Hindawi
International Journal of Agronomy
Volume 2021, Article ID 5719091, 10 pages
https://doi.org/10.1155/2021/5719091

Research Article

Essential Oils as Biocontrol Agents of Early and Late Blight Diseases of Tomato under Greenhouse Conditions

Lydia G. Mugao,[1] **Bernard M. Gichimu**,[1] **Phyllis W. Muturi**,[1] **and Ezekiel K. Njoroge**[2]

[1]*Department of Agricultural Resource Management, University of Embu, P.O. Box 6 60100, Embu, Kenya*
[2]*Chemistry Department, Kenya Agricultural and Livestock Research Organization—Coffee Research Institute, P.O. Box 4 00232, Ruiru, Kenya*

Correspondence should be addressed to Lydia G. Mugao; mugaolydia@gmail.com

Received 18 August 2021; Revised 8 December 2021; Accepted 13 December 2021; Published 26 December 2021

Academic Editor: Mehdi Rahimi

Tomato production worldwide is usually restrained by various infections, among them mainly the late and early blight caused by *Phytophthora infestans* and *Alternaria solani*, respectively. Lately, there has been a growing concern over the use of synthetic fungicides on environmental and food safety, hence the need to explore other alternatives that are friendly to the user, the consumer, and the general environment. This research sought to test the potency of ginger, garlic, and Mexican marigold essential oils against the early and late blight diseases of tomato under greenhouse conditions. A synthetic fungicide (Ridomil Gold®) was used as a positive control while distilled water acted as a negative control. The extraction of essential oils was done by dry steam distillation and then mixed with tween twenty before being topped up with sterile distilled water. They were then used to spray tomato plants that had been inoculated with *A. solani* and *P. infestans* isolates under greenhouse conditions. The tomato plants were evaluated for growth, yield, and disease severity. The data obtained was subjected to ANOVA and separation of means was conducted using Student–Newman–Keul (SNK) test at 95% level of confidence. The three essential oils had a significant potency against the two diseases which is comparable to the synthetic fungicide. Marigold essential oil was also found to have a significant impact on the general growth of sprayed tomato plants. Essential oils of the three plants can be further explored as alternative products management of the two diseases.

1. Introduction

Tomato cultivation in Kenya has intensified in recent years for both processing and fresh market [1] and for commercial and home consumption [2]. It constitutes 7% of the total horticultural produce and 14% of the total vegetables grown in Kenya [1]. The fruit is always in high demand since it is consumed by nearly all the households. It is rich in lycopene which is an antioxidant that is gaining popularity because of its role in mitigating heart disease, cancer, and muscular degradation [3]. It is also rich in minerals such as iron and vitamins A, C, and E [4]. Tomato is hence a common ingredient in many recipes including stews, soups, and salads [3]. Kenya is among the leading tomato producing countries in sub-Saharan Africa with a total production of about 410,033 tons of tomato fruits [1].

The largest percentage of tomatoes produced in Kenya is under open field where they are vulnerable to diseases and pests [5]. Diseases such as late blight (*Phytophthora infestans*) and early blight (*Alternaria solani*) affect the quality, quantity, and profitability of tomato [2]. Early blight is more aggressive under heavy rainfall, high humidity, and temperatures ranging between 24 and 29°C [6]. The disease can affect all the above ground parts of all stages of growth and development of the tomato plant [7]. Irregular black/brown spots appear on aging leaves and then enlarge creating lesions that result in complete leaf fall. The symptoms begin from older lower leaves and then progress to the upper leaves [8]. Late blight is also known to cause extensive losses on

susceptible tomato plants when environmental conditions are conducive [9]. The symptoms appear as irregular water-soaked lesions which extend fast into pale green to brown and then cover the stem and the surface of large leaves [10]. Under high humidity, a grey to white moldy growth covers the lesions consisting of sporangiophores that produce sporangia where the zoospores are formed [10]. The two diseases can cause tomato losses of close to 100% [11].

For disease control in the field, farmers rely largely on synthetic fungicides. However, there is a blooming concern on the use of synthetic fungicides due to their toxicity and residue retention in the food products [12]. Consequently, the consumer markets have come up with strict quality requirement in view of maximum residue levels of pesticides in fresh fruits and vegetables [2]. The fresh fruit and vegetable products that are not able to meet the market requirements have been denied access to the lucrative markets resulting in losses. The rejected products are usually redirected to the local markets where they are sold at low prices to unsuspecting consumers who find them appealing to the eyes and end up consuming the chemical residues. In addition, failure of small-scale farmers to use protective gear during chemical application and to adhere to dilution instructions given by the manufacturers poses a great health risk to them [2]. Some synthetic chemicals are also reportedly toxic to beneficial and nontarget organisms such as natural enemies and pollinators [13–15]. The worldwide trend to explore organic/biological pesticides as alternative options to synthetic ones is gaining popularity because of the negative effects resulting from excessive use of the latter [16]. Most of organic pesticides are easily biodegradable, nonpoisonous, and safe to nontarget organisms and antagonists and leaves no harmful residues on the food products [17].

Several plant compounds have proved to have fungicidal activity against fungal pathogens under both *in vitro* and *in vivo* domain [18]. Essential oils are aromatic and volatile liquids which have abundant bioactive compounds [19, 20] that have demonstrated antifungal activity but are highly degradable under natural conditions [21]. They contain different compounds [22] which have fungicidal, nematicidal, insecticidal, acaricidal, and bactericidal properties [23]. Essential oils are becoming popular because they are safe to use and more acceptable by consumers and they potentially have a multipurpose functional use [24]. The current study is aimed at investigating the antimicrobial activity of ginger (*Zingiber officinale*), Mexican marigold (*Tagetes erecta*), and garlic (*Allium sativum*) essential oils against tomato late and early blight diseases under greenhouse conditions.

2. Materials and Methods

2.1. Collection of Diseased Tomato Plant Materials. Sampling was done in Mwea, Kirinyaga County, because it is an area renown for tomato cultivation and blight diseases are rampant. The area lies within 0.6897° S, 37.3400° E. It is characterized by annual rainfall ranging between 800 mm and 1250 mm usually in two seasons. Annual temperature ranges between 19.6°C and 26.3°C. It has gentle rolling slopes with black cotton soils [25]. Tomato leaves with early and late blight symptoms were randomly collected from the farms by physical examination. They were taken to the laboratory in cool boxes and refrigerated at 4°C for processing and further analysis.

2.2. Isolation of the Pathogens. The pathogen isolation followed the modified procedures of Naik et al. [26]. V8 and Potato Dextrose Agar (PDA) were the standard media used for isolation of *P. infestans* and *A. solani*, respectively, from the diseased tomato samples. The tomato leaves bearing blight symptoms were first washed under clean running tap water and then surface sterilized in 1% sodium hypochlorite for three minutes. They were rinsed in three changes of sterilized distilled water and blotted dry using sterilized blotting paper. A sterilized scalpel was used to cut infected leaf tissues of 3 mm × 3 mm size towards the healthy tissues where the blight pathogens were suspected to be more active. The surface sterilized tissues were directly plated on the sterilized PDA and V8 agar for early and late blight separately and then incubated in the laboratory at room temperature (25°C) for three days. The colonies were then subjected to single spore isolation and subcultured separately on their specific media to obtain pure strains for identification. The isolates were identified using morphological microscopic and macroscopic features [11] and comparing with established identification keys [27]. The isolates were then maintained on plates awaiting their inoculation on tomato plants in the greenhouse.

2.3. Extraction of Essential Oils from the Test Plants. Mexican marigold leaves were collected from the field while garlic cloves and ginger rhizomes were bought from the open air market. Five (5) kg each of the raw plant products were prepared for essential oil extraction following the procedure described by Mugao et al. [11, 22]. The essential oils were extracted following the vertical steam distillation procedure described by Adams [28] as modified by Mugao et al. [11, 22]. The essential oils were put in air tight bottles and stored in the refrigerator at 4°C awaiting the greenhouse experiment.

2.4. Experimental Design and Layout. The greenhouse experiment was a split plot laid out in a Randomized Complete Block Design (RCBD) with five treatments replicated four times. There were two main plots representing the plants inoculated by the two pathogens (*P. infestans* and *A. solani*). The five treatments comprised of essential oils of Mexican marigold, ginger, and garlic, the positive control (Ridomil Gold® synthetic fungicide), and the negative control (distilled water). Ridomil Gold® is a curative fungicide manufactured by Syngenta (https://www.syngenta.co.ke/product/crop-protection/ridomil-gold-mz-68-wg) and comprises Metalaxyl-M 40 g/Kg and Mancozeb 640 g/Kg formulated as wettable granules. The test tomato variety was Kilele F1 also developed by Syngenta and not characterized as being resistant to both early and late blight of tomato

(https://www.syngenta.co.ke/product/seed/tomato/kilele-f1). One-month-old pregerminated tomato seedlings were planted in a greenhouse in plastic pots filled with sterilized potting mixture of soil, sand, and well decomposed manure in a ratio of 3 : 2 : 1. The greenhouse temperatures were 21–29^{0}C and the humidity was 67%–73%.

2.5. Preparation of Inoculum. Fourteen-day-old cultures of *A. solani* and *P. infestans* were used as source of the spores. Spore suspension was prepared by adding 5 ml of sterile distilled water to a pure 14-day-old culture in a Petri dish. Dislodging of spores was done with a bent glass rod and the content sieved using a three-layer cheese cloth to remove the mycelia. The hemocytometer slide was used under a microscope to ascertain the spore suspension concentration and then standardized to 1×10^6 spores per millimeter with sterile water. The inoculum was stored in the laboratory at 4^{o}C awaiting inoculation.

2.6. Inoculation and Application of Treatments. Inoculation was done on actively growing tomato plants three weeks after transplanting by spraying every plant with the 20 ml of the inoculum using a hand sprayer. Symptoms of disease development began to appear on the 6th day after inoculation. Application of treatments was done at fourteen days after inoculation through foliar sprays conducted using a hand sprayer. In the preparation for spraying, 5 ml of each essential oil was first mixed with 5 ml of tween 20 and then topped with sterile distilled water to up to 500 ml and mixed thoroughly. Ridomil Gold® solution was prepared following the manufacturer's instructions of 2.5 g per liter of water. Subsequent applications were done after every fourteen days up to 60 days after planting.

2.7. Data Collection and Analysis. Disease severity was scored per treatment after every two weeks using a 0–5 scale [29] based on the size and number of lesions on the infected leaves as follows:

(i) 0 = healthy (no visible lesions on the leaf)
(ii) 1 = up to 10% of the infected leaf area
(iii) 2 = 11%–25% of the infected leaf area
(iv) 3 = 26–50% of the infected leaf area
(v) 4 = 51–75% of the infected leaf area
(vi) 5 = more than 75% of the infected leaf area

The disease scales were converted into percentage for each plant using the formula described by Chaerani et al. [30] as provided in the equation.

$$\text{Disease severity} = \frac{\text{Sum of all ratings} \times 100}{\text{No. of leaves sampled} \times \text{maximum disease scale}}. \quad (1)$$

The disease severity on each plant was determined according to the average of all leaves of a plant. counted based on visual assessment [31].

Data was also collected on growth and yield parameters including plant height, branch number, leaf number, days to 50% flowering, and number and weight of marketable fruits. All the data was subjected to Analysis of Variance (ANOVA) using XLSTAT version 2019 and separation of means was conducted using Student–Newman–Keul (SNK) test at 95% level of confidence.

3. Results

3.1. Influence of the Test Pathogens on Disease Severity. Severity of early blight disease on tomato plants inoculated with *A. solani* increased from week 2 to week 4 before decreasing in the subsequent weeks. On the other hand, severity of late blight disease on tomato plants inoculated with *P. infestans* kept increasing throughout the experimental period (Table 1). In week 2, the severity of the disease did not vary significantly ($p > 0.05$) between the two pathogens. Within weeks 4–10, the average disease severity differed significantly between the two pathogens with *P. infestans* recording a higher disease severity than *A. solani* (Table 1).

3.2. Efficacy of Essential Oils on Control of Early and Late Blight of Tomato. Severity of early and late blight diseases was significantly reduced by application of essential oils from the selected plants. The essential oils from the three plants gave similar results to the synthetic fungicide used as positive control but varied significantly with the negative control (distilled water). For both pathogens, disease severity in the negative control treatment continued to increase as it decreased in the other treatments (Table 2).

3.3. Effects of Essential Oils on Growth and Yield of Tomato

3.3.1. Effects of the Essential Oils on the Leaf Number of Tomato. The number of leaves on the tomato plants inoculated with *A. solani* isolate varied between the treatments but the leaves increased as the plants continued to grow (Table 3). Among the tomato plants inoculated with *A. solani*, the number of leaves was the same ($p > 0.05$) in all the treatments in the second week. In the fourth week, tomato plants treated with Mexican marigold essential oil had lower number of leaves but did not differ significantly from the control while in week six the number of leaves did not vary significantly ($p > 0.05$) between treatments. However, week eight had significantly ($p < 0.05$) lower number of leaves in the control but did not differ significantly in the

Table 1: Influence of the test pathogen on disease severity.

Pathogen	Disease severity				
	Wk 2	Wk 4	Wk 6	Wk 8	Wk 10
Alternaria solani	9.77[a]	10.80[b]	10.56[b]	10.59[b]	10.48[b]
Phytophthora infestans	9.93[a]	16.36[a]	19.32[a]	20.82[a]	23.76[a]
Pr > F	0.308[NS]	<0.0001	<0.0001	<0.0001	<0.0001
SE	0.109	0.277	0.458	0.279	0.352

Means followed by the same letter within the column are not significantly different at $p = 0.05$; Wk: week; SE: standard error; NS: not significant.

Table 2: Disease severity on inoculated tomato plants.

	Treatment	Wk 2	Wk 4	Wk 6	Wk 8	Wk 10
Early blight	Control	9.20[a]	18.24[a]	19.66[a]	22.68[a]	24.19[a]
	Marigold	9.58[a]	9.12[b]	8.55[b]	7.70[b]	6.89[b]
	Garlic	10.30[a]	9.14[b]	8.55[b]	7.90[b]	7.45[b]
	Ginger	10.25[a]	8.80[b]	8.31[b]	7.82[b]	7.43[b]
	Ridomil Gold®	9.49[a]	8.69[b]	7.75[b]	6.85[b]	6.44[b]
	Pr > F	0.118[NS]	<0.0001	<0.0001	<0.0001	<0.001
	SE	0.276	0.462	0.453	0.332	0.287
	Treatment	Wk 2	Wk 4	Wk 6	Wk 8	Wk 10
Late blight	Control	9.87[a]	46.36[a]	66.38[a]	74.80[a]	90.56[a]
	Marigold	9.75[a]	9.10[b]	7.14[b]	7.00[b]	6.62[b]
	Garlic	10.14[a]	8.85[b]	7.88[b]	7.30[b]	6.99[b]
	Ginger	9.82[a]	8.91[b]	8.50[b]	8.38[b]	8.18[b]
	Ridomil Gold®	10.06[a]	8.59[b]	6.72[b]	6.62[b]	6.46[b]
	Pr > F	0.903[NS]	<0.0001	<0.0001	<0.0001	<0.0001
	SE	0.232	0.754	1.328	0.795	1.080

Means followed by the same letter within the column are not significantly different at $p = 0.05$; Wk: week; SE: standard error; DF: degrees of freedom; NS: not significant.

Table 3: Number of leaves on inoculated tomato plants.

	Treatment	Wk 2	Wk 4	Wk 6	Wk 8	Wk 10
Alternaria solani	Control	9.00a	9.75ab	11.75a	11.75b	12.75c
	Marigold	8.50a	9.00b	11.50a	14.00ab	18.50a
	Garlic	9.25a	10.00ab	13.75a	14.25ab	19.50a
	Ginger	8.25a	10.25ab	13.50a	15.25a	18.50a
	Ridomil Gold®	8.50a	11.25a	14.40a	15.75a	15.00b
	Pr > F	0.112[NS]	0.049	0.060[NS]	0.050	<0.0001
	SE	0.431	0.459	0.771	0.704	0.447
	Treatment	Wk 2	Wk 4	Wk 6	Wk 8	Wk 10
Phytophthora infestans	Control	6.25a	8.00a	11.25c	12.00c	13.75b
	Marigold	6.25a	8.75a	19.50a	20.00a	20.50a
	Garlic	6.25a	8.00a	16.75b	17.50b	17.50ab
	Ginger	6.25a	8.00a	15.00b	16.00b	15.75b
	Ridomil Gold®	6.25a	8.75a	14.00b	15.50b	17.50ab
	Pr > F	0.943[NS]	0.166[NS]	0.001	<0.0001	0.013
	SE	0.258	0.320	0.840	0.592	0.928

Means followed by the same letter within the column are not significantly different at $p = 0.05$; Wk: week; SE: standard error; DF: degrees of freedom; NS: not significant.

other treatments. In week ten, the number of leaves on tomato plants treated with ginger, garlic, and Mexican marigold essential oil did not vary significantly but it was significantly higher than that of plants treated with Ridomil Gold® and the control.

In tomato plants inoculated with *P. infestans*, the number of leaves increased in all the treatments as the plants continued to grow (Table 3). There was no significant ($p > 0.05$) difference in leaf number between all treatments in weeks two and four. In weeks six and eight, there was

Table 4: Effect of the test pathogens on the leaf number of tomato plants.

Pathogen	Number of leaves				
	Wk2	Wk4	Wk6	Wk8	Wk 10
Alternaria solani	8.70[a]	10.05[a]	13.00[b]	14.20[b]	16.85[a]
Phytophthora infestans	6.25[b]	8.30[b]	15.30[a]	16.20[a]	17.00[a]
Pr > F	<0.0001	<0.0001	0.000	<0.0001	0.0730[NS]
SE	0.149	0.181	0.381	0.297	0.306

Means followed by the same letter within the column are not significantly different at $p = 0.05$; Wk: week; SE: standard error; NS: not significant.

significant ($p < 0.05$) difference in leaf number between treatments. Mexican marigold essential oils maintained the highest number of leaves while the control treatment had the lowest number. In week ten, only Mexican marigold treatment differed significantly from the control while ginger, garlic, and Ridomil Gold® did not differ significantly from the control treatment. The plants treated with Mexican marigold essential oils also appeared to have more vigor than other plants.

3.3.2. Effect of the Test Pathogens on Leaf Number of Tomato. The number of leaves increased in all the inoculated tomato plants as the weeks progressed (Table 4). However, the number of leaves varied significantly ($p < 0.0001$) between tomato plants inoculated with different test pathogens in the first eight weeks. More leaves were recorded in tomato plants inoculated with *A. solani* as compared to *P. infestans*. The number of tomato leaves did not differ significantly ($p > 0.05$) between the two pathogens in week 10 (Table 4).

3.3.3. Effects of the Essential Oils on Height of Inoculated Tomato Plant. As expected, the plant height increased with the age of the tomato plants (Table 5). For tomato plants inoculated with *A. solani,* there was no significant ($p > 0.05$) difference in plant height between treatments in weeks two, four, and six. In week eight, there was no significant difference between all the essential oils and synthetic fungicide treatments but these treatments recorded significantly ($p < 0.05$) higher plant height value than the control. In week ten, tomato plants sprayed with Mexican marigold essential oils recorded the highest plant height value (70.10 cm) while the control recorded the lowest (55.77 cm). The plant height of tomato plants sprayed with garlic and ginger essential oil did not vary significantly with those sprayed with Ridomil Gold® (Table 5).

Tomato plants inoculated with *P. infestans* also did not differ significantly in height in all treatments during the second week. In week four, the tomato plants in the control treatment showed significantly ($p < 0.05$) lower plant height value than all the other treatments which did not show significant variation among them in plant height. In week six, the plant height varied significantly ($p < 0.05$) between the treatments with plants in the control treatment being shorter than the plants in other treatments. Tomato plants sprayed with Mexican marigold, ginger, and garlic essential oils did not differ significantly in plant height but Mexican marigold treatment was significantly different from both the positive and negative control treatments. Results of weeks eight and ten showed a similar trend. Mexican marigold essential oil maintained the highest number of leaves in the two weeks. The plant height of tomato plants in the garlic, ginger, and positive control (Ridomil Gold) treatments did not have significant difference. The tomato plants in the negative control treatment were the shortest (Table 5).

3.3.4. Effect of the Test Pathogens on Tomato Plant Height. The plant height increased in all the tomato plants inoculated with the test pathogens (Table 6). However, the plant height varied significantly between the tomato plants inoculated with *A. solani* and *P. infestans* in week 2 and week 10. Tomato plants inoculated with *P. infestans* were taller than those inoculated with *A. solani* (Table 6). In weeks 4, 6, and 8, the plant height increased in all the tomato plants but did not differ significantly between the test pathogens (Table 6).

3.3.5. Effects of Essential Oils on Branch Number. The branch numbers obtained across the treatments varied significantly ($p < 0.05$) with tomato plants sprayed with Mexican marigold essential oil recording the highest number of branches among the plants inoculated with *A. solani.* However, the branch number in the Mexican marigold treatment did not significantly ($p > 0.05$) differ from the ones recorded from tomato plants sprayed with ginger (Table 7). The rest of the treatments did not differ significantly in tomato branch numbers. Among tomato plants inoculated with *P. infestans,* the number of branches differed significantly ($p < 0.05$) between treatments with the negative control recording the lowest branch number while tomato plants sprayed with Mexican marigold essential oil showed more branching but it did not differ significantly from the branching in garlic and ginger treatments. However, tomato plants sprayed with Mexican marigold essential oil had significantly higher number of branches compared to the synthetic fungicide (positive control) treatment (Table 7).

3.3.6. Effects of Essential Oils on Days to Flowering. The treatments significantly ($p < 0.05$) influenced the number of days to flowering on the tomato plants inoculated with *A. solani* (Table 7). Plants sprayed with Mexican marigold essential oil took significantly longer time to flower followed by the positive and the negative control treatments. Tomato plants sprayed with ginger and garlic essential oils took shorter time to flower as compared to the other treatments. Days to flowering did not differ significantly ($p > 0.05$) among tomato plants inoculated with *P. infestans* (Table 7).

3.3.7. Effects of Essential Oils on Fruit Number. The number of tomato fruits varied significantly ($p < 0.05$) between the treatments and the control (Table 7). Among tomato plants inoculated with *A. solani,* the control recorded the lowest

Table 5: Effects of essential oils on height of inoculated tomato plants.

	Treatment	Wk 2	Wk 4	Wk 6	Wk 8	Wk 10
Alternaria solani	Control	34.460[a]	46.020[a]	51.348[a]	52.228[b]	55.770[c]
	Marigold	30.960[a]	46.020[a]	58.323[a]	63.840[a]	70.098[a]
	Garlic	33.153[a]	47.165[a]	55.908[a]	61.040[a]	64.100[b]
	Ginger	34.128[a]	47.375[a]	57.245[a]	60.960[a]	62.640[b]
	Ridomil Gold®	33.310[a]	47.748[a]	57.485[a]	60.615[a]	61.113[b]
	Pr > F	0.293[NS]	0.520[NS]	0.099[NS]	0.027	0.003
	SE	1.147	1.208	1.572	1.823	1.585
	Treatment	Wk 2	Wk 4	Wk 6	Wk 8	Wk 10
Phytophthora infestans	Control	33.153[a]	36.473[b]	40.455[c]	43.810[c]	46.363[c]
	Marigold	36.408[a]	48.038[a]	63.948[a]	71.733[a]	78.208[a]
	Garlic	37.653[a]	47.435[a]	56.928[ab]	62.100[b]	68.365[b]
	Ginger	39.093[a]	49.055[a]	59.463[ab]	64.360[b]	66.953[b]
	Ridomil Gold®	35.980[a]	47.748[a]	53.873[b]	58.955[b]	64.253[b]
	Pr > F	0.146[NS]	0.004	0.000	<0.0001	<0.0001
	SE	1.452	1.750	2.101	1.763	1.283

Means followed by the same letter within the column are not significantly different at $p = 0.05$; Wk: week; SE: standard error; DF: degrees of freedom; NS: not significant.

Table 6: Effect of the test pathogens on plant height.

Pathogen	Height of inoculated tomato plants				
	Wk 2	Wk 4	Wk 6	Wk 8	Wk 10
Alternaria solani	33.202[b]	46.865[a]	56.062[a]	59.737[a]	62.744[b]
Phytophthora infestans	36.457[a]	45.750[a]	54.933[a]	60.192[a]	64.651[a]
Pr > F	0.001	0.275[NS]	0.378[NS]	0.700	0.031
SE	0.610	0.710	0.892	0.827	0.651

Means followed by the same letter within the column are not significantly different at $p = 0.05$; Wk: week; SE: standard error; NS: not significant.

number of fruits while the fruit number did not differ significantly ($p > 0.05$) between tomato plants sprayed with garlic, ginger, Mexican marigold essential oils, and Ridomil Gold® (Table 7). Among tomato plants inoculated with *P. infestans*, all the treatments recorded significantly higher fruit weight than the negative control but only Mexican marigold treatment was significantly different from the positive control (Ridomil Gold) in terms of fruit number (Table 7).

3.3.8. Effects of Essential Oils on Fruit Weight. The average fruit weight also varied significantly ($p < 0.05$) between the treatments. For the plants inoculated with *A. solani*, the negative control treatment recorded the lowest fruit weight compared to the other treatments which did not differ significantly in fruit weight. For the plants inoculated with *P. infestans*, ginger treatment recorded the highest fruit weight which was not significantly different from fruit weight recorded in Mexican marigold treatment. Tomato plants sprayed with essential oils from garlic and Mexican marigold did not differ significantly from the ones sprayed with Ridomil Gold®. The control recorded significantly lower fruit weight than all the other treatments (Table 7).

3.3.9. Effects of the Test Pathogens on Growth and Yield of Tomato. The branch number, days to flowering and fruit number did not differ significantly between tomato plants inoculated with the different test pathogens (Table 8). However, the tomato fruit weight differed significantly ($p < 0.0001$) between the test pathogens with tomato plants inoculated with *P. infestans* recording a lower fruit weight (Table 8).

3.4. Correlation between Disease Severity, Growth, and Yield of Tomato Plants. In the plants inoculated with *A. solani*, the plant height had a significant ($p < 0.05$) positive correlation with the number of leaves, fruit number, and fruit weight but was negatively correlated with disease severity. There was no significant ($p > 0.05$) correlation between plant height and branch number and days to flowering. The leaf number was also positively correlated with the fruit number and fruit weight and negatively correlated with disease severity but had no significant ($p > 0.05$) correlation with branch number and days to flowering. Disease severity was also found to negatively influence the fruit number and fruit weight but did not significantly ($p > 0.05$) affect the branch number and days to flowering. The branch number had no significant ($p > 0.05$) effect on days to flowering. Likewise, the days to flowering had no significant ($p > 0.05$) effect on fruit number and fruit weight (Table 9). In the plants inoculated with *P. infestans*, all the growth and yield parameters were significantly ($p < 0.05$) and positively correlated with each other and negatively correlated with disease severity (Table 9).

4. Discussion

The essential oils from the three plants were found to have significant efficacy against the early and late blight diseases of tomato that was comparable to that of Ridomil Gold synthetic fungicide. This is in consonance with the findings of Lengai et al. [2] and Nashwa and Abo-Elyousr [32] who reported that ginger, garlic, and turmeric extracts had a similar effect to Ridomil fungicide in their fungicidal properties against tomato early blight. According to Nashwa [18], Ridomil and the plant extracts efficacy were reflected in

Table 7: Effects of essential oils on growth and yield of tomato.

	Treatment	Branch number	Days to flowering	Fruit number	Fruit weight
Alternaria solani	Control	3.625[b]	51.083[b]	2.938[b]	31.113[b]
	Marigold	3.625[b]	47.500[c]	7.438[a]	41.193[a]
	Garlic	3.938[ab]	48.000[c]	6.500[a]	44.653[a]
	Ginger	4.438[a]	55.500[a]	10.813[a]	43.918[a]
	Ridomil Gold®	3.313[b]	51.750[b]	8.938[a]	43.263[a]
	Pr > F	0.019	0.001	0.005	0.000
	SE	0.165	0.896	1.029	1.452
	Treatment	Branch number	Days to flowering	Fruit number	Fruit weight
Phytophthora infestans	Control	0.688[c]	57.938[a]	1.563[c]	5.035[c]
	Marigold	3.875[ab]	55.375[a]	5.250[b]	42.333[ab]
	Garlic	4.063[ab]	53.688[a]	6.438[b]	36.225[b]
	Ginger	5.105[a]	57.375[a]	12.125[a]	46.518[a]
	Ridomil Gold®	3.000[b]	53.918[a]	7.438[b]	36.765[b]
	Pr > F	0.001	0.098	<0.0001	<0.0001
	SE	0.470	7.017	0.799	2.018

Means followed by the same letter within the column are not significantly different at $p = 0.05$; Wk: week; SE: standard error; DF: degrees of freedom; NS: not significant.

Table 8: Effects of the pathogen on growth and yield parameters of tomato.

Pathogens	Tomato growth and yield parameters			
	Branch number	Days to flowering	Fruit number	Fruit weight
Alternaria solani	3.788[a]	50.767[a]	7.325[a]	40.828[a]
Phytophthora infestans	3.346[a]	49.659[a]	6.563[a]	33.357[b]
Pr > F	0.058[NS]	0.737[NS]	0.209[NS]	<0.0001
SE	0.159	2.313	0.420	0.811

Means followed by the same letter within the column are not significantly different at $p = 0.05$; SE: standard error; NS: not significant.

Table 9: Correlation between disease severity, growth, and yields of tomato plants.

Variables	Disease severity	Leaf number	Plant height	Branch number	Days to flowering	Fruit number	Fruit weight
Disease severity		**−0.610**	**−0.869**	**−0.778**	**−0.657**	**−0.690**	**−0.945**
Leaf number	**−0.738**		**0.738**	**0.734**	**0.515**	**0.745**	**0.751**
Plant height	**−0.642**	**0.670**		**0.841**	**0.610**	**0.833**	**0.935**
Branch number	−0.202	−0.260	−0.293		**0.463**	**0.666**	**0.830**
Days to flowering	0.013	−0.185	0.251	−0.173		**0.629**	**0.746**
Fruit number	**−0.680**	**0.453**	**0.559**	0.085	0.241		**0.782**
Fruit weight	**−0.834**	**0.568**	**0.543**	0.117	−0.042	**0.579**	

Values in bold are different from 0 with a significance level alpha = 0.05. The upper and the lower values represent the effect of *P. infestans* and *A. solani* inoculation, respectively.

the fruit yield of tomato when compared with the untreated control. Jambhulkar et al. [33] reported that the mechanism of disease suppression may be either by active antimicrobial compounds acting on the pathogen directly by destroying their membranes or by the compounds inducing systemic resistance in host plants thus lowering disease development [34]. The antifungal and antibacterial effects of such compounds are a result of many compounds acting synergistically and there would be negligible chance of pathogens developing resistant races after application of essential oils [24]. Essential oils contain secondary metabolites such as terpenes, organosulfur, phenols, and alkaloids which are antimicrobial [35].

Several other studies have shown that essential oils have remarkable antimicrobial activity against pathogens causing plant diseases. Ngadze [36] reported higher antimicrobial effects of marigold extracts on tomato late blight than garlic extracts. Mexican marigold essential oil reportedly contains antibacterial properties against *Staphylococcus aureus* and *Bacillus subtilis* [37] as influenced by the presence of dihydrotagetone and α-ocimene compounds found in the essential oil. Marigold essential oil has also been reported to have antifungal properties expressed by compounds such as limonene, 1, 8-cineole, and α-pinene found in the essential oil [37]. This shows that essential oils have some broad-spectrum antimicrobial properties. Reports of Mahmoud et al. [38] showed that garlic essential oil portrayed high antimicrobial activity against damping off disease in peanuts. Diallyl disulfide in garlic essential oil portrayed an antifungal activity against *Phytophthora nicotianae* that cause tobacco black shank disease [39]. According to Singh et al. [40], ginger essential oils contain phenolic compounds

such as shogaols, zingerone, and gingerols that portray antimicrobial potency. Silvia et al. [41] reported that fungi are more susceptible to ginger components than bacteria.

The antimicrobial potential of the essential oils may be determined by the chemical composition, method of extraction, and the conditions to which the plant material was subjected in the preparation for essential oil extraction [41]. The essential oils used in this study were extracted from fresh material which reportedly contains higher concentrations of oxygenated compounds (such as borneol, neral, 1,8-cineole, α-terpineol, and geranial) than dried ginger essential oils and therefore low antifungal and antibacterial properties [41]. This could have been the reason behind the higher antifungal activity revealed by the essential oils that significantly reduced the disease severity in the treated plants as compared to the untreated ones. The disease severity may also be influenced by the susceptibility of the cultivar used and the aggressiveness of the test pathogens. *P. infestans* caused a higher disease severity on the tomato plants in the negative control. These results are similar to Quintanilla et al. [42] who reported that *P. infestans* caused damage above 65% in potato varieties. This shows that pathogen species respond differently to the different essential oils and synthetic fungicides. *P. infestans* seemed to be more susceptible to essential oils and the Ridomil fungicide and this corroborated the earlier findings by Lengai et al. [2].

The essential oils used in this study appeared to further influence the growth and yields of inoculated tomato plants as compared to the control. There was a positive correlation between plant height with number of leaves and fruit number. The leaf number was also positively correlated with the fruit number and fruit weight. All these parameters were negatively correlated with disease severity. This corroborated the theory of Naing et al. [13] that some organic pesticides induce disease resistance systems of the plant which lead to healthy growth of the plants and thus better production. Ahmad et al. [43] also reported that tomato plants sprayed with extracts of garlic and ginger were taller and yielded more than the untreated control. Nashwa and Abo-Elyousr [32] also showed that the *Eucalyptus camaldulensis* (eucalyptus), *Ocimum basilicum* (sweat basil), *Allium sativum* (garlic), *Nerium oleander* (oleander), *Datura stramonium* (jimsonweed), and *Azadirachta indica* (neem) plant extracts boosted the yield of tomato as compared to the control. However, Stangarlin et al. [12] cited a contrasting finding that there were no fruit yield differences in plants sprayed with several plant extracts.

In this study, the plants that were sprayed with Mexican marigold essential oil performed better than those in the other treatments. Apparently, Mexican marigold repelled some greenhouse pests such as whiteflies more than ginger and garlic thus improving the growth and consequently the yields of the treated plants. Similar observation was made by Rizvi and Jaffar, [44] who reported that increase in yield may also be due to reduced pests during growth and fruit development due to repellence property of the essential oils. However, some plant extracts and essential oils have growth boosting effects which improve the yield of the plants [13, 45, 46]. Garlic contains allicin compound which is said to promote the plant growth and fruit yield in tomato plants [43] but also contains diallyl disulfide compound which reportedly restricted the growth of tobacco plants [39].

5. Conclusion

The study showed that the essential oils from Mexican marigold, ginger, and garlic were as effective as the Ridomil Gold® synthetic fungicide in managing the early and late blight diseases of tomato. Consequently, the treatments significantly boosted the growth and yields of tomato plants. These essential oils can therefore be incorporated in the early and late blight management programs as eco-friendly option to synthetic pesticides. This will lower the chemical residue levels in fruits and vegetables thus improving the fruit and vegetable quality and reducing the risks and hazards of toxic fungicides. This will in turn ensure access to the best markets of the fresh produce resulting in increased income for the producers and the country at large. This study used the vertical steam distillation method to extract the essential oils from fresh samples of the selected test plants. However, there is a need to compare the extraction efficiency of this method with other methods.

Data Availability

Most of the data used to support the findings of this study are included in the article. Additional data are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this study.

Acknowledgments

This study was funded through a scholarship by Higher Education Loans Board (HELB), Kenya.

References

[1] N. O. Willis, N. N. Gideon, and K. Dora, "Characteristics and production constraints of smallholder tomato production in Kenya," *Scientific African*, vol. 2, Article ID e00014, 2019.

[2] G. M. W. Lengai, J. W. Muthomi, and R. D. Narla, "Efficacy of plant extracts and antagonistic fungi in managing tomato pests and diseases under filed conditions," *Journal of Agriculture and Life Sciences*, vol. 4, no. 2, pp. 2375–4222, 2017.

[3] A. Tijjani, S. A. Adebitan, and A. U. Gurama, "*Invitro* and *invivo* efficacy of some plant extracts for the control of tomato fruit rot caused by *Aspergillus flavus*," *International Journal of Scientific and Research Publications*, vol. 4, no. 4, 2014.

[4] O. Asante, M. Osei, and A. Dankyi, "Producer characteristics and determinants of technical efficiency of tomato based production systems in Ghana," *Journal of Development and Agricultural Economics*, vol. 5, no. 3, pp. 92–103, 2013.

[5] J. M. Wachira, P. M. Mshenga, and M. Saidi, "Comparison of the profitability of small-scale greenhouse and open-field tomato production systems in Nakuru-North District, Kenya," *Asian Journal of Agricultural Sciences*, vol. 6, no. 2, pp. 54–61, 2014.

[6] I. E. Peralta, S. Knapp, and D. M. Spooner, "New species of wild tomatoes (Solanum Section Lycopersicon: Solanaceae) from Northern Peru," *Systematic Botany*, vol. 30, no. 2, pp. 424–434, 2005.

[7] N. Verma and S. Verma, "Alternaria disease of vegetable crops and new approach for its control," *Asian Journal of Experimental Biological Sciences*, vol. 1, no. 3, pp. 681–692, 2010.

[8] J. B. T. Junior, R. Rezende, A. T. Itako, P. S. Freitas, and J. A. Frizzone, "Drip fungigation in early blight control of tomato," *Acta Scientiarum Agronomy*, vol. 3, no. 1, pp. 9–14, 2011.

[9] G. S. E. Mizubuti, V. L. Junior, and G. A. Forbes, "Management of late blight with alternative products," *Pest Technology*, vol. 1, no. 2, pp. 106–116, 2007.

[10] W. E. Fry, H. D. Thurston, and W. R. Stevenson, "Late blight," in *Compendium of Potato Diseases*, W. R. Stevenson, R. Loria, G. D. Franc, and D. P. Weingartner, Eds., pp. 22-23, The American Phytopathological Society, St. Paul, MN, USA, 2nd edition, 2001.

[11] L. G. Mugao, P. W. Muturi, B. M. Gichimu, and E. K. Njoroge, "*In-vitro* control of *Phytophthora infestans* and *Alternaria solani* using crude extracts and essential oils from selected plants," *International Journal of Agronomy*, vol. 2020, Article ID 8845692, , 2020.

[12] J. A. Stangarlin, O. J. Kuhn, L. Assi, and K. R. F. Schwan-Estrada, "Control of plant diseases using extracts from medicinal plants and fungi," *Formatex Microbiology Series*, vol. 1, pp. 1033–1042, 2011.

[13] W. K Naing, M. Anees, H. X. Nyugen, and S. Y. Lee, "Biocontrol of late blight diseases (*Phytophthora capsici*) of pepper and the plant growth promotion by *Paenibacillus chimensis* KWNJ8," *Journal of Phytopathology*, vol. 2, pp. 164-165, 2013.

[14] S. Engindeniz and G. O. Cosar, "An economic comparison of pesticide applications for processing and table tomatoes: a case study for Turkey," *Journal of Plant Protection Research*, vol. 53, no. 3, pp. 230–237, 2013.

[15] R. Bhattacharjee and U. Dey, "An overview of fungal and bacterial bio-pesticides to control plant pathogens and diseases," *African Journal of Microbiology Research*, vol. 8, no. 7, pp. 1749–1769, 2014.

[16] M. Zaker, "Natural plant products as eco-friendly fungicides for plant diseases control- A review," *The Agriculturists*, vol. 14, no. 1, pp. 134–141, 2016.

[17] V. Kimani, "Bio-Pesticides development, use and regulation in Kenya," in *Proceedings of the Regional Experts Workshop on Development, Regulation and Use of Bio-Pesticides in East Africa*, Nairobi, Kenya, May 2014.

[18] M. A. S. Nashwa, "Control of tomato early blight disease by certain aqueous plant extracts," *Plant Pathology Journal*, vol. 10, no. 4, pp. 187–191, 2011.

[19] T. Taghavi, C. Kim, and A. Rahemi, "Role of Natural volatiles and essential oils in extending shelf life and controlling postharvest microorganisms of small fruits," *Microorganisms*, vol. 6, no. 4, 2018.

[20] B. Prakash, A. Kedia, P. K. Mishra, and N. K. Dubey, "Plant essential oils as food preservatives to control moulds, mycotoxin contamination and oxidative deterioration of agri-food commodities - potentials and challenges," *Food Control*, vol. 47, pp. 381–391, 2015.

[21] B. X. Camiletti, C. M. Asensio, M. L. Pecci, and E. I. Lucini, "Natural control of corn postharvest fungi *Aspergillus flavus* and *Penicillium* sp. using essential oils from plants grown in Argentina," *Journal of Food Science*, vol. 79, pp. M2499–M2506, 2014.

[22] L. G. Mugao, B. M. Gichimu, P. W. Muturi, and S. T. Mukono, "Characterization of the volatile compounds of essential oils of selected plants in Kenya," *Biochemistry Research International*, vol. 2020, Article ID 8861798, 2020.

[23] F. D. Lalla, B. Ahmed, A. Omar, and M. Mohieddine, "Chemical composition and biological activity of *Allium sativum* essential oils against *Callosobruchus maculates*," *IOSR Journal of Environmental Science, Toxicology and Food Technology*, vol. 1, no. 1, pp. 30–36, 2013.

[24] S. El Rasheed and A. S. El Rasheed, "Vegetable diseases control by using essential oils to access organic production in Sudan," *Agricultural Research and Technology*, vol. 6, no. 4, Article ID 555694, 2017.

[25] *Kenya County Guide*, Online Publication, Kirinyaga County., 2015, https://www.kenyacountyguide.co.ke/kirinyaga-county/.

[26] M. K. Naik, Y. Prasad, K. V. Bhat, and D. Rani, "Morphological, physiological, pathogenic and molecular variability among isolates of *Alternaria solani* from tomato," *Indian Phytopathology Journal*, vol. 63, no. 2, pp. 168–173, 2010.

[27] C. J. Alexopoulos, C. W. Mims, and M. Blackwell, *Introductory Mycology*, John Wiley & Sons, New York, NY, USA, 2002.

[28] R. P. Adams, *Identification of Essential Oils Components by Gas Chromatography/Quadruple Mass Spectroscopy*, Allured Publishing Corporation, Carol Stream, IL, USA, 4th edition, 2007.

[29] P. Latha, T. Anand, N. Ragupathi, V. Prakasam, and R. Samiyappan, "Antimicrobial activity of plant extracts and induction of systemic resistance in tomato plants by mixtures of PGPR strains and Zimmu leaf extract against *Alternaria solani*," *Biological Control*, vol. 50, no. 2, pp. 85–93, 2009.

[30] R. Chaerani and R. E. Voorrips, "Tomato early blight (*Alternaria solani*): the pathogen, genetics, and breeding for resistance," *Journal of General Plant Pathology*, vol. 72, no. 6, pp. 335–347, 2006.

[31] A. S. Derbalah, M. S. El-Mahrouk, and A. B. El-Sayed, "Efficacy and safety of some plant extracts against tomato early blight disease caused by *Alternaria solani*," *Plant Pathology Journal*, vol. 10, no. 3, pp. 115–121, 2011.

[32] S. M. A. Nashwa and A. M. K. Abo-Elyousr, "Evaluation of various plant extracts against the early blight disease of tomato plants under green house and field conditions," *Plant Protection Science*, vol. 48, no. 2, pp. 74–79, 2012.

[33] P. P. Jambhulkar, N. Jambhulkar, M. Meghwal, and G. S. Ameta, "Altering conidial dispersal of *Alternaria solani* by modifying microclimate in tomato crop canopy," *Plant Pathology Journal*, vol. 32, no. 6, pp. 508–518, 2016.

[34] S. Kagale, T. Marimuthu, B. Thayumanavan, R. Nandakumar, and R. Samiyappan, "Antimicrobial activity and induction of systemic resistance in rice by leaf extract of Datura metel against Rhizoctonia solani and Xanthomonas oryzae pv. oryzae," *Physiological and Molecular Plant Pathology*, vol. 65, no. 2, pp. 91–100, 2004.

[35] N. Din, M. Ahmad, M. Siddique et al., "Phytobiocidal management of bacterial wilt of tomato caused by *Ralstonia solanacearum* (Smith) Yabuuchi," *Spanish Journal of Agricultural Research*, vol. 14, no. 3, 2016.

[36] E. Ngadze, "In-vitro and greenhouse evaluation of botanical extracts for antifungal activity against *Phythopthora infestans*," *Journal of Biopesticides*, vol. 7, no. 2, pp. 198–203, 2014.

[37] M. M. Gakuubi, W. Wanzala, J. M. Wagacha, and S. F. Dossaji, "Bioactive properties of *Targetes minuta* essential oils,"

American Journal of Essential oils and natural products, vol. 4, no. 2, pp. 27–36, 2016.

[38] E. Mahmoud, M. Ibrahim, and T. Essa, "Efficasy of plant essential oils in controlling damping-off and root rot diseases of peanut as fungicide alternatives," *Journal of Applied Sciences Research*, vol. 9, no. 3, pp. 1612–1622, 2013.

[39] Y. Wang, K. Wei, X. Han, D. Zhao, and Y. Zheng, "The antifungal effects of garlic essential oil on *Phytophthora nicotianae* and the inhibitory component involved," *Biomolecules*, vol. 9, no. 10, 2019.

[40] G. Singh, I. P. S. Kapoor, P. Singh, C. S. de Heluani, M. P. de Lampasona, and C. A. N. Catalan, "Chemistry, antioxidant and antimicrobial investigations on essential oil and oleoresins of *Zingiber officinale*," *Food and Chemical Toxicology*, vol. 46, no. 10, pp. 3295–3302, 2008.

[41] C. B. Silvia, H. C. Paola, S. C. Teresa, S. Raul, I. R. Irving, and E. O. Carlos, "Antimicrobial activity of ginger (*Zingiber officinale*) and its application in food products," *Food Reviews International*, vol. 35, no. 5, pp. 407–426, 2019.

[42] P. Quintanilla, *Biological Control in Potato and Tomato to Enhance Resistance to Plant Pathogens – Especially against Phytophthora Infestans in Potato*Swedish University of Agricultural Sciences, Upp-sala, Sweden, 2002.

[43] F. Ahmad, F. Raziq, N. Ullah, H. Khan, and N. Din, "*In-vitro* and *in-vivo* bio-assay of phytobiocidal effect of plant extracts on *Alternaria solani* causing agent of early blight disease in tomato," *Archives of Phytopathology and Plant Protection*, vol. 50, no. 11, pp. 568–583, 2017.

[44] H. A. S. Rizvi and S. Jaffar, "Efficacy of some selected chemical insecticides and bio-pesticides against tomato fruit worm, (*Helicoverpa armigera*) under the agro climatic conditions of Gilgit Baltistan, Pakistan," *Journal of Entomology and Zoology Studies*, vol. 3, no. 4, pp. 50–52, 2015.

[45] M. Culver, T. Fanuel, and Z. A. Chiteka, "Effects of moringa extracts on growth and yield of tomato," *Greener Journal of Agricultural Science*, vol. 2, no. 5, pp. 207–211, 2012.

[46] M. M. Rahman, S. H. Ahmad, and M. T. M. Mohamed, "Antimicrobial compounds from leaf extracts of *Jatropha curcas, Psidium guajava* and *Andrographis paniculata*," *The Scientific World Journal*, vol. 2014, Article ID 635240, 2014.