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RESEARCH PAPER

Management of sucking pests of capsicum by using botanicals under protected condition

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Abstract: Botanical insecticides are derived from plants and their derivatives. In recent years, there has been a significant growth in the use of botanical products for the management of insect pests, which has raised their recognition and market share in the global insecticide market. The field efficacy studies revealed that neem oil (3%) was more effective in controlling sucking pests of capsicum *viz., Thrips parvispinus* (Karny), *Polyphagotarsonemus latus* (Banks), *Aphis gossypii* (Glover) and *Bemisia tabaci* (Gennadius) under protected cultivation. Based on overall observations, minimum thrips and aphid population was recorded in neem oil (3%). The next best treatments in the decreasing order of efficacy were NSKE, pongamia oil and garlic oil. Similarly, neem oil was also found effective and recorded significantly lower number of yellow mites and whiteflies followed by NSKE, garlic oil and pongamia oil. Our results suggested that neem-based products have higher efficacy, diverse mode of actions such as repellent, anti-feedant, oviposition deterrent and moulting inhibitors as a stand-alone management tool for sucking pests and would require integration with other management practices.

Key words: Botanicals, Capsicum, Protected condition, Sucking pests

Introduction

Bell pepper (*Capsicum annuum* Linnaeus), commonly known as sweet pepper or capsicum, is a night shade plant and is originated in Tropical South America (Shoemaker and Teskey, 1955). Capsicum is a high-value, low-volume crop grown in India under natural and protected conditions. In terms of nutrition, 100 g of edible fruits include 23.65 g of crude fat, 21.29 g of crude protein, 4.94 g of ash, 38.76 g of total dietary fiber and 4.48 g of moisture (Perez *et al*., 2015). It is generally grown in open fields as a *rabi* and *kharif* crop in India and it is classified as non-traditional vegetable (Ghose *et al*., 2018). Protected cultivation is a cutting-edge technology that allows for partial to complete control over environmental factors. Capsicum is ideal for greenhouse cultivation due to its optimal plant stature, canopy cover, flower and fruit production at a lower temperature (Thakur *et al*., 2018).

India is the world's largest producer of capsicum. West Bengal, Karnataka, Maharashtra, Uttar Pradesh, Andhra Pradesh, Tamil Nadu and Himachal Pradesh are among the states where the crop is widely grown. Karnataka is the second largest producer and produces 59.37 MT of capsicum with an area of 3820 ha, accounting for 10.54 per cent of India's total capsicum production (Anonymous, 2021).

Bell pepper has been reported to be infested by about 35 species of insect and mite pests. Thrips (*Scirtothrips dorsalis* Hood), aphids (*Myzus persicae* Sulzer), whiteflies (*Trialeurodes vaporariorum* Westwood) and yellow mite are sucking pests that infest capsicum and reduce yield up to 34 per cent (Roopa and Kumar, 2014).

Chemical pesticides are primarily used to control sucking insect pests, but their widespread and indiscriminate use has resulted in insecticide resistance and residual concerns, in addition to health risks (Pappas *et al*., 2013). Botanical pesticides can be advised for the control of horticultural insect pests as an eco-friendly and long-term solution. Plant-based insecticides are thought to play a vital role in attaining the evergreen revolution because of their biodegradable nature, ability to change the behaviour of target pests and favourable safety profile. Botanical pesticides can greatly reduce the use of conventional pesticides when incorporated into integrated pest management programs or they can be used in rotation or in combination with other insecticides, potentially reducing the overall quantities applied and possibly mitigating or delaying the development of pest resistance and preventing the resurgence of insect pests.

Material and methods

Efficacy of botanical insecticides against sucking pests of capsicum

The field experiment was conducted at University of Agricultural Sciences, College of Agriculture, Dharwad during *rabi* season of 2021-22. The soil of experimental plot had fairly uniform topography with deep and well drained sandy loam soil. The weather parameters inside the greenhouse include temperature of 28-30°C and relative humidity of 80 to 84 per cent. The nutrient status of soil contains NPK in the form of 1:0.9:0.8 ratio. The organic carbon content of the soil is 1.3 per cent of the total soil and constitutes 60 per cent of humic acid. The field experiment was laid out in a randomized block design with 9 treatments replicated thrice (Table 1). The seedlings of capsicum California Wonder of 30 days old were transplanted in to the main field and crop was grown according to the recommended agronomical package of practices given by the University of Agricultural Sciences, Dharwad (Karnataka-India). The total area was of 400 m^2 and size of each plot was 24 m^2. The distance from row to row and plant to plant was 45 and 45 cm,

Table 1.Treatment details

Treatments	Scientific name	Conc.Used (%)
Neem oil	*Azadirachta indica*	3
Pongamia oil	*Pongamia pinnata*	3
Garlic oil	*Allium sativum*	3
Brahmastra	-	5
Agniastra	-	3
NSKE (Neem Seed Kernel Extract)	*Azadirachta indica*	5
GCKE (Garlic Chilli Kerosene Extract)	*Allium sativum* & *Capsicum annum*	5
Nimbecidine (3000ppm)	*Azadirachta indica* (Botanical check)	3
Diafenthiuron 50WP	Chemical check	0.1
Untreated check (UTC)	-	-

respectively. No insecticides were used either in soil or as a seed treatment for the trial.

Collection and preparation of botanicals

Botanical oils like neem oil, *Pongamia glabra* oil, nimbecidine and garlic oil were outsourced from AVT Natural Products Limited, Bengaluru, Karnataka, India. The remaining treatments were prepared in the laboratory following standard methods.

Brahmastra

Two kilogram of crushed neem (*Azadirachta indica* De Jussieu) leaves with twigs, 2 kilograms of karanj leaves (*Pongamia glabra*), 2 kilogram crushed leaves of custard apple, 2 kilogram crushed leaves of datura (*Datura alba*) and 2 kilogram crushed leaves of castor plant were mixed in 20 litres of cow urine of Hallikar breed. It was mixed properly and then boiled at 60 to 65^{0}C for about 15 minutes (4 boiling). It was allowed to cool for 48 hours and filtered and stored. It can be stored for six months (Bhullar *et al*., 2021).

Agniastra

Two kilogram neem leaves (*Azadirachta indica*) with twigs, 500 grams tobacco (*Nicotiana tabacum*) and 500 grams crushed spicy green chilli (*C. annum*), 250 grams local garlic cloves (*Allium sativum*) were crushed in 20 litres of cow urine. It was mixed thoroughly and boiled at 60 to 65^{0}C for 15 minutes, allowed to cool for 48 hours. It was stirred twice a day. It was filtered with muslin cloth and stored in shade for 3 months (Bhullar *et al*., 2021).

Garlic chilli kerosene extract (GCKE)

Fifty grams each of dried garlic (*A. sativum*) and green chilli (*C. annum*) were crushed using pestle and mortar separately and soaked in 25 ml of kerosene and kept overnight. On the next day, the contents were mixed and the volume was made up to 100 ml to get 50 per cent GCKE, later 10 ml solution was added in a litre of water to get 5 per cent concentration (Shekhara *et al*., 2014).

Neem seed kernel extract (NSKE)

Fifty grams of peeled neem seeds (*A. indica*) were crushed into small pieces and tied in muslin cloth. It was soaked in water for 8 hours. The squeezed, yellow suspension was taken out and the volume was made up to 1000 ml (Murugan *et al.,* 1996).

Observations recorded

The experiment consists of eight botanical treatments and two standard checks (nimbecidine 3000 ppm and diafenthiuron 50 WP) to demonstrate the efficacy against four main sucking pests in capsicum under protected condition. The field recommended concentration of botanicals was used in the experimentation. The pre treatment observations of sucking pests were recorded a day before spraying and post treatment observations at 3, 7 and 10 days of each spraying. Three sprays were given at an interval of 10 days. The experiments were conducted in a Randomized Block Design (RBD) and the values were converted to square root transformed values. The mean values of treatments were then subjected to Duncan's Multiple Range Test (DMRT) (Gomez and Gomez., 1984).

Results and discussion

Efficacy of botanical insecticides against sucking pests of capsicum Thrips, *Thrips parvispinus* (Karny)

The population of thrips did not vary significantly in all the plots before imposing the treatments (Table 2). At 3 and 7 days after the first spray, all the treatments recorded a considerable reduction in the population of the thrips when compared with the untreated control. The results obtained from the study revealed that neem oil (3%) treated plots recorded significantly lesser infestation of thrips (13.45 thrips/plant) followed by NSKE (5%) (14.87 thrips/plant) which were statistically on par with each other at 10 days after spray. Moderate pest infestation was recorded in pongamia oil (15.32 thrips/plant), garlic oil (18.65 thrips/plant), GCKE (19.21 thrips /plant) and brahmastra (19.54 thrips/plant). Neem oil reduced the number of thrips significantly (15.9, 9.73 and 5.83 thrips/plant) after 3,7 and 10 days of second spray followed by NSKE, pongamia oil, garlic oil, GCKE and brahmastra.

Whereas, diafenthiuron 50 WP effectively reduced the thrips population with minimum of 1.01 thrips/plant followed by nimbecidine (5.97 thrips/plant) at 10 days after spray. All the botanical treatments were found significantly superior over the untreated check. Whereas, untreated plots recorded the maximum population of 45.17 thrips/plant at 10 days after third spray. Diafenthiuron 50WP treated plots registered the higher reduction rate of thrips (0.18 thrips/plant) followed by nimbecidine (0.42 thrips/plant). The mean population of thrips per plant after third spray was in the order of: neem oil > NSKE > pongamia oil > garlic oil.

Several studies have demonstrated even systemic activity of azadirachtin in different herbivore-plant systems (Kleeberg, 1992; Weintraub and Horowitz, 1997). Neem oil (2.5 ml/l) treated plots recorded lesser population of thrips, *Scirtothrips dorsalis* Hood (1.26/plant) than pongamia oil (1.56/plant) (Venkateswarlu *et al*., 2021). Moreover, neem oil and its derivatives reduced the insect population after 7 days of treatment. This was mostly due to antifeedant and deterrent properties, which forced whiteflies, thrips and jassids to leave the treated area (Khattak *et al*., 2009). The superiority of NSKE is in congruent with the results of Sathua *et al.* (2017) who reported that NSKE registered 64.50 per cent reduction of thrips, *S. dorsalis* in chilli. The

Table 2. Field efficacy of botanical insecticides against thrips, *T. parvispinus* infesting capsicum under protected condition

Treatments	Conc. Used (%)	Mean no. of thrips (nymphs and adults) /plant									
		First spray				Second spray			Third spray		
		1DBS	3DAS	7DAS	10DAS	3DAS	7DAS	10DAS	3DAS	7DAS	10DAS
Neem oil	3.0	30.40(5.56)	23.57(4.90)^{c}	17.27(4.22)^{c}	13.45(3.73)^{bc}	15.9(4.05)^{c}	9.73(3.19)^{c}	5.83(2.52)^{b}	7.98(2.91)^{b}	3.74(2.06)^{bc}	1.03(1.24)^{c}
Pongamia oil	3.0	30.98(5.61)	26.87(5.23)^{de}	19.23(4.44)^{cd}	15.32(3.98)^{d}	16.84(4.16)^{cd}	10.54(3.32)^{c}	6.43(2.63)^{b}	10.01(3.24)^{de}	4.79(2.30)^{c}	0.79(1.14)^{bc}
Garlic oil	3.0	29.54(5.48)	26.89(5.23)^{de}	21.38(4.68)^{de}	18.65(4.37)^{e}	17.65(4.26)^{cde}	12.71(3.63)^{d}	9.32(3.13)^{c}	9.43(3.15)^{cd}	3.77(2.07)^{bc}	1.13(1.28)^{c}
Brahmastra	5.0	29.12(5.44)	27.63(5.30)^{de}	22.76(4.81)^{g}	19.54(4.48)^{g}	18.27(4.33)^{def}	16.24(4.09)^{e}	12.87(3.65)^{e}	12.67(3.56)^{e}	6.91(2.72)^{e}	2.55(1.75)^{f}
Agniastra	3.0	32.20(5.71)	27.9(5.33)^{de}	22.53(4.80)^{ef}	18.77(4.39)^{e}	20.25(4.55)^{f}	15.98(4.06)^{f}	11.75(3.50)^{d}	12.32(3.58)^{f}	6.90(2.72)^{d}	2.36(1.69)^{d}
NSKE	5.0	31.76(5.67)	25.8(5.13)^{cd}	18.93(4.41)^{cd}	14.87(3.92)^{cd}	17.96(4.29)^{cdef}	10.48(3.31)^{c}	6.43(2.63)^{b}	8.54(3.01)^{cb}	2.94(1.85)^{ab}	1.08(1.26)^{c}
GCKE	5.0	30.95(5.61)	27.52(5.29)^{ef}	22.69(4.81)^{g}	19.21(4.44)^{f}	18.01(4.30)^{ef}	16.13(4.08)^{f}	12.41(3.59)^{d}	12.21(3.42)^{f}	6.43(2.63)^{d}	2.46(1.72)^{e}
Nimbecidine (3000ppm)	3.0	31.85(5.68)	20.54(4.58)^{b}	14.65(3.89)^{b}	12.32(3.58)^{b}	12.72(3.64)^{b}	8.05(2.92)^{b}	5.97(2.54)^{b}	7.88(2.89)^{b}	3.51(2.00)^{b}	0.42(0.96)^{ab}
Diafenthiuron 50WP	0.10	30.98(5.61)	10.32(3.29)^{a}	6.21(2.59)^{a}	2.82(1.82)^{a}	5.95(2.61)^{a}	3.52(2.00)^{a}	1.01(1.23)^{a}	6.01(2.55)^{a}	2.38(1.70)^{a}	0.18(0.44)^{a}
Untreated check	-	30.24(5.76)	31.65(5.67)^{f}	32.77(5.76)^{h}	34.21(5.89)^{h}	45.01(6.74)^{g}	46.25(6.84)^{g}	49.37(7.05)^{f}	49.26(7.05)^{g}	48.32(6.98)^{f}	5.17(6.75)^{g}
S. Em±		0.29	0.30	0.23	0.19	0.25	0.19	0.27	0.17	0.20	0.11
C.D. (5%)		NS	0.88	0.67	0.58	0.75	0.56	0.79	0.51	0.60	0.33
C.V. (%)		9.04	10.29	8.82	8.28	10.17	8.70	14.15	8.36	13.01	10.28

NSKE- Neem seed kernel extract, GCKE- Garlic chili kerosene extract, DBS: Day before spraying, DAS: Days after spraying, NS- Non-significant

Figures in the parentheses are square root transformed values

Means followed by same alphabets in a column do not differ significantly by DMRT (p=0.05)

Table 3. Field efficacy of botanical insecticides against yellow mites, *P. latus* infesting capsicum under protected condition

Treatments	Conc. Used (%)	Mean no. of yellow mites (nymphs and adults) / 3 leaves									
		First spray				Second spray			Third spray		
		1DBS	3DAS	7DAS	10DAS	3DAS	7DAS	10DAS	3DAS	7DAS	10DAS
Neem oil	3.0	18.56(4.36)	11.31(3.44)^{b}	7.96(2.91)^{b}	5.47(2.44)^{b}	7.52(10.85)^{b}	4.65(2.27)^{b}	3.94(2.11)^{b}	5.29(2.41)^{b}	4.87(2.32)^{bc}	3.04(1.88)^{b}
Pongamia oil	3.0	18.44(4.35)	16.74(4.15)^{e}	14.48(3.87)^{c}	12.78(3.64)^{d}	8.36(9.11)^{c}	5.21(2.39)^{bc}	5.47(2.44)^{b}	5.41(2.43)^{b}	4.57(2.25)^{b}	3.02(1.87)^{b}
Garlic oil	3.0	18.47(4.36)	14.72(3.90)^{d}	10.42(3.30)^{b}	8.99(3.08)^{c}	8.34(9.31)^{c}	5.89(2.53)^{c}	4.85(2.31)^{b}	6.81(2.70)^{b}	7.81(2.88)^{c}	6.12(2.57)^{d}
Brahmastra	5.0	20.03(4.53)	18.58(4.37)^{f}	15.62(4.01)^{c}	11.3(3.43)^{e}	11.34(3.44)^{e}	10.14(3.26)^{d}	8.37(2.98)^{c}	7.27(2.79)^{b}	5.79(2.51)^{c}	4.72(2.28)^{c}
Agniastra	3.0	19.57(4.48)	18.71(4.38)^{f}	15.90(4.06)^{c}	11.94(3.53)^{e}	11.87(3.51)^{e}	10.29(3.28)^{e}	8.58(3.01)^{c}	7.98(2.91)^{c}	5.86(2.52)^{c}	4.87(2.32)^{c}
NSKE	5.0	17.32(4.22)	14.08(3.82)^{c}	11.20(3.42)^{b}	10.11(3.25)^{c}	8.96(10.19)^{d}	6.17(2.58)^{c}	5.41(2.43)^{b}	6.94(2.73)^{b}	5.74(2.50)^{bc}	3.77(2.07)^{c}
GCKE	5.0	19.57(4.48)	18.71(4.38)^{f}	15.90(4.06)^{c}	11.94(3.53)^{e}	11.87(3.51)^{e}	10.29(3.28)^{e}	8.58(3.01)^{c}	7.98(2.91)^{c}	5.86(2.52)^{c}	4.87(2.32)^{c}
Nimbecidine (3000 ppm)	3.0	18.56(4.36)	11.31(3.44)^{b}	7.96(2.91)^{b}	5.47(2.44)^{b}	7.52(10.85)^{b}	4.65(2.27)^{b}	3.94(2.11)^{b}	5.29(2.41)^{b}	4.87(2.32)^{bc}	3.04(1.88)^{b}
Diafenthiuron 50 WP	0.10	19.55(4.48)	5.69(2.49)^{a}	2.04(1.59)^{a}	0.75(1.12)^{a}	1.57(1.06)^{a}	0.51(1.00)^{a}	0.00(0.71)^{a}	0.00(0.71)^{a}	0.00(0.71)^{a}	0.00(0.71)^{a}
Untreated check	-	19.41(4.46)	22.07(4.75)^{g}	25.39(5.09)^{f}	28.61(5.39)^{f}	29.85(11.03)^{f}	26.16(5.16)^{f}	25.73(5.12)^{d}	22.51(4.79)^{d}	20.71(4.61)^{d}	21.72(4.71)^{e}
S. Em±		0.25	0.18	0.20	0.16	0.29	0.15	0.18	0.16	0.19	0.16
C.D. (5%)		NS	0.54	0.58	0.49	0.85	0.45	0.54	0.47	0.56	0.46
C.V. (%)		9.86	8.00	9.77	8.91	7.44	9.45	12.13	10.15	13.14	12.13

NSKE- Neem seed kernel extract, GCKE- Garlic chili kerosene extract, DBS: Day before spraying, DAS: Days after spraying, NS- Non-significant

Figures in the parentheses are square root transformed values Means followed by same alphabets in a column do not differ significantly by DMRT (p=0.05) superiority of azadiractin (0.03%) over NSKE and azadirachtin 10,000 ppm @ 1.00 ml/l was found to be highly effective and greatly reduced the thrips, *T. tabaci* population when compared to NSKE 5% @ 50 g/l which recorded 5.50 and 9.42 thrips per plant, respectively (Shruti *et al*., 2021). Furthermore, repeated application of NSKE and GCKE was found to be effective against sucking insects such as thrips and mites in chilli (Gundannavar *et al*., 2007).

Yellow mites *Polyphagotarsonemus latus* (Banks)

The population of yellow mites among the various treatments did not differ significantly a day before spraying which ranged from 17.32 to 20.03/3 leaves (Table 3). The data on yellow mite population after three days of first spray resulted significantly lower population in the case of neem oil (11.31/3 leaves) and NSKE treated plots (14.08/3 leaves) (Table 3). The yellow mite population was comparatively higher in agniastra (18.71/3 leaves) followed by brahmastra (18.58/3 leaves) and was statistically superior than untreated control (22.07/3 leaves). The same trend in the yellow mite population was followed at 7 and 10 DAS of first spray. After 3 days of second spray, significantly lower population of yellow mites was observed in neem oil (7.52/3 leaves) which was statistically on par with nimbecidine (7.52/3 leaves) followed by garlic oil (8.34/3 leaves), pongamia oil (8.36/3 leaves) and NSKE (8.96/3 leaves) sprayed plots. The same trend in mite population was followed at 7 days after 2nd spraying. At 10 days after 2nd spraying, neem oil (3.94/3 leaves), NSKE (5.41/3 leaves), pongamia oil (5.47/3 leaves) and garlic oil (4.85/3 leaves) recorded the lowest mite population and were statistically on par with nimbecidine (3.94/3 leaves). The mite population reduced significantly during third spray observations and neem oil ranked first in reducing the mite population followed by NSKE, garlic oil, pongamia oil, brahmastra, GCKE and agniastra at 10 days after spray. Ultimately, there was no mite population in diafenthiuron treated plots. The mite population decreased gradually and significantly towards the third spray and at 10 DAS, neem oil was highly effective in control of yellow mites followed by NSKE, garlic oil, pongamia oil, brahmastra, GCKE and agniastra.

The effectiveness of neem oil @ 4 per cent on mites, *T. urticae* (58%) is confirmed by the findings of Singh *et al*. (2018). Neem oil (2%) and pongamia oil (2%) were observed to be effective against many phytophagous mites and are comparable to the findings of Attia *et al*. (2013); Ramaraju and Bhullar (2013) and Rincon *et al*. (2019). Krishnan and Sreekumar (2021) reported that pongamia oil soap (3%) was described as most effective against yellow mites, *P. latus* followed by pongamia oil (2%) soap among the botanicals treated and after seven days of treatment, the effect was remained up to 14 days after spray.

Aphids *Aphis gossypii* (Glover)

Pre treatment observations revealed that aphid population in all treatment did not differ considerably (Table 4). After 1st spray, the aphid population was significantly lower in neem oil (10.54/3 leaves), NSKE (11.07/3 leaves) and pongamia oil (11.35/3 leaves) which were statistically on par with each other. Remaining treatments recorded the aphid population ranging

Table 4. Field efficacy of botanical insecticides against aphids, *A. gossypii* infesting capsicum under protected condition

Treatments	Conc. Used (%)	Mean no. of aphids (nymphs and adults) / 3 leaves									
			First spray			Second spray			Third spray		
		1DBS	3DAS	7DAS	10DAS	3DAS	7DAS	10DAS	3DAS	7DAS	10DAS
Neem oil	3.0	16.73(4.15)	10.54(3.32)^{b}	6.09(2.57)^{b}	3.07(1.89)^{b}	3.96(2.11)^{b}	2.87(1.84)^{b}	1.54(1.43)^{c}	2.34(1.69)^{b}	1.18(1.30)^{b}	0.76(1.12)^{b}
Pongamia oil	3.0	17.50(4.24)	11.35(3.44)^{b}	6.38(2.62)^{b}	3.46(1.99)^{b}	5.37(2.42)^{c}	3.12(1.90)^{b}	2.01(1.58)^{c}	2.63(1.77)^{b}	1.61(1.45)^{b}	0.93(1.20)^{b}
Garlic oil	3.0	15.99(4.06)	11.85(3.51)^{b}	6.47(2.64)^{b}	3.52(2.00)^{b}	5.87(2.52)^{c}	3.54(2.01)^{c}	2.11(1.62)^{d}	2.72(1.79)^{b}	1.63(1.46)^{b}	0.97(1.21)^{b}
Brahmastra	5.0	16.22(4.09)	12.57(3.61)^{b}	8.75(3.04)^{c}	5.86(2.52)^{c}	6.33(2.61)^{c}	3.96(2.11)^{c}	2.35(1.69)^{d}	3.88(2.09)^{c}	2.44(1.71)^{c}	1.20(1.30)^{c}
Agniastra	3.0	17.43(4.23)	12.88(3.66)^{b}	9.03(3.09)^{c}	5.99(2.55)^{c}	6.57(2.66)^{c}	4.21(2.17)^{c}	2.49(1.73)^{d}	4.08(2.14)^{c}	2.63(1.77)^{c}	1.34(1.36)^{c}
NSKE	5.0	14.98(3.93)	11.07(3.40)^{b}	6.34(2.61)^{b}	3.09(1.89)^{b}	4.76(2.29)^{c}	2.98(1.86)^{b}	1.87(1.54)^{c}	2.55(1.75)^{b}	1.49(1.41)^{b}	0.80(1.14)^{b}
GCKE	5.0	14.32(3.85)	12.72(3.63)^{b}	8.99(3.08)^{c}	5.72(2.49)^{c}	6.17(2.58)^{c}	3.72(2.05)^{c}	2.14(1.62)^{d}	3.87(2.08)^{c}	1.94(1.56)^{b}	0.89(1.18)^{b}
Nimbecidine (3000ppm)	3.0	16.98(4.18)	10.24(3.28)^{a}	4.82(2.31)^{b}	2.47(1.72)^{b}	2.71(1.79)^{b}	1.75(1.50)^{b}	0.99(1.22)^{b}	2.07(1.60)^{b}	1.09(1.26)^{a}	0.74(1.11)^{b}
Diafenthiuron 50 WP	0.10	19.55(4.48)	5.69(2.49)^{a}	2.04(1.59)^{a}	0.75(1.12)^{a}	1.57(1.06)^{a}	0.51(1.00)^{a}	0.00(0.71)^{a}	0.00(0.71)^{a}	0.00(0.71)^{a}	0.00(0.71)^{a}
Untreated check	-	15.37(3.98)	16.97(4.18)^{c}	18.32(4.34)^{c}	19.59(4.48)^{d}	19.57(4.48)^{d}	19.08(4.42)^{d}	18.76(4.39)^{e}	17.51(4.24)^{d}	17.95(4.30)^{d}	18.20(4.32)^{d}
S. Em±		0.25	0.28	0.20	0.20	0.16	0.14	0.6	0.15	0.11	0.7
C.D. (5%)		NS	0.82	0.58	0.59	0.48	0.41	0.18	0.45	0.33	0.21
C.V. (%)		10.85	13.75	12.23	15.28	11.30	11.38	10.28	9.45	10.28	13.47

NSKE- Neem seed kernel extract, GCKE- Garlic chili kerosene extract, DBS: Day before spraying, DAS: Days after spraying, NS- Non-significant

Figures in the parentheses are square root transformed values, Means followed by same alphabets in a column do not differ significantly by DMRT (p=0.05)

Table 5. Field efficacy of botanical insecticides against whiteflies, *B. tabaci* infesting capsicum under protected condition

Treatments	Conc. Used (%)	Mean no. of whitefly adults/3 leaves in capsicum under protected condition										
			First spray			Second spray			Third spray			
		1DBS	3DAS	7DAS	10DAS	3DAS	7DAS	10DAS	3DAS	7DAS	10DAS	
Neem oil	3.0	9.87(3.22)	6.15(2.58)^{a}	3.43(1.98)^{b}	1.11(1.27)^{a}	2.79(1.81)^{c}	1.04(1.24)^{a}	1.02(1.20)^{c}	1.24(1.32)^{b}	0.73(1.11)^{b}	0.37(0.93)^{b}	
Pongamia oil	3.0	10.94(3.38)	6.48(2.64)^{b}	3.82(2.08)^{b}	1.38(1.37)^{b}	3.01(1.87)^{c}	1.42(1.39)^{b}	1.67(1.47)^{d}	1.55(1.43)^{b}	0.93(1.20)^{b}	0.61(1.05)^{c}	
Garlic oil	3.0	10.41(3.30)	6.54(2.65)^{b}	3.89(2.09)^{b}	1.44(1.39)^{b}	3.08(1.89)^{c}	1.59(1.45)^{b}	1.92(1.56)^{d}	1.63(1.46)^{b}	0.99(1.22)^{b}	0.68(1.09)^{c}	
Brahmastra	5.0	8.77(3.04)	6.88(2.72)^{b}	4.51(2.24)^{b}	2.34(1.69)^{b}	4.12(2.15)^{c}	2.92(1.85)^{c}	2.06(1.60)^{e}	2.28(1.67)^{c}	1.46(1.40)^{c}	1.08(1.26)^{d}	
Agniastra	3.0	9.56(3.17)	7.02(2.74)^{b}	4.88(2.32)^{b}	2.57(1.75)^{b}	4.30(2.19)^{c}	3.14(1.91)^{c}	3.39(1.97)^{f}	2.32(1.68)^{c}	1.61(1.45)^{c}	1.30(1.34)^{d}	
NSKE	5.0	10.35(3.29)	6.32(2.61)^{a}	3.74(2.06)^{b}	1.23(1.32)^{b}	2.88(1.84)^{c}	1.10(1.26)^{a}	1.52(1.42)^{c}	1.37(1.37)^{b}	0.85(1.16)^{b}	0.42(0.96)^{b}	
GCKE	5.0	9.45(3.15)	6.63(2.67)^{b}	4.05(2.13)^{b}	2.13(1.62)^{b}	3.88(2.09)^{c}	2.84(1.83)^{c}	1.98(1.57)^{c}	2.13(1.62)^{c}	1.32(1.35)^{c}	0.99(1.22)^{d}	
Nimbecidine (3000ppm)	3.0	9.33(3.13)	5.91(2.53)^{a}	2.67(1.78)^{b}	1.05(1.24)^{a}	2.72(1.79)^{b}	1.02(1.23)^{a}	0.47(0.98)^{b}	1.09(1.26)^{b}	0.61(1.05)^{a}	0.27(0.88)^{b}	
Diafenthiuron 50WP	0.10	9.41(3.15)	3.82(2.08)^{a}	0.94(1.20)^{a}	0.12(0.79)^{a}	1.09(1.26)^{a}	0.56(1.03)^{a}	0.08(0.76)^{a}	0.20(0.84)^{a}	0.07(0.75)^{a}	0.00(0.71)^{a}	
Untreated check-		8.64(3.02)	9.07(3.09)^{c}	9.52(3.16)^{c}	10.31(3.29)^{c}	9.45(3.15)^{d}	9.22(3.11)^{d}	9.74(3.20)^{g}	11.56(3.47)^{d}	12.75(3.64)^{d}	12.23(3.57)^{d}	
S. Em±		0.18	0.18	0.19	0.17	0.18	0.09	0.6	0.11	0.11	0.5	
C.D. (5%)		NS	0.55	0.56	0.51	0.54	0.27	0.18	0.33	0.33	0.15	
C.V. (%)		10.01	12.08	15.46	19.01	15.67	9.64	10.28	9.45	10.28	10.28	

NSKE- Neem seed kernel extract, GCKE- Garlic chili kerosene extract, DBS: Day before spraying, DAS: Days after spraying, NS- Non-significant

Figures in the parentheses are square root transformed values, Means followed by same alphabets in a column do not differ significantly by DMRT (p=0.05)

from 11.85 to 12.88/3 leaves. All the botanical treatments were superior over untreated control (16.97/3 leaves). Among the botanicals, neem oil was found to be superior with a population of 6.09 and 3.07/3 leaves followed by pongamia oil (6.38 & 3.46/ 3 leaves), garlic oil (6.47& 3.52/3 leaves), GCKE (8.99 & 5.72/3 leaves) and brahmastra (8.75 & 5.86/ 3 leaves) at 7 and 10 days after 1st spraying respectively. At 3 and 7 days after the second spray, significantly lesser number of aphids were recorded with all the botanical treatments in comparison with the control (19.57/3 leaves). At 3 days after spray, the aphid population declined in the same trend as in the first spray, whereas neem oil (3.96/3 leaves) recorded the lowest aphid population which was statistically superior over all other treatments. At 7 days after spray, the lowest aphid population was observed in neem oil (2.87/3 leaves), NSKE (2.98/3 leaves) and pongamia oil (3.12/ 3 leaves) which were statistically on par with each other. Similar trend in aphid population was recorded at 10 days after 2nd spray. The aphid population was low after third spray and did not exceed 1.4/3leaves. At 10 days after 2nd spray, neem oil (0.76/3leaves), NSKE (0.80/3 leaves), GCKE (0.89/3 leaves), pongamia oil (0.93/3leaves) and garlic oil (0.97/3leaves) which were statistically on par with each other. The highest aphid population was observed in untreated check (18.20/3leaves). Aphid population was very low during third spray and their numbers did not cross above 1.4/3 leaves. The mean population of thrips per plant after third spray was in the following order: neem oil > NSKE > pongamia oil > garlic oil.

Similar kind of reports were made by several authors *viz.,* Suganthy and Sakthivel (2012) reported the superiority of neem oil (1%) over NSKE and pongamia oil against aphids, *A. gossypii* in *Solanum nigrum*. In comparison to other botanicals tested, neem extract 5000 ppm has proven effective in controlling the number of aphids, *A. gossypii* on chilli at four weeks after the treatment (Singh *et al.,* 2013). Besides, the efficacy of neem-based pesticides was well documented by Singh and Kumar (2003) who suggested that neem-based pesticides have been recorded to be superior in controlling sucking pests in vegetable crops than other botanical insecticides. Ali *et al.* (2017) emphasized the efficacy of neem extract which has caused high reduction in the aphid population, *A. gossypii* (96.61%) over the datura and tobacco extract (*Nicotiana tabacum*) (92.85 and 88.93%). The present findings are in line with the findings of Muthukumar *et al.* (2007) and Sujay *et al.* (2015) who revealed that neem oil to be highly effective in controlling aphids, *A. gossypii* in chilli under open field conditions.

Whitefly *Bemisia tabaci* Gennadius

Prior to the application of botanical insecticides, whitefly population was uniform (Table 5) which ranged from 8.64 to 10.94/3leaves. The whitefly population was lower during the first spray compared to other sucking pests. After 3 days of first spray, neem oil (6.15/ 3 leaves) and NSKE (6.32/3 leaves) were more effective against whiteflies which were statistically on par with each other followed by pongamia oil (6.48/3leaves), garlic oil (6.54/3 leaves), GCKE (6.63/3leaves), brahmastra (6.88/ 3leaves) and agniastra (7.02/3leaves) which were statistically at par. At 7 days after 1st spray, the whitefly population reduced significantly in neem oil (3.43/3leaves), pongamia oil (3.82/ 3leaves) and garlic oil (3.89/ 3leaves) which were also statistically on par with each other. The same trend in the whitefly population was followed after 10 days after 1st spray. The second spray data showed least whitefly population (2.79, 1.04 and 1.02 whiteflies/3leaves) at 3, 7 and 10 days after spray in plots treated with neem oil followed by NSKE (2.88, 1.10 and 1.52 whiteflies/3leaves), pongamia oil (3.01, 1.42 and 1.67 whiteflies/ 3leaves) and garlic oil (3.08, 1.59 and 1.92 whiteflies/3leaves). Similar trend in the population of whiteflies was trailed at 7 and 10 days after 2nd spray. All the botanical treatments were significantly superior over the untreated control (12.23/3leaves). Superiority of neem oil, NSKE, pongamia oil and garlic oil in controlling the whitefly population was also noticed after 3rd spray. There is a drastic reduction in whitefly population from first spray to third spray in all the treatments. Among the botanicals, neem oil recorded least population of whiteflies followed by NSKE, garlic oil, pongamia oil, brahmastra, GCKE and agniastra.

The results were partially in line with earlier publications *viz.,* Gupta and Sharma, 1997 found reduced adult and nymphal populations of *B. tabaci* when treated with neem seed extract and neem oil. Khattak *et al.* (2009) reported that neem and its derivatives have lost their efficacy after 14 days of spray. Successive spraying of NSKE at 5 per cent and GCKE at 0.5 per cent was effective against *B. tabaci* in chilli (Gundannavar *et al.*, 2007).

Conclusion

Based on overall observations, minimum thrips and aphid population was recorded in neem oil under protected cultivation system. Similarly, neem oil was also found effective and recorded significantly lower number of yellow mites and whiteflies followed by NSKE, garlic oil and pongamia oil. In recent years, there has been a significant growth in the use of botanical products for the management of insect pests, which has raised their recognition and market share on the global insecticide market.

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