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Biopesticides potential to protect tomato (*Solanum lycopersicum* L.) production from early blight disease (*Alternaria solani*) and leaf miners (*Tuta absoluta*)

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Abstract

Early blight disease (*Alternaria solani*) and leaf miners (*Tuta absoluta*) pose significant biotic constraints to tomato production, causing 80 -100% yield loss. A study involving laboratory, screen house and field experiments evaluated the efficacy of plant and bio-product pesticides including extracts of *Azadirachta indica*, *Lantana camara*, *Cymbopogon citratus, Capsicum frutescens*, *Zingiber officinale* and rabbit urine. We report significant inhibition of fungal mycelial growth ranging from 20% with 5% rabbit urine to 98.25% by 10% hot pepper in the laboratory. Screen-house trials showed a positive inhibitory effect of plant extracts on controlling leaf miners. The most effective extracts were 10% lantana (80%), 10% hot pepper (76.6%) and 10% ginger (72.6%). The most successful four extracts were used in field trials and resulted in an average 50% reduction in disease severity compared to the control. Also, 10% ginger, hot pepper (both 5% and 10%) and 10% lantana were effective in controlling *Tuta absoluta* and significantly reduced leaf damage. A cost benefit analysis showed that the 5% hot pepper treatment had the highest revenue benefit compared to the negative control and conventional tomato production methods. Further research is needed to integrate these biopesticides into crop management practices.

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Introduction

Tomatoes (*Solanum lycopersicum* L.) are a major vegetable crop in sub-Saharan Africa (Fufa *et al.*, 2009) providing important nutritional benefits to consumers (León-García *et al.*, 2017).

In Tanzania's 64% of the tomato crop is produced by smallholder farmers for whom this crop has the potential to reduce poverty by increasing incomes for produce, as it contributes to the total harvested vegetables (URT, 2012; Mutayoba and Ngaruko, 2018). While tomato is one of the most important vegetables in Tanzania, the current fruit yield is very low (7.5 to 8.4 t/ha) compared to the developed countries (40 to 100 t/ha) depending on the location, growing season, the cultivar used and crop management practices (FAO, 2009; Heuvelink and Dorais, 2005). The impact of diseases is reported to be a major limiting factor for tomato production (Lynch, 1999) and these include early blight (*Alternaria solani*), late blight (*Phytophthora infestans*), leaf spot (*Septoria lycopersici*), fusarium wilt (*Fusarium oxysporum, F. lycopersici*), bacterial wilt (*Pseudomonas solanacearum*) (Dimitrios *et al.*, 2018). Insects are also a major constraint with leaf miners (*Tuta absoluta*) being the most damaging pest causing 80 to 100% yield loss (Abada *et al.*, 2008; Brévault *et al.*, 2014).

Currently, small holder farmers use chemical fungicides such as ridomil gold (4% mefenoxam and 64% mancozeb), fungozeb 80 WP (mancozeb 80%), ivory M72 (64% mancozeb and 8% metalaxy), equation pro (famoxadone and cymoxamil) as prophylactic measures against early blight disease; and insecticides like radiant (Spinetoram) and snow thunder (30 g/l thiamethoxam, 10 g/l emactin benzoate) for controlling leaf miners (Nuwamanya *et al.*, 2023). Most of these are harmful to humans and other living organisms in the ecosystem (Sithanantham *et al.*, 2002; Ngowi *et al.*, 2007; Mushobozi and Gautam, 2017).

It is reported that overuse of pesticides has increased in recent years due to a lack of information regarding the chemicals, lack of alternatives and resistance of pests to some pesticides (Abhilash and Singh, 2009; Nuwamanya *et al.*, 2023).

Some smallholder farmers use plant extracts such as lantana (*Lantana camara)*, myrrh *(Commiphora swynnertonii)* and pyrethrin (*Chrysanthemum cinerariifolium)* and animal waste to manage diseases in common beans (Mkindi *et al.*, 2020). For example, early blight disease reduction in tomato has been reported using *Allium sativum* extract (Nashwa and Abo-Elyousr, 2012). Similarly, rabbit urine (LD_{50}) significantly reduced the survival of insect pests for the first, second and third instars (Kemunto *et al.*, 2022). Biopesticides, including plant extracts, offer numerous benefits in disease and pest management in agriculture, including decreased toxicity, increased safety, higher selectivity, and resistance prevention when used in combination with chemical pesticides (Patel *et al.*, 2019; Kemunto *et al.*, 2022).

However, the absence of standardized formulations appropriate for smallholder farmers hinders their adoption and laboratory, screen house and field research trials are required to identify formulations that effectively control early blights disease-causing pathogens and leaf miners (*Tuta absoluta*). Here we test seven (7) plants extracts and two (2) bio products against the early leaf blight (*Alternaria solani*) and the leaf miner (*Tuta absoluta*) in laboratory, screen house and field trials and undertake a cost benefit analysis of using plant extracts for controlling pest and disease in tomato compared with using synthetics pesticides.

Materials and methods

Study location

A laboratory study to assess the efficacy of botanical extracts on *A. solani* was conducted at the Nelson Mandela African Institution of Science and Technology (NM-AIST), Arusha, in 2023. The field and screen-house experiments were conducted at Mailisita located at 3.3717014 S, 37.28944444 E and at altitude 970 m.a.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 - 29 ºC and 15 - 25 ºC while rainfall was 500 - 1800 mm and 500 mm - 1200 mm, respectively. Both sites were selected due to their suitability for tomato growing and, leaf miner pests and early blight disease were the common biotic constraints in these areas.

Table 1. List of materials used and their sources

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

Collection of materials and preparation of biopesticides

Plant materials were collected locally (Table 1) and thoroughly washed with running tap water. They were dried in shade 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 water as extracting solvents using a ratio of 1:10 (w/v), placed on the shaker for 12 hours to obtain infranatant as described by Tadele and Emana (2017), and Abubakar and Haque (2020). The infranatant of each mixture was diluted to make 5% and 10% concentrations using autoclaved distilled water.

Laboratory evaluation of biopesticides on the growth rate of mycelium in Alternaria solani

The laboratory experiment was laid out in a factorial complete randomised design with 20 treatment combinations (7 plant extracts, 2 bio products and 2 concentrations), including negative (media inoculated pathogen) and positive (ridomil gold) controls, replicated thrice with three observations each. Prepared biopesticides in 3.2 were used in the laboratory experiment. *Alternaria solani* isolates used in this experiment were cultured from NM-AIST maintained cultures on highly susceptible Tanya tomato variety. Isolation and multiplication of inoculum (*A. solani*) was done to obtain enough inoculum for 180 petri dishes of 90 mm diameter. Preparation of full-strength potato dextrose agar (PDA) was done by autoclaving the media at 121ºC for 15 minutes in 1l bottle and allowed to cool to 40 °C. Each biopesticides 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 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. Data were collected by measuring the colony growth size (mm) starting from one day after inoculation for seven consecutive days, as described by (Wonglom *et al.*, 2019). The inhibition rate for each treatment was calculated using the formula by Wonglom *et al.* (2019) as in equation 1.

$$\text{Mycelial growth inhibition (\%)} = \frac{\text{Growth in control} - \text{Growth in treatment}}{\text{Growth in control}} \times 100 \qquad \text{Equation 1}$$

The data from mycelial growth inhibition rate (%) were subjected to analysis of variance; a mean separation test was done by using Bonferroni multiple comparison tests to identify effective treatments using GenStat 21st Version (64 bits), and Statistical software from Visual Statistics and Information (VSNi) located at Heslington, United Kingdom.

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

The screen-house experiment was conducted to investigate the efficacy of biopesticides in controlling leaf miner tomato crop damage using a factorial complete randomized design.

The experiment used 20 treatment combinations together with negative (Unsprayed plants) and positive (Radiant 120 SC) controls, replicated six times, totalling 120 plastic pots. The preparations of plant extract and animal waste were prepared as in section 3.3 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. 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. Irrigation using tap water was done regularly. The introduction of 10 larvae of a leaf miner (*Tuta absoluta*) was done one week after transplanting. The larval stage was considered to be the most damaging stage of the pest. Then the leaf miners were left to adopt to the environment for 1 day to start spraying and evaluation. The spraying of 30 ml of each biopesticide was done using the same concentrations as above in section 3.3 was done.

The same sprays were repeated three times at an interval of 5 days. Data collection was done on leaf miner one day after each spray making three total measures.

Tomato leaf damage was assessed and ranked as "mines" or "punctures" using the damage index established by Lopez *et al.* (2020), on the percentage of the leaf area damaged as follows: very low (0-20%), low (20-40%), moderate (40-60%), high (60-80%) and severe (80-100 %). Both data for leaf miner and tomato leaf damage % were recorded on excel sheet. Data analysis, data on leaf miner and tomato leaf damage % were visualized for normality and subjected to analysis of variance, then a mean separation test was done by using the Bonferroni multiple comparison test to identify effective treatments using GenStat 21st Version (64 bits), Statistical software from Visual Statistics and Information (VSNi) located at Heslington , United Kingdom.

Evaaluation of biopesticides in controlling early blight in the field

Field experiment was conducted at Mailisita and Kilala. Each site of area 84 m² was cleared and ploughed and the experiment set up using a randomized complete block design with three replications. Nursery was prepared and Tanya tomato variety was used. Tomato seedlings were transplanted to the experimental plots after 1 month. The size of each block was 12 m² with each having six plots of 2 m² where each plot was transplanted with 13 tomato seedlings at a spacing of 50 cm × 30 cm. Temperature and precipitation were recorded throughout the experiment (Table 2).

Table 2. Temperature and rainfall distribution during the field experimental period

Months,2024	Temperature (°C)						Average rainfall (mm)	
	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

The four best treatment combinations from the laboratory experiment (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. Field management was done according to smallholder farmers' practices to reflect field conditions.

Data collection was done at the fruiting stage on early blight disease severity by randomly selecting five plants in each plot for every treatment 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 by 0 = no infected leaves, 2 = ≥25% or less, 3 = 26-50%, 3 = 51-75% and 4= 76-100% (Weber and Halterman, 2012). The data was used to calculate percentage disease severity using the equation 2 of Ibrahim *et al.* (2004).

$$\text{Disease severity (\%)} = \sum(T/N) \times 100 \qquad \text{Equation 2}$$

Where T = number of infected leaves per plant; N = total number of leaves per plant.

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 and Hughes, 1995). Tomato leaf damage was assessed and ranked as "mines" or "punctures" using the damage index established by Lopez *et al.* (2020), on the percentage of the leaf area damaged as follows: very low (0-20%), low (20-40%), moderate (40-60%), high (60-80%) and severe (80-100 %). Data on plant height, number of tomato fruits per plant and total tomato fruit weight per plant were collected as described by (Balemi, 2008).This was done by randomly selecting five plants in each plot for every treatment once at the harvesting stage.

Data were subjected to analysis of variance, and then the mean separation test was done using the Bonferroni multiple comparison to identify effective treatments by GenStat 21st Version (64 bits), Statistical software from Visual Statistics and Information (VSNi) located at Heslington, United Kingdom.

To perform cost-benefit analysis of using biopesticides as means of controlling early blight in tomato

Cost-benefit analysis

The examination of the cost-benefit analysis involved in the tomato production was observed.

The evaluation survey was conducted in the two sites of Mailisita and Kilala, using a structured questionnaire administered to 20 smallholder farmers in each site as described by (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. 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).

The costs of obtaining plant materials and animal excretes, processing them and cost of tomato production for both conventional and experimental sites production were recorded as average for each item as described by (Sheshma *et al.*, 2022; Malinga and Laing, 2023). It involved the evaluating cost based on conventional tomato production that included costs of purchasing fungicides and insecticides, transport, spraying, and protective gears and other common costs. Furthermore, the cost production based on using biopesticides (10%

lantana, 5% hot pepper, 10% hot pepper and 10% ginger) also evaluated. It included cost of collecting / purchasing botanical plants /animal excretes, transportation, plant extracts preparation, cost of protective gears, plant extracts spray, times of application and common costs. The sum of these expenses indicated the entire cost of plant protection and revenue accrued from the tomato production.

The net benefit was calculated by deducting the total cost of tomato production from the total income, which was calculated by multiplying the total yield per hectare by the current market price (Sheshma *et al.*, 2022; Malinga and Laing, 2023).

Net benefit =Total income -Total cost of production
Equation 3

Treatment advantage over the control was calculated by deducting the control treatment's income from each sprayed treatment income as described by (Sheshma *et al.*, 2022).

Treatment advantage = (Each sprayed treatments' income -Control treatment income) Equation 4

Cost-benefit ratio was calculated according to (Sheshma *et al.*, 2022). Each treatment was derived by subtracting the additional income of production from the net income of production, then were divided by total cost of tomato production for each treatment.

$$\text{C: B ratio} = \frac{\text{Additional income from production}}{\text{Cost of production}} \quad \text{Equation 5}$$

Data were subjected to analysis of variance, and then mean separation test was done by using Bonferroni multiple comparison test to identify effective treatments by GenStat 21st Version (64 bits), Statistical software from Visual Statistics and Information (VSNi) located at Heslington, United Kingdom.

Results and discussion

Effectiveness of biopesticides on invitro 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 20 to 100% reduction in mycelia growth compared with the control. The inhibition rate was highest for the positive control ridomil gold (100%), followed by 10% and 5% hot peppers (98.25% and 97.44%, respectively), which were not significantly (p>.05) different from the positive control (Table 3).

Table 3. Effect of biopesticides on inhibition of mycelia growth of *A. solani* in vitro conditions

Treatments		Inhibition of *A. solani* mycelia growth (%)		
		Concentration		
		5%	10%	Mean
Plant extracts	Lantana	83.71c	90.30bc	87.01c
	Hot pepper	97.44a	98.26a	97.85a
	Papaya	74.16d	83.90c	79.03d
	Ginger	88.83b	91.56b	90.20b
	Fresh lemon grass	65.29e	68.05d	66.67e
	Garlic	59.71f	61.25e	60.48f
	Neem	83.40c	84.32c	83.86cd
Bio products	Jeevamrutham	68.33e	69.88d	69.11e
	Rabbit urine	20.74g	40.76f	30.75g
Positive control	Ridomil gold	100.00a	100.00a	100.00a
Negative control	No extracts	0.00h	0.00g	0.00h
Mean		67.43	71.67	69.55
S.E.D		1.52	2	1.69
CV (%)		4.8	6.5	7.7
L.S.D		3.02	3.9	3.33
F		<.001	<.001	<.001

The reduction in mycelia growth due to plant extracts and rabbit urine on *A. solani* is likely due to the bioactive metabolites contained in them (Abd-El-Khair and Haggag, 2007; Gotora *et al.*, 2014; Mwelasi, 2015). For example, *Azadirachta indica* contains azadirachtin, nimbidin, salannin, azadiradione and beta-sitosterol 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 and Karuppayil, 2014). The most active compounds in hot pepper for controlling *A. Solani* include capsanthin and flavonoids like quercetin and rutin that disrupting the integrity of fungal cell membrane and inhibiting the growth (Matsuoka *et al.,* 2003; Giriraju *et al.*, 2013; Koleva-Gudeva *et al.*, 2013). Lantana contains sesquiterpenes and phenolic like quercetin and caffeic acid which penetrate 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 and Klis, 1999; Gopieshkhanna and Kannabiran, 2007; Abd-El-Khair and Haggag, 2007).

However, rabbit urine contains phenolic acids (gallic, caffeic, ferulic, o-coumaric, cinnamic, and salicylic acids) that disrupt fungal cell membranes, inhibit enzyme activity, and interfere fungal metabolism (Martin, 1982; Singh *et al.*, 2012; Gotora *et al.*, 2014). The higher concentration of compounds led to a greater inhibitory effect on fungal (Mohana and Raveesha, 2007; Yanar *et al.*, 2011; Kalidindi *et al.*, 2015; Zhao *et al.*, 2022).

Table 4. Effect of biopesticides on leaf miner management in the screen house experiment

Extracts	Leaf miner reduction (%)/Spray1/ concentration		Leaf miner reduction (%)/ Spray 2/ concentration		Leaf miner reduction (%)/Spray 3/ concentration		%cumulative leaf miner reduction/ concentration	
	5%	10%	5%	10%	5%	10%	5%	10%
Lantana	26.67d	36.67d	23.33def	26.67ef	10.00b	16.67c	60.00d	80.00ef
Hot pepper	34.00d	38.33d	20.00cdef	21.67cdef	10.00b	16.67c	64.00d	76.67def
Ginger	28.33d	33.33d	25.00ef	25.00def	10.00b	13.33bc	63.33d	71.67de
Fresh lemon grass	11.67b	13.33ab	15.00bcde	13.33bc	11.67b	10.00bc	38.33bc	36.67b
Garlic	15.00bc	16.67bc	13.33bcd	13.33bc	10.00b	10.00bc	38.33bc	40.00bc
Neem	23.33cd	30.00cd	16.67cde	16.00bcde	10.00b	12.00bc	51.67cd	58.00cd
Papaya	13.33bc	16.67bc	18.33cde	15.00bcd	11.67b	11.67bc	41.67c	43.33bc
Jeevamrutham	13.33bc	11.67 ab	10.00abc	16.67bcde	11.67b	10.00bc	35.00bc	38.33b
Rabbit urine	6.67ab	10.00ab	5.00ab	6.67ab	10.00b	10.00bc	21.67b	26.67b
Radiant	60.00e	60.00e	30.00f	30.00f	5.00ab	5.00ab	95.00e	95.00f
Negative control	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a
Mean	20.92	24.15	16.00	16.77	9.08	10.46	46.00	51.8
LSD	6.56	9.04	6.62	6.3	3.89	4.24	10.01	10.70
SED	3.27	4.51	3.30	3.14	1.94	2.12	4.99	5.34
CV (%)	26.8	32.0	35.4	32.2	36.7	34.7	18.6	17.8
F	<0.001	<0.001	<0.001	<0.001	<0.015	<0.001	<0.001	<0.001

The influence of biopesticides on tomato leaf miner population in the screen house experiment

Effect of biopesticides on tomato leaf miner population

Data analysis on the effect of different biopesticides on leaf miner population generally showed a significant decrease in leaf miner numbers. The result was outstanding on water formulated biopesticides, which included 10% lantana (80%), 10% hot pepper (76.67%) and ginger (71.67%) had good performance (Table 4). 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.

Several reports indicated that lantana, ginger, hot pepper has pesticidal effects aided by active compound contained in them (Liambila *et al.*, 2021: Liambila, 2023). For example, 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 (Gopieshkhanna and Kannabiran, 2007; Abd-El-Khair and Haggag, 2007). These compounds in ginger are reported to reduce the desire for leaf miners' larvae to feed on plant tissues (Gopieshkhanna and Kannabiran, 2007; Abd-El-Khair and Haggag, 2007).

Evaluation of tomato leaf damage in the screen house experiment

The result on evaluation of tomato plants larvae damage were analysed and indicated that, there was significantly more damage on the negative control due to leaf miner tunnelling, blotching and discoloration as compared to all other treatments. Biopesticides that resulted in the least tomato leaf damage were 10% lantana (7.83%), 10% ginger (11%), 10% hot pepper (13.53%) and 10% neem (16%) and these did not differ significantly from the positive control radiant (1.67%) (Table 5). According to the scale by Lopez *et al.* (2020), these treatments represented the very low damage which are acceptable by tomato growers.

Table 5. Assessing the efficacy of different biopesticides on tomato leaf damage in the screen house experiment

Extracts	Concentrations	
	5%	10%
Lantana	24.54b	7.83a
Hot pepper	23.78b	13.53a
Ginger	25.37b	11.00a
Fresh lemon grass	50.30cd	51.06bc
Garlic	44.44cd	56.83bc
Neem	37.63bc	16.00a
Papaya	43.37bcd	42.39b
Jeevamruthum	55.50cd	63.17cd
Rabbit urine	60.17d	54.20bc
Radiant	1.67a	1.67a
Negative control	80.76e	80.76d
Mean	40.94	36.53
LSD	10.86	10.24
CV (%)	22.0	24.0
SED	5.42	5.11
F	<.001	<.001

Damage was recorded on the remaining treatments ranged 20% to 80.70% which is considered moderate to severe damages (Lopez *et al.*, 2020).

The effects of leaf miner tunnelling, 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). The use of biopesticides can disrupt the leaf miner life cycle and discourage them from feeding (Kashiwagi, 2005; Liambila *et al.*, 2021: Liambila, 2023; Mendoza, 2023,).

Azadirachtin, a deterrent and active compound in neem, has been shown to have a high mortality rate against *T. absoluta* and could explain the activity reported (Kubo *et al.*, 2012; Frank *et al.*, 2014). *L. camara* also had good insecticidal efficacy and repellence, with higher mortality rates of larvae

(Liambila *et al.*, 2021), suggesting it as an environmentally friendly alternative to synthetic pesticides.

Field evaluation of four biopesticides on early blight disease incidence, severity and tomato growth parameters

Early blight disease incidence

Early blight disease incidence in Kilala showed that all the treatments were significantly ($p < 0.05$) different and lower than the negative control which suffered 84.4% damage. The most effective treatments, 10% ginger (37.8% damage), 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 result 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 6). For both sites, disease incidence was slightly higher in Kilala (84.4%) compared to Mailisita (77.8%) on negative control. The effect of sites (blocks) did not affect disease incidence (Table 6).

Here we have shown that biopesticides and especially plant extracts have the potential to reduce early blight disease incidence by over 50% in the field and across two field sites.

Table 6. General variation comparison of the two sites, Mailisita and Kilala

Parameter analysed	Plant height	Number of tomato/Plant	Tomato weight	Disease severity%	Disease incidence %
Block (Villages)	0.634	< 0.006	> 0.05	0.113	0.307
Replications	> 0.05	> 0.05	> 0.05	> 0.05	0.001

Table 7. Effect of biopesticides on early blight disease severity and incidence in two locations

Treatments/Concentration	Disease severity (%)		Disease incidence (%)	
	Kilala	Mailisita	Kilala	Mailisita
Negative control	83.7a	79.3a	84.4a	77.8a
Rabbit urine (10%)	60.7b	47.0b	62.2ab	55.6b
Lantana (10%)	46.7bc	42.2bc	46.7bc	31.1c
Hot pepper (5%)	40.9c	39.5bc	33.3c	31.1c
Hot pepper (10%)	40.0c	31.1cd	26.7c	28.9c
Ginger (10%)	39.8c	39.6bc	37.8c	37.8bc
Positive control (Ridomil gold)	32.3c	27.2d	24.4c	22.2c
Mean	49.16	43.7	45.07	40.64
SED	4.52	3.76	7.53	7.18
CV (%)	19.5	18.2	35.4	37.5
L.S.D	9.06	3.76	15.1	7.18
F	<.001	<.001	<.001	<.001

Metabolites reported from hot pepper and lantana, include phenolics, flavonoids and terpenoids which could explain the efficacy while gingerol, shogaol, and zingerone in ginger are known to inhibit fungal growth (Brul and Klis, 1999; Gopieshkhanna and Kannabiran, 2007; Abd-El-Khair and 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 defence responses and enhance its ability to resist pathogens (Abd-El-Khair and Haggag, 2007; Nashwa and Abo-ElyouSr, 2012; Sallam *et al.*, 2022) and are also deterrent to some pests that may vector early blight pathogens (Spochacz *et al.*, 2018). Biopesticides can target specific pathogens while having limited effects on beneficial organisms and contribute to healthier ecosystems and more sustainable agricultural practice (Shuping and Eloff, 2017; Lengai and Muthomi, 2018; Tembo *et al.*, 2018).

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 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 efficacy of the treatments from two sites, biopesticides were more effective in Kilala than Mailisita with three treatments (10% ginger, 5% and 10% hot pepper) performing as well as the positive control whereas in Mailisita only one biopesticides (10% hot pepper) performed as well as the positive control (Table 7). This might be due to the high rainfall at Mailisita during the experiment providing conditions that encourage fungal growth (Singh *et al.*, 2020).

Table 8. 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
Negative control	70.40a	61.10a	1.56a	3.11a	0.09a	0.20a
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
Positive control (Ridomil gold)	122.70b	116.00b	10.56b	14.67b	1.22c	1.83cd
Mean	106.17	108.3	8.27	11.64	0.87	1.39
S. E.D	8.2	18.99	1.19	7.236	0.11	0.63
CV (%)	0.46	1.6	10.1	26.8	18.1	26
L.S.D	16.45	9.46	2.39	3.6	0.22	0.31
F	<.001	<.001	<.001	<.001	<.001	<.001

The bioactive components of ginger (gingerol, shogaol, and zingerone), lantana (lantadene A, lantadene B, terpenoids, and flavonoids), and hot pepper (flavonoids and phenolic acids) extracts inhibit fungal growth and initiate plant defence responses that increase resistance to pathogens (Abd-El-Khair and Haggag, 2007; Nashwa and Abo-ElyouSr, 2012; Langai *et al.* 2017; Fuentefria *et al.*, 2018; Vaou *et al.*, 2021; Abdule *et al.*, 2022). Plant extracts offer additional benefits such as their natural abundance, low cost, non-persistence, and low adverse environmental consequences (da Cruz Cabral *et al.*, 2013). These results showed that biopesticides are promising means for disease management for smallholder farmers in developing countries.

Growth and performance of tomato

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 village (114.3cm) (Table 8). 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). Similarly, higher number and weight of tomato per plant was observed in Mailisita. These 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 and 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).

Effect of biopesticides on tomato leaf miner damage

Field assessment of biopesticides on reducing tomato leaf miner (*Tuta absoluta*) damage on tomato leaf, indicated that at Kilala there all biopesticides were significantly more efficacious than the control but significantly less effective than the positive control which only had 4.4% damage (10% ginger 32.8%, 10% hot pepper 29.8%, 5% hot pepper 29.1% and 10% lantana 32.8%) (Table 9). The greater efficacy of the positive control might be due to the fact that radiant is a systemic insecticides (Tescari *et al.*, 2014) whereas, the plant extract 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).

Table 9. Effect of biopesticides on tomato leaf damage in two locations

Treatments	Tomato leaf damage %	
	Kilala	Mailisita
Negative control	76.8a	72.2a
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
Positive control (Ridomil & Radiant)	4.4c	10.0c
Mean	34.94	35.86
SED	4.45	5.18
CV (%)	27.1	32.4
L.S.D	8.91	10.39
F	<.001	<.001

For the Mailisita site, 10% ginger (24.4%) and 5% hot pepper (28.3%) were also effective at controlling the insect but significant less so than the positive control (radiant with 10.0%).

The rest of the treatments were all significantly better at controlling the insect than the negative control which had a higher leaf damage of 72.2%. The pest pressure on both sites was similar in Kilala (76.8%) and Mailisita (72.2%) on the highly susceptible control (Tanya). This suggests that all the biopesticides used in this experiment had negative effect on leaf miner (*Tuta absoluta*) larvae. Biopesticides (neem, hot peeper, ginger, lantana) disturb larvae life cycle and discourage them from feeding, resulting in death and reducing damage (Kashiwagi, 2005; Langai *et al.*, 2018; Ibrahim *et al.*, 2019; Rahardjo *et al.*, 2019; Liambila *et al.*, 2021: Liambila, 2023; Mendoza, 2023).

To examine the cost-benefit analysis of using biopesticides as means of controlling early blight

Treatment advantage

Analysis of variance on treatment advantage showed that, there were significant differences 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 10). This 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 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 and 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. This result gives an opportunity for smallholder farmers to invest on medicinal plants production, which will help in lowering the cost of these important plants for pest and disease management.

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 10). 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).

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-radiant (pest control) and ridomil gold (*Alternaria solani*). Generally, all the biopesticides were an effective means of pest and disease management in the study.

Table 10. Tomato production cost based on biopesticides

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	18.16.97b	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 conventional tillage	860.00	3157.89b	2297.89b	2458.53b	1:2.7b
Negative control	468.42	267.58a	-200.84a	0a	1:- 0.4a
Mean		2548.32	1834.06	2032.22	1:2
CV (%)		21.03	29.31	26.37	28.9
SED		626.87	626.87	626.87	1:0.81
LSD		1611.40	1611.40	1611.40	1:2.09
F		0.028	0.043	0.043	0.035

Conclusion

The current study indicated that extracts of 5% hot pepper, 10% hot pepper, 10% ginger, and 10% lantana proved successful in controlling early blight (*A. solani*) and leaf miners in both laboratory, screen house and field experiments. These plant extracts may be used instead of fungicides and insecticides, which will lower the cost of fungicides and insecticides and their residual effects that pollute the environment and climate. Moreover, the study reveals significant differences in treatment advantage revenue between conventional tomato production methods and biopesticides, with the 5% hot pepper treatment having the highest revenue. The cost-benefit ratio analysis shows all biopesticides treatments are financially successful. We therefore recommend the research on identifying the best time of application; assess the adjuvants and additives that can be used in combination with plant extracts to enhance their efficacy. Nevertheless, this research recommends further experiments to evaluate the best method of applying plant extracts that can influence their distribution, coverage, and penetration into plant tissues.

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