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Antifungal activity of aqueous extract of garlic and oils of carapa and neem on the causal agent of tomato late blight disease

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ABSTRACT

This study evaluated the antifungal activity of plant extracts against *Phytophthora infestans*, the causal agent of tomato late blight. It was conducted in an insect-proof high tunnel using a randomized complete block design with three replicates. Treatments included aqueous garlic extract (0.2 g/mL), carapa oil (12% (v/v)) and neem oil (20% (v/v)), mancozeb 80 WP-based fungicide (5 g/L), and the untreated control. The biopesticides were applied once a week, while the chemical fungicide was applied once a fortnight. Applications were done before or after inoculation with 3×10^5 zoospores/mL of the pathogen. Recorded disease incidence varied from 50-100% for mancozeb to neem oil for preventive treatments and 100% for curative treatments. There was no significant difference in the severity of symptoms between aqueous garlic extract and mancozeb. The severity index ranged from 13.33 to 17.22% before inoculation to 20.0 to 25.0% after inoculation at the fruiting stage. The severity index of the untreated control was 58.34%. However, the net potential yield after inoculation with mancozeb (8.08 t/ha) was higher than that obtained with aqueous garlic extract (6.56 t/ha), carapa oil (4.95 t/ha), and neem oil (4.66 t/ha) compared to 4.55 t/ha for the untreated control. Hence, aqueous garlic extract can be used in integrated tomato late blight control programs.

Keywords: Curative and Preventive Treatments, Efficacy Test, Plant Extracts, Tomato Late Blight.

INTRODUCTION

In recent years, market gardening has emerged as a viable strategy for satisfying urban food demand (Groga et al., 2018). In Côte d'Ivoire, a considerable proportion of the population is engaged in this activity, with nearly 60% of those involved being women and young people in rural and peri-urban areas (FIRCA, 2020). Tomatoes are among the most profitable vegetable crops, providing producers a substantial income to meet their basic needs (Neha and Praveen, 2014; Zekeya et al., 2017). Tomatoes are a rich source of minerals, lycopene, carotenoids, vitamins A, C, and E (Daniel et al., 2012; Yéo et al., 2021), and phenolic antioxidants (Martine et al.,

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2008). Consequently, they are among the most widely consumed and cultivated vegetables in more than 170 countries worldwide (FAO, 2021).

Despite the nutritional, therapeutic, and socio-economic importance of tomatoes, annual production in Côte d'Ivoire (40,306 tons) remains insufficient to meet the country's total demand for fresh vegetables, which is estimated at 1,800,000 tons per year following FAO and WHO recommendations (FAO, 2021). These data indicate the existence of a de facto market for increased vegetable production in the country, with upstream implications for the quantities produced (FIRCA, 2019). As with other crops, the cultivation of tomatoes is subject to several biotic constraints, namely diseases and pests that result in considerable losses in production (Fondio et al., 2013; Koffi et al., 2021). One of the most destructive diseases of tomatoes is late blight, caused by the Oomycetes *Phytophthora infestans*. The disease affects the entire plant, causing necrotic lesions on stems and leaves and rotting fruit (Blancard et al., 2012; Rabab and Lorenzo, 2017). In 2022, the resurgence of this disease resulted in production losses estimated at more than 30% in a vegetable production zone in Didiévi in central Côte d'Ivoire (CNRA, 2022). In response, vegetable growers have resorted to the overuse of chemical pesticides despite the harmful environmental and human health effects of such practices (Rahman et al., 2021; Sulaiman et al., 2021).

Over three decades ago, the World Health Organization (WHO) estimated that there were approximately three million cases of poisoning associated with pesticide residues globally, with 220,000 deaths annually (Shakhaoat et al., 2013). It is evident that the utilization of chemical pesticides has enhanced agricultural output; nevertheless, it is also a well-established fact that they have become a significant hazard to public health and the environment. It is recommended that integrated control approaches combine different techniques and methods to reduce the risk associated with chemical pesticides, with a preference for applying biopesticides for pest management (Deravel et al., 2014). One of the most effective approaches involves utilizing secondary pesticide plant metabolites (Castillo-Sánchez et al., 2015). Regarding these metabolites, fresh garlic is a rich source of flavonoids, polyphenols, saponins, terpenoids, phenylpropanoids, and organosulfur compounds, among others (Mandez Langunas, 2007; Regnault-Roger et al., 2008). Conversely, neem oil is characterized by azadirachtin, whereas carapa oil contains triterpenoids, flavonoids, alkaloids, and tannins (Konan et al., 2023). In this context, the antifungal activity of the aqueous extract of garlic (*Allium sativum* L.) and oils of carapa (*Carapa procera* L.) and neem (*Azadirachta indica* L.) was evaluated on *P. infestans*, the agent responsible for tomato late blight.

MATERIALS AND METHODS

Study area

The experiment was conducted at the Food Crops Research Station of the National Centre for Agronomic Research in Bouaké, central Côte d'Ivoire. The geographical coordinates of the station are as follows: latitude 7°40'42.94" N, longitude 5°5'59.37" W, and an elevation of 401 m above sea level. The precipitation levels recorded during the study period (August to November 2022) ranged from 245.9 to 6.8 mm, with temperatures fluctuating between 24.2 and 26.3°C.

Isolation and purification of *P. infestans*

The *P. infestans* strain was isolated from the stems of the Cobra 34 F1 tomato variety, which had been affected by brown rot, in a farm located at Kongoué Kouadiokro (latitude 7°03'14" N, longitude 4°85'58.7" W), in the Didiévi department. The isolation was conducted using the methodology described by Siéné et al. (2021). Subsequently, the strain was purified through two consecutive subcultures on a pea-based agar medium, as described by Coulibaly et al. (2013), over a seven-day incubation period at 26 ± 2°C in an oven. The purified cultures were stored at 24 ± 1°C for efficacy testing.

P. infestans inoculum production

The inoculum was obtained from a 14-day-old pure culture of *P. infestans*. Single-zoospore culture was performed to ensure homogeneity, a technique first described by Coulibaly et al. (2013). Briefly, the culture was incubated under a 12-hour photoperiod for three days. Following this period, the culture was flooded with 40 mL of sterile distilled water and placed at 4°C for 15 minutes. Subsequently, the culture was exposed to light from a 60 W incandescent lamp for 45 minutes. The suspension of zoospores obtained in the Roux flask was enumerated using a Malassez cell and adjusted to a concentration of 3×10^5 zoospores/mL, as described by Mpika et al. (2009).

Fungicide treatments preparation

The carapa (*C. procera*) and neem (*A. indica*) oils were obtained from commercial suppliers. The carapa oil was diluted to a concentration of 88% with sterile distilled water, while the neem oil was diluted to a concentration of 80%. Subsequently, each solution (1 L) was combined with 5 g of black soap, resulting in a homogeneous solution. Black soap was utilized as an emulsifying agent. To prepare garlic extract, 200 grams of garlic cloves (*Allium sativum* L.) were pulverized using a Midea BL2516A blender. The resulting powder was then added to 1 L of distilled water, and the solution was filtered through a white poplin cloth. Subsequently, five grams of black soap and five milliliters of oil were added, and the mixture was homogenized to obtain a homogeneous solution. The recommended concentration of 5 g/L was used for the reference mancozeb-based chemical fungicide. The treatments were designated as T0 for the untreated plant (control), TNe for neem oil (20% (v/v)), TCa for carapa oil (12% (v/v)), TGa for aqueous garlic extract (0.2 g/L), and TMa for the mancozeb-based chemical fungicide (5 g/L).

Experimental procedure

The trial was conducted under a high tunnel with small-mesh insect-proof netting (65 mesh/m²). The tomato plants were individually transplanted into pots with a diameter of 12 cm and a depth of 17 cm, containing soil with a high organic matter content that had been disinfected with a solution of sodium hypochlorite (bleach) at a dilution of 95%. The experimental design was a randomized complete block design comprising five fungicide treatments and three blocks. The experimental units were arranged in blocks, with two rows of pots spaced 1 m apart and 1.5 m between blocks. Each experimental unit comprised six plants per treatment. The distance between plants within the same experimental unit was 0.5 m, and between experimental units within the same block was 1.5 m. Two treatment modes were employed: pre-inoculation and post-inoculation of the pathogen.

Regarding the pre-inoculation mode, foliar applications were conducted weekly for the biofungicides and once every two weeks for the chemical fungicide, using a 1-liter sprinkler at 30 cm from the nozzle 30 days after transplanting. One week after the initial application, each plant was inoculated with an identical dose of 1 mL of 3×10^5 zoospores/mL of *P. infestans* inoculum. The same procedure was employed for the post-inoculation mode, except that the plants were infected by the pathogen 30 days after transplanting, one week prior to the application of the fungicide treatments.

Measurements and observations

Observations and measurements were made on growth and vegetative development parameters, yield components, infection rate of tomato plants, and symptom severity index. Healthy fruits are those that show no symptoms of the disease.

Vegetative vigor Indices

To measure vegetative growth and development, plant height (H) and root collar diameter (D) were employed to calculate the vegetative vigor index (VVI) according to the following formula:

$$\mathbf{VVI = \log (0.785 \times H \times D^2)}$$

Disease incidence

The incidence of disease was evaluated by calculating the ratio of the number of plants exhibiting visible disease symptoms to the total number of inoculated plants using the following formula:

$$\mathbf{IM}\ (\%) = \frac{\mathbf{Ni}}{\mathbf{Nt}} \times \mathbf{100}$$

With IM: average incidence of the disease; Ni: number of plants infected by a type of symptom Nt: total number of plants observed.

Disease Severity

The severity of the disease was evaluated using a modified visual rating scale (Cardoso et al., 2004). The scale ranges from 0 to 5, with 0 indicating the absence of typical disease symptoms and 1 to 5 representing the presence of brown spots. The severity levels were as follows: 1 (1 to 5% of leaves, stems, and fruits infected), 2 (6 to 10%), 3 (11 to 25%), 4 (26 to 50%), and 5 (>50%). The disease severity index (IS) was calculated for each treatment according to the following equation, as proposed by Kranz (1988):

$$\mathbf{IS} = \frac{\sum(\mathbf{xi} \times \mathbf{Ni})}{\mathbf{NZ}} \times \mathbf{100}$$

With IS: severity indices; xi: disease score i; Ni: number of plants with score i; N: total number of plants assessed and Z: highest score.

Statistical analysis of data

The collected data were subjected to a one-way analysis of variance (ANOVA 1) using SPSS version 22.0 software. When a significant difference between concentrations was observed, the Duncan test at the 5% level was used to classify the means into homogeneous groups.

RESULTS

Vegetative vigor indices

The vegetative vigor indices demonstrate that the treated tomato plants exhibited enhanced growth and vegetative development compared to the untreated plants (Figure 1). This indicates that the applied treatments significantly influenced the growth and vegetative development of the tomato plants. This effect of the treatments was more pronounced in the preventive treatment, particularly with aqueous garlic extracts (TGa) and mancozeb (TMa). The statistical analysis of variance demonstrated no statistically significant difference ($p \geq 0.11$) between the two treatments for this parameter at the different phenological stages. The preventive treatments resulted in optimal growth and vegetative development of tomato plants during the fruiting and ripening stages, as indicated by the vegetative vigor indices (VVI) ranging from 1.77 to 1.86 for TAi, from 1.75 to 1.85 for TC, from 1.71 to 1.77 for TCa, and from 1.70 to 1.75 for TNe (Figure 1).

Disease incidence

The results demonstrated that the preventive or pre-inoculation treatments based on aqueous garlic extract (TGa) and mancozeb (TMa) preserved at least 30% of the tomato plants against mildew infection, in contrast to the untreated control (T0) where all the plants were infected (Table 1). The statistical analysis of variance indicated no significantly different effect ($p = 0.209$) between the TGa and TMa pre-inoculation treatments on disease incidence. In contrast, tomato plants treated with carapa oil (TCa) and neem oil (TNe) biopesticides exhibited the same behavior as the untreated control plants (T0) during the fruiting and ripening stages. The preventive or pre-inoculation treatments demonstrated superior protection of the tomato plants against late blight compared to the curative or post-inoculation treatments, where the disease infected all treated plants.

Severity of *P. infestans* symptoms on tomato plants

Using biopesticides and the reference chemical fungicide significantly reduced the severity of disease symptoms compared with untreated control plants (Table 2). Statistical analysis of variance revealed a significant fungicide effect ($F_{(4, 55)} \geq 4.444$ with $P \leq 0.003$) between treatments in reducing the intensity of downy mildew symptoms at fruiting and ripening stages. The chemical fungicide (TMa) and aqueous garlic extract (TGa) were more effective in reducing disease symptom expression, with mean indices ranging from 13.33 to 15% and 17.22 to 20.56%, respectively (Table 3). Statistical analysis of variance demonstrated no significant difference ($p \geq 0.058$) between these two treatments (TMa and TGa). Conversely, treatments based on carapa oil (TCa) and neem oil (TNe) exhibited statistically disparate effects ($p < 0.05$) in reducing the severity of late blight symptoms, except for the post-inoculation stage at the tomato fruit ripening stage.

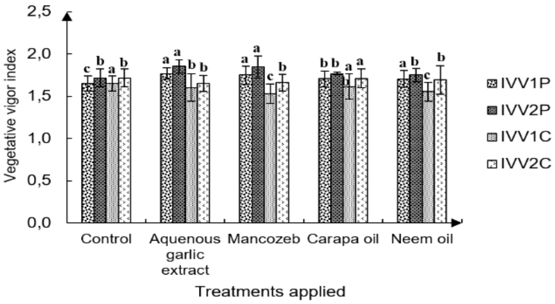
Treatment effects on yield and its components

Healthy and infected fruit rates

Preventive or pre-inoculation treatments resulted in healthy fruit rates of between 65.83 and 94.67%, compared with 18.22% for the untreated control (Table 3). These rates are higher than those obtained with curative or post-inoculation treatments, where the rate of healthy fruit varied from 45.37 to 88.15%. A statistically significant difference was observed between pre- and post-inoculation treatments ($F_{(4, 55)} = 4.536$ with $P = 0.003$). The TGa and TMa pre-inoculation and post-inoculation treatments yielded more than 75% healthy fruit, in contrast to the TNe and TCa treatments, where the healthy fruit rate varied between 45.37 and 77.02% (Table 4). However, the TCa treatment produced a higher rate of healthy fruit, at least 58%, than the TNe treatment. Moreover, the results demonstrate that the incidence of infected fruit is significantly elevated when the tomato plants are not treated or when the treatments are applied after the disease has taken hold. In these instances, the rate of spoiled fruit reached 81.78%. Conversely, when the treatments were applied prior to the onset of the disease, the incidence of infected fruit was considerably lower, at 41.92%.

Net and gross potential yields

The results demonstrate considerable variability in potential net and gross yields. This variation in yields is a function of the treatments employed and the preventive and curative treatment methods. The preventive treatment yielded the highest potential net and gross yields, with an average of 6.55 and 7.68 tons per hectare (t/ha), respectively, in comparison to the curative treatment, which yielded 5.76 and 7.14 tonne/ha, respectively (Table 4). Aqueous garlic extract (TGa) induced higher net (7.05 and 6.56 t/ha) and gross (7.72 and 7.46 t/ha) potential yields than the untreated control (T0) and the carapa oil (TCa) and neem oil (TNe) treatments. However, the best yields were observed with the reference chemical fungicide based on mancozeb.



IVV1P: Index of vegetative vigor preventive treatment at fruiting stage
IVV2P: Index of vegetative vigor preventive treatment at ripening stage
IVV1C: Index of vegetative vigor curative treatment at fruiting stage
IVV2C: Index of vegetative vigor curative treatment at ripening stage
According to Duncan's test, mean values ± standard error followed by the same letter on the bars are not significantly different at the 5% significance level.

Figure 1: Indices of vegetative vigor as a function of the treatments applied.

Table 1: Disease incidence.

		Fructification		Maturation	
Treatments	**Concentrations**	**Preventive**	**Curative**	**Preventive**	**Curative**
Control (T0)	-	100.0 ± 0.0^{a}	100.0 ± 0.0^{a}	100.0 ± 0.0^{a}	100.0 ± 0.0^{a}
Aqueous garlic extract (TGa)	0.2 g/L	66.67 ± 49.24^{b}	100.0 ± 0.0^{a}	83.33 ± 38.92^{a}	100.0 ± 0.0^{a}
Mancozeb (TMa)	5 g/L	50.0 ± 52.22^{b}	100.0 ± 0.0^{a}	50.0 ± 52.22^{b}	100.0 ± 0.0^{a}
Carapa oil (TCa)	12% (v/v)	100.0 ± 0.0^{a}	100.0 ± 0.0^{a}	100.0 ± 0.0^{a}	100.0 ± 0.0^{a}
Neem oil (TNe)	20% (v/v)	100.0 ± 0.0^{a}	100.0 ± 0.0^{a}	100.0 ± 0.0^{a}	100.0 ± 0.0^{a}
	$F_{(4, 55)}$	149.875	-	45.925	-
	P	0.0001	-	0.0001	-

According to Duncan's test, mean values ± standard error followed by the same letter in the same column are not significantly different at the 5% significance level.

Table 2: Symptom severity.

		Fructification		Maturation	
Treatments	**Concentrations**	**Preventive**	**Curative**	**Preventive**	**Curative**
Control (T0)	-	58.34 ± 19.46^{a}	58.34 ± 19.46^{a}	71.66 ± 27.25^{a}	71.66 ± 27.25^{a}
Aqueous garlic extract (TGa)	0.2 g/L	17.22 ± 10.81^{cd}	25.00 ± 5.22^{cd}	20.56 ± 10.03^{d}	33.89 ± 6.49^{c}
Mancozeb (TMa)	5 g/L	13.33 ± 9.85^{d}	20.00 ± 9.85^{d}	15.00 ± 9.04^{d}	25.00 ± 5.22^{c}
Carapa oil (TCa)	12% (v/v)	24.45 ± 3.28^{c}	35.00 ± 5.22^{c}	35.00 ± 5.22^{c}	51.11 ± 16.90^{b}
Neem oil (TNe)	20% (v/v)	35.56 ± 6.56^{b}	42.22 ± 16.41^{b}	51.11 ± 22.98^{b}	53.34 ± 19.69^{b}
	$F_{(4, 55)}$	4.444	6.341	321.530	6.899
	P	0.003	0.0001	0.0001	0.0001

According to Duncan's test, mean values ± standard error followed by the same letter in the same column are not significantly different at the 5% significance level.

Table 3: Rates of healthy and infected fruit.

		Rate of healthy fruit		Rate of infected fruit	
Treatments	**Concentrations**	**Preventive**	**Curative**	**Preventive**	**Curative**
Control (T0)	-	18.22 ± 7.15^{d}	18.22 ± 7.15^{e}	81.78 ± 7.15^{a}	81.78 ± 7.15^{a}
Aqueous garlic extract (TGa)	0.2 g/L	90.78 ± 6.62^{a}	79.66 ± 4.07^{b}	9.22 ± 6.62^{d}	20.34 ± 4.07^{d}
Mancozeb (TMa)	5 g/L	94.67 ± 4.77^{a}	88.15 ± 3.07^{a}	5.33 ± 4.77^{d}	11.29 ± 3.11^{e}
Carapa oil (TCa)	12% (v/v)	77.02 ± 19.85^{b}	58.46 ± 7.99^{c}	22.98 ± 19.85^{c}	41.54 ± 7.99^{c}
Neem oil (TNe)	20% (v/v)	65.83 ± 16.56^{c}	45.37 ± 6.19^{d}	34.17 ± 16.56^{b}	54.63 ± 6.16^{b}
	Mean	69.30 ± 30.27	57.97 ± 25.84	30.69 ± 30.27	41.92 ± 25.98
	$F_{(4, 55)}$	4.442	4.536	4.441	4.515
	P	0.004	0.003	0.004	0.003

According to Duncan's test, mean values ± standard error followed by the same letter in the same column are not significantly different at the 5% significance level.

Table 4: Potential net and gross yields.

		Net potential yield (t/ha)		**Gross potential yield (t/ha)**	
Treatments	Concentrations	Preventive	Curative	Preventive	Curative
Control (T0)	-	4.55 ± 0.05[e]	4.55 ± 0.05[d]	6.53 ± 0.34[c]	6.53 ± 0.34[c]
Aqueous garlic extract (TGa)	0.2 g/L	7.05 ± 0.14[b]	6.56 ± 0.40[b]	7.72 ± 0.29[b]	7.46 ± 0.22[b]
Mancozeb (TMa)	5 g/L	9.28 ± 0.25[a]	8.08 ± 0.34[a]	10.06 ± 0.26[a]	8.28 ± 0.13[a]
Carapa oil (TCa)	12% (v/v)	6.80 ± 0.34[c]	4.95 ± 0.51[c]	7.58 ± 0.26[b]	6.77 ± 0.53[c]
Neem oil (TNe)	20% (v/v)	5.09 ± 0.24[d]	4.66 ± 0.44[cd]	6.50 ± 0.39[c]	6.65 ± 0.36[c]
	Mean	6.55 ± 1.69	5.76 ± 1.43	7.68 ± 1.34	7.14 ± 0.74
	$F_{(4, 55)}$	6.459	28.673	0.911	7.269
	P	0.001	0.0001	0.154	0.0001

According to Duncan's test, mean values ± standard error followed by the same letter in the same column are not significantly different at the 5% significance level.

DISCUSSION

This study demonstrated the comparative effect of plant extracts and a reference chemical fungicide on the infection rate of tomato plants, the development of late blight symptoms, and yield components. The infection rate of tomato plants and the severity of late blight were reduced on tomato plants treated preventively with the biopesticide based on aqueous garlic extracts (*Allium sativum* L.) and the reference chemical fungicide based on mancozeb. This suggests that the active ingredients mancozeb and the natural substances present in garlic extracts from the *Allium* genus were effective against the parasite *Phytophthora infestans*, the agent responsible for tomato late blight.

Several studies have demonstrated the antifungal activity of garlic extracts from the *Allium* genus against fungi (Irkin and Korukluoglu, 2007; Benmeddour et al., 2015; Mylona et al., 2019). According to these authors, the antifungal activity of garlic extracts from the *Allium* genus is due to chemical substances at different concentrations. These substances may be monoterpenes that act on the hyphae of the mycelium. This causes the cell wall to lose its rigidity and integrity, leading to its collapse and the death of the mycelium. The fungicidal effect induced by the aqueous garlic extracts was not statistically different ($p \geq 0.209$) from that of the chemical reference fungicide based on mancozeb, whose in vivo efficacy has already been proven on *P. infestans* in a study carried out by Foto et al. (2016).

Torres et al. (2020) have shown that neem (*Azadirachta indica*) and carapa (*Carapa procera*) oils contain substances with antifungal activity on certain fungi. However, in this study, the effect of these pesticidal plant extracts was less effective on *P. infestans* compared with aqueous garlic extracts and mancozeb. The fungitoxicity of mancozeb lies in its multisite action by contact with fungi. Mancozeb acts as a thiol-reactive compound, causing extensive oxidation of protein cysteine residues, as Dias et al. (2010) stated. In an aqueous solution (slurry), it breaks down to release ethylene disulfide thiocyanate, which in turn is converted to ethyl isothiocyanate under the action of UV light; these two derivative compounds deactivate specific essential biochemical processes underway in fungal cells, such as respiratory function and spore germination (Gullino et al., 2010).

The high effect of mancozeb, a synthetic chemical fungicide in the carbamate family, compared with the pesticidal plant extracts used in this study could be explained by the fact that mancozeb is an isolated pure molecule whose concentrations and active principle are well known. This is not the case for the plant extracts used. This hypothesis is supported by Tsopmbeng et al. (2014), who state that crude extracts contain many different compounds that do not necessarily have antifungal functions. In contrast, synthetic fungicides contain optimal amounts of antifungal compounds that can effectively control plant pathogens.

However, this study shows that the aqueous extract of garlic of the *Allium* genus may respond to the reduction in the use of mancozeb in the phytosanitary protection of tomatoes against late blight. This could protect tomatoes from chemical pesticide residues, especially as this vegetable fruit is widely consumed in Côte d'Ivoire and worldwide. Studies have demonstrated the presence of chemical pesticide residues in tomatoes (Rahman et al., 2021; Sulaiman et al., 2021) and the health risks associated with the consumption of this vegetable fruit treated with chemical pesticides from the organophosphorus, carbamate, and pyrethroid families has also been highlighted (Shakhaoat et al., 2013). The latest authors showed that the pesticide residues assessed in twelve tomato samples exceeded the maximum residue limit (MRL), except for chlorpyrifos, with a hazard risk index (HRI) for carbaryl (1.09). There is an urgent requirement for formulations that are environmentally and human-health friendly and protect crops against pests and diseases. In this context, pesticidal plant extracts could be one of the solutions for sustainable pest management.

The significant difference observed between the treatment methods (pre-inoculation or preventive treatment and post-inoculation or curative treatment) showed that the preventive treatments provided good phytosanitary protection for the tomato plants and resulted in a high rate of healthy fruit and a good net potential yield. These results reveal a significant fungicidal and/or fungistatic effect of the concentrations used in reducing attacks by the tomato downy mildew pathogen. According to Djeugap et al. (2011), essential oils have fungistatic and fungicidal activities on fungi. These results support one of the conclusions of Huat et al. (2013), who report that it is possible to increase yields by improving the quality of the fruit produced through effective crop protection practices.

Conclusion

This study revealed the antifungal activity of biopesticides in reducing late blight virulence. The effect of these treatments was greater as a preventive than a curative measure. The biopesticide based on aqueous garlic extract at 0.2 g/L and the reference fungicide based on mancozeb concentrated at 5 g/L resulted in at least 75% healthy fruit, regardless of the treatment method used (preventive or curative). Analysis of variance showed no statistically different effect ($p > 0.05$) between aqueous garlic extract and mancozeb treatments. These results suggest that garlic aqueous extract should be used as an alternative to chemical control or as part of integrated control programs against late blight in tomato crops.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

This work was carried out in perfect collaboration between all the authors. AAGG developed the protocol, conducted the field and post-harvest agricultural activities, conducted the statistical analyses of the data collected, and drafted the manuscript. NDK contributed to the statistical analyses of the data collected, helped draft the manuscript, and participated in translating the manuscript into English. Author 3 (EOT) contributed to the statistical analysis of the data, edited the manuscript, and translated the manuscript into English. Authors 4 (CLO), 5 (FAN), and 6 (MN) contributed to the trial setup and the provision of materials. Authors 7 (LF) and 8 (KA) corrected the manuscript in French and English.

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