Scholars Academic Journal of Biosciences
Abbreviated Key Title: Sch Acad J Biosci
ISSN 2347-9515 (Print) | ISSN 2321-6883 (Online)
Journal homepage: https://saspublishers.com
National Library of Medicine
NLM ID:101629416
OPEN ACCESS
Agronomic Sciences

Evaluation of the Effectiveness of an Agroecological Management System for the Phytosanitary Protection of Tomato Crops (*Solanum lycopersicum* L.) in Central Côte d'Ivoire

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DOI: https://doi.org/10.36347/sajb.2025.v13i11.008 | **Received:** 23.09.2025 | **Accepted:** 18.11.2025 | **Published:** 24.11.2025

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Abstract **Original Research Article**

Tomato (*Solanum lycopersicum* L.) is the most widely consumed fruit vegetable worldwide due to its nutritional value. However, pests and diseases limit its production, leading to frequent and often excessive use of chemical pesticides that pose risks to human health and the environment. This study evaluated the efficacy of an agroecological management system against tomato pests in the context of sustainable agriculture. The trial was conducted using a completely randomised block design with four replicates and five treatments. Results showed that the combination of insect-net and neem and carapa oils-based biopesticide (F-TB) significantly reduced the incidence (9.2 to 11.21%) of viral and fungal diseases as well as infestations of *Bemisia tabaci*, larvae of *Helicoverpa armigera*, and *Spodoptera* spp. Consequently, 95% of the fruit harvested under F-TB was healthy, compared to 57.04% under chemical treatment (TC) and 39.99% in the untreated plots (T0). Net yield with F-TB (16.39 t/ha) was more than double that of TC (7.63 t/ha) and substantially higher than the untreated control (3.99 t/ha). Conversely, untreated plots exhibited high incidence of tomato yellow leaf curl virus and severe necrotic symptoms on leaves and stems (severity index 4.2). This study demonstrates that the agroecological management system offers a promising, environmentally sustainable alternative to chemical control for pest management and yield improvement in tomatoes.
Keywords: Agroecology, Biopesticide, Côte d'Ivoire, Insect-net, Tomato pests.

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is a major horticultural crop worldwide, valued both for its nutritional importance and economic contribution. In Côte d'Ivoire, it constitutes a strategic sector that supplies urban and rural markets while providing an essential source of income for many smallholder farmers (Neha & Praveen, 2014; Zekeya *et al.*, 2017). Despite its nutritional and economic potential, the tomato value chain is characterized by low productivity, leading to a growing reliance on imports of fresh vegetables (FIRCA, 2019).

One of the major constraints limiting tomato production in Côte d'Ivoire is the heavy pressure from pests and diseases, including viral, fungal, and bacterial pathogens, as well as insect pests such as whiteflies, tomato leaf miners, *Helicoverpa armigera* larvae, and *Spodoptera* spp. (Konan *et al.*, 2023; Gadji *et al.*, 2024). These biotic stresses cause substantial yield losses, thereby undermining the profitability of vegetable farming (Fondio *et al.*, 2013; Konan *et al.*, 2023). To address these challenges, producers often rely heavily on synthetic chemical pesticides. However, this dependence poses several problems, including the development of resistance among pests, pesticide residues in fruits, risks to human and animal health, and environmental degradation (Shakhaoat *et al.*, 2013; Damalas and Koutroubas, 2018; Soro *et al.*, 2019).

The active ingredients of synthetic pesticides are generally broad-spectrum and negatively affect parasitoids and natural predators of crop pests. Their widespread use in agriculture over the past five decades has accelerated the emergence of resistant pest populations, particularly among key insect species (Martin *et al.,* 2002). In this context, the development and promotion of sustainable alternatives for pest management have become imperative. Integrated pest management (IPM), which combines the use of tolerant varieties, improved cultural practices, biopesticides, and biological control, offers a promising pathway to reduce dependence on chemical pesticides while ensuring sustainable and competitive production. Within this framework, the present study was initiated to evaluate an agroecological management approach for controlling tomato pests and diseases through the use of insect-nets combined with biopesticide.

MATERIALS AND METHODS

Study Area

The trial was conducted at the food crop research station of the Centre National de Recherche Agronomique (SRCV/CNRA) located at Bouaké in central Côte d'Ivoire at latitude 7°40'42.94" N, longitude 5°5'59.37" W and altitude 401 m. Precipitation recorded during the study period (December 2020 to May 2021) varied between 58 and 98.5 mm, with temperatures ranging from 24.33 to 30.09 °C and relative humidity between 58.33 and 83.68%.

Pest management materials

The pest management materials consisted of a biopesticide formulated from neem (*Azadirachta indica* L.) and carapa (*Carapa procera* L.) oils, an insect-net, and chemical pesticides (insecticide and fungicide). The chemical insecticide contained lambda-cyhalothrin (15 g/L) and acetamiprid (20 g/L), while the chemical fungicide was based on copper oxychloride (50%). These were used as the reference chemical treatment. The insect-proof net, with a mesh size of 63 holes/cm², served as a physical barrier.

Experimental design and agricultural practices

The trial was conducted on the tomato variety Cobra 34 F1, commonly cultivated by market gardeners. A randomized complete block design was used, with four replications and five treatments. The design consisted of 20 experimental units (plots), each measuring 10 m × 5 m (50 m²). Blocks were separated by 2 m, and plots within blocks by 1 m. Tomato seedlings were transplanted into four rows per plot, with 15 plants per row. The treatment factor included five levels: insect-net alone (F), insect-net combined with biopesticide (F-TB), untreated control (T0), biopesticide alone (TB), and chemical treatment (TC). Irrigation was provided using a drip system connected to a closed borehole, with four drip lines installed per plot.

Preparation of mixture and treatment applications

Neem oil (150 mL, 50% concentration) was mixed with 150 mL of carapa oil (48%) in 15 L of water. Subsequently, each solution was combined with 5 g of black soap, resulting in a homogeneous solution. Black soap was utilized as an emulsifying agent. The homogenized mixture was used for treating tomato plants. For synthetic pesticides, 20 mL of the commercial insecticide (K-Optimal) and 75 g of the wettable powder fungicide (Callicuivre 50 WP) were diluted in 8 L and 15 L of spring water, respectively. Each diluted product was separately agitated in a 16-L manual knapsack sprayer with continuous pressure to obtain a homogeneous suspension. The resulting sprays were applied to tomato plants. Biological treatments (TB) were carried out once a week between 7:00 and 8:00 a.m. using the sprayer. Chemical treatments were applied biweekly, alternating between the insecticide and the fungicide, at the same time of day.

Data Collection

Observations and measurements were conducted from the 14th to the 70th day after transplanting (DAT). Ten plants per plot were randomly selected along a diagonal sampling pattern (two plants from row 1, three from row 2, three from row 3, and two from row 4). Data collected included vegetative growth and development parameters, yield and yield components, infection rates, and symptom severity index. In addition, pest inventories and monitoring were carried out. The proportion of healthy versus damaged fruits was also determined, with healthy fruits defined as those showing no disease symptoms.

Pest monitoring

An inventory and monitoring of pest population dynamics were carried out following the observation technique described above. Counts of piercing-sucking insects and lepidopteran larvae were conducted on the 10 plants selected per plot at 14 and 70 days after transplanting (DAT).

Disease incidence

Disease incidence was assessed as the ratio of the number of plants showing visible symptoms of fungal infection to the total number of plants observed, according to the following formula:

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

With **IM**: average disease incidence; **Ni**: number of plants infected with a specific type of symptom; **Nt**: total number of plants observed.

Evaluation of symptom severity

For fungal diseases, severity was assessed using a modified visual rating scale (Groth *et al.,* 1999; Cardoso *et al.*, 2004). The scale ranged from 0 to 5, where 0 indicated the absence of disease symptoms and 1-5 indicated the presence of brown spots, with 1: 1-5%

of leaves, stems, and fruits infected; 2: 6-10%; 3: 11-25%; 4: 26-50%; and 5: >50%. The disease severity index (Is) for each treatment was calculated using the following equation (Kranz, 1988):

$$\mathbf{IS} = \frac{\sum(\mathbf{xi} * \mathbf{Ni})}{\mathbf{NZ}} \, \boldsymbol{X}\, \mathbf{100}$$

With **IS**: severity index; **xi**: the i-th disease score; **Ni**: the number of plants with score i; **N**: the total number of plants assessed; and **Z**: the highest score.

In contrast, for viral disease, severity was assessed using a modified version of the symptom severity index scale described by Huang *et al*. (2025). The scale ranged from 0 to 5, where: 0 = no symptoms (vigorous plant, normal leaves, no yellowing or curling); 1 = very mild (1-10% of foliage affected: slight cupping of a few apical leaves, without pronounced yellowing); 2 = mild (11-25% of leaves affected: initial marginal yellowing, visible curling of young leaves, growth slightly affected); 3 = moderate (26-50% of leaves affected: obvious curling on several leaves, clear yellowing, onset of stunting or reduced growth); 4 = severe (51-75% of leaves affected: pronounced cupping of leaves, marked yellowing, moderate to severe stunting, reduced flowering); and 5 = very severe (>75% of leaves affected: extreme leaf curling, generalized yellowing, severe stunting, drastic reduction in vigor and fruiting). The disease severity index (Is) was calculated using the formula described previously.

Statistical data analysis

The collected data were subjected to one-way analysis of variance (ANOVA) using SPSS software version 22.0. When significant differences were observed among treatments, Tukey's HSD test at a 5% significance level was performed to group the means into homogeneous subsets.

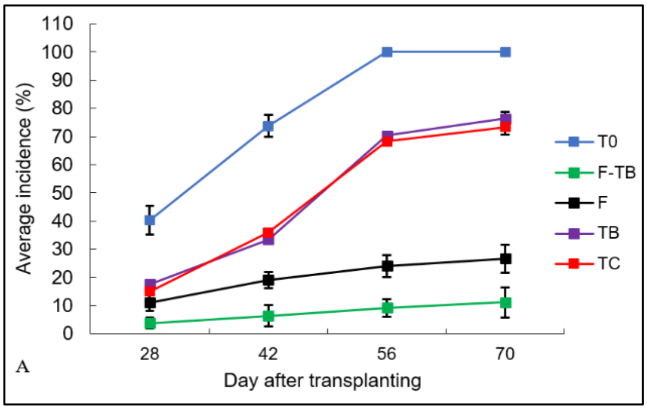
RESULTS

Effect of treatments on disease incidence and symptom severity index

Disease incidence

Figure 1 presents the temporal evolution of the mean incidence of fungal and viral diseases from the appearance of the first symptoms at 28 to 70 days after transplanting (DAT). The results indicate that variability in disease incidence was associated with the different treatments applied. In the untreated control (T0), all plants were affected by fungal diseases by 56 DAT, characterized by necrotic spots on leaves and stems and collar rot (Figure 1A). Disease incidence ranged from 9.20 ± 3.22% to 11.21 ± 5.30% in plots treated with insect-net combined with biopesticide (F-TB), compared with 68.3 ± 1.15% to 73.3 ± 2.58% in the chemical treatment (TC) plots between 56 and 70 DAT. Statistical analysis revealed no significant difference ($p \geq 0.153$) between TB and TC treatments.

Regarding viral disease, 93.56 ± 3.78% of plants in untreated plots (T0) were infected with tomato yellow leaf curl virus (TYLCV) (Figure 1B). In contrast, incidence ranged from 5.40 ± 3.48% to 6.77 ± 3.52% in plots treated with F-TB, compared with 31.60 ± 2.50% to 35.50 ± 3.26% in TC plots from 56 to 70 DAT. Statistical analysis indicated significant differences ($p < 0.05$) among the applied treatments.



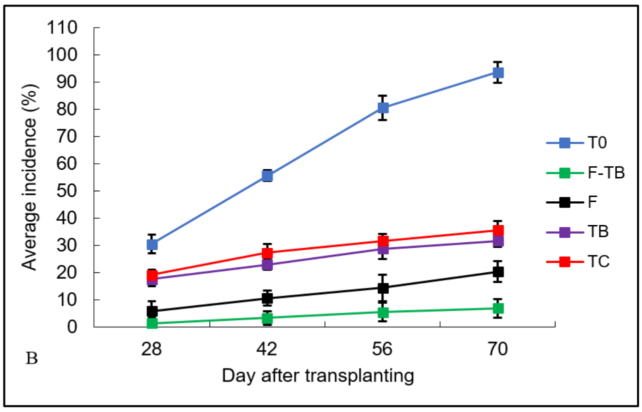


Figure 1: Evolution of the incidence of fungal (A) and viral (B) diseases on tomato plants

T0: untreated plot or control; **F-TB:** insect-net combined with neem and carapa oils-based biopesticide; **F:** insect-net; **TB:** neem and carapa oils-based biopesticide; **TC:** chemical treatment (chemical insecticide and fungicide).

Disease Severity

Figure 2 illustrates the variation in severity of fungal and viral diseases. This variation in severity was influenced by the treatments applied. Results showed changes in the symptom severity index over the observation period. However, symptoms such as necrotic spots on leaflets and stems (Figure 2A), stunted growth, chlorosis, and upward curling of leaves into a spoon shape (Figure 2B) were minimal (1.5 ± 0.17 and 1.5 ± 0.16) in plots under insect-net combined with biopesticide (F-TB), compared with chemical treatment (TC) and untreated plots (T0). Fungal and viral disease symptoms were more severe between 42 and 70 DAT, corresponding to the fruiting period, particularly in untreated plants. Nevertheless, statistical analysis indicated no significant differences ($p \geq 0.05$) between the effects of TB and TC treatments. The most effective phytosanitary protection of tomato plants was achieved with insect-net (physical barrier) combined with neem and carapa oils-based biopesticide.

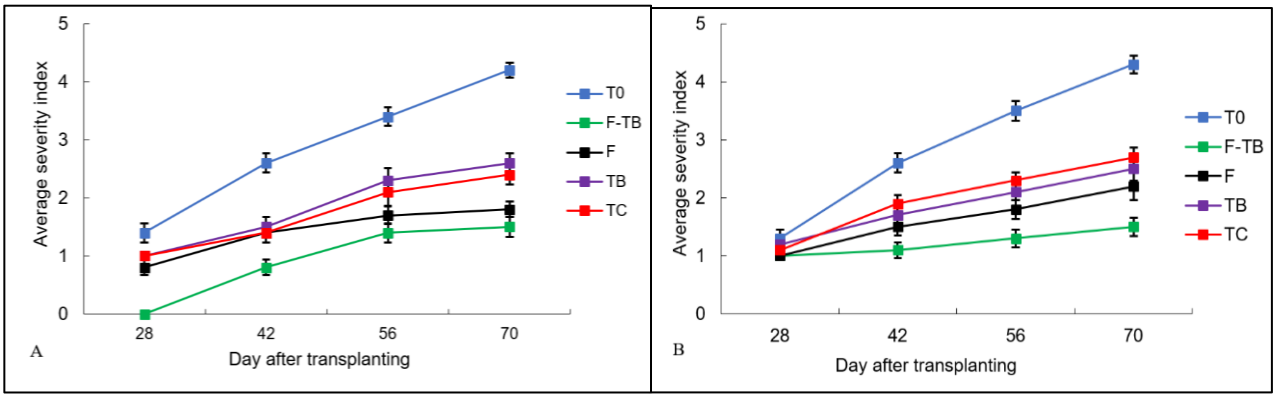


Figure 2: Evolution of the severity index of fungal (A) and viral (B) diseases on tomato plants
T0: untreated plot or control; **F-TB:** insect-net combined with neem and carapa oils-based biopesticide; **F:** insect-net; **TB:** neem and carapa oil-based biopesticide; **TC:** chemical treatment (chemical insecticide and fungicide).

Effect of treatments on the control of major pests

Figure 3 shows the variation in the mean number of whiteflies, *Helicoverpa armigera* larvae, and *Spodoptera* spp. larvae on tomato plants from 14 to 70 days after transplanting (DAT). The F-TB treatment reduced whiteflies to one individual per leaf, compared with chemical treatment (TC), where the mean number ranged from 2.7 ± 0.59 to 4.38 ± 1.05; 0 to 0.67 ± 0.07; and 0 to 0.9 ± 0.1, respectively. From 49 DAT, whitefly populations peaked in untreated plots (T0), whereas they remained around two individuals per leaf in TB and F treatments (Figure 3A). Moreover, almost no *Helicoverpa armigera* or *Spodoptera* spp. larvae were observed under the F-TB treatment, compared with at least one larva per plant in untreated plots (T0) and one *Spodoptera* spp. larva per plant in TC plots (Figures 3B and 3C). Statistical analysis indicated significant differences ($p < 0.05$) among treatments in pest control.

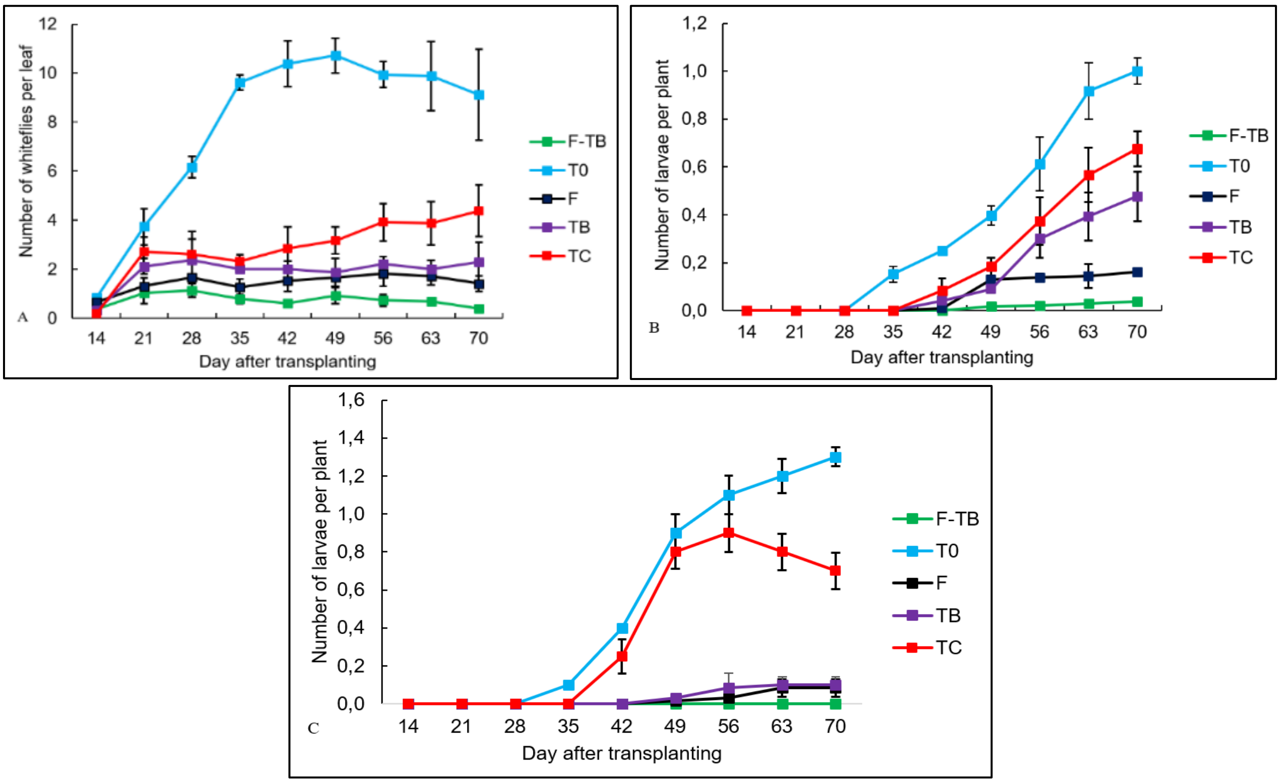


Figure 3: Evolution of the number of whiteflies (A), *Helicoverpa armigera* (B) and *Spodoptera* spp (C) larvae on tomato plants
T0: untreated plot or control; **F-TB:** insect-net combined with neem and carapa oil-based biopesticide; **F:** insect-net; **TB:** neem and carapa oils-based biopesticide; **TC:** chemical treatment (chemical insecticide and fungicide).

Effect of treatments on yield and damage to fruit and leaves

The highest yield was obtained in plots protected with the insect-net combined with the biopesticide, reaching 16.39 ± 3.58 t/ha (Table 1). In contrast, plots treated with the chemical insecticide, the biopesticide alone, and untreated plots produced lower yields, ranging from 3.99 ± 2.58 to 7.63 ± 2.96 t/ha. Statistical analysis revealed significant differences among treatments (F = 7.225; p = 0.002).

Plots protected with the net combined with the biopesticide and those with the net alone had the lowest proportions of damaged fruits, ranging from 4.84 ± 2.01% to 21.62 ± 6.45% (Table 1). Conversely, plots treated with chemical pesticides, the biopesticide alone, and untreated plots had higher proportions of damaged fruits, ranging from 40.70 ± 11.70% to 60.72 ± 17.82%. Statistical analysis indicated significant differences among treatments for both healthy and damaged fruit rates (F = 16.713; *p* = 0.0001).

The plants had more damaged leaves In the untreated plots (T0) than in those treated with chemical (TC) or biological (TB) pesticides. Between 14 and 70 days after transplanting (DAT), the number of damaged leaves per plant ranged from 0.45 to 4.15. By contrast, plots protected with a simple net (F) or a net combined with a biological pesticide (F-TB) had fewer damaged leaves per plant, ranging from 0.075 to 1.475 (Figure 4).

Table 1: Yield and rates of healthy and damaged fruit according to treatment

Traitements	**Rendement net (t/kg)**	**Taux de fruits sains**	**Taux de fruits avariés**
F-TB	16.39 ± 3.58^{a}	95.16 ± 2.01^{a}	4.84 ± 2.01^{c}
F	11.83 ± 6.02^{ab}	78.38 ± 6.45^{ab}	21.62 ± 6.45^{bc}
TB	5.48 ± 2.45^{b}	59.3 ± 11.70^{bc}	40.70 ± 11.70^{ab}
TC	7.63 ± 2.96^{b}	57.04 ± 7.17^{bc}	42.96 ± 7.17^{ab}
T0	3.99 ± 2.58^{b}	39.28±17.82^{c}	60.72 ± 17.82^{a}
F	7.225	16.713	16.713
P	0.002	0.0001	0.0001

Average ± standard deviation. Values sharing same letters differ non-significantly (*p* > 0.05).

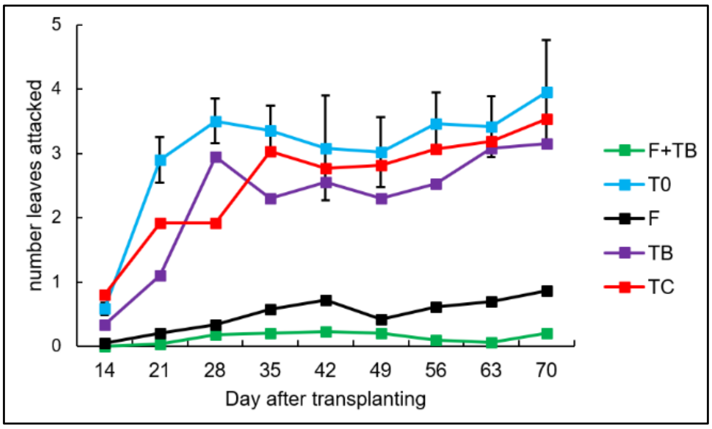


Figure 4: Evolution of the number of leaves attacked following treatment

T0: untreated plot or control; **F-TB:** insect-net combined with neem and carapa oil-based biopesticide; **F:** insect-net; **TB:** neem and carapa oils-based biopesticide; **TC:** chemical treatment (chemical insecticide and fungicide).

DISCUSSION

This study highlighted the comparative effects of an agroecological management system and a conventional chemical treatment (insecticide and fungicide) commonly used in Côte d'Ivoire for the phytosanitary protection of horticultural crops. Results showed that the combination of an insect-net with neem and carapa oils-based biopesticide (F-TB) significantly reduced disease incidence and the abundance of tomato pests compared to conventional synthetic pesticide practices. These findings confirm the relevance of agroecological approaches for pest management and yield improvement.

The variability observed in disease incidence (fungal and viral) and symptom severity can be attributed to the effects of the applied treatments. Both biological and chemical pesticide treatments contributed significantly to reducing whitefly populations and mitigating the impact of fungal pathogens on treated plants. These findings corroborate those of Gadji *et al.* (2024), who reported the antifungal effect of neem and carapa oils against *Phytophthora infestans*, the causal agent of tomato blight. However, it is noteworthy that studies increasingly report resistance of whiteflies to lambda-cyhalothrin and acetamiprid, a pyrethroid and a neonicotinoid, respectively (Martin *et al.*, 2002; Romba *et al.*, 2020). This may explain the slightly higher attack rate (35.5%) of tomato plants by tomato yellow leaf curl virus compared to the biopesticide treatment (31.5%).

Neem (*Azadirachta indica*) and carapa (*Carapa procera*) oil extracts are of particular interest. Khan *et al*. (2023) demonstrated the antifungal activity of a volatile neem oil compound (propyl disulfide) against several fungal species, including *Colletotrichum* spp., responsible for mango anthracnose. Furthermore, Owusu *et al*. (2021) suggested that carapa extracts could serve as a potential source for controlling bacterial and fungal pathogens. These findings align with the present study, where disease incidence and symptom severity were markedly lower compared to untreated controls.

The mechanisms of action of essential oils are multiple and rely on bioactive compounds that disrupt cell membranes, inhibit vital enzymes, and generate oxidative stress, resulting in growth inhibition or death of phytopathogens. Kumar and Kudachikar (2019) suggested that the antifungal activity of plant extracts may be attributed to membrane disruption and leakage of cellular components.

The effectiveness of neem and carapa oil extracts against major tomato pests is well documented. Studies in Côte d'Ivoire have shown that neem extracts efficiently reduce populations of *Bemisia tabaci* and *Helicoverpa armigera*, with results comparable to synthetic insecticides (Konan *et al.*, 2023). Similarly, in Niger, neem oil reduced *B. tabaci* populations by 70% (Zakari *et al.*, 2016), likely due to the efficacy of azadirachtin, the active ingredient of neem oil. Other studies also reported significant reductions in whitefly infestation (Gnago *et al.*, 2010; Sane *et al.*, 2018). In addition to its insecticidal effect (Drabo *et al.*, 2017), carapa oil has a notable repellent effect on tomato pests, affecting larval survival and development (Konan *et al.*, 2023). This complementary mode of action to neem likely explains the enhanced efficacy of the F-TB treatment. These results are consistent with the present study, in which F-TB maintained 95.16% healthy fruits compared to 57.04% under chemical treatment and 39.28% in the untreated control.

The use of an insect-proof net also provides an effective physical barrier against viral disease vectors and multiple pests. In East Africa, Nordey *et al*. (2019) demonstrated that small mesh nets significantly reduce pest pressure and increase net yield in tomatoes. Similar results were reported by Martin *et al*. (2018), where netting against tomato leaf miners limited damage while improving yield. These observations align with the present study, indicating that the synergistic effect of the net and biopesticide offers more effective control than a single management approach.

The net yield obtained with F-TB (16.39 t/ha) was more than double that of chemical treatment (7.63 t/ha), highlighting the limitations of synthetic pesticides. Several studies emphasize the emergence of resistance in *B. tabaci* and *H. armigera* populations exposed repeatedly to conventional insecticides (Desneux *et al.*, 2007; Horowitz *et al.*, 2020). Exclusive reliance on these products, in addition to their environmental and health impacts (Aktar *et al.*, 2009), is therefore less sustainable than agroecological solutions. Nevertheless, as noted by Martin *et al*. (2018), insect-nets do not offer complete protection for crops against small piercing-sucking insects such as whiteflies. This assertion is consistent with the results of this study, in which an average of two whiteflies per leaf were observed on plots covered with single mesh insect-net (untreated with the biopesticide).

Further research should focus on the long-term sustainability of high tunnels with mesh insect- nets, how widely they are adopted by farmers, and how they can be integrated into broader integrated crop management strategies. This would enhance the effectiveness and sustainability of the system, thereby promoting food security and environmental preservation.

CONCLUSION

This study demonstrated the effectiveness of an agroecological management system that combines insect-net and biopesticide for controlling tomato pests. The results showed that this system significantly reduced the incidence of disease and the presence of the main tomato pests, achieving a higher net yield (16.39 t/ha) than conventional practices (7.63 t/ha). Overall, the findings suggest that this combination of an insect-net and a biopesticide represents a promising option for the sustainable protection of tomatoes against pests and diseases. However, scaling up this system requires continuous technical support, capacity building for vegetable producers and institutional assistance to strengthen the transition to agroecological vegetable production.

Conflict of Interests

The authors declare no conflict of interest.

ACKNOWLEDGEMENTS

We sincerely thank the administrative authorities of CNRA, particularly the Director of the Food Crops Research Station (SRCV) in Bouaké, for allowing us to conduct this research, and the Coordinator of the Hortinet project for funding this study. We also extend our gratitude to the technicians and interns of the Horticultural and Legume Crops Program (CMP) for their assistance in the establishment and monitoring of the trial.

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