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Comparative toxicity of certain medicinal plants against invasive chili thrips, *Thrips parvispinus* (Karny)

Elaiyabharathi T[1*], Satya Bhanu G[2*], Saikumar T[2], Suganthi A[2], Kavitha C[3] & Karthikeyan[4]

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

[2]Department of Agricultural Entomology, 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

[4]Centre for Crop Health, School of Agriculture and Environmental Science, University of Southern Queensland, Toowoomba, Queensland 4350, Australia.

*Email: giddisatya1999@gmail.com, elaiyabharathi.t@tnau.ac.in

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Abstract

Chilli thrips, *Thrips parvispinus*, is an invasive pest causing significant yield losses of up to 80%. To manage this, pest farmers rely only upon insecticides and this situation leads to insecticidal residues being higher than the maximum residual level (MRL). To find out alternative strategies to insecticides, a laboratory bioassay was conducted to evaluate the effectiveness of leaf extracts from medicinal and aromatic plants, including *Adhatoda vasica*, *Andrographis paniculata* and *Coleus aromaticus*, against *T. parvispinus*. The plant extracts were tested at a concentration of 20%, and adult mortality was observed within 24 h of exposure. The results showed that *A. vasica* leaf extract had the highest toxicity with an LC_{50} of 7.90%, followed by *A. paniculata* with an LC_{50} of 11.14%, and *C. aromaticus* with the lowest toxicity at an LC_{50} of 13.92%. A field study was also conducted to evaluate the efficacy of *A. vasica* leaf extract against the invasive thrips, *T. parvispinus,* in chilli under field conditions. The results indicated that *A. vasica* leaf extract at 5 mL/L (43.91 to 45.52%) and 7 mL/L (49.32 to 50.98%) were the most effective doses against *T. parvispinus* at both locations, besides being safer to natural enemies chilli. The present findings confirm that *A. vasica* leaf extract (10%) could be a potential eco-friendly alternative to chilli farmers against *T. parvispinus.*

Keywords

chilli; chilli thrips; ecofriendly management; LC_{50}; leaf extract; medicinal and aromatic plants; mortality; *T. parvispinus*

Introduction

Chilli (*Capsicum annum* L.) is a vegetable cum spice crop of the family Solanaceae grown in sub-tropical and tropical parts of the world (1). Chilli has been a known crop for over 9000 years. It is native to South America and was originally cultivated in Peru around 7500 BC (2). It was introduced to India by Portuguese from Brazil toward the end of the fourteenth century (3). As a major crop in tropical and subtropical nations, India possesses 42.2% of the world's cultivable land for chilli production and produces 21.4% of the world's chilli es (4). According to the Press Information Bureau (PIB, 2024), India's chilli production for the 2023-24 agricultural year is projected at 25.97 lakh tonnes, with Andhra Pradesh, Telangana, Madhya Pradesh, Karnataka, and Odisha being the leading chilli-producing states.

The country accounts for 40% of the world's green chilli production and exports 17% of its output. Additionally, it is regarded as a secondary center of diversification for chilli, particularly *C. annum*, the most widely cultivated species (5).

Despite its importance as a spice grown worldwide, chilli production is hampered by many constraints, including pests and diseases, which cause significant yield losses. Among these constraints, insect pests such as *Thrips parvispinus* (Karny) (6, 7), *Scirtothrips dorsalis* (Hood) (8), *Myzus persicae* (Sulzer) (9), and mites, *Polyphagotarsonemus latus* (Banks) (10), cause yield losses ranging from 50–90% (11). Among these, *S. dorsalis* is the most destructive, causing yield losses of 11% to 75% quantitatively and 60% to 80% qualitatively (12). Non-insect pests like mites *and P. latus* (Banks) can also cause yield losses of 34% (10). Recently, the invasive thrips, *T. parvispinus*, chilli is a serious concern in chillies causing yield losses of 85% to 95% in southern Indian states (13).

The increasing use of pesticides poses a significant threat to the ecosystem supporting chilli plants, with insecticidal sprays applied at a rate of 5.13 a.i. kg/ha (IIVR, 2013). Furthermore, sundried red chilli powder has been reported to contain insecticidal residues, including cypermethrin (0.15 mg/kg), ethion (1.41 mg/kg), and miticides such as dicofol (4.03 mg/kg), all of which surpass the maximum residue limits (MRL) (14). In contrast, medicinal and aromatic plants (MAPs) offer a promising eco-friendly alternative for pest management, as they contain biologically active compounds effective against pests and plant diseases when mixed with water or alcohol (15, 16). Additionally, the aromatic nature of MAPs allows for the extraction of essential oils, which have allelochemical properties and can be used in a variety of applications, including aromatherapy, perfumery, and food flavoring (17). As a result, MAPs represent a valuable resource, combining both medicinal and insecticidal qualities, offering a sustainable and environmentally friendly alternative to conventional synthetic pesticides. Given the adverse effects of insecticides, this research aims to explore various formulations and essential oils derived from MAPs with insecticidal potential to establish an eco-friendly pest management strategy.

Materials and Methods

Collection of plant material

The leaf material of *Adhatoda vasica*, *Andrographis paniculata* and *Coleus aromaticus*, was collected from the natural habitats of the Department of Medicinal and Aromatic Crops at the Horticultural College and Research Institute (HC&RI) of the Tamil Nadu Agricultural University (TNAU) in Coimbatore (Latitude: 11° 07' 3.36" N Longitude: 76° 59' 39.91" E). The fresh plant material 123 acquired was independently verified using morphological characteristics by an expert 124 taxonomist. (T. Elaiyabharathi Department of Medicinal and Aromatic Crops, TNAU) (Fig. 1 & 2, Table 1).

Preparation of selected plant leaf extracts

Fresh leaves were collected and chopped into pieces. Five to ten leaves were macerated in a mortar and pestle to a fine powder. Twenty grams of powdered leaves were added to 100 mL of distilled water at room temperature (26 ± 0.3°C; 74 ± 12% RH). The solution was filtered using filter paper to remove any large particles. The filtrate was then combined with 100 mL of acetone solvent. The solution was shaken for about 30 min with a mechanical shaker. The mixture was allowed to be separated by a separating funnel. The required fraction was taken from the separating funnel and transferred to a flask. The solvent was removed from the extract using a rotary evaporator at 56 °C and 200 rpm. The crude extract (25mL) was moved to a clean vial or 50 mL conical flask and stored in a refrigerator (3.0 ± 0.2 °C) until used for bioassay studies (18) (Fig. 3).

Selection of treatments

The crude leaf extracts were prepared at a concentration of 20%. A standard botanical, neem seed kernel extract (NSKE 5%) and a chemical check (Fipronil 5% SC) were also used as standard checks. The laboratory study was conducted in a completely randomized block design (CRD)

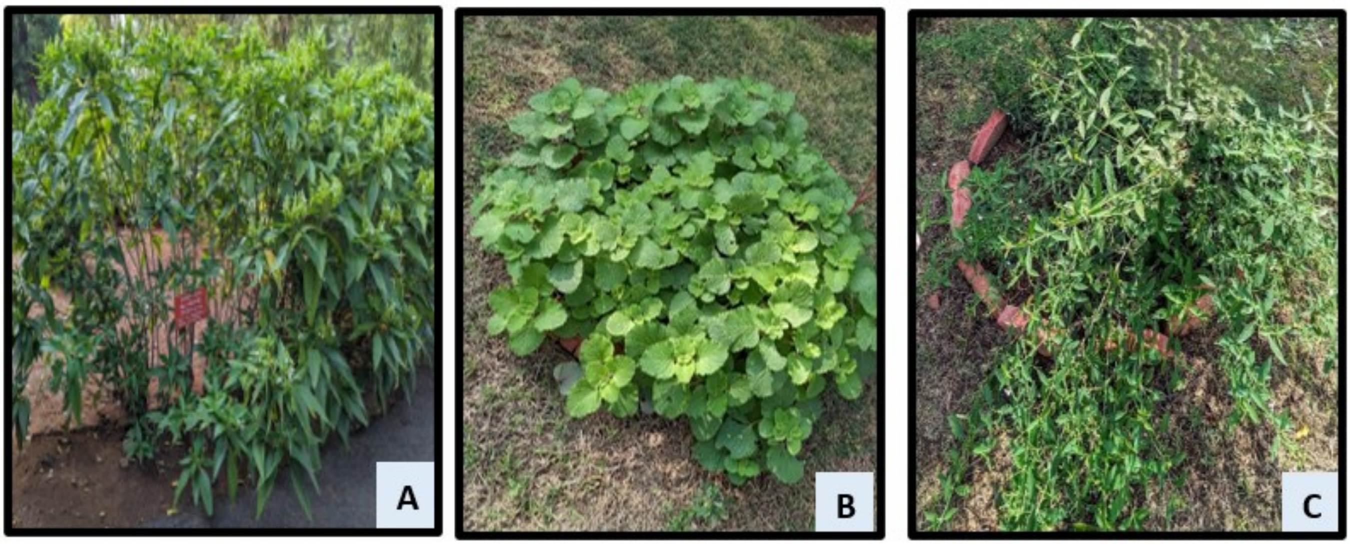

Fig. 1. Fresh plant samples of A. *A. vasica*, B. *A. paniculata*, and C. *C. aromaticus* collected from natural habitats of the Department of Medicinal and Aromatic Crops, Horticultural College and Research Institute (HC&RI), TNAU, Coimbatore.

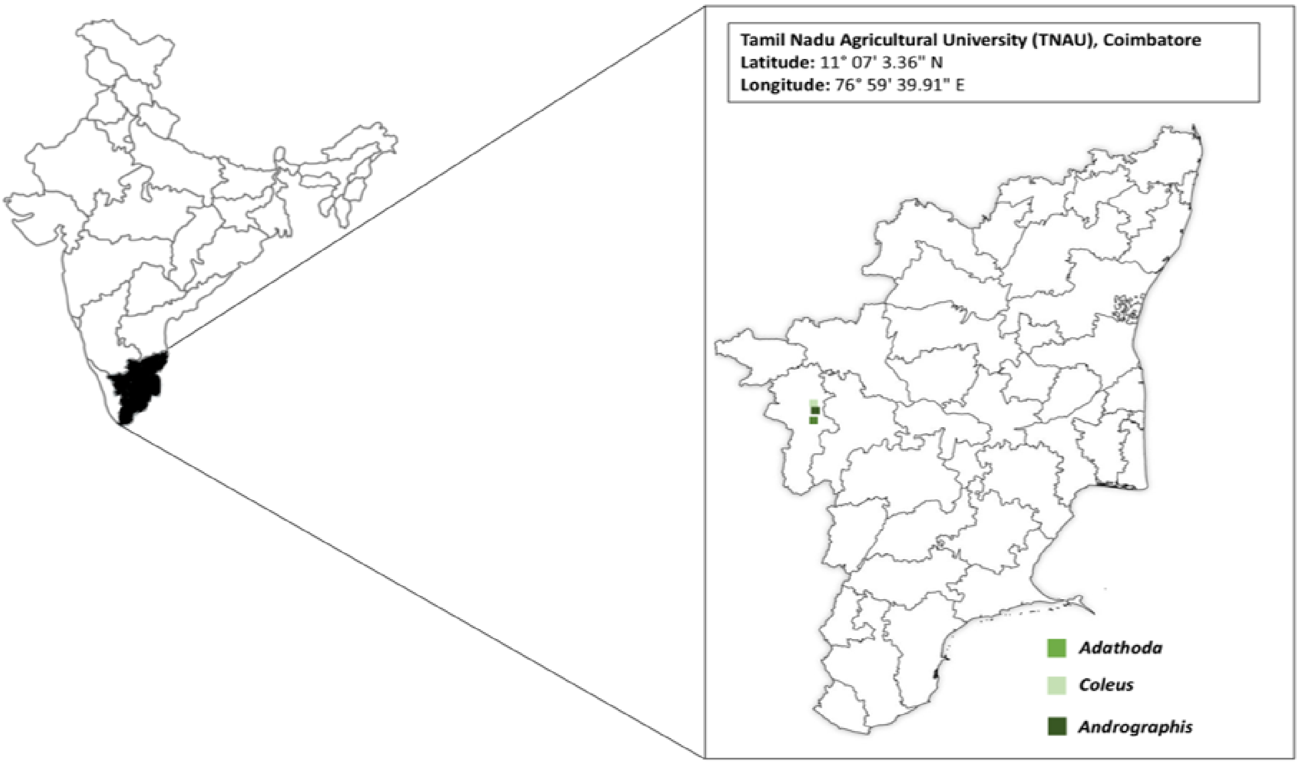

Fig. 2: Map showing sampling locations of plant materials (*A. vasica, C. aromaticus* and *A. paniculata*) in Tamil Nadu, India.

Table 1. Details of sampling location and plant materials used for the study

S.No.	Common name	Scientific name	Family	Location	Plant part
1	Malabar nut	*A. vasica*	Acanthaceae	TNAU, Coimbatore	Leaves
2	Green chiretta	*A. paniculata*	Acanthaceae	TNAU, Coimbatore	Leaves
3	*Coleus*	*C. aromaticus*	Lamiaceae	TNAU, Coimbatore	Leaves

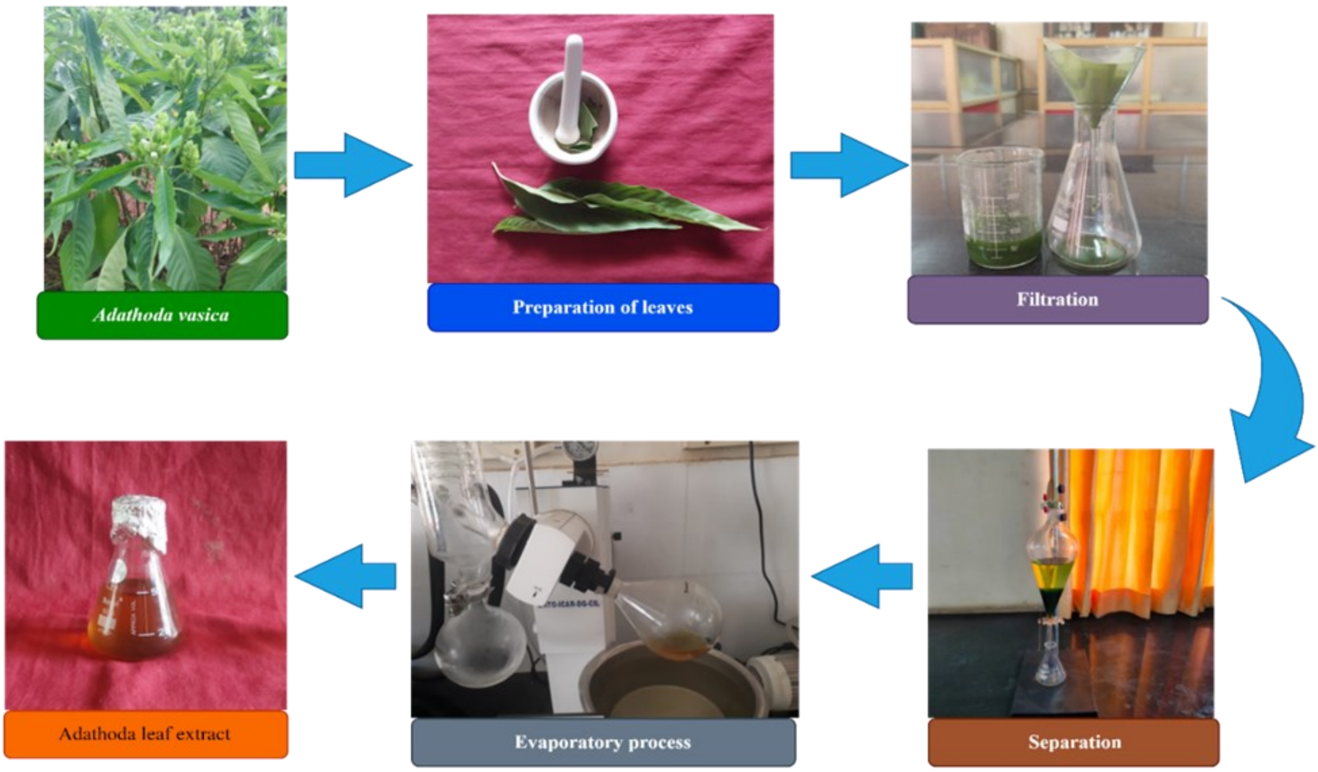

Fig. 3. Preparation of leaf extract of medicinal plants.

with 7 treatments (Table 2) and 3 replications, along with a control.

Table 2. Treatments used for bioassay under laboratory conditions

S.No.	Treatments	Concentration (%)
T_1	Crude extract of *A. vasica* leaves	10
T_2	Crude extract of medicinal *Coleus*	12.5
T_3	Crude extract of *Andrographis*	15
T_4	NSKE 5 % (Botanical check)	5
T_5	Fipronil 5% SC (Chemical check)	0.5 ppm
T_6	Untreated control	-

Mass culturing of Test insect *T. parvispinus* (Karny)

Initially, thrips were collected from infected Chilli crop areas using an aspirator. The thrips collected in the field were stored in plastic boxes with sufficient aeration, or in perforated covers. Each container was regularly supplemented with fresh, clean, regular beans (*Phaseolus vulgaris*). The containers were kept in an insect growth chamber at a temperature of 20°C, with 16 h of light and 64% humidity. Under these conditions, a synchronous stage of a thrips colony completes its cycle, from oviposition to adult emergence, in 2–3 weeks. Approximately, 300 mature female thrips were initially obtained and allowed to deposit their eggs on the surface of fresh pods for 24 h. The adults were then removed, and the beans were incubated for 6 days until the nymphs emerged. Fresh common beans were provided to the nymphs twice a week until they developed into adults after two weeks (19) (Fig.4).

Fig. 4. Mass culturing of *T. parvispinus* on French beans.

Bouquet bioassay method with *T. parvispinus* adults

Healthy shoots (3 leaves and a bud) of the chilli plant were collected from the field, thoroughly washed with distilled water, and air dried. These shoots were placed in a 5 cm plastic tube containing water with the open end sealed using cotton. The tip of each shoot was positioned to reach the bottom of the plastic tube, allowing the shoot to absorb water and maintain its freshness, (Fig. 5), until mortality readings were recorded after 24 h. Due to the small size of thrips, which could escape under open conditions and complicate data collection, cylindrical mylar cages were used to restrict their movement. One side of each cage was covered with cauda cloth to prevent thrips from escaping. The tubes containing the shoots were sprayed with the required concentrations of extracts, and thrips were introduced onto the treated shoots using an aspirator. The shoots were then enclosed in the mylar cages (20).

Fig. 5. Modified Bouquet method for *T. Parvispinus.*

Field evaluation of *A. vasica* 10% leaf extract against *T. parvispinus*

The bio efficacy of *A. vasica* 10% soap formulations against *T. parvispinus* (Karny) was assessed under field conditions in July 2023 at two locations: TNAU Orchard, Horticultural College & Research Institute (Latitude: 10.989484˚N, Longitude: 76.791494˚E), and farmers field at Sattakal Pudur (Latitude: 10° 49' 17.38" N, Longitude: 76° 55' 46.89" E) within Coimbatore district. The study was conducted using a randomized block design (RBD) with six treatments *viz., A. vasica* 10% leaf extract applied at four different dosages: 1 mL/L (T1), 3 mL/L (T2), 5 mL/L (T3), and 7 mL/L (T4), fipronil 5% SC at 0.5 mL/L (T5) and untreated control (T6) replicated four times (Fig. 6).

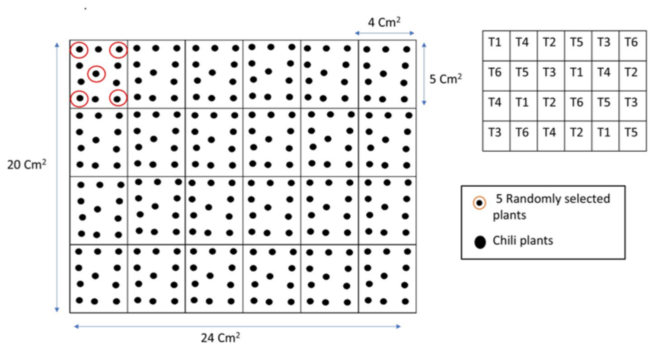

Fig. 6. Field efficacy of *A. vasica* 10% leaf extract Schematic representation of the treatment pattern sample.

Different treatments were prepared by mixing the specified concentrations of *A. vasica* leaf extract and chemical insecticide. The prepared solutions were applied using a 2-litre hand sprayer during the morning hours, with the sprayer carefully rinsed after each application to prevent contamination. The population of *T. parvispinus* was monitored before and after treatment, with pre-treatment counts recorded a day prior to application and post-treatment counts on 1, 3, 5 and 7 days after treatment (DAT). The population of thrips was assessed by tapping of flower parts on a white paper which dislodges the nymphs and adults of thrips. Five plants were randomly selected per plot, and the nymph and adult populations were assessed visually using a hand lens to ensure accuracy.

Statistical analysis

In the laboratory bioassay of medicinal plants, Probit analysis was conducted to determine the LC_{50} value, which indicates the concentration at which 50% of the subjects are affected. This method was chosen for its effectiveness in analysing dose-response relationships.

In field evaluation studies, mean thrips population was arrived at. One way ANOVA was performed and the means were differentiated through LSD. This analysis, performed using SPSS (version 22), aimed to assess the significance and effectiveness of the treatment methods.

Results

Toxicity assessment of *A. vasica* leaf extract

The bioassay results showed that 50% mortality was observed at the preliminary range dose of 10% while minimum mortality was observed at 1% dosage. Upon further narrowing down, an LC_{50} value of 7.90% was obtained for *A. vasica* (Table 3).

Table 3. Comparative toxicity of different plant extracts with botanicals and insecticide on adults of *T. parvispinus*

Plant Extracts	LC_{50} value	95% C. I	Slope ± SE	Chi-square
A. vasica	7.90	5.76-10.04	1.444±1.092	0.10098
Andrographis	11.14	7.93 - 14.34	2.351± 1.636	0.21158
Coleus	13.92	10.69-17.14	3.720±1.645	0.15393
NSKE-5%	3.14	2.82-3.45	1.05±0.163	0.1145
Fipronil	0.248	0.032-0.46	1.091 ± 0.110	3.9847

Number of adults = 30; LC50= concentration (%) calculated to give 50% mortality, S.E = Standard Error, C. L= Confidence limit, Df (Degree. of freedom) = 20.

Toxicity assessment of *A. paniculata* leaf extract

The bioassay results revealed 50% mortality in preliminary range finding tests at 12.5% concentration. The LC_{50} value of 11.14 % was obtained for *A. paniculata* (Table 3).

Toxicity assessment of *C. aromaticus* leaf extract

The 15% concentration exhibited 50% mortality while the lowest mortality percentage was observed at 1% in preliminary range finding test. Finally, the LC_{50} was obtained at 13.92% concentration (Table 3).

Comparison of LC50 values with standard botanicals and insecticides

In comparison with standard botanicals and insecticides, the maximum mortality of 97% was obtained with Fipronil, at an LC_{50} value of 0.248 ppm as against the conventional botanical like NSKE 5% showing 60% mortality with an LC_{50} value of 3.14%. Among the studied plant extracts, *A. vasica* outperformed the others, with a mortality rate of 54% and an LC_{50} value of 7.90%.

Bio efficacy of *A. vasica* 10% leaf extract against *T. parvispinus* in Chilli at location I (TNAU Orchard)

The efficacy of *A. vasica* 10% leaf extract against *T. parvispinus* revealed that the average number of thrips before the application of *A. vasica* leaf extract ranged from 6.26 to 7.65 thrips/plant in location I (Table 4). At 1 DAT, the *A. vasica* leaf extract @ 5mL/L (5.21 thrips/plant) and 7 mL /L (5.18 thrips/plant) were significantly superior to the other dosages. At 7 DAT too, the *A. vasica* leaf extract dosages 5mL/L (3.09 thrips/plant) and 7mL/L (3.0 thrips / plant) were found significantly superior to the other dosages. The treatment dosages of 5 and 7mL/L at 1 DAT and 7 DAT days showed significant reduction of the thrips population next to Fipronil 5% SC (3.05 and 1.25 thrips/ plant, at 1 DAT and 7 DAT, respectively). The mean percent reduction of the thrips population after imposing the treatment dosages was highest in 7mL/L (49.32%) which was next only to Fipronil 5%SC (71.50%) followed by 5 mL/ L (43.91%.), 3 mL/L (30.72%) and 1 mL/L (20.77%.) in the trials conducted at TNAU orchard (Location I).

The cost economics of the management practice revealed that 5 m/L and 7 mL/L resulted in yields of 2.50 and 2.95 q ha^{-1} respectively, with benefit-cost ratios (B: C) of 1:2.0 and 1:2.36. These yields were comparable to the yield of 3.78 q ha^{-1} with a B: C ratio of 1:3.78 obtained with Fipronil 5% SC. The effective dosages of 5 and 7 mL/L were almost as effective as Fipronil 5% SC in terms of yield, but they were more cost-effective. This means that the

Table 4. Bio efficacy of *A. vasica* 10% leaf extract against *T. parvispinus* at TNAU orchard, Coimbatore (Location-I)

A. vasica 10% leaf extract dosages (mL/litre)	Number of thrips/ plants					Per cent reduction over control (%)	Yield (q ha^{-1})	B: C ratio
	PTC	Post-treatment Count						
		1DAS	3DAS	5DAS	7DAS			
A. vasica leaf extract – 1 mL / L	6.26	5.56 (2.35)^b	5.1 (2.25)^b	4.82 (2.19)^b	4.36 (2.08)^b	20.77	1.14	0.91
A. vasica leaf extract – 3 mL / L	6.57	5.32 (2.3)^c	4.28 (2.06)^c	3.95 (1.98)^c	3.25 (1.8)^c	30.72	1.95	1.56
A. vasica leaf extract – 5 mL / L	6.38	5.21 (2.28)^c	4.34 (2.08)^c	3.44 (1.85)^e	3.09 (1.75)^d	43.91	2.50	2.00
A. vasica leaf extract – 7 mL / L	7.39	5.18 (2.27)^c	4.02 (2)^d	3.75 (1.93)^d	3 (1.73)^d	49.32	2.95	2.36
T_5 – Fipronil 5%SC 0.5 mL/ L	7.85	3.06 (1.74)^d	2.05 (1.43)^e	1.95 (1.39)^f	1.25 (1.11)^e	71.50	3.78	3.02
T_6– Control (Untreated)	7.50	7.25 (2.69)^a	7.05 (2.65)^a	7.55 (2.74)^a	7.85 (2.8)^a	1.25	1.05	0.84
S.E ±	1.82	1.69	1.57	1.79	1.70	-	-	-
LSD (0.05)	NS	1.85	1.65	1.15	0.96	-	-	-

PTC= Pre-treatment count; DAS = Days After Spraying, S.E = Standard Error LSD = Least Significant Difference; NS = non-significant
Means in a column followed by a common letter are not significantly different (LSD= 0.05), Values in parenthesis are square root transformed values.

effective dosages of 5 m/L and 7 mL/L resulted in higher profits similar to Fipronil 5% SC.

Bio efficacy of *A. vasica* 10% against *T. parvispinus* in Chilli at location II (Sattakalpudur, Coimbatore)

At location II (Sattakalpudur, Coimbatore), the pre -count of thrips ranged from 7.26 to 7.85 per plant (Table 5). On 1 DAT, the *A. vasica* leaf extract @ 5 m/L (5.55 thrips/plant) and 7 mL/L (5.25 thrips/plant) exhibited superiority to the other treatments viz., 1mL/L (6.77 thrips/plant) and 3mL/L (6.26 thrips/plant). On 7 DAT, the *A. vasica* leaf extract @ 5mL/L (3.01 thrips/plant) and 7mL/L (2.55 thrips /plant) were found significantly superior. It was observed that *A. vasica* leaf extract at 5 mL/L and 7mL/L at 1 DAT and 7 DAT showed a significant reduction in thrips population next to Fipronil 5% SC (3.55 and 1.02 thrips/plant, respectively at 1 DAT & 7 DAT). The mean percent reduction of the thrips population after imposing the treatment was highest in Fipronil 5%SC (70.43%) followed by *A. vasica* leaf extract @ 7mL/L (50.98%), 5 m/L (45.52%), 3 mL/L (34.77%), and 1 mL/L (21.50%) in Location II.

The cost economics of the management practice revealed that *A. vasica* leaf extract @ 5 mL/L and 7 mL/ L, resulted in yields of 3.04 and 5.34 q ha^{-1} respectively, with benefit-cost ratios (B: C) of 1: 2.43 and 1: 4.27. These yields were comparable to the yield of 6.42 qha^{-1} with a B: C ratio of 1:5.13 obtained with Fipronil 5% SC. The effective dosages of 5 mL/L and 7 mL/L were almost as effective as Fipronil 5% SC in terms of yield.

Discussion

Toxicity effect of medicinal plant extracts on T. parvispinus under laboratory conditions

Toxicity studies on various medicinal plants revealed that *A. vasica* exhibited the highest toxicity against *T. parvispinus*, with an LC_{50} of 7.50%, followed by *A. paniculata* (LC_{50} of 11.14%) and *C. aromaticus* (LC_{50} of 13.92%). These findings establish the superior insecticidal potential of *A. vasica* leaf extract against *T. parvispinus* in comparison to other medicinal plants. Similar results have been reported in other studies where *A. vasica* methanolic leaf extract exhibited strong antifeedant and toxic effects against *Spodoptera littoralis* larvae, with efficacy ranging from 63.4% to 90.4%, causing reduced growth, delayed pupation, and lower pupation rates (21). Ethanolic extracts of *A. vasica* also demonstrated notable antifeedant activity (76.33%) against *Spodoptera litura* larvae at a 5% concentration (22). Furthermore, *A. vasica* leaf extract effectively controlled *Brevicoryne brassicae* on cabbage crops, achieving 100% nymph mortality and 81.6% adult mortality when applied as 5% acetone and methanol extracts (23). A 10% aqueous leaf extract also showed 80% larval toxicity against *Rhesala imperata*, a defoliator of *Albizia lebbek* (24). These findings collectively highlight the exceptional pesticidal efficacy of *A. vasica*, positioning it as a potent alternative for managing *T. parvispinus* effectively.

Efficacy of *A. vasica* 10% leaf extract against *T. parvispinus* in Chilli in field condition

Field trials conducted at two locations in Tamil Nadu, India, demonstrated the efficacy of *A. vasica* leaf extract in controlling the population of *T. parvispinus* in chilli crops. The treatment dosages of 5 mL/L and 7 mL/L resulted in significant mortality, leading to a substantial reduction in the thrips population. The performance of *A. vasica* leaf extract was comparable to that of the chemical insecticide Fipronil 5% SC in managing thrips populations (Fig. 7). These findings align with previous research highlighting the pesticidal properties of *A. vasica*. For instance, studies on aphids reported 44.98% mortality one day after spraying *A. vasica* leaf extract and its effectiveness increased with higher concentrations (25). Additionally, a 10% *A. vasica* leaf extract showed potent antifeedant activity against *Spodoptera litura* under field conditions (26). These results collectively underscore the broad-

Table 5. Bio efficacy of *A. vasica* 10% leaf extract against *T. parvispinus* at Sattakalpudur, Coimbatore (Location II)

A. vasica leaf extract dosages (mL/litre)	No of thrips/plant					Thrips reduction percent over the control (%)	Yield (q ha^{-1})	B: C ratio
	PTC	Post-treatment Count						
		1DAS	3DAS	5DAS	7DAS			
A. vasica leaf extract – 1 mL / L	7.26	6.77 (2.60) [b]	5.85 (2.41) [b]	5.23 (2.28) [b]	4.76 (2.18) [b]	21.50%	1.43	1.14
A. vasica leaf extract – 3 mL / L	7.52	6.26 (2.50) [c]	4.65 (2.15) [c]	3.95 (1.98) [c]	3.15 (1.77) [b]	34.77%	2.11	1.61
A. vasica leaf extract – 5 mL / L	7.25	5.55 (2.35) [d]	4.14 (2.03) [d]	3.57 (1.88) [d]	3.01 (1.73) [b]	45.52%.	3.04	2.43
A. vasica leaf extract – 7 mL / L	7.65	5.25 (2.29) [e]	4.05 (2.01) [d]	3.15 (1.77) [e]	2.55 (1.59) [b]	50.98%.	5.34	4.27
T_5 – Fipronil 5%SC 0.5 mL/ L	7.95	3.65 (1.88) [f]	2.85 (1.68) [e]	1.85 (1.36) [f]	1.02 (1.00) [c]	70.43%	6.42	5.13
T_6– Control (Untreated)	7.45	7.15 (2.67) [a]	7.55 (2.74) [a]	7.65 (2.76) [a]	7.3 (2.70) [a]	0.67%.	1.30	1.04
S.E ±	0.32	0.61	0.71	0.935	1.02	-	-	-
LSD (0.05)	NS	1.13	1.05	0.892	0.567	-	-	-

PTC= Pre-treatment count; DAS = Days After Spraying, S.E = Standard Error LSD = Least Significant Difference; NS = non-significant
Means in a column followed by a common letter are not significantly different (LSD= 0.05), Values in parenthesis are square root transformed values.

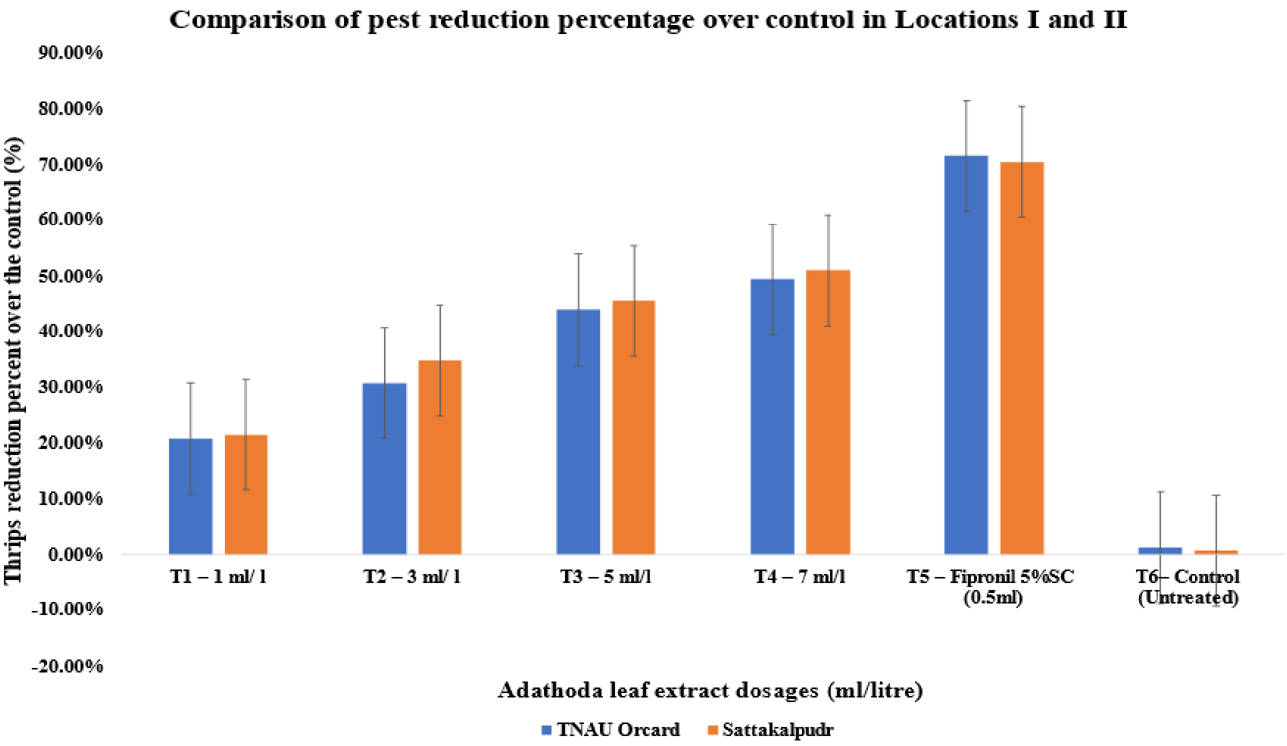

Fig. 7. Performance of *A. vasica* 10% leaf extract on *T. parvispinus* at Locations I and II.

spectrum insecticidal potential of *A. vasica*, reinforcing its utility as a sustainable alternative to chemical insecticides.

A. vasica leaf extract is safe for the environment, with studies demonstrating having no impact on natural enemies. Some studies on the impact of *A. vasica* leaf extract on natural enemies indicate that the extract did not affect coccinellids, with an average of 0.87 *Coccinella* spp. per plant in the mustard ecosystem (27). Additionally, *A. vasica* leaf extracts up to 10% concentration were found to be safe, resulting in a high population of coccinellids (2.14 beetles per plant) and spiders (0.97 spiders per plant) (28). The yield and benefit-cost ratio (B: C) of a 10% *A. vasica* leaf extract at concentrations of 5 mL/L and 7 mL/L proved to be more reliable and was comparable to the commercial synthetic pesticide fipronil 5% SC. Overall, the studies suggest that 10% *A. vasica* leaf extract is a viable alternative to chemical pesticides under field conditions and can be integrated into Integrated Pest Management (IPM) practices for effective insect pest control.

Conclusion

The results of this study demonstrated that *A. vasica* leaf extracts are effective in controlling chilli thrips. The present studies demonstrated that *A. vasica* leaf extract at concentrations of 5 mL/L and 7 mL/L proved effective against chilli thrips. These extracts are safe, and environmentally friendly and do not leave residual effects on the chilli . As chilli pests develop resistance to chemical insecticides and concern about pesticide residues increases, botanical insecticides offer a promising alternative. These results emphasize the potential for incorporating botanicals into integrated pest management strategies, which can control pests effectively while minimizing harm to natural enemies, thus supporting sustainable and eco-friendly agricultural practices.

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Authors' contributions

GS, TE, AS and TS contributed to the original idea and wrote the original draft. TE, AS, CK and TS contributed to conceptualization, review, and editing. GS, TE, AS and MK contributed to preparation of figures and tables, and systematization of references. All authors read 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

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