PLANT SCIENCE TODAY
ISSN 2348-1900 (online)
Vol 11(sp4): 01–06
https://doi.org/10.14719/pst.5706

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RESEARCH ARTICLE

Comparative effectiveness of plant-derived insecticides against whiteflies *Bemisia tabaci* Gennadius and thrips, *Thrips tabaci* Lindeman in tomatoes: A laboratory study

G Satya Bhanu[1], Elaiyabharathi T[2*], Suganthi A[1], Kavitha C[3] & Santhanakrishnan VP[2]

[1] Department of Agricultural Entomology, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

[2] Department of Medicinal and Aromatic Crops, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

[3] Department of Fruit Science, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

*Email: elaiyabharathi.t@tnau.ac.in

OPEN ACCESS

ARTICLE HISTORY
Received: 10 October 2024
Accepted: 22 October 2024
Available online
Version 1.0 : 13 December 2024

Check for updates

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

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Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
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CITE THIS ARTICLE
Bhanu GS, Elaiyabharathi T, Suganthi A, Kavitha C, Santhanakrishnan VP. Comparative effectiveness of plant-derived insecticides against whiteflies *Bemisia tabaci* Gennadius and thrips, *Thrips tabaci* Lindeman in tomatoes: A laboratory study. Plant Science Today.2024;11(sp4):01-06. https://doi.org/10.14719/pst.5706

Abstract

Whiteflies (*Bemisia tabaci*) and thrips (*Thrips tabaci*) are significant sucking pests of tomatoes, posing increasing threats to crop health and leading to considerable economic losses, particularly in the context of climate change. These pests are also vectors for viral transmission, further diminishing crop quality and yield. A laboratory bioassay was conducted to assess the efficacy of several plant-derived insecticide formulations, including Adathoda leaf extract soap (10 %) @ 7 g/L, Azadirachtin (1000 ppm) @ 2 mL/L, Neem Seed Kernel Extract (NSKE) (5 %) @ 5 mL/L, Neem soap (10 %) @ 7 g/L and the microbial insecticide *Lecanicillium lecanii* (1×10^8 cfu/g) @ 5mL/L, along with Thiamethoxam 25% WG @ 0.3g/L as a chemical control. The results indicated that Thiamethoxam 25% WG achieved the highest mortality rate against whiteflies at 72 hr post-treatment (72 %), followed by Adathoda leaf extract soap (10%) (64.00 %), Azadirachtin (63.2 %), *L. lecanii* (60 %), Neem soap (61.5 %) and NSKE (59.2 %). For thrips, Thiamethoxam 25% WG again demonstrated the greatest effectiveness (71.20 %), with Adathoda leaf extract soap (10%) (65.60 %), Azadirachtin (64.25 %), *L. lecanii* (58.20%), Neem soap (60.80 %) and NSKE (59.80 %) following. This research highlights the potential of Adathoda leaf extract soap (10 %) as an eco-friendly alternative to traditional neem formulations, suggesting its suitability for integration into future Integrated Pest Management (IPM) programs for tomatoes.

Keywords

eco-friendly management; formulations; neem; plant-derived pesticides; sucking pests; tomato

Introduction

Tomato (*Lycopersicon esculentum* Mill.) is the most extensively cultivated vegetable from Mexico. According to the Press Information Bureau (PIB, 2024), India is the second-largest producer, with a cultivation area of 8.49 lakh hectares and an annual production of approximately 208.19 lakh metric tons. Native to western South and Central America, tomatoes are now cultivated year-round in tropical, subtropical and temperate regions across the globe. In India, tomato-producing states are Andhra Pradesh, Madhya Pradesh, Karnataka, Gujarat, Bihar, Odisha, West Bengal, Telangana, Chhattisgarh, Haryana, Tamil Nadu, Uttar Pradesh and Maharashtra which account for nearly 90 % of the country's total production (1). Tomatoes are grown mainly as an important vegetable worldwide and they are an essential ingredient in daily cuisine. They are also exclusively used for culinary purposes due to their savory flavor. They are a primary and cost-effective source of essential nutrients, including vitamins A, C and E, fiber and minerals (2). Additionally, tomatoes help elevate antioxidant levels in the body and are rich in vitamins C and E, proteins, essential amino acids, monounsaturated fatty acids, carotenoids and phytosterols (3). Tomato cultivation is significantly impacted by several insect pests, including whiteflies (*Bemisia tabaci* Gennadius), aphids (*Aphis gossypii* Glover), leafhoppers (*Amrasca biguttula biguttula* Ishida), thrips (*Thrips tabaci* Lindeman) and fruit borers (*Helicoverpa armigera* Hubner). Among these, whiteflies are particularly destructive as they serve as vectors for the tomato leaf curl virus (TLCV) (4). TLCV represents a major threat to tomato production in India, leading to severe yield losses ranging from 47 % to 95 %, especially during the early growth stages (5). Controlling *B. tabaci* is difficult due to its high reproductive rate, ability to move between crops and preference for inhabiting the undersides of leaves (6).

Recently, there has been a significant increase in the incidence of sucking pest damage on tomatoes and lablab beans in India. lists the major sucking pests affecting these crops. Among the pests, thrips (*T. tabaci*) and whiteflies (*B. tabaci*) have emerged as the most destructive pests for tomato production globally (7, 8). These pests puncture the leaf surface to feed on the sap and later lay their eggs on the leaf tissue (9). Additionally, whiteflies transmit begomoviruses, which cause TLCV, while thrips carry tospoviruses, leading to tomato spotted wilt virus (TSWV). Both of these viruses cause severe damage to both foliage and fruit production, thereby reducing crop quality and productivity by up to 80 to 90 % (10). Farmers commonly rely on conventional pest management methods, often using synthetic insecticides that are systemic, leaving harmful residues and leading to pest resistance (11). As an alternative, plant-derived pesticides like neem, tobacco and some medicinal plants are being developed to improve insect control (12). These plant-derived pesticides include secondary metabolites such as alkaloids, steroids, terpenoids, essential oils and phenolics (13, 14), which have various pest control properties, including toxicity, lethality, repellency, antifeedant activity, fumigation, growth regulation and oviposition deterrence (15). They are cheap, safe, environment-friendly, have no residual effects and significantly affect many insects (16). Plant-derived pesticides IPM presents a sustainable and cost-effective approach for future agricultural practices.

Materials and Methods

Experimental design

Laboratory experiments were carried out in the Department of Entomology, Tamil Nadu Agricultural University (TNAU), Coimbatore, Tamil Nadu, India. The experimental design (in AGRES 3.01 and AGDATA software) used is a completely randomized design (CRD) with seven treatments and five replications for each spray and each sucking insect.

Test insecticides

The insecticides used are Plant-derived pesticide formulations *viz.*, Adathoda leaf extract soap (10%) @ 7 g/L, Azadirachtin (1000 ppm) @ 2 mL/L, Neem Seed Kernel Extract (NSKE) (5 %) @ 5 mL/L, Neem soap (10%) @ 7 g/L, microbial insecticides, *Lecanicillium lecanii* (1X10^8 cfu/g) @ 5mL/L and chemical insecticide Thiamethoxam 25 % WG @ 0.3g/L (Table 1).

Table 1. Treatments for bioassay

S.no	Treatment	Dose (gm or mL/L)	Product details
T_1	Adathoda leaf extract soap (10%)	7g/L	Prepared in the department of entomology
T_2	Azardirachtin (1000 ppm)	1mL/L	Neemazal 1% (Coromandel, India)
T_3	Neem seed kernel extract (5%)	5mL/L	Prepared from seeds
T_4	Neem soap (10%)	7g/L	Soap formulation (ICAR-IIHR, Bengaluru)
T_5	Thiamethoxam 25% WG (chemical check)	0.3g/L	Actara,25% WG, Syngenta company, India.
T_6	*L. lecanii* -1x 10^{8}cfu/ml (Bio-pesticide check)	5mL/L	*Verticillium lecanii* 1.0 % W.P powder (1x10^8 CFU) (Organic Dews, Gurgaon, India
T_7	Control	Untreated	-------

Insect rearing

Test insects included are Thrips (*T. tabaci*), Whiteflies (*B. tabaci*)

Rearing of whiteflies (B. tabaci) on tomato and brinjal plants

The initial culture of *B. tabaci* was collected from cotton and tomato plants using an aspirator. Tomato seeds are put in pot trays for germination and then transferred to larger pots. The pots are then placed in cages (60cm x 40cm x 30cm) for further inoculation with white flies. The collected white flies are released into the cages. A colony of adult white flies is introduced into the cages every two days to increase the chance of infection. The underside of leaves is examined for eggs under a microscope. The infected plants are left for another 3 to 4 weeks for further emergence of adult insects in large numbers while maintaining the temperature at 25^{0}C and 75 % relative humidity (17).

Rearing of thrips (T. tabaci) on tomato and onion plants

The population of *T. tabaci* is collected from onion and tomato plants using an aspirator. Tomato seeds are initially sown in pot trays for germination before being transferred to larger pots. These pots are then placed inside cages measuring 60 cm x 40 cm x 30 cm for further inoculation with thrips. The collected thrips are introduced into the cages every two days to enhance the likelihood of infection. The infected plants are monitored for eggs under a microscope and left for 2 to 3 weeks to allow adult thrips to emerge while maintaining a temperature of 25°C and 75 % relative humidity (18).

Bioassay studies

The efficacy of plant-derived pesticide formulations on tomato-sucking pests was observed under laboratory conditions in the Department of Entomology, Tamil Nadu Agricultural University, Coimbatore.

Leaf dip method- whiteflies

Brinjal leaves are made into discs for whiteflies and bean leaves are used for aphids. These leaves are dipped in different treatment solutions for 30 seconds. Boxes with a mess on the lid are taken and a layer of agar is placed at the bottom. After dipping, the leaves were carefully drained of the excess solution and air-dried for an hour. The leaf discs were then placed on the agar to prevent wilting, ensure leaf freshness and provide a continuous food source for the insects. After 20 adult insects are released per replication, this entire set is maintained at 25 ± 2°C and 70 ± 5 RH %. A total of five replications are conducted for each treatment, with mortality observations recorded at 24, 48 and 72hr. This method ensures even distribution of the product on the leaf surface, allowing for assessment of the effectiveness of formulation for pest control (IRAC, 2009) (Fig.1.).

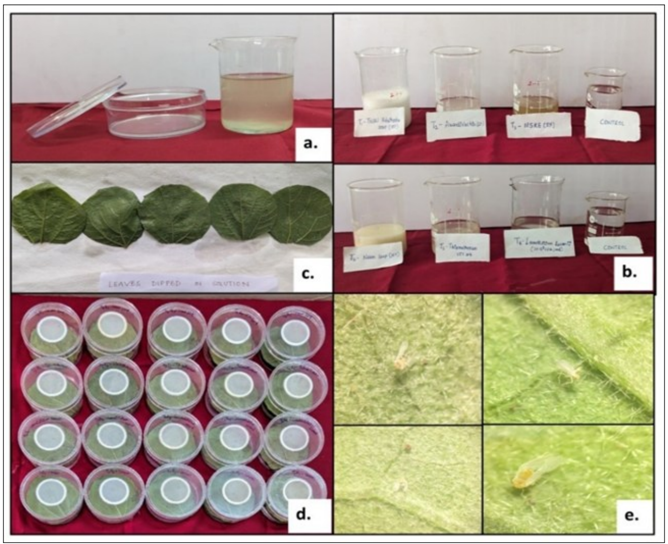

Fig. 1. Leaf dip bioassay: a. Setting of agar solution in the box, b. Treatment solutions, c. Leaf dipped in solution, d. Whiteflies and aphids released in boxes, e. observations under the microscope after treatment.

Bean dip method-thrips

Bean pods are cut into 20 mm long sections and sealed with Vaseline. This will prevent insects from entering the cut ends and prevent beans from drying. The botanical formulation solutions are made in 250 mL beakers. The cut beans are dipped into the solutions and agitated for 30 seconds to increase contact with the formulation. Now, these beans are placed in rearing boxes with a mesh on top for aeration and 20 adult thrips are realized into each box of replication per treatment. The boxes are placed at a temperature of 25⁰C and 70 % RH. Totally 5 replications were carried out for each treatment and a mortality count was taken for 24, 48 and 72 hr, respectively (IRAC, 2009) (Fig.2.).

Statistical analysis

The experimental data, obtained from a completely randomized design in the laboratory, were analyzed using analysis of variance (ANOVA) with AGRES 3.01 and AGDATA software. Percentage values were transformed using arcsine transformation and treatment means were compared through Duncan's Multiple Range Test (DMRT) at a 5 % level of significance.

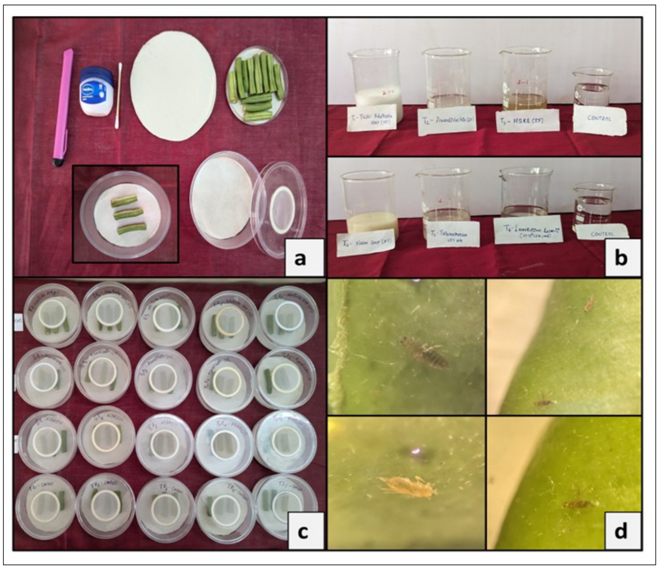

Fig.2. Bean dip bioassay: Materials for bioassay, b. Treatment solutions, c. Thrips released in boxes, d. Insects observed under the microscope after treatment.

Results

Toxicity of plant-derived formulations against whiteflies (*B. tabaci*)

The highest mortality rate of whiteflies was observed with Thiamethoxam 25 % WG demonstrated the highest mortality rate, of 64.0, 71.2 and 72.0 % at 24, 48 and 72 hrs after treatment (HAT), respectively. However, the botanical treatments, including Adathoda leaf extract soap (10 %), had the highest mortality of 56.8, 63.4 and 64.0 % at 24, 48 and 72 hrs after treatment next to Thiamethoxam 25 % WG. Azadirachtin (10000 ppm) and neem soap showed comparable effectiveness, with mean mortality rates of 63.20 and 61.40 % at 24, 48 and 72 HAT, respectively. As per the microbial control, *L. lecanii* ($1X10^8$cfu/g) also showed equal effectiveness as the Adathoda leaf extract soap (10%) and azardirachtin, with a total mortality of 60.60 % is detailed in Table 2 and Fig.3. The treatments using NSKE 5 % were less effective, with the total

Table 2. Toxicity of plant-derived formulations against whiteflies (*B. tabaci*) under laboratory conditions

Treatment	Dose (g or mL/L)	Mortality of whiteflies (%)			
		28 hrs	48hrs	72hrs	Mean Mortality (%)
T1-Adathoda leaf extract soap (10 %)	7	56.8 $(48.9)^{a}$	63.4 $(52.61)^{ab}$	64.0 $(53.1)^{ab}$	64.0
T2-Azadirachtin (1%) 10000 ppm	2	57.6 $(49.4)^{a}$	60.8 $(51.25)^{bc}$	63.2 $(52.69)^{bc}$	63.2
T3-NSKE (5%)	5	45.6 $(42.4)^{b}$	55.2 $(48.00)^{cd}$	59.8 $(50.61)^{c}$	59.8
T4-Neem soap (10%)	7	57.6 $(49.4)^{a}$	60.8 $(51.27)^{bc}$	61.4 $(52.21)^{c}$	61.4
T5-Thiamethoxam 25 % WG	0.3	64.0 $(53.1)^{a}$	71.2 $(57.61)^{a}$	72.0 $(58.05)^{a}$	72.0
T6- *L. lecanii* ($1X10^8$ cfu/g)	5	35.2 $(36.2)^{c}$	52.0 $(46.15)^{d}$	60.6 $(51.34)^{c}$	60.6
T7-Untreated control	--	0	0	0	0.00
SE d	-	2.63	1.80	1.57	--
CD (p=0.05)	-	5.38	3.69	3.27	--

S.E = Standard Error, LSD = Least Significant Difference, mean values sharing the same letters a, b, c and d are not significantly different (LSD= 0.05).

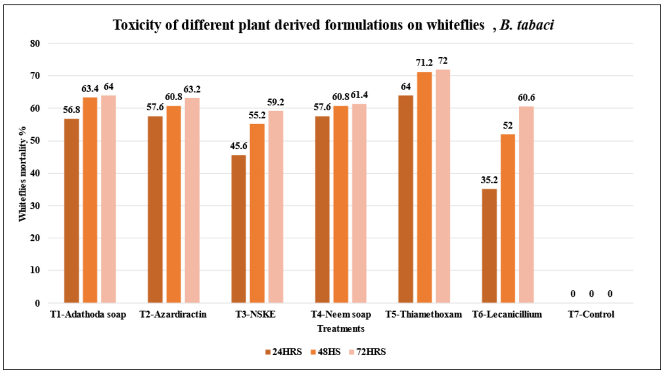

Fig. 3. Bioassay of different plant-derived formulations on whiteflies (*B. tabaci*).

mortality of whiteflies at 59.80 %. The untreated control showed no mortality and significant differences were observed across treatments.

Toxicity of plant-derived formulations to thrips (*T. tabaci*)

The acute toxicity of plant-based formulations, including neem products, Thiamethoxam 25 % WG and entomopathogens against *T. tabaci*, is summarized in Table 3 and Fig.4. Thiamethoxam 25 % WG showed the highest efficacy, causing 63.2 %, 67.2 % and 71.2 % mortality at 24, 48 and 72 hr after treatment (HAT), respectively. Adathoda leaf extract soap (10 %) and azadirachtin (1 %) followed, with mortality rates of 56.2% and 56.4 % at 24 HAT, increasing to 60.0 % and 58.9 % at 48 HAT and reaching 65.6 % and 64.0 % at 72 HAT. However, neem soap (10 %) and NSKE 5 % were less effective, with mean mortality rates of 60.8 % and 59.2 %, respectively. *L. lecanii* (1x10^{8} cfu/g) was similarly effective, with a mean mortality of 58.20 %. The untreated control showed no mortality and significant differences were observed across treatments.

Table 3. Toxicity of plant-derived formulations against thrips (*T. tabaci*) under laboratory conditions

Treatment	Dose (g or mL/L)	Mortality of thrips (%)			
		28 hrs	48hrs	72hrs	Mean Mortality (%)
T1- Adathoda leaf extract soap (10 %)	7	56.2 (48.56)^{b}	60.00 (50.85)^{ab}	65.6 (54.13)^{ab}	65.60
T2-Azadirachtin (1 %) 10000 ppm	2	56.4 (48.68)^{b}	58.9 (50.13)^{ab}	64.00 (53.31)^{ab}	64.25
T3-NSKE (5 %)	5	49.6 (44.77)^{b}	52.00 (46.17)^{b}	59.2 (50.36)^{b}	59.20
T4-Neem soap (10 %)	7	50.4 (45.23)^{b}	57.6 (49.49)^{ab}	60.8 (51.33)^{b}	60.80
T5-Thiamethoxam 25 % WG	0.3	63.2 (52.78)^{a}	67.2 (55.17)^{a}	71.2 (57.57)^{a}	71.20
T6- *L. lecanii* (1X10^{8} cfu/g)	5	25.6 (30.02)^{c}	54.4 (47.56)^{b}	58.2 (50.06)^{b}	58.20
T7-Untreated control	--	0	0	0	0
SE d	-	3.06	3.52	2.42	---
CD (p=0.05)	-	6.56	7.20	4.95	----

S.E = Standard Error, LSD = Least Significant Difference, mean values sharing the same letters a, b, c and d are not significantly different (LSD= 0.05).

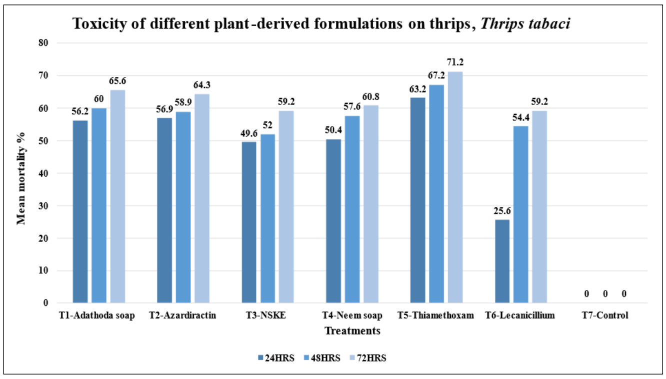

Fig. 4. Bioassay of different plant-derived formulations on thrips (*T. tabaci*).

Discussion

In a bioassay of botanical formulations against *B. tabaci*, the highest mortality was achieved with Thiamethoxam 25 % WG, resulting in 64.00 % mortality at 24 hr, 71.20 % at 48 hr and 72.00 % at 72 hr post-treatment. Similar findings, with thiamethoxam achieving approximately 58.8% mortality in whiteflies 24 hr after application on lab bean crops (19). Treatments with Adathoda leaf extract soap (10 %), azadirachtin 10,000 ppm and neem soap showed comparable effectiveness, recording 64.00, 63.20 % and 61.40 % mortality, respectively, at 24, 48 and 72 hr post-treatment. Previous research has shown that insecticidal soap is effective against aphids, mealybugs, whiteflies, mites and other soft-bodied pests (20).

Additionally, *L. lecanii* (1x10^{8}cfu/g) demonstrated 60.60 % mortality in whiteflies 72 hr post-treatment, while NSKE 5 % exhibited a lower mortality rate of 59.80 %. It is found that NSKE 5 % achieved 60.63 % and 58.83 % control of whiteflies on cotton crops (21). In line with these findings, another study reported that *L. lecanii* caused 71.09 % mortality in whiteflies three days after treatment (22). Among the botanicals tested, Adathoda leaf extract soap (10 %) showed the highest efficacy against *B. tabaci* under laboratory conditions.

The efficacy of various biorational treatments was also evaluated against *T. tabaci* in tomatoes under laboratory conditions. Thiamethoxam 25 % WG exhibited the highest efficacy, with mortality rates of 63.8 %, 67.2 % and 71.2 % at 24, 48 and 72 hr post-treatment, respectively. Similarly other research reported a 58.8 % mortality rate in thrips seven days after treatment with thiamethoxam (23). A 10 % formulation of Adathoda leaf extract soap (10%) demonstrated mortality rates of 56.20 %, 60.00 % and 65.60 % at 24, 48 and 72hr post-application. A 65 % mortality rate was observed four weeks after the application of insecticidal soap against *T. tabaci* (24).

Azadirachtin (1%) was highly effective as well, achieving mortality rates of 56.40 %, 58.90 % and 64.00 % at 24, 48 and 72 hr post-treatment, respectively, with similar efficacy reported for *L. lecanii* (1x10^{8} cfu/g). (25) et al. (2023) found that neem-based formulations, particularly neem soap at 7g/L and azadirachtin 1 % at 1.5 mL/L, provided 72.24 % and 71.10 % control of the thrips population, respectively. Neem soap (10 %) yielded 60.80 % mortality. *L. lecanii* achieved 58.20 % mortality, while NSKE 5 % was less effective, with a mortality rate of 59.20 %. (26) et al. (2019) recommended neem soap, neem seed powder extract and essential oils as potential alternatives to synthetic insecticides for managing thrips in capsicum. Among the botanicals, Adathoda leaf extract soap (10 %) at 7g/L showed notably higher efficacy in reducing thrips populations.

Conclusion

The results of this study demonstrated that Thiamethoxam 25 % WG showed the highest mortality of 72.00 and 71.2 %, which is comparable to the Adathoda 10% soap and azadirachtin 1 % showed high effectiveness in sucking pests of tomatoes among the botanicals formulations. The present studies demonstrated that Adathoda leaf extract soap (10%) and Azadirachtin 1 % showed a mortality of 64.00 and 63.2 % for whiteflies and 65.6 and 64.25 % mortality for thrips, indicating that Adathoda leaf extract soap (10 %) are equally effective and can be used as an alternative to synthetic and neem formulations available in the market. These Adathoda (10 %) soaps are safe and environmentally friendly and do not leave residual effects on the tomato plants. These results emphasize the potential for incorporating Adathoda leaf extract soap (10 %) into integrated pest management strategies, which can control pests effectively while minimizing harm to natural enemies, thus supporting sustainable and eco-friendly agricultural practices.

Acknowledgements

The authors sincerely extend thanks to the Professor and head of the Department of Entomology Dr. M. Murgan, for evaluating and correcting the present study. We thank all the authors who contributed to the article for providing their technical help and writing assistance.

Authors' contributions

The original idea and initial draft were contributed by GSB, ET and SA. The process of conceptualization, along with the review and editing, was undertaken by ET, SA and KC. The preparation of figures and tables, as well as the systematization of references, were collaboratively carried out by GSB, ET, SA and SVP. All authors have thoroughly reviewed and approved the final manuscript.

Compliance with ethical standards

Conflict of Interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical issues: None

References

1. Abdel-Baky NF, Al-Deghairi M. Role of host plants on the biological aspects and parasitism levels of *Eretmocerus mundus* Mercet (Hymenoptera: Aphelinidae), a parasitoid of *Bemisia tabaci* (Gennadius)(Hemiptera: Aleyrodidae). Journal of Entomology. 2008;5(6):356-68. https://doi.org/10.3923/je.2008.356.368.
2. Olaniyi J, Akanbi W, Adejumo T, Akande O. Growth, fruit yield and nutritional quality of tomato varieties. African Journal of Food Science. 2010;4(6):398-402.
3. Ali Q, Kurubas MS, Ustun H, Erkan M. Determination of nutritional values and postharvest performance in different types of tomatoes stored under shelf-life conditions. Mediterranean Agricultural Sciences. 2020;33(1):9-14. https://doi.org/10.29136/mediterranean.620859.
4. Yadav AK, Singh R, Yadav GK, Mishra AK, Patel A. Host range of tomato leaf curl virus and managing its vector whitefly (*Bemisia tabaci*) for suppressing the virus. Journal of Entomological Research. 2023;47(suppl):849-53. https://doi.org/10.5958/0974-4576.2023.00157.3.
5. Haider I, Riaz M, Ali S, Ali Q, Noman A, Hussain D, et al. Efficacy of different insecticides alone and in combination with salicylic acid against cotton whitefly *Bemisia tabaci* Gennadius (Homoptera: Aleyrodidae). Pak J Agric Res. 2023;36(1):58. https://doi.org/10.17582/journal.pjar/2023/36.1.58.62.
6. Fouly A, Al-Deghairi M, Baky NA. Biological aspects and life tables of *Typhlodromips suvirskii* (Acari: Phytoseiidae) Fed *Bennisia tabaci* (Hemiptera: Aleyroididae). Journal of Entomology. 2011;8(1):52-62. https://doi.org/10.3923/je.2011.52.62.
7. Tonnang HE, Mohamed SF, Khamis F, Ekesi S. Identification and risk assessment for worldwide invasion and spread of Tuta absoluta with a focus on Sub-Saharan Africa: implications for phytosanitary measures and management. PloS One. 2015;10(8):e0135283. https://doi.org/10.1371/journal.pone.0135283.
8. Biondi A, Guedes RNC, Wan F-H, Desneux N. Ecology, worldwide spread, and management of the invasive South American tomato pinworm, *Tuta absoluta*: past, present, and future. Annual Review of Entomology. 2018;63(1):239-58. https://doi.org/10.1146/annurev-ento-031616-034933.
9. Knodel J, Kamnuansilpa P, Chamratrithirong A. Infant feeding practices, postpartum amenorrhea, and contraceptive use in Thailand. Studies in family planning. 1985;16(6):302-11. https://doi.org/10.2307/1967052.
10. Alam M, Islam M, Haque M, Humayun R, Khalequzzaman K. Bio-rational management of whitefly (*Bemisia tabaci*) for suppressing tomato yellow leaf curl virus. 2016. https://doi.org/10.3329/bjar.v41i4.30693.
11. Mondal AR, Miah MRU, Miah MY, Afroz M, Mazed MK, Suh SJ, et al. Management of sucking insect pests of tomato (*Solanum lycopersicum*) with insecticides and their impact on beneficial arthropods. Indian Journal of Agricultural Sciences. 2023;93(6):637-41. https://doi.org/10.56093/ijas.v93i6.134069.
12. Muhammad A, Kashere M. Neem, *Azadirachta indica* L.(*A. Juss*): An eco-friendly botanical insecticide for managing farmersâ€™ insects pest problems-a review. FUDMA Journal of Sciences. 2020;4(4):484-91. https://doi.org/10.33003/fjs-2020-0404-506.
13. Lengai GM, Muthomi JW, Mbega ER. Phytochemical activity and role of botanical pesticides in pest management for sustainable agricultural crop production. Scientific African. 2020;7:e00239. https://doi.org/10.1016/j.sciaf.2019.e00239.
14. Guo C, Wang L, Chen N, Zhang M, Jia J, Lv L, et al. Advances in research and utilization of botanical pesticides for agricultural pest management in inner mongolia, China. Chinese Herbal Medicines. 2024;16(2):248-62. https://doi.org/10.1016/j.chmed.2023.04.002.
15. Phokwe OJ, Manganyi MC. Medicinal plants as a natural greener biocontrol approach to "The Grain Destructor" Maize Weevil (*Sitophilus zeamais*) Motschulsky. Plants. 2023;12(13):2505. https://doi.org/10.3390/plants12132505.
16. Ranatunga M, Kellar C, Pettigrove V. Toxicological impacts of synthetic pyrethroids on non-target aquatic organisms: A review. Environmental Advances. 2023;12:100388. https://doi.org/10.1016/j.envadv.2023.100388.
17. Borisade O. Rearing tomato whitefly and field evaluation of modified and unmodified conidia of *Beauveria bassiana*, *Isaria farinosa*, *Metarhizium anisopliae* and low rates of chlorpyrifos under tropical conditions. African Crop Science Journal. 2015;23(2):177-95.

18. Steiner MY, Goodwin S. Methods for collecting and rearing thrips (Thysanoptera) and their natural enemies. Australian Journal of Entomology. 1998;37(2):101-6. https://doi.org/10.1111/j.1440-6055.1998.tb01554.x.

19. Suresh MRP. Evaluation of biorational insecticides against major pest complex of cucumber (*Cucumis sativus* L.). [Master's thesis]. Rahuri, Maharashtra: Department of Agricultural Entomology, Post Graduate Institute, Mahatma Phule Krishi Vidyapeeth; 2024.

20. Liu TX, Stansly PA. Insecticidal activity of surfactants and oils against silverleaf whitefly (*Bemisia argentifolii*) nymphs (Homoptera: Aleyrodidae) on collards and tomato. Pest Management Science: formerly Pesticide Science. 2000;56(10):861-6. https://doi.org/10.1002/1526-4998(200010)56:10<861::AID-PS217>3.0.CO;2-Y.

21. Wawdhane P, Nandanwar V, Mahankuda B, Ingle A, Chaple K. Bio-efficacy of insecticides and bio pesticides against major sucking pests of Bt-cotton. J Entomol Zoo Stud. 2020;8:829-33.

22. Chouikhi S, Assadi B, Ettaib R, Grissa KL, Belkadhi MS. Effectiveness of chemical insecticides and entomopathogenic fungi *Lecanicillium muscarium* against *Bemisia tabaci* (Gennadius)(Homoptera: Aleyrodidae) infesting geothermal crops in southern Tunisia. Journal of Oasis Agriculture and Sustainable Development. 2023;5 (1):6-14. https://doi.org/10.56027/JOASD.022023.

23. Athivarman R, Kumar A. Field efficacy of selected insecticides against thrips infesting tomato (*Lycopersicon esculentum* Mill.). Uttar pradesh Journal of zoology. 2022;43(18):32-8. https://doi.org/10.56557/upjoz/2022/v43i183169.

24. Ashraf SE, Ahmad SS, Abdelhalim EK. Field trials to control *Thrips tabaci* (Thysanoptera: Thripidae) infesting onion crop. 2019.

25. Manideep S, Muthuswami M, Shanmugam P, Suganthi A, Boopathi NM. Field evaluation of biorationals and chemical insecticides against *Thrips parvispinus* (Karny)(Thysanoptera: Thripidae), in Chrysanthemum. International Journal of Plant & Soil Science. 2023;35(19):179-86. https://doi.org/10.9734/ijpss/2023/v35i193540.

26. Elango E, Sridharan S, Saravanan P, Balakrishnan S. Efficacy of biopesticides against pomegranate sucking pests under laboratory condition. Journal of Biopesticides. 2019;12(1):30-5. https://doi.org/10.57182/jbiopestic.12.1.30-35.