Field Evaluation of Aqueous Ginger (*Zingiber officinale*) Extract Concentrations for Suppression of Tomato Early Blight and Improvement of Fruit Yield

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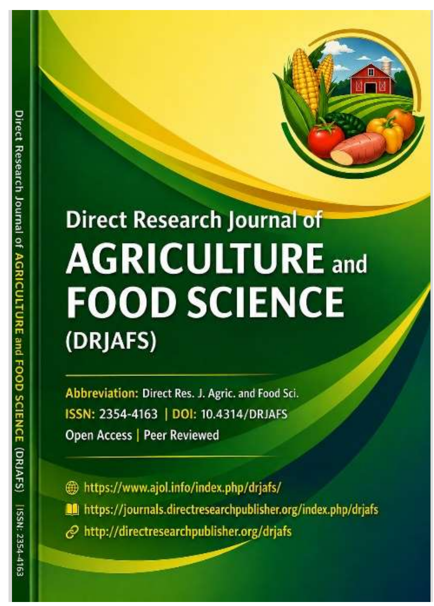
ABSTRACT

Early blight causes significant yield losses in tomato in tropical and subtropical regions. Synthetic fungicides commonly used for the management have limitations such as high costs, inconsistent quality, risk of pathogen resistance, safety and environmental concerns that call for sustainable botanical alternatives. Thus, the study evaluated different concentrations of aqueous ginger (Zingiber officinale) extract for suppression of tomato early blight and improvement of fruit yield under field conditions. The experiment was conducted at the Research and Demonstration Farm of Enugu State Polytechnic, Iwollo, Nigeria. The treatments consisted of 0 (negative control), 5, 10, 15, and 20% v/v aqueous ginger extract, and Redforce (a.i. Metalaxyl 12% + Copper (I) oxide 60% WP) as standard positive control. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. Data were collected on incidence and severity of early blight, disease suppression, survival percentage, total fruit yield, and percentage of marketable fruits and subjected to Analysis of Variance (ANOVA) at 5% level of significance. Treatment means with significant difference were separated using Fisher's Least Significant Difference (F-LSD) at 0.05 probability level. The results showed significant differences (p < 0.01) among the treatments in all the parameters evaluated. Aqueous ginger extract treatments significantly (p < 0.01) suppressed early blight development and increased total fruit yield and percentage of marketable fruits compared to negative control. The 20% v/v treatment recorded the highest performance among the ginger-extract treatments and suppressed early blight by 86.23% compared to the negative control and resulted in a 253.85% increase in fruit yield. It could be concluded from the findings of the study that aqueous ginger extract was effective in the management of early blight in tomato under field conditions. The 20% v/v aqueous ginger extract was the most effective treatment and could therefore be recommended as a botanical alternative for sustainable management of early blight in rainfed tomato production. However, further studies involving multi-location and multi-season evaluations are recommended to validate its performance under different production environments.

Keywords: *Alternaria solani, Biopesticides, Botanical fungicide, Plant extracts, Solanum lycopersicum, Sustainable agriculture*



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INTRODUCTION

Global food demand continues to rise as the world population increases and is projected to reach 9.7 billion by 2050 (Bahar *et al*., 2020). Meeting this demand requires sustainable production of economically important staple and horticultural crops, as well as improved disease and post-harvest management to increase global food supply. Tomato (*Solanum lycopersicum* L.) is the most widely cultivated and consumed vegetable globally due to its nutritional and economic importance, ranked only after potato (Panno *et al*, 2021). It plays important role in food security and contributes to the income of farmers, especially smallholder farmers (Panno *et al*, 2021). Global tomato production exceeds 190 million metric tonnes annually with Egypt and Nigeria the leading tomato-producing countries in Africa (FAO, 2024; Norbert, S. *et al*., 2023). It is a rich source of vitamins A and C, potassium, and antioxidants like lycopene (Collins *et al.*, 2022; Panno *et al*., 2021).

Climate variability, rising temperatures, irregular rainfall, drought, and increased pest and disease incidence affect crop production (Dube *et al*., 2020; Norbert, K. *et al*., 2023; Omokaro, 2025). These factors reduce tomato yield per unit area (Krishna *et al*., 2022). Disease is one of the most important biotic constraints to tomato production in many growing regions due to low genetic diversity of the cultivated types (Panno, *et al*. 2021). In all the diseases that affect tomato production, fungal diseases are among the most devastating. One of the most destructive is early blight, caused by a toxigenic fungus *Alternaria solani* (Makhuvelea *et al*., 2020). The disease affects tomatoes at all growth stages, initially presenting as concentric dark brown lesions on older leaves, often surrounded by yellow halos (Choudhary *et al*., 2024). As the infection progresses, defoliation occurs, causing reduced photosynthetic capacity, which leads to yield loss and poor fruit quality. Early blight of tomato thrives in warm and humid conditions with frequent rainfall, which makes it prevalent in many tropical and subtropical regions. It is a polycyclic disease and more common in fields with history of early blight. Close plant spacing and prolonged leaf wetness favour its development and spread. Globally, yield losses due to early blight can reach up to 80% in severe cases (Chaerani & Voorrips, 2006). Early blight is commonly managed with synthetic fungicides such as mancozeb, chlorothalonil, and copper-based products. While these synthetic fungicides are somewhat effective, they are not cost effective and are associated with water contamination, soil toxicity, effects on non-target organisms, and residues in crops; with their repeated use leading to the emergence of resistant *A. solani* strains, which reduces their long-term efficacy (Bhandari *et al*., 2021; Anaduaka *et al*., 2023; Ebisa &Tamiru, 2023).These limitations have increased interest in botanical alternatives for sustainable disease management in tomato production. In recent years, botanicals such as plant extracts and essential oils have received attention as eco-friendly and sustainable alternatives to synthetic fungicides. These extracts contain bioactive compounds and offer a biodegradable, health-conscious approach to managing fungal diseases (Prakash *et al*., 2020; Choudhary *et al*., 2024). They are considered more affordable and provide a synergistic effect by acting as organic protectants while stimulating natural defence mechanisms in plants (Gacem *et al*., 2020; Meng *et al*., 2020). Several studies have established the efficacy of some botanicals in controlling fungal pathogens on crops due to the fungistatic and fungicidal photochemicals in their extracts (Bhandari *et al*., 2021; Ebisa & Tamiru, 2023; Choudhary *et al*., 2024). Their antifungal activity is associated with phenolics, flavonoids, alkaloids, terpenoids and other secondary metabolites that inhibit fungal growth (Bhandari *et al*., 2021; Ebisa & Tamiru, 2023; Choudhary *et al*., 2024).

The advantages of plant extracts lie in their complex mixtures of bioactive compounds, which make it difficult for pathogens to develop resistance strains; unlike single-site synthetic fungicides, and; low or no phytotoxicity at all concentrations (Ebisa & Tamiru, 2023). Extracts from plants such as neem, garlic, moringa, and ginger are bio stimulants and contain bioactive compounds that influence plant growth and physiological processes (Aremu *et al*., 2024; du Jardin, 2015; García-García *et al*., 2020; Rouphael & Colla, 2020). Reported effects include improved root development, improved nutrient uptake, increased chlorophyll content, improved photosynthetic performance, activation of antioxidant systems, and induction of plant defence mechanisms (Rouphael & Colla, 2020; Palmieri *et al*., 2022). The efficacy of botanical extracts depends on extraction method, concentration, application frequency, environmental conditions, and crop species (Hassan *et al*., 2021; Chakanaka *et al*., 2025). Organic solvents, such as methanol, ethanol, acetone, hexane and ethyl acetate, generally extract higher concentrations of bioactive compounds from plants than water (Azwanida, 2015; Dai & Mumper, 2010). However, their adoption by smallholder farmers, who account for a substantial proportion of horticultural crop production in sub-Saharan Africa, is constrained by high cost, limited availability, and safety considerations (Elsorady & Elgindy, 2022). Aqueous plant extracts can be prepared from locally available materials without specialized equipment and are therefore more suitable for resource-limited production systems in sub-Saharan Africa. Among the botanicals investigated for crop protection, ginger (*Zingiber officinale*), a widely cultivated spice and medicinal plant, has gained attention for its fungicidal properties (Irfan *et al*., 2023; Ebisa & Tamiru, 2023). Ginger rhizomes contain bioactive compounds including gingerols, shogaols, zingerone, and paradols (Ebisa & Tamiru, 2023; Hyder *et al*., 2024; Mao *et al*., 2019). These compounds inhibit fungal growth through disruption of cell membranes, inhibition of enzymatic activity, interference with spore germination, and suppression of mycelial development (Hyder *et al*., 2024;

Mao *et al*., 2019; Semwal *et al*., 2015). Ginger extracts have been shown to have antifungal activity against several plant pathogens, including fungal species (Irfan *et al*., 2023; Ebisa & Tamiru, 2023). Ginger compounds are associated with enhanced antioxidant activity and improved physiological performance in plants (Elsorady & Elgindy, 2022; Ballester *et al*., 2023). Studies have reported inhibitory effects of ginger extract against *A. solani* and its use in the management of early blight of tomato mostly under controlled environments. Pooja *et al*. (2026) reported that ginger rhizome extract reduced early blight intensity and increased fruit yield per hectare across three cropping seasons under field conditions. Similarly, Latake *et al*. (2022) reported significant suppression of early blight under field conditions using aqueous ginger extract and concentration-dependent inhibition of *A. solani* in vitro. However, information remains limited on the evaluation of different concentrations of aqueous ginger extract for early blight suppression and associated productivity responses of tomato under field conditions. Thus, the study aimed to investigate different concentrations of aqueous ginger (*Zingiber officinale*) extract for suppression of tomato early blight and improvement of fruit yield under field conditions. The specific objectives were: (i) to evaluate the effects of different concentrations of aqueous ginger extract on the incidence and severity of early blight in tomato under field conditions; (ii) to determine the effects of different concentrations of aqueous ginger extract on plant survival, total fruit yield, and marketable fruit production; (iii) to determine the relationship between early blight suppression and tomato performance parameters, including survival percentage, total fruit yield, and marketable fruit production; and (iv) to identify the concentration of aqueous ginger extract with the greatest suppressive potential against early blight under field conditions. The findings provide evidence on the potential of aqueous ginger extract as a botanical alternative for sustainable management of early blight and enhancement of productivity in tomato production.

MATERIALS AND METHODS

Description of the study area

The experiment was conducted in 2025 in Enugu State Polytechnic, Iwollo, Enugu State, Nigeria, during the rainy season as late planting (September to November). The area is at coordinates 007° 16.834' E and 06° 16.834' N, and 252 meters above sea level with an average annual temperature range of 23.0–27.9 °C (Climate-data, 2025). The rainfall pattern is bimodal from April to November, with a short spell in August often referred to as the August break. The average annual rainfall is 1726 mm (Climate-data, 2025). The precipitation varies from 9 mm in the driest month of December to 301 mm in the wettest month of September (Climate-data, 2025). Iwollo belongs to Group A (Aw – Tropical wet climate) according to the Köppen-Geiger climatic classification (Peel *et al*., 2007). The climate is characterized by high rainfall with hot and humid conditions. The location has a history of early blight of tomato.

Source of materials

Fresh rhizomes of ginger (*Zingiber officinale*) variety, Taffin Giwa (Yellow UG1) (Appendix A) with characteristics pungent properties were used for the preparation of the aqueous ginger extract treatments used for the study and were sourced from the market in Enugu, Nigeria. Redforce (a.i. Metalaxyl 12% + Copper (I) oxide, 60% WP) synthetic fungicide (Appendix A) was used as standard positive control in the study and was sourced from an agro-allied dealer in Enugu, Nigeria. Tomato cultivar Roma VF commonly cultivated in the study area was used for the experiment and was also source from an agro-allied dealer in Enugu, Nigeria.

Preparation of ginger extracts treatments

The extraction procedure described by Choudhary *et al*. (2024), which can easily be adopted by farmers, was followed. Fresh ginger rhizomes with an average moisture content of 79.4% were washed thoroughly in clean water, weighed and ground with an equal amount of sterile water (1:1 v/w). The solution was heated at 80°C for 10 minutes in a hot water bath and filtered through double-layered muslin cloth and then through Whatman No. 1 filter paper to obtain a stock ginger extract solution (100%) (Appendix A). The ginger extract was freshly prepared for each application and used without storage. Five concentrations of ginger extract treatments (Appendix A) for the study were prepared by diluting the stock extract in water as follows:

T1 - 0% v/v = no part of ginger extract to water (100% water) per volume
T2 - 5% v/v = 1 part of ginger extract to 19 parts of water (5% ginger extract, 95% water) per volume
T3 - 10% v/v = 1 part of ginger extract to 9 parts of water (10% ginger extract, 90% water) per volume
T4 - 15% v/v = 3 parts of ginger extract to 17 parts of water (15% ginger extract, 85% water) per volume
T5 - 20% v/v = 1 part of ginger extract to 4 parts of water (20% ginger extract, 80 % water) per volume.

Nursery operation

The tomato seedlings used for the study were raised in a ground nursery similar to the practice used by local farmers. A raised nursery bed measuring 1.5m x 1m (1.5m^2) was prepared near the experimental field by clearing and tilling of the soil. Well cured poultry manure at the rate of 15 tons per hectare was incorporated into the nursery bed. The tomato seeds were sown to a depth of about 2.5cm in lines that were 4cm apart. The nursery was watered at when due throughout the nursery duration.

Experimental Design and Treatments

The experiment was laid out in a randomized complete block design (RCBD) with three replications. The treatments comprised four aqueous ginger extract concentrations, a negative control and a standard positive control as follows:

T1 – 0% v/v aqueous ginger extract (negative control)
T2 – 5% v/v aqueous ginger extract
T3 – 10% v/v aqueous ginger extract
T4 – 15% v/v aqueous ginger extract
T5 – 20% v/v aqueous ginger extract
T6 – Redforce (positive control)

The treatments were randomly assigned to the experimental units within each block by balloting without replacement.

Field preparation

A land area measuring 11.5 x 8 meters (92 m^2) was marked out, cleared, and tilled manually for the experiment. The land was divided into three blocks, each containing six plots (2m x 1.5m), corresponding to one of the six treatments. The blocks were arranged perpendicular to the slope of the land to account for variation associated with the field gradient. Adjacent blocks and plots were separated by 1m and 0.5m alleys, respectively. Well cured poultry manure at the rate of 15 tons per hectare was incorporated into the soil during land preparation.

Agronomic practices and Treatment application

Healthy looking tomato seedlings from the nursery were transplanted into the field four weeks after sowing using 75 cm x 50 cm in-between rows and within rows spacing, giving a plant density of 9 per plot (30,000 stands per hectare). The transplanting was done in the evening. The treatments were applied using a 2-litre handheld sprayer (Appendix A). A soil drench of the treatments was done at 400 litres per hectare two weeks before transplanting as first treatment application. The subsequent treatments applications were foliar at 400 litres per hectare every 2 weeks from 2 to 8 weeks after transplanting. Each plot (3 m^2) received 120 ml of treatments spray per application.Redforce fungicide (standard positive control) was prepared according to the manufacturer's recommended rate of 2.5 g per litre of water. Weeding was done manually using hoe as at when due.

Isolation and Identification of the causative pathogen

Early blight infected tomato leaves were collected from the experimental farm and taken to the laboratory for isolation and identification of the causative pathogen. The causative pathogen was isolated as described by Adomako *et al*. (2016), with modification. Lesions on the infected leaves were excised using a razor blade and stirred up in 10 mL of sterilized distilled water in a Petri dish. The conidial suspension that was obtained was filtered through cheesecloth to remove leaf remnants, mounted on a slide and observed using a KYOWA TOKYO JAPAN monocular microscope at x100 magnification to identify the pathogen.

Pathogenicity test

The pathogenicity was confirmed using Koch's postulates (Byrd & Segre, 2016). Sterilized filter paper was moistened with distilled water and placed in a Petri dish. Disease-free tomato leaves were placed on the moistened filter paper and inoculated with 2 ml of a conidial suspension of the isolated pathogen, following the procedure described by Adomako *et al*. (2016), with modification of the inoculum used. The inoculated leaves were observed for the development of symptoms similar to those observed on the naturally infected leaves. The pathogen was subsequently re-isolated from the symptomatic inoculated leaves and examined microscopically to confirm the presence of the same pathogen.

Data collection

Observations were made on incidence and severity of early blight. Percentage suppression of early blight, relative efficacy of the treatments against early blight, survival percentage, total fruit yield, percentage of marketable fruits, yield gain, relative yield and yield index were determined.

Incidence and severity of early blight

Observations on incidence and severity of early blight were made at 4 and 8 weeks after transplanting. All nine plants in each plot were assessed for visible symptoms of early blight. The plants showing symptoms of early blight in each plot were counted for determination of disease incidence. For disease severity, the total number of leaves and number of leaves showing visible early blight symptoms were counted on the infected plants, and the respective counts were summed across the infected plants per plot, following the approach described by Ugwuanyi *et al*. (2016). Disease incidence and disease severity were calculated as follows:

$$\text{Disease incidence (\%)} = \frac{\text{Number of infected plants per plot} \times 100}{\text{Total number of plants per plot}}$$

$$\text{Disease severity (\%)} = \frac{\text{Total number of affected leaves per plot} \times 100}{\text{Total number of leaves on infected plants per plot}}$$

Disease severity was rated as described by Omeje *et al*. (2025) as follows: <1% = no infection, 1 – 25% = low infection, 26 – 50% = moderate infection, 51 – 75% = high infection, >75% = very high infection.

Early blight suppression

Percentage suppression of early blight for each of the treatments was calculated using the formula:

$$\% \text{ Suppression} = \frac{\text{Severity in negative control} - \text{Severity in treatment} \times 100}{\text{Severity in negative control}}$$

Relative efficacy of the aqueous ginger extract

Relative efficacy of the aqueous ginger extract treatments was calculated using the formula:

$$\text{Relative efficacy (\%)} = \frac{\text{Percentage suppression of aqueous ginger treatment} \times 100}{\text{Percentage suppression of the standard positive control}}$$

Survival percentage (%)

Survival percentage was determined by counting the number of survived plants per plot at 8 WAT and calculated using the formula:

$$\text{Survival percentage (\%)} = \frac{\text{Number of survived plants per plot} \times 100}{\text{Number of plants transplanted per plot}}$$

Total fruit yield per plot (kg)

Mature and ripe fruits were harvested regularly from each plot and weighed using an electronic weighing scale. Total fruit yield per plot was obtained by summing the weights of all individual harvests.

Total Fruit Yield per hectare (tons)

Total fruit yield per hectare was calculated by extrapolating the total fruit yield per plot using the plot area and the area of a hectare. The total fruit yield was calculated as follows:

$$\text{Total fruit yield per hectare (tons)} = \frac{\text{Total fruit yield per plot (kg)} \times \text{Area of a hectare } (m^2)}{\text{Area of a plot } (m^2) \times 1000}$$

Where;
Area of a hectare = 10,000 m^2
Area of a plot = 3 m^2

Percentage of marketable fruits (%)

The marketable fruits per plot was separated from the unmarketable ones by physical observation of the fruits for each harvest and weighed. The total marketable fruit yield per plot (kg) was obtained by summing the weights of marketable fruits from all individual harvests. Percentage of marketable fruits was determined using the formula:

$$\text{Percentage of marketable fruits (\%)} = \frac{\text{Weight of marketable fruits per plot (kg)} \times 100}{\text{Total fruit weight per plot (kg)}}$$

Yield gain (%)

Yield gain was determined by comparing the yield in each treatment with the yield in negative control. It was calculated using the formula:

$$\text{Yield gain (\%)} = \frac{\text{Treatment means yield (kg)} - \text{Negative control means yield (kg)} \times 100}{\text{Negative control means yield (kg)}}$$

Relative yield (%)

The relative yield for the treatments was determined by comparing the total fruit yield from each treatment with the total fruit yield from the standard positive control. It was calculated using the formula:

$$\text{Relative yield (\%)} = \frac{\text{Treatment means yield (kg)} \times 100}{\text{Standard positive control means yield (kg)}}$$

Yield index

Yield index was calculated using the formula:

$$\text{Yield index} = \frac{\text{Treatment means yield (kg)}}{\text{Negative control means yield (kg)}}$$

Data analysis

Data on incidence and severity of early blight, early blight suppression, survival percentage, total fruit yield per plot, total fruit yield per hectare and percentage of marketable fruits were subjected to Analysis of Variance (ANOVA) for randomized complete block design (RCBD) using GenStat Release 17.1 software at 5% significance level. Disease incidence, disease severity and disease suppression assessed at 4 and 8 weeks after transplanting (WAT) were analyzed independently for each assessment period using the single-factor RCBD model. The assessment periods were used to monitor disease development over time and were not treated as additional experimental factors. The statistical model used was:

$$Y_{ij} = \mu + T_i + B_j + \varepsilon ij$$

Where:
Y_{ij} = observation of the ith treatment in the jth block
μ = overall mean
T_i = effect of the ith treatment
B_j = effect of the jth block
εij = experimental error

Treatment means with significant difference were separated using Fisher's least significant difference (F-LSD) at 0.05 probability level. Percentage data were subjected to arcsine transformation before analysis. Pearson correlation analysis was performed to determine the relationship between early blight suppression and survival percentage, total fruit yield, and percentage of marketable fruits. Descriptive data analysis was used for relative efficacy, yield gain, relative yield and yield index.

Table 1: Effect of different concentrations of aqueous ginger extract on incidence, severity and suppression of early blight; and relative efficacy of the treatments.

Treatment	Disease Incidence (%)		Disease Severity (%)		Disease Suppression (%)		Relative Efficacy (%)	
	4 WAT	8 WAT	4 WAT	8 WAT	4 WAT	8 WAT	4 WAT	8 WAT
0% (negative control)	51.85^{a}	70.37^{a}	50.69^{a}	61.65^{a}	0.00^{d}	0.00^{d}	–	–
5% ginger extract	37.03^{b}	55.56^{ab}	35.30^{a}	45.76^{a}	30.70^{c}	26.99^{c}	33.20	29.48
10% ginger extract	29.63^{b}	33.33^{bc}	35.35^{a}	17.56^{b}	29.92^{c}	69.60^{b}	32.36	76.02
15% ginger extract	11.11^{c}	29.63^{cd}	18.72^{b}	10.64^{c}	63.10^{b}	81.09^{ab}	68.25	88.57
20% ginger extract	7.41^{c}	25.92^{cd}	11.07^{bc}	8.05^{c}	79.44^{ab}	86.23^{a}	85.92	94.19
Red force (standard positive control)	3.70^{c}	14.81^{d}	3.51^{c}	4.32^{c}	92.46^{a}	91.55^{a}	–	–
Grand mean	23.46	38.27	25.77	24.66	49.27	59.24	–	–
F pr.	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	–	–
F-$LSD_{0.05}$	8.14	12.93	10.73	11.27	18.84	9.12	–	–
SE	4.47	7.11	5.90	6.19	10.36	5.02	–	–
CV (%)	16.3	18.9	20.2	22.2	23.2	9.9	–	–

WAT =Weeks After Transplanting; F pr.=Fisher's Probability (p-value); F-$LSD_{0.05}$ = Fisher's Least Significant Difference at 5% level of probability; SE = Standard Error of Mean; CV (%) = Coefficient of Variation. Means followed by the same letter within a column are not statistically different. Statistical analysis was performed on arcsine-transformed data; original treatment means are presented. SE, CV, and LSD values were derived from the transformed data

RESULTS

Confirmation of *Alternaria solani* as the causal pathogen of early blight

A laboratory examination of blighted tomato leaves collected from the experimental field confirmed the presence of *Alternaria solani*. The morphological characteristics of the pathogen observed were consistent with those described for *A. solani*, including septate mycelia and dark, muriform conidia with transverse and longitudinal septa (Mugao *et al*., 2021). The pathogenicity test based on Koch's postulates confirmed *A. solani* as the causal pathogen of the early blight observed in the study. The inoculated leaves developed the same symptoms as those observed on the naturally infected leaves collected from the experimental field.

Effect of different concentrations of aqueous ginger extract on Early Blight

Early blight incidence

The results of the analysis of variance on early blight incidence showed that there were highly significant ($p < 0.01$) treatment effects at both 4 and 8 WAT (Table 1). At 4 WAT, Redforce (standard positive control), 20% aqueous ginger extract and 15% aqueous ginger extract treatments recorded significantly lower early blight incidence of 3.70%, 7.41% and 11.11%, respectively, than the 10%, 5% and 0% (negative control) aqueous ginger extract treatments, which had 29.63%, 37.03% and 51.85% early blight incidence, respectively. All the treatments performed significantly better than the negative control. At 8 WAT, early blight incidence increased across all treatments. Redforce recorded the lowest incidence (14.81%) and was statistically at par with the 20% and 15% aqueous ginger extract treatments, which had 25.92% and 29.63% early blight incidence, respectively. This was followed by the 10%, 5% and 0% (negative control) aqueous ginger extract treatments with 33.33%, 55.56% and 70.37% early blight incidence, respectively. All the treatments performed significantly better than the negative control.

Early blight severity

Representative images of early blight severity in treated tomato plants are shown in Appendix B. The results of the analysis of variance on early blight severity showed that there were highly significant ($p < 0.01$) treatment effects at both 4 and 8 WAT (Table 1). At 4 WAT, Redforce (standard positive control) recorded the lowest early blight severity (3.51%) and was statistically at par with the 20% aqueous ginger extract treatment (11.07%), which was also statistically at par with the 15% aqueous ginger extract treatment (18.72%). All three treatments recorded significantly lower early blight severity than the 10%, 5% and 0% (negative control) aqueous ginger extract treatments, which had 35.35%, 35.30% and 50.69% early blight severity, respectively, and were statistically at par.

At 8 WAT, Redforce (standard positive control), 20% and 15% aqueous ginger extract treatments recorded early blight severity of 4.32%, 8.05% and 10.64%, respectively, and were statistically at par. These treatments had significantly lower early blight severity than the 10%, 5% and 0% (negative control) aqueous ginger extract treatments, which had 17.56%, 45.76% and 61.65% early

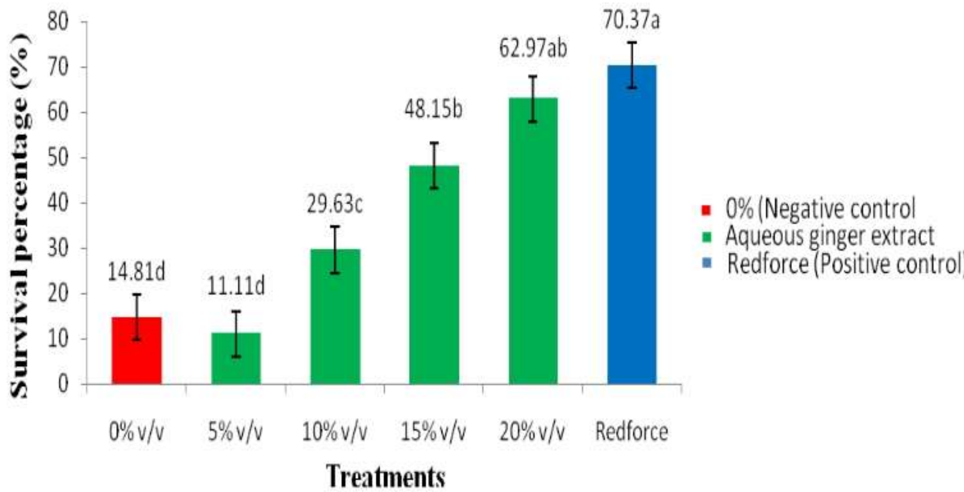

Figure 1: Survival percentage of tomato treated with different concentrations of aqueous ginger extract against early blight. *Bars represent treatment means ± SE. Means with different letters are statistically different*

blight severity, respectively. The 5% and 0% aqueous ginger extract treatments were statistically at par.

Early blight suppression

The results of the analysis of variance on early blight suppression showed that there were highly significant ($p < 0.01$) treatment effects at both 4 and 8 WAT (Table 1). At 4 WAT, Redforce (standard positive control) treatment produced the highest early blight suppression (92.46%), which was statistically at par with the 79.44% recorded in the 20% aqueous ginger extract treatment. The 15% aqueous ginger extract treatment recorded 63.10% early blight suppression and was significantly superior to the 10% and 5% aqueous ginger extract treatments, which had 29.92% and 30.70% suppression, respectively, and were statistically at par. There was no early blight suppression in the negative control treatment. At 8 WAT, Redforce (standard positive control) treatment also produced the highest early blight suppression (91.55%) and was statistically at par with the 20% and 15% aqueous ginger extract treatments, which recorded 86.23% and 81.09% suppression, respectively. This was followed by the 10% and 5% aqueous ginger extract treatments with 69.60% and 26.99% early blight suppression, respectively. There was no early blight suppression in the negative control treatment.

Relative efficacies of aqueous ginger extract treatments against early blight

At 4 WAT, the 20% aqueous ginger extract treatment produced the highest relative efficacy (85.92%) relative to Redforce (standard positive control) against early blight, followed by the 15% (68.25%), 5% (33.20%) and 10% (32.36%) aqueous ginger extract treatments, in that order (Table 1). At 8 WAT, the relative efficacy of the 20% aqueous ginger extract treatment increased to 94.19%, followed by the 15% (88.57%), 10% (76.02%) and 5% (29.48%) aqueous ginger extract treatments, in that order (Table 1).

Effect of different concentrations of aqueous ginger extract on survival percentage of tomato

The result of the analysis of variance as presented in Figure 1 showed a highly significant treatment effect ($p < 0.01$) in survival percentage. The highest survival percentage (70.37%) was obtained in the Redforce (positive control) treatment, which was statistically similar to the 62.97% recorded in the 20% ginger extract treatment. This was followed by 48.15% in the 15% ginger extract treatment and 29.63% in the 10% ginger extract treatment. The 5% ginger extract treatment recorded a survival percentage of 11.11%, which was statistically at par with the 14.81% obtained in the negative control.

Effect of different concentrations of aqueous ginger extract on yield of tomato fruits

Total fruit yield per plot (kg)

The result of the analysis of variance as presented in Table 2 showed a highly significant treatment effect ($p < 0.01$) on

Table 2: Yield and percentage of marketable fruits of tomato treated with different concentrations of aqueous ginger extract against early blight

Treatments	TFYPP (kg)	%MF	TFYPH (tons)	YG (%)	RY (%)
0% (negative control)	1.04e	56.60e	3.47e	-	23.11
5% ginger extract	1.65d	57.61d	5.50d	58.65	36.67
10% ginger extract	2.89c	63.77c	9.64c	177.88	64.22
15% ginger extract	3.60b	67.45b	12.01b	246.15	80.00
20% ginger extract	3.68b	73.89a	12.26b	253.85	81.78
Redforce (standard positive control)	4.50a	74.28a	15.00a	332.69	-
Grand mean	2.89	65.60	9.65	-	-
F pr.	<0.001	<0.001	<0.001	-	-
F-LSD$_{0.05}$	0.08	0.48	0.26	-	-
SE	0.043	0.261	0.143	-	-
CV (%)	1.5	0.4	1.5	-	-

F pr.=Fisher's Probability (p-value); F-LSD$_{0.05}$ = Fisher's Least Significant Difference at 5% level of probability; SE = Standard Error of Mean; CV (%) = Coefficient of Variation; TFYPP =Total fruits yield per plot; %MF = Percentage of marketable fruits; TFYPH = Total fruit yield per hectare; YG = Yield gain; RY = Relative yield. Means followed by the same letter within a column are not statistically different. Statistical analysis on %MF was performed on arcsine-transformed data; the original treatment means are presented. SE, CV, and LSD values were derived from the transformed data

total fruit yield per plot. The highest total fruit yield per plot (4.50kg) was obtained in Redforce (standard positive control) treatment, followed by 3.68 kg obtained in 20% aqueous ginger extract treatment which was statistically at par with 3.60kg obtained in 15% aqueous ginger extract treatment; followed by 2.89kg in 10% ginger extract treatment and 1.65kg in 5% aqueous ginger extract treatment in that order. All the treatments were significantly superior to negative control which had 1.04kg of tomato fruits per plot.

Total fruit yield per hectare (tons)

The result of the analysis of variance as presented in Table 2 showed a highly significant treatment effect ($p < 0.01$) on total fruit yield per hectare. The highest total fruit yield per hectare (15.00 tons) was obtained in Redforce (standard positive control) treatment, followed by 12.26 tons obtained in 20% aqueous ginger extract treatment which was statistically at par with 12.01 tons obtained in 15% aqueous ginger extract treatment; followed by 9.64 tons in 10% aqueous ginger extract treatment and 5.50 tons in 5% aqueous ginger extract treatment, in that order. All the treatments were significantly superior to negative control which had 3.47 tons of tomato fruits per hectare.

Percentage of marketable fruits

The result of the analysis of variance presented in Table 2 showed a highly significant ($p < 0.01$) treatment effect on percentage of marketable fruits. The highest percentage of marketable fruits (74.28%) was obtained in Redforce (standard positive control) treatment which was statistically similar with 73.89% obtained in 20% aqueous ginger extract treatment, followed by 67.45% in 15% ginger extract treatment, 63.77% in 10% aqueous ginger extract treatment and 57.61% in 5% aqueous ginger extract treatment in that order. All the treatments were significantly superior to the negative control which had 56.60%. of marketable total fruits.

Yield gain (%)

The 20% aqueous ginger extract treatment resulted in a massive increase in yield (253.85%) compared to the untreated plants (Table 2). The 15% aqueous ginger extract treatment had 246.15% yield gain, followed by 10% (177.88% yield gain), and 5% (58.65% yield gain) among the aqueous ginger extract treatments. The highest yield gain (332.69) was however obtained in Redforce (standard positive control) treatment.

Relative yield (%)

Relative yield was used to show how well the ginger extract treatments competed with the Redforce (standard positive control) in yield. The result presented in Table 2 revealed that the 20% aqueous ginger extract treatment produced 81.78% yield relative to Redforce (standard positive control) treated plants; The 15% aqueous ginger extract treatment had 80% yield relative to Redforce (standard positive control) treatment, followed by 10% (64.22% yield), and 5% (36.67% yield) among the aqueous ginger extract treatments. The least was in negative control with 23.11% yield relative to the standard positive control.

Yield Index

The tomato yield index increased with increase in aqueous ginger extract concentrations (Figure 2). The 5, 10, 15 and

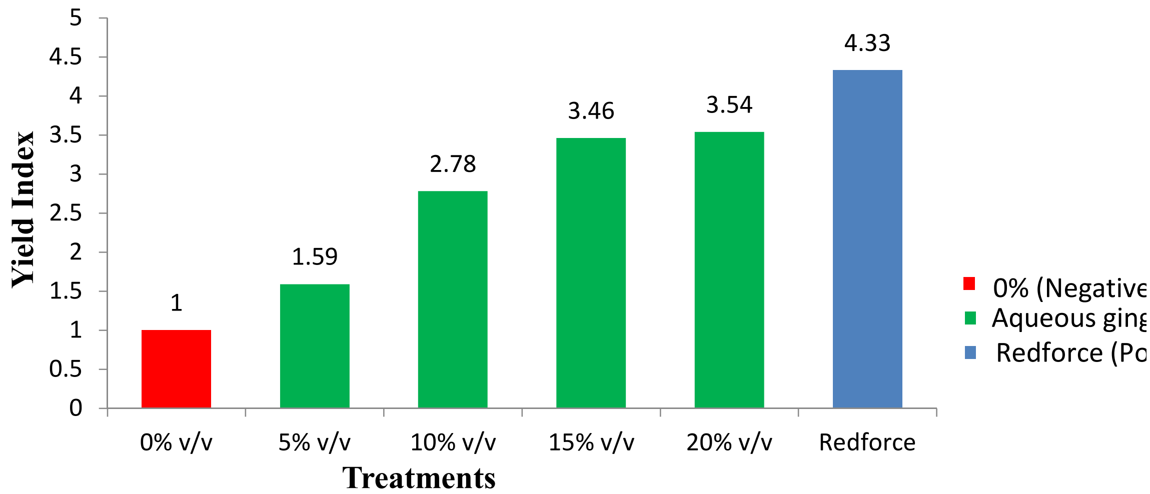

Figure 2: Yield index of tomato treated with different concentrations of aqueous ginger extract against early blight

20% aqueous ginger extract treatments resulted to yield indices of 1.59, 2.78, 3.46, and 3.54, respectively. The Redforce (standard positive control) treatment produced the highest yield index of 4.33 (Figure 2).

Relationship between Early blight suppression and survival percentage, total fruit yield and percentage of marketable fruits

The result of the Pearson correlation analysis as presented in Table 3 showed a highly significant ($p < 0.01$) relationship between early blight suppression and survival percentage, total fruit yield and percentage of marketable fruits. Suppression of early blight strongly and positively correlated with survival percentage ($r = 0.78$), total fruit yield per hectare ($r = 0.94$), and percentage of marketable fruit yield ($r = 0.89$) (Table 3). As the suppression of early blight increased, survival percentage, total fruit yield, and percentage of marketable fruits increased.

Table 3: Pearson correlation coefficients (*r*) showing the relationship between early blight suppression and survival percentage, total fruit yield and percentage of marketable fruits for tomato plants treated with different concentrations of aqueous ginger extract

Variable	Early blight suppression
Survival percentage	0.78**
Percentage of marketable fruits	0.89**
Total fruit yield per hectare	0.94**

*** Highly significant at the 0.01 level (2 –tailed)*

DISCUSSION

The results of the study showed that aqueous ginger extract suppressed early blight development and improved productivity in tomato under field conditions. The suppressive effect of aqueous ginger extract against early blight under field conditions was concentration dependent with higher concentrations, particularly 15% and 20% v/v producing better performance than lower concentrations and recorded values comparable to those obtained with the synthetic fungicide treatment. Early blight incidence and severity decreased with increasing ginger extract concentration. Similar reductions in early blight following ginger extract application have also been reported under field conditions. Latake *et al*. (2022) reported 54.40% control of early blight following application of ginger extract, while Pooja *et al*. (2026) reported 11.75% pooled control of early blight with 20% ginger rhizome extract across three cropping seasons. The suppressive effect may be associated with phenolics, flavonoids, terpenoids, and related bioactive compounds present in ginger rhizomes. Ginger compounds such as gingerol, shogaol, and zingerone inhibit fungal growth, interfere with spore germination, alter membrane permeability in fungal pathogens, and induce plant defense mechanism (Elhamouly *et al*., 2022; Anjali *et al*., 2023; Ebisa & Tamiru, 2023; Irfan *et al*., 2023). These reported activities provide plausible explanations for the suppressive effect observed in the present study. The greater suppression observed at higher extract concentrations may therefore be associated with increased availability of these bioactive compounds. This finding is consistent with Hassan *et al*. (2021), who reported that concentration influences the effectiveness of botanical extracts against plant pathogens. Survival percentage of the tomato plants increased significantly in response to the treatments compared with the negative control, with higher concentrations producing greater survival. This demonstrates the importance of effective early blight management in sustaining plant population under field conditions. Plant death associated with early blight is largely a consequence of pathogen induced foliar necrosis and vascular dysfunction. Early blight damages leaf tissues, thereby reducing the photosynthetic capacity of infected plants. If the disease is not effectively managed, severe infections may result in premature plant death and substantial crop loss (Panno *et al*., 2021). The higher survival percentages recorded in the 15% and 20% v/v aqueous ginger extract treatments were therefore associated with the lower disease incidence and severity observed in those treatments.

The increase in total fruit yield and marketable fruit production observed in the study was associated with suppression of early blight development. Early blight reduces photosynthetically active leaf area through lesion development and premature defoliation, resulting in reduced assimilates production and allocation to developing fruits. Plants protected from severe disease pressure are able to maintain canopy function and support fruit development. Similar finding was reported by Choudhary *et al.* (2024) in tomato treated with botanic extracts. The yield response may also be associated with the phyto-biostimulant activity of ginger extract. Ginger rhizomes contain phenolic compounds, flavonoids, and other bioactive constituents that have been shown to associate with improved physiological performance in plants (Irfan *et al*., 2023). Similarly, the increase in marketable fruits obtained in the treated plants was associated with reduction in disease severity observed in the treated plants. Early blight reduces fruit quality through premature canopy loss, exposure of fruits to environmental stress, and direct impact on the fruits. Effective disease suppression allows plants to maintain a healthier canopy and support normal fruit development. Mrosso *et al*. (2023) reported a similar relationship between disease management and marketable fruits in tomato affected by foliar pathogens. The superior performance of the higher ginger extract concentrations indicates that the suppressive potential and productivity enhancement achieved were concentration dependent. Botanical extracts contain mixtures of biologically active compounds, and their effectiveness is influenced by the quantity of these compounds available at the site of application. Hassan *et al*. (2021) reported that concentration is one of the major factors affecting the performance of plant extracts against plant pathogens. The greater effectiveness of the higher concentrations observed in the present study may therefore be associated with increased availability of antifungal compounds such as gingerols, shogaols, and related phytochemicals in the higher concentrated treatments. The highly significant and strong positive correlations observed between early blight suppression and survival percentage, total fruit yield, and percentage of marketable fruits indicated that effective suppression of early blight was strongly associated with enhanced tomato productivity. The statistically comparable performance of the 20% v/v aqueous ginger extract and the synthetic fungicide observed in most of the parameters evaluated in the study has important implications for sustainable tomato production, particularly among smallholder farmers in sub-Saharan Africa, who account for a substantial proportion of tomato cultivation in the region. Because the extract can be prepared using water, locally available materials, and simple equipment, its adoption for early blight management under field conditions is feasible within resource-limited production systems.

Conclusion

The findings of the study showed that aqueous ginger extract possessed strong early blight suppressive potential in tomato under field conditions. Application of the extract, particularly at higher concentrations, reduced early blight incidence and severity, resulting in greater disease suppression, improved plant survival, and enhanced total fruit yield and marketable fruit production. Among the concentrations evaluated, 20% v/v aqueous ginger extract recorded the highest disease suppression and showed performance comparable with the synthetic fungicide treatment. The results indicated that effective suppression of early blight by aqueous ginger extract was associated with improved tomato productivity. The 20% v/v aqueous ginger extract may therefore be considered a promising botanical alternative for sustainable management of early blight in rain-fed tomato production systems. Further studies involving multi-location and multi-season evaluations are recommended to validate its performance under different production environments, while economic evaluation of the 20% v/v aqueous ginger extract is recommended to determine its economic implications for early blight management.

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APPENDICES

Appendix A: Research materials

Plate A1: Stock aqueous ginger extract

Plate A2: Ginger rhizomes used for the extraction

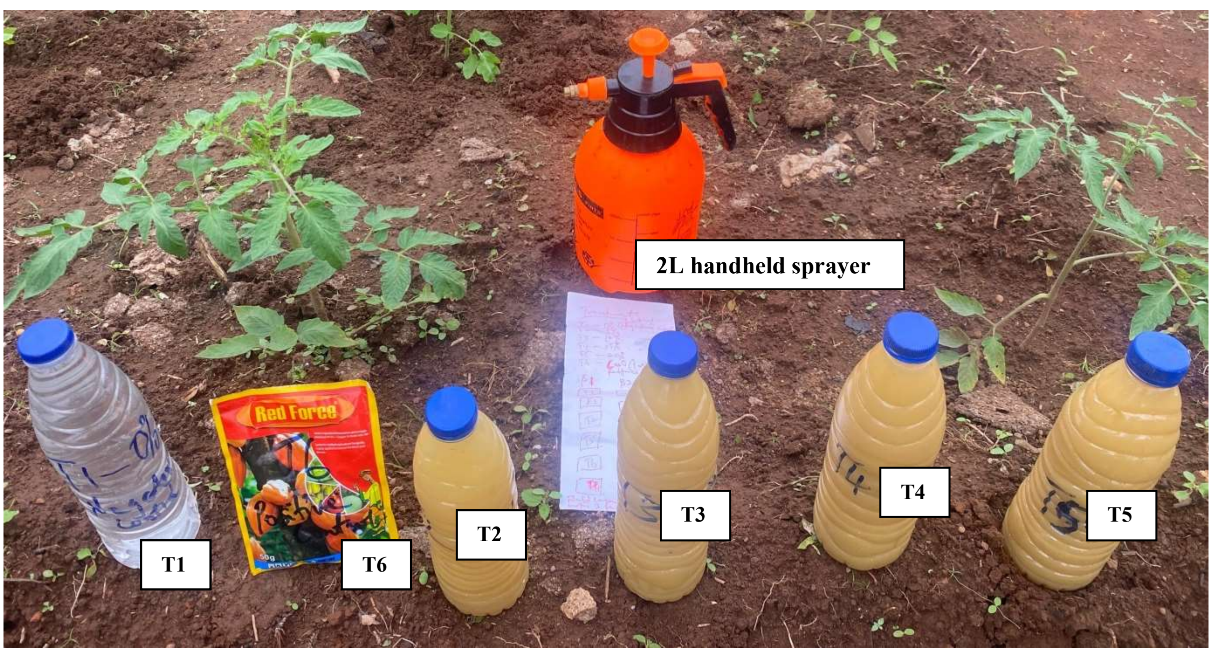

Plate A3: The treatments comprising different concentrations of aqueous ginger extract, ordinary water (negative control) and Redforce (positive control) and; the sprayer used for the application of the treatments

Appendix B: Tomato plants treated with different concentrations of aqueous ginger extract

Plate B1: Tomato plants treated with 5% v/v aqueous ginger extract (T2)

Plate B2: Tomato plants treated with Redforce (positive control) (T6)

Plate B3: Tomato plants treated with 20% v/v aqueous ginger extract (T5)

Plate B4: Tomato plants treated with 0% v/v aqueous ginger extract (negative control) (T1)

Plate B5: Tomato plants treated with 15% v/v aqueous ginger extract (T4)

Plate B6: Tomato plants treated with 10% v/v aqueous ginger extract (T3)