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RESEARCH ARTICLE

Bioefficacy of plant based insecticides against thrips, *Pseudodendrothrips mori* (Niwa) and leaf webber, *Diaphania pulverulentalis* (Hampson) in mulberry ecosystem and their bio safety to natural enemies

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Abstract

Morus spp. is the sole food for mulberry silkworms, *Bombyx mori* L. However, this crop is infested by two major pests, the leaf webber, *Diaphania pulverulentalis* (Hampson) and thrips, *Pseudodendrothrips mori* (Niwa). To address this, two field trials were conducted in two different locations to assess the efficacy of botanicals against thrips and leaf webber in mulberry ecosystem. Results indicated that TNAU Bio 3G extract @ 5% showed the highest per cent population reduction of thrips (56.24 and 47.24 % in first and second trial, respectively) over untreated control after neem oil @ 3% and neem seed kernel extract @ 5% used as standard check, whereas for leaf webber *Eupatorium adenophorum* extract @ 3 % showed the highest effectiveness with 61.22 and 61.86 % reduction over control in first and second trial, respectively. The different botanicals applied against mulberry thrips and leaf webber were tested for their effect on mortality of silkworm. It was found that when treated leaves were fed one day after treatment highest larval mortality (25.00%) was recorded in Neem oil @ 3% but it was very low in case of TNAU Bio 3G extract @ 5% (4.99%). Larval death steadily decreased in all the treatments except Neem oil @3 %, when fed two days later, whereas, no mortality was noticed in case of TNAU Bio 3G extract @ 5% and *E. adenophorum* at 2 DAT. To conclude, TNAU Bio 3G extract @ 5% and *E. adenophorum* extract @ 3% can be recommended for an eco-friendly and sustainable management of thrips and leaf webber in mulberry ecosystem.

Keywords

mulberry; pests; bioefficacy; silkworms; adenophora; 3G extract

Introduction

Mulberry (*Morus alba*), a fast-growing deciduous woody tree of the family Moraceae, is grown widely in Asian countries for its leaves to feed the silkworm *Bombyx mori*, which feeds exclusively on mulberry leaves (1). Hence, mulberry is one of the most important components that decide the sustainability of this multi-billion dollar industry (2, 3). There are more than 70 countries which produce silk, among which China, India, Vietnam, Uzbekistan, Brazil, Thailand, and Bangladesh are the leaders (4).

In recent years, the use of synthetic insecticides in the fight against moriculture pests has developed unintended damages on both silkworms and the environment. Over 98 per cent of insecticides and 95 per cent of herbicide sprays have reached non-target species through air, water, bottom sediments, and food (5, 6). The main method to control insect pests is still based on synthetic pesticides. However, the development of resistance to those products, the high operational cost and environmental pollution has created the need for developing alternative approaches to control many insects (7).

The thrips *Pseudodendrothrips mori* Niwa was found to be most dominant species in different parts of world and one of the important sap sucking insect pests of mulberry, belonging to the order Thysanoptera: Thripidae. In Tamil Nadu, thrips were considered as less important pests of mulberry earlier. But during January 2000, leaf damage by *P.mori* ranged from 14.02 to 49.14% in 24 mulberry genotypes (8). The estimated leaf loss due to this pest is about 42.55 % (9) and 40 – 50 % of the total leaf produced. In India, damage by *P. mori* caused reduction in leaf area and leaf weight up to 20 to 50 % (10).

The mulberry leaf webber, *Diaphania pulverulentalis* (Hampson) is a monophagous insect feeding solely on mulberry. The larvae of *D. pulverulentalis* feed on parenchyma and lower epidermis of leaves; fold the leaves and leave the black faeces which causes loss of quality in mulberry leaves for silkworm rearing (11). It causes considerable loss of yield ranging from 24.18 per cent under field conditions to 34.83 per cent in glass house conditions (12). The peak period of incidence is during September- November when the pest infestation reaches the economic injury level. Studies have reported that the pest completed several overlapping generations from June to December ranging from 1-2 larvae to 5-6 larvae per leaf (12).

Reddy and Kotikal (13) recommended spraying endosulfan (3 ml/l), monocrotophos (1 ml/l), or dimethoate (2 ml/l) for severe infestations, with a waiting period of over 15 days. However, the insecticide dichlorvos at 0.02% has been commonly used against thrips due to its lower residual toxicity, lasting less than 10 days (14). Recent research, though, indicates that thrips have developed resistance to dichlorvos (15). Although Dichlorvos 76 EC has been widely recommended for controlling defoliator pests in mulberry, a Government of India notification from December 28, 2016, mandated a complete ban on its use after December 31, 2020. Therefore, it is crucial to explore new plant-based insecticides for managing thrips and leaf webber, keeping in mind the safety of mulberry silkworms.

Botanical insecticides, derived from natural plant sources, offer ecological benefits over synthetic pesticides by ensuring the safety of non-target organisms and the environment (15 - 17). Plants produce a range of chemical compounds as defense mechanisms against pests, with metabolites like flavonoids, alkaloids, terpenoids, and phenols showing strong pest control potential by disrupting vital insect processes (18, 19). Ginger, for example, contains active compounds such as gingerol and shogaol, which exhibit insecticidal, aphicidal, ovicidal, and antifeedant properties (19, 20). These compounds interfere with insect metabolic functions, such as chitin synthesis and respiration, ultimately leading to insect death (21). Garlic oil, rich in dipropyl disulfide and trisulfide, has demonstrated antimicrobial and insecticidal effects (22, 23). There were insecticidal effects of ginger on *Spodoptera litura* F. and *Plutella xylostella* Saunders in cabbage (24). Madhuca is also called Mahua or butternut tree, belonging to sapotaceae family. Mahua cake possessed significant insecticidal and pesticidal activity against phytonematode (25). Mahua has good pesticidal activity against *Tetranychus urticae* (26).

Several studies have highlighted the insecticidal properties of Asteraceae family plants, including *Ageratina adenophora* (Spreng.) or *Eupatorium adenophorum*, commonly known as Crofton weed. Native to Mexico and Costa Rica, this invasive perennial plant contains a variety of compounds such as flavonoids, terpenes, sesquiterpenes, and triterpenoids (27). Its leaves possess larvicidal, antiviral, antibacterial, and insecticidal properties (28, 29). Extracts and essential oils from *Ageratina* species have shown effectiveness against pests like *Spodoptera litura* and *Spodoptera littoralis* (30, 31), with notable antifeedant and larvicidal activity (17).

To examine different plant extracts and bioactive chemicals for potential development as botanical insecticides, substantial research is required, as there is currently a dearth of phytochemical research on most plant species in the mulberry ecosystem in India. Therefore, this work was taken to find a plant based alternative for management of thrips and leaf webber in mulberry with less phytotoxicity and greater yield.

Materials and Methods

Study on bioefficacy of insecticides

Field study

There were two field trials at two locations, one each at Kariyampalayam (11 ^{0}12´10.8 " N, 77 ^{0} 5´ 2.8" E) (Trial I) and other at Kurukkiliyampalayam (11 ^{0}14´20.76 " N, 77 ^{0} 4´ 40.8" E) (Trial II), Tiruppur District, Tamil Nadu, India to test the bioefficacy of different botanicals against mulberry thrips. Similarly, two field trials were conducted, each at Department of Sericulture, Forest College and Research Institute, Mettupalayam (11 ^{0}11´24 " N, 77 ^{0} 33´36" E) (Trial I) and Alangombu (11 ^{0}18´37.08 " N, 76 ^{0} 59´ 40.2" E) (Trial II), Tamil Nadu, India to test the bioefficacy of botanicals against mulberry leaf webber. The trials for mulberry thrips were conducted from March to July 2023 and those against leaf webber were conducted from September to January 2024 using V1 mulberry variety. Three replications of the study were conducted utilizing Randomized Block Design (RBD). The treatments used in the study are mentioned in the Table 1. The botanicals neem oil, pongamia oil and mahua oil were purchased from the local traders in Coimbatore. The bioprotectant TNAU Bio 3G extract was obtained from Nammazhvar Organic Farming Research Centre (NOFRC), TNAU, Coimbatore. Two rounds of spraying were done at 15 day intervals after the 30^{th} day of pruning, using a pneumatic knapsack sprayer @ 500 litres of spray fluid per hectare. The spray combination was made by mixing the appropriate botanical concentration with regular tap water, and just water was sprayed in the control plot.

Table. 1. List of botanicals used in the study.

Tr. No.	Botanicals	Dose %
T_1	Mahua oil	5
T_2	TNAU Bio G3 (Ginger, garlic and green chilli extract)	5
T_3	Pongamia oil	3
T_4	*Eupatorium adenophorum* (Mexican devil)	3
T_5	Neem Seed Kernal Extract (NSKE) (Standard check)	5
T_6	Neem oil (Standard check)	3
T_7	Untreated control	-

Preparation of botanicals

Fresh leaves of *E. adenophorum* were collected from the Horticultural Research Station, Udhagamandalam, Nilgiris and their identity was confirmed by the Botanical Survey of India (Regional centre), Coimbatore. The leaves were completely washed in running water, shade-dried, pulverized to fine powder and stored for future use. The required quantity of powder was soaked in water overnight and the spray volume was made up before spraying. Dried neem seed kernels were also pulverized to a powder and 500 g of it was soaked overnight in 1 litre of water. The next morning it was filtered through a muslin fabric and the volume was made to 10 litres, to which 1 % detergent was added. To prepare 3G extract, ginger, garlic and green chilli (340 g each) were taken in the ratio of 1:1:1, ground to a fine paste, tied loosely in a 'khadi' cloth and soaked in 1 litre of cow's urine for 10 days. The extract was sprayed at the rate of 20 ml per litre of water as adopted by Preethi et al. (32).

Observations

Ten plants per treatment were selected at random from every trial plot and labelled for observation. Pest population data and percentage reduction in contrast to the control group were recorded. The number of insects on each leaf was counted during a pre-treatment count (PTC), a day prior to treatment commencement and again at 1, 3, 5, 7, 10, and 14 days after treatment from 3 leaves, one each located at the top, middle and bottom of selected plants per plot.

Data on the population were converted into ($\sqrt{x}$ + 0.5) values, and analyzed in randomized block design (RBD) using IBM SPSS 21 program for the least notable variation (Critical difference) testing. Two locations' worth of data was merged replication-wise. Duncan's Multiple Range Test (DMRT) was employed to discern the average values (33). The means in the tables that are separated by a similar letter between the treatments do not differ substantially at the five percentile level by DMRT.

Biosafety from natural enemies

The population of all predatory coccinellids and spiders irrespective of species per plant were recorded after spray. The counting was taken up during cooler hours preferably 6 AM-7 AM (34). Per cent reduction in population over control was calculated and the data were analyzed statistically.

Residual effect on silkworm mortality

For laboratory experimental purposes, silkworm rearing was done following the standard procedures (33) during January – March 2024 at Mulberry silkworm rearing room, Department of Sericulture, FC&RI, Mettupalayam. Experiments were conducted using the popular bivoltine double hybrid, DH 1 ((CSR 2 × CSR 27) × (CSR 6 × CSR 26)). Chawki worms for the experiments were purchased from the private Chawki Rearing Centre, Annur, Coimbatore district, Tamil Nadu. The leaves were harvested and fed to the silkworms on first, second and third day after spray to know the residual effect of the plant extracts on growth and development of silkworm.

Results

The thrips population varied from 21.00 to 27.00 per plant during Trial 1 with non-significant differences among various treatments one day before imposing the treatments (Table 2). Neem oil @ 3% reduced the thrips population significantly and the mean population after the first spray was 5.06 per plant which was followed by NSKE @ 5 % (7.28 per plant) and TNAU Bio 3G extract @ 5% (9.17 per plant) whereas the population in untreated control was 26.72 per plant. The order of relative efficacy based on per cent reduction over untreated control after the second spray was, Neem oil @ 3 % (70.14 %) > NSKE @ 5 % (64.15 %) > TNAU Bio 3G extract @ 5% (56.27 %) > *E. adenophorum* @ 3 % (50.87 %) > Pongamia oil @ 3 % (44.27 %) > Mahua oil @ 5% (35.97 %).

The population of thrips before the application of insecticides ranged from 16.33 to 27.00 per plant (Table 2) during Trial 2. Mean population during first spray infers that Neem oil @ 3 % (7.56 thrips per plant) and NSKE @ 5 % (8.17 thrips per plant) were on par in controlling *P.mori* population, followed by TNAU Bio 3G extract @ 5% (10.39 thrips per plant). After two rounds of spraying, Neem oil @ 3 % recorded a 77.02 % reduction of thrips over untreated control followed by NSKE @ 5 % (52.46 %) and TNAU Bio 3G extract @ 5% (47.24 %). *E. adenophorum* @ 3 %, Pongamia oil @ 3 % and Mahua oil @ 5% recorded 42.03, 30.35 and 23.44 per cent reduction over untreated control, respectively.

The population of leaf webber before imposing treatment ranges from 6.00 to 8.50 in the different treatment plots (Table 3). TNAU Bio 3G extract @ 5% recorded least mean population of webbers (1.83 larvae per plant) during the first spray at Trial 1, followed by *E. adenophorum* @ 3 % (2.17 larvae per plant), which was on par with NSKE @ 5 % (2.50 larvae per plant). This was followed by Neem oil @ 3 % (2.83 larvae per plant). Pongamia oil @ 3 % and Mahua oil @ 5% were at par with each other with the least bioefficacy (3.17 and 3.50 larvae per plant, respectively. After second spray, TNAU Bio 3G extract @ 5%, *E. adenophorum* @ 3 % and NSKE @ 5 % recorded the highest per cent reduction of webbers over untreated

Table. 2. Bioefficacy of botanicals against mulberry thrips, *P. mori.*

Treatments	Trial 1						Trial 2					
	First Spray			Second Spray			First Spray			Second Spray		
	PTC	Mean	PRC	PTC	Mean	PRC	PTC	Mean	PRC	PTC	Mean	PRC
Mahua oil @ 5%	24.67^{a} (4.97)	14.78^{f} (3.84)	34.09	25.33^{a} (5.03)	14.17^{f} (3.76)	35.97	26.67^{a} (4.08)	11.50^{e} (3.39)	26.83	19.00^{a} (4.36)	14.06^{d} (3.75)	23.44
TNAU Bio G3 @ 5 %	24.00^{a} (4.90)	9.17^{c} (3.03)	56.24	26.33^{a} (5.13)	8.84^{c} (2.97)	56.27	16.33^{a} (4.04)	8.17^{c} (2.86)	41.97	24.00^{a} (4.69)	12.00^{bc} (3.46)	47.24
Pongamia oil @ 3 %	24.67^{a} (4.97)	13.17^{e} (3.63)	42.43	26.00^{a} (5.10)	12.22^{e} (3.50)	44.27	21.67^{a} (4.66)	15.22^{d} (3.90)	33.24	18.66^{a} (4.32)	12.28^{c} (3.50)	30.35
Eupatorium adenophorum @ 3%	24.33^{a} (4.93)	11.33^{d} (3.37)	48.15	26.33^{a} (5.13)	10.50^{d} (3.24)	50.87	23.67^{a} (4.87)	15.56^{c} (3.95)	41.84	19.67^{a} (4.44)	10.78^{b} (3.28)	42.03
Neem Seed Kernal Extract (NSKE) @ 5%	24.00^{a} (4.90)	7.28^{b} (2.70)	62.32	27.00^{a} (5.20)	7.06^{b} (2.66)	64.15	21.97^{a} (4.32)	10.39^{b} (3.22)	42.70	27.00^{a} (5.20)	15.89^{e} (3.99)	52.46
Neem oil @ 3%	23.67^{a} (4.87)	5.06^{a} (2.25)	69.36	26.67^{a} (5.16)	4.89^{a} (2.21)	70.14	20.67^{a} (4.55)	7.56^{a} (2.75)	67.43	24.00^{a} (4.90)	7.67^{a} (2.77)	77.02
Untreated control	21.00^{a} (4.58)	26.72^{g} (5.17)	-	23.67^{a} (4.87)	31.17^{g} (5.58)	-	18.67^{a} (4.32)	19.22^{e} (4.38)	-	18.67^{a} (4.32)	21.39^{f} (4.62)	-
SEm±	-	0.25	-	-	0.26	-	-	0.42	-	-	0.39	-
SEd	-	0.37	-	-	0.36	-	-	0.60	-	-	0.55	-
CD (LSD) 5%	-	0.79	-	-	0.79	-	-	1.30	-	-	1.21	-
C.V.		3.59	-		3.49	-	-	5.84	-	-	5.05	-

PTC – Pre Treatment Count, **PRC** – Percentage Reduction to Control; The population values enclosed in parenthesis are √X + 0.5 transformed values; Number followed by the same alphabet in the column denotes statistically not significant.

control followed by Neem oil @ 3 % (49.32 %), Pongamia oil @ 3 % (45.08 %) and Mahua oil @ 5% (36.55 %).

Leaf webber population during pre-treatment count ranged from 6.70 to 7.80 larvae per plant at Trial 2 (Table 3). After first round of spray of insecticides, at 14 Days after Spray (DAS), TNAU Bio 3G extract @ 5% treated plots recorded the least mean population of 2.17 larvae per plant, whereas untreated control plots registered 7.07 larvae

Table. 3. Bioefficacy of botanicals against leaf webber, *D. pulverulentalis.*

Treatments	Trial 1						Trial 2					
	First Spray			Second Spray			First Spray			Second Spray		
	PTC	Mean	PRC	PTC	Mean	PRC	PTC	Mean	PRC	PTC	Mean	PRC
Mahua oil @ 5%	6.00^{a} (2.45)	3.50^{d} (1.87)	31.63	6.67^{a} (2.58)	3.83^{d} (1.96)	36.55	6.80^{a} (2.61)	3.83^{e} (1.96)	41.90	7.10^{a} (2.66)	4.17^{c} (2.04)	40.59
TNAU Bio G3 @ 5 %	7.33^{a} (2.71)	1.83^{a} (1.35)	69.63	8.33^{a} (2.89)	2.83^{a} (1.68)	70.76	6.90^{a} (2.63)	2.17^{a} (1.47)	66.94	7.10^{a} (2.66)	2.50^{a} (1.58)	63.70
Pongamia oil @ 3 %	6.00^{a} (2.45)	3.17^{d} (1.78)	35.86	7.00^{a} (2.65)	3.50^{c} (1.87)	45.08	6.70^{a} (2.59)	3.50^{d} (1.87)	45.21	7.20^{a} (2.68)	3.83^{c} (1.96)	46.60
Eupatorium adenophorum @ 3%	7.00^{a} (2.65)	2.17^{b} (1.47)	61.22	8.00^{a} (2.83)	3.17^{b} (1.78)	62.23	6.80^{a} (2.61)	2.50^{b} (1.58)	60.80	7.30^{a} (2.70)	2.83^{a} (1.68)	61.86
Neem Seed Kernal Extract (NSKE) @ 5%	6.67^{a} (2.58)	2.50^{bc} (1.58)	52.81	7.33^{a} (2.71)	2.83^{a} (1.68)	57.90	6.70^{a} (2.59)	2.83^{c} (1.68)	54.66	7.30^{a} (2.70)	3.17^{b} (1.78)	57.23
Neem oil @ 3%	6.33^{a} (2.52)	2.83^{c} (1.68)	44.27	6.33^{a} (2.52)	2.50^{a} (1.58)	49.32	6.90^{a} (2.63)	3.17^{cd} (1.78)	52.77	7.20^{a} (2.68)	3.50^{b} (1.87)	51.22
Untreated control	8.50^{a} (2.92)	7.90^{e} (2.81)	-	8.30^{a} (2.88)	7.78^{e} (2.79)	-	7.50^{a} (2.74)	7.07^{f} (2.66)	-	7.80^{a} (2.79)	7.22^{d} (2.69)	-
SEm±	-	0.10	-	-	0.08	-	-	0.09	-	-	0.10	-
SEd	-	0.14	-	-	0.12	-	-	0.13	-	-	0.14	-
CD (LSD) 5%	-	0.31	-	-	0.26	-	-	0.29	-	-	0.32	-
C.V.		5.20	-		3.90	-	-	4.55	-	-	4.61	-

PTC - PreTreatment Count, **PRC** – Percentage Reduction to Control; The population values enclosed in parenthesis are √X + 0.5 transformed values; Number followed by the same alphabet in the column denotes statistically not significant.

per plant. It was followed by *E. adenophorum* @ 3 % (2.50 larvae per plant). The same trend was observed during the second spray. The order of relative efficacy of test botanicals based on mean population during second spray were, TNAU Bio 3G extract @ 5% (63.70 %) > *E. adenophorum* @ 3 % (61.86 %) > NSKE @ 5 % (57.23 %) > Neem oil @ 3 % (51.22%) > Pongamia oil @ 3 % (46.60%) > Mahua oil @ 5% (40.59 %).

Biosafety to natural enemies

Treatment of plants with neem oil @ 3%, NSKE @ 5% and mahua oil @ 5% was recorded as relatively more toxic to the coccinellids and spiders, with a per cent reduction of 55.87, 43.47 and 49.605 respectively at 1 DAS (Table 4). Among the other botanicals, *E. adenophurum* and TNAU Bio 3G extract exhibited low toxicity to coccinellids and spiders causing only 34.72 and 27.80 % mortality, respectively. The persistent toxicity of all the botanicals reduced significantly at 10 DAS. The pooled data revealed that all botanicals and their synergists exhibited relatively safer than Neem oil @ 3% with 34.74 % mortality even after 10 DAS.

Residual effect on silkworm mortality

From Table 5, it was observed that the maximum larval mortality (25.00%) was recorded in plants treated with Neem oil @ 3 % but it was very low in the case of TNAU Bio 3G extract (4.99%) at 5 per cent concentration at one day after treatment. Later, the larval death steadily decreased in all the treatments with an increase in the waiting period, except Neem oil @ 3% and NSKE @ 5 %with 13.78 and 10.01 per cent larval mortality at 2 DAT. No larval mortality

Table. 4 Effect of botanicals on the population of predatory coccinellids and spiders in mulberry.

Treatments	Percent Mortality (%)					Mean
	PTC	1 DAT	3 DAT	7 DAT	10 DAT	
Predatory coccinellids						
Mahua oil @ 5%	6.73	3.86 (49.60)	4.00 (45.42)	5.33 (23.85)	6.20 (21.12)	4.85 (27.97)
TNAU Bio G3 @ 5 %	6.86	5.00 (34.72)	5.55 (24.28)	6.27 (10.42)	7.03 (7.30)	5.96 (13.08)
Pongamia oil @ 3 %	7.00	4.78 (37.59)	5.00 (31.78)	6.00 (14.28)	6.88 (12.46)	5.67 (19.07)
Eupatorium adenophorum @ 3%	6.93	5.53 (27.80)	5.20 (29.05)	5.80 (17.14)	7.00 (10.94)	5.88 (15.12)
Neem Seed Kernal Extract (NSKE) @ 5%	6.93	4.33 (43.47)	4.29 (41.47)	5.20 (25.71)	6.86 (12.72)	5.17 (25.40)
Neem oil @ 3%	6.80	3.38 (55.87)	3.84 (47.61)	4.53 (35.28)	6.00 (23.66)	4.44 (34.74)
Untreated control	7.06	7.66	5.00	6.06	6.66	6.35
SEm ±	-	0.52	0.25	0.23	0.15	-
C.D. (p=0.05)	-	1.27	0.62	0.56	0.37	-
C.V. (%)	-	28.24	13.83	10.90	6.09	-
Spiders						
Mahua oil @ 5%	3.13	2.93 (17.00)	2.86 (14.11)	2.86 (10.62)	3.06 (8.10)	2.93 (6.47)
TNAU Bio G3 @ 5 %	3.06	2.80 (20.68)	2.80 (15.91)	3.13 (6.00)	2.73 (18.01)	2.87 (6.37)
Pongamia oil @ 3 %	3.13	2.73 (22.66)	2.66 (20.12)	2.80 (12.50)	3.00 (9.91)	2.80 (10.62)
Eupatorium adenophorum @ 3%	3.00	2.80 (20.68)	2.73 (18.01)	2.86 (10.62)	3.13 (6.00)	2.88 (4.00)
Neem Seed Kernal Extract (NSKE) @ 5%	2.93	2.33 (34.00)	2.33 (30.03)	2.53 (20.93)	2.93 (12.02)	2.53 (13.65)
Neem oil @ 3%	3.09	2.60 (26.34)	2.26 (32.13)	2.53 (20.93)	3.13 (6.00)	2.63 (14.89)
Untreated control	3.00	3.53	3.33	3.20	3.33	3.35
SEm ±	-	0.13	0.14	0.09	0.07	-
C.D. (p=0.05)	-	0.34	0.35	0.24	0.18	-
C.V. (%)	-	13.10	13.26	9.19	6.52	-

DAT - Days after treatment.

Table 5. Effect of botanicals on larval mortality of silkworm (*Bombyx mori* L.).

Treatments	Larval mortality (%)		
	1 DAT	2 DAT	3 DAT
Mahua oil @ 5%	12.76 (2.05)[c]	6.98 (1.51)[b]	0.00 (0.00)
TNAU Bio G3 @ 5 %	4.99 (1.28)[a]	1.01 (0.58)[a]	0.00 (0.00)
Pongamia oil @ 3 %	17.49 (2.40)[d]	9.75 (1.79)[c]	0.00 (0.00)
Eupatorium adenophorum @ 3%	6.79 (1.49)[b]	1.07 (0.59)[a]	0.00 (0.00)
Neem Seed Kernal Extract (NSKE) @ 5%	21.03 (2.63)[e]	10.01 (1.81)[d]	0.00 (0.00)
Neem oil @ 3%	25.00 (2.87)[f]	13.78 (2.13)[d]	0.00 (0.00)
Untreated control	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
SE(m) ±	0.28	0.10	-
SEd	0.40	0.15	-
CD (p = 0.05)	0.88	0.32	-
C.V.	3.97	3.04	-

DAT= Days after treatments; Figures in then parenthesis are Arc sine transformed values; Number followed by the same alphabet in the column denotes statistically not significant.

was observed with TNAU Bio 3G extract @ 5 % and *E. adenophorum* @ 3 % two days after treatment. All the plant extracts tested had no toxic effect at three days after treatment.

Discussion

Neem oil at a 3% concentration has been found to be effective in controlling thrips, particularly in agricultural systems like mulberry cultivation. Specifically, neem oil has demonstrated greater efficacy against mulberry thrips (*Pseudodendrothrips mori*) when compared to other botanical alternatives such as pongamia oil. While it shows promise in reducing thrips populations, its potency remains lower than some synthetic insecticides, such as dimethoate (35). The combination of neem oil application followed by water jetting resulted in a 67.02% reduction in thrips, while two rounds of water jetting alone achieved an 84.35% decrease. A key advantage of neem oil is its lower impact on beneficial insects compared to synthetic insecticides, making it more environmentally friendly (36).

In another study, neem seed kernel extract (NSKE) was shown to significantly reduce thrips populations in cotton, achieving a 68.02% mortality rate, comparable to synthetic insecticides such as imidacloprid (37-39). This suggests that NSKE could be a suitable alternative for thrips management in mulberry crops as well.

Additional studies have explored the use of ginger and garlic extracts as natural pesticides for thrips control. While these botanical extracts are effective, their efficacy generally falls short of synthetic insecticides. For instance, a study on mungbean thrips showed that a mixture of ginger, garlic, and green chilli extracts could reduce thrips populations, though not as effectively as chemical pesticides (40). Similarly, garlic extract was found to reduce thrips populations by 55.98% in chilli crops, reflecting a moderate level of efficacy (41). Furthermore, a combination of plant extracts, including green chilli, demonstrated up to a 95.6% reduction in thrips when used in conjunction with other botanicals (42).

One of the primary benefits of using botanical extracts such as ginger, garlic, and green chilli is their environmental safety and non-target specificity. These extracts have been proven safe for beneficial organisms like spiders and coccinellids, which naturally help control pest populations (42, 43). Compared to neem oil, pongamia oil shows reduced efficacy. Neem oil, particularly at a 1% concentration, has been the most effective in controlling the mulberry leaf webber, with notable improvements in the effective rate of rearing (ERR) and the shell ratio (SR) in silkworms, both crucial parameters in sericulture (44). Integrated Pest Management (IPM) strategies incorporating neem oil have resulted in significant reductions in pest infestations, including leaf webber while promoting ecosystem health by increasing populations of beneficial insects such as coccinellids and spiders (45).

Ginger (*Zingiber officinale*) has demonstrated safety for silkworms, showing minimal toxicity and no observed mortality when silkworms were fed mulberry leaves treated with ginger extract two days post-application (46). Moreover, ginger extract improved key growth parameters such as larval and cocoon weights, and silk quality, suggesting that it may stimulate protein synthesis in the silk gland (47). Additionally, ginger has proven effective for pest control, reducing pest populations without harming beneficial organisms like spiders and coccinellids (42, 43). Ginger extract, in particular, has been linked to improvements in growth metrics in silkworms, including increased larval and cocoon weights (44). Garlic extract has also shown promise, especially when used as a volatile treatment, where it enhanced silk production traits, indicating potential applications in sericulture. The shell ratio and length of silk filament were determined for 15, 30, 45 and 60 minute exposure duration with respect to single, double, and triple, treatment of 5th, 4th-5th and 3rd, 4th and 5th instar larvae respectively. With the increasing 15 to 45 minute exposure duration and stage of larval treatment from single to triple, the shell ratio and silk filament length increased but further increased exposure of garlic as plant volatile for 60 minute exposure caused a declining trend.

The shell ratio increased from 12.81±0.52% (control) to 15.34±0.30% and silk filament length increased from 816.41±12.21 m (control) to 989.86±9.75 m in case of the triple treatment with 45 minute exposure duration. Further increase exposure duration causes notable reduction in shell ratio and silk filament length in case of triple treatment for 60 minute exposure (47).

While research on green chilli extract alone remains limited, its combination with garlic and ginger has been investigated for pest management. TNAU 3G extract, although less effective than other botanicals, in reducing pest populations was found to be safe for beneficial insects and indirectly to silkworms (43). Green chilli, in combination with other botanical extracts, shows potential for organic pest control, contributing to sustainable agricultural practices. Garlic (*Allium sativum*) has demonstrated positive effects on silk production traits, such as the shell ratio and silk filament length when used as a volatile treatment (47). Additionally, garlic has been shown to be safe for silkworms, with no adverse effects on their growth and development (48). Its insecticidal properties have been observed in the control of pests like mealy bugs and leaf rollers, without harming silkworms (49 -52).

Furthermore, *Ageratina adenophora* has shown considerable insecticidal activity against various pests. For example, its extract has demonstrated a median lethal concentration (LC_{50}) of 26.014 mg/ml against the oriental fruit fly (*Bactrocera dorsalis*), exhibiting strong contact toxicity and oviposition deterrence (53- 55). The plant contains bioactive compounds such as tannins, flavonoids, and saponins, which contribute to its pest control efficacy by reducing the survival and growth rates of pests like *Limax maximus*, a common agricultural pest (51). While pongamia oil has demonstrated efficacy in reducing pest populations, including leaf webber (*Glyphodes pyloalis Walker*) on mulberry for up to 15 days post-application, neem oil has proven more effective in terms of economic and residual toxicity (56). In another study, pongamia oil resulted in a 42.49% reduction in jassid populations, offering insights into its broader pest control capabilities in mulberry cultivation (56). This proves that pongamia oil has efficacy for management of both sucking pests and defoliators.

Conclusion

TNAU Bio 3G extract @ 5% reduced the thrips population significantly and the mean population after the first and second spray was 9.17 and 10.39 nos. per plant, respectively. TNAU Bio 3G extract @ 5% recorded the least mean population of webbers (1.83 larvae per plant) during first spray at Trial 1, followed by *E. adenophorum* @ 3 % (2.17 larvae per plant), which was on par with NSKE @ 5 % (2.50 larvae per plant). *E. adenophurum* and TNAU Bio 3G extract exhibited low toxicity to coccinellids and spiders causing only 34.72 and 27.80 % mortality, respectively. No larval mortality was observed with TNAU Bio 3G extract @ 5 % and *E. adenophorum* @ 3 % at two days after treatment. The present study suggests that repeated field application of chemical insecticides could be reduced to a greater extent by the use of botanicals as an alternative to manage the major pests of mulberry like *P.mori* and *D. pulverulentalis* successfully as well as to conserve the natural enemy complex in the mulberry ecosystem. The study also suggests that botanicals like TNAU bio 3G extract and *E. adenophorum* extract have sufficient potential to be exploited in the management of pests of mulberry with almost no residual toxicity effects on the silkworm, *B.mori*.

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Authors' contributions

PRN contributed to the investigation, validation, formal analysis and writing. SM and BV helped in on conceptualization and oversight and took leadership responsibility for the research activity planning. AS worked on methodology and investigation, and mentored the whole work. RS helped in the provision of field evaluation facilities and mentoring. PR designed the methodology and investigated the research work.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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