.*) (Jang & Kuk, 2019). Neem extracts are effective in controlling canker, early blight, wilt, leaf spot and fruit spot (Nahak & Sahu, 2015). Moreover, neem seed kernel extract inhibiting growth of *Alternaria solani* (Datre *et al.*, 2024). Similarly, population of white fly (*Bemisia tabaci*) is reduced by using neem extracts (Lengai & Muthomi, 2018).

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In conclusion, biopesticides are crucial as effective tool for pest and disease management. Their adoption by smallholder farmers needs thoroughly assessing several potential biopesticides options that could help in curbing the challenge in tomato production. Additionally, usage of biopesticides could ensure higher quality tomato fruits, potentially fetching better market prices. This evidence highlights the urgent need for comprehensive research spanning laboratory, screen house, and field studies to evaluate and validate biopesticide options for effective management of leaf miners and early blight in tomato farming.

1.4 Research objectives

1.4.1 Overall objective

To improve the management of leaf miner and early blight disease in tomato using selected biopesticides.

1.4.2 Specific objectives

- (i) To determine the in vitro inhibitory effects of biopesticides on *Alternaria solani*.
- (ii) To assess the effect of biopesticides on tomato leaf miner population and associated leaf damage.
- (iii) To evaluate the effectiveness of biopesticides in managing early blight, leaf miners, and their effects on tomato growth and fruits yield.
- (iv) To analyse a cost-benefit of using biopesticides to manage early blight and leaf miners in tomato.

1.5 Research questions

- (i) Which biopesticides are most effective in managing early blight and leaf miner in tomato?
- (ii) How do biopesticides affect tomato plant growth and fruit yield?
- (iii) What are the costs and benefits of using biopesticides compared to synthetic pesticides in tomato production?

1.6 Significance of the study

This study focused on evaluating the inhibitory effects of in vitro biopesticides on the radial mycelial growth of *A. solani*. The impact of biopesticides on tomato leaf miners, early blight disease and the growth and performance of tomato crop was assessed. Additionally, a cost-benefit analysis of using biopesticides for pests was conducted. The benefit of using biopesticides for managing tomato leaf miners and early blight have been demonstrated in this study. Biopesticides are less costly because the materials are readily available in smallholder farmers' environment. Moreover, biopesticides are beneficial for both tomato producers and consumers, and they improves the ecosystem. The efficient use of appropriate biopesticides may help reduce reliance on synthetic fungicides and insecticides in tomato production.

1.7 Delineation of the study

This study involved laboratory, screen house, and field experiments. The laboratory experiment aimed to evaluate the inhibitory effects of botanical extracts and rabbit urine on the radial

mycelial growth of *A.solani*. The screen house and field experiments focused on the management of leaf miner and assessment of tomato plant growth and fruit yield. Botanical extracts were consistently used in all experiments, with foliar applications conducted in screen house and field trials to manage leaf miners and early blight. The findings will inform small holder farmers an appropriate concentration, solvent and formulations of biopesticides. This knowledge will support effective management of *A.solani* and leaf miners, while enhancing tomato growth and yield, thereby reducing reliance on synthetic fungicides and insecticides.

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin and domestication

Tomato (*Solanum lycopersicum*) is an herbaceous annual plant and a member of the dicot family Solanaceae (Peralta & Spooner, 2005; Kole & Hall, 2008). This family includes well-known plant species such as potato, tobacco, eggplant and pepper (Peralta & Spooner, 2005; Kole & Hall, 2008). The clade *Lycopersicon* comprises the domesticated tomato and its 12 closest wild relatives (Peralta & Spooner, 2005). Cultivated tomatoes and their wild relatives originated in South America (Lin *et al.*, 2014; Saavedra *et al.*, 2016; Knapp & Peralta, 2016). Previous studies have suggested that the wild red-fruited *Solanum pimpinellifolium* L. was domesticated in South America to give rise to *S. lycopersicum* L. var. *cerasiforme*, which is considered the probable ancestor of the large-fruited tomato (Lin *et al.*, 2014).

Two theories have been proposed regarding the original location of tomato domestication: one Peruvian and the other Mexican (Bai & Lindhout, 2007). The history of tomato domestication is typically described as a "two-step" process. In this model, fruit size increases from the blueberry-sized *Solanum pimpinellifolium* L. to the generally cherry-sized *S. lycopersicum* L. var. *cerasiforme*, and finally to the very large-fruited common tomato (Lin *et al.*, 2014).

There is substantial genetic diversity among the tomato's wild relatives and intermediate forms (landraces or creoles) (Peralta & Spooner, 2005; Ranc *et al.*, 2008; Lin *et al.*, 2014). These forms represent valuable genetic resources for conservation and crop improvement initiatives (Peralta & Spooner, 2005; Sánchez-Peña *et al.*, 2006). According to Vijay *et al.* (2011), tomato is categorized as a climacteric fruit, meaning that its respiration rate and ethylene production increase during ripening.

There are more than 7000 varieties of tomato within the single species *Solanum lycopersicum* (Gerszberg *et al.*, 2015). Based on growth pattern, tomatoes are classified into two types. The first is the determinate type, which is bushy, short-statured, and early-maturing, characterized by the formation of inflorescences at the apical meristem (Gerszberg *et al.*, 2015; Saavedra *et al.*, 2016). Determinate tomatoes have a short main stem and are ideal for mechanical harvesting and field cultivation of fresh-market tomatoes (Shishkova *et al.*, 2008). The second type is indeterminate, which can grow to heights of 2 meters or more. These plants continue their vegetative growth while producing inflorescences in a centripetal pattern (Saavedra *et al.*,

2016). Indeterminate varieties, if properly maintained, can take advantage of a longer growing season. They are well-suited for green house production, where they can reach height of over 10 metres within 9 to 10 months (Shishkova *et al.*, 2008).

2.2 Economic importance

Tomato, ranks 1st in the world for vegetables and is grown mainly as a cash crop (Bauchet & Causse, 2012). In Tanzania, tomatoes constitute the largest portion of vegetable produced by smallholder farmers and the single most dominant vegetable crop (URT, 2012). The cherries of tomato are rich source of micronutrients and vitamins for human diet (Bauchet & Causse, 2012).

According to a study by Barrett *et al.* (2010), tomatoes are appreciated worldwide for their unique flavor, vibrant color and ability to enhance the taste of other foods. They are widely used in various cuisines worldwide. It can be consumed as raw fruit adding it to salads or cooking it as a vegetable or processing it into tomato paste, jam, sauce, juice, ketchup, canned tomatoes etc (Saha *et al.*, 2016; Bilalis *et al.*, 2016; Wu *et al.*, 2022). Worldwide, more than 80% of tomatoes are processed (Bilalis *et al.*, 2018). The majority of the tomato by-product (59.03%) is fiber, which is followed by total sugars (25.73%), protein (19.27%), pectin (7.55%), total fat (5.85%), and minerals (3.92%) (De Valle *et al.*, 2006). It is also recognized as a model species for studies on metabolite accumulation and fruit development (Bauchet & Causse, 2012).

2.3 Tomato production

Tomato production is largely dominated by smallholder farmers in many countries of the developing world (Paul *et al.*, 2011; Gerszberg *et al.*, 2015; Olubanjo & Alade, 2018). Global tomato production was reached about 186 107 972 metric tons in 2022, china was the largest producer, accounted about 37% of the total tomato produced (Paul *et al.*, 2011; Gerszberg *et al.*, 2015; Olubanjo & Alade, 2018). Egypt, Nigeria, Morocco, Tunisia and Cameroon are the top five producers of tomatoes, collectively accounting for 11.8% of the world's total production (Dube *et al.*, 2020).

Tanzania is 11th in Africa in tomato production that has increased from 34 000 t in 1973 to 464 170.98 t in 2022 growing at an average annual rate of 5.74% (Lukumay *et al.*, 2016).

According to FAO estimates, North Africa which comprises Egypt, Tunisia, Morocco and Algeria has the largest land area and the highest production levels in Africa. In contrast, Southern and Central Africa have the smallest areas and lowest production output respectively (FAO, 2009). The average yield in Central Africa varies from 6 t/ha, while southern Africa sees yields of up to 34 t/ha (FAO, 2029). In Tanzania, tomato production surpasses that of other vegetable crops, with an annual output of 129 578 tons, making up 51% of the country's total vegetable production (De Putter, 2009). However, the average yield of tomatoes in Tanzania is quite low, ranging from 2.2 to 3.3 t/ha, significantly lower than the African average of 19.1 t/ha, 23 t/ha in Asia, and the global average of 27.5 t/ha (Asgedom *et al.*, 2010; Luzi-Kihupi *et al.*, 2015).

2.4 Factors affecting tomato production

In spite of having great potentials on tomato production, Tanzania's export levels are extremely lower compared to other countries in the world (Mutayoba & Ngaruko, 2018). The lower yield has been attributed by several factors including the following:

2.4.1 Diseases and pests

Several pests and pathogens are reported to affect tomato production worldwide, the effect is higher especially during the rainy season in highland areas of Eastern and Southern Africa (Dube *et al.*, 2020). Fungal disease-causing pathogens, like *Phytophthora infestans* causes late blight, *Alternaria solani* causes early blight and *Phytophthora parasitica* causes fruit rot, are endemic and problematic in the warm summer months (Fufa *et al.*, 2009; Ivanov *et al.*, 2021). Red spider mites (*Tetranychus urticae*), cotton bollworm (*Helicoverpa armigera*), root knot nematodes (*Meloidogyne incognita*), white flies (*Bemisia tabaci*) and leaf miner (*Tuta absoluta*) are among the economically significant pests (Brévault *et al.*, 2014; Sadashiva *et al.*, 2017). Early blight caused by *Alternaria solani* and *Tuta absoluta* are among the most destructive pests of tomato that causes up to 100% yield loss, threatening tomato production (Brévault *et al.*, 2014; Dube *et al.*, 2020).

2.4.1 Soil fertility

Soil fertility is essential for tomato crop growth and productivity, influencing land sustainability (Hossain *et al.*, 2020). Continuous crop production depletes nutrients, leading to imbalances that reduce soil productivity (Vitousek *et al.*, 2009). Additionally, the scarcity of arable land has increased the pressure for higher yields and resulting in land degradation, soil

erosion and toxic metal accumulation from excessive agrochemical use (Mng'ong'o *et al.*, 2023). Fertile soil is vital for developing effective biopesticides, particularly for managing pests like early blight and leaf miners in tomatoes (Mergawy *et al.*, 2022). Soil health indicator such as pH, organic matter and microbial diversity, significantly enhancing effectiveness of biopesticides (Diaz-Perez & Eaton, 2015).

2.4.1 Climatic conditions

Tomato requires temperature between 20°C and 24°C for its optimum growth and fruit set, if temperature is below 12°C or above 35°C shading of fruits normally occurs and restrict red coloration, hence low yield (Brévault *et al.*, 2014). In such situations, the quality of the fruits become poor (Brévault *et al.*, 2014). High humidity encourages the spread of these diseases, whereas low humidity can lead to flower drop and hinder pollination (Grange *et al.*, 1987; Biratu *et al.*, 2018). Adequate sunlight, ideally 6 to 8 hours per day, is essential for photosynthesis and healthy fruit development; insufficient light often results in poor flowering and low yields (Biratu *et al.*, 2018). Wind conditions also matter, strong winds can physically damage plants and spread pests and diseases, while mild winds assist in pollination (Ramsay, 2005). Climate change also impact tomato production and yield due to reduced leaf size and photosynthetic area with during soil moisture stress (Diaz-Perez & Eaton, 2015). It is reported that if water stress and high temperatures occur concurrently the tomato plant will produce soft fruit (Solankey *et al.*, 2015).

2.5 Leaf miners and early blight disease management in tomato

2.5.1 Leaf miner management and its challenge

Tomato leaf miner (*Tuta absoluta*), belongs to order Lepidoptera and is considered to be a most damaging pest of tomatoes. The larvae that live and forage inside leaves (Dai *et al.*, 2011; Dos Santos *et al.*, 2011; Liu *et al.*, 2015). According to Dai *et al.* (2011), Dos Santos *et al.* (2011), and Liu *et al.* (2015), the tiny insect larvae tunnel between the upper and lower leaf surfaces, forming meandering, discolored tracks or "mines" in the leaves. Based on Dos Santos *et al.* (2011) and Abisgold *et al.* (2016), leaf mining and fruit trails can both significantly lower a plant's degree of photosynthesis and result in a 100% reduction in tomato fruit yield. Fruit may become sunburned and lack shade as a result of widespread leaf mining, which causes early leaf drop (Dos Santos *et al.*, 2011). Bacterial and fungal infections can also enter through wounding of the leaves (Dos Santos *et al.*, 2011). Some key management strategies for leaf

miners in tomatoes include: regular inspection and removing affected plant leaves promptly to disrupt the leaf miner life cycle (Iqbal, 2023), use row covers or floating row covers to physically exclude adult leaf miners from laying eggs on the plants (Iqbal, 2023), encouraging natural predators like parasitic wasps by planting nectar-producing flowers nearby (Iqbal, 2023) and applying insecticidal soaps or spinosad-based insecticides targeted at the larval stage (Dos Santos *et al.*, 2011; Iqbal, 2023).

Despite of the endeavors to control the pest using several approaches, research reports that *Tuta absoluta* resistance to insecticides is caused by lack of integrated pest management, limited biological control options, inadequate monitoring, poor cultural practices and lack of farmer awareness and training contribute to its persistence in the field (Siqueira *et al.*, 2000; Dos Santos *et al.*, 2011; Liu *et al.*, 2015; Iqbal, 2023). This calls for the need to identify some more methods to help smallholder farmers to combat this serious pest of tomato.

2.5.1 Early blight disease management

Early blight, which is caused by the fungal pathogen *Alternaria solani*, ranks among the most prevalent diseases affecting tomatoes (Chaerani & Voorrips, 2006). The disease causes significant damage up to 100%, affecting tomato leaves, stems, and fruits throughout the year (Chaerani & Voorrips, 2006; Abisgold *et al.*, 2016). The symptoms of the disease is observed on foliage (blight), basal stem of seedlings (collar rot) and stem of adult plants (stem lesions), and on fruits (fruit rot) of tomato (Chaerani & Voorrips, 2006).

To manage early blight disease in tomatoes, smallholder farmers' select resistant varieties and maintain good sanitation practices by removing and destroying any infected plant material (Gleason & Edmunds, 2005; Roy *et al.*, 2019; Sreenivasulu *et al.*, 2019). Pruning of extra suckers, proper spacing of plants and mulching are recommended for good growth of tomato plants (Gleason & Edmunds, 2005; Roy *et al.*, 2019; Sreenivasulu *et al.*, 2019). Furthermore, application of preventative fungicides containing chlorothalonil or mancozeb at the first sign of disease onset as recommended by manufacturer (Roy *et al.*, 2019; Sreenivasulu *et al.*, 2019). Regular watering of plants at the base minimize leaf wetness that could positive influence fungal spore germination (Roy *et al.*, 2019).

2.5.2 Challenge in managing early blight disease (*Alternaria solani*)

The *A. solani*, has developed resistance to various fungicides groups reducing their effectiveness. The fungus due to its soil borne nature can persist in soil as spores and in crop

residues for over 8 months, making it difficult to eradicate (Patel & Chandhary, 2010; Gudmestad *et al.*, 2013). Early blight, a widespread disease, can spread rapidly due to warm, humid, and rainy weather conditions (Patel & Chandhary, 2010; Gudmestad *et al.*, 2013). Furthermore, management of this disease is complicated by lack of resistant cultivars, inadequate crop rotation, lack of integrated approaches, and limited farmer awareness and training on early blight disease.

2.6 The use of biopesticides in controlling pest and diseases

Several research studies have demonstrated that biopesticides are effective in managing insect pests and diseases in tomatoes, such as leaf miner and early blight, particularly when compared to synthetic pesticides. Biopesticides offer several benefits over synthetic pesticides, including reduced risk of resistance development, compatibility with integrated pest management (IPM), reduced environmental impact, improved crop safety, consumer preference, and effectiveness against specific pests and diseases (Ayilara *et al.*, 2023). They have different modes of action, making them less toxic to non-target organisms and ecosystem (Anakwue, 2019; Ayilara *et al.*, 2023). Biopesticides are also more environmentally friendly, making them a more desirable option for agricultural products (Ayilara *et al.*, 2023). They can be highly effective against specific pests and diseases when applied properly and in conjunction with other management strategies.

The biological pest control in agriculture began with Agostine Bassi's 1835 studies, which showed how to employ the white-muscadine fungus to infect silkworms and induce an infectious sickness (Olson, 2015; Anakwue, 2019). Mineral oils were applied as plant protectors in the 1800s and expanding in agricultural research in the early 20th century resulted in the creation of bio-controls (Olson, 2015). *Bacillus thuringiensis* (Bt), initially isolated in 1901 and rediscovered in 1911, was the first commonly utilized biocontrol agent. France started utilizing Bt as a pesticide in the 1920s, and in 1938, sporeine was introduced (Olson, 2015; Anakwue, 2019). Phyto-pesticides use in agriculture dates back in the sixteen centuries when tobacco, pyrethrum and neem was first important biopesticides used by early farmers to control pests and disease of agricultural importance (Saxena *et al.*, 2014).

Pesticide use, is a crucial aspect of modern agriculture, has led to widespread poisoning globally, especially in low- and middle-income countries like Africa (Anakwue, 2019; Comite *et al.*, 2021). The need for an array of research for safe to biota, and environmentally friendly means of controlling pest and disease is the priority in this contemporary world that deserves

non-chemical foods. Biopesticides are best alternative since they are specific, affordable and ecologically friendly substitutes for synthetic pesticides, reduce threat to human health and release less greenhouse gases (Anakwue, 2019; Comite *et al.*, 2021; Ayilara *et al.*, 2023). They are derived from microorganisms, plants, animal excreted and biological nanoparticles (Ayilara *et al.*, 2023).

Currently, there are botanicals which are easily prepared and reduce the use of inorganic fungicide and insecticides (Liljeroth *et al.* 2016). For example, according to Forrer *et al.* (2017), buckthorn (*Frangula alnus*) extract was found to be effective as copper in controlling early blight of tomato. An invitro study by Nashwa and Abo-Elyousr (2012), found that leaf extracts of *Datura stramonium*, *Allium indica*, and *Allium sativum* reduced radial mycelial growth of *Alternaria solani* by 47%. Moreover, garlic, neem and lantana are commonly botanicals used to control tomato disease and pests such as earl blight and leaf miners (Mulugeta *et al.*, 2020). It is reported that numbers were reduced up to 100% when neem and lantana were used as plant extracts to control the population of leaf miners in tomato fields (Kihampa, 2010; Dos Santos *et al.*, 2011; Abisgold *et al.*, 2016).

It has also been reported that the use of botanical treatments enhances the processability of tomatoes by boosting levels of antioxidants, total phenolic acids, and ascorbic acid (Toor *et al.*, 2006). Likewise, the use of *Datura stramonium* and *Allium sativum* at 5% concentration resulted in increases of the fruit yield by 76.2% and 66.7% compared to the infected control (Nashwa & Abo-Elyousr, 2012). Moreover, biopesticides enhance sustainable agriculture by promoting environmental health, economic viability, and social responsibility (Boyetchko *et al.*, 2020; Fenibo *et al.*, 2021; Fenibo *et al.*, 2022). They aid in managing pest resistance and improving crop resilience, contributing to long-term productivity and soil health (Meena *et al.*, 2020).

Biopesticides wide use in developing countries is facing serious challenges of misuses by smallholder farmers, which is leading to issues with their effectiveness and efficacy. This is reported to be due to a lack of correct formulations and application methods (Herrmann & Lesueur, 2013; Khan *et al.*, 2023; Mawar *et al.*, 2021). The formulation of biopesticides can greatly impact its effectiveness and stability under field conditions that makes it critical issue in management of pest and disease management.

Biopesticides like plant extract have complex active chemicals and thus formulating them into a stable chemical compound is challenging that needs thoroughly testing (Nuruzzaman, 2019;

Šunjka & Mechora, 2022). Their integrity and stability during the formulation process are affected by factors like pH, temperature, and shear forces (Nuruzzaman, 2019). In Agricultural environments, conditions are often harsh, with exposure to sunlight, moisture, temperature fluctuations and microbial activities, which can degrade the active ingredients in plant-based formulations (Nuruzzaman, 2019; Tudi *et al.*, 2021). Developing effective preservation strategies and ensuring long-term viability of biopesticide is crucial for their practical application, as active compounds can be susceptible to degradation during storage and transportation (Kyriakoudi *et al.*, 2021; Khan *et al.*, 2023). Therefore, assessing the effective is crucial for ensuring the quality result of biopesticides use in smallholder farmers' scenarios.

2.7 Cost-benefit analysis of biopesticides

Biopesticides benefits to human in the ecosystem and other living organisms, are overly realized by smallholder farmers in developing countries and elsewhere (Kumar *et al.*, 2021). To facilitate the acceptance and broader use of biopesticides among smallholder farmers, it has been noted that understanding a cost-benefit analysis is essential (Mkindi, 2021). A cost-benefit analysis is a systematic process that businesses use to analyze or compares expected costs and benefits, it determines whether a project decision is viable from a business standpoint view (Kee, 2007; Thomas & Chindarkar, 2019; Mkindi, 2021). It is reported the cost of plant protection using attack (synthetic pesticides) was higher than any of the botanicals and the highest cost: Benefit ratio of 1: 2.23 was observed for plots sprayed with extract of neem leaf @ 10% as compared to untreated control (1: 1.14) (Sheshma *et al.*, 2022). Then was followed by arjun leaf @ 10% (1: 2.13), alovera leaf @ 10 (1: 2.08), aswagandha leaf @ 10% (1: 1.85), datura leaf @ 10% (1: 1.80) and garlic clove @ 10% (1: 1.51) (Sheshma *et al.*, 2022). This implied that botanicals were beneficial compared to using of synthetic fungicides in controlling *Cercospora canescens* of *Vigna radiata* L.

The cost-benefit analysis of biopesticides versus synthetic pesticides considers factors like production costs and product prices, enabling the optimal choice for agricultural settings (Laing, 2023). Financial values for inputs and outputs are frequently used in cost-benefit analyses of new technologies, with advantages derived from computed differences (Thomas & Chindarkar, 2019; Laing, 2023). There three apparently straightforward steps make up the cost-benefit analysis: (a) Ascertain the advantages of a suggested or current program and assign a monetary value to those advantages; (b) Compute the program's overall expenses; and (c) Contrast the advantages and the expenses (Kee, 2007).

In conclusion, formulations of biopesticides maximize efficacy by taking into account the active component, carrier materials, and delivery systems. A cost-benefit analysis is essential for widespread adoption. By carefully weighing the costs and benefits, growers and policymakers can make informed decisions about the adoption and integration of biopesticides into their agricultural practices, contributing to a more sustainable and environmentally-friendly food production system.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

Laboratory, screen house and field experiments were conducted from June to December 2023, with the aim to evaluate the effectiveness of pesticidal plant-based and non-plant-based materials in managing tomato pests and diseases. Plant extract and animal excretes materials were locally collected from smallholder farmers' vicinity (Table 1). Pure culture of *Alternaria solani* isolates (NM-AIST- 0025) used in this experiment was obtained from NM-AIST Tengeru campus and it was maintained on the susceptible ‘Tanya’ tomato variety.

Table 1: List of materials used and their sources

Name of the material	Part collected/ formulation	Source of the material
Garlic (<i>Allium sativum</i>)	Bulbs	Mang’ola- Karatu
Hot pepper (<i>Capsicum frutescens</i>)	Leaves	Tengeru- Arusha
Lantana (<i>Lantana camara</i>)	Leaves	Kiseriani- Arusha
Neem (<i>Azadirachta indica</i>)	Leaves	Moshono-Arusha
Papaya (<i>Carica papaya</i>)	Leaves	Tengeru –Arusha
Fresh lemon grass (<i>Cymbopogon citratus</i>)	Leaves	Moshono –Arusha
Ginger (<i>Zingiber officinale</i>)	Rhizome	Kilombelo market -Arusha
Jeevamrutham	Water, cow dung, cow urine, jaggery, flour of common beans	-Cow dung & cow urine- Kiseriani-Arusha -Jaggery & Flour of common beans-Kilombelo market - Arusha
Animal excretes	(<i>Phaseolus vulgaris</i>) and fertile soil	-Fertile soil –NM-AIST
Positive control (Ridomil gold (Metalaxy-M 40g/Kg & Mancozeb 640 g/kg) and Radiant 120 SC (Spinotoram)	Rabbit urine Powder form Liquid	-Rhotia-Karatu Syngenta Corteva Agriscience

3.2 Site location and descriptions

The laboratory study was conducted at NM-AIST laboratory, located at latitude 3.401420 S, longitude 36.795820 E and altitude of 1199 m a.s.l. The average temperature for this location ranges between 15 - 32⁰C while rainfall is 1180 mm to 1475 mm per annum. The field and screen-house experiments were conducted at Mailisita located at 3.3717014 S, 37.28944444 E and at altitude 970 m a.s.l, Hai district, Kilimanjaro. Another field experiment was conducted

at Kilala- Arumeru district, Arusha located at 3.366667 S, 36.85 E. Mailisita and Kilala sites' temperature and rainfall averages ranged 17 - 29⁰C and 15 - 25⁰C while, rainfall was 500 - 1800 mm and 500 mm - 1200 mm, respectively. Both sites were chosen for their suitability for tomato cultivation, where leaf miner and early blight disease were prevalently challenge to smallholder farmers.

3.3 To determine the inhibitory effects of biopesticides on *Alternaria solani* in invitro conditions

3.3.1 Experimental preparation, design and layout for laboratory experiment

The laboratory experiment was laid in a factorial complete randomised design with 34 treatment combinations (7 Plant extracts, 2 bio product, 2 solvents and 2 levels of concentrations), including negative (Media inoculated pathogen) and positive (ridomil gold) controls, replicated thrice with three observations each. The following below describes how each biopesticides, jeevamrutham, animal excretion and media were prepared.

(i) Plant extracts preparation

Plant materials were locally collected (Table 1) and thoroughly washed with running tap water. They were air dried in the screen house for four (4) days, followed by grinding into a powder using pestle and mortar. The plant pounded materials were dissolved in ethanol (99.9%) and water as extracting solvents using a ratio of 1:10 (w/v) (10 g plant powder: 100 ml solvent), placed on the shaker for 12 h then filtrated by two layers of cheesecloth before passing into Whitman's No. 2 filter paper to obtain infranatant (concentrated solution) as far as water used as solvent (Al-Samarrai *et al.*, 2012; Tadele & Eman, 2017; Abubakar & Haque, 2020). For ethanol, the filtrates were placed at the rotary evaporator at 60⁰C for 60 min to remove ethanol and remained with concentrated solution (Al-Samarrai *et al.*, 2012). The concentrated stock of 50 ml per each mixture was diluted to make 5% and 10% concentrations using autoclaved distilled water and kept in the refrigerator at 4⁰C until used.

(ii) Jeevamrutham preparation

Jeevamrutham was prepared according to Ashmeet (2020), Cow dung (1 kg), cow urine (1 L), jaggery (200 g), common bean flour (200 g), and fertile soil (100 g) were all combined in the bucket (20 L). For nine (9) days in the shade, the bucket was being stirred vigorously three times daily for 10 to 15 minutes with a wooden stick, and it was covered with a junk sack to

ensure aeration. Water was added to the mixture to bring the volume up to 20 L after 9 days and the solution was sterilized with 0.2 μ disposable syringe filters that was used in the laboratory experiment with 5% and 10% concentrations.

(iii) Animal excrete preparation

One (1) litre of rabbit urine was collected and diluted to formulate 5% and 10% concentrations followed by sterilization with 0.2 μ disposable syringe filters.

(iv) Media preparation, culturing and inoculation

Preparation of full-strength potato dextrose agar (PDA) (39 g/l) was done by autoclaving the media at 121°C for 15 minutes in 1l bottle and allowed to cool to 40°C before pouring into 90 mm petri-dishes, which were then allowed to solidify. *Alternaria solani* isolates was cultured on the PDA from highly susceptible tomato variety (Tanya). Multiplication of *A. solani* isolates by sub culturing on full strength PDA to obtain a sufficient inoculum for inoculating 306 petri-dishes was done in plant pathology laboratory (Table 2). Each plant extract was added in the media petri dishes by ratio of 1:4 v/v (5 ml biopesticides: 20 ml media), shook for 10 minutes before solidification. Inoculation of *A. solani* was done using mycelium agar plug (MAPs, 5 mm in diameter) from a full-grown petri dish (Wonglom *et al.*, 2019). All the petri dishes were incubated at room temperature of 24 to 25°C.

Table 2: Treatments combination used in the laboratory experiment

Total combination treatments (34)	7 plant extracts (<i>A. sativum</i> , <i>C. frutescens</i> , <i>L. camara</i> , <i>A. indica</i> , <i>C. papaya</i> , <i>C.citratus</i> and <i>C.officinale</i>) x 2 concentrations (5% and 10 %) x 2 solvents (water & ethanol) + 2 bio products (jeevamrutham & rabbit urine) x 2 concentrations (5% and 10%) x 1 solvent (water) + 1 positive control + 1 negative control.
Total combination treatments (34) with 3 replications and 3 observation per replication.	34 total treatments combination x 3 replications x 3 observations =306

3.3.2 Data collection

Data was collected by measuring the size of radial colony growth (mm) starting from day one after inoculation for seven consecutive days and the mycelial growth inhibition for each treatment was calculated using the Equation 1 by Wonglom *et al.* (2019).

$\text{Mycelial growth inhibition (\%)} = \frac{\text{Growth in control} - \text{Growth in treatment}}{\text{Growth in control}} \times 100$	Equation 1
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The obtained data from mycelial growth inhibition rate (%) were visualized for normality before performing the analysis of variance. Effective treatments were identified through mean separation using the Bonferroni multiple comparison test.

3.4 To assess the effect of biopesticides on tomato leaf miner populations and leaf damage

3.4.1 Experimental design for screen house experiment

The screen house experiment was conducted to investigate the efficacy of biopesticides in controlling leaf miner (*Tuta absoluta*) using a factorial complete randomized design. The experiment used 34 treatment combinations together with negative (water) and positive controls (Radiant 120 SC- Spinotoram), replicated six times (Table 3).

Table 3: Treatments combination used in the screen house experiment

Total combination treatments (34)	7 plant extracts (<i>A. sativum</i> , <i>C. frutescens</i> , <i>L. camara</i> , <i>A. indica</i> , <i>C. papaya</i> , <i>C. citratus</i> , <i>C. officinale</i>) x 2 concentrations (5% & 10%) x 2 solvents (Water & ethanol) + 2 bio products (Jeevamrutham & rabbit urine) x 2 concentrations (5% & 10%) x 1 solvent (water) + 1 positive control + 1 negative control
Total combination treatments (34) with 6 replications	34 total treatments combination x 6 replication =204

The preparations of plant extract and animal excrete were as in Section 3.3.1 above. Tanya tomato variety was raised in the nursery for three weeks then transplanted into the plastic pot using 2 kg sterilized forest compost soil. The soil was sterilized to remove other organisms that could interrupt the experimentation. Then 10 larvae (larvae stage was considered to be the most damaging stage of the pest) of a leaf miner were introduced one week after transplanting (Lopez-Vaamonde *et al.*, 2021; Magwe *et al.*, 2023). Then the pots were covered by fine-meshed netting of 0.4 mm size cage to prevent leaf miners from moving out from the pots and other insects from getting into the pots. The leaf miners were left to adopt to the environment for 1 day before start spraying and evaluation. The spraying of 30 ml of each biopesticide was done using the same concentrations as above in Section 3.3.1 was done. The same sprays were repeated three times at an interval of 5 days. Irrigation was done regularly using tap water.

3.4.2 Data Collection

Data collection was done by counting leaf miner, one day after each spray resulting in three data collections. Tomato leaf damage was assessed and ranked as “mines” or “punctures” using the damage index established by Lopez *et al.* (2020). The percentage of the leaf area damaged was classified as follows: Very low (0-20%), low (20-40%), moderate (40-60%), high (60-80%) and severe (80-100 %) (Lopez *et al.*, 2020). Data was subjected to analysis of variance, then a mean separation test was done by using the Bonferroni multiple comparison test to identify effective treatments.

3.5 To evaluate the effect of biopesticides to control early blight, leaf miners, tomato growth and fruits yield

3.5.1 Experimental design for a field experiment

Field experimental areas at Mailisita and Kilala, the area of 84 m² per site was cleared and ploughed using a hand hoe for setting field experiment using randomized complete block design with three replications. The size of each block was 12 m², with each having 6 plots of 2 m². Nursery was prepared and Tanya tomato variety used. Tomato seedlings were transplanted to the experimental plots after 1 month where each plot had 13 tomato seedlings at a spacing of 50 cm x 30 cm. Field management was done according to smallholder farmers' practices to reflect field conditions. The four best treatment combinations from the laboratory and screen house experiments (5% hot pepper, 10% hot pepper, 10% lantana, and 10% ginger) were used, with negative and positive controls. Each treatment was applied 8 times in each block, on a weekly basis starting from one week after transplanting. Temperature and precipitation were recorded throughout the experiment (Table 4).

Table 4: Temperature and rainfall distribution during the field experimental period

Months, 2024	Temperature (°C)						Average rainfall (mm/ month)	
	Kilala			Mailisita			Kilala	Mailisita
	Min	Max	Mean	Min	Max	Mean		
September	17.7	29.2	23.5	18.9	27.9	23.4	4.2	25.3
October	18.6	30.6	24.6	18.8	27.9	23.4	9.4	85.3
November	19.1	26.7	22.9	18.3	26.6	22.5	181.9	158.0
December	19.2	29.3	24.3	18.7	29.0	23.9	270.0	216.1
Mean	18.7	29.0	23.8	18.7	27.9	23.3	116.4	121.2

3.5.2 Data Collection

Data collection was done at the fruiting stage (7 to 10 weeks after tomato transplanting) on early blight disease severity as described by Weber and Halterman (2012). Infected leaves were classified into five categories (0, 1, 2, 3 and 4) according to blighted area of leaves, where 0 = no infected leaves, 1 = $\geq 25\%$ or less, 2 = 26-50%, 3 = 51-75% and 4= 76-100% (Weber & Halterman, 2012). Tomato leaf damage was assessed and ranked as “mines” or “punctures” using the damage index established by Lopez *et al.* (2020) The percentage of the leaf area damaged was categorized as follows very low (0-20%), low (20-40%), moderate (40-60%), high (60-80%) and severe (80-100 %).

(i) Disease incidence

Disease incidence (%) in tomato plants involved counting of tomato plants to quantify the proportion of plants affected by early blight disease within a population (Madden & Hughes, 1995).

$$\begin{aligned} \text{Disease incidence (\%)} \\ = (\text{Number of plants affected} / \text{Total number of plants observed}) \times 100 \end{aligned}$$

Equation 1

(ii) Disease Severity Index (DSI)

Disease severity index (%) was used to determine the severity of disease in tomato plants. The formula for calculating the Disease Severity Index (DSI) for tomato plants was:

$$\text{DSI (\%)} = \sum \left(\frac{n \times v}{N \times Z} \right) \times 100 \quad \text{Equation 2}$$

Where:

n = number of tomato leaves in each disease severity category

v = numerical value (score) of the disease severity category

N = total number of tomato leaves observed

Z = maximum disease severity score

(iii) Tomato growth and performance

Data on tomato growth and performance were collected by measuring plant height, counting number of tomato fruits per plant and tomato fruit weight per plant as described by Balemi,

(2008). This was done once by randomly selecting five plants in each plot for every treatment at the harvesting stage.

3.6 To perform cost-benefit analysis of using biopesticides for controlling early blight and leaf miners in tomato

3.6.1 Experimental design for cost-benefit analysis

A cost-benefit evaluation was conducted to compare conventional and biopesticides-based tomato production at Mailisita and Kilala. A structured questionnaire (Appendix 1) was administered to 20 randomly selected smallholder farmers from each site to obtain data of tomato production, following Mkindi (2021).

The selection of 20 smallholder farmers was based on the total average number 200 and 250 smallholder farmers from Mailisita and Kilala villages, respectively. The respondents in both sites were selected at random from pre-selected tomato farmers with a history of tomato growing in these areas for at least three (3) years. Second part was the cost benefit analysis involved the two experimental sites of Mailisita and Kilala, where the use of biopesticide was done. The activities and cost attached to each site and on each biopesticide were evaluated as described by Sheshma *et al.* (2022).

3.6.2 Data collection

The cost data included procurement of botanical materials and animal excrete, processing costs, and overall tomato production costs for both conventional and experimental setups. These costs are presented as averages per hectare (Tables 5 and 6), adapted from Sheshma *et al.* (2022) and Malinga and Laing (2023).

Table 5: Assessing costs based on conventional tomato production

S/N	Items description	Units	Quantity	Market Price/unit	Total cost (USD)/ha
1	Purchasing of fungicide				
2	Purchasing of insecticide				
3	Transport cost				
4	Spraying cost				
5	Cost of protective gears				
6	Common cost (Land preparation, weeding and fertilizer application)				
7	Total cost of production/ha				
8	Total yield / ha				
9	Total revenue				

Table 6: Assessing costs based on biopesticides tomato production

S/N	Item description	Hot pepper 10% (USD/ha)	Hot pepper 5% (USD/ha)	Lantana 10% (USD/ha)	Ginger 10% (USD/ha)	Rabbit urine (USD/ha)	+ve control (USD/ha)	-ve control (USD/ha)
1	Cost of collecting / purchasing botanical plants /animal excretes							
2	Transportation							
3	Plant extracts preparation							
4	Cost of protective gears							
5	Plant extracts spray							
6	Times of application							
7	Common costs							
8	Total cost of production/ha							
9	Total yield / ha							
10	Total revenue							

(i) Net benefit

Total income, which was calculated by multiplying the total yield per hectare by the current market price per kilogram (kg) used to calculate the total income (Sheshma *et al.*, 2022; Malinga & Laing, 2023). The net benefit was calculated using Equation 4.

$\text{Net benefit} = \text{Total income} - \text{Total cost of production}$	Equation 4
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(ii) Treatment advantage

Treatment advantage used to indicate the benefit of using treatment over the negative control. It was calculated by using the formula below as described by Sheshma *et al.* (2022).

$\text{Treatment advantage} = \text{Treatment income} - \text{Negative Control income}$	Equation 5
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(iii) Cost-Benefit Ratio

Cost - benefit ratio was calculated using equation 6 (Sheshma *et al.*, 2022)

$\text{C: B ratio} = \frac{\text{Additional income from production (net benefit)}}{\text{Cost of production}}$	Equation 6
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3.7 Data analysis

All collected data were subjected to analysis of variance (ANOVA), Bonferroni multiple comparison tests were applied to separate treatment means. Statistical analysis was conducted using GenStat 21st Edition (64-bit) by Visual Statistics and Information (VSNi), Heslington, UK.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

Results from laboratory, screen house, and field experiments showed variable responses among different treatment types and levels. This variability indicating that their effectiveness depends on specific conditions unique to each experimental setting. The upcoming sections outline the results and discussions for each research objective, showing how various treatments performed under different circumstances. The output of analysis from each objective included comparisons of biopesticides effectiveness, observed trends, and insights into the implications for future research and practical applications. Each objective is systematically addressed to provide a comprehensive understanding of the outcomes.

4.2 To determine the inhibitory effects of biopesticides on *Alternaria solani* in in vitro conditions

4.2.1 Effects of biopesticides on in vitro *Alternaria solani* mycelial growth

Analysis of variance and mean separation test on in vitro *A. solani* mycelia growth indicated significant ($P < .001$) differences among all tested biopesticides ranging from 0 to 100% reduction in mycelia growth. The inhibition rate was higher for ridomil gold (100%), followed by 10% hot pepper (98.26%) and 5% hot peppers (97.44%), which were not significant ($p > .05$) different from the positive control (ridomil gold) (Table 7). The higher concentration of biopesticides had a strong inhibition of growth *A. solani*. The 5% concentration had 54.29% and 10% concentrations had 68.42% as averages of inhibiting mycelia growth (Fig. 1).

Table 7: Effect of biopesticides, concentration and solvent on inhibition (%) of mycelia radial growth of *A. solani*

Treatments		Inhibition of <i>A. solani</i> mycelia radial growth (%)						
		Solvent/ Concentration						
		Ethanol			Water			Grand Mean
5%	10%	Mean	5%	10%	Mean			
Plant extracts	Lantana	29.81de	58.01c	43.91c	83.71c	90.30bc	87.01c	65.46cd
	Hot pepper	46.78c	73.67b	60.23b	97.44a	98.26a	97.85a	79.04b
	Papaya	24.50ef	50.23d	37.37cd	74.16d	83.90c	79.03d	58.20de
	Ginger	35.59d	57.88c	46.74c	88.83b	91.56b	90.20b	68.47bcd
	Fresh lemon grass	23.30f	35.66e	29.48d	65.29e	68.05d	66.67e	48.08e
	Garlic	45.00c	75.81b	60.41b	59.71f	61.25e	60.48f	60.44de
	Neem	56.03b	71.19b	63.61b	83.40c	84.32c	83.86cd	73.74bc
Bio products	Jeevamrutham	NA	NA	NA	68.33e	69.88d	69.11e	69.11bcd
	Rabbit urine	NA	NA	NA	20.74g	40.76f	30.75g	30.8f
Mean of biopesticides		37.29	60.35	46.36	71.29	76.48	73.88	61.48
Positive control	Ridomil gold	100.00a	100.00a	100.00a	100.00a	100.00a	100.00a	100.00a
Negative control	No extract	0.00g	0.00f	0.00e	0.0h	0.00g	0.00h	0.00g
LSD		3.80	3.40	7.61	3.02	3.90	3.33	8.48
SED		1.91	1.72	3.85	1.52	2.00	1.69	4.31
CV (%)		10.10	6.30	23.60	4.80	6.50	7.70	29.00
P-Value		<.001	<.001	<.001	<.001	<.001	<.001	<.001

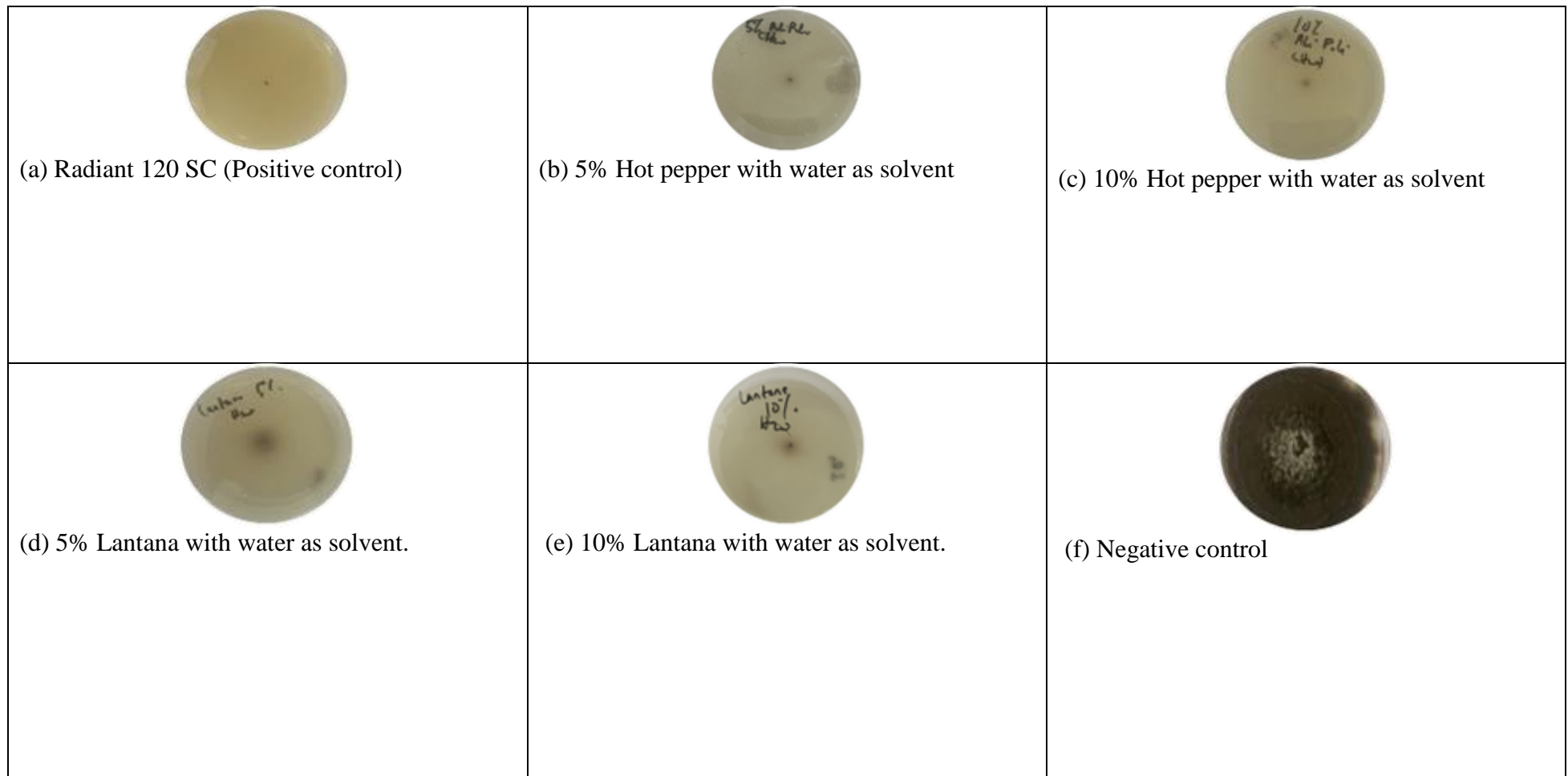


Plate 1: Plates showing effectiveness of biopesticides to inhibit mycelial growth of *A. solani*

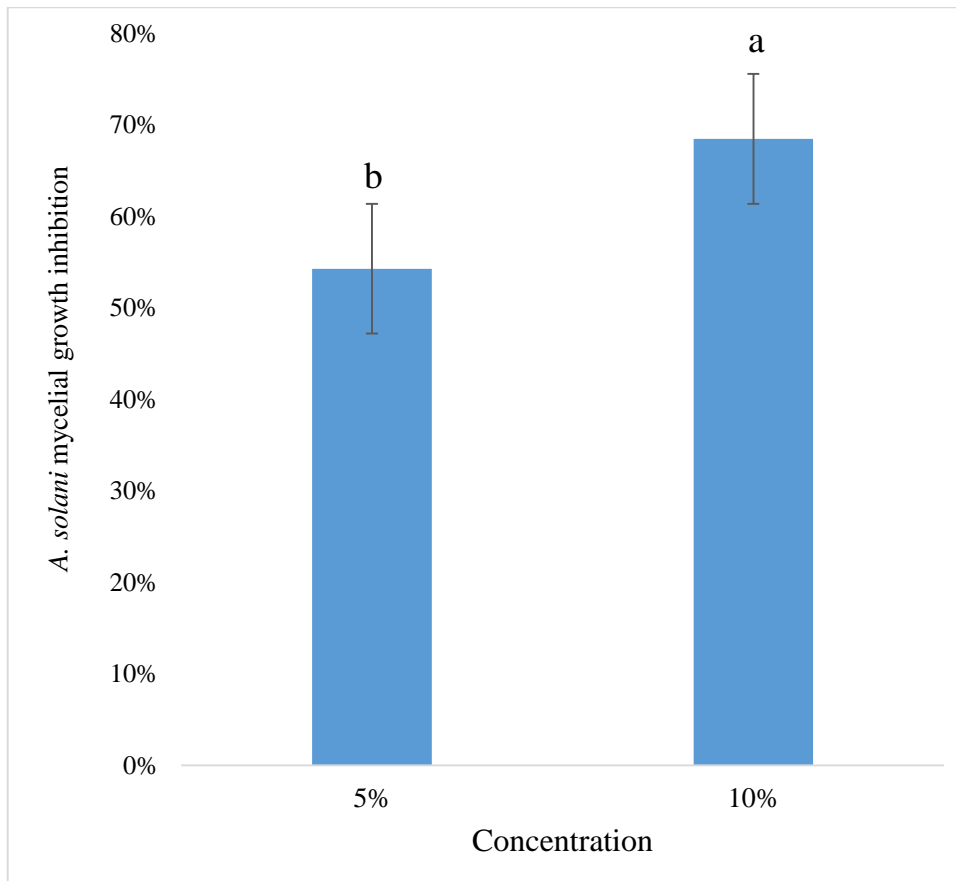


Figure 1: Effect of concentration of biopesticides on mycelial growth inhibition of *A. solani*

4.2.2 Influence of solvent on efficacy of biopesticides for mycelial inhibition growth

Across all tested biopesticides, water was found to be the best solvent, with a higher efficacy and effectiveness in inhibiting radial mycelial growth (73.88%) than ethanol (46.36%) (Fig. 2).

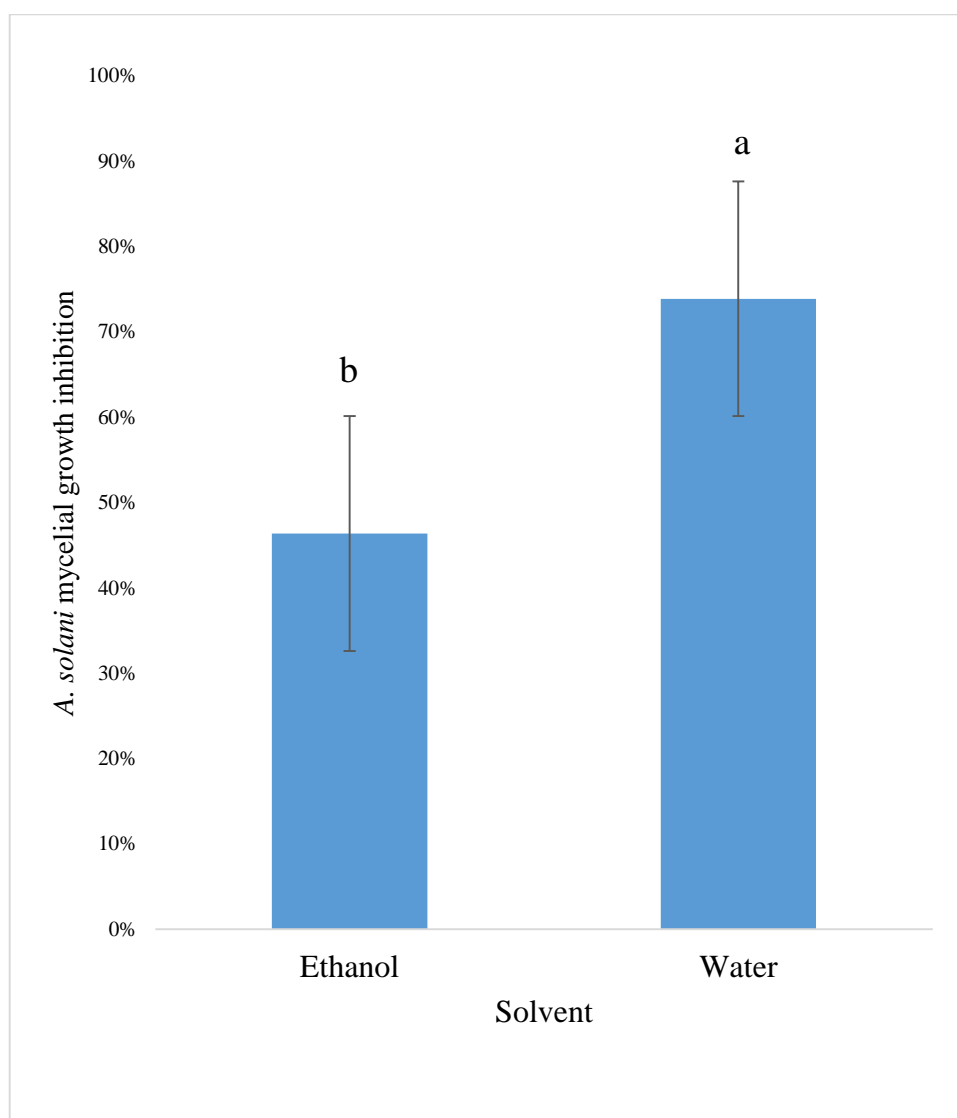


Figure 2: Influence of solvent on efficacy of biopesticides for *A. solani* mycelial growth inhibition

4.3 To assess the effect of biopesticides on tomato leaf miner populations and leaf damage

4.3.1 Influence of biopesticides on tomato leaf miner population in the screen house experiment

The best biopesticide treatment which reduced leaf miners in spray 1 was 10% hot pepper (38.33%), followed by 10% Lantana (36.67%) and 5% hot pepper (34.00%). For spray 2 and 3, 10% lantana highly reduced leaf miners by 26.67% and 16.67%, respectively. In general, biopesticides significantly reduced the number of leaf miners compared with the negative control. The result of cumulative leaf miners reduction was outstanding on water formulated biopesticides, which included 10% lantana (80%), 10% hot pepper (76.67%) and ginger

(71.67%) had good performance (Table 8). Followed by 5% hot pepper (64.00%) and 5% ginger (63.33%) leaf miner population decrease.

All the treatment differed significantly ($p < .05$) with the positive control (96.67%) which was the highest and most effective whereas the negative control marked 0.00% leaf miner decrease. These result implied that water formulated biopesticides were the best and effective compared to ethanol based biopesticides. The effect with all the biopesticides indicated to be concentration dependent with 10% being most effective than 5% concentrations. Comparing the biopesticides effect with the negative control shows that all the biopesticides had pesticidal effect.

Table 8: Effect of biopesticides extracted in ethanol and water on tomato leaf miner reduction across three sprays and cumulative impact in screen house condition

Extracts	Solvent/concentrations															
	Ethanol								Water							
	Leaf miner reduction (%) /Spray 1		Leaf miner reduction (%) /Spray 2		Leaf miner reduction (%) /Spray 3		%Cumulative leaf miner reduction		Leaf miner reduction (%) /Spray 1		Leaf miner reduction (%) /Spray 2		Leaf miner reduction (%) /Spray 3		%cumulative leaf miner reduction	
	5%	10%	5%	10%	5%	10%	5%	10%	5%	10%	5%	10%	5%	10%	5%	10%
Lantana	21.67c	18.33b	11.67b	16.67b	11.67b	15.00cd	45.00b	50.00bcd	26.67d	36.67d	23.33def	26.67ef	10.00b	16.67c	60.00d	80.00ef
Hot pepper	20.00bc	20.00b	15.71b	18.33b	11.43b	18.33d	47.14b	56.67cd	34.00d	38.33d	20.00cdef	21.67cdef	10.00b	16.67c	64.00d	76.67def
Ginger	16.67bc	25.00b	11.67b	16.67b	11.67b	16.67cd	40.00b	58.33cd	28.33d	33.33d	25.00ef	25.00def	10.00b	13.33bc	63.33d	71.67de
Fresh lemon grass	16.67bc	16.67b	13.33b	13.33b	10.00b	10.00bc	40.00b	40.00bc	11.67b	13.33ab	15.00bcde	13.33bc	11.67b	10.00bc	38.33bc	36.67b
Garlic	15.00bc	16.67b	10.00b	10.00b	10.00b	11.67 bcd	35.00b	38.33b	15.00bc	16.67bc	13.33bcd	13.33bc	10.00b	10.00bc	38.33bc	40.00bc
Neem	16.67bc	17.14b	15.00b	14.29b	11.67b	15.71cd	43.33b	47.14bcd	23.33cd	30.00cd	16.67cde	16.00bcde	10.00b	12.00bc	51.67cd	58.00cd
Papaya	10.00ab	15.00b	11.67b	10.00b	11.67b	10.00bc	33.33b	35.00b	13.33bc	16.67bc	18.33cde	15.00bcd	11.67b	11.67bc	41.67c	43.33bc
Jeevamrutham	NA	NA	NA	NA	NA	NA	NA	NA	13.33bc	11.67 ab	10.00abc	16.67bcde	11.67b	10.00bc	35.00bc	38.33b
Rabbit urine	NA	NA	NA	NA	NA	NA	NA	NA	6.67ab	10.00ab	5.00ab	6.67ab	10.00b	10.00bc	21.67b	26.67b
Mean of biopesticides	16.67	18.40	12.72	14.18	11.16	13.91	40.54	46.50	19.15	22.96	16.30	17.15	10.56	12.26	46.00	52.37
Radiant 120 SC	60.00d	60.00c	30.00c	30.00c	6.67ab	6.67 ab	96.67c	96.67e	60.00e	60.00e	30.00f	30.00f	6.67ab	6.67 ab	96.67e	96.67f
Negative control	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a
LSD	6.44	7.59	4.51	5.52	4.00	4.67	8.74	10.65	6.56	9.04	6.62	6.30	3.89	4.24	10.01	10.70
SED	3.20	3.77	2.24	2.74	1.99	2.32	4.34	5.29	3.27	4.51	3.30	3.14	1.94	2.12	4.99	5.34
CV (%)	28.40	31.50	29.50	33.30	11.67	34.80	17.90	19.70	26.80	32.00	35.40	32.20	36.70	34.70	18.60	17.80
P-value	<0.001	<0.001	<0.001	<0.001	<0.014	<.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.015	<0.001	<0.001	<0.001

Treatments with the same letter are not significantly different ($p > 0.05$).

4.3.2 Evaluation of the influence of biopesticides on tomato leaf damage caused by leaf miners in the screen house experiment

The result on evaluation of tomato plants larvae damage were analyzed and indicated that, there significant damage on a negative control due to leaf miner tunneling, blotching and discoloration as compared to all other treatments. The biopesticides with water formulated indicated least tomato leaf damage were recorded on 10% lantana (7.83%), 10% ginger (11%), 10% hot pepper (13.53%), 10% neem (16%) (Table 9). According to the scale by Lopez *et al.* (2020), these treatments represented the very low damage which are acceptable by tomato growers. The rest of the treatments had their damage above 20% to 80.70% which is marked by moderate to severe damages (Lopez *et al.*, 2020). However, there was no significant different ($P>.05$) between the 10% lantana (7.83%), 10% ginger (11%), 10% hot pepper (13.53%), 10% neem (16%) biopesticides and positive control radiant (1.67%). 10% concentration recorded lower tomato leaf damage (38.76%) as compared to 5% concentration which had 41.75%. The best four treatments from the laboratory and screen house experiments namely 10% hot pepper, 5% hot pepper, 10% ginger, 10% lantana were used in the field experiment.

Table 9: Evaluation of the influence of biopesticides on tomato leaf damage (%) caused by leaf miners

Extracts	Tomato leaf miner damage (%)			
	Ethanol		Water	
	5%	10%	5%	10%
Lantana	46.20b	50.41c	24.54b	7.83a
Hot pepper	43.89b	27.70b	23.78b	13.53a
Ginger	42.61b	41.67bc	25.37b	11.00a
Fresh lemon grass	45.00b	55.15c	50.30cd	51.06bc
Garlic	50.39b	38.70bc	44.44cd	56.83bc
Neem	32.24b	38.75bc	37.63bc	16.00a
Papaya	40.09b	42.41bc	43.37bcd	42.39b
Jeevamrutham			55.50cd	63.17cd
Rabbit urine			60.17d	54.20bc
Mean of Biopesticides	42.92	42.11	40.57	35.11
Radiant 120 SC	1.67a	1.67a	1.67a	1.67a
Negative control	80.76c	80.76d	80.76e	80.76d
LSD	12.29	10.42	10.86	10.24
CV (%)	25.1	21.6	22.0	24.0
SED	6.61	5.17	5.42	5.11
P-value	>.001	>.001	<.001	<.001

Treatments with the same letter are not significantly different ($p > 0.05$).

4.4 To evaluate the effect of biopesticides to control early blight, leaf miners and their impact on tomato growth and fruits yield in two field sites

Analysis of variance and mean separation tests were used to compare the effects of different biopesticide treatments. The results on early blight disease and tomato leaf miner damage at the two sites (Mailisita and Kilala) are presented in Tables 10, 11 and 12.

4.4.1 Effect of biopesticides on early blight disease incidence and severity

(i) Early blight disease incidence

Among two sites, disease incidence was higher in Kilala (84.4%) compared to Mailisita (77.8%) in the negative control. However, the use of biopesticides significantly ($p < 0.05$) reduced the disease incidence in both the sites. In Kilala, the most effective treatments, 10% ginger (37.8 %), 5% hot pepper (33.3%) and 10% hot peppers (26.7%) were not significantly different ($p > 0.05$) from the positive control (24.4%) (ridomil gold). The results in Mailisita indicated that, 5% hot pepper (31.1%), 10% hot pepper (28.9%), 10% lantana (31.1%) were more effective in reducing disease incidence but differed significantly ($p < 0.05$) with the positive control (ridomil gold) (Table 10).

(ii) Early blight disease severity

Analysis of variance on early blight disease severity data from Kilala showed that there were no significant differences among 10% ginger (39.8%), 5% hot pepper (40.9%), 10% hot pepper (40.0%) and positive control (ridomil gold) (32.3%). Disease severity in Mailisita showed that, the positive control (27.2%) differed slightly with 10% hot pepper (31.1%) but differed significantly ($P < 0.001$) from the negative control (79.3%) and rest of the treatments (10% lantana (42.2%), 10% ginger (39.6%), 5% hot pepper (39.5%). Comparing the effectiveness of the treatments from two sites, indicated that biopesticides were more effective in Kilala than Mailisita with three treatment (10% ginger, 5% hot pepper and 10% hot pepper) performed better as positive control whereas in Mailisita only one biopesticides (10% hot pepper) performed relatively better as the positive control (Table 10). This might be due to high rainfall (121.2 mm) at Mailisita experienced during the experimentation.

Table 10: Effect of selected biopesticides on tomato early blight disease incidence and severity at two field sites (Kilala and Mailisita)

Treatments	Disease incidence (%)		Disease severity (%)	
	Kilala	Mailisita	Kilala	Mailisita
Rabbit urine (10%)	62.2ab	55.6b	60.7b	47.0b
Lantana (10%)	46.7bc	31.1c	46.7bc	42.2bc
Hot pepper (5%)	33.3c	31.1c	40.9c	39.5bc
Hot pepper (10%)	26.7c	28.9c	40.0c	31.1cd
Ginger (10%)	37.8c	37.8bc	39.8c	39.6bc
Mean of biopesticides	41.34	36.90	47.08	47.08
Positive control (Ridomil gold)	24.4c	22.2c	32.3c	27.2d
Negative control	84.4a	77.8a	83.7a	79.3a
L.S.D	15.1	7.18	9.06	9.06
SED	7.53	7.18	4.52	3.76
CV (%)	35.4	37.5	19.5	3.76
P-value	<.001	<.001	<.001	<.001

Treatments with the same letter are not significantly different ($p > 0.05$).

4.4.2 Effect of biopesticides on tomato leaf damage caused by leaf miners.

Field assessment of biopesticides for reducing tomato leaf damage caused by leaf miner (*Tuta absoluta*) revealed that all biopesticides tested at Kilala were significantly more effective than the negative control. However, their efficacy was still lower than that of positive control (Radiant 120 SC), which exhibited only 4.4% damage compared to 10% ginger (32.8%), 10% lantana (32.8%), 10% hot pepper (29.8%), 5% and hot pepper (29.1%) (Table 11). For the Mailisita site, 10% ginger (24.4%) and 5% hot pepper (28.3%) were also effective at controlling the insect but significantly lesser than the positive control (10.0%). The rest of the treatments were all significantly ($P < 0.05$) better at controlling the insect than the negative control which had a higher leaf damage of 72.2%. The pest pressure was almost similar in Kilala (76.8%) and Mailisita (72.2%) in negative control.

Table 11: Effect of biopesticides on tomato leaf damage caused by leaf miners in two locations

Treatments	Tomato leaf damage %	
	Kilala	Mailisita
Rabbit urine 10%	38.9b	33.9b
Lantana 10%	32.8b	35.1b
Hot pepper 5%	29.1b	28.3bc
Hot pepper 10%	29.8b	33.1b
Ginger 10%	32.8b	24.4bc
Mean of biopesticides	32.68	30.96
Negative control	76.8a	72.2a
Positive control (Radiant 120 SC)	4.4c	10.0c
SED	4.45	5.18
CV (%)	27.1	32.4
L SD	8.91	10.39
P-Value	<.001	<.001

Treatments with the same letter are not significantly different ($p > 0.05$)

4.4.3 Influence of biopesticides on tomato Growth and fruit yield

The effect of different treatments on plant height, number and weight of tomato fruits per plant on both sites were significantly greater than the negative control ($p < 0.05$). The plant height was relatively higher in Mailisita (123.3 cm) compared to Kilala (114.3 cm) (Table 12). At Kilala, number of fruits per plant was higher in 10% hot pepper (11.33), followed by 10% Lantana (9.44) whereby the negative control was the least (1.5). For Mailisita, 10% Lantana had highest number of tomato fruits (16.56); followed by 5% hot pepper (14.44), 10% hot pepper (12.67). Tomato fruits weight was higher in positive control (1.22 kg) at Kilala and 10% hot pepper (2.29 kg) at Mailisita.

Table 12: Effect of different biopesticides on tomato plant height and fruit parameters in two locations

Treatments	Plant height (cm)		Number of fruits/plant		Fruit weight/plant (kg)	
	Kilala	Mailisita	Kilala	Mailisita	Kilala	Mailisita
Rabbit urine 10%	105.20b	112.60b	7.89b	10.44ab	0.81b	0.73ab
Lantana 10%	109.00b	120.40b	9.44b	16.56b	1.04bc	1.66bcd
Hot pepper 5%	110.00b	123.30b	11.33b	14.44ab	1.04bc	2.22d
Hot pepper 10%	111.60b	110.60b	8.89b	12.67ab	0.9bc	2.29d
Ginger 10%	114.30b	114.10b	8.22b	9.56ab	1.01bc	1.05abc
Mean of biopesticides	110.02	116.20	9.55	12.73	0.96	1.57
Negative control	70.40a	61.10a	1.56a	3.11a	0.09a	0.20a
Positive control (Ridomil gold & Radiant 120 SC)	122.70b	116.00b	10.56b	14.67b	1.22c	1.83cd
S ED	8.2	18.99	1.19	7.236	0.11	0.63
CV (%)	0.46	1.6	10.1	26.8	18.1	26
LSD	16.45	9.46	2.39	3.6	0.22	0.31
P-Value	<.001	<.001	<.001	<.001	<.001	<.001

Radiant 120 SC (Insecticide), Ridomil gold (Fungicide); Treatments with the same letter are not significantly different ($p > 0.05$).

4.4.4 General variation comparison of the two sites, Mailisita and Kilala

A general comparison of the two sites regarding the effect of sites (blocks) on the different measured parameters indicated that sites had no effect on plant height, disease severity, diseases incidence, and tomato weight and tomato damage (Table 13). Number of tomatoes per plant showed a significant variation between the two sites. Mailisita had higher number of tomatoes per plant compared to Kilala. Replication effect showed no significant different on plant height, number of tomatoes per plant, tomato weight and disease severity. The disease incidence and tomato leaf damage showed significant different between the sites.

Table 13: General variation comparison of the two sites, Mailisita and Kilala

Parameter Analyzed	Plant height	Number of Tomato/Plant	Tomato Weight	Disease Severity%	Disease Incidence %	Tomato to Leaf Damage %
Block (Villages)	0.634	< 0.006	> 0.05	0.113	0.307	0.803
Replications	> 0.05	> 0.05	> 0.05	> 0.05	0.001	0.043

4.5 Cost-benefit analysis of using biopesticides as means of controlling early blight and leaf miners

4.5.1 Treatment advantage

Analysis of variance on treatment advantage showed that, there were significant differences ($P < .05$) on revenue accrued between negative control and all treatments applied including the conventional tomato production method with synthetic pesticide. Among the test treatments 5% hot pepper (2818.48 USD) had the highest treatment advantage revenue followed by the positive control (2611.79 USD), 10% hot pepper (2585.31 USD), 10% lantana (2459.66 USD), conventional tomato production method (2458.53 USD), 10% ginger (2018.81 USD), 10% rabbit urine (1519.37 USD) and the negative control was the least (Table 14). The market price of organic tomato was 0.51 USD/ kg and inorganic tomato produced was 0.42 USD/kg. Analysis on total cost of production showed no significant difference ($P > .05$) treatments and, positive and negative control.

4.5.2 Cost-benefit ratio

Result on cost-benefit analysis indicated that, 5% hot pepper (1:3.5), positive control (1:3.3), 10% hot pepper (1:3.1), 10% lantana (1:3.0), conventional tillage practices (1:2.7), 10% ginger (1: 2.4), rabbit urine (1:2.0) had their cost benefit ratio greater than 1.0 whereas the negative control (1:-0.4) had its cost-benefit ratio below 1.0 (Table 14). The 5% hot pepper (1:3.5) treatment can be considered the most beneficial biopesticide used in this study even compared to the positive control and ridomil gold (*Alternaria solani*). Generally, all the biopesticides were an effective means of pest and disease management in the study.

Table 14: Assessing the influence of biopesticides on Tomato production cost

Treatments	Total cost of production (USD)	Total Revenue (USD)	Net Revenue (USD)	Treatment advantage (USD)	C: R
Rabbit urine 10%	674.74	1993.26b	1318.53ab	1519.37ab	1:2.0b
Ginger 10%	760.63	2577.60b	1816.97b	2017.81ab	1:2.4b
Lantana 10%	763.16	3021.98b	2258.82b	2459.66b	1:3.0b
Positive control	737.89	3148.84b	2410.95b	2611.79b	1:3.3b
Hot pepper 10%	767.37	3151.83b	2384.46b	2585.31b	1:3.1b
Hot pepper 5%	754.74	3372.38b	2617.64b	2818.48b	1:3.5b
Farmers	860.00	3157.89b	2297.89b	2458.53b	1:2.7b
Conventional tillage					
Negative control	468.42	267.58a	-200.84a	0.00a	1:- 0.4a
Mean		2548.32	1834.06	2032.22	1:2
LSD		1611.40	1611.40	1611.40	1:2.09
SED		626.87	626.87	626.87	1:0.81
CV (%)		21.03	29.31	26.37	28.9
P-Value		0.028	0.043	0.043	0.035

Treatments with the same letter are not significantly different ($p > 0.05$).

4.6 Discussion

Reduction in mycelial growth of *A.solani* due to plant extracts might be attributed by the chemical compounds they contain, such as phenolics and terpenes which have distinct modes of action (Abd-El-Khair & Haggag, 2007; Gotora *et al.* 2014, Mwelasi, 2015; Dua *et al.*, 2023). *Azadirachta indica* contains azadirachtin, nimbidin, salannin, azadiradione and beta-stosterol which exhibit potent antifungal properties (Iqba *et al.*, 2003; Anwar *et al.*, 2007). These compounds inhibit fungal growth through disruption of cell wall membranes, inhibition of cell wall synthesis, inhibit spore germination and interfere with metabolic pathway (Wedge *et al.*, 2002; Kumar *et al.*, 2006). Ginger contains gingerol, paradol, shogaols and zingerone that possess significant antifungal activity against *A. solani* (Khatun *et al.*, 2015; Alam *et al.*, 2016). These compounds act through various mechanism such as disrupting fungal cell walls, affecting cell membrane integrity and blocking fungal growth (Yoshinda *et al.*, 2011; Satyal *et al.*, 2013; Raut & Karuppayil, 2014). The most active compounds in hot pepper for controlling *A. Solani* include capsanthin and flavonoids like quercetin and rutin that disrupts the integrity of fungal cell membrane and inhibits the growth of fungus (Matsuoka *et al.*, 2003; Giriraju *et al.*, 2013; Koleva-Gudeva *et al.*, 2013). Lantana contains sequiterpenes and phenolic like quercetin and caffeic acid that penetrates the microbial membrane and enter the fungal cell,

resulting in a notable reduction in the synthesis of essential components, including ergosterol (the primary component of fungal membranes), glucosamine (an indicator of growth) and proteins (Brul & Klis, 1999; Gopieskhanna & Kannabiran, 2007; Abd-El-Khair & Haggag, 2007; Giriraju *et al.*, 2013; Koleva-Gudeva *et al.*, 2013). However, rabbit urine contains phenolic acids (gallic, caffeic, ferulic, o-coumaric, cinnamic and salicylic acids) that disrupt fungal cell membranes, inhibits the enzyme activity, and interfere fungal metabolism (Martin, 1982; Singh *et al.* 2012; Gotora *et al.*, 2014).

The higher concentration of biopesticides led to a stronger inhibitory effect on fungal growth due to increased availability and interaction of these bioactive compounds with the fungal cells (Mohana & Raveesha, 2007; Yanar *et al.*, 2011; Kalidindi *et al.*, 2015; Zhao *et al.*, 2022).

Isolation of bioactive molecules from biopesticide matrices can be challenging due to their bounds with cell wall components, solubility, mass transfer, and matrix effect (Waszkowiak & Gliszczyn´ska-S´wigło, 2015; Abubakar & Haque, 2020; Mihaylova *et al.*, 2023). Factors such as solvent type, concentration and conditions significantly influence extraction efficiency (Khoddami *et al.*, 2013; Castro-Puyana *et al.*, 2017). Water is a highly effective solvent for extracting bioactive compounds due to its physiochemical properties, efficient traction (Castro-Puyana *et al.* 2017; Borges *et al.*, 2020; Plaskova & Mlcek, 2023), its optimal extraction capacity and stability of chemical structure (Mihaylova & Lante, 2023).

Lantana, ginger, hot pepper have pesticidal effects aided by active compound contained in them which used to reduce the population of leaf miners (Liambila *et al.*, 2021; Liambila, 2023). Lantana has chemical compounds like phenolic and terpenes, tetra-terpenoids with different mode of actions that can interfere the *Tuta absoluta* larvae's regular metabolic processes, disrupt feeding and inhibits the synthesis of ecdysteroid hormones (Liambila *et al.*, 2021; Liambila, 2023). Hot pepper contains flavonoids and phenolic acid that have repelling effect, which lessens the attraction of tomato plants to larvae and have poisonous effects, which result in death or stunted growth of leaf miner larvae (Kashiwagi, 2005; Mendoza, 2023). Neem contains azadirachtin, a tetranortriterpenoid compound that interferes the growth and development of larvae, it is antifeedant and it directly poisons larvae, causing their demise up to 100% (Nisbet, 2000; Kihampa, 2010; Dos Santos *et al.*, 2011; Roychoudhury, 2016; Mulugeta *et al.*, 2020). Moreover ginger, a plant well-known for its volatile components, might have impacted negatively on tomato leaf miner (*Tuta absoluta*) due to gingerol, paradol, shogaols, and zingerone that contained it (Gopieskhanna & Kannabiran, 2007; Abd-El-Khair

& Haggag, 2007). These compounds in ginger are reported to reduce the desire for leaf miners' larvae to feed on plant tissues (Gopieskhanna. & Kannabiran, 2007; Abd-El-Khair & Haggag, 2007).

The effects of leaf miner tunneling, blotching and discoloration affects photosynthesis ultimately affecting plant growth, development and performance (Liambali, 2023). Tomato fruit yield and quality are both significantly impacted by direct feeding of the leaf miner as well as secondary pathogens entering host plants through wounds made by the pest (Chhetri, 2018).

Similarly, biopesticides have demonstrated the potential to reduce disease incidence and severity by over 50% in the most effective treatments across both sites (Kilala and Mailisita). This might be due to the presence of flavonoids and phenolic acid in hot pepper, flavonoids and terpenoids in lantana, gingerol, shogaol, and zingerone in ginger that inhibit fungal activities (Brul & Klis, 1999; Gopieskhanna & Kannabiran, 2007; Abd-El-Khair & Haggag, 2007; Giriraju *et al.*, 2013; Raza *et al.*, 2016; Ahmad *et al.*, 2017). Moreover, hot pepper, ginger, and lantana extracts trigger a plant's innate defense responses that enhance its ability to resist pathogens (Abd-El-Khair & Haggag, 2007; Nashwa & Abo-ElyouSr, 2012; Sallam *et al.*, 2022), and deterrent to some pests that may vector early blight pathogens (Spochacz *et al.*, 2018). Plant extracts offer additional benefits such as their natural abundance, low cost, easy biodegradability, and absence of adverse environmental consequences (Da Cruz Cabral *et al.*, 2013; Fuentefria *et al.*, 2018; Vaou *et al.*, 2021). Their ability on maintaining beneficial organisms contributes to healthier ecosystems and more sustainable agricultural practice (Shuping & Eloff, 2017). Moreover, the plant extracts have a multitude of effects including toxic, sub lethal, antifeedant or neurotoxic activity, ultra structural malformation and effects on prooxidant/antioxidant balance (Spochacz *et al.*, 2018).

Likewise, higher number and weight of tomato fruits per plant was observed in Mailisita. This might be due to high rainfall in Mailisita that boosted plant growth by enhancing stronger root systems and nutrient absorption (Zafar *et al.*, 2024). Data suggests up to 50% increase in plant growth through the use of plant extracts either as growth regulator or bio control agent for disease (Abdel-Kader & El-Mougy, 2016). Plant extracts sprayed to control pests and diseases could act additionally as a nutrient supplement boosting plant growth and yield (Mkindi *et al.*, 2020). Moreover, biochemical ingredients from hot peppers, lantanas, and ginger might affect plant hormone levels including auxins and gibberellins, which are essential for cell elongation

and other unique modes of action (Badr *et al.*, 2021; Chtioui *et al.*, 2022; Sohrabi *et al.*, 2024; Manish *et al.*, 2024). Alterations in these hormones could lead changes in plant growth (Ashraf *et al.* 2018). Mailisita had higher number of tomatoes per plant compared to Kilala; this might be due to the fact that Mailisita may be suitable site for tomato production than the Kilala site due to good weather condition (good rain distribution and temperature).

Low treatment advantage revenue exhibited on the negative control indicated the importance of pest and disease management in tomato production. Analysis on total cost of production showed no significant difference ($P>0.05$) on all the treatments and, positive and negative control. This indicates that biopesticides for this case are expensive as the conventional pesticides though, all were profitable (Malinga & Laing, 2023). However, biopesticides are cheaper than chemical pesticides when locally produced especially for small scale agricultural use or for domestic pest management (Agboola *et al.*, 2022; Ayilara *et al.*, 2023). The treatment advantage accrued in this study is the result of price fetched by organically produced tomato at the marketplace. These results give an opportunity for smallholder farmers to invest on pesticidal plants production, which will help in lowering the cost of these important plants for pest and disease management. According to the profitability index rule, a result of more than 1.0 typically considered financially viable and likely to be successfully; a reading of 1.0 indicates that the costs and benefits are equal; and a reading of less than 1.0 indicates that the costs outweigh the benefits (Gharib *et al.*, 2017).

Generally, these results showed that biopesticides (5% hot pepper, 10% hot pepper, 10% lantana 10% ginger) are promising means for early blight disease and leaf miners management for smallholder farmers in developing countries.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Biopesticides effectively manage early blight and leaf miners, providing a sustainable alternative to synthetic fungicides and insecticides that harm environmental. Botanical extracts such as hot pepper, lantana, ginger and neem demonstrated strong activity against *A. solani* and *T. absoluta*. Their active compounds disrupt the pest metabolism and development. The choice of solvent, concentration, and type of extract significantly influenced efficacy, with water proving to be a more effective and accessible solvent than ethanol. Additionally, biopesticide treatments increased tomato yield and quality due to their organic nature. Cost-benefit analysis revealed that biopesticide use is economically viable and offers a competitive advantage, especially considering the high costs of imported synthetic inputs.

5.2 Recommendations

Farmers are encouraged to adopt biopesticides such as hot pepper extracts, ginger, and lantana as effective alternatives to synthetic fungicides for managing *Alternaria solani*, a common fungal disease affecting tomato plants, and for controlling tomato leaf miners (*Tuta absoluta*). These biopesticides not only offer comparable disease control but also provide environmental benefits, including lower residue levels, minimal impact on ecosystems, and reduced harm to pollinators. Additionally, the study recommends the use of water as a solvent, as it is more effective and environmentally accessible than ethanol for preparing these biopesticides. From a financial standpoint, biopesticides are cost-effective, particularly for smallholder farmers, since they are locally available and less expensive than most imported synthetic chemicals. Furthermore, organically grown tomatoes treated with biopesticides can command higher market prices, increasing overall profitability. The favorable cost-benefit ratio further supports the recommendation to use biopesticides like hot pepper extracts as a financially viable and sustainable solution for disease and pest management in tomato farming. Moreover, encouraging further research to identify the best time of application, assess the potential adjuvants and additives that can be used in combination with plant extracts to enhance their efficacy on leaf miner (*T. absoluta*) and early blight (*A. solani*).

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APPENDICES

Appendix 1: Conventional tomato production data collection at Mailisita-Hai District and Kilala –Arumeru District

S/N	Question	Response
1	What is the cost for land preparation?	
2	Which common variety is preferred by many smallholder farmers?	
3	What amount is incurred during seed bed preparation?	
4	Do small holder farmers incur planting and transplanting cost? If yes, how much?	
5	Is there any cost for water application/Irrigation? If yes how much per irrigation.	
6	Is there any inorganic fungicide/ insecticide used to manage early bright and leaf miners?	
7	What is the cost to buy fungicide and insecticide as well?	
8	Do smallholder farmers incur any cost for transport as they buy fungicides and insecticides, how much?	
9	Cost for buying PPE if are used?	
10	How many times fungicide/ Insecticide are applied?	
11	What is the tomato yield per ha	
12	The estimation price of tomato fruits per kg.	
13	What is approximated revenue of tomato production per hector?	

RESEARCH OUTPUTS

(i) Publication

Abel, F., Mkindi, A. G., Mbega, E. R., Stevenson, P. C., Belmain, S. R., & Venkataramana, P. (2025). Biopesticides potential to protect tomato (*Solanum lycopersicum L.*) production from early blight disease (*Alternaria solani*) and leaf miners (*Tuta absoluta*). *International Journal of Biosciences*, 26(2), 39–55.

(ii) Poster presentation