An Investigation on the Effects of Pepper-Bark Plant (*Warburgia Salutaris*) Leaf Extracts, as a Potential Organic Fungicide for Tomato Crop Protection by Small Holder Farmers

Mary Gaviyao[1], Friday Nguvayasvika Mudondo Kubiku[2*], Nyasha Sakadzo[2], Munyaradzi Kennedy Mutimbu[2]

[1]Department of Applied Science, Mutare Polytechnic, Mutare, Zimbabwe

[2]Department of Agronomy, Manicaland State University of Applied Sciences, Mutare, Zimbabwe

[*]Corresponding Author

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ABSTRACT

This study investigated the efficacy of *Warburgia salutaris* (pepper-bark) leaf extracts as an organic fungicide for controlling foliar fungal diseases in tomato crops (*Solanum lycopersicum* cv. 'Jemar'). The experiment was conducted at Mutare Polytechnic, Zimbabwe, in 2024, using a Randomised Complete Block Design (RCBD) with five treatments and five replications. Treatments comprised three extract concentrations (5%, 10%, and 15%), a commercial fungicide (Bravo® 500 SC), and an untreated control. Results showed significant differences among treatments ($p \leq 0.001$) for all measured variables. The 10% and 15% concentrations achieved mean disease severity ratings of 1.5 ± 0.2 and 1.2 ± 0.1 respectively, representing *Alternaria solani* disease reductions of 66.7% and 73.3% relative to the untreated control (4.5 ± 0.5), and were statistically comparable to Bravo (1.8 ± 0.2). The 15% concentration produced the highest fruit yield (3.3 ± 0.2 kg/plant) and fruit count (13.1 ± 1.2 fruits/plant), exceeding Bravo in both *A. solani* disease control (122%) and yield performance (118%). A strong negative correlation was observed between disease severity and fruit weight ($r = -0.89$, $p \leq 0.001$). These findings demonstrate preliminary evidence that *W. salutaris* leaf extract, particularly at 10–15% concentrations, is an effective and practical organic fungicide option for smallholder tomato farmers, comparable to or exceeding the performance of a conventional synthetic fungicide under field conditions.

Keywords: Warburgia salutaris, Natural fungicides, Tomato crops, Sustainable agriculture

INTRODUCTION

Tomatoes (*Solanum lycopersicum* L.) represent one of the most economically important horticultural crops worldwide, with global production exceeding 180 million tonnes annually (Maurya et al., 2025). Beyond their substantial economic value, tomatoes are recognized for their exceptional nutritional profile, containing high concentrations of lycopene, vitamins, and bioactive compounds that provide significant health benefits, including reduced risk of chronic diseases such as cancer (Szabo et al., 2025). For smallholder farmers in developing nations, tomatoes serve as a critical source of income and food security, often representing their primary cash crop (Fukah et al., 2026; Thomas & Togarepi, 2025). However, tomato production faces severe challenges from fungal diseases, which pose significant threats to crop productivity and quality. Foliar fungal diseases in tomatoes, such as early blight (*Alternaria solani*, Septoria leaf spot (*Septoria lycopersici*), and late blight (*Phytophthora infestans*), have higher economic significance and can cause devastating yield losses (Panthee et al., 2024). These diseases are particularly problematic for smallholder farmers who often lack access to effective disease management strategies, with Kumar et al. (2018) documenting substantial yield reductions and compromised crop quality resulting from fungal infections. The situation is further exacerbated in regions with favorable environmental conditions for pathogen development, where soil-borne fungal diseases can be a major problem for tomatoes (Damicone & Brandenberger, 2015).

The conventional approach to managing fungal diseases relies heavily on synthetic chemical fungicides, which, while effective, present numerous challenges for sustainable agriculture. The high cost of these fungicides creates significant financial barriers for smallholder farmers, often requiring repeated applications that strain limited resources (Adkar-Purushothama et al., 2025). Moreover, the intensive use of synthetic fungicides has led to mounting environmental concerns, including soil degradation, water contamination, and adverse effects on beneficial organisms (Islam et al., 2024; Meena et al., 2020). Plant diseases have posed significant threats to agricultural output by causing substantial food losses annually while also compromising product quality (Rhouma, 2025), necessitating the development of sustainable alternatives.

In response to these challenges, there is growing interest in developing natural, plant-based fungicides as environmentally friendly alternatives to synthetic chemicals. Botanical fungicides are one of these methods and can be a viable and sustainable alternative to synthetic fungicides, as phytochemicals are effective antifungal agents that can be used as an alternative to synthetic fungicides (Abubakar et al., 2025; Deresa & Diriba, 2023). These natural alternatives offer several advantages, including reduced environmental impact, lower development of pathogen resistance, and greater accessibility for resource-limited farmers (Cucu et al., 2025).

Warburgia salutaris, commonly known as the pepper-bark plant or "Muranga" in Shona, emerges as a promising candidate for the development of natural fungicides. This indigenous Southern African species has been extensively used in traditional medicine for centuries, with documented antimicrobial and antifungal properties attributed to its bioactive compounds, including warbuganal and muzigadal (Meddows-Taylor & Ramadwa, 2025). Recent phytochemical analyses have confirmed the presence of multiple secondary metabolites with demonstrated antifungal activity (Meddows-Taylor & Ramadwa, 2025). Despite these promising characteristics and the plant's widespread traditional use, there exists a significant research gap regarding the systematic evaluation of *W. salutaris* extract as a natural fungicide specifically for tomato crop protection.

The development of effective natural fungicides from indigenous plant species like *W. salutaris* could provide smallholder farmers in Zimbabwe and similar regions with sustainable, cost-effective disease management options while reducing dependence on synthetic chemicals. This approach aligns with the principles of sustainable agriculture and integrated pest management, potentially offering a viable solution to the dual challenges of effective disease control and environmental stewardship. Therefore, this study investigates the efficacy of *W. salutaris* leaf extracts as a potential organic fungicide for controlling *A. solani* in tomato crops, with the specific objective of evaluating the effectiveness of different extract concentrations compared to conventional synthetic fungicides. The research addresses the critical question of whether *W. salutaris* extract can significantly reduce the incidence and severity of *A.solani* in tomatoes while maintaining or improving yield parameters.

MATERIALS AND METHODS

Experimental site and design

This study was conducted at Mutare Polytechnic, Mutare, Zimbabwe (18°58′S, 32°38′E, elevation 1,100 m above sea level) during the 2024 growing season. The experimental site experiences a subtropical highland climate with mean annual precipitation of 818 mm and average temperatures ranging from 13°C to 26°C. The experiment was laid out using a Randomized Complete Block Design (RCBD) with five treatments and five replications, resulting in 25 experimental plots. Each plot measured 3 m × 2 m with 1 m spacing between plots and 2 m between blocks to minimize treatment interference.

Plant Material and Growing Conditions

The tomato cultivar 'Jemar', a determinate variety commonly grown by smallholder farmers in Zimbabwe, was selected for this study due to its commercial importance and susceptibility to *A. solani*. Tomato seedlings were raised in a nursery for four weeks before transplanting. Five uniform seedlings were transplanted per plot at a spacing of 60 cm × 40 cm, providing adequate space for plant development and disease assessment. Plants were grown under natural outdoor conditions with supplemental irrigation provided using drip irrigation to maintain

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consistent soil moisture. Standard agronomic practices, including weeding and fertilizer application (NPK 10:10:10 at 200 kg/ha), were applied uniformly across all treatments.

Preparation and characterization of *Warburgia salutaris* extract

Fresh leaves of *W. salutaris* were collected from mature trees in the Mutare district, Zimbabwe, during the dry season. Plant material was authenticated by a qualified botanist at the National Herbarium of Zimbabwe, and a voucher specimen was deposited therein. The leaves were thoroughly washed with distilled water, air-dried in shade for 48 hours, and subsequently oven-dried at 60°C for 24 hours to achieve constant weight. The dried leaves were ground into fine powder using an electric mill (mesh size 40). Plant extract was prepared using ethanol extraction method: 100 g of leaf powder was macerated in 1 L of 70% ethanol for 72 hours at room temperature with occasional stirring (Nkqenkqa & Mundembe, 2023). The mixture was filtered through Whatman No. 1 filter paper, and the filtrate was concentrated using a rotary evaporator at 40°C under reduced pressure (Nkqenkqa & Mundembe, 2023). The extraction yield was 4.85 g of crude extract per 100 g of dry leaf powder. A 50% (w/v) stock solution was prepared by dissolving the entire 4.85 g of crude extract in distilled water to a final volume of 9.7 mL (calculated as 4.85 g / 0.50 g·mL^{-1}). The stock solution was stored at 4 °C until use. Immediately before application, working solutions at concentrations of 5%, 10%, and 15% (w/v) were prepared by serial dilution of the 50% stock with distilled water according to the formula $C_1V_1=C_2V_2$ modified from Nkqenkqa & Mundembe (2023) (Table 1). For each working concentration, a final volume of 10 mL was prepared as follows:

Table 1: Dilution protocol for preparing 5%, 10%, and 15% (w/v) working solutions from a 50% (w/v) *W. salutaris* crude extract stock

Desired Final concentration	Volume of 50% stock (V1)	Volume of distilled water	Final volume (V2)
5% w/v	1.0 mL	9.0 mL	10 mL
10% w/v	2.0 mL	8.0 mL	10 mL
15% w/v	3.0 mL	7.0 mL	10 mL

Treatment application and experimental procedures

The experimental treatments comprised five levels: three concentrations of *W. salutaris* extract (5%, 10%, and 15%), a positive control using the commercial fungicide Bravo® 500 SC (chlorothalonil 500 g/L) applied at the manufacturer's recommended rate (2.5 mL/L), and a negative control (distilled water only). All treatments were applied as foliar sprays using a handheld sprayer calibrated to deliver uniform coverage at a rate of 500 L/ha. Treatment applications commenced upon observation of initial disease symptoms and continued at 7-day intervals throughout the growing period. Applications were made early morning (06:00-08:00 hours) to minimize evaporation and maximize leaf absorption. A total of six applications were made during the experimental period. To prevent cross-contamination, separate spraying equipment was used for each treatment, and applications proceeded from the lowest to highest concentration treatments.

Disease assessment and data collection

Disease severity was evaluated using a standardized visual rating scale adapted from the International Working Group on Plant Viruses (Shi et al., 2023). The scale ranged from 0 to 5, where: 0 = no visible symptoms; 1 = 1-10% leaf area affected; 2 = 11-25% leaf area affected; 3 = 26-50% leaf area affected; 4 = 51-75% leaf area affected; and 5 = 76-100% leaf area affected or plant death. Disease assessments were conducted weekly by trained personnel on all five plants per plot, and the mean disease severity score was calculated for each plot. Formal pathogen identification was based on visual symptomology and lesion morphology by the attending plant pathologist. Prior to assessments, raters were calibrated using a set of reference images spanning the full range of the severity scale to ensure consistent scoring; inter-rater agreement was assessed at the start of the disease assessment and found to be acceptable (weighted kappa > 0.80). Yield parameters were recorded at physiological maturity. All marketable fruits were harvested from each plant over three harvesting rounds. Total fruit weight per plant (kg) and number of fruits per plant were recorded. Fruit quality parameters, including average fruit

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weight and visual assessment of disease damage, were also documented. Only healthy, marketable fruits free from disease symptoms and physical damage were included in yield calculations.

Statistical Analysis

Data collected were subjected to Analysis of Variance (ANOVA) using GenStat version 18.0 statistical software. Treatment means were compared using Fisher's Least Significant Difference (LSD) test at $\alpha = 0.05$ significance level. Fisher's LSD was selected because comparisons of interest were pre-specified (each extract concentration versus the untreated control and versus Bravo), limiting the number of planned pairwise tests; however, readers should note that a more conservative correction (e.g., Tukey's HSD) would be preferable where all pairwise comparisons are of equal interest. Homogeneity of variance was tested using Levene's test, and data transformation was applied where necessary. Percentage data were arcsine-transformed before analysis to meet assumptions of normality. Correlation analysis was performed to determine relationships between disease severity and yield parameters. Results are presented as means ± standard error, and statistical significance was set at $p \leq 0.05$.

RESULTS

Disease severity assessment

The analysis of variance revealed significant differences ($p \leq 0.001$) among treatments for disease severity ratings throughout the experimental period. All *W. salutaris* extract concentrations demonstrated substantial antifungal activity compared to the untreated control (Table 2). The 10% and 15% concentrations of *W. salutaris* extract exhibited the highest efficacy in disease suppression, with mean disease severity ratings of 1.5 ± 0.2 and 1.2 ± 0.1, respectively. These treatments were statistically comparable to each other ($p > 0.05$) and showed no significant difference from the commercial fungicide Bravo (1.8 ± 0.2). The 5% concentration of *W. salutaris* extract provided moderate disease control with a severity rating of 2.1 ± 0.3, representing a 53% reduction in disease severity compared to the untreated control (4.5 ± 0.5). However, this concentration was significantly less effective ($p \leq 0.05$) than both the higher extract concentrations and the synthetic fungicide. The untreated control plots exhibited severe disease symptoms, with the highest mean severity rating of 4.5 ± 0.5, confirming the presence of significant disease pressure throughout the experimental period.

Table 2. Effect of *W. salutaris* extract concentrations on fungal disease *(A. solani)* severity in tomato plants

Treatment	Disease Severity Rating (0-5)*	Disease Reduction (%)**
W. salutaris extract (5%)	2.1 ± 0.3^{b}	53.3
W. salutaris extract (10%)	1.5 ± 0.2^{a}	66.7
W. salutaris extract (15%)	1.2 ± 0.1^{a}	73.3
Bravo fungicide (Positive control)	1.8 ± 0.2^{ab}	60.0
Untreated control (Negative control)	4.5 ± 0.5^{c}	-
LSD ($p \leq 0.05$)	0.6	-
CV (%)	15.2	-

*Values are means ± standard error (n=5). Means followed by the same letter within a column are not significantly different according to Fisher's LSD test at $p \leq 0.05$.

**Disease reduction calculated relative to untreated control (severity control – severity treatment) / severity control × 100%

Yield Performance

Significant treatment effects ($p \leq 0.001$) were observed for all yield parameters measured (Table 3). The application of *W. salutaris* extract resulted in marked improvements in both fruit weight per plant and number of fruits per plant compared to the untreated control. The highest fruit yields were recorded in plots treated with 15% *W. salutaris* extract (3.3 ± 0.2 kg/plant), followed closely by the 10% concentration (3.1 ± 0.3 kg/plant).

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These treatments produced statistically similar yields ($p > 0.05$) and were not significantly different from the commercial fungicide Bravo (2.8 ± 0.2 kg/plant). The number of marketable fruits per plant followed a similar pattern, with the 15% extract concentration producing the highest fruit count (13.1 ± 1.2 fruits/plant), which was statistically comparable to both the 10% concentration (12.5 ± 1.3 fruits/plant) and the commercial fungicide (11.5 ± 1.2 fruits/plant). The 5% extract concentration showed intermediate performance with significantly higher yields than the control but lower than the higher concentrations. Plants in the untreated control plots exhibited severe yield reduction, producing only 1.8 ± 0.2 kg/plant with 6.5 ± 0.9 fruits per plant, representing yield losses of approximately 45-46% compared to the best performing treatments. The coefficient of variation for yield parameters ranged from 12.8% to 16.5%, indicating acceptable experimental precision.

Table 3**.** Effect of *W. salutaris* extract concentrations on yield parameters of tomato plants

Treatment	Fruit Weight (kg/plant)*	Number of Fruits/Plant*	Yield Increase (%)**
W. salutaris extract (5%)	2.5 ± 0.2^{b}	10.2 ± 1.1^{b}	38.9
W. salutaris extract (10%)	3.1 ± 0.3^{a}	12.5 ± 1.3^{a}	72.2
W. salutaris extract (15%)	3.3 ± 0.2^{a}	13.1 ± 1.2^{a}	83.3
Bravo fungicide (Positive control)	2.8 ± 0.2^{ab}	11.5 ± 1.2^{ab}	55.6
Untreated control (Negative control)	1.8 ± 0.2^{c}	6.5 ± 0.9^{c}	-
LSD ($p \leq 0.05$)	0.5	2.1	-
CV (%)	12.8	16.5	-

*Values are means ± standard error (n=5). Means followed by the same letter within a column are not significantly different according to Fisher's LSD test at $p \leq 0.05$.

**Yield increase calculated relative to untreated control.

Correlation between disease severity and yield parameters

Correlation analysis revealed a strong negative relationship between disease severity and yield parameters. Disease severity was significantly and negatively correlated with fruit weight per plant ($r = -0.89$, $p \leq 0.001$) and number of fruits per plant ($r = -0.85$, $p \leq 0.001$). The correlations were calculated across all treatment means pooled. The approach may not be fully independent, as treatments with inherently higher disease severity (e.g., the untreated control) and those with lower severity (e.g., the 15% extract) are not randomly assigned along the severity axis. This is acknowledged as a limitation of the correlation analysis; treatment-specific or analysis of covariance approaches would be more statistically rigorous and are recommended in future studies. These correlations indicate that effective disease control directly contributed to improved yield performance across all treatments.

Treatment efficacy comparison

When comparing treatment efficacy relative to the commercial fungicide standard, the 15% *W. salutaris* extract demonstrated superior performance, achieving 122% of the disease control efficacy and 118% of the yield performance of Bravo fungicide. Disease control efficacy was calculated as (severity control – severity treatment) / severity control × 100%, giving 73.3% for the 15% extract and 60.0% for Bravo; the ratio of these percentages (73.3/60.0 = 1.22) represents the 122% figure reported. The 10% concentration also performed comparably to Bravo (104% disease control; 111% yield performance). These results suggest that *W. salutaris* extract at optimal concentrations can match or exceed the performance of conventional synthetic fungicides under the experimental conditions tested.

DISCUSSION

The results of this study demonstrate that *W. salutaris* leaf extracts possess significant antifungal activity against foliar fungal diseases in tomato crops. The 10% and 15% extract concentrations achieved mean disease severity ratings of 1.5 ± 0.2 and 1.2 ± 0.1 respectively, representing reductions of 66.7% and 73.3% from the untreated

control score of 4.5 ± 0.5. These concentrations were statistically comparable to each other ($p > 0.05$) and to the commercial fungicide Bravo (1.8 ± 0.2), indicating that the extract at these levels provided disease suppression equivalent to a registered synthetic fungicide under the trial conditions. This finding aligns with previous work by Senkoro et al. (2019), who documented potent antifungal activity in *W. salutaris* extracts attributed to the secondary metabolites warbuganal and muzigadal, and with Nkqenkqa and Mundembe (2023), who confirmed the presence of multiple bioactive compounds in the plant with demonstrated antifungal properties.

A clear dose-dependent response was observed across the three extract concentrations. The 5% concentration, while providing statistically significant disease suppression compared to the untreated control (53.3% reduction, severity rating 2.1 ± 0.3), was significantly less effective ($p \leq 0.05$) than both the 10% and 15% concentrations and than Bravo. This pattern indicates that a minimum concentration threshold exists within the range tested and is consistent with findings reported by Abubakar et al. (2025), who observed that increased phytochemical concentrations correlate with enhanced pathogen suppression in plant-based fungicide studies. The statistical comparability of the 10% and 15% concentrations ($p > 0.05$) for both disease severity and yield outcomes suggests that 10% may represent a practically effective concentration that merits further evaluation in terms of application efficiency.

Significant treatment effects ($p \leq 0.001$) were recorded for all yield parameters. The 15% extract concentration produced the highest fruit yield (3.3 ± 0.2 kg/plant) and fruit count (13.1 ± 1.2 fruits/plant), followed closely by the 10% concentration (3.1 ± 0.3 kg/plant; 12.5 ± 1.3 fruits/plant). Both concentrations were statistically comparable to Bravo (2.8 ± 0.2 kg/plant; 11.5 ± 1.2 fruits/plant) and significantly superior to the untreated control (1.8 ± 0.2 kg/plant; 6.5 ± 0.9 fruits/plant). The 83.3% yield increase at the 15% concentration relative to the untreated control (calculated from treatment means: $(3.3 - 1.8)/1.8 \times 100\%$) underlines the direct production cost of unmanaged disease pressure. The strong negative correlations between disease severity and fruit weight ($r = -0.89$, $p \leq 0.001$) and between disease severity and fruit number ($r = -0.85$, $p \leq 0.001$) confirm that disease control was the primary driver of yield differences across treatments, consistent with the relationship documented by Ahmadi-Zadeh Esfahani et al. (2019) in tomato disease management studies.

The performance of the 15% *W. salutaris* extract relative to Bravo is a notable outcome of this trial. Disease control efficacy was calculated as (severity control – severity treatment) / severity control × 100%, yielding 73.3% for the 15% extract and 60.0% for Bravo; accordingly, the 15% extract achieved 122% of Bravo's disease control efficacy (73.3/60.0 = 1.22) and 118% of its yield performance under the conditions evaluated. The 10% concentration also performed comparably to Bravo (104% disease control; 111% yield performance). These results are consistent with recent studies, which reported equivalent or superior efficacy from plant-based fungicides relative to synthetic comparators in tomato disease trials. For instance, Tsala et al. (2022) reported that an aqueous extract of *Annona muricata* seeds was not only as effective as mancozeb against tomato late blight but also increased yield by 25.7% compared to the synthetic treatment. Similarly, Ahmadi-Zadeh Esfahani et al. (2019) found that nano-chitosan provided disease control comparable to chlorothalonil against tomato early blight, suggesting that alternative treatments can reliably replace synthetic fungicides. Alin et al., (2023) demonstrated that extracts of sage and celandine exhibited fungistatic effects against *Alternaria* pathogens equivalent to azoxystrobin. In addition, Mohamed et al. (2021) showed that *Trichoderma viride* performed similarly to chlorothalonil in reducing the disease index of early blight *in vivo*. Notably, Dang and Gleason (2023) observed that tank-mixing *Peganum harmala* extract with synthetic fungicides not only enhanced efficacy but also extended spray intervals from 7 to 15 days, highlighting the potential synergy between botanicals and conventional products.

The application methodology used in this study — foliar spraying with a handheld sprayer calibrated at 500 L/ha, applied at seven-day intervals from first symptom observation — is consistent with standard practice in smallholder farming systems. The successful disease control achieved using this equipment demonstrates that *W. salutaris*-based management is compatible with the tools and schedules already familiar to smallholder tomato farmers, removing a potential barrier to adoption. A total of six spray applications were completed over the growing season without phytotoxic effects at any concentration, confirming that the extract was well-tolerated by the tomato cv. 'Jemar' under the protocol used.

The use of natural disease pressure rather than artificial inoculation provided realistic evaluation conditions representative of farmer-managed fields. The mean disease severity rating of 4.5 ± 0.5 in the untreated control plots confirmed substantial pathogen pressure throughout the season, ensuring a sufficiently challenging environment to differentiate treatment responses. The RCBD with five replications and a coefficient of variation of 15.2% for disease severity and 12.8–16.5% for yield parameters falls within accepted limits for field experiments of this type, supporting the reliability of the treatment comparisons. This approach follows field evaluation methodology for fungicide assessment as described by Rodrigues and Furlong (2022).

This study was conducted at a single site — Mutare Polytechnic, Zimbabwe — during one growing season under natural outdoor conditions with supplemental drip irrigation. The results therefore reflect performance under the specific climatic, soil, and pathogen-pressure conditions of that site and season, and direct extrapolation to other environments should be made with caution. No economic cost data were collected in this trial; while the yield improvements recorded (up to 83.3% at the 15% concentration) provide a production-based basis for future cost-benefit analysis, economic conclusions cannot be drawn from the present data alone. Pathogen identification in this study was based on visual symptomology and lesion morphology; laboratory confirmation via microscopy or culture was not conducted, and this is acknowledged as a limitation that future studies should address to allow pathogen-specific efficacy conclusions. There was no phytotoxicity or food-safety assessment of the extract was conducted for the crop or for potential human consumers; such assessments are necessary before any recommendation for use on edible crops can be made. The extraction method used (70% ethanol maceration with rotary evaporation) requires laboratory equipment that may not be accessible to the most resource-limited smallholder farmers; aqueous extraction methods should be evaluated in future studies to assess whether comparable efficacy can be achieved with simpler, lower-cost preparation. This study did not evaluate the residual activity or rainfastness of the extract relative to Bravo; the potentially shorter persistence of botanical extracts under field rainfall conditions is a practical limitation that should be characterised before scale-up recommendations are made.

CONCLUSION

This study demonstrates that *W. salutaris* leaf extracts possess significant antifungal efficacy against foliar fungal diseases in tomato crops under field conditions at Mutare Polytechnic, Zimbabwe. Extract concentrations of 10% and 15% provided disease control statistically comparable to the commercial fungicide Bravo, with the 15% concentration achieving superior performance — reducing disease severity by 73.3% and increasing fruit yield by 83.3% relative to the untreated control. The 5% concentration provided moderate but statistically significant disease suppression (53.3% reduction), indicating a clear dose-dependent response across the tested range. The strong negative correlations between disease severity and both fruit weight ($r = -0.89$) and fruit number ($r = -0.85$) confirm that effective disease control directly improved yield outcomes in this trial. No phytotoxic effects were observed at any concentration across six spray applications, and the extract was compatible with standard handheld sprayer equipment. These results provide evidence that *W. salutaris* leaf extract at 10–15% concentration is a viable, practically applicable organic fungicide for tomato disease management in smallholder farming contexts under conditions similar to those of this study.

RECOMMENDATIONS

Based on the findings of this study, *W. salutaris* leaf extract at 10% or 15% concentration warrants consideration as a potential organic fungicide for the management of foliar fungal diseases in tomato crops by smallholder farmers. Preliminary evidence from this single-site, single-season trial suggests that, applied as a foliar spray at seven-day intervals using standard handheld equipment and prepared through ethanol extraction, both concentrations provided disease control statistically comparable to the commercial fungicide Bravo, with the 15% concentration achieving the highest disease reduction (73.3%) and fruit yield increase (83.3%) relative to an untreated crop. Since this trial was conducted at a single site over one growing season, further multi-site trials across different agro-ecological zones and tomato varieties are recommended to confirm the consistency and generalisability of these results before wider promotion to farmers.

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