PONGAMIA OIL SOAP FOR THE MANAGEMENT OF MAJOR PESTS OF BRINJAL (*Solanum melongena* L.)

JEEVITHA P

(2018-11-121)

DEPARTMENT OF AGRICULTURAL ENTOMOLOGY

COLLEGE OF AGRICULTURE

PADANNAKKAD, KASARAGOD - 671314

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by

JEEVITHA P

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2020

DECLARATION

I, hereby declare that this thesis entitled **"PONGAMIA OIL SOAP FOR THE MANAGEMENT OF MAJOR PESTS OF BRINJAL (*Solanum melongena* L.)."** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Place: Padannakkad

Date: 30/11/2020

Jeevitha P

(2018-11-121)

CERTIFICATE

Certified that this thesis entitled **"PONGAMIA OIL SOAP FOR THE MANAGEMENT OF MAJOR PESTS OF BRINJAL (*Solanum melongena* L.)."** is a record of research work done independently by Ms. Jeevitha P under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

Place: Padannakkad

Date: 30/11/2020

30/11/20

Dr. K. M. Sreekumar
(Major Advisor)
Professor and Head
Department of Agricultural Entomology
College of Agriculture
Padannakkad- 671314

CERTIFICATE

We, the undersigned members of the advisory committee of Ms. Jeevitha P, a candidate for the degree of **Master of Science in Agriculture** with major in Agricultural Entomology, agree that the thesis entitled **"PONGAMIA OIL SOAP FOR THE MANAGEMENT OF MAJOR PESTS OF BRINJAL (*Solanum melongena* L.)."** may be submitted by Ms. Jeevitha P., in partial fulfilment of the requirement for the degree.

Dr. K. M. Sreekumar
(Major Advisor)
Professor and Head
Department of Agricultural Entomology
College of Agriculture
Padannakkad- 671314

Dr. B. Ramesha
(Member, Advisory Committee)
Associate Professor
Department of Agricultural Entomology
College of Agriculture
Padannakkad- 671314

Dr. C. K. Yamini Varma
(Member, Advisory Committee)
Associate Professor (Plant Pathology)
AICRP on Spices
Pepper Research Station
Panniyur – 670142

Dr. N. K. Binitha
(Member, Advisory Committee)
Assistant Professor
Department of Soil Science and Agricultural Chemistry
College of Agriculture
Padannakkad - 671314

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Jeevitha P

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Introduction

1. INTRODUCTION

Diverse climate prevailing in India encourages the cultivation of wide range of vegetables. Brinjal, *Solanum melongena* L. is also known as eggplant or aubergine believed to have originated in India. Being "King of vegetables" brinjal is one of the principal vegetables' crops in the country. Though brinjal is a warm season crop, it is being cultivated throughout the year under assured irrigation. About 1.79 million hectares of land is under brinjal cultivation worldwide with a total production of 51.29 million tonnes (2016-17) (National Horticulture Board, 2018). India ranks second in brinjal production (12.80 million tonnes during 2017-18) which contribute 24.5% share of the total vegetable production. In India, brinjal is cultivated in 0.7 million hectares of land with 17.5t/ha of productivity. Major brinjal producing states include West Bengal, Odisha, Gujarat, Madhya Pradesh and Bihar. In Kerala, brinjal is cultivated in an area of 1920 hectares with a production of 24,050 tonnes during 2017-18 (National Horticulture Board, 2018).

Brinjal is a non-tuberous species from nightshade (Solanaceae) family which can provide significantly high nutritive benefits. The nutritional profile of 1 cup (82g) cooked brinjal contains 19.7 kilo calories of energy, 4.7g carbohydrates, 92.7 per cent water, 2.8g fibre, 0.8g protein, 0.2g fat, along with vitamins like vitamin A (22.1 IU), vitamin B1 (0.08 mg), vitamin B2 (0.02 mg), vitamin B3 (0.59 mg), vitamin B5 (0.07 mg), vitamin B6 (0.09 mg) and vitamin C (1.29 mg) and minerals like calcium (7.4 mg), iron (0.25 mg), magnesium (11.5 mg), phosphorus (20.5 mg), potassium (189 mg), sodium (1.6 mg), manganese (0.11 mg), copper (0.06 mg) and zinc (0.12 mg). A cup of brinjal provides at least 5 per cent of a person's daily requirement of fibre, copper, manganese, B-6, and B-1. Additionally, brinjal serves some phenolic compounds also which acts as antioxidants.

Brinjal is subjected to serious infestation by different pests right from the time of planting to harvesting. The severe pest infestation is considered as a major limiting factor in profitable brinjal cultivation. About 140 species of insects and non-insect pests are known to attack the crop. Among which, fruit and shoot borer (FSB), *Leucinodes orbonalis* (Lepidoptera: Crambidae); jassid, *Amrasca biguttula biguttula* (Hemiptera:

Cicadellidae); Hadda beetles, *Epilachna vigintioctopunctata* and *E. dodecastigma* (Coleoptera: Coccinellidae); aphids: *Aphis gossypii* and *Myzus persicae* (Hemiptera: Aphididae); whitefly, *Bemisia tabaci* (Hemiptera : Aleyrodidae); red spider mites, *Tetranychus* spp. (Tetranychidae: Acari); leaf roller, *Autoba olivacea* (Lepidoptera: Erebidae); leaf webber, *Herpetogramma bipunctalis* (Lepidoptera: Crambidae); and grey weevils, *Myllocerus subfasciatus* (Coleoptera: Curculionidae) have been reported as important pests.

The notorious and destructive pest of brinjal is fruit and shoot borer which causes enormous yield loss. The larvae bore into the tender shoot or petiole or even midrib of the leaf at the early stage of the crop causing withering and drooping. The pest also bores into flower buds and flowers which results in no fruit formation from them. The shoot damage become very less or fully disappear once the fruit setting has been started. As high as 70 - 92 per cent yield loss has been reported in India (Rosaiah, 2001). The pest is also reported to cause 3.3 - 68.9 per cent flower damage and 47.6-85.8 per cent fruit damage (Patnaik, 2000).

Leafhopper is the second major pest of brinjal which causes 50% yield loss in South Asia (Bindra and Mahal, 1981). Both vegetative and reproductive stages are likely to be suffered by leafhopper infestation. Group of nymphs and adults suck the plant sap from underneath of leaves and also inject toxins into the plant tissue which ultimately leads to stunted growth of plants with burnt leaves and low fruit set. The other sucking pests such as aphids, mites and whiteflies are also causing severe damage to the crop and reduces the yield significantly when the infestation is high. The hadda beetle/spotted leaf beetle is a key pest in solanaceous and cucurbitaceous crops causing 60% yield loss in brinjal due to the voracious feeding by grubs and adults (Mall *et al*., 1992). Brinjal ecosystem is rich in arthropod diversity which also include various natural enemy species other than these destructive pests. According to Latif *et al.* (2009), out of 30 species reported in brinjal ecosystem 10 species were predacious arthropods.

The successful brinjal cultivation is depending on proper management of pests and diseases. Indian farmers mainly rely on conventional management practices for its immediate results. Un-scientific, irrational and over use of synthetic insecticides in vegetables resulted in development of resistance genes, pollution of soil, air and water bodies, health hazards of farm workers, adverse effects on non-target organisms, expensive management practice and contamination of products. Waiting period is also an issue in vegetable cultivation due to their frequent harvests. Rising concerns on these problems necessitates the development of environmentally safe and sustainable pest control strategies such as use of plant extracts and oils, entomopathogenic organisms, use of predators and parasitoids, *etc*. Pongamia/karanj oil is one such plant derived insecticides which can be used against wide range of insect and mite pests.

Pungam/pongam/Indian beech/karanj, *Pongamia pinnata* (L.) Pierre is a glabrous shrub or tree, evergreen or briefly deciduous annually, fast-growing, medium-sized with broad crown. Pungam is a multipurpose tree, particularly valued for its oil which is derived from their seeds. Seeds have 27 – 40 % oil which is yellowish or reddish-brown, bitter, thick oil and non-edible. The oil is used as a medicine for treating leukoderma (for skin pigmentation), dyspepsia, rheumatism and sluggish liver, can also be used in soap making industries, as varnish, lubricant, fuel, *etc*. According to Pavela (2004), numerous defensive chemicals have been reported to cause physiological and behavioural effects in insects from various botanicals like *Azadirachta indica*, *Melia* sp., and *Leuzea carthomoides*. In case of pongamia, secondary metabolites such as flavonoids, chalcones, steroids and terpenoids are the compounds associated with insecticidal nature (Pavela, 2007). The toxicity of pongamia oil against pests is mainly attributed to furanoflavones such as karanjin, pongapin, kanjone, diketone pongamol *etc*., and these compounds makes the oil unsuitable for edible purpose (Bringi, 1987). Various extracts of pongamia were showed antifeedant and oviposition deterrent activity against different crop pests.

Considering the above facts in view, the present investigation entitled **"Pongamia oil soap for the management of major pests of brinjal (*Solanum melongena* L.)"** was proposed for evaluating the efficiency of pongamia oil soap at different concentrations in the management of brinjal pests and its impact on natural enemies.

Review of Literature

2. REVIEW OF LITERATURE

Several works were undertaken to analyse various aspects of biopesticides in the management of different crop pests. The literatures pertaining to the potential of pongamia in the management of crop pests and its impact on natural enemies have been reviewed and arranged here under.

2.1. EFFICACY OF PONGAMIA IN THE MANAGEMENT OF FRUIT AND SHOOT BORER (FSB), *Leucinodes orbonalis*

Ajabe (2019) conducted an experiment to evaluate the management options for BFSB, where the minimum shoot infestation was recorded in the treatment of emamectin benzoate 5% SG with 3.30% and 6.83% in first and second spray respectively on 7 DAS, followed by NSKE @ 5% with 5.83% and 7.27%, pruning of infested shoots and fruits with 6.53% and 9.77% and pongamia oil at 5 per cent with 7.00% and 10.83% whereas the control recorded 17.97% and 18.33% shoot infestation. The number of fruits infested was also minimum in emamectin benzoate 5% SG (8.90) and the pongamia oil recorded 29.71 on number basis, both were significantly superior over control (52.70).

In an experiment conducted by Dehariya *et al.* (2017), different botanicals like neem oil 1 %, NSKE 5%, Achook 5 %, karanj oil 1% and eucalyptus oil 1% were analysed against brinjal fruit and shoot borer along with the standard check Triazophos 40 EC (0.04%). The borer incidence in fruits was significantly reduced by Triazophos 40 EC (12.45%) treatment followed by Achook (13.40%) which was superior to neem oil (15.42%) and karanj oil (18.48%) while fruit damage in control was 32.18%.

Kumar (2017) evaluated the efficacy of three different modules for the management of fruit and shoot borer in brinjal which included recommended practice of SKUAST-Jammu (Module I), farmers' practice (Module II) and BIPM (Bio-intensive Integrated Pest Management) comprising different biopesticides including pongamia oil 2 per cent (Module III). He witnessed that the lowest number of infested fruits (17.60/5 plants) and larval population (4.63/5 plants) on shoots in Module III which was followed by Module I with 32.33 infested fruits and 5.71 larval population on shoots per 5 plants.

Pandey and Thakur (2017) reported that cypermethrin 25 EC @ 0.02% had highest efficiency with only 5.83 and 4.41 per cent shoot and fruit infestation respectively whereas, the plant origin insecticides like NSKE 2.5%, neem leaf extract, and pongamia leaf extract recorded 8.36, 9.36 and 9.87 per cent fruit infestation respectively in brinjal.

According to Sahana and Tayde (2017), the lowest shoot and fruit infestation (4.78 % and 6.38%) by brinjal shoot and fruit borer was recorded in the treatment of spinosad 0.1 mL/L while among the selected botanicals, neem oil 3% caused minimum infestation (8.47% and 9.66%) followed by pongamia oil 3% with 9.85% and 10.28% shoot and fruit infestation respectively.

Sureshsing and Tayde (2017) carried out an experiment with the aim of evaluating certain biorationals against BFSB such as cypermethrin 25% EC @ 2 mL/L, spinosad 45% SC @ 0.5 mL/L, pongamia oil @ 30 mL/L, neem oil @ 20 mL/L, NSKE @ 50 gm/L, garlic bulb extract @ 50 mL/L and neem leaf extract @ 50 mL/L. The study revealed that the minimum shoot damage was recorded in spinosad (6.87%) and cypermethrin (8.57%) followed by neem oil (9.27), NSKE (9.60) and pongamia oil (10.93). The fruit infestation was also less in case of spinosad and pongamia oil with 7.15 and 11.9% which were significantly superior over control.

Certain biopesticides and newer insecticides were tested on brinjal FSB by Patra *et al*. (2016) and reported that among the newer insecticides (emamectin benzoate 5 SG @ 0.4 g l^{-1}, chlorpyriphos 20 EC @ 2 mL L^{-1}, flubendiamide 480 SC @ 0.3 mL L^{-1}, chlorantraniliprole 18.5 SC @ 0.4 mL L^{-1}), chlorantraniliprole proved to be best treatment with 2.46% overall mean shoot infestation followed by flubendiamide (3.08%) and emamectin benzoate (3.76%) whereas biocides *viz*., azadirachtin 1 EC @ 2 mL L^{-1} (7.71%), annonin 1 EC @ 2 mL L^{-1} (8.19) and karanjin 2 EC @ 2 mL L^{-1} (8.99%) were significantly superior over control in shoot infestation. The overall mean fruit infestation was less in chlorantraniliprole and flubendiamide with 5.76% and

5.93% and reduction of per cent fruit infestation were 79.45% and 78.84% while karanjin treated plants show 21.79 % fruit infestation from biocides.

Kushwaha and Painkara (2016) analysed the efficacy of certain botanical insecticides on brinjal fruit and shoot borer. He observed that the plots treated with cypermethrin 10 EC showed minimum shoot (7.93%) and fruit (7.68%) infestation while among the botanicals, the maximum reduction of shoot and fruit damage showed in neem oil (8.20% & 8.09%) followed by NSKE (8.20% & 8.87%), pongamia oil (9.05% & 9.24%), iluppai oil (9.47% & 10.40%), garlic bulb extract (9.83% & 11.32%) and Tobacco leaf extract (10.265% & 11.93%).

Patel *et al*. (2015) evaluated different biopesticides among which, *Paecilomyces fumosoroseus* @ 1L/ha recorded 1.51% fruit infestation by shoot and fruit borer in brinjal, while pongamia soap @ 2.5 kg/ha recorded 6.85% infestation which was significantly different from control (10.89%).

In pre-kharif season, a field experiment was carried out by Bhumita *et al*. (2013) to study the potential of eight insecticides along with one pheromone against FSB and the treatments were neem oil 0.3% (3 mL L^{-1}), karanjin 2EC (2 mL L^{-1}), NSKE 5%, *Bacillus thuringiensis* 8l (500g ha^{-1}), *Annona squamosa* 1EC (2 mL L^{-1}), spinosad 45 SC (75g a.i. ha^{-1}), *Beauveria bassiana* (Baba 2 mL L^{-1}), pheromone trap (Lucilure @ 100 traps ha^{-1}), Endosulfan 35 EC (0.07%). After two sprays, least mean infestation of shoot was reported in endosulfan treated plots (72.59% reduction and 5.28% infestation) which was at par with spinosad (5.52%) and lucilure (5.65%) with 71.33 and 70.63% reduction respectively while karanjin 2EC recorded 10.55% shoot infestation with percent reduction of 45.18. When the minimum fruit infestation was achieved by lucilure with 7. 42%, karanjin recorded 18.55% fruit infestation which was significantly higher than control.

Among the different IPM modules tested by Prasad *et al*. (2013) on brinjal shoot and fruit borer, neem oil 0.4% + pongamia oil 0.1% + traps was very effective in minimizing the shoot and fruit damage with 93.5 and 85.35 % respectively over untreated control. The next best treatment was neem oil 0.4 % + pongamia oil 0.1% which showed 89.4 and 79.0 per cent shoot and fruit damage respectively followed by farmers practice and entomopathogenic fungi have produced shoot damage of 83.0 and 65.1 per cent and fruit damage of 66.9 and 45.1 per cent respectively.

Mathur *et al.* (2012) stated that shoot and fruit damage in brinjal by BFSB were effectively supressed by both iluppai and pongamia oil @ 2% which were on par with Endosulfan 35 EC (0.07%). Among the newer botanicals evaluated, pungam and iluppai oil @ 2% found to be effective against BFSB with 4.63 & 4.72% shoot damage and 16.30 and 15.93% fruit damage respectively while endosulfan showed 4.31 and 14.23% shoot and fruit damage.

In the study conducted by Shobharani and Nandihalli (2010) to analyse the efficacy of biorationals in the management of shoot borer (*Leucinodes orbonalis*) on potato during kharif season, Nimbecidine @ 5 mL/L and NSKE @ 5% were found to be significantly superior over other treatments in all the three sprays with 27.23 and 29.06% shoot infestation respectively. The efficacy of Nimbecidine and NSKE were on par with pongamia oil @ 2% (29.98%) and neem oil @ 3% (32.11%). Higher tuber yield also was recorded in Nimbecidine (35.82 q/ha), NSKE (33.38 q/ha) and pongamia oil (30.91 q/ha) with B:C ratio of 6.78, 4.48 and 3.21 respectively.

Murugesan and Murugesh (2009) carried out an experimentation for examining the efficiency of some ten plant products (*Azadirachta indica* leaf extract @ 5.0 %, neem cake extract @ 5.0 %, *Lantana camera* leaf extract @ 5.0 %, *Pongamia glabra* leaf extract @ 5.0 %, *Calotropis gigantea* leaf extract @ 5.0 %, neem oil @ 2.0 %, Nimbecidine @ 2 mL/L, *Prosopis juliflora* leaf extract @ 5.0 %, *Vitex negundo* leaf extract @ 5.0 %, and garlic (*Allium sativum*) extract @ 5.0%) against *Leucinodes orbonalis* in brinjal and carbaryl (Sevin 50 WP) was used as a standard check. The consistent reduction of shoot damage was recorded in neem oil and Nimbecidine with 57.29 % and 52.67 % respectively and the *P. glabra* leaf extract shown 42.90 per cent reduction of shoot damage in *rabi* season. The maximum reduction of fruit damage was observed in the treatment of neem oil and Nimbecidine with 60.06 and 56.38 per cent while leaf extract of pongamia caused 40.86% fruit damage reduction over control.

In the laboratory experiment conducted by Rahman *et al.* (2009), the larval survivability of brinjal shoot and fruit borer, *Leucinodes orbonalis* was effectively reduced by three botanicals including pongamia oil at three different concentrations (2, 3 and 4%). Among different concentrations, 4 per cent of neem oil showed lowest (26.67%) larval survivability which is significantly superior over others, the next best treatment is karanj oil @ 4% with 38.90% larval survivability while mahogany oil @ 2% recorded highest larval survivability (68.68%). He also investigated the effectiveness of neem, karanj and mahogani at 4% each, (4% + 250 kg/ha) and neem cake (250 kg/ha) against BFSB in the field. The maximum reduction of per cent shoot infestation was recorded in the treatment of neem oil + neem cake (70.44%) followed by neem oil @ 4% (63.78%) and karanj oil @ 4% (44.18%). The similar trend was reported in case of fruit infestation also.

Adiroubane and Raghuraman (2008) studied the efficacy of plant products along with some microbial and chemical insecticides on FSB. He observed that the high reduction of shoot damage was recorded in the treatment of Oxymatrine 1.2 EC @ 0.2 % (89.02%) followed by Spinosad 45 SC @ 225g a.i./ ha (87.02 %) and Carbaryl 50 WP (79.67 %). The use of iluppai plus pongamia oil combination (1+1) @ 2% and pongamia oil 2% recorded 76.5% and 62.2% shoot damage reduction respectively. The highest per cent reduction of fruit damage reported in Spinosad (90.71%) followed by oxymatrine (88.49) and carbaryl + wettable sulphur (78.71) with per cent fruit damage of 5.07, 6.28, and 11.62% respectively. Among the plant products, the per cent reduction of fruit damage recorded by pongamia oil (69. 04%) was superior over other botanicals like iluppai + pongamia oil 2% (67.94%), NSKE (66.75%), and 62.04%.

2.2. EFFICACY OF PONGAMIA FOR THE MANAGEMENT OF IMPORTANT SUCKING PESTS

Bhavyasree (2019) conducted an experiment to develop a ready to use oil-based formulation of *Andrographis paniculata*, to study the shelf life and also to fix the optimum dose for managing the sucking pest complex. Both laboratory and field experiment were conducted by on chilli against mites, thrips and aphids. In the laboratory study, different concentrations (5, 10 and 20%) of the different oil-based combinations (neem, pongamia and castor oils) were tested. The study revealed that among the different combinations, extract of *A. paniculata* + pongamia oil + Triton X-

100 (surfactant) and *A. paniculata* + neem oil + Triton X-100 at 5% concentration showed 100 per cent mortality of aphids @ 24 h of treatment and it was on par with *A. paniculata* + castor oil + Triton X-100 @ 5%. The same was reported in thrips and mites also. In a pot culture experiment (field study), 5% extract of *A. paniculata* + pongamia oil + Triton X- 100 showed lowest population of thrips, aphids and mites. Pongamia based formulation @ 5% had low aphid population (0.33 aphids/leaf) and recorded highest per cent population reduction of thrips (98.97%) and mites (90.16%).

The insecticidal activity of plant oils *viz.*, pongamia oil, castor oil, sesame oil, neem oil and neem-based formulations were evaluated by Kumar *et al.* (2019) against whitefly (*Bemisia tabaci*) on cotton under both field and laboratory condition. Pongamia oil @ 1% showed 58.4 & 51.7 per cent reduction in population in laboratory condition after 72 hours of treatment. Field investigation caused 44.9 and 39.2 per cent reduction in the population at seven days of the spray.

Sajay (2019) carried out both laboratory and field evaluation of pongamia oil soap @ 0.6%, 1% and 2% against major pests of cowpea during rabi and summer season 2019 at College of Agriculture, Padannakkad. He observed that the pongamia oil soap @ 2% was found to be significantly superior over all the treatments which recorded maximum aphid (*Aphis craccivora*) population reduction and the pod bug population was also effectively reduced at 7 days after second and third spray. Laboratory experiment showed 100 per cent mortality of aphids after 2, 4 and 12 hours of treatment by pongamia soap 2%, 1% and 0.6% respectively.

In the laboratory bioassay conducted on bhindi by Thomas (2019), 100% mortality of leafhopper (*Amrasca biguttula biguttula*) was recorded after 16 and 24 h of treatment by pongamia oil soap @ 2 and 0.6% respectively. The field efficacy of pongamia oil soap was also superior which showed significant population reduction.

Bopache *et al*. (2018) conducted a study to investigate the efficacy of biopesticides such as Neem Seed Kernel Extract @ 5%, *Metarrhizium anisopliae* @ 1 x 10^8 cfu/mL, *Verticillium lecanii* @ 1 x 10^8 cfu/mL, Hingenbet fruit extract @ 5 %, karanj oil @ 1 % and Ritha fruit extract @ 5 % on safflower aphid, *Uroleucon* *compositae* and indicated that aphid infestation was hindered by *M. anisopliae* (27.92/5 cm apical twig) which was the most effective treatment and *V. Lecanii* (29.11) was at par with it. Next best treatment was NSKE (32.03) which was on par with karanj oil (32.78) and other remaining treatments.

The field experiment was conducted on brinjal sucking pests by Dehariya *et al.* (2018) to evaluate the performance of five plant derived products including NSKE 5%, neem oil 1%, Achook 0.5%, pongamia oil 1% and eucalyptus oil 1% and triazophos 40 EC (0.04 %) was taken as standard check. The results disclosed that triazophos achieved maximum aphid population reduction with mean aphid population of 7.00/15 leaves, from botanicals, neem oil recorded 13.00/15 leaves which was at par with pongamia oil (13.50/15 leaves) followed by NSKE (16.00/15 leaves) and Achook (21.00/ 15 leaves). In case of jassid population reduction, neem oil was found to be superior among botanicals (13.25/15 leaves) followed by pongamia oil (14.25), NSKP (14.5/15 leaves), eucalyptus oil (15.25 /15 leaves) and Achook (17 /15 leaves). After triazophos (24.76q/ha), neem oil treated plots recorded highest yield (20.54q/ha) followed by eucalyptus oil (19.57q/ha) and pongamia oil (17.81q/ha).

Bharathi and Muthukrishnan (2017) evaluated various botanicals including NSKE 5%, PSKE 5%, MSKE (Mahua Seed Kernel Extract) 5%, neem oil 3%, pongamia oil 3%, mahua oil 3% and fish oil rosin soap 25g/L against cotton mealy bug (*Phenacoccus solenopsis*) by both laboratory and field experiments. The results indicated that treatment of FORS, neem oil, NSKE, pongamia oil and PSKE caused 94.3, 75.7, 72.9, 58.6 and 45.7 per cent mortality of mealy bugs in laboratory study. The preliminary and confirmatory field trials also followed the same order of efficiency with 5.5, 7.5, 9.3, 11.5, 13.6 and 5.9, 7.4, 8.0, 11.5, 12.2 adults/crawlers population per 5 cm apical shoot and the respective per cent reductions were 85.3, 79.8, 74.9, 69.2, 63.6 and 84.0, 79.8, 78.2, 68.7, 66.9.

Sridhar *et al.* (2017) carried out an experiment to study the effectiveness of biopesticides (neem, pongamia and fish oils) and insecticides (spinosad, imidacloprid and fipronil) each alone and in combination against whitefly, *Bemisia tabaci* under poly house conditions on tomato. Insecticides *viz.*, spinosad, imidacloprid and fipronil were recorded 84.55, 84.17 and 79.39% mortality respectively. Neem/pongamia/fish oils when used together @ 3mL/L each, resulted in 75 per cent mortality. Up to 48.75% mortality was reported when used oils alone. Synergistic activity of all oils with different insecticides was also tried against whitefly and highest synergistic activity was observed with neem oil followed by fish and pongamia oil. About 16% additional mortality was observed when these oils used in combination with insecticides and as much as 92.31% mortality recorded by neem oil plus spinosad combination.

A laboratory experiment was carried out by Tran *et al*. (2016) for evaluating the efficacy of pongamia leaf extract in the management of turnip aphid, *Lipaphis pseudobrassicae*. The study revealed that acute toxicity was shown by pongamia leaf extract with LC_{50} values of 0.585%, 0.15% and 0.113% after 24, 48 and 72 h, respectively. The study also revealed that at low concentration, pongamia showed nonlethal chronic toxicity by significantly reducing the vitality and fertility in the subsequent generations thereby it affected the overall pest numbers indirectly.

According to Ghosh (2015), methanolic fruit extract of *Pongamia pinnata* @ 1% and 5% recorded 49.57 and 29.32 per cent mean population reduction of aphids (*Myzus persicae* and *Aphis gossypii*) on potato and also 200.33 and 203.66q/ha tuber yield respectively while imidacloprid (Confidor 17.8 S.L.) @ 1 mL/5L recorded 83.16% mean population reduction and 216.23q/ha tuber yield respectively().

Ghosh and Chakraborty (2015) carried out the field evaluations to investigate the effectiveness of plant extracts and microbial insecticides like *Polygonum hydropiper*, *Pongamia pinnata*, spinosad 45 SC (*Saccharopolyspora spinosa*) and *Beauveria bassiana* on bhindi leafhopper (*Amrasca biguttula biguttula*). The study indicated that imidacloprid found to be more effective for jassid followed by spinosad. The experiment also revealed that plant extracts of *Polygonum* and *Pongamia* at 7% concentration gave more than 50% mortality of the pest and the respective yields were 37.23 and 36.98q/ha.

Netram (2015) tested the bio efficacy of some synthetic chemicals and biopesticides including Hinganbet fruit extract (5%), NSKE (5%), Karanj oil (1%) and Ritha fruit extract (5%) along with $1x10^8$ cfu/mL of *M. anisopliae* and *V. lecanii* against safflower aphid, *Uroleucon compositae*. He reported that Thiamethoxam (7.08/twig) found to be best treatment among chemicals, whereas in botanicals the overall field efficacy was higher in *M. anisopliae* (17.93) followed by *V. lecanii* (19.02), NSKE (26.10), Hinganbet extract (27.46), Karanj oil (28.34) and Ritha fruit extract (29.81).

Sridharan *et al*. (2015) studied the bio efficacy of the mineral oils alone and in combination with neem and pongamia oil @ 1 and 2% each against whitefly, *Bemisia tabaci* on okra with the help of pot culture and laboratory experiment. 95.00 and 93.33% mortality of leafhoppers was recorded by 2% mineral + neem oil and mineral + pongamia oil respectively after 48 h of treatment application whereas 91.11% mortality caused by 2% mineral oil alone under lab study. About 81.83 and 81.53% whitefly mean population reduction was recorded by 2% mineral + neem oil and mineral + pongamia oil respectively in pot culture study.

Hittalamani (2014) evaluated 7 biopesticides including neem oil 3%, pongamia oil 3%, dashaparni 5%, *Vinca rosea* leaf extract 5%, cow urine 10%, *Calotropis* leaf extract 5% and chilli + garlic extract 5% against mulberry thrips (*Pseudodendrothrips mori*) with the aim of reducing the waiting period (up to 15 days) of mulberry leaves to be used for silkworms. The treatment of dichlorvos 0.02% significantly reduced the thrips population to 11.19 thrips per top 3 leaves while pongamia oil 3% showed 12.04 with the waiting period of 9 days.

Stepanycheva *et al*. (2014) tested the efficacy of different formulations of pongamia oil at different concentrations (0.375, 0.75, 1.5 and 3%) against green peach aphid (*Myzus persicae*) and he proved that almost all the formulations at high concentration (3%) resulted in above 90% mortality of aphids, especially the PO emulsified with Tween 85 (1:9 ratio) showed maximum population reduction of both nymphs and adults and rest of the treatments were on par with tween 85 emulsified PO treatment except Pongam + *Sapindus saponaria* extract.

According to Basavaraju *et al.* (2013), neem and pongamia oil @ 3% showed significant reduction of mealy bug, *Dysmicoccus brevipes* population in arecanut with 1.07 and 1.13 mealybugs per nut which was significantly lower population than untreated control (4.53/nut).

Gundappa *et al*. (2013) carried out an field experiment to test the efficacy of certain botanicals and insecticides *viz*., neem soap @ 10g/L, neem guard @ 5g/L, triazophos @ 1.5mL/L, lambda – cyhalothrin @ 0.5 mL/ L, dichlorvos @ 1 mL/ L, pongamia oil @ 10g/L, pongamia soap @ 10 g/L and dichlorvos + PO on spiralling whitefly, *Aleurodicus disperses* in guava. Neem guard, neem soap and dichlorvos with pongamia were found to be significantly superior in reducing pupal population over other treatments on a day after treatment whereas neem guard was effective in reducing both nymphal and adult population.

Various insecticidal and botanical formulations were investigated by Kaur and Singh (2013) against sucking pests (thrips, aphids and yellow mite) of capsicum at PAU, Ludhiana including Decis 2.8 EC (deltamethrin) @ 0.025 and 0.05 %, Confidor 17.8 SL (imidacloprid) @ 0.025 % and 0.05%, Asataf 75 SP (Acephate) @ 0.05 % and 0.10%, neem soap @ 1.0% and pongamia soap @ 1.0%. The study disclosed that the pooled mean population reduction of aphids, thrips and yellow mites was significantly lower in neem and pongamia soap treated plants which recorded 0.76 and 0.87 aphids/3cluster/plant. Also observed that neem and pongamia soaps recorded low mean rating of thrips and yellow mite with 0.90 and 1.20 and 2.45 and 2.85 respectively.

Three sprays (at new flush, panicle emergence and nut, fruit developmental stages) of biopesticides (pongamia oil, neem oil, NSKE, PSKE and *B. bassiana*) and chemicals were done in cashew to study the effect against TMB-tea mosquito bug (*Helopeltis antonii*) by Naik and Chakravarthy (2013). Though the other botanicals were not much effective when applied solely, PSKE (Pongamia Seed Kernel Extract) @ 2% found to be effective in combating the peril which showed 7.50, 12.13 and 1.90 per cent TMB damage after 30 days of treatment followed by pongamia oil @ 2% with

9.64, 15.13 and 2.56 per cent damage at the time of new flush, panicle and nut & fruit development stages respectively.

Shrinivas (2013) conducted a field experiment to evaluate the performance of some plant products namely, neemazal-T/S 1.0 EC (0.2%), margosom 0.15 EC (0.3%), NSKE (5.0%), neem oil (1.0%), *M. anisopliae* (0.1%), pongamia oil (1.0%), *Beauveria bassiana* (0.5%), fish oil rosin soap (1.0%) and *V. lecanii* (0.5%) against sucking pests of brinjal and revealed that pongamia oil treated plot reduced aphid population to 11.45 aphids/plant while the control plot recorded an average of 25.06 aphids/plant. The pongamia oil treated plot showed average survival population of 6.38 jassids/plant while the untreated plot recorded 16.00 jassids/plant. The average survival population of whitefly in the pongamia oil treated plot was 4.69 whiteflies/plant while the control plot showed 15.77 whiteflies/ plant.

Sakthivel *et al.* (2012) tested the efficiency of sole and combination application of some botanicals *viz.*, neem oil (3%), pongamia oil (3%), NSKE 5% and Fish Oil Rosin Soap (2%) along with DDVP 76 EC (0.076%) as standard check on mulberry jassid (*Empoasca flavescens*). Neem oil, FORS and pongamia oil showed 48.73%, 46.88% and 42.49% population reduction respectively when applied solely. When applied in combination, the synergistic effect of botanicals increased the effectiveness to 72.64%, 62.81% and 60.16% for neem oil and FORS, pongamia oil + FORS and neem oil + pongamia oil respectivelys.

Nine biocides *viz.*, Vanguard (azadirachtin 0.15%), Gronim (azadirachtin 0.30%), NeemAzal (azadirachtin 1%), NSKE 5%, neem oil 0.3%, pongamia oil 0.3% , mahua oil 5%, *Verticillium lecanii* 2 x 10^8 cfu/g and *Metarrhizium anisopliae* @ 1 x 10^8 cfu/g were studied for the management of sucking pests of cluster bean by Pachundkar (2011). The treatment of NSKE recorded low jassid (*Empoasca kerri*) population (1.53/3 leaves) and it was at par with Gronim (1.64) & Vanguard (1.71) and next best treatments were pongamia and mahua oils. NSKE itself showed higher effectiveness against whitefly, *Bemisia tabaci* (2.19/3 leaves) which was on par with

Gronim (2.39) & Vanguard (2.46) and NeemAzal, mahua and pongamia oil resulted 3.15, 3.19 and 3.19 whiteflies respectively. NSKE stood best in the control of thrips, *Megalurothrips distalis* (2.60 thrips/3 leaves) which was on par with Gronim, Vanguard, NeemAzal and pongamia (1.83).

Vinodhini and Malaikozhundan (2011) carried out a field experiment to study the effect of certain botanicals including NSKE (50mL/L), neem oil (3mL/L), pongamia oil (3mL/L) and pongamia seed kernel extract (PSKE) (50mL/L) along with standard check Rogor 30 EC @ 2mL/L for controlling sucking pests of cotton. Rogor 30 EC recorded high population reduction of leafhoppers (*Amrasca devastans*) with 70.30 per cent leafhoppers and the botanicals were showed 43.99, 42.27, 40.57 and 35.51 per cent population reduction by NSKE, PSKE, neem oil and pongamia oil at 24 h after treatment. For aphid population reduction also, the same trend was observed with 35.26, 34.85, 28.10 and 25.35 per cent reduction.

Cholla (2009) studied the potential of certain organic fertilizers and botanicals on important brinjal pests and reported that neemgold (azadirachtin) 5 mL/L and NSKE 5% produced least overall mean population of leafhopper with 14.73 and 15.77 leafhoppers while pongamia leaf extract at 5% reported 16.78 leafhoppers. Again, neemgold and NSKE found to be effective against whitefly also which recorded least mean population of 66.00 and 66.28 whiteflies per 5 leaves and next best treatments were pongamia leaf extract (75.17) and *Annona squamosa* (75.56).

Pavela (2009) carried out a greenhouse experiment to evaluate the efficiency of botanical insecticides such as neem, pongamia and pyrethrum extract at 0.5, 1, and 3% against *Myzus persicae* and reported that higher concentration (3%) of all botanicals caused 100 per cent mortality of *M. persicae* after twelve days of treatment. The experiment also reported that the lower concentrations (0.5 and 1%) of pongamia oil achieved 96% to 97% and 76% to 82% mortality of aphids after 12 days of application while neem oil @ 0.5% was the lowest efficient concentration.

According to Ramanna (2009), neem oil @ 5mL/L, Nimbecidine @ 3 mL/L pongamia oil 4 mL/L, NSKE 5%, GCKE (garlic chilli kerosene extract) 5% and *Verticillium lecanii* @ 1.6 x 10^8 cfu/mL 2g/L were effective on the major pests of Ashwagandha. The standard check malathion 50EC @ 2 mL/L reported to be the best treatment followed by *Verticillium lecanii* recorded lowest number of aphids with 0.89 aphids/leaf which was on par with GCKE, NSKE, pongamia oil, nimbecidine and neem oil recording 1.05, 1.50, 1.72, 1.77 and 1.77 aphids. In case of mite population reduction, the order of efficacy of organic products is *Verticillium lecanii* (2.11 mites/leaf), neem oil (4.17), nimbecidine (4.77), GCKE (5.33), NSKE (6.50) and pongamia oil (7.60).

Ravikumar (2009) carried out laboratory and field experiment to evaluate some selected biopesticide in the form of cakes and oils on cowpea (*Vigna unguiculata*) pests and also to study their influence on growth, development, yield and quality. Seed treatment with oil (3 mL/kg) and cake (100 g/kg) of neem, pongamia, castor, mahua, garlic and jatropha along with gouch (imidacloprid) @ 3 g/kg were less aphid incidence. Among the different botanical cakes and oils, garlic paste and oil recorded minimum number of aphids with 20.00 and 20.00% aphid population respectively and pongamia cake and oil showed 26.67 and 40.00%.

Anitha and Nandihalli (2008) studied the impact of biopesticides and mycopathogens against sucking pests of bhindi. Among the different botanicals and mycopathogens tested, neem oil 2% caused minimum leafhopper population with 1.13 leafhoppers/3 leaves which is followed by pongamia oil 2% caused 1.53 leafhoppers, azadirachtin (1.60 leaf hoppers) and *V. negundo* (1.90 leafhoppers) while oxydemeton methyl recorded 0.91 leafhoppers after 1 day of treatment. The aphid population was effectively reduced by standard check (1.60 aphids/3 leaves) which was on par with NSKE 5% (2.06) followed by neem oil, azadirachtin 1mL/L, pongamia oil, *V. negundo* leaf extract, *V. lecanii* 1g/L and *M. anisopliae* 1g/L with 3.11, 3.39, 3.95, 4.12, 4.97 and 5.11 aphids per 3 leaves on one day after first spray. Out of seven biopesticides, NSKE found to be the economical treatment with net return of Rs. 6,418/ha and C:B ratio of 1:8.56 and oxydemeton gave C:B ratio of 1:8.37.

According to Kumar *et al.* (2007), Methanic extract of neem (NSOME) and methanic extract pongamia oil (PSOME) when tested against chrysanthemum aphid, *Macrosiphoniella sanborni* solely and in combination, 100 per cent mortality was reported in combined formulation of NSOME and PSOME after 48 h of treatment. The study also indicated that sole application of NSOME and PSOME recorded 68.4 and 52.9 per cent population reduction respectively.

Patidar (2007) carried out a field experiment to test various botanicals on the safflower aphids, *Uroleucon compositae* and revealed that NSKE 5% showed minimum aphid population with 912.92 aphids / 5 cm apical twig). The nest best treatments were neem oil 1% (22.36 aphids) and pongamia oil 0.5% (23.69 aphids) while the control plot reported 36.70 aphids.

Pongamia oil suspension @ 0.5, 1, 2% were tested in Chrysanthemum plants to manage greenhouse whitefly (*Trialeurodus vaporariarum*) by Pavela and Herda (2007). All the three concentrations tested showed feeding deterrence and oviposition repellence by lowering the adult and egg numbers. The efficacy was declining over time and concentration and the effect lasted for 12 days of application.

Dhurua (1998) tested the karanj (pongamia) oil @ 2% along with other biopesticides *viz.*, neem oil, neem cake, mahua oil, cow urine, vermi spray, *Bt*, jatropha leaf extract and garlic oil on brinjal pests. All the treatments proved to be significantly superior over untreated control. Neem cake and neem oil recorded reduction of leafhoppers and whiteflies with 28.61 and 32.63%, while Karanj oil recorded 28.14 and 26.10% of leafhopper and whitefly population reduction over control.

Jothi *et al.* (1990) evaluated the potential of oils and extracts of neem, mahua and pongamia on the citrus aphid (*Toxoptera citricidus*). Based on the efficacy and profit, the best treatments recommended in descending order are mahua oil 1%>pongamia oil 1%>neem seed extract 2%>pongamia seed extract 2% and all the treatments were recommended when the new flush is emerging.

2.3. EFFICACY OF PONGAMIA FOR THE MANAGEMENT OF EPILACHNA BEETLE

Ghosh and Chakraborty (2012) used the methanol extracts of *Pongamia* seeds (1 and 5%) in the management of *Epilachna* beetle in potato along with other biopesticides such as tobacco leaf extracts (5 and 10%), azadirachtin (1500 ppm) and *Beauveria bassiana* (10^7 conidia/mL). The cartap hydrochloride (50% SP) gave the best suppression of beetle population (64.53%) and out of five botanical treatments, 62.91% and 53.50% population reduction were achieved by azadirachtin and *Pongamia* seed extract @ 5% after 4 days of spray.

Swaminathan *et al*. (2010) conducted a laboratory investigation of anti-feedant activity of some biopesticides such as *Pongamia glabra* seed oil; *Azadirachta indica* (neem) leaf extract, seed kernel extract, and seed oil; *Madhuca latifolia* (Macbeth) oil and two fungal origin biopesticides, *i.e*., conidia of *Metarhizium anisopliae* and the enzyme preparation of the fungus, *Myrothecium verrucaria* against the adult *H. vigintioctopunctata* using leaf discs of *Withania somnifera* (L.) Dunal. The maximum anti-feedant activity was shown by *P. glabra* oil at the concentration of 0.625, 1.25, 2.5 and 5%. No feeding was observed up to 24 and 48 hours after treatment, after 72 hours mortality was noticed and 100 per cent mortality was observed in all the concentrations of *Pongamia* at 7 days of spray. Neem oil was the next best treatment which showed 60% mortality @ 5% concentration.

According to Cholla (2009), the leaf extract of *Pongamia glabra* (5%) caused reduction of mean population of spotted leaf beetle, *Epilachna vigintioctopunctata* to 9.11 when tested on brinjal while NSKE 5%, *Annona squamosa* 5% leaf extract, *Murraya koenigi* 5% leaf extract, Neemgold (Azadirachtin) 5 mL/L and Chilli-Garlic 5% extract reduced the *Epilachna* population to 8.11, 9.32, 10.15, 7.72 and 10.40 respectively.

Murugesan and Murugesh (2008) evaluated the efficacy of ten botanicals against *E. vigintioctopunctata viz., Azadirachta indica* (Neem) leaf extract (@ 5.0 %), *Lantana camera* leaf extract @ 5.0 %, *Calotropis gigantea* leaf extract @ 5.0 %, neem oil @ 2.0 %, neem cake extract @ 5.0 %, Nimbecidine @ 2 mL /L, *Pongamia glabra*

(Pungam) leaf extract @ 5.0 %, *Prosopis juliflora* leaf extract @ 5.0 %, *Allium sativum* (Garlic) extract (@ 5.0 % and *Vitex negundo* (Notchi) leaf extract (@ 5.0 %) revealed that the plant products were brought higher population reduction of *Epilachna* from 87.86 to 71.97 per cent on third day after spray. The superior per cent population reduction was recorded in neem oil (87.86) which was on par with *C. gigantea* (86.77), Nimbecidine (85.52) and *L. camera* (85.19); *P. glabra* (81.68), neem cake extract (80.97) and *V. negundo* extract (78.48) were the next best treatments but all were inferior when compared to standard check carbaryl 50 WP (100.00).

Reddy *et al.* (1990) conducted a field experiments on brinjal to evaluate the efficacy of *A. indica*, *Eucalyptus globulus*, *P. pinnata*, *C. gigantea*, *A. squamosa* and *L. camara* by 1% petroleum ether extracts for the control of *E. vigintioctopunctata*. The most effective treatments were those obtained from *A. indica* and *A. squamosa* which reduced the number of larvae by 88.0 and 92.99, and 85.98 and 91.02% respectively after 24 hours and 3 days after spraying. The efficacy was followed by *L. camara*, *P. pinnata*, *C. gigantea* and *E. globulus*.

2.4. EFFICACY OF PONGAMIA PRODUCTS FOR THE MANAGEMENT OF MITES

In vitro evaluation of methanolic seed and leaf extracts of karanj was carried out by Jangra *et al*. (2019) at different concentrations (10.0, 7.5, 5.0, 2.5, 1.25, 0.75 and 0.37%) against chilli mite, *Polyphagotarsonemus latus*. The highest mortality of mite population and lowest number of live mites were observed in highest concentration tested (10.0%) with 3.27 and 3.61 live mites respectively in seed and leaf extracts of pongamia and followed by 7.5, 5.0, 2.5, 1.25% concentration than 0.75 and 0.37%. The per cent mortality of mites at 10% seed and leaf extracts were 67.27 and 63.89 respectively.

Sathish *et al*. (2019) evaluated different bio-pesticides against coconut eriophyid mite (*Aceria guerreronis*) by laboratory experiment. Among the tested treatments, *Hirsutella thompsonii* @ 5g/L found to be best treatment which showed highest mortality of mites (58.89%) and the next best treatments in descending order was neem oil @ 20mL/L (51.11%)> *B. bassiana* @ 5g/L (32.68) > *Verticillium lecanii* @ 5g/L (32.55%) > karanj oil @ 20mL/L (32.29%).

According to Arvind *et al*. (2018), various concentrations (0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0%) of methanolic leaf extract of pongamia were effective against *Tyrophagus putrescentia* by direct spray and bioassay methods. Each concentration of bioassay showed significant difference in inhibition of mite population and the higher concentration showed higher efficiency. High reduction of mite population (41.33 - 76.00%) and lower LC_{50} value (0.629 mL/100 mL) was observed in direct spray and the treated bioassay showed 28.00-63.33% population reduction and LC_{50} value recorded was 0.638 mL/100 mL ().

Handique *et al.* (2018) studied the acaricidal property of plant originated oils against tea mite (*Oligonychus coffeae*) in laboratory condition. The results proved that pongamia and nirgundi oil were superior over neem oil and the LC_{50} value of nirgundi, pongamia oil and neem oil were 78.40, 194.20 and 1469.88 ppm.

Roy *et al.* (2018) studied adulticide and ovicidal properties of various botanicals on coffee red spider mite, *Oligonychus coffeae.* Karanj oil treated plots showed lowest LC_{50} value of 117.24 ppm for adults which is followed by mustard and olive oil with 360.04 and 345.70 ppm respectively. After rose oil, karanj and olive oil were best as an ovicidal biocides.

Seasonal incidence and bio-efficacy of certain botanicals and acaricides were evaluated against red spider mite (*Tetranychus urticae*) on okra. The pooled data of two sprays on mite population reduction revealed that abamectin found to be most effective one (74.64%) from acaricides and among the biocides pongamia oil 2 EC (Derrisom) 2 mL/L @ showed maximum population reduction (46.32%) followed by neem oil (42.68%) (Singh *et al*., 2018).

Acaricidal activity of *Beauveria bassiana*, certain plant oils (neem, mahogany and karanj) and insect growth regulators (buprofezin and lufenuron) was evaluated on two-spotted spider mite, *Tetranychus urticae* by Islam *et al*., 2017 under laboratory condition. The results revealed that plant oils of pongamia and mahogany caused high mortality of adult mites which recorded lowest LC_{50} values (0.008 and 0.009) whereas LC_{50} value of neem oil and *Beauveria* was 0.230 and 0.562% after 24 h of treatment application.

Malik *et al.* (2017) tested the effectiveness of leaf powder of *Withania somnifera*, *Pongamia pinnata* and *Azadirachta indica* at different concentrations (0.5, 0.6, 0.7, 1.0 and 2.0%) on *Tyrophagus putrescentiae* on wheat grains under laboratory condition. Protection against mite was 2.3 to 100, 8.2 to 100 and 9.8 to 100% by *P. pinnata* leaf powder at 15, 30 and 45 days after spray respectively while *A. indica* leaf powder caused 15.9 to 100, 45.7 to 100 and 33.9 to 100 per cent protection.

Certain botanical insecticides (Multineem, Nimbecidine, Neemazal, pongamia oil and Neemguard) when tested to know the acaricidal action against yellow mite (*Polyphagotarsonemus latus*), foliar spray of neem oil found to be highly effective which showed 71.50% mortality with maximum yield of 96.80q/ha whereas pongamia oil @ 5 mL/L recorded 68.50% mortality and yield was 92.40q/ha (Prasad *et al.*, 2017).

An *in-vitro* screening of some plant products and oils was carried out on two spotted spider mite, *Tetranychus urticae* by Raghavendra *et al.* (2017) and reported that propargite 57 EC @ 2.00mL/L (standard check) in terms of adult mortality (84.63%) and egg reduction (81.82%) however pongamia oil at 5 and 3% recorded 69.94 and 69.72% adult mortality and 63.53 and 62.98% egg reduction in *T. urticae* respectively.

According to Veena *et al.* (2017), out of 24 treatments consisting botanicals and chemical insecticides alone and in combination, castor oil found to be best plant oil to increase the efficiency of chemicals (synergistic action) and castor oil + dicofol gave the high adult mortality (56.67, 70, 83 and 93.33% at 24, 48, 72 and 96 HAT respectively) whereas pongamia oil + dicofol showed 33.33, 53.33, 53.33 and 63.33% mortality @ 24, 48, 72 and 96 HAT respectively.

Rahman *et al.* (2016) reported the acaricidal action of three plant oils *viz.*, mahogany, neem and karanj oils and one microbial derivative insecticide ambush (abamectin 1.8 EC) on chilli mite (*Polyphagotarsonemes latus*). Abamectin resulted in 80.25% mite population reduction whereas, neem, mahogany and karanj oils recorded 60.55, 55.89 and 35.00 per cent reduction after 10 days of treatment.

Raina (2016) tested the potential of pongamia oil 2 EC @ 2mL/L on pests of cowpea, *Vigna unguiculata* with special reference to bean mite (*Tetranychus ludeni*) along with chemicals such as spiromesifen fenpyroximate, chlorfenapyr, propargite, abamectin, dimethoate, dicofol and imidacloprid by two sprays. He reported that abamectin 1.8 EC @ 0.6mL/L was the best treatment which caused 70.32% of population reduction of bean mite after 14 days of first spray followed by spiromesifen 1mL/L causing 60.43% and fenpyroximate 5 EC @ 2.5mL/L caused 58.68% reduction, on the other hand pongamia oil resulted in 49.58% reduction in bean mite population.

Root feeding of biological pesticides (karanj, neem and castor) were evaluated for their efficacy solely and in combination with each other against coconut mite, *Aceria guerreronis* by Das *et al*. (2015). The best results obtained by karanja + neem + mahogany oil combination at 1:1:1 ratio with 96% mite population reduction from 3 days to 6 months of application and the sole application gave less efficacy.

Ghosh and Chakraborty (2014) carried out an experiment in the view of finding efficiency of 1 botanical insecticide azadirachtin i.e. neem (neemactin 0.15 EC) @ 2.5 mL/L, and 4 botanical extracts, tulsi (*Ocimum tenuiflorum*) leaf extract @ 5.0%, *Pongamia pinnata* fruit extracts @ 10.0%, *Polygonum hydropiper* floral part extract @ 10.0% and garlic (*Allium sativum*) extract @ 5.0%, and one combination treatment of neem and dicofol (@ 2.5 mL + 1 mL/L and compared with dicofol (kelthane 18.50 EC) @ 3mL/L in brinjal against mite (*Tetranychus* sp.). After dicofol (83.16%), Neem + dicofol gave best suppression of the mite population (71.41%) while pongamia fruit extract caused 33.49% population suppression with 25.55 t/ha yield.

An experiment carried out to evaluate the acaricidal activity *Morinda tinctoria*, *Vitex negundo*, *Pongamia glabra*, *Gliricidia maculata* and *Wedelia chinensis* aqueous leaf extracts (@ 2.5, 5 and 7%) on red spider mite (*Oligonychus coffeae*) by Vasanthakumar *et al*. (2012). The best treatments were *M. tinctoria* and *P. glabra* which recorded maximum oviposition repellence, ovicidal action and 100% mortality of adults after 72 h of treatment application.

Roobakkumar *et al*. (2010) carried out a laboratory experiment with pongam kernel aqueous extract (PKAE) @ 5%, neem kernel aqueous extract (NKAE) @ 5%, garlic aqueous extract (GAE) @ 5% Derrimax @ 0.25 mL/L and propargite @ 1.1 mL/L to study the potential on tea red spider mite (*Oligonychus coffeae*). Among the tested treatments, Derrimax and NKAE showed more than 90% egg mortality and PKAE and GAE resulted in more than 70 and 50 per cent mortality respectively. Except NKAE, all other treatments showed 100 per cent adult mortality after 72 h of treatment.

According to Pavela (2009), Pongamia, neem and pyrethrum each @ 0.5, 1 and 3% concentrations were lethal on *Tetranychus urticae* under greenhouse condition. Pongamia oil at 1 and 3 per cent resulted in 100% mortality of mites after 12 days of application while 0.5% pongamia oil caused 92.1% mortality at 7 days after treatment.

Methanolic extracts of neem and karanj oil were tested alone and in combination for the synergistic action on *Tetranychus* sp. by Kumar *et al*. (2007). Because of synergistic activity, combined formulation of NSOME and PSOME found to be highly effective with lowest LC_{50} value (0.11%) and the activity increased to 70 and 11.36 times higher over NSOME (7.7%) and PSOME (1.25%) in laboratory environment. During field experiment in *Withania somnifera*, combined formulation gave more than 90% protection at 0.25% whereas, 78.6 and 71.9% protection was obtained by PSOME and NSOME @ 1%.

Among six IPM modules evaluated against yellow mite, *Polyphagotarsonemes latus* on sweet pepper of protected environment, module 1 (abamectin-ethion-abamectin) and module 2 (abamectin-profenophos-abamectin) were the first two effective modules (3.91-6.58 mites/leaf) followed by module 3 (dicofol-pongamia-NSKE) with 5.79 -6.95 mites/leaf from the first 2 trials (Reddy and Kumar, 2006a).

Reddy and Kumar (2006b) evaluated different IPM modules to find out the best module for the management of *Tetranychus urticae* infesting tomato cultivated under protected environment. IPM module II (abamectin-wettable sulphur-abamectin) was most effective (1.23-2.08 mites/leaf) followed by module I (dicofol - wettable sulphur - dicofol) (4.05-4.23 mites/leaf) and module 3 (dicofol-pongamia oil-neem seed kernel extract) (4.68-4.80 mites/leaf).

2.5. EFFECT OF PONGAMAI ON NATURAL ENEMIES AND CROP PLANTS

The insecticidal and phytotoxicity activity of certain plant originated products (neem oil, sesamum oil, castor oil, pongamia oil and NSKE) was tested by Kumar *et al*. (2019) under laboratory and field conditions. The general predators like spiders and lacewings were at good population in all the plant products treated plots and found to be safe. The castor, sesame and pongamia crude oils were sprayed at two and 5 times of recommended doses resulted in non-phytotoxicity symptoms.

Sakthivel (2019) carried out an experiment to evaluate eco-friendly management of mulberry thrips, *Pseudodendrothrips mori* and their impact on coccinellid population. Two sprays at 10 and 20 days after pruning were done with the following treatments, neem oil (2 sprays), pongamia oil (2 sprays), pongamia oil followed by neem oil, neem oil followed by pongamia oil, pongamia oil followed by water jetting, neem oil followed by water jetting, two sprays of water jetting, dichlorovos followed by water jetting and two spray of dichlorovos. Maximum coccinellid population was observed in 2 times water jetting plots (6.83 coccinellids/plant) after control (7.24 coccinellids/plant) followed by pongamia-water jetting treatment (4.82 coccinellids/plant).

Seven botanicals and standard check spinosad were tested for its effect on natural enemy population of brinjal ecosystem by Sahana and Tayde (2017). Including spinosad, all treatments (NSKE 3%, neem oil 3%, pongamia oil 3%, garlic extract 50mL/L, neem leaf extract 50mL/L and papaya leaf extract 50mL/L) showed uniform coccinellid and spider population with 0.66-1.00/plant and 0.46-0.63/plant respectively.

The study proved that pongamia and other plant products are safe to natural enemy population in brinjal ecosystem.

Netram (2015) conducted an experiment on eco-friendly management safflower aphid (*Uroleucon compositae*) and its impact on coccinellids. The mean population of coccinellid grubs was 4.33, 4.17, 3.62, 3.55, 3.25 and 3.24 per plant respectively from *M. anisopliae, V. lecanii*, Hingenbet fruit extract, NSKE, karanj oil, ritha fruit extract treated plots whereas untreated control and chemical insecticides treated plots recorded 5.48 and 0.49 -3.10 coccinellids. The study indicated that coccinellid population was at safer and good numbers. Karanj oil 1% produced no phytotoxicity symptoms like wilting, necrosis, vein clearing, epinasty and hyponasty.

According to Sridharan *et al.* (2015), mineral + neem oil and mineral + pongamia oil at 2% showed no toxic symptom on egg hatchability and mortality of eggs & grubs of green lacewings (*Chrysoperla carnea*) and also no phytotoxic effect on plants. However, mineral oil application at 7, 10, 15, and 20% produced injury to leaf tips and surfaces with rating of 2.0, 2.0, 3.33, and 6.33 on 30 days plants.

According to Stephanycheva *et al*. (2014), treatment of pongamia oil @ 1% had no negative impact on pollinating insects *viz.*, Hymenopterans (*Apis florea, A. dorsata*) and dipterans (Muscidae and Syrphidae). The study also revealed that pongamia oil at high concentration (3%) did not produce any leaf burns on pepper and beans.

Impact of botanical insecticides on coccinellids and spiders of mulberry ecosystem was tested by Sakthivel *et al.* (2012). When dichlorvos eliminated 90% of spiders and predatory coccinellids, bio-pesticides found to be relatively safer with 20.10, 35.12, 25.12 and 21.18% reduction of coccinellids and 12.57, 24.25, 16.16 and 16.46% reduction of spiders respectively by NSKE (5%), neem oil (3%), pongamia oil (3%) and FORS (2%). The mean population of 5.66 coccinellids and 2.80 spiders per plant was reported in pongamia oil 3% treated plants.

Mukhopadhyay and Santhakumar (2010) tested the biosafety of neem oil, nicotine extract and pongamia oil at various concentrations solely and in combination on beneficial coccinellids *viz.*, *Micraspis discolor*, *M. crocea*, *Brumus suturalis and Scymnus bourdillon* found in mulberry field. High percent mortality of coccinellids was reported by standard check (dimethoate and dichlorvos @ 1%) whereas botanicals (alone and in combinations) *viz.*, pongamia oil (1.5 and 2%), neem oil (1 and 2 %), nicotine extract (1 and 2%), nicotine extract + pongamia oil (1:1) @ 1%, neem oil + pongamia oil (1:1) @ 1% and neem oil + pongamia oil (10:1) @ 10% were proved to be relatively safe to coccinellids. Maximum per cent survival of coccinellids reported by pongamia oil at both concentrations with 11.33 to 28.33% and control recorded 22.00 to 33.66% coccinellid survivability.

Toxicity of certain synthetic insecticides and biopesticides studied by Basappa (2007) on egg parasitoid, *Trichogramma chilonis* coccinellid, and *Cheilomenes sexmaculata*. NSKE 5% recorded highest adult emergence of *T. chilonis* from a day-old sprayed egg with 82.66% followed by neem oil @ 2% (79.33%), pongamia seed extract @ 5% (74.00%), pongamia oil @ 2% (70.66%). The study also indicated that the tested botanicals were safe to *C. sexmaculata* with 8.88 to 22.21% adult mortality, whereas synthetic insecticides showed 42.22 to 84.44 % adult mortality.

Krishnamoorthy and Visalakshi (2007) tested the compatibility of ten pesticides with *Lecanicillium lecanii*, including pongamia oil. Among all the treatments tested, maximum conidial germination (99.3%) and sporulation (47.2×10^6 conidia/mL) were obtained from pongamia oil (2mL/L) because of its positive synergistic activity.

Patidar (2007) recorded the number of bees before and after the treatment of some botanicals during aphid management in safflower. The plots treated with karanj oil 0.5% witnessed 27.2 and 26.4 bees before and after 2 days of application and the chemical insecticides treated plot reported 33.0 and 16.2 bees before and after application.

Materials and methods

3. MATERIALS AND METHODS

This chapter deals with the description of materials used and methodology carried out during proposed investigation of evaluating the potential of pongamia oil soap against major pests of brinjal including fruit and shoot borer, leaf hoppers, Epilachna beetle, aphids, mites, and whiteflies and also its consequences on natural enemies.

3.1. LABORATORY BIOASSAY OF PONGAMIA OIL SOAP

Laboratory bioassay was carried out in the Department of Entomology, College of Agriculture (COA), Padannakkad, Kasaragod during *rabi* season 2019-20. The pongamia oil was obtained from Tamil Nadu Agricultural University, Coimbatore in order to prepare pongamia soap required for the laboratory bioassay and field experiment. The saponification value of the oil (194 mg KOH/g of oil) was estimated in the laboratory of Soil Science and Agricultural Chemistry, COA, Padannakkad to detect the purity of the oil.

3.1.1. Laboratory bioassay

The laboratory experiment was emphasized on evaluating the feeding deterrency and growth retardation potential of pongamia soap by using the grubs of hadda or spotted leaf beetle, *Epilachna dodecastigma* as this is a major pest of brinjal. Feeding deterrency property of pongamia soap was evaluated in the fourth instar larvae of *Epilachna* beetle and growth retardation property was studied in all the four instars. Feeding deterrency index (FDI), growth index (GI) and relative growth index (RGI) were computed by using appropriate formulae. The grubs were exposed to seven treatments with three replications and the data obtained were analysed with the help of completely randomised design (CRD).

3.1.2. Details of laboratory experiment

Crop : Brinjal

Variety : Surya

Design of experiment : CRD (Completely Randomised Design)

No. of treatments : 07

No. of replications : 03

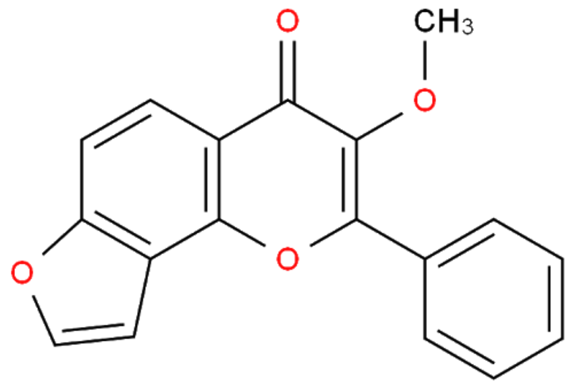
Treatment details : As mentioned in Table 1

Table 1. Treatments details at laboratory level

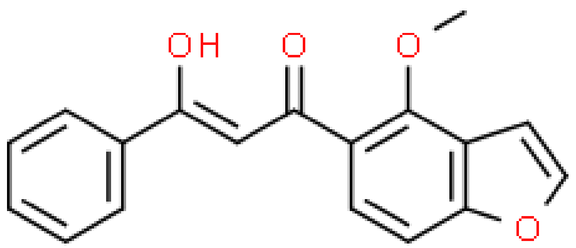
Sl. No.	Treatment details	Concentration/L
T_1	Pongamia oil soap @ 3%	30g
T_2	Pongamia oil soap @ 2%	20g
T_3	Pongamia oil soap @ 1%	10g
T_4	Pongamia oil soap @ 0.6%	6g
T_5	Soap solution @ 0.5%	5g
T_6	Water spray	
T_7	Absolute control	

3.1.3. Pongamia oil soap preparation

Pongamia oil soap was made as per the technology used for the preparation of 'Ready To Use neem oil garlic soap', the first released botanical of Kerala Agricultural University (Varma, 2018). Pongamia oil, soap stone powder and caustic soda were taken at appropriate quantity then properly blended to get pongamia oil soap. pH of the pongamia oil soap solution prepared was determined (10.5) in Soil Science and Agricultural Chemistry lab, COA, Padannakkad with the help of pH meter.



(a) Karanjin (3-methoxy-2-phenylfuro [2, 3-h] chromen-4-one)



(b) Pongamol (1-(4-methoxy-1-benzofuran-5-yl)-3-phenylpropane-1, 3-dione)

Fig. 1. Chemical structure of karanjin and pongamol

(a) Pongamia oil

(b) Pongamia oil soap

Plate 1. Preparation of pongamia oil soap

3.1.4. Collection of eggs

Female Epilachna beetle lay eggs in batches of 5-40 on undersides of leaves, preferably on young leaves. The egg batches were collected along with the leaves from brinjal crop grown in Instructional farm II, Karuvachery, CoA, Padannakkad. The eggs were allowed to hatch and first instar larvae were immediately taken for growth retardation study. To carry out the feeding deterrency study, the uniform larval instars were obtained by rearing larvae on fresh leaves and fourth instar larvae were recognized and separated based on the head capsule width.

3.1.5. Feeding deterrence index

Different concentrations of pongamia oil soap solutions, soap solution 0.5% and brinjal leaf discs of 10 cm diameter were prepared. The leaf discs were dipped in the treatment solutions prepared in order to get uniform coating of solution and then air dried for about 10 minutes. A fourth instar grubs of *Epilachna* with an average weight: 0.02g were starved for 4 h and released into the center of every petri dish of size 140 mm internal diameter x 20 mm height containing the treated leaves. All dishes were lined with moistened filter paper to avoid drying of leaf discs quickly. The petri dishes then kept in a climatic chamber maintained at relative humidity 60 - 70%), temperature 25˚C ± 2˚C and 16L: 8D h. The grubs were allowed to feed for 10 h and removed and the extent of leaf area consumed was calculated using transparent millimeter-square graph paper. The Feeding Deterrency Index (FDI) of pongamia against *Epilachna* was calculated with the help of the formula proposed by Li *et al.* (2014).

$$\textbf{Feeding deterrence index} = \frac{(\mathbf{C-T})\ \mathbf{100}}{(\mathbf{C+T})}$$

where,

C = average consumed area of control leaf disc

T = average consumed area of treated leaf disc

3.1.6 Growth index and relative growth index

Ten-centimetre diameter brinjal leaf discs were cut and uniformly applied with treatment solutions and air dried for 10 minutes. The freshly hatched first instar grubs of *Epilachna* were released at 5 numbers into each petri dish containing treated leaf discs. Growth of grubs observed daily and the leaf discs were changed whenever required. When 95 per cent of the introduced grubs in control dishes underwent pupation, the dead and live grubs present in remaining treatments were checked and separated into appropriate instars (5 including pupa) and then counted. Based on the observations made, Growth index (GI) and Relative growth index (RGI) were computed with the help of following formula developed by Zhang *et al.* (1993).

$$\textbf{Growth index} = \sum_{i=1}^{i_{max}} [n_{(i)} \times i] + \sum_{i=1}^{i_{max}} [n'_i \times (i-1)] \div \text{N x } i_{\text{max}}$$

where,

i is the stage number

$n_{(i)}$ is number of live larvae at i

n'_i is number of dead larvae at i

i_{max} is total number of stages (here stages are 5 including pupa)

N is total number of larvae in the group

After calculating GI of treated and control group, RGI was calculated by the formula mentioned below:

Relative growth index = GI of tested group / GI of control group

3.2. FIELD EXPERIMENT OF PONGAMIA OIL SOAP EVALUATION AGAINST IMPORTANT PESTS OF BRINJAL

The field evaluation of pongamia oil soap was conducted at Instructional farm II, Karuvachery, CoA, Padannakkad during *rabi* season of year 2019-2020 against all the major pests of brinjal.

3.2.1. Details of the field experiment

Design	: Randomized Block Design (RBD)
Treatments	: 08
Replications	: 03
Crop	: Brinjal
Variety	: Surya
Seed rate	: 500g/ha
Spacing	: 60 X 60 cm^2
Area of a single plot	: 3.4 X 2.8m^2
Method of sowing	: Transplanting
Season	: *Rabi* (2019-2020)
Date of sowing	: October 10, 2019
Date of transplanting	: November 19, 2019
Number of sprays	: Three

3.2.2 Details of the treatments imposed

Table 2. Treatments imposed at field level

Sl. No.	Treatment details	Concentration/L
T_1	i) Chlorantraniliprole 18.5 SC (Spray I & III) ii) Thiamethoxam 25 WG (Spray II)	0.3 mL 0.2g
T_2	Pongamia oil soap @ 3%	30g
T_3	Pongamia oil soap @ 2%	20g
T_4	Pongamia oil soap @ 1%	10g
T_5	Pongamia oil soap @ 0.6%	6g
T_6	Neem oil soap @ 0.6%	6g
T_7	Soap solution @ 0.5%	5g
T_8	Control	

3.2.3. Raising of seedlings

Seeds of variety ‘Surya’ was obtained from Department of Olericulture, College of Horticulture, KAU, Thrissur. The seeds were sown in pot trays containing coir pith and perlite growing media and watered regularly at College of Agriculture, Padannakkad. *Pseudomonas fluorescens* @ 2% solution was drenched for the management of damping off in seedlings.

3.2.4. Preparation of experimental field

Thorough ploughing of the land was carried out and land layout was done before transplanting. Individual beds were formed with three trenches in each treatment plot with 15 cm depth. Farm yard manure (FYM) and lime were applied immediately after bed preparation as per the recommendations of Kerala Agricultural University, Package of Practices: Crops 2016 (POP, KAU).

3.2.5. Transplanting and other cultural practices

Thirty-day old seedlings were planted in the furrows prepared at 60 X 60 cm spacing and irrigated. Temporary shade was given for 5 days. Each treatment was replicated three times. A week later, recommended basal dose of fertilizers were applied as per KAU Package of Practices: Crops 2016.

Irrigation was done at 3 days interval throughout the field experiment. The remaining cultural practices including weeding, earthing up and fertilizer applications were carried out as per the recommendations of KAU Package of Practices: Crops 2016 (POP, KAU).

3.2.6. Schedule of treatments

Field experiment contained three rounds of spraying. Treatment applications were started at reproductive stage of the crop after the incidence of fruit and shoot borer and hoppers. First, second and third sprays of pongamia oil soap solution (Table 2) were given at 60, 90 and 140 days after transplanting (DAT) respectively and the

(a) Field ploughing

(b) Beds with ridges and furrows

(c) Crop at 30 DAT

(d) Crop at 45 DAT

(e) Crop at 90 DAT

Plate 2. Experimental field view

sprayer used was 16 L Knapsack sprayer. All the treatments were applied during early morning hours to avoid drift.

3.2.7. Observations on incidence of different pests

Randomly selected five represented plants were tagged for taking observations from each treatment plot. Observations were made on one day before treatment application (DBT) and 1, 3, 5, 7 and 14 days after treatment application (DAT) for counting sucking pests (leafhoppers, aphids, whiteflies and mites) and natural enemies. Observations on damage symptoms caused by fruit and shoot borer and Epilachna beetle were recorded at 1 DBT and 7 and 14 DAT.

3.2.7.1 Observation method for brinjal fruit and shoot borer (Leucinodes orbonalis) and Epilachna damage

Shoot infestation by fruit and shoot borer was negligible so observations on shoot infestation was not made. Fruit infestation by FSB was recorded by counting number of fruits damaged and the total number of fruits present in the tagged plants. Leaf damage by hadda beetle was recorded as number of damaged leaves and total number of leaves present. The observation was taken on 1 DBT and 7 and 14 DAT from each treatment plot. The per cent fruit infestation and leaf infestation were calculated with the following formulae,

Per cent fruit damage = (No. of damaged fruits ÷ Total no. of fruits) X 100

Per cent leaf damage = (No. of damaged leaves ÷ Total no. of leaves) X 100

3.2.7.2. Observation method for counting leafhopper, aphids, mites and whiteflies

Number of nymphs and adults from five leaves (one top, two middle and two lower) from five tagged plants were counted to calculate the average population density of leaf hoppers and whiteflies. Aphids was counted from three leaves of 5 cm^2 (one top, one middle and one lower) on tagged plants. The adult red spider mites were counted from 3 cm^2 leaf area of three leaves (one top, one middle and one lower) from represented plants. For all sucking pests, observations were recorded one day before, 1, 3, 5, 7 and 14 days after imposing the treatments. For the calculation of per cent reduction in leafhopper population, Henderson and Tilton formula was used (Henderson and Tilton, 1955).

$$\textbf{Per cent reduction} = \left\{1 - \left(\frac{\text{n in C before treatment x n in T after treatment}}{\text{n in C after treatment x n in T before treatment}}\right)\right\} \text{x}100$$

Where,

n = Population of pest species

C = Control

T = Treatment

3.2.7.3. Observation method for counting natural enemies

The predators and parasitoids of different pests of brinjal were counted from five tagged plants at one day before, 1, 3, 5, 7 and 14 days after treatment.

3.2.8. Record of yield parameters

The efficacy of pongamia oil soap treatment on fruit yield of brinjal was recorded to evaluate their impact on yield parameters. Fruits were started harvesting from 50 DAT and later at seven days interval. Totally eight harvests were made during the experiment. Friut length were measured by taking average of 10 randomly selected fruits. Fruit yield was recorded seperately as g/plant basis. Fresh weight of fruit (g/plant), total yield (g/plant) and marketable yield obtained (g/plant) were also recorded and the economics was computed for all the treatments.

3.2.9. Statistical analysis of data

The per cent fruit and leaf damage data were analysed after arc sine transformation while population count of different pests was analysed after square root transformation. Square root transformation was done for yield data and cost – benefit ratio also. The data were analysed by using analysis of variance (ANOVA). Web Agri Stat Package (WASP) software was used to compare the significant difference between each treatment applied.

Results

4. RESULTS

The present investigation was carried out to evaluate the efficacy of a botanical insecticide, pongamia oil soap against major pests of brinjal, *Solanum melongena* L. and also to derive their effect on natural enemies at different concentrations. The chapter deals with brief description of study results obtained under laboratory and field evaluation of pongamia oil soap. The findings of research work conducted during 2019-2020 are presented here under different sub headings;

4.1. LABORATORY BIOASSAY OF PONGAMIA OIL SOAP AGAINST *EPILACHNA* GRUBS

Two different laboratory experiments including Feeding Deterrence Index and Relative Growth Index were carried out at Department of Entomology, College of Agriculture, Padannakkad. The grubs of Epilachna beetle were used for the bioassay studies of evaluating four different concentrations of pongamia oil soap.

4.1.1. Study on feeding deterrency index of pongamia oil soap against Epilachna beetle, *Epilachna dodecastigma*

The leaf area consumed by fourth instar Epilachna grubs was measured in all the treatments. Based on the consequences obtained, the antifeedant property of pongamia oil soap @ 0.6%, 1%, 2%, 3% and soap solution 0.5%, water spray and absolute control was computed and presented in Table 3.

Pongamia oil soap @ 3 per cent was found to be significantly superior to all other treatments by exhibiting 100 per cent feeding deterrency against Epilachna grubs while control showed 0 per cent feeding deterrency in grubs. The next best treatment was pongamia oil soap @ 2 per cent with 94.35 per cent feeding deterrency followed by pongamia oil soap @ 1 and 0.6 per cent with 92.07 and 90.48 per cent respectively and were found to be on par with each other. Soap solution @ 0.5 per cent and water spray showed 24.27 and 9.38 per cent feeding deterrency respectively which was significantly lower than all the concentrations of pongamia oil soap tested.

Table 3. Feeding deterrency index of pongamia oil soap in fourth instar grubs of *Epilachna dodecastigma* beetle under laboratory condition

Treatments	Feeding deterrency index
Pongamia oil soap @ 3%	100.00 [a]
Pongamia oil soap @ 2%	94.35 [ab]
Pongamia oil soap @ 1%	92.07 [b]
Pongamia oil soap @ 0.6%	90.48 [b]
Soap solution @ 0.5%	24.27 [c]
Water spray	9.38 [d]
Control	0.00 [e]
C.D (*P*=0.05)	**7.678**

Means superscripted by same letters are not significantly different from each other by DMRT @ 0.05%

4.1.2. Growth index and relative growth index under different treatments

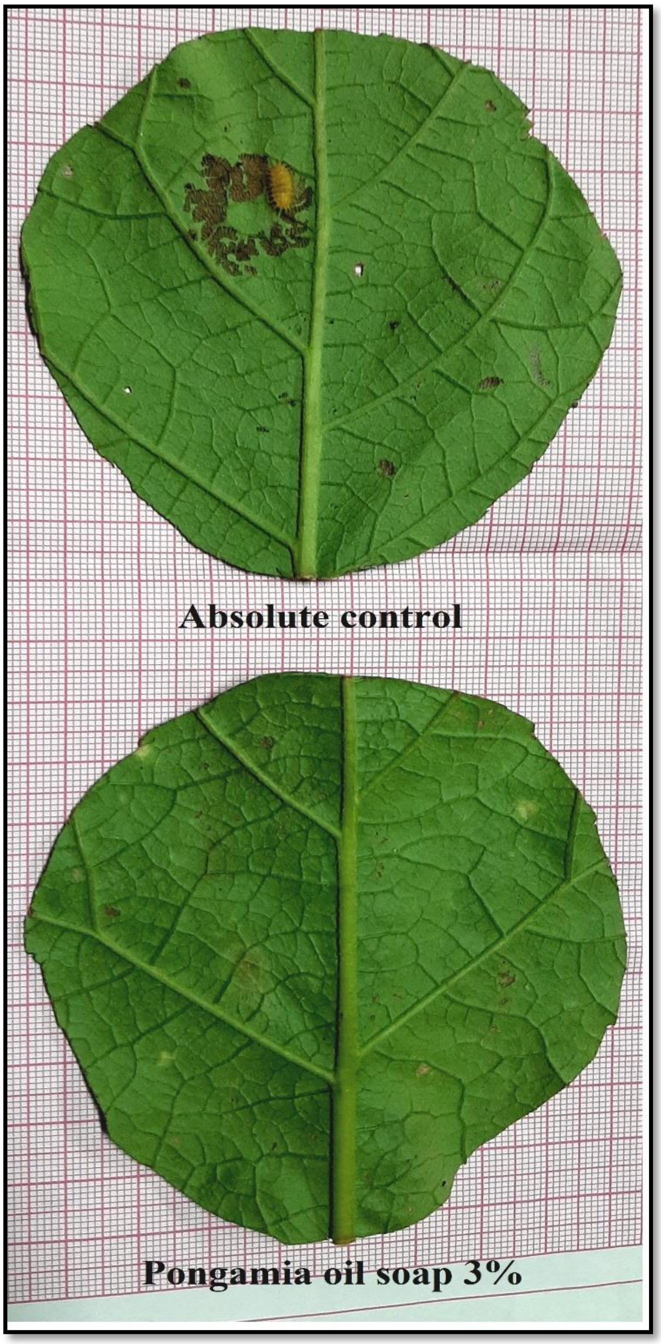
Both live and dead grubs of different instars observed in different treatments were counted when 100 per cent pupation occurred in absolute control. Growth Index was prepared and presented in Table 4. The rate of increase in size of Epilachna grubs in pongamia treatment to the rate of increase in control *i.e.* Growth Index was computed and presented in Table 4. Relative growth index of the grubs was also calculated by using GI values, then analysed and tabulated.

Pongamia oil soap @ 3 per cent showed 100% growth retardation in Epilachna in which all the five grubs were died in the first instar itself followed by pongamia oil soap @ 2 per cent with two grubs survived up to second instar and remaining three died at first instar itself. In case of pongamia oil soap @ 1 per cent, four grubs survived up to second instar and in 0.6 per cent treatment, three grubs survived up to third instar. None of the grubs were affected in soap treated, water spray and absolute control instead they reached 100 per cent pupation.

Relative growth index of pongamia oil soap @ 3 per cent was the lowest among other treatments (0.00) which was significantly different from absolute control (1.00). The next lowest growth rate was noticed in pongamia oil soap @ 2 per cent with 0.08 RGI which was also significantly different from remaining two concentrations *i.e.* pongamia oil soap @ 1 and 0.6 per cent with the RGI of 0.16 and 0.32. Soap solution @ 0.5 per cent, water spray and control were on par with each other with the RGI of 1.00 (Table 5).

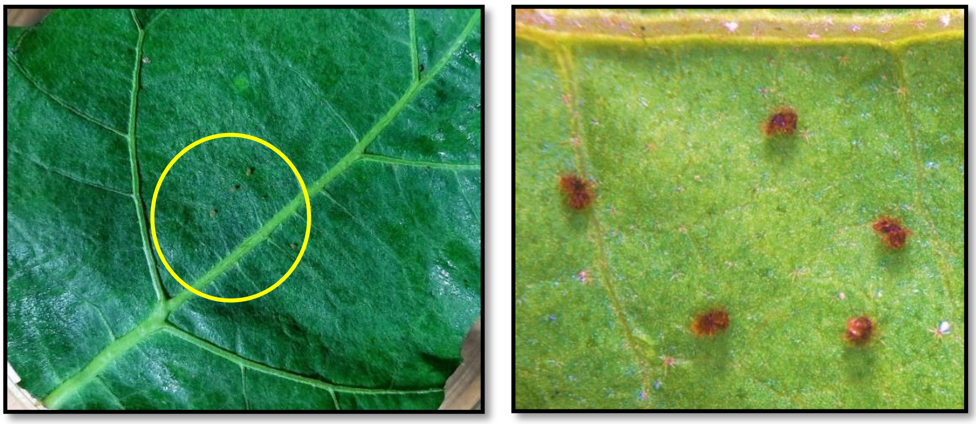
Table 4. Growth index of *Epilachna* grub under different pongamia oil soap treatments

Treatments	No. of 1st instar grubs released at the beginning of the experiment	No. of live grubs present in different instars					No. of dead grubs present in different instars					Growth Index
		1	2	3	4	Pupa	1	2	3	4	Pupa	
Pongamia oil soap @ 3%	5	**-**	**-**	**-**	**-**	**-**	**5**	**-**	**-**	**-**	**-**	**0.00**
Pongamia oil soap @ 2%	5	**-**	**-**	**-**	**-**	**-**	**3**	**2**	**-**	**-**	**-**	**0.08**
Pongamia oil soap @ 1%	5	**-**	**-**	**-**	**-**	**-**	**1**	**4**	**-**	**-**	**-**	**0.16**
Pongamia oil soap @ 0.6%	5	**-**	**-**	**-**	**-**	**-**	**-**	**2**	**3**	**-**	**-**	**0.32**
Soap solution @ 0.5%	5	**-**	**-**	**-**	**-**	**5**	**-**	**-**	**-**	**-**	**-**	**1.00**
Water spray	5	**-**	**-**	**-**	**-**	**5**	**-**	**-**	**-**	**-**	**-**	**1.00**
Absolute control	5	**-**	**-**	**-**	**-**	**5**	**-**	**-**	**-**	**-**	**-**	**1.00**



(a) Leaf area consumed by fourth instar grub of *Epilachna*

Plate 3. Feeding deterrency study on *Epilachna* grubs



(a) Normal and microscopic view of dead first instar grubs of *Epilachna* in Pongamia oil soap @ 3%

(b) Fourth instar grubs and pupae of *Epilachna* fed on untreated leaves in absolute control

Plate 4. Laboratory bioassay of growth index and relative growth index on *Epilachna* grubs

Table 5. Relative growth index of *Epilachna dodecastigma* grubs under different pongamia oil soap treatments

Treatments	Relative growth index
Pongamia oil soap @ 3%	0.00^{e}
Pongamia oil soap @ 2%	0.08^{d}
Pongamia oil soap @ 1%	0.16^{c}
Pongamia oil soap @ 0.6%	0.32^{b}
Soap solution @ 0.5%	1.00^{a}
Water spray	1.00^{a}
Control	1.00^{a}
C.D (*P*=0.05)	**0.04**

Means indicated by similar superscript alphabets shows non- significant differences among each other @ 0.05 DMRT

4.2. FIELD EVALUATION OF PONGAMIA OIL SOAP AGAINST MAJOR PESTS OF BRINJAL DURING RABI SEASON, 2019-2020

The field investigation was conducted to evaluate the potential of pongamia oil soap in the management of major pests of brinjal at Instructional farm II, Karuvachery, CoA, Padannakkad during *rabi* season, 2019-20. The results obtained from different brinjal pests are presented here in a brief manner under different sub-headings.

4.2.1. Field evaluation of pongamia oil soap against brinjal fruit and shoot borer (BFSB), *Leucinodes orbonalis* damaging brinjal fruits

Pongamia oil soap was evaluated for its efficacy in the management of brinjal fruit and shoot borer (BFSB), *Leucinodes orbonalis* at four different concentrations during *rabi* season, November 2019-April 2020. Three rounds of spray were applied with various treatments and observations on number of healthy and damaged fruits were taken on one day before, seventh and fourteenth days after application. Data recorded during three sprays were analysed after arc sine/angular transformation and presented in the Table 6. The shoot damage by fruit and shoot borer (FSB) was not recorded as it was negligible.

4.2.1.1. Mean per cent fruit damage by fruit and shoot borer (FSB) during first application

The efficacy of different treatments like pongamia oil soap @ 0.6 per cent, 1 per cent, 2 per cent and 3 per cent, neem oil @ 0.6 per cent, soap solution @ 0.5 per cent, Chlorantraniliprole 18.5 SC @ 3 mL/10L - 1st and 3rd application and Thiamethoxam 25 WG @ 2g/10L - 2nd application and control against fruit and shoot borer (FSB), *Leucinodes orbonalis* was investigated and the mean per cent of fruits damaged was computed.

The mean per cent damage by fruit and shoot borer in the pre-treatment observation ranged from 38.03 to 44.00 per cent, revealing that there were no significant differences among various treatments and the pest infestation was uniform in all treatments on 24h before application.

Fig.2. Feeding deterrency index of pongamia oil soap in fourth instar grubs of *Epilachna dodecastigma* beetle

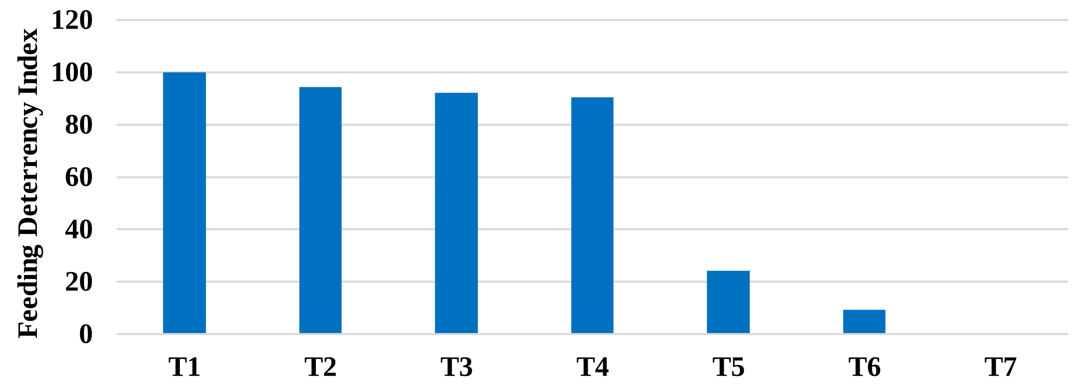
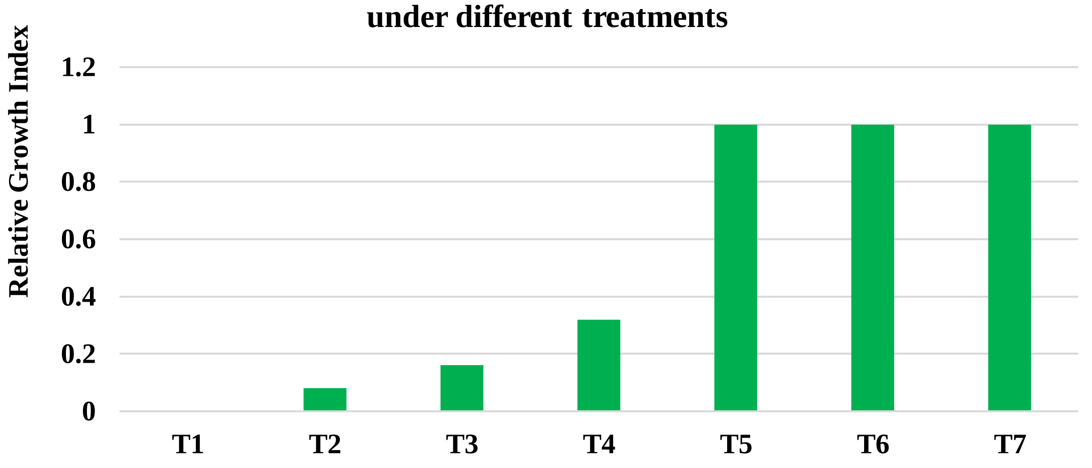


Fig.3. Relative growth index of *Epilachna dodecastigma* grubs under different treatments



T_1 – Pongamia oil soap 3%; T_2 – Pongamia oil soap 2%;

T_3 – Pongamia oil soap 1%; T_4 – Pongamia oil soap 0.6%

T_5 – Soap solution 0.5%; T_6 – Water spray T_7 – Control

The fruit and shoot borer incidence were significantly reduced by pongamia oil soap @ 3% with only 15.66 per cent fruit damage on seven days after first application. It was on par with pongamia oil soap @ 2% (15.77%), Chlorantraniliprole 18.5 SC @ 3 mL/10L (standard check) (16.92%) and pongamia oil soap @ 1% (20.51%). Highest fruit infestation was noticed in control with 46.52%. Pongamia oil soap @ 0.6 per cent showed 22.64% fruit damage which was significantly different from neem oil soap @ 0.6 per cent (29.78%) and soap solution @ 0.5 per cent (31.25%). The per cent fruit damage reduction by pongamia oil soap @ 0.6% was statistically on par with pongamia oil soap @ 1, 2, 3 per cent and standard check.

Lowest fruit and shoot borer (FSB) infestation was observed in pongamia oil soap @ 3 per cent (16.28%) on fourteenth day after application also followed by standard check (18.28%), pongamia oil soap @ 2 per cent (20.36%), pongamia oil soap @ 1 per cent (21.81%) and pongamia oil soap @ 0.6 per cent (25.26%). Untreated control plot recorded highest fruit and shoot borer (FSB) infestation of 60.03%. The efficacy of neem oil soap @ 0.6% was decreased on fourteenth day of treatment application (57.71%) which was statistically on par with soap solution @ 0.5% (44.90%) and control (60.03%). The fruit damage recorded in pongamia oil soap @ 3, 2, 1 and 0.6 per cent and standard check were statistically on par with each other on fourteenth day after application.

4.2.1.2. Mean per cent fruit damage by fruit and shoot borer (FSB) during second application

Mean per cent of fruit damage by FSB ranged from 41.84 to 48.23 per cent under different treatments which was statistically non-significant from one another on the day prior to second application.

Fruit and shoot borer incidence was effectively reduced by pongamia oil soap @ 3 per cent with 22.17% fruit damage which was significantly different from all other treatments. The next best treatment was pongamia oil soap @ 2 per cent with 29.52% fruit damage followed by pongamia oil soap @ 1 per cent (30.63%), standard check-Thiamethoxam 25 WG (38.14%) and pongamia oil soap @ 0.6 per cent (42.61%). The efficacy of neem oil soap @ 0.6 per cent started to decrease from second spray onwards which showed 61.64 per cent fruit damage which was on par with control and soap solution @ 0.5% per cent with 64.22 and 57.04 per cent fruit damage respectively. Pongamia oil soap @ 2 per cent, pongamia oil soap @ 1 per cent and standard check were statistically on par with pongamia oil soap @ 3 per cent which showed best results among all the treatments while pongamia oil soap @ 0.6 per cent was on par with pongamia oil soap @ 2 and 1 per cent concentrations, standard check and neem oil soap @ 0.6 per cent. Among the botanical insecticides, neem oil soap @ 0.6 per cent alone was on par with soap solution @ 0.5 per cent and control at the same time soap solution was on par with control on seventh day after treatment application.

Pongamia oil soap @ 3 per cent remained effective in reducing fruit and shoot borer (FSB) infestation which produced 32.77% fruit damage on fourteenth day after spray followed by pongamia oil soap @ 2 per cent (38.06%), pongamia oil soap @ 1 per cent (40.30%) and pongamia oil soap @ 0.6 per cent (49.10%). Control had maximum fruit damage of 84.26% while neem oil soap @ 0.6 per cent and soap solution @ 0.5 per cent expressed similar results with 80.51% and 76.18% fruit damage and both were on par with control. Standard check showed 64.23% mean fruit damage which was statistically on par with pongamia oil soap @ 0.6 per cent, soap solution @ 0.5 per cent and neem oil soap @ 0.6 per cent. Pongamia oil soap @ 0.6, 1, and 2 per cent were statistically on par with pongamia oil soap @ 3 per cent after fourteen days of spray.

4.2.1.3. Mean per cent fruit damage by fruit and shoot borer (FSB) during third application

Mean per cent of FSB infestation were found to be at a range of 77.43 to 90.58 per cent under different treatments which had statistically no significant difference prior to the third application.

The per cent fruit damage was effectively reduced to 12.94% in pongamia oil soap @ 3 per cent treated plants on seventh day after application which was significantly superior than all other treatments followed by pongamia oil soap @ 2 per

Table 6. Mean per cent of damaged fruits by larvae of fruit and shoot borer, *Leucinodes orbonalis* recorded during November 2019 to May 2020 under field conditions

Treatments	Mean per cent of infested fruits *								
	First application			Second application			Third application		
	1 DBS	7 DAS	14 DAS	1 DBS	7 DAS	14 DAS	1 DBS	7 DAS	14 DAS
Chlorantraniliprole 18.5 SC 3 mL/10L - 1st & 3rd application & Thiamethoxam 25 WG 2g/10L - 2nd application	41.88 (40.30)	16.92 (24.17) c	18.38 (25.37) b	43.15 (46.83)	38.14 (37.60) cd	64.23 (53.27) bc	77.43 (61.93)	30.36 (33.32) cd	34.49 (35.92) de
Pongamia oil soap 3%	39.55 (38.92)	15.66 (23.25) c	16.28 (23.49) b	41.84 (43.88)	22.17 (28.04) d	32.77 (34.82) d	81.78 (65.39)	12.94 (20.93) e	30.95 (33.76) e
Pongamia oil soap 2%	38.60 (38.41)	15.77 (23.38) c	20.36 (26.80) b	45.35 (50.61)	29.52 (32.86) cd	38.06 (38.09) d	90.58 (72.19)	24.91 (29.77) d	37.54 (37.77) de
Pongamia oil soap 1%	42.54 (40.70)	20.51 (26.88) c	21.81 (27.49) b	43.50 (46.90)	30.63 (33.60) cd	40.30 (39.42) d	89.47 (71.29)	31.53 (34.12) cd	39.73 (39.07) cd
Pongamia oil soap 0.6%	44.00 (41.54)	22.64 (28.29) bc	25.26 (29.83) b	42.90 (46.37)	42.61 (40.72) bc	49.10 (44.48) cd	81.98 (64.89)	38.98 (38.57) c	47.84 (43.76) c
Neem oil soap 0.6%	42.90 (40.88)	29.78 (32.85) b	57.71 (49.70) a	46.17 (52.04)	61.64 (51.81) a	80.51 (64.76) ab	83.02 (66.25)	67.51 (55.36) b	85.94 (68.29) b
Soap solution 0.5%	38.03 (38.07)	31.25 (33.98) b	44.90 (42.03) a	48.23 (55.61)	57.04 (49.08) ab	76.18 (61.19) ab	84.12 (66.88)	70.27 (57.26) b	85.08 (67.51) b
Control	41.13 (39.88)	46.52 (43.00) a	60.03 (50.82) a	45.95 (51.66)	64.22 (53.36) a	84.26 (68.24) a	79.87 (64.10)	82.77 (65.70) a	93.57 (75.37) a
C.D. (*P*=0.05)	**NS**	**8.78**	**17.80**	**NS**	**17.00**	**17.20**	**NS**	**12.80**	**6.91**

* Mean of five observations
Means superscripted by same letters are not significantly different by DMRT at 0.05
Figures in parentheses indicates arc sine transformed values
DBS- Day Before Spray; DAS- Days After Spray; NS – Non significant

cent, standard check - Chlorantraniliprole 18.5 SC and pongamia oil soap @ 1 per cent with 24.91, 30.36 and 31.53% damaged fruits respectively. Maximum fruit and borer infestation observed in control plots with 82.77% fruit damage followed by soap solution @ 0.5 per cent (70.27%). Pongamia oil soap @ 0.6 per cent (38.98%) was on par with pongamia oil soap @ 1 per cent and standard check while standard check and pongamia oil soap @ 1 per cent produced similar results and both were statistically at par with pongamia oil soap @ 2 per cent. Neem oil soap 0.6 per cent (67.51%) was on par with soap solution @ 0.5 per cent (70.27%) in fruit damage.

Even after fourteen days of application, pongamia oil soap @ 3 per cent was remained statistically superior over all other treatments with 30.95% damaged fruits followed by standard check and pongamia oil soap @ 2 per cent, both gave statistically similar results of 34.49 and 37.54% fruit damage respectively. Highest FSB infestation was recorded in control with 93.57% fruit damage. Pongamia oil soap at @ 1 and 0.6 per cent also significantly reduced the fruit and shoot borer infestation which had 39.73 and 47.84% damaged fruits and found to be statistically on par with each other while 1 per cent pongamia oil soap found to be on par with standard check and pongamia oil soap @ 2 per cent. Soap solution 0.5 per cent and neem oil soap 0.6 per cent were less effective in managing fruit and shoot borer which showed 85.08 and 85.94 mean per cent fruit damage, both were on par with each other.

There was a significant reduction of fruit and shoot borer infestation in all the concentrations of pongamia oil soap at seven days after application during all the three sprays except control and soap solution @ 0.5%. Pongamia oil soap @ 3 per cent recorded the maximum percentage reduction in fruit damage followed by chlorantraniliprole 18.5 SC and pongamia oil soap @ 2 per cent had more or less similar results, then pongamia oil soap @ 2 per cent, pongamia oil soap @ 1 per cent, thiamethoxam 25 WG, pongamia oil soap @ 0.6 per cent, and neem oil soap @ 0.6 per cent.

A gradual increase in fruit and shoot borer infestation was observed by fourteenth day of spray in all the tested treatments while chlorantraniliprole 18.5 SC showed a slight accumulation of fruit damage only. The maximum reduction was observed in pongamia oil soap @ 3 per cent followed by chlorantraniliprole 18.5 SC > pongamia oil soap @ 2 per cent > pongamia oil soap @ 1 per cent > pongamia oil soap @ 0.6 per cent. Thiamethoxam 25 WG, neem oil soap @ 0.6 per cent, soap solution @ 0.5 per cent and control showed an increased per cent fruit damage after fourteen days of spray.

4.2.2. Field evaluation of pongamia oil soap against leafhopper, *Amrasca biguttula biguttula* in brinjal during *rabi* season from November 2019 to May 2020

Pongamia oil soap at different concentrations of 0.6, 1, 2 and 3 per cent were evaluated against leaf hopper, *Amrasca biguttula biguttula* by the field study conducted during *rabi* season 2019-20. Observations were made from two sprays on one day prior to, 1, 3, 5, 7 and 14 days after spray application. Since the leafhopper population was insignificant between treatments during the third spray, it was not recorded. Data on leafhopper population were analysed with square root transformation and presented in Table 7.

4.2.2.1. Average leafhopper, Amrasca biguttula biguttula population during the field evaluation of pongamia oil soap at first application

The leafhopper population was uniform among different treatments before the first spray application which ranged from 8.87 to 10.13 leafhoppers per 5 leaves per plant.

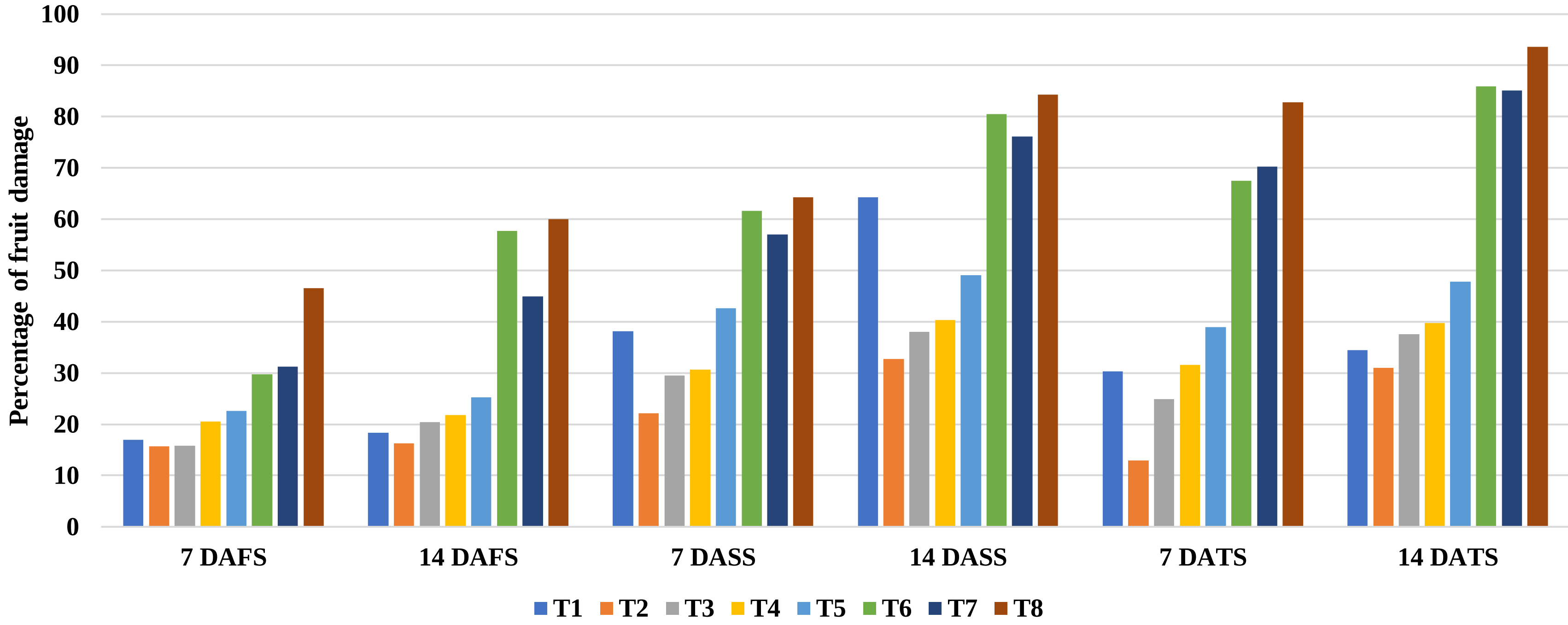
The plants treated with pongamia oil soap @ 3 per cent recorded minimum leafhopper count of 3.80 leafhoppers/5 leaves followed by neem oil soap @ 0.6 per cent (4.20 leafhoppers/5 leaves), both were statistically on par with each other on a day after spray application. Soap solution @ 0.5 per cent recorded 6.73 leafhoppers/5 leaves and found to be on par with control (9.20 leafhoppers/5 leaves) which showed highest count of leafhoppers. Pongamia oil soap @ 2 per cent (4.60 leafhoppers/5 leaves), pongamia oil soap @ 1 per cent (4.77 leafhoppers/5 leaves), standard check - chlorantraniliprole 18.5 SC (4.80 leafhoppers/5 leaves) and pongamia oil soap @ 0.6 per cent (4.87

leafhoppers/5 leaves) were found to be statistically on par with each other. Soap solution 0.5 per cent was also on par with pongamia oil soap @ 0.6, 1, 2 per cent and standard check.

Observations on three days after application revealed that pongamia oil soap 3 per cent showed highest efficiency against leafhoppers with 3.80 leafhoppers/5 leaves which was significantly different from remaining treatments followed by neem oil soap @ 0.6 per cent (4.47 leafhoppers/5 leaves). It was followed by pongamia oil soap @ 2 per cent (4.67 leafhoppers/5 leaves), standard check - chlorantraniliprole 18.5 SC (5.80 leafhoppers/5 leaves) and pongamia oil soap @ 1 per cent (5.80 leafhoppers/5 leaves) gave similar results and these three were found to be on par with each other. Pongamia oil soap @ 0.6 per cent (6.00 leafhoppers/5 leaves) was on par with pongamia oil soap @ 1 per cent, standard check, neem oil soap @ 0.6 per cent and pongamia oil soap @ 2 per cent. Soap solution and control recorded highest count of leafhoppers with 8.13 and 8.60 leafhoppers/5 leaves respectively and both were at par with each other and the soap solution was on par with pongamia oil soap @ 0.6 and 1 per cent.

On fifth day of treatment, minimum leafhopper population was reported by pongamia oil soap @ 3 per cent itself with 4.07 leafhoppers/5 leaves followed by standard check - chlorantraniliprole 18.5 SC (5.87 leafhoppers/5 leaves), neem oil soap @ 0.6 per cent (6.00 leafhoppers/5 leaves) and pongamia oil soap @ 2 per cent (6.00 leafhoppers/5 leaves). The next best treatments were pongamia oil soap @ 1 and 0.6 per cent with 7.17 and 7.47 leafhoppers/5 leaves respectively, both were at par with each other and also on par with control and soap solution @ 0.5 per cent. Leafhopper infestation was high in soap solution @ 0.5 per cent treated plants with 9.93 leafhoppers/5 leaves which found to be on par with control (9.87 leafhoppers/5 leaves). Chlorantraniliprole 18.5 SC and neem oil soap 0.6 per cent (6.00 leafhoppers/5 leaves) were statistically on par with pongamia oil soap @ 3 per cent while pongamia oil soap @ 2 per cent was on par with standard check and neem oil soap @ 0.6 per cent.

Fig.4. Mean per cent of damaged fruits by larvae of fruit and shoot borer, *Leucinodes orbonalis* recorded during field evaluation



DAFS – Days After First Spray, DASS – Days After Second Spray, DATS – Days After Third Spray

T_1 – Chlorantraniliprole 18.5 SC 3 mL/10L (Spray I & III) & Thiamethoxam 25 WG 2g/10L (Spray II); T_2 – Pongamia oil soap 3%;

T_3 – Pongamia oil soap 2%; T_4 – Pongamia oil soap 1%; T_5 – Pongamia oil soap 0.6%;

T_6 – Neem oil soap 0.6 %; T_7 – Soap solution 0.5%; T_8 – Control

Observations on seventh day after first spray showed that pongamia oil soap @ 3 per cent with 4.87 leafhoppers per five leaves as significantly superior followed by standard check (5.47 leafhoppers/5 leaves). Neem oil soap @ 0.6 per cent, pongamia oil soap @ 2 per cent and pongamia oil soap @ 1 per cent were statistically on par with each other with 6.93, 7.20 and 7.47 leafhoppers/ 5 leaves respectively while neem oil soap @ 0.6 per cent alone was on par with pongamia oil soap @ 3 per cent. Pongamia oil soap @ 0.6 per cent was on par with pongamia oil soap @ 1 and 2 per cent and also with soap solution @ 0.5% and control. Highest population was recorded in control and soap solution @ 0.5% treated plot with 10.33 and 10.13 leafhoppers/5 leaves.

Except pongamia oil soap @ 3 and 2 per cent, all other treatments showed a steady increase in leafhopper population with 7.27 and 7.73 leafhoppers/5 leaves in pongamia oil soap @ 3 and 2 per cent treated plots respectively both were significantly different over others. It was followed by chlorantraniliprole 18.5 SC, pongamia oil soap @ 1 per cent and neem oil soap @ 0.6 per cent which recorded 9.60, 9.93 and 10.20 leafhoppers/5 leaves respectively which were on par with each other. Pongamia oil soap @ 0.6 per cent showed high leafhopper population among botanicals with 11.60 leafhoppers/5 leaves which was on par with control and soap solution @ 0.5 per cent which had 12.07 and 12.33 leafhoppers/5 leaves. Chlorantraniliprole 18.5 SC, pongamia oil soap @ 1 per cent and neem oil soap @ 0.6 per cent were found to be statistically at par with pongamia oil soap @ 2 and 3 per cent.

4.2.2.2. Average leafhopper (Amrasca biguttula biguttula) population during field evaluation of pongamia oil soap at second application

Leafhopper population was not significantly different among different treatments which ranged from 15.73 to 18.93 leafhoppers/5 leaves on a day before second spray.

Table 7. Average population density of leafhopper, *Amrasca biguttula biguttula* during November 2019 to May 2020

Treatments	**Leaf hopper density per five leaves***											
	First application						**Second application**					
	1 DBS	**1 DAS**	**3 DAS**	**5 DAS**	**7 DAS**	**14 DAS**	**1 DBS**	**1 DAS**	**3 DAS**	**5 DAS**	**7 DAS**	**14 DAS**
Chlorantraniliprole 18.5 SC 3 mL/10L - 1st application & Thiamethoxam 25 WG 2g/10L - 2nd application	8.87 (2.97)	4.80 (2.16) ^{bc}	5.80 (2.39) ^{cd}	5.87 (2.4) ^{bc}	5.47 (2.32) ^{cd}	9.60 (3.09) ^{ab}	16.73 (4.09)	7.00 (2.64) ^{c}	4.13 (2.01) ^{c}	3.80 (1.84) ^{d}	3.60 (1.76) ^{c}	2.93 (1.80) ^{b}
Pongamia oil soap 3%	9.60 (3.10)	3.80 (1.94) ^{c}	3.80 (1.95) ^{d}	4.07 (2.01) ^{c}	4.87 (2.21) ^{d}	7.27 (2.67) ^{b}	18.33 (4.27)	7.93 (2.81) ^{c}	9.07 (2.98) ^{bc}	11.87 (3.43) ^{c}	13.87 (3.68) ^{b}	16.11 (4.07) ^{a}
Pongamia oil soap 2%	9.80 (3.13)	4.60 (2.13) ^{bc}	4.67 (2.14) ^{cd}	6.00 (2.45) ^{b}	7.20 (2.65) ^{bc}	7.73 (2.77) ^{b}	15.73 (3.93)	9.53 (3.08) ^{bc}	14.27 (3.72) ^{ab}	15.53 (3.93) ^{bc}	18.53 (4.29) ^{ab}	19.40 (4.51) ^{a}
Pongamia oil soap 1%	9.87 (3.14)	4.77 (2.18) ^{bc}	5.80 (2.40) ^{bcd}	7.17 (2.71) ^{ab}	7.47 (2.72) ^{bc}	9.93 (3.13) ^{ab}	18.93 (4.33)	12.27 (3.49) ^{b}	14.53 (3.72) ^{ab}	17.33 (4.14) ^{abc}	19.33 (4.34) ^{ab}	20.87 (4.62) ^{a}
Pongamia oil soap 0.6%	10.13 (3.18)	4.87 (2.19) ^{bc}	6.00 (2.44) ^{bc}	7.47 (2.72) ^{ab}	9.47 (3.02) ^{ab}	11.60 (3.40) ^{a}	16.93 (4.11)	13.20 (3.60) ^{b}	17.27 (4.08) ^{a}	18.87 (4.32) ^{ab}	19.87 (4.45) ^{ab}	21.60 (4.75) ^{a}
Neem oil soap 0.6%	8.93 (2.99)	4.20 (2.02) ^{c}	4.47 (2.12) ^{cd}	6.00 (2.43) ^{bc}	6.93 (2.60) ^{bcd}	10.20 (3.18) ^{ab}	18.80 (4.32)	18.60 (4.29) ^{a}	19.13 (4.33) ^{a}	23.33 (4.79) ^{a}	26.33 (5.10) ^{a}	27.53 (5.32) ^{a}
Soap solution 0.5%	9.13 (3.02)	6.73 (2.56) ^{ab}	8.13 (2.83) ^{ab}	9.93 (3.13) ^{a}	10.13 (3.18) ^{a}	12.33 (3.51) ^{a}	17.33 (4.16)	20.80 (4.55) ^{a}	20.40 (4.50) ^{a}	21.93 (4.67) ^{a}	25.20 (4.50) ^{a}	25.50 (5.0) ^{a}
Control	9.13 (3.02)	9.20 (3.03) ^{a}	8.60 (2.93) ^{a}	9.87 (3.13) ^{a}	10.33 (3.18) ^{a}	12.07 (3.47) ^{a}	18.33 (4.27)	20.40 (4.50) ^{a}	20.60 (4.51) ^{a}	23.60 (4.83) ^{a}	26.40 (5.11) ^{a}	27.60 (5.34) ^{a}
C.D. (*P*=0.05)	**NS**	**0.47**	**0.47**	**0.42**	**0.44**	**0.52**	**NS**	**0.53**	**0.97**	**0.72**	**0.84**	**1.46**

* Mean of five observations
Means followed by similar letters are not significantly different by DMRT at 5%
Figures in parentheses indicates square root transformed values
DBS- Day Before Spray; DAS- Days After Spray; NS – Non significant

The observations made on a day after second spray application revealed that leafhopper population was effectively reduced by standard check - thiamethoxam 25 WG which was immediately followed by pongamia oil soap @ 3 per cent with 7.00 and 7.93 leafhoppers/5 leaves respectively which were found to be statistically on par with each other. The pongamia oil soap @ 2 per cent (9.53 leafhoppers/5 leaves) was the next best treatment which was on par with standard check and pongamia oil soap @ 3 per cent followed by pongamia oil soap @ 0.6 and 1 per cent with 12.27 and 13.20 leafhoppers/5 leaves respectively, both were on par with each other. Maximum leafhopper population was recorded in soap solution 0.5 per cent, control and neem oil soap 0.6 per cent which had 20.80, 20.40 and 18.60 leafhoppers/5 leaves and were statistically similar in results.

At third day of spray application, least population of leafhoppers was observed in standard check with 4.13 leafhoppers/5 leaves followed by pongamia oil soap @ 3 per cent (9.07 leafhoppers/5 leaves). Maximum number of leafhoppers found in untreated control (20.60 leafhoppers/5 leaves), soap solution 0.5 per cent (20.40 leafhoppers/5 leaves) and neem oil soap 0.6 per cent (19.13 leaf hoppers/5 leaves) which were on par with each other. Pongamia oil soap @ 2, 1 and 0.6 per cent showed 14.27, 14.53 and 17.27 leafhoppers/ 5 leaves respectively however, pongamia oil soap @ 2 and 1 per cent were on par with pongamia oil soap @ 3 per cent. Pongamia oil soap @ 0.6 per cent was on par with neem oil soap 0.6 per cent, soap solution 0.5 per cent and control.

Standard check recorded lowest population of leafhopper at five days after spray which had 3.80 leafhoppers/5 leaves subsequently pongamia oil soap @ 3 per cent (11.87 leafhoppers/5 leaves). More number of leafhoppers were observed in control, neem oil soap 0.6 per cent and soap solution 0.5 per cent which had 23.60, 23.33 and 21.93 leafhoppers/5 leaves respectively and were statistically similar. Leafhopper population found in pongamia oil soap @ 0.6, 1 and 2 per cent was 18.87, 17.33 and 15.53 leafhoppers/ 5 leaves respectively. Pongamia oil soap @ 2 and 1 per cent were on par with pongamia oil soap @ 3 per cent although pongamia oil soap @ 1 and 2 per cent were statistically on par with control, neem oil soap 0.6% and soap solution 0.5%.

At seven days of second spray application, lowest population was recorded by standard check with 3.60 leafhoppers/5 leaves which was statistically different from other treatments. Pongamia oil soap @ 3 per cent showed next best result of 13.87 leafhoppers/5 leaves followed by pongamia oil soap @ 2, 1 and 0.6 per cent with 18.53, 19.33 and 19.87 leafhoppers/ 5 leaves respectively and were found to be on par with pongamia oil soap @ 3 per cent. Untreated plot showed maximum population of the pest (26.40 leafhoppers/5 leaves) similarly neem oil soap 0.6 per cent (26.33 leafhoppers/5 leaves) and soap solution 0.5 per cent (25.20 leafhoppers/5 leaves) were not effective at seven days after treatment application and these three were statistically on par which each other.

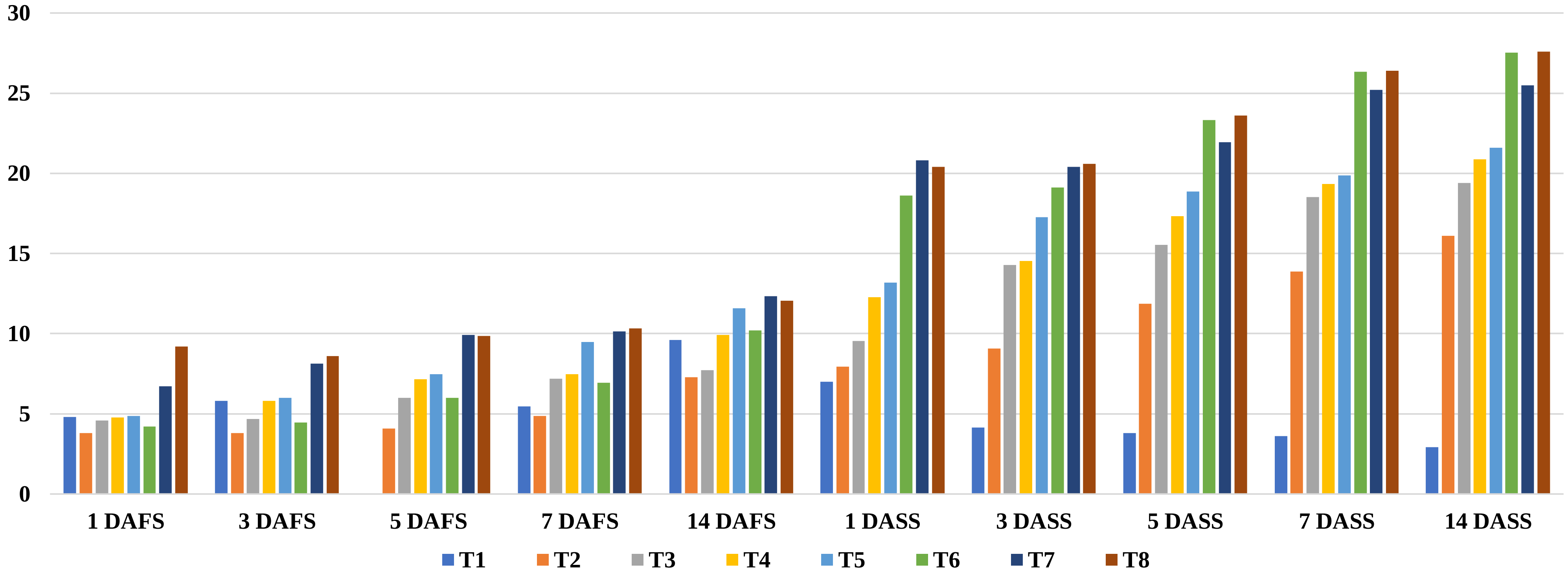
Leafhopper incidence was significantly low in the thiamethoxam - standard check treated plots with only 2.93 leafhoppers/5 leaves followed by pongamia oil soap @ 3 per cent (16.11 leafhoppers/5 leaves) among the botanicals. The leafhopper population in remaining pongamia oil soap treatments such as pongamia oil soap @ 2, 1, 0.6 per cent was 19.40, 20.87 and 21.60 leafhoppers/ 5 leaves respectively. While control, neem oil soap 0.6 per cent and soap solution 0.5 per cent showed high leafhopper population with 27.60, 27.53 and 25.05 leafhoppers/5 leaves. On fourteenth day of treatment application, leafhopper population became non-significant among different treatments except standard check.

4.2.2.3. Percentage reduction in leaf hopper **(*Amrasca biguttula biguttula*)** *population during field evaluation of pongamia oil soap*

Per cent reduction in the leafhopper population was computed for the different concentrations of pongamia and other treatments, statistically analysed and presented in Table 8.

At a day after first spray, pongamia oil soap @ 0.6, 1, 2, 3 per cent and neem oil soap 0.6 per cent were found to be effective in reducing leafhopper population with 42.77, 52.90, 55.23, 61.07 and 53.53% respectively followed by chlorantraniliprole 18.5 SC (34.33%). Soap solution 0.5 per cent was not effective against leafhopper which showed only 27.77% reduction in population.

Fig.5. Average leafhopper, *Amrasca biguttula biguttula* population during the field evaluation from November 2019 to May 2020



DAFS – Days After First Spray, DASS – Days After Second Spray

T_1 – Chlorantraniliprole 18.5 SC 3 mL/10L (Spray I) & Thiamethoxam 25 WG 2g/10L (Spray II); T_2 – Pongamia oil soap 3%;

T_3 – Pongamia oil soap 2%; T_4 – Pongamia oil soap 1%; T_5 – Pongamia oil soap 0.6%;

T_6 – Neem oil soap 0.6 %; T_7 – Soap solution 0.5%; T_8 – Control

Pongamia oil soap @ 3 per cent was significantly superior over others in population reduction which showed 60.70% reduction at three days of spray. It was followed by pongamia oil soap @ 2 per cent (49.97%), neem oil soap 0.6 per cent (46.93%), chlorantraniliprole 18.5 SC (41.43%), pongamia oil soap @ 1 per cent (38.70%) and pongamia oil soap @ 0.6 per cent (37.03%) while soap solution 0.5% showed only 15.27% reduction. On fifth day after first spray, 57.70% reduction was recorded by pongamia oil soap @ 3 per cent followed by pongamia oil soap @ 2 per cent (42.10%). Standard check was the next best treatment in population reduction with 37.57% followed by neem oil soap 0.6 per cent, pongamia oil soap @ 1 per cent and 0.6 per cent which recorded 36.53%, 32.40% and 30.83% reduction. Soap solution 0.5 per cent (11.17%) and control plots were statistically on par with each other at five days of first spray. There was a decrease in population reduction on seventh day on cumulative basis except pongamia oil soap @ 3 per cent and standard check which showed 53.07 and 44.53 per cent leafhopper reduction. This was followed by pongamia oil soap @ 2, neem oil soap 0.6 per cent, pongamia oil soap @ 1 and 0.6 per cent with the population reduction of 35.07, 30.37, 28.83 and 18.73% reduction. Soap solution 0.5 per cent was least effective with 9.07% reduction which was on par with control. A gradual decrease in population reduction was noted on fourteenth day on cumulative basis except soap solution 0.5% (9.83%) and untreated plots. Pongamia oil soap @ 3 per cent (43.80%) was the statistically superior treatment at fourteenth day of spray application also, which was followed by pongamia oil soap @ 2 (39.70%) and 1 per cent (24.43%), neem oil soap 0.6 per cent (18.67%), pongamia oil soap @ 0.6 per cent (14.53%) and standard check (14.47%).

Data on per cent reduction at a day after second spray revealed that 3 per cent pongamia oil soap was statistically on par with standard check – thiamethoxam 25WG which had 63.57 and 50.30% reduction respectively. Pongamia oil soap @ 3% was also on par with pongamia oil soap 2 per cent, 1 per cent and 0.6 per cent with 47.70, 37.60 and 36.67 per cent leafhopper reduction respectively. Neem oil soap 0.6 per cent and soap solution 0.5 per cent had 12.67 and 13.53% reduction and were on par with untreated control. 79.17% population reduction of leafhopper was recorded by standard check on third day of spray application followed by pongamia oil soap @ 3 per cent (46.00%) > pongamia oil soap @ 2 per cent (30.33%) > pongamia oil soap @ 1 per cent (29.20%) > pongamia oil soap @ 0.6 per cent (23.04%) in decreasing order. Neem oil soap 0.6 per cent and soap solution 0.5 per cent with 7.04 and 8.60% were on par with untreated control. Maximum per cent reduction of leafhopper population was observed in standard check treated plots with 85.40% which was followed by pongamia oil soap @ 3 per cent (43.17%) on fifth day of second application. Pongamia oil soap @ 2 and 1 per cent were on par with pongamia oil soap @ 3 per cent with 32.43 and 31.73% population reduction. Pongamia oil soap @ 0.6 per cent (19.32%) found to be on par with neem oil soap 0.6 per cent (13.44%) and soap solution 0.5 per cent (8.60%). Standard check – thiamethoxam 25 WG was significantly superior over other treatments after seventh and fourteenth day of second treatment application respectively with 85.73 and 88.00% reduction in leafhopper population. Pongamia oil soap @ 3 per cent showed next best results of 41.90 and 34.87% which was on par with pongamia oil soap @ 2 per cent on seventh (26.20%) and fourteenth (25.50%) day of second spray. Pongamia oil soap @ 1 and 0.6 per cent were on par with soap solution 0.5 per cent and neem oil soap 0.6 per cent which showed 23.93, 15.33, 12.99 and 10.04% respectively on seventh day and all these treatments were on par with control except pongamia oil soap @ 1 per cent. Soap solution 0.5 per cent (30.83%), pongamia oil soap @ 1 (24.85%) and 0.6 per cent (20.13%) and neem oil soap 0.6 per cent (11.10%) became insignificant in population reduction which were found to be on par with pongamia oil soap @ 3 per cent and untreated control on fourteenth day of second spray.

4.2.3. Field evaluation of pongamia oil soap on Epilachna beetle, *Epilachna* sp. in brinjal during *rabi* season from November 2019 to May 2020

Pongamia oil soap at four different concentrations along with other treatments were evaluated for their efficacy in reducing leaf damage caused by Epilachna beetle, *Epilachna dodecastigma* and *E. vigintioctopunctata.* The Epilachna leaf damage was recorded as average number of damaged leaves on every seven days once and the observation data recorded during all the three sprays furnished below. The data obtained underwent the statistical analysis and presented here in Table 9.

4.2.3.1. Mean percentage of damaged leaves by Epilachna grubs and adults (Epilachna sp.) during field evaluation of pongamia oil soap at first spray

The mean per cent of damaged leaves by grubs and adult beetles of Epilachna was statistically non-significant in the eight treatments prior to the first application which ranged from 14.65% to 18.53%.

At seven days after spray, the damaged leaves recorded by pongamia oil soap @ 3 per cent was the lowest among different treatments which showed only 3.21% and was statistically on par with standard check - chlorantraniliprole 18.5 SC (4.11%). Pongamia oil soap @ 2 per cent exhibited 5.94% leaf damage considered as next best treatment followed by neem oil soap 0.6 per cent (5.95%) which were statistically similar in results. Leaf damage caused by pongamia oil soap @ 0.6 per cent (8.31%) was statistically on par with pongamia oil soap @ 1% (6.68%). Maximum per cent of leaf damage was observed in untreated control (22.40%) followed by soap solution 0.5 per cent (17.01%). Standard check was on par with pongamia oil soap @ 2 and 1% and neem oil soap 0.6 per cent also.

After fourteen days of treatment application, standard check recorded the lowest Epilachna leaf damage of 4.65% which was on par with pongamia oil soap @ 3 per cent, 2 per cent and neem oil soap 0.6 per cent with 5.20, 7.46 and 7.98% damage respectively. Pongamia oil soap @ 1 and 0.6 per cent were on par with each other which exhibited 8.63 and 10.86% damage however, they were significantly different over control and soap solution even at fourteenth day of spray also. Soap solution 0.5 per cent was on par with untreated control which had 23.42 and 24.29% leaf damage. Pongamia oil soap @ 1 per cent found to be on par with pongamia oil soap @ 2 per cent, 3 per cent and neem oil soap 0.6 per cent.

Table 8. Percentage reduction in leaf hopper population during field evaluation from November 2019 to May 2020

Treatments	Percentage reduction in leaf hopper population *									
	First application					Second application				
	1 DAS	3 DAS	5 DAS	7 DAS	14 DAS	1 DAS	3 DAS	5 DAS	7 DAS	14 DAS
Chlorantraniliprole 18.5 SC 3 mL/10L - 1st application & Thiamethoxam 25 WG 2g/10L - 2nd application	34.33 bc	41.43 b	37.57 b	44.53 ab	14.47 c	63.57 a	79.17 a	85.40 a	85.73 a	88.00 a
Pongamia oil soap @ 3%	61.07 a	60.70 a	57.70 a	53.07 a	43.83 a	50.30 ab	46.00 b	43.17 b	41.90 b	34.87 b
Pongamia oil soap @ 2%	55.23 a	49.97 ab	42.10 b	35.07 bc	39.70 a	47.70 b	30.33 c	32.43 b	26.20 bc	25.50 bc
Pongamia oil soap @ 1%	52.90 ab	38.70 b	32.40 b	28.83 cd	24.43 b	37.60 b	29.20 c	31.73 b	23.93 c	24.85 bc
Pongamia oil soap @ 0.6%	42.77 abc	37.03 b	30.83 b	18.73 de	14.53 c	36.67 b	23.04 c	19.32 c	15.33 cd	20.13 bc
Neem oil soap @ 0.6%	53.53 ab	46.93 ab	36.53 b	30.37 cd	18.67 bc	12.67 c	7.04 d	13.44 c	10.04 cd	11.10 bc
Soap solution @ 0.5%	27.77 c	15.27 c	11.17 c	9.07 ef	9.83 c	13.53 c	8.60 d	8.60 cd	12.99 cd	30.83 bc
Control	0.00 d	0.00 d	0.00 c	0.00 f	0.00 d	0.00 c	0.00 d	0.00 d	0.00 d	0.00 c
C.D. (*P*=0.05)	**28.35**	**14.27**	**15.55**	**12.60**	**21.00**	**15.13**	**10.38**	**12.19**	**21.59**	**33.42**

* Mean of observations of five plants.
Means followed by similar letters are not significantly different by DMRT at 5%
DAS- Days After Spray

4.2.3.2. Mean percentage of damaged leaves by Epilachna grubs and adults (Epilachna sp.) during field evaluation of pongamia oil soap at second spray

Pre count observations on damaged leaves by Epilachna grubs and beetles during second spray was found to be statistically non-significant which indicates that per cent damage was uniform and ranged in between 14.58% to 22.08%.

Significant reduction of per cent leaf damage was observed in pongamia oil soap @ 3 per cent treated plants which was statistically on par with standard check – thiamethoxam 25 WG and the per cent damage were 1.99% and 6.11% respectively. Pongamia oil soap @ 2 per cent with 7.64 per cent accounted as next best treatment which found to be on par with pongamia oil soap @ 1 per cent (9.47%). Pongamia oil soap @ 0.6 per cent showed 14.20% leaf damage and it was on par with pongamia oil soap @ 1 per cent and neem oil soap 0.6 per cent (14.42%). Soap solution 0.5 per cent showed maximum mean per cent damage of 25.34 which was statistically on par with control plot (24.72%).

Plots treated with standard check showed minimum per cent damage (5.80%) by Epilachna at fourteenth day after treatment which was on par with pongamia oil soap @ 3 and 2 per cent with 7.44 and 9.52% respectively. Leaf damage of 11.88% caused by pongamia oil soap @ 1 per cent was on par with pongamia oil soap @ 2 per cent followed by 17.25% and 18.70% leaf damage caused by pongamia oil soap @ 0.6 per cent and neem oil soaps at 0.6 per cent.

Untreated plot showed highest per cent damage by Epilachna (29.61%) which found to be on par with soap solution 0.6 per cent (25.60%).

Table 9. Mean per cent of damaged leaves by grubs and adults of Epilachna beetle, *Epilachna* sp. recorded during 2019 – 2020 under field evaluation

Treatments	Mean per cent of damaged leaves *								
	First application			Second application			Third application		
	1 DBS	7 DAS	14 DAS	1 DBS	7 DAS	14 DAS	1 DBS	7 DAS	14 DAS
Chlorantraniliprole 18.5 SC 3 mL/10L - 1st & 3rd application & Thiamethoxam 25 WG 2g/10L - 2nd application	15.32 (22.89)	4.11 (11.50) ^{de}	4.65 (12.37) ^{d}	14.75 (22.58)	6.11 (14.21) ^{d}	5.80 (13.89) ^{d}	20.07 (26.58)	6.85 (15.16) ^{e}	8.65 (17.11) ^{e}
Pongamia oil soap 3%	17.93 (25.03)	3.21 (10.30) ^{e}	5.20 (13.19) ^{cd}	14.76 (22.55)	1.99 (8.02) ^{d}	7.44 (15.79) ^{d}	33.23 (34.87)	10.44 (18.85) ^{d}	12.31 (20.49) ^{de}
Pongamia oil soap 2%	15.65 (23.16)	5.94 (14.10) ^{cde}	7.46 (15.74) ^{bcd}	17.14 (24.44)	7.64 (15.98) ^{c}	9.52 (17.95) ^{cd}	23.05 (28.62)	13.71 (21.69) ^{c}	17.10 (24.40) ^{cd}
Pongamia oil soap 1%	16.25 (23.69)	6.68 (14.98) ^{cd}	8.63 (17.08) ^{bc}	16.01 (23.51)	9.47 (17.85) ^{bc}	11.88 (20.15) ^{c}	21.80 (27.80)	18.62 (25.55) ^{b}	23.33 (28.85) ^{b}
Neem oil soap 0.6%	16.90 (24.20)	5.95 (14.09) ^{cde}	7.98 (16.28) ^{bcd}	14.58 (22.38)	14.42 (22.26) ^{b}	18.70 (25.61) ^{b}	23.81 (21.61)	18.03 (25.10) ^{b}	22.37 (28.21) ^{bc}
Pongamia oil soap 0.6%	14.65 (22.49)	8.31 (16.69) ^{c}	10.86 (19.19) ^{b}	19.63 (26.21)	14.20 (22.12) ^{b}	17.25 (24.46) ^{b}	35.87 (36.66)	29.78 (33.07) ^{a}	36.20 (36.96) ^{a}
Soap solution 0.5%	14.98 (22.65)	17.01 (24.26) ^{b}	23.42 (28.84) ^{a}	22.08 (27.93)	25.34 (30.16) ^{a}	25.60 (30.38) ^{a}	26.49 (30.81)	31.80 (33.31) ^{a}	38.95 (38.60) ^{a}
Control	18.53 (25.04)	22.40 (28.19) ^{a}	24.29 (29.45) ^{a}	20.57 (26.56)	24.72 (29.67) ^{a}	29.61 (32.82) ^{a}	28.17 (31.83)	34.30 (35.83) ^{a}	42.38 (40.59) ^{a}
C.D. (*P*=0.05)	**NS**	**3.80**	**4.10**	**NS**	**4.61**	**4.29**	**NS**	**2.77**	**4.12**

* Mean of five observations
Means superscripted by same letters are not significantly different by DMRT at 0.05
Figures in parentheses indicates arc sine transformed values
DBS- Day Before Spray; DAS- Days After Spray; NS – Non significant

4.2.3.3. Mean percentage of damaged leaves by Epilachna grubs and adults (Epilachna sp.) during field evaluation of pongamia oil soap at third spray

Per cent damage caused by Epilachna in different treatments found to be non-significant at a day before third spray and the value ranges between 20.07% to 35.87%.

The per cent damage recorded at seven days after third spray in standard check – chlorantraniliprole 18.5 SC (6.85%) was the superior one followed by pongamia oil soap @ 3 per cent (10.44%). Pongamia oil soap @ 2 per cent showed next best result of 13.71% followed by neem oil soap 0.6 per cent (18.03%) and pongamia oil soap @ 1 per cent (18.62%) and both were statistically on par with each other. Untreated control showed 34.30% leaf damage which was the highest over other treatments and found to be on par with soap solution 0.5 per cent and pongamia oil soap @ 0.6 per cent with 31.80 and 29.78% damaged leaves respectively.

At fourteenth day after third treatment application, lowest per cent damaged leaves was recorded in chlorantraniliprole 18.5 SC treated plants with 8.65% which found to be on par with pongamia oil soap @ 3 per cent (12.31%) among the botanicals. Highest leaf damage was observed in control plot, soap solution 0.5 per cent and @ pongamia oil soap 0.6 per cent which were on par with each other with 42.38, 38.95 and 36.20% leaf damage respectively. Neem oil soap 0.6 per cent (22.37%) was statistically on par with pongamia oil soap @ 2 per cent and 1 per cent which had 17.10 and 23.33% damaged leaves respectively. Epilachna leaf damage was significantly reduced in all the concentrations of pongamia oil soap and other treatments except soap solution and control treated plots on seventh and fourteenth day of all the three sprays. Pongamia oil soap @ 3 per cent and standard check were the superior treatments which showed significantly different results on seventh and fourteenth days followed by pongamia oil soap @ 2 per cent, pongamia oil soap @ 1 per cent, neem oil soap 0.6 per cent and pongamia oil soap @ 0.6 per cent in order. Control and soap solution were statistically on par with each other at seven and fourteen days after treatments.

4.2.4. Field evaluation of pongamia oil soap on aphids, *Aphis gossypii* of brinjal during *rabi* season from November 2019 to May 2020

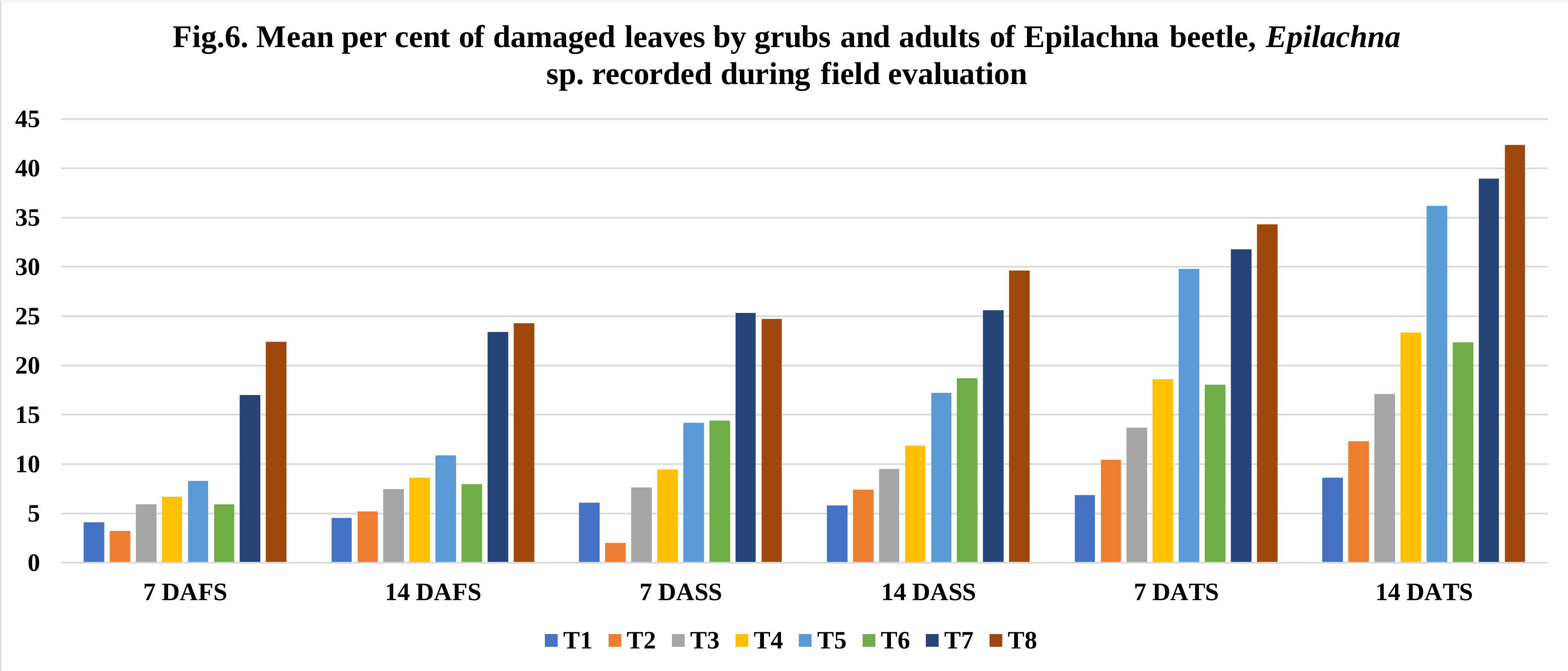
Four different concentrations of pongamia oil soap including pongamia oil soap @ 0.6 per cent, 1 per cent, 2 per cent and 3 per cent along with neem oil 0.6 per cent, soap solution 0.5 per cent, chlorantraniliprole 18.5 SC and thiamethoxam 25 WG and control were tested for their effectiveness on the population of aphids, *Aphis gossypii* during *rabi* season from November 2019 to May 2020. Data were collected from three sprays on a day prior to, 1, 3, 5, 7 and 14 days after spray applications. Data on aphid population were analysed after square root transformation and presented in Table 10.

4.2.4.1. Mean population density of aphids, Aphis gossypii recorded during field evaluation of pongamia oil soap at first application

Mean population of aphids among the different treatments found to be statistically non-significant indicating that there was no difference among them which ranged from 13.26 to 16.93 aphids/ 3 leaves.

The plots treated with pongamia oil soap @ 3 per cent was statistically superior in reducing aphid population to 2.47 aphids/3 leaves while chlorantraniliprole 18.5 SC recorded highest of 22.27 aphids/3 leaves since it is not effective against sucking pests. Pongamia oil soap @ 2 per cent and 1 per cent showed statistically similar results with 4.47 and 5.47 aphids/3 leaves respectively followed by neem oil soap 0.6 per cent (7.33 aphids/3 leaves) on a day after first spray. Control plot showed 12.93 aphids/3 leaves which was on par with pongamia oil soap @ 0.6 per cent (9.87 aphids/3 leaves). Soap solution 0.5 per cent with 20.93 aphids/3 leaves found to be on par with chlorantraniliprole 18.5 SC.

Pongamia oil soap @ 3 per cent stood statistically superior against aphids on three days after application of treatments with 2.73 aphids/3 leaves followed by pongamia oil soap @ 2 per cent and 1 per cent with 7.13 and 7.27 respectively. The next best treatment was pongamia oil soap @ 0.6 per cent (10.47 aphids/3 leaves) which found to be on par with control plot (12.00 aphids/3 leaves) and neem oil soap 0.6 per cent (13.73 aphids/ 3 leaves). Highest aphid count was recorded in chlorantraniliprole



DAFS – Days After First Spray, DASS – Days After Second Spray, DATS – Days After Third Spray

T_1 – Chlorantraniliprole 18.5 SC 3 mL/10L (Spray I & III) & Thiamethoxam 25 WG 2g/10L (Spray II); T_2 – Pongamia oil soap 3%; T_3 – Pongamia oil soap 2%; T_4 – Pongamia oil soap 1%; T_5 – Pongamia oil soap 0.6%; T_6 – Neem oil soap 0.6 %; T_7 – Soap solution 0.5%; T_8 – Control

18.5 SC with 28.70 aphids/3 leaves which was followed by soap solution 0.5 per cent (19.33 aphids/3 leaves).

At fifth day of first spray application also, pongamia oil soap @ 3 per cent showed lowest aphid count of 4.40 aphids/3 leaves which was on par with pongamia oil soap @ 2 per cent (6.40 aphids/3 leaves). Pongamia oil soap @ 1 per cent recorded 9.33 aphids/3 leaves which found to be on par with neem oil soap 0.6 per cent (13.87 aphids/3 leaves). Chlorantraniliprole 18.5 SC exhibited highest aphid population of 28.33 aphids/3 leaves followed by soap solution 0.5 per cent, control plot and pongamia oil soap @ 0.6 per cent which were statistically on par with each other with the aphid count of 17.73, 17.47 and 15.67 aphids/3 leaves respectively.

Observations taken on seventh day after first spray showed that pongamia oil soap @ 3 per cent treated plots was recorded minimum aphid population (4.73 aphids/3 leaves) which was significantly superior than others. Pongamia oil soap @ 1 and 0.6 per cent found to be statistically similar with each other which had 11.87 and 13.33 aphids/3 leaves respectively and were on par with pongamia oil soap @ 2 per cent (9.33 aphids/3 leaves). Chlorantraniliprole 18.5 SC (28.27 aphids/3 leaves) recorded maximum aphid count followed by control plot (22.13 aphids/3 leaves). Neem oil soap 0.6 per cent showed 15.80 aphids/3 leaves which was at par with soap solution 0.5 per cent (20.93 aphids/3 leaves), pongamia oil soap @ 1 and 0.6 per cent.

All the treatments showed a gradual rise in aphid count on fourteen days after spray application with pongamia oil soap @ 3 per cent showed 6.80 aphids/3 leaves whereas soap solution 0.5 per cent marked highest of 42.00 aphids/3 leaves. Pongamia oil soap @ 2, 1 and 0.6 per cent expressed statistically similar results with 13.40, 14.60 and 16.33 aphids/ 3 leaves respectively followed by 20.93 aphids/3 leaves in neem oil soap 0.6 per cent treated plot. Chlorantraniliprole 18.5 SC and control plot with 36.00 and 27.07 aphids/3 leaves respectively found to be on par with soap solution 0.5 per cent.

Table 10. Mean population density of aphids, *Aphis gossypii* recorded during *rabi* 2019 - 2020 under field evaluation

Treatments	Aphid population per three leaves*																	
	First application						Second application						Third application					
	1 DBS	1 DAS	3 DAS	5 DAS	7 DAS	14 DAS	1 DBS	1 DAS	3 DAS	5 DAS	7 DAS	14 DAS	1 DBS	1 DAS	3 DAS	5 DAS	7 DAS	14 DAS
Standard check	16.80 (3.97)	22.27 (4.64) ^{a}	28.40 (5.29) ^{a}	28.33 (5.32) ^{a}	28.27 (5.33) ^{a}	36.00 (5.84) ^{ab}	27.07 (5.19)	0.80 (1.09) ^{e}	0.53 0.70) ^{c}	0.40 (0.91) ^{d}	0.13 (0.78) ^{d}	0.27 (0.85) ^{c}	25.60 (5.01)	14.07 (3.74) ^{cd}	15.27 (3.89) ^{cd}	21.17 (4.59) ^{c}	26.47 (5.13) ^{c}	32.87 (5.73) ^{c}
Pongamia oil soap 3%	13.87 (3.72)	2.47 (1.57) ^{e}	2.73 (1.65) ^{e}	4.40 (2.09) ^{e}	4.73 (2.26) ^{f}	6.80 (2.58) ^{d}	22.07 (4.69)	3.40 (1.94) ^{d}	9.13 (3.00) ^{bc}	11.73 (3.50) ^{c}	14.13 (3.81) c	17.33 (4.13) ^{b}	22.13 (4.66)	5.40 (2.20) ^{e}	8.40 (2.88) ^{e}	10.80 (3.28) ^{e}	14.80 (3.84) ^{d}	18.60 (4.30) ^{e}
Pongamia oil soap 2%	13.33 (3.63)	4.47 (2.11) ^{de}	7.13 (2.67) ^{d}	6.40 (2.53) ^{de}	9.33 (3.13) ^{e}	13.40 (3.64) ^{cd}	22.20 (4.71)	5.27 (2.39) ^{cd}	9.27 (3.02) ^{ab}	12.33 (3.56) ^{c}	15.00 (3.92) ^{c}	20.07 (4.51) ^{b}	28.33 (5.31)	12.00 (3.46) ^{d}	13.47 (3.66) ^{d}	15.20 (3.89) ^{d}	17.73 (4.21) ^{d}	24.93 (4.99) ^{d}
Pongamia oil soap 1%	15.28 (3.89)	5.47 (2.33) ^{de}	7.27 (2.69) ^{d}	9.33 (3.05) ^{cd}	11.87 (3.51) ^{de}	14.60 (3.81) ^{cd}	23.20 (4.81)	9.20 (3.10) ^{bc}	11.80 (3.38) ^{ab}	13.07 (3.67) ^{bc}	18.20 (4.30) ^{c}	21.36 (4.66) ^{b}	24.73 (4.87)	14.40 (3.79) ^{cd}	17.87 (4.22) ^{c}	20.20 (4.49) ^{c}	24.80 (4.97) ^{c}	28.80 (5.36) ^{cd}
Pongamia oil soap 0.6%	13.26 (3.63)	9.87 (3.14) ^{bc}	10.47 (3.23) ^{cd}	15.67 (3.96) ^{b}	13.33 (3.71 de	16.33 (3.99) ^{cd}	23.67 (4.86)	10.27 (3.28) ^{b}	12.87 (3.58) ^{a}	14.00 (3.80) ^{bc}	19.53 (4.45) ^{c}	33.60 (5.79) ^{ab}	32.48 (5.68)	18.47 (4.28) ^{bc}	22.00 (4.68) ^{b}	23.40 (4.83) ^{c}	28.20 (5.31) ^{c}	32.53 (5.70) ^{c}
Neem oil soap 0.6%	16.93 (4.11)	7.33 (2.70) ^{cd}	13.73 (3.70) ^{c}	13.87 (3.70) ^{bc}	15.80 (4.03) ^{cd}	20.93 (4.56) ^{bc}	26.13 (5.10)	20.07 (4.52) ^{a}	33.67 (5.79) ^{a}	36.67 (6.08) ^{a}	36.93 (6.12) ^{a}	50.93 (6.99) ^{a}	30.60 (5.51)	21.47 (4.63) ^{b}	25.27 (5.02) ^{b}	28.93 (5.37) ^{b}	32.20 (5.67) ^{b}	41.80 (6.46) ^{b}
Soap solution 0.5%	14.73 (3.83)	20.93 (4.57) ^{a}	19.33 (4.37) ^{b}	17.73 (4.19) ^{b}	20.93 (4.61) ^{bc}	42.00 (6.38) ^{a}	23.33 (4.82)	22.67 (4.80) ^{a}	23.13 (4.65) ^{a}	32.27 (5.32) ^{ab}	39.87 (6.32) ^{a}	37.33 (6.07) ^{ab}	27.80 (5.27)	34.73 (5.88) ^{a}	33.97 (5.82) ^{a}	38.07 (6.16) ^{a}	42.07 (6.47) ^{a}	45.80 (6.76) ^{ab}
Control	15.80 (3.96)	12.93 (3.57) ^{b}	12.00 (3.46) ^{c}	17.47 (4.14) ^{b}	22.13 (4.73) ^{ab}	27.07 (5.18) ^{abc}	22.40 (4.73)	20.33 (4.53) ^{a}	21.47 (4.63) ^{a}	25.67 (5.11) ^{abc}	27.47 (5.28) ^{b}	53.53 (7.26) ^{a}	32.60 (5.70)	37.27 (6.10) ^{a}	36.60 (6.04) ^{a}	42.40 (6.51) ^{a}	47.47 (6.88) ^{a}	49.40 (7.02) ^{a}
C.D. (*P*=0.05)	**NS**	**0.78**	**0.66**	**0.68**	**0.66**	**1.66**	**NS**	**0.70**	**1.14**	**1.75**	**0.65**	**2.04**	**NS**	**0.64**	**0.44**	**0.44**	**0.48**	**0.51**

* Mean of five observations
Means followed by similar alphabets don’t differ significantly by DMRT at 5%
Figures in parentheses indicates square root transformed values
DBS- Day Before Spray; DAS- Days After Spray; NS – Non significant

4.2.4.2. Mean population density of aphids, Aphis gossypii recorded during field evaluation of pongamia oil soap at second application

Aphid population during a day before second spray application showed no significant difference among the treatments which was at a range of 22.07 – 27.07 aphids/3 leaves/plant.

After a day of second treatment application, a reduction in the aphid population was observed in all the treatments and the maximum reduction was recorded in thiamethoxam 25 WG treated plants with 0.80 aphids/3 leaves. Among the botanicals, pongamia oil soap @ 3 per cent showed least population of aphids (3.40 aphids/3 leaves) which was at par with pongamia oil soap @ 2 per cent (5.27 aphids/3 leaves). Soap solution 0.5 per cent recorded highest aphid population (22.67 aphids/3 leaves) followed by control (20.33 aphids/3 leaves) and neem oil soap 0.6 per cent (20.07 aphids/3 leaves) and were statistically on par with each other. Pongamia oil soap @ 1 per cent showed 9.20 aphids/3 leaves which was on par with pongamia oil soap @ 0.6 (10.27 aphids/3 leaves) and 2 per cent.

After three days of spray, standard check exhibited significantly lowest population of aphids (0.53 aphids/3 leaves) followed by 9.13 aphids/3 leaves in pongamia oil soap @ 3 per cent treated plants. Highest aphid count was observed in neem oil soap 0.6 per cent treated plots (33.67 aphids/3 leaves) followed by soap solution 0.5% (23.13 aphids/3 leaves) and untreated control (21.47 aphids/3 leaves). Pongamia oil soap @ 2 and 1 per cent expressed statistically similar results with 9.27 and 11.80 aphids/3 leaves respectively followed by pongamia oil soap @ 0.6 per cent with 12.87 aphids/3 leaves.

Standard check was the superior treatment on fifth day of second spray which exhibited 0.13 aphids/3 leaves while soap solution showed highest of 36.67 aphids/3 leaves. Pongamia oil soap @ 3 per cent was the best treatment among botanical insecticides which was statistically at par with pongamia oil soap @ 2 per cent (12.33 aphids/3 leaves).

Pongamia oil soap @ 1 and 0.6 per cent showed statistically same results which had 13.07 and 14.00 aphids/3 leaves respectively. Neem oil soap 0.6 per cent exhibited maximum count of 36.67 aphids/3 leaves and it was statistically on par with soap solution 0.5 per cent (32.27 aphids/3 leaves) and control plot (25.67 aphids/3 leaves).

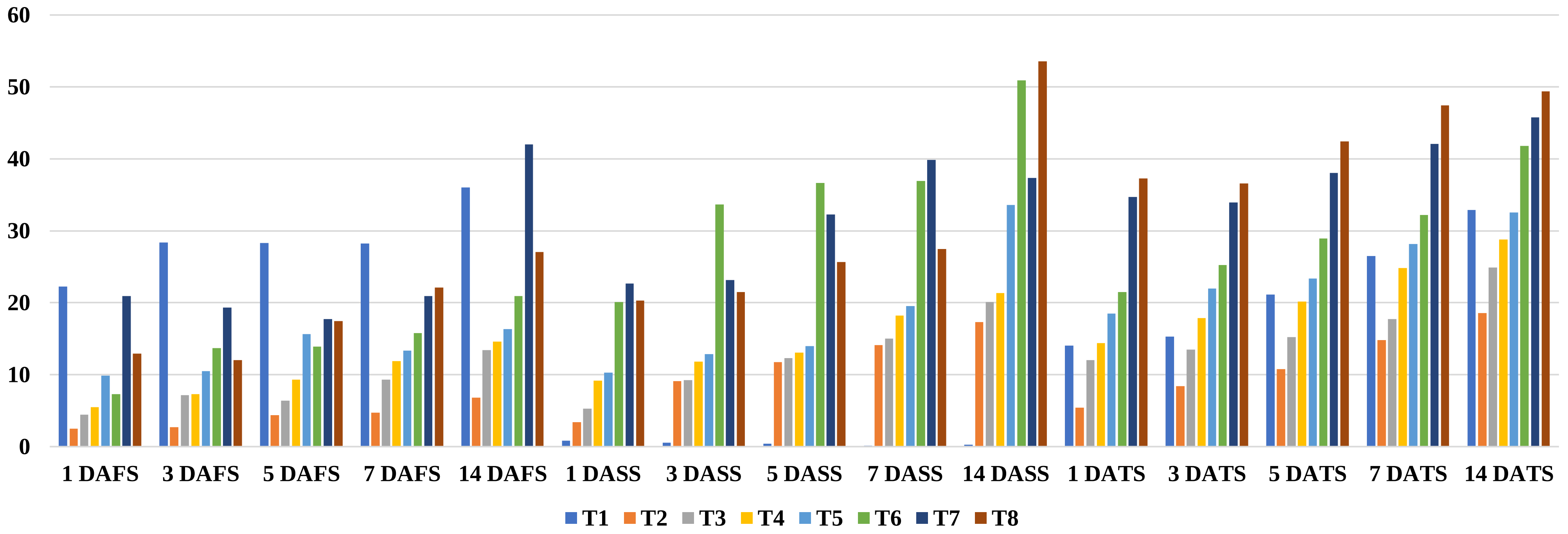
Observations made on seventh day of second application revealed that standard check treated plot as statistically superior which recorded lowest aphid population of 0.40 aphids/3 leaves followed by pongamia oil soap @ 3 per cent (14.13 aphids/3 leaves). Pongamia oil soap @ 2 per cent, 1 per cent and 0.6 per cent were statistically on par with each other in which 15.00, 18.20 and 19.53 aphids/3 leaves were recorded. Soap solution 0.5 per cent was the highest in aphid population with 39.87 aphids/3 leaves which was on par with neem oil soap 0.6 per cent (36.93 aphids/3 leaves) followed by untreated plants (27.47 aphids/3 leaves).

All the treatments showed a steady increase in the population of aphids except standard check – thiamethoxam 25 WG (0.27 aphids/3 leaves) at fourteenth day after second treatment application. Among the botanicals, pongamia oil soap @ 3 per cent showed lowest aphid population of 17.33 aphids/3 leaves which found to be on par with pongamia oil soap @ 2 and 1 per cent with 20.07 and 21.36 aphids/3 leaves respectively. Soap solution 0.5 per cent showed 37.33 aphids/3 leaves which found to be on par with pongamia oil @ 0.6 per cent (33.60 aphids/3 leaves). Control plot showed highest aphid population of 53.53 aphids/3 leaves followed by neem oil soap 0.6 per cent (50.93 aphids/3 leaves).

4.2.4.3. Mean population density of aphids, Aphis gossypii recorded during field evaluation of pongamia oil soap at third spray application

Pre count found to be statistically non-significant among various treatments during third spray which was in the range of 22.13 – 32.60 aphids/ 3 leaves.

Fig.7. Mean population density of aphids, *Aphis gossypii* recorded during field evaluation from November 2019 to May 2020



DAFS – Days After First Spray, DASS – Days After Second Spray, DATS – Days After Third Spray

T_1 – Chlorantraniliprole 18.5 SC 3 mL/10L (Spray I & III) & Thiamethoxam 25 WG 2g/10L (Spray II); T_2 – Pongamia oil soap 3%;

T_3 – Pongamia oil soap 2%; T_4 – Pongamia oil soap 1%; T_5 – Pongamia oil soap 0.6%;

T_6 – Neem oil soap 0.6 %; T_7 – Soap solution 0.5%; T_8 – Control

One day after third spray, the lowest aphid count was shown by pongamia oil soap 3 per cent (5.40 aphids/3 leaves) which was significantly superior over other treatments. It was followed by pongamia oil soap @ 2 per cent (12.00 aphids/3 leaves) which found to be statistically on par with chlorantraniliprole 18.5 SC and pongamia oil soap 1 per cent with 14.07 and 14.40 aphids/3 leaves respectively. The next best result was by pongamia oil soap @ 0.6 per cent followed by neem oil soap 0.6 per cent which showed 18.47 and 21.47 aphids/3 leaves respectively. Soap solution and untreated control plots were on par with each other which had 34.73 and 37.27 aphids/3 leaves.

After three days of third spray, significantly lowest aphid count was observed in pongamia oil soap @ 3 per cent treated plants with 8.40 aphids/3 leaves while control plot expressed highest population of 36.60 aphids/3 leaves which was on par with 33.97 aphids/3 leaves from soap solution 0.5 per cent treated plants. Next best results were obtained from pongamia oil soap @ 2 per cent treated plants (13.47 aphids/3 leaves) which was on par with chlorantraniliprole 18.5 SC and pongamia oil soap @ 1 per cent with 15.27 and 17.87 aphids respectively. Pongamia oil soap @ 0.6% and neem oil soap at 0.6 per cent showed statistically similar results with 22.00 and 25.27 aphids/3 leaves respectively.

Pongamia oil soap @ 3 per cent expressed the best result of 10.80 aphids/3 leaves over other treatments which was followed by pongamia oil soap @ 2 per cent which showed 15.20 aphids/3 leaves on five days after third treatment application. Maximum count of aphids was observed in control plot followed by soap solution 0.5 per cent and were statistically similar in results with 42.40 and 38.07 aphids/3 leaves respectively. Pongamia oil soap @ 1 per cent, chlorantraniliprole 18.5 SC and pongamia oil soap @ 0.6 per cent were on par with each other with 20.20, 21.17 and 23.40 aphids/ 3 leaves respectively. However, all the treatments were found to be significantly different from control and soap solution including neem oil soap 0.6 per cent (28.93 aphids/3 leaves).

Observations taken on seven days after third spray showed that, pongamia oil soap at @ 3 and 2 per cent concentrations showed statistically similar results of 14.80

and 17.73 aphids/3 leaves respectively whereas control and soap solution 0.5 per cent recorded highest of 47.47 and 42.07 aphids per 3 leaves respectively. Pongamia oil soap @ 1, pongamia oil soap 0.6 per cent and chlorantraniliprole 18.5 SC gave statistically same results of 24.80, 26.47 and 28.20 aphids/ 3 leaves respectively. Neem oil soap 0.6 per cent was shown 32.20 aphids/3 leaves which was the last best treatment among botanicals however, it was significantly different from control and soap solution.

There was a gradual rise in population density of aphids on fourteenth day of third application when the pongamia oil soap @ 3 per cent showing 18.60 aphids/ 3 leaves which was significantly different over other treatments. Highest population density was observed in control with 49.40 aphids/ 3 leaves which was on par with soap solution 0.5 per cent (45.80 aphids/ 3 leaves). The second-best treatment was pongamia oil soap @ 2 per cent followed by pongamia oil soap 1 and 0.6 per cent and chlorantraniliprole 18.5 SC which showed 24.93, 28.80, 32.53 and 32.87 aphids/3 leaves respectively. Neem oil soap 0.6 per cent recorded 41.80 aphids which was on par with soap solution.

4.2.5. Field evaluation of pongamia oil soap on red spider mites, *Tetranychus urticae* infestation in brinjal during *rabi* season from November 2019 to May 2020

Pongamia oil soap at four different concentrations such as pongamia oil soap @ 0.6, 1, 2 and 3 per cent along with neem oil 0.6 per cent, soap solution 0.5 per cent, chlorantraniliprole 18.5 SC and thiamethoxam 25 WG and control were investigated to derive their effectiveness against red spider mites, *Tetranychus urticae* during rabi season from November 2019 to May 2020. Observations were recorded on a day prior to, 1, 3, 5, 7 and 14 days after spray application. Since the infestation of red spider mites was absent during first and third spray, it was recorded from second spray application only. Data recorded on mite population were analysed after square root transformation and presented in Table 11.

4.2.5.1. Average population density of red spider mites (RSM), Tetranychus urticae recorded during field evaluation of pongamia oil soap

Red spider mite population recorded on a day before treatment application revealed that there was no significant difference among the treatments which was at a range of 43.67 – 54.53 RSM/ 3 leaves.

Pongamia oil soap @ 3 per cent showed significantly lowest population of red spider mites with 5.53 RSM/ 3 leaves which found to be on par with pongamia oil soap @ 2 per cent. Soap solution recorded highest red spider mite’s population of 91.40 RSM/ 3 leaves, it was on par with control plot (48.53 RSM/ 3 leaves). Pongamia oil soap @ 1 per cent and 0.6 per cent showed statistically same results in reducing red spider mite population with 11.53 and 12.67 RSM/ 3 leaves. Neem oil soap 0.6 per cent (20.20 RSM/ 3 leaves) found to be on par with thiamethoxam 25 WG (33.73 RSM/ 3 leaves) and both were on par with pongamia oil soap @ 0.6 and 1 per cent. Neem oil soap 0.6 per cent was on par with pongamia oil soap @ 2 and 3 per cent also on a day after spray application.

On three days after spray, pongamia oil soap @ 3 per cent showed lowest red spider mite population of 16.33 RSM/ 3 leaves followed by pongamia oil soap @ 2, 1, 0.6 per cent and neem oil soap 0.6 per cent with 20.47, 21.07, 21.93 and 27.27 RSM/ 3 leaves respectively and they were on par with each other. Soap solution 0.5 per cent recorded highest mite count (55.07 RSM/ 3 leaves) which was on par with control 50.73 RSM/ 3 leaves. Thiamethoxam 25 WG treated plants was on par with all other tested treatments with 35.13 RSM/ 3 leaves.

Observations taken on five days after treatment application indicated that pongamia oil soap @ 3 per cent expressed minimum of 24.40 RSM/ 3 leaves followed by pongamia oil soap @ 2 per cent and 1 per cent, neem oil soap and pongamia oil soap at @ 0.6 per cent with 34.87, 35.67, 37.93 and 38.93 RSM/ 3 leaves. Soap solution 0.5 per cent recorded highest mite count of 76.67 RSM/ 3 leaves which was on par with control (64.73 RSM/ 3 leaves) and thiamethoxam 25 WG (61.53 RSM/ 3 leaves).

Mite population was lowest in pongamia oil soap @ 3 per cent treated plants (35.13 RSM/ 3 leaves) on seven days after treatment application which was on par with pongamia oil soap @ 2 and 1 per cent with 36.60 and 41.67 RSM/ 3 leaves respectively. Pongamia oil soap @ 0.6 per cent (50.60 RSM/ 3 leaves) was on par with neem oil soap 0.6 per cent (53.93 RSM/ 3 leaves) and pongamia oil soap @ 1 and 2 per cent. Maximum population was observed in soap solution 0.5 per cent with 85.13 RSM/ 3 leaves which was on par with thiamethoxam 25 WG (74.47 RSM/ 3 leaves) followed by control (59.40 RSM/ 3 leaves).

Increased population of mites was observed in all the treatments after fourteen days of the spray with pongamia oil soap @ 3 per cent showing 47.67 RSM/ 3 leaves which was on par with pongamia oil soap @ 2 per cent (55.73 RSM/ 3 leaves), 1 per cent (62.47 RSM/ 3 leaves) and 0.6 per cent (64.93 RSM/ 3 leaves). Neem oil soap 0.6 per cent (65.47 RSM/ 3 leaves) was on par with soap solution 0.5 per cent (73.20 RSM/ 3 leaves) pongamia oil soap @ 0.6 and 1 per cent, control plot (74.73 RSM/ 3 leaves) and thiamethoxam treated plot which showed maximum mite population.

4.2.5.2. Percentage reduction in red spider mite* (*Tetranychus urticae*) *population during field evaluation of pongamia oil soap

Percentage reduction in red spider mite population for the different treatments was calculated and presented in Table 12.

Pongamia oil soap @ 3, 2 and 1 per cent were statistically on par with each other in reducing the red spider mite population which showed 86.50, 84.57 and 79.27% respectively while soap solution 0.5 per cent (0.17%) and the insecticide thiamethoxam 25 WG (19.60%) were on par with control (0.00%) in the population reduction. Pongamia oil soap @ 0.6 per cent with 76.40% population reduction was on par (57.13%), pongamia oil soap @ 1, 2 and 3 per cent at one day after treatment application.

Table 11. Average population density of red spider mites, *Tetranychus urticae* recorded during November 2019 to May 2020 under field evaluation

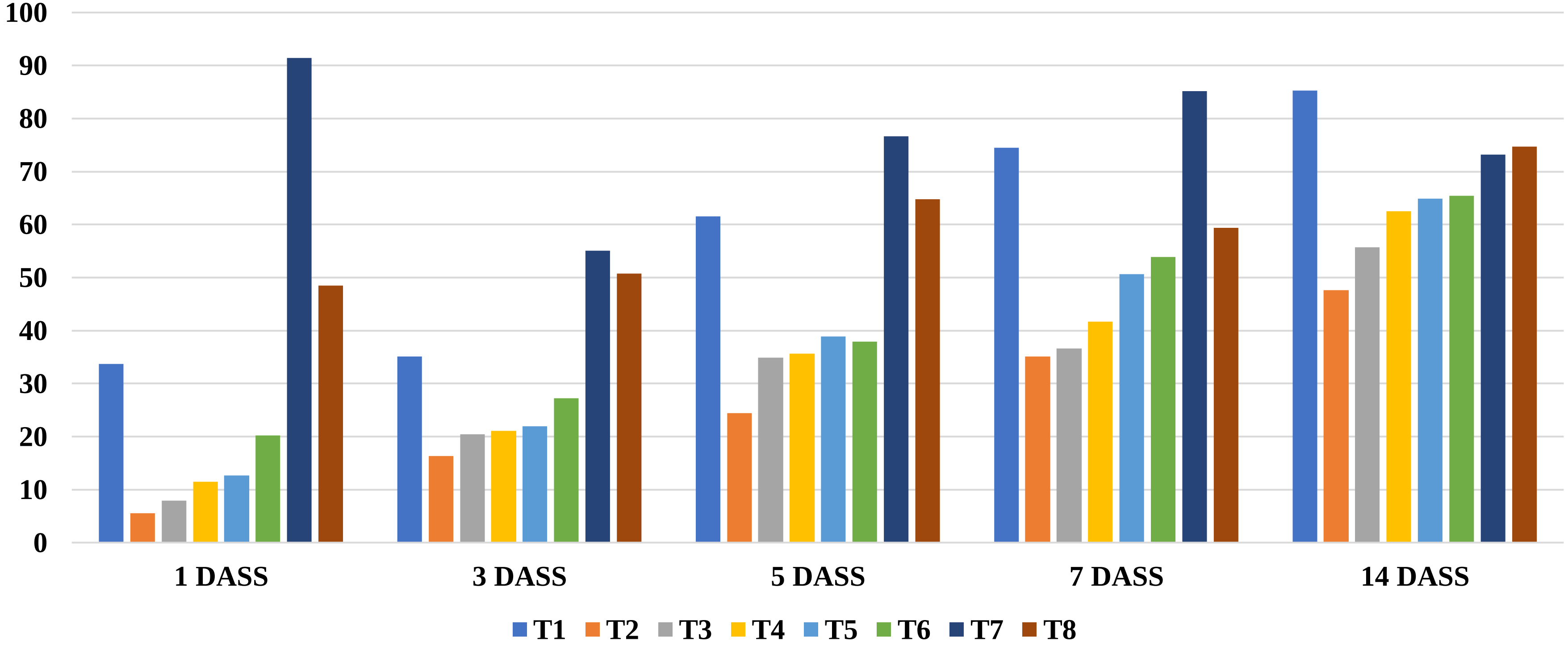
Treatments	Number of mites per 3 cm^2 area of three leaves *					
	Second application					
	1 DBS	1 DAS	3 DAS	5 DAS	7 DAS	14 DAS
Thiamethoxam 25 WG 2g/10L	54.53 (6.93)	33.73 (5.74) ^{bc}	35.13 (5.69) ^{ab}	61.53 (7.83) ^{a}	74.47 (8.61) ^{ab}	85.33 (9.22) ^{a}
Pongamia oil soap 3%	43.67 (6.59)	5.53 (2.23) ^{d}	16.33 (4.02) ^{b}	24.40 (4.93) ^{c}	35.13 (5.92) ^{f}	47.67 (6.92) ^{d}
Pongamia oil soap 2%	50.47 (7.09)	7.87 (2.78) ^{d}	20.47 (4.50) ^{b}	34.87 (5.89) ^{bc}	36.60 (6.03) ^{ef}	55.73 (7.43) ^{cd}
Pongamia oil soap 1%	46.20 (6.70)	11.53 (3.34) ^{cd}	21.07 (4.55) ^{b}	35.67 (5.96) ^{b}	41.67 (6.43) ^{def}	62.47 (7.93) ^{bcd}
Pongamia oil soap 0.6%	51.00 (7.11)	12.67 (3.45) ^{cd}	21.93 (4.63) ^{b}	38.93 (6.22) ^{b}	50.60 (7.10) ^{cde}	64.93 (8.07) ^{abcd}
Neem oil soap 0.6%	47.13 (6.85)	20.20 (4.37) ^{bcd}	27.27 (5.16) ^{b}	37.93 (6.13) ^{b}	53.93 (7.33) ^{cd}	65.47 (8.09) ^{abc}
Soap solution 0.5%	67.00 (7.70)	91.40 (9.10) ^{a}	55.07 (7.30) ^{a}	76.67 (8.74) ^{a}	85.13 (9.18) ^{a}	73.20 (8.58) ^{ab}
Control	47.47 (6.89)	48.53 (6.96) ^{ab}	50.73 (7.09) ^{a}	64.73 (8.02) ^{a}	59.40 (7.70) ^{bc}	74.73 (8.67) ^{ab}
C.D. (*P*=0.05)	**NS**	**2.60**	**1.86**	**1.03**	**1.17**	**1.16**

* Mean of five observations
Means followed by similar alphabets don’t differ significantly by DMRT at 5%
Figures in parentheses denotes square root transformed values
DBS- Day Before Spray; DAS- Days After Spray; NS – Non significant

On three days after spray application, highest population reduction was observed in pongamia oil soap @ 3 per cent which was on par with pongamia oil soap @ 2, 1 and 0.6 per cent with 61.17, 57.90, 55.10 and 53.93% decrease in population of mites respectively. Soap solution 0.5 per cent with only 16.00% reduction was on par with control (0.00%) and thiamethoxam 25 WG (32.43%). Neem oil soap 0.6 per cent was the last best treatment among botanicals with 45.73% reduction it was on par with pongamia oil soap @ 3, 2, 1 and 0.6 per cent. Population reduction in pongamia oil soap @ 3 per cent (55.67%) was the highest among all the treatments while soap solution showed increased population of mites with negative sign (-23.3%) which was on par with thiamethoxam 25 WG (5.33%) and control (0.00%) at fifth day of spray. Pongamia oil soap @ 2 per cent, 1 per cent and neem oil soap 0.6 per cent were statistically similar in population reduction which recorded 44.00, 41.40 and 38.00% respectively.

On seven days after spray, pongamia oil soap @ 3 per cent and 2 per cent were on par with each other with 42.00 and 40.33 per cent reduction of mite population. Pongamia oil soap @ 1 and 0.6 per cent expressed statistically similar results in reducing the mite population with 18.00% and 17.02%. However, soap solution 0.5 per cent, thiamethoxam and untreated plot showed no reduction in population indeed and negative results were recorded (-47.00, -35, and 0.00% respectively). On fourteenth day of the spray, population reduction of red spider mites turned into statistically non-significant in pongamia @ 3, 2, 1, 0.6 per cent and neem oil soap 0.6 per cent treated plots which recorded 31.33, 19.00, 18.67, 17.67 and 16.33% respectively. However, thiamethoxam 25 WG and soap solution 0.5 per cent failed to reduce mite population which indicated by negative sign of -32% and -4.3% and both were on par with control plot.

Fig.8. Average population density of red spider mites, *Tetranychus urticae* recorded during field evaluation from November 2019 to May 2020



DASS – Days After Second Spray

T_1 –Thiamethoxam 25 WG 2g/10L (Spray II); T_2 – Pongamia oil soap 3%;

T_3 – Pongamia oil soap 2%; T_4 – Pongamia oil soap 1%; T_5 – Pongamia oil soap 0.6%;

T_6 – Neem oil soap 0.6 %; T_7 – Soap solution 0.5%; T_8 – Control

4.2.6. Field evaluation of pongamia oil soap on whiteflies, *Bemisia tabaci* of brinjal during *rabi* season from November 2019 to May 2020

Different concentrations of pongamia oil soap (3, 2, 1 and 0.6 per cent), neem oil 0.6 per cent, soap solution 0.5 per cent, chlorantraniliprole 18.5 SC and thiamethoxam 25 WG and control were tested for their efficacy on whitefly (*Bemisia tabaci*) during *rabi* season from November 2019 to May 2020. observations were recorded from three sprays on a day prior to, 1, 3, 5, 7 and 14 days after spray application. Data on aphid population were analysed after square root transformation and presented in Table 13.

4.2.6.1. Average population density of whiteflies, Bemisia tabaci recorded during field evaluation of pongamia oil soap at first spray application

No significant difference was recorded in the population density of whiteflies on one day prior to spray application and the count ranged from 4.60 to 6.00 whiteflies/ 3 leaves.

After a day of spray application, minimum population of whiteflies recorded in pongamia oil soap @ 3 per cent (0.80 whiteflies/ 3 leaves) which was statistically on par with pongamia oil soap @ 2 per cent (0.93 whiteflies/ 3 leaves) and pongamia oil soap @ 1 per cent (1.20 whiteflies/ 3 leaves). Soap solution 0.5 per cent and untreated control recorded highest population of 6.20 and 6.00 whiteflies/ 3 leaves and were on par with each other. Pongamia oil soap @ 0.6 per cent (1.60 whiteflies/ 3 leaves) and neem oil soap 0.6 per cent (1.67 whiteflies/ 3 leaves) gave statistically similar population density of whiteflies followed by chlorantraniliprole 18.5 SC (3.60 whiteflies/ 3 leaves).

Observations of third day after spray revealed that pongamia oil soap @ 3% was significantly superior over others with 0.87 whiteflies/ 3 leaves followed by pongamia oil soap @ 2% (1.40 whiteflies/ 3 leaves). Pongamia oil soap @ 1 and 0.6% were statistically on par with each other with 1.73 and 2.13 whiteflies/ 3 leaves respectively. Chlorantraniliprole showed 2.27 whiteflies/ 3 leaves which was statistically on par with neem oil soap 0.6 per cent (2.60 whiteflies/ 3 leaves). Maximum population was observed in control plot followed by soap solution 0.5% which had 6.00 and 5.73 whiteflies/ 3 leaves.

Pongamia oil soap @ 3% recorded a smaller number of whiteflies about 1.00 per 3 leaves which was the superior treatment over others on the fifth day of spray. Pongamia oil soap @ 2 and 1 per cent were on par with each other showing 1.40 and 1.53 whiteflies/ 3 leaves respectively followed by pongamia oil soap @ 0.6% (2.20 whiteflies/ 3 leaves). Soap solution recorded high number of whiteflies (6.07 whiteflies/ 3 leaves) which was on par with untreated control (6.00 whiteflies/ 3 leaves). Neem oil soap 0.6% with 2.40 whiteflies/ 3 leaves was on par with chlorantraniliprole 18.5 SC (3.47 whiteflies/ 3 leaves).

On seventh day after spray, pongamia oil soap @ 3 per cent showed best result of 1.40 whiteflies/ 3 leaves which was on par with pongamia oil soap @ 2%, neem oil soap 0.6%, pongamia oil soap @ 1% and 0.6% and chlorantraniliprole 18.5 SC with the whitefly population of 1.60, 1.60, 1.67, 2.00 and 3.53 whiteflies per 3 leaves respectively. Control with highest population of 7.47 whiteflies/ 3 leaves was on par with soap solution (7.13 whiteflies/ 3 leaves).

On fourteen day of spray, pongamia oil soap @ 3%, neem oil soap @ 0.6%, pongamia oil soap @ 2%, 1% and 0.6% were on par with each other with 1.47, 2.27, 2.93, 3.53 and 3.73 whiteflies/ 3 leaves respectively. Control plot recorded maximum population of 7.40 whiteflies/ 3 leaves followed by soap solution and chlorantraniliprole with 7.33 and 7.27 whiteflies/ 3 leaves respectively.

4.2.6.2. Average population density of whiteflies, Bemisia tabaci recorded during field evaluation of pongamia oil soap at second spray application

Pre count of whitefly population was non-significant among different treatments before second spray which was in between 5.20 – 5.80 whiteflies/ 3 leaves.

Table 12. Percentage reduction in red spider mite's population during field evaluation from November 2019 to May 2020

Treatments	Percentage reduction in mites *				
	Second application				
	1 DAS	3 DAS	5 DAS	7 DAS	14 DAS
Thiamethoxam 25 WG 2g/10L	19.60 [c]	32.43 [bc]	5.33 [c]	-35 [c]	-32 [b]
Pongamia oil soap 3%	86.50 [a]	61.17 [a]	55.67 [a]	42.00 [a]	31.33 [a]
Pongamia oil soap 2%	84.57 [a]	57.90 [a]	44.00 [ab]	40.33 [a]	19.00 [a]
Pongamia oil soap 1%	79.27 [a]	55.10 [a]	41.40 [ab]	18.00 [b]	18.67 [a]
Pongamia oil soap 0.6%	76.40 [ab]	53.93 [a]	37.07 [b]	17.02 [b]	17.67 [a]
Neem oil soap 0.6%	57.13 [b]	45.73 [ab]	38.00 [ab]	6.33 [bc]	16.33 [a]
Soap solution 0.5%	0.17 [c]	16.00 [cd]	-23.3 [c]	-47.00 [c]	-4.3 [b]
Control	0.00 [c]	0.00 [d]	0.00 [c]	0.00 [c]	0.00 [b]
C.D. (*P*=0.05)	**21.03**	**21.04**	**17.78**	**13.14**	**15.96**

* Mean of observations of five plants.
Means followed by similar letters are not significantly different by DMRT at 5%
DAS- Days After Spray; NS – Non-Significant

Among the botanicals, pongamia oil soap @ 3% recorded lowest population of 0.67 whiteflies/ 3 leaves which found to be statistically on par with standard check – thiamethoxam 25 WG (0.73 whiteflies/ 3 leaves), pongamia oil soap @ 2% (1.00 whiteflies/ 3 leaves) and pongamia oil soap 1% (1.13 whiteflies/ 3 leaves). Pongamia oil soap @ 0.6% and neem oil soap 0.6% expressed statistically same results of 2.27 whiteflies/ 3 leaves. Untreated control and soap solution 0.5% plot were on par with each other with 5.13 and 4.80 whiteflies/ 3 leaves respectively.

On three days after spray application, the effectiveness of the treatments in the following order; pongamia oil soap @ 3% (0.80 whiteflies/ 3 leaves) > standard check (0.93 whiteflies/ 3 leaves) > pongamia oil soap @ 2% (1.13 whiteflies/ 3 leaves) > pongamia oil soap @ 1% (1.13 whiteflies/ 3 leaves) > pongamia oil soap @ 0.6% (1.20 whiteflies/ 3 leaves) > neem oil soap 0.6% (1.27 whiteflies/ 3 leaves). Soap solution 0.5% showed highest population of 5.33 whiteflies/ 3 leaves which was on par with control (5.13 whiteflies/ 3 leaves).

Data recorded on fifth day of second application showed that 0.97 whiteflies/ 3 leaves in pongamia oil soap @ 3% as best treatment while control plot showed highest population of 5.67 whiteflies/ 3 leaves. Pongamia oil soap @ 2 and 1%, neem oil soap 0.6% and pongamia oil soap @ 0.6% gave statistically similar results with 1.33, 1.67, 1.67 and 1.87 whiteflies/ 3 leaves respectively. Soap solution 0.5% with 5.53 whiteflies/ 3 leaves was on par with control plot.

Observations of seventh day proved that pongamia oil soap @ 3% was superior over others with 1.40 whiteflies/ 3 leaves followed by pongamia oil soap @ 2% and 1% with 2.33 and 2.47 whiteflies/ 3 leaves. Standard check and neem oil soap 0.6% were on par with each other followed by pongamia oil soap @ 0.6% with 3.00, 3.47 and 3.80 whiteflies/ 3 leaves respectively. Highest count was recorded in soap solution 0.5% followed by control with 6.00 and 5.80 whiteflies/ 3 leaves respectively.

On fourteenth day of spray, standard check showed lowest count with 0.87 whiteflies/ 3 leaves followed by pongamia oil soap @ 3%, neem oil soap 0.6%, pongamia oil soap @ 2%, 1% and 0.6% with 2.27, 2.33, 2.53, 2.87 and 3.07 whiteflies/ 3 leaves respectively. Control plot showed maximum count of 6.67 whiteflies/ 3 leaves followed by soap solution 0.5% (6.27 whiteflies/ 3 leaves).

4.2.6.3. Average population density of whiteflies, Bemisia tabaci recorded during field evaluation of pongamia oil soap at third spray application

Pre count of whiteflies was non-significant at third spray which ranged from 5.33 to 6.00 whiteflies/ 3 leaves.

One day after third spray, lowest population was observed in pongamia oil soap @ 3% treated plants followed by pongamia oil soap @ 2% with 1.57 and 2.20 whiteflies/ 3 leaves respectively. Pongamia oil soap @ 2% and neem oil soap 0.6% were on par with each other with 2.53 and 3.33 whiteflies/ 3 leaves respectively. Pongamia oil soap @ 0.6% and chlorantraniliprole 18.5 SC expressed statistically same results with 3.93 and 4.20 whiteflies/ 3 leaves respectively. Control plot recorded maximum count of 7.07 whiteflies/ 3 leaves followed by 4.93 whiteflies/ 3 leaves.

The best results showed by pongamia oil soap @ 3 per cent on third after spray followed by pongamia oil soap @ 2 and 1 per cent with 2.13, 3.27 and 3.40 whiteflies/ 3 leaves respectively. Highest whitefly population was recorded in untreated plot (7.53 whiteflies/ 3 leaves). Pongamia oil soap @ 0.6%, soap solution 0.5% and neem oil soap 0.6% were statistically similar with 4.73, 5.27 and 5.60 whiteflies/ 3 leaves respectively. Chlorantraniliprole 18.5 SC (4.67 whiteflies/ 3 leaves) was on par with pongamia oil soap @ 2%, 1% and 0.6%, neem oil soap 0.6% and soap solution 0.5%.

Table 13. Average population density of whiteflies, *Bemisia tabaci* recorded during November 2019 to May 2020 under field evaluation

Treatments	Whitefly population per five leaves*																	
	First application						Second application						Third application					
	1 DBS	1 DAS	3 DAS	5 DAS	7 DAS	14 DAS	1 DBS	1 DAS	3 DAS	5 DAS	7 DAS	14 DAS	1 DBS	1 DAS	3 DAS	5 DAS	7 DAS	14 DAS
Standard check	5.47 (2.33)	3.60 (1.96) b	2.27 (1.55) b	3.47 (1.77) b	3.53 (1.87) ab	7.27 (2.47) a	5.33 (2.31)	0.73 (0.81) c	0.93 (1.15) b	1.67 (1.29) bc	3.00 (1.71) bc	0.87 (0.91) c	5.53 (2.35)	4.20 (1.96) bc	4.67 (2.08) b	5.33 (2.55) abc	5.80 (2.35) c	5.53 (2.31) cd
PO 3%	6.00 (2.45)	0.80 (1.10) c	0.87 (0.92) d	1.00 (0.94) d	1.40 (1.17) b	1.47 (1.21) b	5.80 (2.40)	0.67 (1.07) c	0.80 (0.89) b	0.97 (0.95) c	1.40 (1.18) d	2.27 (1.45) b	5.47 (2.33)	1.67 (1.28) d	2.13 (1.46) c	3.00 (1.73) c	3.67 (1.91) d	4.87 (2.20) d
PO 2%	5.80 (2.41)	0.93 (1.16) c	1.40 (1.17) cd	1.40 (1.18) cd	1.60 (1.25) b	2.93 (1.60) b	5.20 (2.28)	1.00 (1.22) c	1.13 (1.04) b	1.33 (1.15) bc	2.33 (1.51) cd	2.53 (1.58) b	5.40 (2.32)	2.20 (1.48) cd	3.27 (1.81) bc	3.87 (1.97) bc	4.47 (2.11) d	5.27 (2.29) cd
PO 1%	4.60 (2.12)	1.20 (1.30) c	1.73 (1.31) bc	1.53 (1.21) cd	1.67 (1.22) b	3.53 (1.72) b	5.33 (2.31)	1.13 (1.28) c	1.13 (1.06) b	1.67 (1.28) bc	2.47 (1.57) bcd	2.87 (1.69) b	5.33 (2.31)	2.53 (1.56) bcd	3.40 (1.83) bc	4.33 (2.07) bc	5.27 (2.29) c	6.33 (2.51) bcd
PO 0.6%	5.53 (2.35)	1.60 (1.45) bc	2.13 (1.44) bc	2.20 (1.48) bcd	2.00 (1.40) b	3.73 (1.93) ab	5.27 (2.29)	2.27 (1.64) b	1.20 (1.08) b	1.87 (1.35) bc	3.80 (1.95) b	3.07 (1.73) b	5.47 (2.34)	3.93 (1.98) bc	4.73 (2.16) ab	5.80 (2.40) ab	6.27 (2.49) c	7.40 (2.71) abc
Neem soap 0.6%	5.87 (2.42)	1.67 (1.45) bc	2.60 (1.60) b	2.40 (1.55) bc	1.60 (1.25) b	2.27 (1.40) b	5.53 (2.35)	2.27 (1.65) b	1.27 (1.11) b	2.47 (1.48) b	3.47 (1.79) bc	2.33 (1.52) b	5.53 (2.35)	3.33 (1.82) bcd	5.60 (2.37) ab	5.93 (2.43) ab	6.40 (2.53) b	7.67 (2.77) ab
Soap solution 0.5%	5.87 (2.42)	6.20 (2.58) a	5.73 (2.39) a	6.07 (2.46) a	7.13 (2.67) a	7.33 (2.71) a	5.40 (2.32)	4.80 (2.30) a	5.33 (2.31) a	5.53 (2.35) a	6.00 (2.45) a	6.27 (2.50) a	5.60 (2.37)	4.93 (2.20) ab	5.27 (2.29) ab	6.13 (2.47) ab	6.93 (2.63) a	7.73 (2.78) ab
Control	5.87 (2.42)	6.00 (2.55) a	6.00 (2.45) a	6.00 (2.45) a	7.47 (2.73) a	7.40 (2.72) a	5.73 (2.39)	5.13 (2.37) a	5.13 (2.27) a	5.67 (2.38) a	5.80 (2.41) a	6.67 (2.58) a	6.00 (2.44)	7.07 (2.65) a	7.53 (2.74) a	7.87 (2.79) a	8.40 (2.89) a	9.20 (3.03) a
C.D. (*P*=0.05)	**NS**	**0.36**	**0.53**	**0.55**	**0.91**	**0.80**	**NS**	**0.35**	**0.35**	**0.50**	**0.42**	**0.44**	**NS**	**0.66**	**0.59**	**0.54**	**0.48**	**0.45**

* Mean of five observations; Means followed by similar alphabets do not differ significantly by DMRT at 5%; Figures in parentheses denotes square root transformed values; DBS- Day Before Spray; DAS- Days After Spray; NS – Non significant; PO 0.6% - Pongamia oil soap 0.6% PO 1% - Pongamia oil soap 1%; PO 2% - Pongamia oil soap 2%; PO 3% - Pongamia oil soap 3% Standard check - Chlorantraniliprole 18.5 SC 3 mL/10L for 1st & 3rd application & Thiamethoxam 25 WG 2g/10L for 2nd application

Observations on fifth day after third spray showed that pongamia oil soap @ 3% as best treatment with 3.00 whiteflies/ 3 leaves while control plot showed highest count of 7.87 whiteflies/ 3 leaves. The next best treatment was pongamia oil soap @ 2% (3.87 whiteflies/ 3 leaves) which was on par with pongamia oil soap @ 1% (4.33 whiteflies/ 3 leaves). Chlorantraniliprole 18.5 SC was on par with pongamia oil soap @ 0.6%, neem oil soap @ 0.6% and soap solution 0.5% with 5.33, 5.80, 5.93 and 6.13 whiteflies/ 3 leaves respectively.

On seventh day of spray, pongamia oil soap @ 3 and 2% were statistically on par with each other which had 3.67 and 4.47 whiteflies/ 3 leaves respectively whereas, control plot recorded highest population of 8.40 whiteflies/ 3 leaves which found to be on par with soap solution 0.5% (6.93 whiteflies/ 3 leaves). Next best treatment was pongamia oil soap @ 1 per cent (5.27 whiteflies/ 3 leaves) which found to be on par with chlorantraniliprole and pongamia oils soap @ 0.6% treated plants which had 5.80a and 6.27 whiteflies/ 3 leaves respectively.

Whitefly population was gradually increased in all the treatments after fourteen days of spray with control plot showed highest count of 9.20 whiteflies/ 3 leaves however, pongamia oil soap @ 3% was significantly different over other treatment (4.87 whiteflies/ 3 leaves). Pongamia oil soap @ 2% was statistically on par with chlorantraniliprole which showed 5.27 and 5.53 whiteflies/ 3 leaves respectively while pongamia oil soap @ 1% (6.33 whiteflies/ 3 leaves) was on par with pongamia oil soap @ 0.6% (7.40 whiteflies/ 3 leaves). Neem oil soap 0.6% and soap solution 0.5% became statistically similar in results with 7.67 and 7.73 whiteflies/ 3 leaves respectively.

4.2.7. Relative abundance of predators and parasitoids in brinjal ecosystem at field evaluation of pongamia oil soap during *rabi* season from November 2019 to May 2020

In the brinjal ecosystem, not only the destructive pests but the natural enemies also prevailing as predators and parasitoids. In the present study, diversity of natural enemies observed in the field were recorded under different concentrations of pongamia oil soap along with neem oil soap 0.6%, soap solution 0.5%, chlorantraniliprole 18.5 SC and thiamethoxam 25 WG and control treatments. Relative abundance of natural enemies was recorded on one day prior to, 1, 3, 5, 7 and 14 days after spray application and observations were taken from five whole plants per plot.

The documentation of natural enemies was carried out in four different systems;

1. Relative abundance of spiders
2. Relative abundance of coccinellids, syrphids and green lacewings
3. Relative abundance of hemipteran predators and hymenopteran parasitoids
4. Relative abundance of red spider mite predators

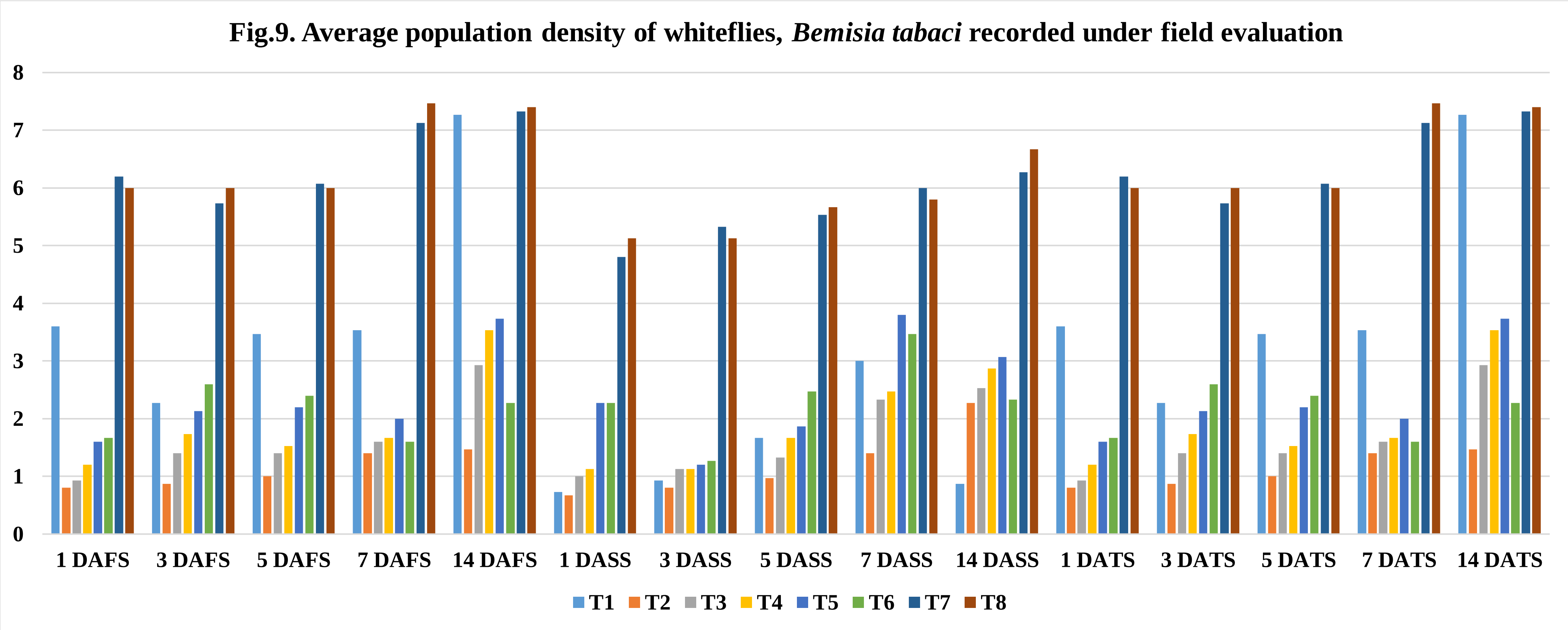
4.2.7.1. Relative abundance of spiders during field evaluation of pongamia oil soap from November 2019 to May 2020

The major spider species observed in brinjal ecosystem such as *Oxyopes assamensis, Peucetia viridana, Olios* sp. and *Thomisus projectus* were recorded from five plants of each treatment during all the three sprays under various treatments. Data were undergone a statistical analysis after square root transformation and presented in Table 14.

First spray application

Pre count of the spiders was statistically uniform among different treatments which ranged from 0.67-1.67 spiders/5 plants.

Spider population was statistically non-significant at one day after treatment application with pongamia oil soap @ 3% showed maximum numbers (3 spiders/5 plants) followed by control, neem oil soap 0.6%, pongamia oil soap @ 2, 1 and 0.6%, soap solution and chlorantraniliprole 18.5 SC with 1.67, 1.67, 1.33, 1.33, 1.00, 1.00 and 1.00 spiders/5 plants respectively.



DAFS – Days After First Spray, DASS – Days After Second Spray, DATS – Days After Third Spray

T_1 – Chlorantraniliprole 18.5 SC 3 mL/10L (Spray I & III) & Thiamethoxam 25 WG 2g/10L (Spray II); T_2 – Pongamia oil soap 3%;

T_3 – Pongamia oil soap 2%; T_4 – Pongamia oil soap 1%; T_5 – Pongamia oil soap 0.6%;

T_6 – Neem oil soap 0.6 %; T_7 – Soap solution 0.5%; T_8 – Control

On third day after treatment, the results showed a non-significant spider population under various treatments with pongamia oil soap @ 3% and soap solution 0.5% recorded maximum of 2.00 spiders/5 plants followed by 1.67, 1.67, 1.33, 1.33, 1.33 and 1.33 spiders/5 plants in pongamia oil soap @ 2%, chlorantraniliprole 18.5 SC, pongamia oil soap @ 1 and 0.6 %, control and neem oil soap 0.6% treated plots respectively.

There was no significant difference in spider population under various treatments at fifth day after application also. Maximum spider count was recorded in chlorantraniliprole treated plot (2.00 spiders/5 plants) followed by pongamia oil soap @ 1%, neem oil soap 0.6% and control which had 1.67 spiders/5 plants. It was followed by pongamia oil soap @ 2 (1.33 spiders/5 plants) and 3% (1.33 spiders/5 plants), soap solution 0.5% (1.33 spiders/5 plants) and pongamia oil soap @ 0.6 per cent (1.00 spiders/5 plants).

Observations made on seventh day after spray also showed no significant difference among different treatments. The order of maximum count of spiders was control plot (2.67 spiders/5 plants) > pongamia oil soap @ 2% (2.33 spiders/5 plants) > neem oil soap 0.6% (2.33 spiders/5 plants) > soap solution 0.5% (2.33 spiders/5 plants) > pongamia oil soap @ 3% (2.00 spiders/5 plants) > chlorantraniliprole (1.67 spiders/5 plants) > pongamia oil soap @ 1% (1.33 spiders/5 plants) > pongamia oil soap @ 0.6% (1.00 spiders/5 plants).

The observations taken on fourteen days after treatment application showed a significant difference among treatments with soap solution 0.5% had maximum number of spiders (4.00 spiders/5 plants) which was on par with pongamia oil soap @ 3% (2.33 spiders/5 plants) and neem oil soap 0.6% (2.33 spiders/5 plants). Pongamia oil soap @ 2% with 1.33 spiders/5 plants was statistically similar with pongamia oil soap @ 1%, 0.6% and control plot with 2.00 spiders/5 plants. The least population was observed in chlorantraniliprole 18.5 SC treated plants.

Second spray application

Observations on one day before treatment application showed that there was no significant difference among different treatments and the count found to be in between 1.67-4.00 spiders/5 plants.

A day after second spray, all treatments expressed statistically similar results and the highest spider population was observed in control plot with 3.33 spiders/5 plants. 3.00 spiders/5 plants were observed in pongamia oil soap @ 3% (3.00 spiders/5 plants) and 2% (3.00 spiders/5 plants) followed by neem oil soap 0.6 per cent, pongamia oil soap @ 1%, soap solution 0.5%, pongamia oil soap @ 0.6% and thiamethoxam treated plants with 2.67, 2.33, 2.33, 2.00 and 2.00 spiders/5 plants respectively.

Non-significant results were observed on third day after second spray also with pongamia oil soap @ 0.6% showed highest spider count of 7.00 spiders/5 plants followed by control (6.33 spiders/5 plants), pongamia oil soap @ 1% (5.67 spiders/5 plants), pongamia oil soap @ 2% (4.33 spiders/5 plants), pongamia oil soap @ 3% (4.00 spiders/5 plants), soap solution 0.5% (3.67 spiders/5 plants), neem oil soap 0.6% (3.33 spiders/5 plants) and thiamethoxam 25 WG (3.00 spiders/5 plants).

After five days of spray also, pongamia oil soap @ 0.6% recorded highest spider population (5.67 spiders/5 plants) while pongamia oil soap @ 3% showed 1.33 spiders/5 plants however, all the treatments were significant statistically. It was followed by neem oil soap 0.6%, pongamia oil soap @ 2%, thiamethoxam 25 WG, pongamia oil soap @ 1%, control and soap solution 0.5% with the spider population of 5.00, 4.67, 4.67, 4.00, 3.33, and 2.33 spiders/5 plants respectively.

At seventh day of spray, control plants showed maximum spiders (7.33 spiders/5 plants) followed by pongamia oil soap @ 0.6%, neem oil soap 0.6%, pongamia oil soap @ 1 and 2%, soap solution 0.5%, pongamia oil soap 3% and thiamethoxam 25 WG treated plots with 5.67, 5.67, 5.33, 5.33, 5.00, 4.00 and 3.67 spiders/5 plants respectively, however, all the treatments showed no significant difference statistically.

Table 14. Relative abundance of spiders during field evaluation of pongamia oil soap from November 2019 to May 2020

Treatments	Number of spiders/ 5 plants																	
	First application						Second application						Third application					
	1 DBS	1 DAS	3 DAS	5 DAS	7 DAS	14 DAS	1 DBS	1 DAS	3 DAS	5 DAS	7 DAS	14 DAS	1 DBS	1 DAS	3 DAS	5 DAS	7 DAS	14 DAS
Standard check	1.33 (1.34)	1.00 (1.00)	1.67 (1.24)	2.00 (1.38)	1.67 (1.28)	1.00 (1.00) c	2.33 (1.47)	2.00 (1.41)	3.00 (1.69)	4.67 (2.26)	3.67 (1.91)	3.33 (1.73) e	3.67 (1.86)	2.33 (1.49)	3.33 (1.77)	3.67 (1.91)	3.33 (1.82)	3.67 (2.04) c
PO 3%	0.67 (1.05)	3.00 (1.67)	2.00 (1.33)	1.33 (1.14)	2.00 (1.38)	2.33 (1.52) ab	3.33 (1.82)	3.00 (1.71)	4.00 (1.97)	1.33 (1.29)	4.00 (1.99)	7.33 (2.71) d	3.33 (1.76)	2.00 (1.38)	3.00 (1.86)	2.67 (1.63)	3.67 (1.91)	4.00 (2.12) bc
PO 2%	1.00 (1.22)	1.00 (1.00)	1.67 (1.28)	1.33 (1.14)	2.33 (1.49)	1.33 (1.14) bc	4.00 (1.89)	3.00 (1.67)	4.33 (2.08)	4.00 (2.11)	5.33 (2.28)	7.67 (2.77) cd	6.33 (2.47)	2.67 (1.63)	3.33 (1.95)	3.00 (1.73)	4.00 (1.99)	4.67 (2.27) abc
PO 1%	1.00 (1.22)	1.33 (1.14)	1.33 (1.14)	1.67 (1.24)	1.33 (1.14)	2.00 (1.38) bc	1.67 (1.28)	2.33 (1.47)	5.67 (2.37)	4.67 (2.22)	5.33 (2.23)	9.00 (3.00) bc	4.67 (2.00)	2.67 (1.63)	3.00 (1.87)	3.67 (1.91)	3.33 (1.82)	4.00 (2.12) bc
PO 0.6%	1.00 (1.22)	1.33 (1.14)	1.33 (1.14)	1.00 (1.00)	1.00 (1.00)	2.00 (1.38) bc	2.67 (1.48)	2.00 (1.33)	7.00 (2.60)	5.67 (2.38)	5.67 (2.26)	9.67 (3.11) ab	3.67 (1.91)	4.00 (2.00)	3.33 (1.95)	3.33 (1.79)	4.00 (1.99)	6.00 (2.55) a
Neem soap 0.6%	1.00 (1.22)	1.67 (1.24)	1.33 (1.14)	1.67 (1.24)	2.33 (1.49)	2.33 (1.52) ab	2.33 (1.47)	2.67 (1.58)	3.33 (1.76)	5.00 (2.28)	5.67 (2.35)	7.67 (2.76) cd	3.67 (1.75)	2.67 (1.55)	3.33 (1.95)	4.33 (2.08)	4.67 (2.15)	5.00 (2.34) ab
Soap solution 0.5%	1.33 (1.22)	1.00 (1.00)	2.00 (1.38)	1.33 (1.14)	2.33 (1.47)	4.00 (1.99) a	2.67 (1.58)	2.33 (1.47)	3.67 (1.86)	2.33 (1.65)	5.00 (2.19)	10.67 (3.21) a	6.33 (2.50)	2.67 (1.63)	3.33 (1.95)	3.00 (1.71)	3.67 (1.91)	4.33 (2.20) bc
Control	1.67 (1.46)	1.67 (1.28)	1.33 (1.14)	1.67 (1.24)	2.67 (1.58)	2.00 (1.38) bc	3.00 (1.67)	3.33 (1.79)	6.33 (2.51)	3.33 (1.93)	7.33 (2.70)	8.00 (2.82) cd	6.33 (2.50)	4.00 (1.99)	2.67 (2.09)	2.33 (1.52)	3.67 (1.91)	5.00 (2.32) abc
C.D. (*P*=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**0.50**	**NS**	**NS**	**NS**	**NS**	**NS**	**0.27**	**NS**	**NS**	**NS**	**NS**	**NS**	**0.29**

Means followed by similar alphabets do not differ significantly @ 0.05 DMRT; Figures in parentheses denotes square root transformed values; DBS- Day Before Spray; DAS- Days After Spray; NS – Non significant; PO 0.6% - Pongamia oil soap 0.6% PO 1% - Pongamia oil soap 1%; PO 2% - Pongamia oil soap 2%; PO 3% - Pongamia oil soap 3%
Standard check - Chlorantraniliprole 18.5 SC 3 mL/10L for 1st & 3rd application & Thiamethoxam 25 WG 2g/10L for 2nd application

Soap solution 0.5% exhibited highest spider count (10.67 spiders/5 plants) on fourteenth day after spray application while thiamethoxam 25 WG showed only 3.33 spiders/5 plants. The second maximum spider population was recorded in pongamia oil soap @ 0.6% with 9.67 spiders/5 plants which found to be on par with pongamia oil soap @ 1%. Control plot, pongamia oil soap @ 2% and neem oil soap 0.6% exhibited statistically similar results with 8.00, 7.67 and 7.67 spiders/5 plants respectively while pongamia oil soap @ 3% showed 7.33 spiders/5 plants

Third spray application

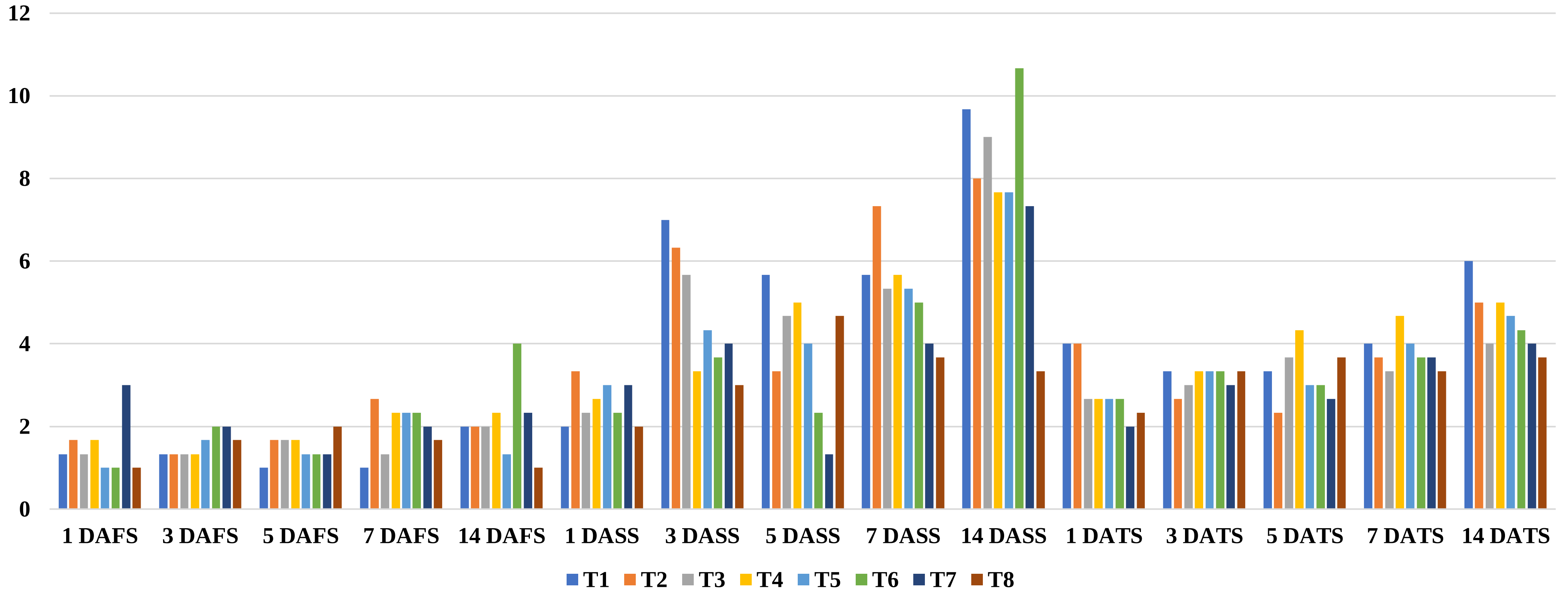
Pre count of relative abundance of spiders during third spray was not statistically differing between the treatments which was at a range of 3.33 to 6.33 spiders/5 plants.

Observations on one day after third spray showed highest of 4.00 spiders/5 plants in pongamia oil soap @ 0.6% treated plot and control plot followed by pongamia oil soap @ 1 and 2%, neem oil soap 0.6% and soap solution 0.5% with 2.67 spiders/5 plants. Chlorantraniliprole 18.5 SC and pongamia oil soap @ 3% showed 2.33 and 2.00 spiders/5 plants respectively however, there was no significant difference between treatments.

Third day after third spray showed a smaller number of spiders with highest number of 3.33 spiders/5 plants in pongamia oil soap @ 0.6%, pongamia oil soap @ 2%, neem oil soap 0.6%, soap solution 0.5% and chlorantraniliprole treated plants followed by 3.00 and 2.67 spiders/5 plants in pongamia oil soap @ 1% and 3% treated plants yet all the treatments were statistically similar.

On fifth day of third application, highest spider count of 4.33 spiders/5 plants was recorded in neem oil soap 0.6% treated plot followed by 3.67 spiders/5 plants in pongamia oil soap @ 1% and chlorantraniliprole treated plants however, all the treatments were not differing statistically. Pongamia oil soap @ 2% and soap solution 0.5% recorded 3.00 spiders/5 plants while pongamia oil soap @ 3% and control recorded 2.67 and 2.33 spiders/5 plants respectively.

Fig.10. Relative abundance of spiders during field evaluation of pongamia oil soap from November 2019 to May 2020



DAFS – Days After First Spray, DASS – Days After Second Spray, DATS – Days After Third Spray

T_1 – Chlorantraniliprole 18.5 SC 3 mL/10L (Spray I & III) & Thiamethoxam 25 WG 2g/10L (Spray II); T_2 – Pongamia oil soap 3%;

T_3 – Pongamia oil soap 2%; T_4 – Pongamia oil soap 1%; T_5 – Pongamia oil soap 0.6%;

T_6 – Neem oil soap 0.6 %; T_7 – Soap solution 0.5%; T_8 – Control

On seventh day after treatment application, all the treatments were found to be statistically non-significant and the highest population of spiders was recorded in neem oil soap 0.6% with 4.67 spiders/5 plants followed by pongamia oil soap @ 0.6% and 2% with 4.00 spiders/5 plants. Pongamia oil soap @ 3%, soap solution 0.5% and control plot recorded 3.67 spiders/5 plants while pongamia oil soap @ 1% and chlorantraniliprole showed 3.33 spiders/5 plants.

Observations on fourteenth day after spray application revealed that pongamia oil soap @ 0.6% recorded highest spider population of 6.00 spiders/5 plants while chlorantraniliprole treated plot showed lowest of 3.67 spiders/5 plants. Pongamia oil soap @ 0.6% was on par with neem oil soap 0.6% (5.00 spiders/5 plants), control plot (5.00 spiders/5 plants) and pongamia oil soap @ 2% (4.76 spiders/5 plants). Soap solution 0.5%, pongamia oil soap @ 1% and 3% gave statistically similar count with 4.33, 4.00 and 4.00 spiders/5 plants respectively.

The spider population was statistically uniform throughout the experimental plots on a day before spray application. There was no significant variation in the population of spiders (generalist predator) immediately after spray indicating that the instant death of spiders had not occurred by treatment exposure. The spider population was remained significantly even up to seven days after spray. At fourteenth day of all the three sprays, the spider population varied significantly between the treatments with chemical treated plots showed least population whereas botanicals and untreated plots expressed statistically same spider count.

4.2.7.2. Relative abundance of coccinellids, syrphids and green lacewings during field evaluation of pongamia oil soap from November 2019 to May 2020

The observed coccinellid species such as *Coccinella transversalis, Cheilomenes sexmaculata*, *Scymnus latemaculatus* and *Pseudaspidimerus trinotatus*, syrphid namely *Paragus serratus* and green lacewing namely *Chrysoperla zastrowi* were recorded per five plants from various treatments at three sprays. Data on these natural enemies were statistically analysed after square root transformation and presented in Table 14. Population of coccinellids, syrphids and green lacewings was negligible during third spray hence, it was not recorded in this study. The coccinellid species such as *Scymnus latemaculatus* and *Pseudaspidimerus trinotatus*, syrphid- *Paragus serratus* and green lacewing - *Chrysoperla zastrowi* were recorded from aphid colonies and *Cheilomenes sexmaculata* and *Coccinella transversalis* were general predators.

First spray application

Pre count of coccinellids, syrphids and green lacewing fly's population was statistically non-significant indicating uniform count among treatments which ranged between 1.00 to 3.00/5 plants.

Relative abundance of coccinellids, syrphids and green lacewings was highest in chlorantraniliprole 18.5 SC treated plot (8.33/ 5 plants) at a day after treatment application since the aphid numbers was abundant in chlorantraniliprole treated plots and it was on par with neem oil soap 0.6% (6.33/5 plants). All the concentrations of pongamia oil soap (3, 2, 1, and 0.6%), soap solution 0.5% and control plot showed statistically similar results with 2.33, 3.33, 3.67, 3.67, 2.00 and 3.00/5 plants.

On third day of first spray, maximum population of coccinellids, syrphids and green lacewings was recorded in chlorantraniliprole 18.5 SC treated plants (11.67/5 plants) and all the remaining treatments showed non-significant population. Second maximum population was observed in soap solution 0.5% (5.00/5 plants) followed by pongamia oil soap @ 0.6%, neem oil soap 0.6% and control plot with 4.00, 3.00 and 3.00/5 plants respectively.

The treatments expressed statistically non-significant count on coccinellids, syrphids and green lacewings after five days of treatments except chlorantraniliprole 18.5 SC (14.33/5 plants). It was followed by pongamia oil soap @ 0.6%, soap solution 0.5%, pongamia oil soap @ 1%, control plot, pongamia oil soap @ 2%, neem oil soap 0.6% and pongamia oil soap @ 3% with 3.33, 3.0, 2.33, 2.33, 2.00, 2.00 and 1.67/5 plants respectively.

Table 15. Relative abundance of coccinellids, syrphids and lacewings during *rabi* 2019 - 2020 under field condition

Treatments	Number of coccinellids, syrphids and lacewings/ 5 plants											
	First application						Second application					
	1 DBS	1 DAS	3 DAS	5 DAS	7 DAS	14 DAS	1 DBS	1 DAS	3 DAS	5 DAS	7 DAS	14 DAS
Chlorantraniliprole 18.5 SC 3 mL/10L - 1st & 3rd application & Thiamethoxam 25 WG 2g/10L - 2nd application	2.67 (1.77)	8.33 (2.88) [a]	11.67 (3.49) [a]	14.33 (3.81) [a]	19.00 (4.37) [a]	13.67 (3.75) [a]	7.00 (2.63)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.33 (0.88)	0.67 (1.00) [b]
Pongamia oil soap 3%	1.00 (1.22)	2.33 (1.52) [b]	2.00 (1.56) [b]	1.67 (1.46) [b]	1.67 (1.39) [b]	1.67 (1.46) [c]	7.67 (2.76)	2.33 (1.64)	3.00 (1.61)	2.33 (1.65)	2.00 (1.56)	3.33 (1.93) [a]
Pongamia oil soap 2%	1.33 (1.34)	3.33 (1.82) [b]	2.33 (1.65) [b]	2.00 (1.56) [b]	2.00 (1.47) [b]	2.33 (1.64) [c]	4.33 (1.97)	2.67 (1.74)	3.00 (1.82)	2.67 (1.74)	2.67 (1.77)	3.67 (2.04) [a]
Pongamia oil soap 1%	1.67 (1.46)	3.67 (1.82) [b]	2.33 (1.68) [b]	2.33 (1.68) [b]	2.67 (1.65) [b]	2.67 (1.44) [bc]	4.33 (2.08)	3.00 (1.86)	3.00 (1.86)	3.00 (1.86)	3.00 (1.86)	5.00 (2.34) [a]
Pongamia oil soap 0.6%	1.33 (1.34)	3.67 (1.88) [b]	4.00 (2.11) [b]	3.33 (1.95) [b]	3.00 (1.72) [b]	3.00 (1.82) [bc]	4.00 (1.96)	3.33 (1.90)	3.67 (1.94)	3.33 (1.93)	4.00 (2.08)	8.33 (2.96) [a]
Neem oil soap 0.6%	3.00 (1.84)	6.33 (2.51) [a]	3.00 (1.86) [b]	2.00 (1.47) [b]	2.33 (1.68) [b]	2.33 (1.60) [bc]	4.33 (1.97)	3.00 (1.81)	4.67 (2.16)	6.00 (2.24)	10.33 (2.69)	10.33 (3.28) [a]
Soap solution 0.5%	1.00 (1.17)	2.00 (1.41) [b]	5.00 (2.10) [b]	3.00 (1.72) [b]	2.67 (1.64) [b]	5.67 (2.48) [b]	4.33 (2.02)	2.67 (1.74)	2.67 (1.74)	3.00 (1.81)	3.67 (1.97)	5.00 (2.32) [a]
Control	1.33 (1.34)	3.00 (1.71) [b]	3.00 (1.87) [b]	2.33 (1.54) [b]	3.67 (2.04) [b]	3.67 (2.00) [bc]	5.00 (2.16)	4.00 (2.11)	4.00 (2.06)	4.33 (2.15)	3.33 (1.90)	8.00 (2.77) [a]
C.D. (*P*=0.05)	**NS**	**0.61**	**1.00**	**1.02**	**1.07**	**0.50**	**NS**	**0.72**	**NS**	**NS**	**NS**	**NS**

Means followed by similar alphabets do not differ significantly @ 0.05 DMRT

Figures in parentheses denotes square root transformed values

DBS- Day Before Spray; DAS- Days After Spray; NS – Non significant

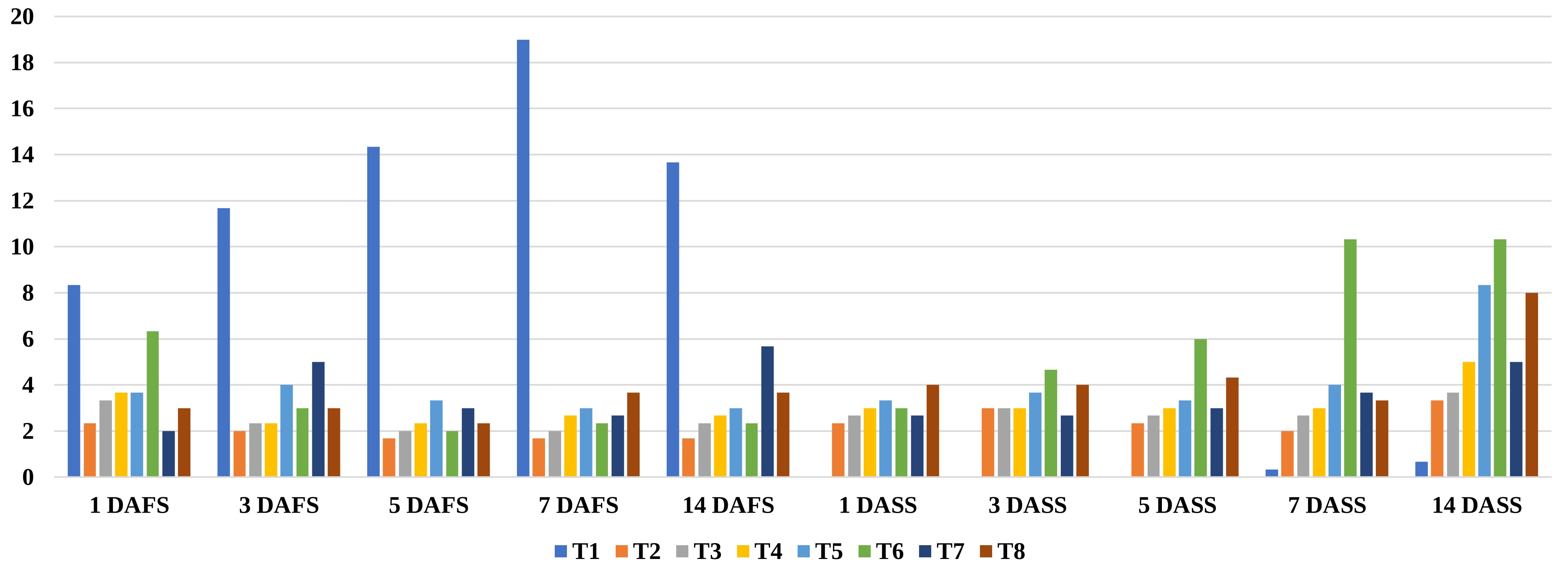
At seven days of treatment application, the coccinellids, syrphid and green lacewing count was highest in chlorantraniliprole treated plants (19.00/5 plants) which was significantly different from remaining treatments. Second highest population recorded in control treatment with 3.67/5 plants followed by 3.00, 2.67, 2.67, 2.33, 2.00, 1.67/5 plants in pongamia oil soap @ 0.6% and 1%, soap solution 0.5%, neem oil soap 0.6%, pongamia oil soap @ 2% and 3 % treated plots respectively.

Coccinellids, syrphid and green lacewing population was highest in chlorantraniliprole treated plot (13.67/5 plants) and lowest in pongamia oil soap @ 3% (1.67/5 plants) however it was on par with untreated control plot at fourteen days after treatment. Soap solution 0.5% with 5.67/ 5 plants was the next best treatment. Control, pongamia oil soap @ 0.6 and 2% and neem oil soap 0.6% were statistically on par with each other with 3.67, 3.00, 2.67 and 2.33/5 plants respectively.

Seventh day observations proved that all the treatments were not varied significantly in the population of coccinellids, syrphids and green lacewings and maximum population was observed in neem oil soap 0.6% (10.33/5 plants) followed by pongamia oil soap @ 0.6% (4.00/5 plants), soap solution 0.5% (3.67/5 plants), control (3.33/5 plants), pongamia oil soap @ 1% (3.00/5 plants), 2% (2.67/5 plants), 3% (2.00/5 plants) and the least was standard check (0.33/5 plants).

On fourteenth day of second spray, standard check alone recorded significantly lowest population of coccinellids, syrphids and green lacewings (0.67/5 plants) and all the other treatments were statistically on par with each other. Neem oil soap 0.6% showed 10.33/5 plants followed pongamia oil soap @ 0.6%, control plot, pongamia oil soap @ 1%, soap solution 0.5%, pongamia oil soap @ 2 and 3% which had 8.33, 8.00, 5.00, 5.00, 3.67 and 3.33/5 plants.

Fig.11. Relative abundance of coccinellids, syrphids and lacewings during field evaluation from November 2019 to May 2020



DAFS – Days After First Spray, DASS – Days After Second Spray

T_1 – Chlorantraniliprole 18.5 SC 3 mL/10L (Spray I) & Thiamethoxam 25 WG 2g/10L (Spray II); T_2 – Pongamia oil soap 3%;

T_3 – Pongamia oil soap 2%; T_4 – Pongamia oil soap 1%; T_5 – Pongamia oil soap 0.6%;

T_6 – Neem oil soap 0.6 %; T_7 – Soap solution 0.5%; T_8 – Control

4.2.7.3. Relative abundance of Hemipteran predators and Hymenopteran parasitoids during field evaluation of pongamia oil soap from November 2019 to May 2020

Relative abundance of hemipteran predators such as assassin bug (*Irantha armipes*) and mirid bug (*Cyrtorhinus lividipennis*) and the hymenopteran parasitoids such as egg parasitoid of Epilachna (*Tetrastichus* sp.), pupal parasitoid of Epilachna (*Pediobius foveolatus*) and parasitoid of leafhoppers (*Anagrus* sp.) were registered from five plants of each treatments. Data were statistically analysed after square root transformation and presented in Table 16. Hemipteran predators and hymenopteran parasitoids were not observed during third spray application hence it was not recorded.

First spray application

Relative abundance of hemipteran predators and hymenopteran parasitoids was statistically non-significant among different treatments at a day before spray which was ranged in between 0.67 to 1.67/5 plants.

Soap solution 0.5% and chlorantraniliprole 18.5 SC showed highest population of hemipteran predators and hymenopteran parasitoids with 3.00/5 plants followed by pongamia oil soap @ 0.6%, 1% and control plot with 2.33/5 plants, pongamia oil soap @ 2 and 3% with 1.33/5 plants and neem oil soap 0.6% with 1.00/5 plants on a day after first spray application.

On third day of spray application, pongamia oil soap @ 0.6% and control plots recorded similar results of 2.33/5 plants while pongamia oil soap @ 2 and 3% and neem oil soap 0.6% showed 1.00/5 plants however, all the treatments were significantly not differed in the population of hemipteran predators and hymenopteran parasitoids. Soap solution 0.5% showed 1.67/5 plants while chlorantraniliprole and pongamia oil soap @ 3% recorded 2.00/5 plants.

Fifth day observation showed that pongamia oil soap @ 0.6 and 1% were similar in results which was the highest count among all however, all the treatments were not differed significantly. Pongamia oil soap @ 2% and control plot as next best treatments, showed 1.67/5 plants followed by pongamia oil soap @ 2%, soap solution 0.5%, neem oil soap 0.6% and standard check with 1.33, 1.33, 1.00 and 0.67/5 plants respectively.

After seven days of spray application, population of hemipterans and hymenopterans was highest in pongamia oil soap @ 0.6% treated plants with 3.00/5 plants and the lowest population was observed in pongamia oil soap @ 3% (1.00/5 plants). However, there was no significant difference between all the treatments. Second highest population was observed in pongamia oil soap @ 1% (2.33/5 plants) followed by pongamia oil soap @ 3%, soap solution 0.5%, chlorantraniliprole 18.5 SC and control plot with 1.67/5 plants.

Non-significant results were observed on fourteenth day after spray application also with 3.33/5 plants followed by pongamia oil soap @ 1% (2.67/5 plants). Pongamia oil soap @ 2%, neem oil soap 0.6%, soap solution 0.5% and control plot were recorded same count (2.00/5 plants) on hemipteran and hymenopteran natural enemies. Pongamia oil soap @ 3% and standard check showed 1.67/5 plants.

Second spray application

Relative abundance of hemipteran predators and hymenopteran parasitoids was statistically uniform at a day before spray application which was at a range of 1.33 to 2.67/5 plants.

After a day of spray application, control and soap solution 0.5% was highest in count (0.67/5 plants) followed by pongamia oil soap @ 0.6%, 1% and neem oil soap 0.6% with 1.00/5 plants found to be on par with each other. Pongamia oil soap @ 2 and 3% expressed statistically similar results with 0.67/5 plants whereas thiamethoxam 25 WG treated plots showed lowest of 0.00/5 plants.

Table 16. Relative abundance of Hemipteran predators and Hymenopteran parasitoids during field evaluation from November 2019 to May 2020

Treatments	Number of Hemipteran predators and Hymenopteran parasitoids/ 5 plants											
	First application						Second application					
	1 DBS	1 DAS	3 DAS	5 DAS	7 DAS	14 DAS	1 DBS	1 DAS	3 DAS	5 DAS	7 DAS	14 DAS
Chlorantraniliprole 18.5 SC 3 mL/10L - 1st & 3rd application & Thiamethoxam 25 WG 2g/10L - 2nd application	1.33 (1.34)	3.00 (1.81)	2.00 (1.56)	0.67 (1.05)	1.67 (1.42)	1.67 (1.46)	1.33 (1.34)	0.00 (0.71) [c]	0.00 (0.88) [c]	0.33 (0.71) [c]	1.00 (1.09)	1.00 (1.17)
Pongamia oil soap 3%	1.33 (1.34)	1.33 (1.34)	1.00 (1.17)	1.67 (1.44)	1.00 (1.17)	1.67 (1.44)	1.33 (1.34)	0.67 (1.05) [bc]	1.33 (1.27) [bc]	1.33 (1.34) [b]	1.67 (1.46)	1.67 (1.46)
Pongamia oil soap 2%	1.67 (1.46)	1.33 (1.27)	1.00 (1.17)	1.33 (1.34)	1.67 (1.44)	2.00 (1.47)	1.67 (1.44)	0.67 (1.05) [bc]	1.33 (1.34) [bc]	1.67 (1.46) [b]	2.00 (1.56)	2.00 (1.48)
Pongamia oil soap 1%	1.00 (1.22)	2.33 (1.68)	2.00 (1.48)	2.67 (1.77)	2.33 (1.68)	2.67 (1.74)	1.67 (1.46)	1.00 (1.22) [ab]	1.67 (1.46) [bc]	1.67 (1.39) [b]	2.00 (1.56)	2.00 (1.52)
Pongamia oil soap 0.6%	1.67 (1.46)	2.33 (1.68)	2.33 (1.64)	2.67 (1.74)	3.00 (1.86)	3.33 (1.95)	1.33 (1.31)	1.00 (1.22) [ab]	3.00 (1.87) [ab]	3.33 (1.95) [a]	3.33 (1.93)	2.33 (1.68)
Neem oil soap 0.6%	1.00 (1.22)	1.00 (1.17)	1.00 (1.17)	1.00 (1.17)	1.33 (1.34)	2.00 (1.52)	2.67 (1.64)	1.00 (1.22) [ab]	2.67 (1.61) [abc]	3.33 (1.93) [a]	1.33 (1.34)	3.33 (1.77)
Soap solution 0.5%	1.00 (1.22)	3.00 (1.68)	1.67 (1.44)	1.33 (1.34)	1.67 (1.44)	2.00 (1.56)	2.00 (1.58)	1.67 (1.44) [a]	3.33 (2.34) [a]	5.00 (1.95) [a]	2.67 (1.74)	1.67 (1.39)
Control	0.67 (1.05)	2.33 (1.60)	2.33 (1.68)	1.67 (1.46)	1.67 (1.39)	2.00 (1.56)	2.67 (1.72)	1.67 (1.46) [a]	1.67 (1.44) [bc]	1.67 (1.46) [b]	2.67 (1.77)	4.67 (2.22)
C.D. (*P*=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**0.36**	**0.45**	**0.45**	**NS**	**NS**

Means followed by similar alphabets do not differ significantly @ 0.05 DMRT
Figures in parentheses denotes square root transformed values
DBS- Day Before Spray; DAS- Days After Spray; NS – Non significant

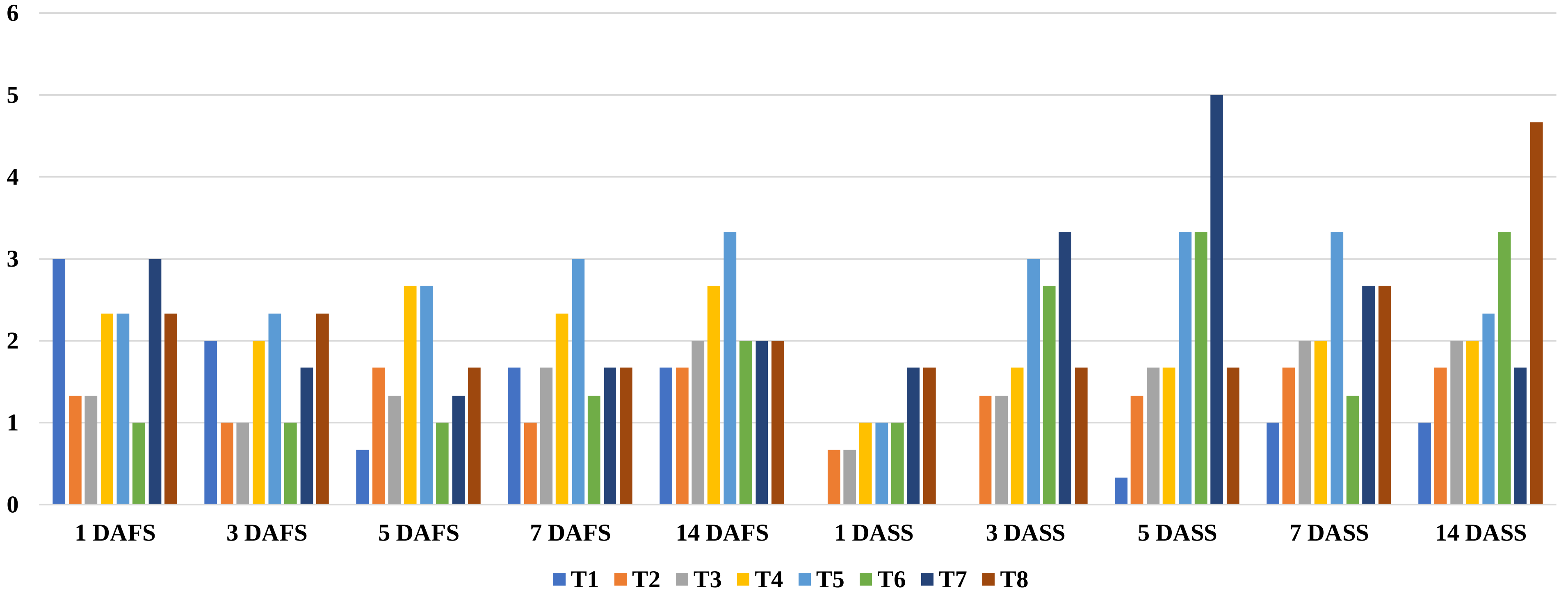
On third day of second spray application, soap solution 0.5% showed 3.33/5 plants followed by pongamia oil soap @ 0.6% (3.00/5 plants) and neem oil soap 0.6% (2.67/5 plants) which were on par with each other. Pongamia oil soap @ 1%, control plot, pongamia oil soap @ 2% and pongamia oil soap @ 3% were on par with each other with 1.67, 1.67, 1.33 and 1.33/5 plants respectively. However, thiamethoxam 25 WG treated plot was the lowest with 0.00/5 plants on third day.

At fifth day of spray, soap solution 0.5%, pongamia oil soap @ 0.6% and neem oil soap 0.6% were at par with each other with 5.00, 3.33 and 3.33/5 plants respectively. Thiamethoxam 25 WG treated plots showed lowest population of 0.33/5 plants. Pongamia oil soap @ 1, 2 and 3% were on par with control plot in hemipteran and hymenopterans populations which recorded 1.67, 1.67, 1.67 and 1.33/5 plants respectively.

On seventh day after treatment application, the population was rich in pongamia oil soap @ 0.6% with 3.33/5 plants followed by soap solution 0.5% and control plot with 2.67/5 plants. Pongamia oil soap @ 1 and 2% showed same results of 2.00/5 plants while pongamia oil soap @ 3%, neem oil soap 0.6% and thiamethoxam treated plot showed 1.67, 1.33 and 1.00/5 plants respectively. However, all the treatments were statistically non-significant.

Fourteenth day observation revealed that hemipterans and hymenopterans count was increased in control plot and neem oil soap 0.6% treated plants with 4.67 and 3.33/5 plants respectively. It was followed by pongamia oil soap @ 0.6, 1 and 2 % with 2.33, 2.00 and 2.00/5 plants respectively whereas standard check expressed lowest population count of 1.00/5 plants. Pongamia oil soap @ 3% and soap solution 0.5% were similar in results with 1.67/5 plants.

Fig.12. Relative abundance of Hemipteran predators and Hymenopteran parasitoids under field evaluation from November 2019 to May 2020



DAFS – Days After First Spray, DASS – Days After Second Spray

T_1 – Chlorantraniliprole 18.5 SC 3 mL/10L (Spray I) & Thiamethoxam 25 WG 2g/10L (Spray II); T_2 – Pongamia oil soap 3%;

T_3 – Pongamia oil soap 2%; T_4 – Pongamia oil soap 1%; T_5 – Pongamia oil soap 0.6%;

T_6 – Neem oil soap 0.6 %; T_7 – Soap solution 0.5%; T_8 – Control

4.2.7.4. Relative abundance of mite predators during field evaluation of pongamia oil soap from November 2019 to May 2020

Richness of red spider mite predators such as rove beetle, *Oligotus* and predatory gall midge, *Feltiella acarisuga* were also recorded from red spider mite colonies under different treatment applications. Data on mite predators were recorded and presented per five plants from each treatment after statistical analysis (Table 17). Since the red spider mite infestation was observed only on second spray application, mite predators count was not recorded during first and third spray application.

Second spray application

Data on a day before second spray application revealed that the mite predator's numbers didn't differ significantly among different treatments and it was at a range of 1.33 to 4.00/5 plants.

Richness of mite predators didn't vary significantly on a day after spray application and the maximum population was observed in soap solution 0.5% treated plants (4.33/5 plants) followed by pongamia oil soap @ 0.6% (3.00/5 plants). The predators count in pongamia oil soap @ 1% was equal to that of control plot with 2.67/5 plants and pongamia oil soap @ 2% recorded 2.33/5 plants. The lowest number of mite predators was registered in neem oil soap 0.6% with 1.33/5 plants while pongamia oil soap @ 3% and standard check showed 2.00 and 1.67/5 plants respectively.

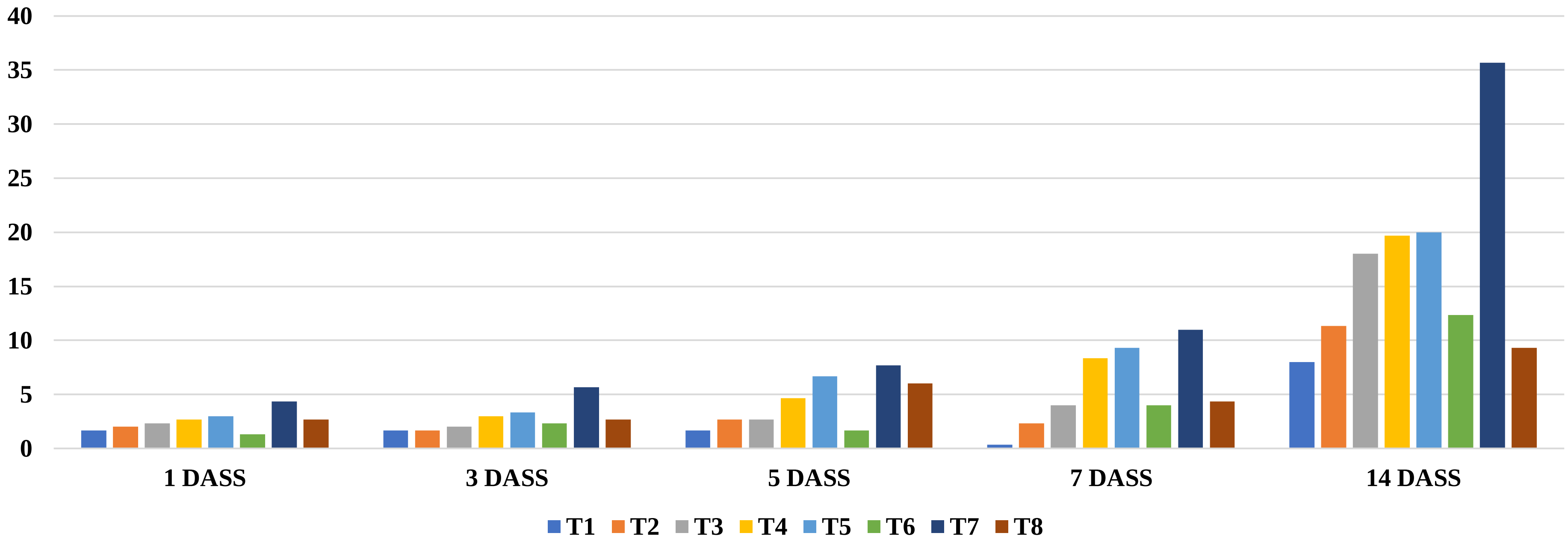
Third day after spray application also, population of mite predators found to be statistically non-significant among treatments and uniform in distribution. Highest population marked by soap solution 0.5% with 5.67/5 plants followed by pongamia oil soap @ 0.6% (3.33/5 plants). Lowest count of 1.67/5 plants were recorded in thiamethoxam and pongamia oil soap @ 3% treated plants (1.67/5 plants) whereas pongamia oil soap @ 1 and 2%, neem oil soap 0.6%, and control plot showed 3.00, 2.00, 2.33 and 2.67/5 plants respectively.

Table 17. Relative abundance of mite predators during field evaluation from November 2019 to May 2020

Treatments	Number of mite predators per 3 cm^2 area of three leaves*					
	Second application					
	1 DBS	**1 DAS**	**3 DAS**	**5 DAS**	**7 DAS**	**14 DAS**
Thiamethoxam 25 WG 2g/10L	1.67 (1.46)	1.67 (1.24)	1.67 (1.35)	1.67 (1.39)	0.33 (1.68) d	8.00 (2.67) b
Pongamia oil soap 3%	1.67 (1.46)	2.00 (1.41)	1.67 (1.46)	2.67 (1.76)	2.33 (1.68) cd	11.33 (3.09) b
Pongamia oil soap 2%	2.33 (1.68)	2.33 (1.52)	2.00 (1.56)	2.67 (1.77)	4.00 (2.12) c	18.00 (4.15) ab
Pongamia oil soap 1%	2.00 (1.56)	2.67 (1.63)	3.00 (1.86)	4.67 (2.13)	8.33 (2.96) b	19.67 (4.32) ab
Pongamia oil soap 0.6%	2.00 (1.56)	3.00 (1.71)	3.33 (1.95)	6.67 (2.64)	9.33 (3.13) ab	20.00 (4.42) ab
Neem oil soap 0.6%	1.33 (1.27)	1.33 (1.14)	2.33 (1.68)	1.67 (1.25)	4.00 (2.09) c	12.33 (3.50) b
Soap solution 0.5%	4.00 (2.03)	4.33 (1.94)	5.67 (2.43)	7.67 (2.81)	11.00 (3.38) a	35.67 (5.92) a
Control	4.00 (2.09)	2.67 (1.61)	2.67 (1.74)	6.00 (2.41)	4.33 (2.18) c	9.33 (3.05) b
C.D. (*P*=0.05)	**NS**	**NS**	**NS**	**NS**	**0.50**	**1.89**

Means followed by similar alphabets do not differ significantly @ 0.05 DMRT
Figures in parentheses denotes square root transformed values
DBS- Day Before Spray; DAS- Days After Spray; NS – Non significant

Fig.13. Relative abundance of mite predators during field evaluation from November 2019 to May 2020



DASS – Days After Second Spray

T_1 –Thiamethoxam 25 WG 2g/10L (Spray II); T_2 – Pongamia oil soap 3%;

T_3 – Pongamia oil soap 2%; T_4 – Pongamia oil soap 1%; T_5 – Pongamia oil soap 0.6%;

T_6 – Neem oil soap 0.6 %; T_7 – Soap solution 0.5%; T_8 – Control

After five days of spray application, there was no significant difference in mite predator population and soap solution itself stood as a best treatment with highest population (7.67/5 plants) followed by pongamia oil soap @ 0.6% and control plot with 6.67 and 6.00/5 plants respectively. Lowest mite predator's count was observed in thiamethoxam 25WG and neem oil soap 0.6% treated plots with 1.67/5 plants. Pongamia oil soap @ 1, 2 and 3% showed 4.67, 2.67 and 2.67/5 plants mite predator's population respectively.

Seventh day observation revealed that soap solution 0.5% with 11.00/5 plants mite predator's population showed highest count which was significantly different from other treatments. Pongamia oil soap @ 0.6% with 9.33/5 plants was statistically on par with soap solution 0.5% followed by pongamia oil soap @ 1% (8.33/5 plants). Pongamia oil soap @ 2% and neem oil soap 0.6% were statistically similar by results which was on par with control plot with 4.00, 4.00 and 4.33/5 plants respectively, however standard check and pongamia oil soap @ 3% showed lowest population of 0.33 and 2.33/5 plants respectively.

Richness of mite predators was relatively high in all the treatments at fourteenth day of spray application. Soap solution 0.5% marked highest of 35.67/5 plants which was at par with pongamia oil soap @ 0.6, 1 and 2% with the mite predator population of 20.00, 19.67 and 18.00/5 plants respectively. All the remaining treatments were at par with control plot (9.33/5 plants) including neem oil soap @ 0.6%, pongamia oil soap @ 3% and standard check and the respective mite predator's population was 12.33, 11.33 and 8.00/5 plants.

4.3. BIOMETRIC OBSERVATIONS TAKEN DURING FIELD EVALUATION – NOVEMBER 2019 TO MAY 2020

Impact of pongamia oil soap treatments on brinjal fruit length was recorded by means of measuring the average fruit length of fifteen fruits at each harvest and the data were analysed statistically after square root transformation and presented in Table 18.

Average fruit length of brinjal was maximum in pongamia oil soap 3% treated plot (8.53 cm) which was statistically at par with standard check (Chlorantraniliprole 18.5 SC 3 mL/10L and/or Thiamethoxam 25 WG 2g/10L) with 8.49 cm average fruit length. Control plot showed minimum fruit length of 7.85 cm which was on par with soap solution 0.5% (7.96 cm). Pongamia oil soap @ 2% was statistically second-best treatment with 8.23 cm. Pongamia oil soap @ 1%, neem oil soap 0.6% and pongamia oil soap @ 0.6% furnished statistically similar results with 8.16, 8.15 and 8.10 cm average fruit length respectively.

4.4. YIELD ATTRIBUTES OF BRINJAL TAKEN DURING FIELD EVALUATION AT *RABI* SEASON FROM NOVEMBER 2019 TO MAY 2020

Brinjal fruits were harvested at seven days intervals and totally there were ten harvests done during the study period. Fresh weight of brinjal fruits was measured after each harvest after which total and marketable yield were computed for all the treatments. Data were statistically analysed after square root transformation and presented in Table 19.

Highest fresh yield of harvested fruits was recorded in standard check treated plot with 194.40g/plant followed by pongamia oil soap @ 3% (191.70g/plant), soap solution 0.5% (177.20g/plant), pongamia oil soap 2% @ (170.00g/plant), neem oil soap @ 0.6% (156.67g/plant), pongamia oil soap @ 1% (146.37g/plant) and pongamia oil soap @ 0.6% (131.10g/plant). Control plot recorded lowest fresh weight of fruits with 121.67g/plant at first harvest. Pongamia oil soap @ 3% was the best treatment at the time of second harvest which recorded 187.10g/plant followed by standard check (183.32g/plant). Pongamia oil soap @ 2, 1 and 0.6%, soap solution @ 0.5% and neem oil soap @ 0.6% recorded 168.03, 166.67, 152.77, 152.20 and 125.06g/plant respectively while control plot recorded lowest yield of 116.66g/plant.

Third harvest showed that highest yield was achieved in pongamia oil soap @ 3% treated plants with 208.33g/plant followed by standard check treated plants (202.78g/plant) and pongamia oil soap @ 2% treated plots (194.42g/plant).

Minimum fresh yield of 150.00g/plant was recorded in control plot followed by neem oil soap 0.6% (161.11g/plant) and soap solution 0.6% (163.89g/plant). Pongamia oil soap @ 1% and pongamia oil soap @ 0.6% gave 177.78 and 172.21g/plant respectively. At fourth harvest, standard check treated plot recorded highest fresh yield of 225.00g/plant and minimum fruit yield was recorded in control plot (140.24g/plant). Among botanicals, pongamia oil soap @ 3% showed maximum fresh weight of brinjal fruits (183.33g/plant) followed by pongamia oil soap @ 2%, soap solution 0.5%, pongamia oil soap @ 1% and 0.6% and neem oil soap 0.6% with 180.56, 174.98, 156.77 and 133.33g/plant respectively.

Pongamia oil soap @ 3% recorded highest fresh fruit yield of 210.00g/plant which was on par with pongamia oil soap @ 2% (203.89g/plant) at fifth harvest. Standard check with 195.00g/plant found to be on par with pongamia oil soap @ 2%. Soap solution 0.5% and pongamia oil soap @ 1% gave 161.11 and 158.32g/plant fresh weight of fruits respectively. Minimum fruit yield was recorded by control plot with 106.17g/plant. pongamia oil soap @ 0.6 and neem oil soap 0.6% gave 125.00 and 116.11g/plant respectively.

At the time of seventh harvest, standard check gave the highest fresh yield with 286.11g/plant which was on par with pongamia oil soap @ 3% (263.78g/plant), neem oil soap 0.6% (261.11g/plant), pongamia oil soap 2% @ (255.55g/plant), and pongamia oil soap @ 1% (252.33g/plant). Pongamia oil soap @ 0.6% showed fresh weight of 250.00g/plant which was at par with control plot (241.11g/plant) while soap solution 0.5% recorded lowest yield of 188.89g/plant.

Standard check again stood superior in fresh weight of brinjal fruits (220.71g/plant) followed by pongamia oil soap @ 3% (187.89g/plant) at seventh harvest. Soap solution 0.5% gave minimum fresh weight of 134.44g/plant which was at par with control (145.55g/plant). Pongamia oil soap @ 2 and 1% were at par with each other which gave 173.89 and 169.44g/plant yield respectively. Neem oil soap @ 0.6% with 148.89g/plants was on par with pongamia oil soap @ 0.6% (166.11g/plant).

Table 18. Average length of fifteen fruits per treatment taken under field evaluation

Treatments	Average length of fruits (cm)*
Chlorantraniliprole 18.5 SC 3 mL/10L - 1st & 3rd application & Thiamethoxam 25 WG 2g/10L - 2nd application	8.49 a
Pongamia oil soap 3%	8.53 a
Pongamia oil soap 2%	8.23 b
Pongamia oil soap 1%	8.16 bc
Pongamia oil soap 0.6%	8.10 bc
Neem oil soap 0.6%	8.15 bc
Soap solution 0.5%	7.96 cd
Control	7.85 d
C.D. (*P*=0.05)	**0.22**

* Average of fifteen observations

During eighth harvest, pongamia oil soap at @ 3% recorded maximum fruit yield of 178.60g/plant which was on par with 2% pongamia oil soap (176.91g/plant), 1% pongamia oil soap (175.04g/plant) and standard check (172.65g/plant). Control plot expressed lowest yield of 127.82g/plant while neem oil soap @ 0.6% and soap solution 0.5% were on par with each with the yield of 155.00 and 148.70g/plant respectively. Pongamia oil soap at @ 0.6% recorded 162.00g/plant which was on par with standard check, pongamia oil soap @ 1 and 2%.

On ninth harvest, standard check recorded maximum fruit yield (232.84g/plant) followed by pongamia oil soap @ 3 and 2% with 193.50 and 192.06g/plant respectively. Soap solution 0.5% marked minimum yield of 148.94g/plant which found to be on par with control (150.12g/plant) and neem oil soap 0.5% (157.89g/plant). Pongamia oil soap @ 1 and 0.6% found to be on par with each other recording 184.99 and 170.17g/plant respectively. At the time of tenth harvest, pongamia oil soap @ 3% gave the highest yield of 253.89g/plant while soap solution gave minimum yield (179.83g/plant). Pongamia oil soap @ 2%, standard check and pongamia oil soap @ 1% were on par with each other in the fresh weight of fruits with 244.62, 243.83 and 223.57g/plant respectively. Neem oil soap 0.6% recorded 219.03g/plant which found to be on par with pongamia oil soap @ 0.6% (217.13g/plant). Control plot was on par with soap solution 0.5% in the fresh weight of brinjal fruit with 183.34g/plant.

Based on the brinjal fruit's fresh weight, total yield and marketable yield were calculated for all the treatments and statistically analysed. From the Table 19, standard check achieved best total yield with 2156.64g/plant followed by pongamia oil soap @ 3%, 2%, 1% and 0.6% with 2056.44, 1961.62, 1829.49 and 1703.25g/plant respectively.

Highest marketable yield was marked in standard check treated plants with 2058.44g/plant followed by pongamia oil soap @ 3%, 2%, 1% and 0.6% with the marketable fruit yield of 1919.04, 1809.02, 1661.29 and 1507.75g /plant respectively. Minimum marketable fruit yield was obtained in control plot (1257.28g/plant) which was on par with soap solution 0.5% (1436.80g/plant). Neem oil soap 0.6% recorded 1436.80g/plant marketable yield which was on par with pongamia oil soap @ 0.6%.

4.5. ECONOMICS OF PRODUCTION OF BRINJAL UNDER DIFFERENT TREATMENTS

Economic analysis was done for the treatments based on the production cost including cost of farm yard manure, seeds, insecticides, labour charge and the prevailing market price and the B:C ratio was calculated (Table 20). B:C ratio of all the treatments found to be more than one and the highest B:C ratio and maximum net return of 2.00 and 554500/- per hectare were recorded in standard check. Pongamia oil soap @ 3% had highest net income of 483315.00/- per hectare among botanicals with 1.87 B:C ratio followed by pongamia oil soap @ 2% (427260.00/- per hectare), pongamia oil soap @ 1% (350745.00/- per hectare), and pongamia oil soap @ 0.6% (268935.00/- per hectare) whereas net income of control plot was low (135960.00/-) which recorded lowest B:C ratio of 1.25 followed by soap solution 0.5% with net income and B:C ratio of 199095.00/- and 1.37.

Among botanicals, neem oil soap 0.6% recorded minimum net return and B:C ratio of 229610.00/- and 1.42 respectively.

4.6. INCIDENCE OF OTHER PESTS AND DISEASES

Other insect pest incidence *viz.*, serpentine leaf miner, mealy bug, sphingid caterpillar, leaf webber, lacewing bug, grasshoppers and root grub attack were also noted during field examination and proper physical and mechanical management practices were carried out as it was insignificant. Diseases such as damping off and Phomopsis blight were observed in brinjal and proper management practices were carried out.

4.6.1. Other pests' incidence

The other pests like serpentine leaf minor (*Liriomyza trifolii*), mealy bug (*Coccidohystrix insolita*), sphingid caterpillar (*Acherontia styx*), leaf roller (*Autoba olivacea*), leaf webber (*Herpetogramma bipunctalis*), lacewing bug (*Urentius hytricellus*), grasshopper (*Attractomorpha crenulata*) and root grubs (*Leucopholis coneophora*) and the diseases like damping off and Phomopsis blight were also noted in brinjal field with minor incidence.

Table 19. Effect of different treatments on the yield attributes of brinjal during field evaluation from November 2019 to May 2020

Treatments	Fresh weight of brinjal fruits (g/plant) *										Total yield (g/plant)	Marketable yield (g/plant)	Difference
	First harvest	Second harvest	Third harvest	Fourth harvest	Fifth harvest	Sixth harvest	Seventh harvest	Eight harvest	Ninth harvest	Tenth harvest			
Standard check	194.40	183.32	202.78	225.00	195.00	286.11	220.71	172.65	232.84	243.83	2156.64	2058.44	98.2
PO 3%	191.70	187.10	208.33	183.33	210.00	263.78	187.89	178.60	193.50	253.89	2056.44	1919.04	137.4
PO 2%	170.00	168.03	194.42	180.56	203.89	255.55	173.89	176.92	192.06	244.62	1961.62	1809.02	152.6
PO 1%	146.37	166.67	177.78	174.98	158.32	252.33	169.44	175.04	184.99	223.57	1829.49	1661.29	168.2
PO 0.6%	131.10	152.77	172.21	156.77	125.00	250.00	166.11	162.00	170.17	217.12	1703.25	1507.75	195.5
Neem soap 0.6%	156.67	125.06	161.11	133.33	116.11	261.11	148.89	155.40	157.89	219.03	1634.60	1436.80	197.8
Soap solution 0.5%	177.20	152.20	163.89	161.11	161.11	188.89	134.44	148.70	148.94	179.83	1616.30	1374.70	241.6
Control	121.67	116.66	150.00	140.24	106.17	241.11	145.55	127.82	150.12	183.34	1482.68	1257.28	225.4
CD (0.05)	**1.27**	**1.39**	**1.10**	**0.37**	**0.35**	**1.14**	**0.81**	**0.62**	**1.20**	**1.15**	**9.40**	**11.84**	

*Mean observations from twelve plants

PO 0.6% - Pongamia oil soap 0.6% PO 1% - Pongamia oil soap 1% PO 2% - Pongamia oil soap 2%

PO 3% - Pongamia oil soap 3% Standard check - Chlorantraniliprole 18.5 SC 3 mL/10L for 1st & 3rd application & Thiamethoxam 25 WG 2g/10L for 2nd application

Serpentine leaf minor maggots were observed in the leaves of brinjal seedlings and to control the pest, affected leaves were clipped off and crushed in order to kill the maggots. As the eggs of sphingid caterpillar were easily visible to naked eye, it was removed and destructed and some caterpillars were removed at early stages. Some webbed new fleshes were destructed along with leaf webber larvae at early stages of the crop. Lacewing bugs were noticed in some plants and disappeared after spray application. Root grubs cut the seedlings at collar region after transplantation and to manage that, grubs were identified and killed. Grasshoppers were the major leaf feeder but it was not significant in damage. Damping off was appeared at seedling stage of the crop and drenching of *Pseudomonas fluorescens* @ 2% reduced the incidence totally. In Phomopsis blight, water soaked and soft tissues in fruits was observed in the experimental plots and the affected fruits were removed immediately after noticing in order to control the spread.

4.7. PHYTOTOXICITY SYMPTOMS

Leaf fall and reduced leaf lamina size were noticed in pongamia oil soap @ 3% treated plants after second and third spray application however the yield was remained unreduced in 3% pongamia oil soap plot. Oil formulations are generally phytotoxic at higher concentrations on vegetable crops. The cause of phytotoxicity is not easily explained however the maximum temperature of more than 31^0C at the time of spray hours in the field may be one of the reasons for these symptoms (Table 21).

(a) Damaged and malformed fruits by FSB

(b) Larva of FSB inside an infested fruit

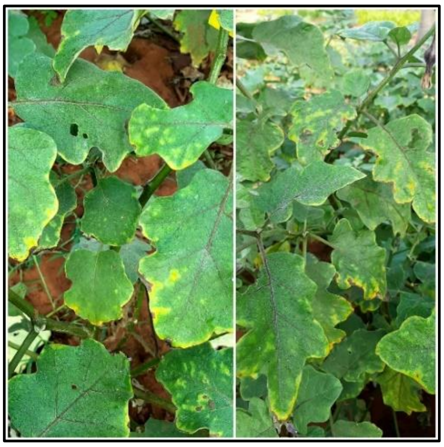
(c) Ladder like scrapping by hadda beetles

(d) Grubs of hadda beetle

(e) Adults of *Epilachna dodecastigma*

(f) Adult of *E. vigintioctopuntata*

Plate 5. Incidence of fruit and shoot borer and hadda beetle in the experimental plot



(a) Hopper burn symptoms in the field **(b) Leafhopper incidence in brinjal leaves**

(c) Leaf curling by aphid infestation

(d) Microscopic view of dead aphids in pongamia oil soap 3% treated plot

(e) Microscopic view of red spider mites **(f) Whitefly incidence in the field**

Plate 6. Incidence of leafhoppers, aphids, mites and whiteflies

(a) Lynx spider, *Oxyopes assamensis*

(b) Green lynx spider, *Peucetia viridans*

(c) Huntsman spider, *Olios* sp.

(d) Crab spider, *Thomisus projectus*

(e) Predatory ladybird beetle, *Scymnus* sp.

(f) Six spotted zigzag ladybird beetle, *Cheilomenes sexmaculata*

Plate 7. Documentation of predatory spiders and ladybird beetles

(a) Aphidophagus coccinellid predator, *Pseudaspidimerus trinotatus* (left) and Syrphid, *Paragus serratus* (right)

(b) Green lacewing fly, *Crysoperla zastrowi*

(c) Egg parasitoid of Epilachna, *Tetrasticus* sp.

(d) Pupal parasitoid of Epilachna, *Pediobius foveolatus*

(e) Assassin bug, *Irantha armipes*

(f) Mite predators - Predatory gall midge (*Feltiella acarisuga*) and predatory rove beetle (*Oligotus* sp.)

Plate 8. Documentation of ladybird beetles, syrphids, green lacewing, hymenopteran and hemipteran natural enemies and mite predators

Fig.14. Effect of different treatments on the yield attributes of brinjal during field evaluation from November 2019 to May 2020

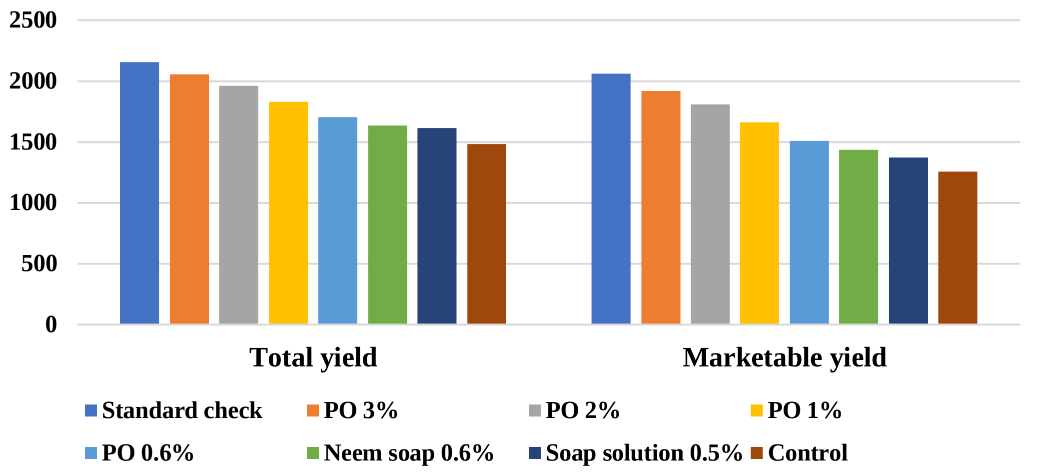
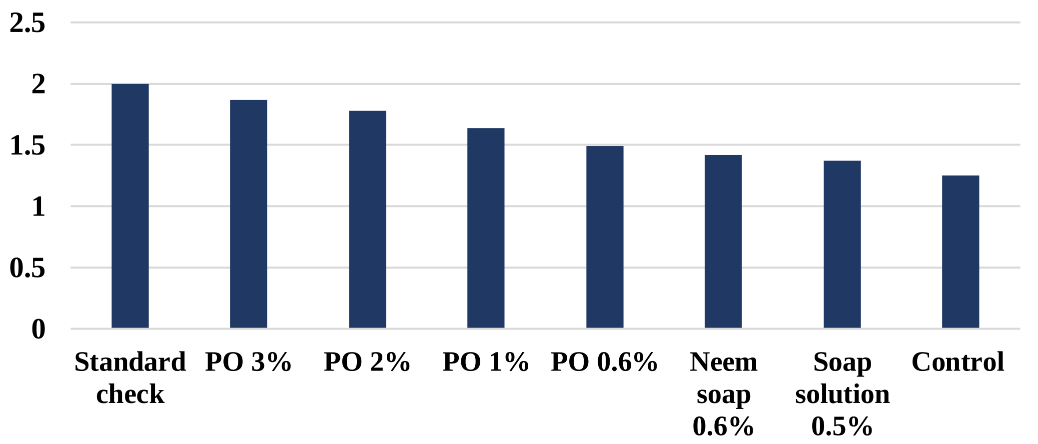


Fig.15. B:C ratio



PO 0.6% - Pongamia oil soap 0.6%; PO 1% - Pongamia oil soap 1%;

PO 2% - Pongamia oil soap 2%; PO 3% - Pongamia oil soap 3%;

Standard check - Chlorantraniliprole 18.5 SC 3 mL/10L for 1st & 3rd application & Thiamethoxam 25 WG 2g/10L for 2nd application

(a) Serpentine leaf miner, ***Liriomyza trifolii***

(b) Mealy bug, ***Coccidohystrix insolita***

(c) Grasshopper, ***Attractomorpha crenulata***

(d) Sphingid caterpillar, ***Acherontia styx***

(e) Leaf webber, ***Herpetogramma bipunctalis***

(f) Leaf roller, ***Autoba olivacea***

(g) Lacewing bug, ***Urentius hytricellus***

(h) Phomopsis blight incidence

Plate 9. Other pests and disease incidence

Table 20. Economics of cultivation of brinjal during field evaluation from November 2019 to May 2020

Treatments	Economics of brinjal					
	Production cost excluding insecticides (Rs/ha)	Cost of insecticides (Rs/ha)	Total Expenditure (Rs/ha)	Gross Income (Rs/ha)	Net Income (Rs/ha)	B:C ratio
Chlorantraniliprole 18.5 SC 3 mL/10L - 1st & 3rd application & Thiamethoxam 25 WG 2g/10L - 2nd application	542820.00	14000.00	556820.00	1111320.00	554500.00	2.00
Pongamia oil soap 3%	542820.00	10125.00	552945.00	1036260.00	483315.00	1.87
Pongamia oil soap 2%	542820.00	6750.00	549600.00	976860.00	427260.00	1.78
Pongamia oil soap 1%	542820.00	3375.00	546195.00	896940.00	350745.00	1.64
Pongamia oil soap 0.6%	542820.00	2025.00	544845.00	813780.00	268935.00	1.49
Neem oil soap 0.6%	542820.00	3550.00	546370.00	775980.00	229610.00	1.42
Soap solution 0.5%	542820.00	585.00	543405.00	742500.00	199095.00	1.37
Control	542820.00	0.00	542820.00	678780.00	135960.00	1.25

Table 21. Meteorological data for the year 2019-2020

Month	Max. Temp	Min. Temp	Mean RH		Cum. Rainfall in mm	No. of rainy days	BSH
			Max	Min			
April 2019	33.5	25.3	81	61	41.7	1	8.1
May 2019	33.3	26.1	86	66	42.3	5	9.0
June 2019	31.3	25.1	92	74	698.2	22	5.4
July 2019	29.3	24.0	94	81	1129.3	28	2.7
August 2019	28.7	23.9	95	83	1061.6	29	2.4
September 2019	29.5	24.0	93	78	510.1	23	3.5
October 2019	29.7	23.8	92	78	487.2	16	4.8
November 2019	31.5	23.5	91	68	93.6	3	8.5
December 2019	31.6	22.8	92	62	91	3	7.4
January 2020	31.6	21.7	91	58	0	-	9.4
February 2020	32.0	22.4	91	58	45.8	1	8.8
March 2020	32.6	24.2	88	68	3.0	1	8.4
April 2020	34.0	26.0	87	64	3.4	3	8.5

(a) Reduced leaf lamina

(b) Less number of leaves caused by leaf fall in plants

Plate 10. Phytotoxicity symptoms in pongamia oil soap @ 3% treated plants

Discussion

5. DISCUSSION

Among the tropical vegetable crops, brinjal is more popular and demanding vegetable because of its high nutritious nature. One of the most challenging factors of brinjal cultivation is the pest management in a safe and non-toxic means. The laboratory and field experiments were conducted on 'Pongamia oil soap for the management of major pests of brinjal (*Solanum melongena* L.) during 2018-20 with the objective of evaluating the pongamia oil soap on major brinjal pests like fruit and shoot borer, leafhopper, hadda beetle, aphids, mites and whiteflies and its influence on the natural enemies as mentioned in the technical program. Since the literatures on influence of pongamia oil soap against major pests of brinjal are scarce, results of the study attained in the laboratory and field experiment are compared with pongamia oil and discussed in this chapter.

5.1. LABORATORY BIOASSAY OF PONGAMIA SOAP ON EPILACHNA GRUBS

Epilachna grubs and adults are highly destructive to the brinjal crop which extensively damage leaves and even fruits when the timely action is not given. Incidence of this pest is common throughout the cultivation period. Hence, grubs are administered with pongamia oil soap at four concentrations and the results obtained are discussed here.

5.1.1. Study on feeding deterrency index (FDI) of pongamia oil soap against Epilachna beetle, *Epilachna dodecastigma*

Pongamia oil soap @ 3 per cent exhibited maximum Feeding Deterrency against final instar grubs of Epilachna, *Epilachna dodecastigma* where 3% treated leaves were not consumed by the grubs at 10 h of treatment. The other concentrations also recorded more than 90% feeding deterrency with 94.35, 92.07 and 90.48% in pongamia oil soap @ 2 per cent, 1 per cent and 0.6 per cent respectively. Earlier, Swaminathan *et al.* (2010) reported that among all the seed oils tested, pongamia oil at 0.625, 1.25, 2.5 and 5.0% concentration exhibited maximum antifeedant activity against *Epilachna vigintioctopunctata* which showed no feeding up to 48 h after treatment and 100% mortality after one week of spray.

This study is also in line with the results given by Sajay (2019). In his study, pongamia oil soap @ 2% showed feeding deterrence of 93.96% in *Spodoptera litura* followed by pongamia oil soap @ 1% (83.91%) and 0.6% (55.70%). According to Kumar *et al.* (2006), high concentration of pongamia furano-flavonoids such as karanjin, pongamol, glabrin etc. were effective against *Spodoptera litura* where the methanolic extract of pongamia crude seed oil showed highest growth retardation and antifeedant activity. According to the study conducted by Ponnuvel *et al*. (2013), third formulation containing karanj oil 4 mL, neem oil 4 mL, zinger oil 1 mL and tween 20 emulsifier 1 mL (totally 10 mL) recorded maximum antifeedant activity of 80.06% out of five formulations when it was used against *E. vigintioctopunctata* grubs. The minimum leaf area consumption was recorded by final instar larvae of *S. litura* in NSKE treated leaves (46.12%) followed by *Acacia arabica, Nicotiana. tabacum* and Pongamia Seed Kernel Extract (PSKE) with 48.12%, 56.00% and 57.20% respectively (Pramod, 2014). Thomas (2019) conducted a study using pongamia oil soap @ 2, 1 and 0.6% against okra leaf roller, *Sylepta derogata* and the results showed 97.33, 82.33 and 72.33% feeding deterrency in the first experiment and 98.33, 83.67 and 72.33% feeding deterrency in the second experiment by 2, 1 and 0.6% pongamia soap respectively.

Soap solution 0.5% and water spray treated plants recorded almost similar results which undoubtedly indicates that antifeedant property of pongamia oil soap is not due to the addition of soap powder but it is due to the insecticidal property of active components present in the pongamia oil. This observation was in line with the results got by Thomas (2019) and Sajay (2019).

5.1.2. Growth index (GI) and relative growth index (RGI) in Epilachna grubs under different treatments

The growth retardation property of pongamia oil soap at all the concentrations was high when tested against Epilachna grubs in the laboratory experiment. From the results obtained, it can be concluded that 3% pongamia oil soap was the superior treatment with 100% growth retardation in grubs however efficacy was decreasing with the decreasing concentrations. No growth retarding activity was observed in soap solution 0.5% which was proven by the 100% pupation of grubs as observed in control and water spray. According to Sajay (2019), 2% pongamia oil soap showed maximum growth retardation in *Spodoptera litura* followed by 1 and 0.6% with 0.00, 0.17 and 0.14 RGI respectively. Similar statement was given by Thomas (2019), she got RGI of 0.16 & 0.16, 0.42 & 0.45 and 0.57 and 0.60 by 2, 1 and 0.6% pongamia soap in first and second experiment respectively. Maximum growth retardation activity was observed under methanolic extract of pongamia oil and followed by crude pongamia oil treatments in *S. litura* and it was added that presence of active compounds such as karanjin, pongamol, glabrin and pinnatin of pongamia oil contributed in the insecticidal activity (Kumar *et al*., 2006). Ghosh and Chakraborty (2012) stated that plant extract of pongamia at 5% was effective against *Henosepilachna vigintioctopunctata* and recorded more than 50% mean population reduction (both grubs and adults) in potato.

5.2. FIELD EVALUATION OF PONGAMIA OIL SOAP AGAINST MAJOR PESTS OF BRINJAL DURING RABI SEASON, 2019-2020

The field investigation was conducted to evaluate the potential of pongamia oil soap at different concentrations in the management fruit and shoot borer (*Leucinodes orbonalis*), leafhopper (*Amrasca biguttula biguttula*), hadda beetle (*Epilachna vigintioctopunctata*), aphids (*Aphis gossypii*), mites (*Tetranychus urticae*) and whiteflies (*Bemisia tabaci*) and also to test their impact on spiders, coccinellids, syrphids, green lacewings, hemipteran predators and hymenopteran parasitoids and mite predators' population. The results of field study are discussed here under this chapter.

5.2.1. Field evaluation of pongamia oil soap against brinjal fruit and shoot borer (BFSB), *Leucinodes orbonalis* from November 2019 to May 2020

All the pongamia oil soap concentrations tested against FSB are effective in reducing the fruit damage at first, second and third application at seventh and fourteen day after application.

Pongamia oil soap @ 3% reduced the fruit damage caused by fruit and shoot borer to the lowest level in all the three sprays at seventh and fourteenth days after treatment application. Similarly, next to the spinosad 0.1 mL/L (6.38%) and neem oil soap 3% (9.66%), pongamia oil @ 3% recorded minimum fruit infestation of 10.28% when Sahana and Tayde (2017) evaluated certain botanicals on brinjal shoot and fruit borer. In the study conducted by Sureshsing and Tayde (2017), 3% pongamia oil was effective against FSB in reducing the fruit damage significantly on third, seventh and fourteenth day after spray with the mean fruit infestation of 11.57 and 12.40% during second and third spray.

Next to 3% pongamia oil soap, chlorantraniliprole 18.5 SC recorded minimum fruit borer infestation of 16.92% at seventh day after first spray and the effectiveness was persisted up to 14 days when compared to 2%, 1% and 0.6% pongamia soap. This result was in line with the results obtained by Patra *et al*. (2016) where chlorantraniliprole 18.5 SC recorded lowest fruit damage among all the treatments tested with 79.45% protection over control while karanjin showed 22.27% protection at lowest concentration of 0.2%. Tripura *et al.* (2017) stated similar observations in which chlorantraniliprole 18.5 SC recorded 8.37 and 8.13 mean per cent fruit infestation followed by chlorfenapyr 10 SC (2mL/L) with 11.10 and 13.05% during 2015 and 2016. Chlorantraniliprole 20 EC recorded minimum fruit infestations from 2.77% to 4.97% followed by flubendiamide 39.35 EC (Kushwaha and Painkara, 2016). Rajavel *et al*. (2011) reported that chlorantraniliprole at 60g a.i./ha was the best treatment over other chemicals which recorded minimum mean fruit damage of 4.99% followed by 50g a.i./ha.

In the present study, 2% pongamia oil soap were also equally effective as chlorantraniliprole 18.5 SC in reducing fruit and shoot borer infestation followed by 1, 0.6% pongamia oil soap and neem oil soap 0.6% on seventh day after spray application. Mathur *et al*. (2012) reported same observations that botanicals such as pongamia and iluppai oil proved to be the best alternative for neem oil with high insecticidal activities.

He stated that pongamia oil @ 2% showed 56.24% protection over control from fruit and shoot borer infestation while endosulfan recorded 61.79% protection. Among the botanicals, NSKE 5% and pongamia oil 5% were the superior treatments by weight basis which showed 12.70, 16.20 and 22.33 per cent and 33.95, 31.82 and 34.24 per cent fruit damage respectively on I, II and III pickings (Ajabe, 2019).

Except in pongamia oil soap and chlorantraniliprole treated plots, fruit damage was found to be increased in other treatments generally during second and third spray at seventh and fourteenth day of spray. The higher antifeedant property of pongamia oil soap might be the reason for reduced fruit borer infestation and also due to the richness of general natural enemies. This study was supported by the statement, methanolic seed extract, petroleum ether, chloroform extract of seeds, aqueous seed extract of pongamia and pongamia oil at different concentrations had antifeedant activity (Prabhakar *et al*. 1994; Chandel *et al*. 1995; Deka *et al*. 1998) against pests.

Prior to the last spray, all the treatments showed highest fruit damage which ranged from 77.43 to 90.58% however all the botanicals except neem oil soap and chlorantraniliprole reported to lower the damage at seven days after treatment. Higher temperature recorded during April 2020 month might be the cause for this heavy infestation. Ghosh and Senapati (2009) mentioned that fruit and shoot borer was more active during summer months and more particularly from May to August and up to 81.00% fruit damage was reported.

However, there was no fruit damage reduction in soap solution 0.5% treated plants and control plot throughout the study period. Maximum of 93.57% fruit and shoot borer infestation was observed at fourteenth day after third spray in control plot. The observation proves that soap solution has no insecticidal action against fruit and shoot borer. Thomas (2019) also stated same results, she reported that soap solution 0.5%

5.2.2. Field evaluation of pongamia oil soap against leafhopper, *Amrasca biguttula biguttula* during *rabi* season from November 2019 to May 2020

Insecticidal action of pongamia oil soap, thiamethoxam 25 WG, neem oil soap and soap solution 0.5% was evaluated against leafhopper (*Amrasca biguttula biguttula*) during the field study and from the results obtained it is clear that all the treatments were effective in managing leafhoppers except soap solution and control.

The data recorded from field study confirms that all the pongamia oil soap concentrations were efficient in reducing leafhopper numbers during the field study with 3% soap found to be the best treatment among botanicals. However, thiamethoxam 25 WG being a neonicotinoid was the superior one than the 3% pongamia oil soap treatment during second spray application. A day after second spray application, per cent population reduction in leafhoppers was 63.57 which was the highest reduction over other treatments and the efficacy was increased in the subsequent days with maximum efficacy recorded on fourteenth day after second application. This finding is in agreement with Lekha *et al.* (2018), they reported that Dinotefuran 20% SG at 30g a.i./ha (90.87% and 85.64%), at 25g a.i./ha (89.96% and 84.29%) and Imidacloprid 17.8% SL at 22.25g a.i./ha (89.07% and 83.40%) were the superior treatments which showed maximum per cent reduction in jassids population during *rabi* 2016 and *kharif* 2017 (seventh day). As a fourth best treatment, thiamethoxam 25 WG @ 50g a.i./ha showed maximum per cent reduction on seventh day (84.18% and 81.91%) and falls on tenth and fifteenth day but in present study efficacy was lasted up to fourteenth day.

This present observation is also in accordance with Anand *et al.* (2013) who proved the persistent efficacy of neonicotinoids such as thiamethoxam and acetamiprid against leafhoppers in brinjal. In his studies, the effectiveness of thiamethoxam against *Amrasca* was lasted till thirteenth day after all the three sprays in both of his study years (2010 and 2011). In the present findings, minimum leafhopper population was observed on fourteenth day after second spray with 2.93 leafhoppers/ 5 leaves by thiamethoxam treated plants whereas it was 7 leafhoppers/5 leaves on one day after spray application. The same findings were reported by Arya (2015) where, after dinotefuran 20SG 30g a.i./ha (0.30/plant), thiamethoxam 25 WG @ 50g a.i./ha recorded least population of leafhoppers with 0.42/plant on the last day of observation after spray application (ninth day) while 2.20/plant was recorded on third day after first spray application and the same trend was found in the second spray also. The results stated by Shaikh *et al*. (2014) also supports the current observation in which thiamethoxam found to be most effective among all the treatments against sucking pests of brinjal. According to the study conducted by Naik *et al*. (2009), leafhoppers was effectively managed by thiamethoxam.

Maximum of 61.07% reduction in leafhopper population was recorded by 3% pongamia oil soap among botanicals followed by 2%, 1% and 0.6%. In both the sprays, population reduction was maximum on the immediate day after spray after which efficacy tend to be decreasing and the highest population has reached on fourteenth day of the spray. However, thiamethoxam stood as a superior one over all the botanicals. Results obtained by Sakthivel *et al*. (2012) supports the present findings, they reported that mulberry jassid population was effectively reduced by pongamia oil @ 3% and the per cent reduction recorded was 42.49% in the sole application of oil. Leafhoppers numbers were lower on 3DAS and the population was increased at the subsequent days with the maximum population of 5.01/leaf recording on 10DAS but the oil was inferior to dichlorvos both in sole and in combination. Vinodhini and Malaikozhundan (2011) derived the efficiency of pongamia oil and other biopesticides for leafhoppers (*Amrasca devastans*). Pongamia oil soap @ 3mL/L exhibited 35.51% population reduction in leafhoppers which was significantly higher than control.

Though chlorantraniliprole is more effective in managing the lepidopteran pests, it also reduced the leafhopper population of 44.53% over control on seventh day of first spray application. Potai *et al*. (2018) studied the efficacy of newer insecticides at different doses on okra sucking pests and found the results in accordance with the present study. They reported that BAS 450 01 I 300 SC @ 18.5g a.i./ha as highly effective treatment with mean population of 2 jassids/plant followed by the same chemical at 12.5g a.i./ha concentration (2.17).

Chlorantraniliprole 18.5 SC showed third best result with minimum population of 2.45 jassids/plant on seventh day after treatment and attained maximum population on tenth day observation. The current findings are also in conformity with the results given by Sathyan *et al*. (2016) who reported that chlorantraniliprole 18.5 SC could show 20.36% population reduction in leafhoppers (*Amrasca devastans*) of cotton when evaluated nineteen synthetic insecticides on cotton sucking pests. Reddy *et al*. (2018) reported that chlorantraniliprole 18.5 SC showed minimum population of pod bugs (0.67/plant) at one day after spray and thiamethoxam was the best treatment (0.33/plant) however all the treatments were reached highest population on fifteenth day of spray.

Neem soap was equally effective as pongamia oil soap @ 2 and 1% in the first spray which recorded 53.53 per cent reduction on a day after first spray application. This result is in line with the findings of Anitha and Nandihalli (2008). When she evaluated the potential of some botanicals against okra sucking pests, lowest number of leafhoppers was recorded in neem oil treated plants with 1.13/3 leaves followed by 2% pongamia oil recorded 1.53/3 leaves. Dehariya *et al*. (2018) reported that among five plant derived products, lowest leafhopper population was associated with neem oil 1% treated plants which was closely followed by pongamia oil 1%. The leafhopper population was not effectively reduced by neem oil soap 0.6% in the second spray and the reason might be the heavy numbers of the pest which ranged between 15.73 to 18.93 leafhoppers per 5 leaves which is higher than the ETL.

Negligible leafhopper population was observed during third spray and so it wasn't recorded. Low population of leafhoppers might be due to the higher temperature observed at April 2020. This observation can be supported by the results of Chandrakumar *et al*. (2008) in which he stated that sucking pests of brinjal including leafhoppers has negative correlation with maximum temperature. The report of minimum population of leafhoppers is in accordance with Kadgonkar *et al*. (2018) statement where he reported the negative correlation of maximum and minimum temperature in the leafhopper population.

The leafhopper population also was not reduced by soap solution 0.5% spray which came up with the results similar to untreated control plots representing that the decline in leafhopper population by pongamia oil soap was just the pesticidal property of oil not the soap powder added.

5.2.3. Field evaluation of pongamia oil soap on Epilachna beetle, *Epilachna* sp. in brinjal during *rabi* season from November 2019 to May 2020

Based on the results obtained, botanicals and chemical treatments evaluated were effective in reducing the hadda beetle damage on brinjal leaves when comparing to the control and soap solution 0.5%.

Though 3% pongamia oil soap proved to be the effective treatment, chlorantraniliprole and thiamethoxam were persisted in its insecticidal action against leaf damage caused by Epilachna. During the first and third spray, leaf damage caused by hadda beetles and grubs was lowest in chlorantraniliprole treated plants at seventh and fourteenth day of spray which showed 4.11 and 4.65% leaf damage on first spray and 6.85 and 8.65% damage on third spray respectively on seven and fourteen days after spray while pongamia oil soap treated plants were most effective on seventh day after spray. Results of Kodandaram *et al.* (2014) is in line with the present observation. In their study, ovicidal action of chlorantraniliprole was reported with minimum of 20.5 per cent egg hatching and highest of 70.0 per cent inhibition in egg hatching. Along with this, chlorantraniliprole, indoxacarb, imidacloprid and thiacloprid showed 100 per cent mortality of hatched grubs. When they directly treated the grubs and adults by insecticide, after thiacloprid and imidacloprid, chlorantraniliprole showed 43.3 and 86.7 per cent mortality in grubs and 10.0 and 10.0 per cent mortality in adults.

Thiamethoxam was also showed a decline in Epilachna infestation and its efficacy was persisted up to fourteen days with 5.80 per cent damage when comparing to the botanicals tested (second spray). Efficacy of thiamethoxam against brinjal pests was evaluated by Patnaik *et al*. (2004) at different doses. Thiamethoxam 25 WG @ 50g a.i./ha as a foliar spray found to be most effective against *E. vigintioctopunctata* and *A. biguttula biguttula* and he also stated that soil drenching of thiamethoxam also gave a satisfactory reduction in the pest infestation.

3% pongamia oil soap was able to bring about the leaf damage to minimum among the different botanicals evaluated against Epilachna followed by pongamia oil soap @ 2% and 1%, neem oil soap @ 0.6% and pongamia oil soap @ 0.6%. The leaf damage recorded in 3% soap treated plots varied from 1.99% to 12.31% on 7 days after second and fourteen days after third sprays however all the pongamia concentrations were effectively reduced the leaf damage on 7DAS. Efficacy of *Pongamia glabra* oil at various concentrations was best explained by Swaminathan *et al.* (2010) who reported that pongamia oil at all the concentrations (0.625, 1.25, 2.5 and 5.0%) had maximum antifeedant activity and he observed no feeding up to 48 h after treatment.

Pongamia oil alone recorded 100 per cent mortality at all the concentrations evaluated whereas *A. indica* oil at maximum concentration (5%) exhibited only 60% mortality on seventh day under laboratory condition. Cholla (2009) reported the efficacy of pongamia as 5% leaf extract which caused reduction in mean population of spotted leaf beetle, *E. vigintioctopunctata*. In his study, Neemgold (Azadirachtin) 5mL/L and NSKE 5% found to be the effective treatments against *E. vigintioctopunctata* followed by pongamia leaf extract 5% reduced the population to 9.11 (mean of observations on 2, 4, 8 and 11 days after spray).

Neem oil soap 0.6% was equally effective as pongamia oil soap @ 2 and 1 per cent during first and third spray which showed maximum efficiency on seventh day itself as pongamia and it was gradually increased at fourteenth day. Neem oil 2% was the superior treatment among ten botanicals evaluated by Murugesan and Murugesh (2008) against *H. vigintioctopunctata*. Maximum population reduction was reported in carbaryl treated plants (91.99%) followed by neem oil (69.77%) and the pongamia leaf extract 5% recorded 62.37% reduction.

Untreated control and soap solution 0.5% treated plants recorded increased leaf damage after spray application hence in can be concluded that soap solution has no role in the reduction of leaf damage caused by Epilachna grubs and adults but it is the antifeedant, ovicidal and larvicidal property of pongamia oil soap.

5.2.4. Field evaluation of pongamia oil soap on aphids, *Aphis gossypii* of brinjal during *rabi* season from November 2019 to May 2020

When compared to the control and soap solution 0.5% remaining treatments comprising botanicals and chemical treatments showed a significant reduction in the aphid, *Aphis gossypii* numbers and the results on that are discussed below.

The results on average population density of aphids during field evaluation proves that thiamethoxam found to be significantly superior treatment which recorded lowest of 0.13 aphids/3 leaves on seventh day after second spray application. A day after spray, thiamethoxam showed 0.80 aphids/3 leaves which was the highest aphid numbers recorded by this insecticide and it found to be falling in the subsequent days with minimum number recorded on seventh day. On fourteenth day, it showed little rise in aphid population (0.27/3 leaves) however, it was significantly lowest over all the other treatments tested. Results obtained by Lekha *et al.* (2018) found to be similar to the present observation having dinotefuran 20 SG at 30 and 25g a.i./ha and imidacloprid 17.8 SL at 22.25g a.i./ha as most effective treatments followed by thiamethoxam 25 WG 50g a.i./ha. It showed maximum per cent reduction on seventh day with 61.10 and 65.64 during *rabi* 2016 and *kharif* 2017 respectively and decreased in the subsequent days as of present study.

Bhatt *et al*. (2018) reported that thiamethoxam 25WG was the highly effective treatment when six insecticides were evaluated against aphids (*Aphis gossypii*) on okra. Minimum population was observed on 3DAS (5.10/3 leaves and 5.71/ 3 leaves) with 75.99% and 76.27% overall population reduction over control during first and second spray respectively. Thiamethoxam 25%WG @ 75g a.i./ha recorded significantly superior results with 1.05 and 0.09 aphids/leaf in the first and second spray respectively. The per cent population reduction was highest in 75g a.i./ha thiamethoxam itself showing 92.65% and 99.47% which was at par with thiamethoxam 50 and 25g a.i./ha (Ghosh *et al*., 2016). The result obtained in the present study can also be correlated with the findings of Netram (2015), who reported that thiamethoxam found to be the most effective treatment (7.08 aphids/twig) followed by imidacloprid (8.25 aphids/twig).

Aphid population was effectively reduced by all the concentrations of pongamia oil soap with 3% soap proved to be the most effective among botanicals. Throughout the observation 3% pongamia oil soap recorded lowest aphid numbers (2.47 aphids/3 leaves on 1DAS of first spray) on very next day of spray which was closely followed by 2% and 1%. The study results obtained by Sajay (2019) is in accordance with the present findings, in which 2% pongamia oil soap proved to be the most effective treatment against *Aphis craccivora* among botanicals and the maximum population reduction was observed on seventh day of field spray. He also noticed 100 per cent mortality of aphids at 2, 4 and 12 h of treatment application by pongamia oil soap @ 2, 1 and 0.6% respectively. Netram (2015) evaluated the efficacy of synthetic insecticides and botanicals and he found that *M. anisopliae*, *V. lecanii*, NSKE, Hinganbet extract and karanj oil 1% were the first five best treatments among biopesticides with aphid numbers of 17.93, 19.02. 26.10, 27.46 and 28.34 per twig respectively.

Efficacy of pongamia oil soap was increasing with the increase in concentration against *Aphis gossypii* also in the present study and this is in accordance with the results of Stepanycheva *et al*. (2014) who found that pongamia oil @ 3 and 1.5 per cent were effective against green peach aphids. Almost all the formulations at 3% pongamia oil showed more than 90% mortality of treated females except pongam oil + *Sapindus saponaria* extract. He also noticed that nearly 80% inhibition was recorded by all the formulations at 3% except pongam+ *Cinnamomum verum* oil. Shrinivas (2013) reported that brinjal aphids was reduced to 11.45 aphids/plant by the treatment of pongamia oil 1% and the control showed 25.06 aphids/plant. Findings of Anitha and Nandihalli (2008) also supports the efficacy of pongamia where 2% pongamia oil recorded 3.95 aphids/3 leaves which was equally effective as neem oil 2% (3.11) and azadirachtin 1mL/L (3.39).

The present study revealed that the efficacy of pongamia oil soap @ 0.6% and neem oil soap @ 0.6% was same in the first spray and the efficacy of neem soap @ 0.6% was reduced in the subsequent sprays. This reduction in efficacy might be due to the higher population of aphid recorded at prior 24 h of second and third spray. Kaur and Singh (2013) also reported the same results in which neem and pongamia soap @ 1% showed statistically same population of 0.76 and 0.87 aphids/3 clusters/plant respectively in capsicum.

There was no reduction in the population of aphids by chlorantraniliprole 18.5 SC after first spray and during third spray the chemical found to be effective up to fifth day of spray. The results are supported by the findings of Reddy *et al*. (2018). They reported that chlorantraniliprole in combination with thiamethoxam and lamba cyhalothrin showed 0.00 aphids/15 cm shoot whereas it showed 30.00 aphids/15 cm shoot by sole application and found to be at par with control (121.67 aphids/15 cm shoot). The results of third spray is in accordance with Potai *et al.* (2018) where chlorantraniliprole 18.5 SC reduced the population to 7.54 aphids/plant from the pre count of 8.10 aphids/plant.

Aphid population reduction by soap solution 0.5% was not observed in the course of study and it found to be statistically similar to that untreated control hence the reduction in aphid population is associated with pongamia oil only.

5.2.5. Field evaluation of pongamia oil soap on red spider mites, *Tetranychus urticae* infestation in brinjal during *rabi* season 2019-20

Based on the data obtained, it is apparent that all the treatments tested against red spider mites showed acaricidal activity except soap solution 0.5% significantly when compared to the untreated control. Maximum population reduction in red spider mites was recorded in 3% pongamia oil soap treated plants with 86.50% after one day of spray.

On the whole, pongamia oil soap @ 0.6, 1, 2 and 3% were superior over control in reducing RSM population. Maximum reduction was observed on immediate day of the spray and all the treatments except soap solution remained effective up to 5 days after spray and found to be decreasing after that. The observation is in conformity with acaricidal activity of pongamia oil reported by Raina (2016) against bean mite (*Tetranychus ludeni*). Among the various chemical treatments sprayed, 0.6mL/L abamectin 1.8 EC exhibited maximum reduction in mite population (70.32%) at fourteenth day of spray followed by spiromesifen and fenpyroximate while 49.58% reduction was reported by pongamia oil at 2mL/L on fourteenth day. Rahman *et al.* (2016) reported 31.00 and 35.00 per cent reduction in yellow mite population (*Polyphagotarsonemus latus*) in chilli after 7 and 10 days after spray application.

The current findings are also supported by the results of Ragavendra *et al*. (2017), in their study, propargite 57 EC @ 2.00mL/L recorded 84.63% and 81.82% of adult mortality and egg reduction respectively on two spotted spider mite, *Tetranychus urticae*. Among botanicals, tulsi leaf extract (5 and 10%), neem oil (3 and 5%) and notchi leaf extract (5 and 10%) recorded superior results followed by 69.94 and 69.72% adult mortality and 63.53 and 62.98% egg reduction were recorded by pongamia oil soap at 3 and 5% respectively.

From the results obtained it is clear that acaricidal activity of pongamia oil soap @ 0.6% was superior when compared to neem oil soap 0.6%. This result is in line with the findings of Islam *et al*., 2017. Among the botanicals evaluated, pongamia oil was significantly superior treatment which recorded high mortality at low LC_{50} value of

0.008% whereas neem oil showed highest LC_{50} value of 0.230% at 24 h after treatment against two spotted spider mite, *Tetranychus urticae* and the same trend was continued up to fourth day of treatment. Singh *et al*. (2018) also gave same results where abamectin recorded highest efficacy with 74.64% population reduction in red spider mite (*Tetranychus urticae*) infesting okra. Among the bio-pesticides tested, 46.32% population reduction was observed in pongamia oil 2 EC at 2 mL/L treated plants followed by 42.68% reduction in neem oil treated plants.

The present findings are also in line with Handique *et al*. (2018) findings. He observed that nirgundi and pongamia oil were the superior treatments over neem oil which was proved by the lowest LC values of 78.40 and 194.20 ppm respectively whereas neem oil was effective at 1469.88 ppm against tea mite (*Oligonychus coffeae*). When compared to the botanicals, less acaricidal activity was recorded in the thiamethoxam 25 WG treated plants. Maximum of 32.43% reduction was recorded on third day after spray and its effectiveness was started to decline from fifth day onwards by showing an increased mite population on seventh and fourteenth day. These results can be supported by the findings of Szczepaniec *et al*. (2013). They explained that thiamethoxam, clothianidin and imidacloprid on cotton, corn and tomato respectively showed increased abundance in spider mite population and also recorded 30% elevated spider mite population on cotton plants treated with thiamethoxam at the end of study while in the present study, it is 32% more mite numbers on 14DAS. They found that application of neonicotinoids affected the expressions of genes contributing in the plant defenses through SA-mediated pathway and JA-associated defenses.

Soap solution 0.5% also recorded elevated red spider mite population from fifth day onwards and found to be statistically at par with untreated control plants which indirectly shows soap powder as a component of pongamia oil soap did not contribute in the insecticidal activity and it purely due to the presence of active components of pongamia oil.

5.2.6. Field evaluation of pongamia oil soap on whiteflies, *Bemisia tabaci* of brinjal during *rabi* season from November 2019 to May 2020

Results data on average population density of whiteflies in brinjal proved that 3 per cent pongamia oil soap treated plants showed minimum whitefly numbers followed by thiamethoxam 25 WG, pongamia oil soap @ 2 and 1 per cent, neem oil soap 0.6 per cent and pongamia oil soap @ 0.6 per cent. Thiamethoxam applied plants during second spray showed minimum population of whiteflies at one day after second spray and gradual increase was observed up to seven days after treatment yet it was the most effective treatment at fourteenth day of spray. Similar results were recorded by Jadhav *et al*. (2018), in which application of thiamethoxam 25 WG @ 25g a.i./ha showed minimum whitefly population after fourteen days of treatment in brinjal followed by clothianidin @ 25g a.i./ha and flonicamid @ 75g a.i./ha. When Ghosh *et al.* (2016) evaluated the bio efficacy of thiamethoxam 25 WG against brinjal sucking pests at five different concentrations, minimum number of whiteflies (1.93/leaf and 0.43/leaf) was recorded in 75g a.i./ha concentration in both first and second spray and the per cent mortality in whitefly population were 83.80 and 96.93% respectively.

According to the findings of Kumar *et al.* (2017), it is evident that all the treatments evaluated against whitefly in brinjal were effective and the superior treatment was thiamethoxam 25 WG @ 100g/ha recording 0.00 population on third day after fourth spray. Lekha *et al.* (2018) recorded the efficacy of some insecticides against brinjal whiteflies where, 30g a.i./ha dinotefuran caused maximum reduction (67.62%) in the population at the same time thiamethoxam showed 63.48% reduction at 50g a.i./ha on seventh day of spray I.

Efficacy of pongamia oil soap was highest on immediate day after spray and found to be decreasing in the subsequent days. Most effective concentration was 3% and recorded 0.80, 0.67 and 1.67/5 leaves only at one day after first, second and third spray respectively. Pongamia oil soap @ 2% was superior than pongamia oil soap @ 1%, both were statistically not differed yet. While pongamia oil soap and neem oil soap @ 0.6% were similar in reducing whitefly population. Efficacy of pongamia oil @ 1% against cotton whitefly (*Bemisia tabaci*) was reported by Kumar *et al.* (2019).

Under laboratory condition, 58.4% and 51.7% population reduction were reported after 3 days of application during 2016-17 and 2017-18 respectively. During field evaluation, 44.9 and 39.2% whitefly population reduction was observed at seven days of the spray on same period.

The present results can also be supported by the findings of Sridhar *et al*. (2017). When they tested the efficacy of some insecticides and biopesticides by sole and combination application against whitefly, *Bemisia tabaci* under poly house tomato, spinosad, imidacloprid and fipronil were the most effective treatments showing 84.55, 84.17 and 79.39% mortality respectively in sole application. Highest mortality of 75% was recorded when the neem, pongamia and fish oils applied in combination whereas sole application of these oils gave highest of 48.75% mortality.

The additional mortality was also reported by synergistic action of these oils with chemical insecticides and maximum of 16% additional mortality was reported. Shrinivas (2013) reported the performance of some biopesticides including pongamia oil @ 1% against brinjal sucking pests. Neemazal (0.2%) was the most effective treatment against whiteflies followed by margosom 0.15 EC (0.3%) while pongamia oil recorded the less survival population of 4.69 whiteflies/plant and control showed 15.77 whiteflies/plant.

The present findings show that pongamia and neem oil soap at 0.6% exhibited almost same whitefly population throughout three sprays with pongamia oil soap is more effective than neem. Gundappa *et al*. (2013) evaluated botanicals and insecticides for their efficacy on guava spiralling whitefly, *Aleurodicus disperses*. Most effective treatments were Neem guard, neem soap and dichlorvos + pongamia oil which reduced the pupal population significantly and neem guard reduced the nymphal and adult population significantly on 24 h after treatment. Efficacy of dichlorvos + pongamia oil, neem guard and neem soap were continued up to 21 days after treatment in reducing nymphal and pupal population. It also has been reported that pongamia soap found to be equally effective as neem soap as observed in current study.

Chlorantraniliprole 18.5 SC at first and third spray showed less efficacy when compared to pongamia oil soap, neem oil soap and thiamethoxam against whiteflies in all the three sprays. Minimum population of whiteflies by this chemical was recorded on third day after first spray (2.27/5 leaves) and remained effective up to seventh day of first spray and fifth day of third spray. Similar findings were stated by Potai *et al* (2018) where chlorantraniliprole showed maximum population on one day after spray (2.18/plant) then reduced the population to minimum (1.33/plant) on seventh day. After seventh day, whitefly population was increased to 1.85/plant and the same findings was observed in the current study also.

Whitefly population recorded by soap solution 0.5% treated plants was at par with untreated plants hence there is no insecticidal activity present in soap solution.

5.2.7. Relative abundance of predators and parasitoids in brinjal ecosystem at field evaluation of pongamia oil soap during *rabi* season 2019-20

Based on the data obtained on the relative abundance of spiders, coccinellids, syrphids and green lacewings, hemipteran predators and hymenopteran parasitoids and red spider mite predators was not significantly differed immediately after the spray application among treatments and so it proves the safety of these treatments on natural enemies.

5.2.7.1. Relative abundance of spiders during field evaluation of pongamia oil soap from November 2019 to May 2020

The four major spider species recorded during three sprays were distributed uniformly in all the treatments at pre count as well as post counts except on fourteenth day after spray. Pongamia oil soap @ 0.6, 1, 2 and 3 per cent and neem oil soap 0.6 per cent, chlorantraniliprole and thiamethoxam were statistically uniform in spider population on 1, 3, 5 and 7 days after treatment while on fourteenth day significant difference was observed. Chemical treatments such as chlorantraniliprole on first and third spray (1.00 and 3.67 per plant) and thiamethoxam on second spray (3.33/plant) recorded the lowest numbers of spiders.

At the same time, all the botanical treatments (both pongamia and neem oil soap) found to be statistically on par with untreated control plot and soap solution in spider population.

Kumar *et al*. (2019) reported the safety of biopesticides on spiders including pongamia oil. They reported non-significant difference between botanicals and chemical check in spider numbers with pongamia oil + detergent powder (10 mL/L) showing 1.3/plant while the crude neem oil (6.7 mL/L) and control recorded 0.9 and 1.7 spiders/plant. Impact of pongamia oil and neem oil at 3% along with other botanicals was recorded by Sahana and Tayde (2017) in which statistically uniform population with 0.50 and 0.55 spiders/plant was observed in pongamia and neem oil treated plants respectively on seventh day. According to the findings of Sakthivel *et al.* (2012), 90% of spiders and coccinellids were destructed by dichlorvos but NSKE 5%, neem oil @ 3%, pongamia oil @ 3% and FORS @ 2% eliminated only 12.57, 24.25, 16.16 and 16.46 per cent spider population.

Patel *et al*. (2016) reported that chlorantraniliprole 35 WG at 22, 26 and 30g a.i./ha and chlorantraniliprole 18.5 SC at 30g a.i./ha showed 1.11, 1.09, 1.08 and 1.15 spiders/plant respectively and all were statistically at par with untreated control (1.19). Study conducted by Bhatt *et al*. (2018) in okra revealed that Thiamethoxam 25%WG @ 25g a.i./ha and Chlorantraniliprole 18.5% SC @ 25g a.i./ha were harmless to the spiders and recorded 2.30 and 2.69 spiders/plant at spray I and 2.69 and 3.03 spiders/plant at spray II respectively.

5.2.7.2. Relative abundance of coccinellids, syrphids and green lacewings during field evaluation of pongamia oil soap from November 2019 to May 2020

From the results data obtained on coccinellids, syrphids and green lacewing population it is clear that none of the pongamia oil soap concentrations is toxic to these predators. Chlorantraniliprole 18.5 SC at first spray had high aphid population hence it recorded highest coccinellids, syrphids and green lacewings accordingly. So, except chlorantraniliprole all the remaining treatments were statistically on par with each other including 3% pongamia soap at first spray. Safety of chlorantraniliprole to coccinellid predators was reported by Bhatt *et al*. (2018) where, it recorded 2.06 and 2.93 coccinellids/plant during first and second spray respectively in okra.

Thiamethoxam showed least coccinellids, syrphids and green lacewing population during second spray which recorded 0.00/plant up to fifth day of spray and 0.33 and 0.67/plant on seventh and fourteenth day of spray respectively. All the remaining treatments showed statistically similar population throughout second spray. Jadhav *et al*. (2018) reported that thiamethoxam and acetamiprid had least population of predatory lady bird beetles among different insecticides tested in brinjal with 1.25 beetles/plant. In the study conducted by Bhatt *et al*. (2018), minimum coccinellids population was recorded by carbofuran 3% CG 1000g a.i./ha and thiamethoxam 25 WG 25g a.i./ha 1.08 and 1.98/plant at first spray and 1.19 and 2.78/plant at second spray respectively. Acetamiprid and thiamethoxam were recorded significantly low population of coccinellids in brinjal (Anand *et al*., 2013). The mean numbers of coccinellids recorded by thiamethoxam at first, second and third spray were 0.19 and 0.15, 0.12 and 0.12 and 0.16 and 0.12 respectively during 2010 and 2011 in brinjal.

Pongamia and neem oil soap were statistically at par with control and soap solution and the numbers recorded at post treatment were high when compared to pre count in both of the sprays. This result is in line with the findings of Sakthivel (2019) who reported highest coccinellid population in two consecutive water jetting plot, control and pongamia oil - water jetting treated plot with 6.83, 7.24 and 4.82 coccinellids/plant respectively. Netram (2015) reported that karanj oil recorded mean population of 3.25 coccinellid grubs which was at par with control (5.48). When Sakthivel *et al*. (2012) evaluated botanical insecticides on coccinellids of mulberry ecosystem, neem and pongamia oil @ 3% showed 25.12 and 21.18% reduction in coccinellid population whereas dichlorvos eliminated 90%.

Mukhopadhyay and Santhakumar (2010) recorded the biosafety of neem and pongamia oil on beneficial coccinellids at various concentrations in mulberry. Pongamia oil @ 1.5 and 2% recorded maximum per cent survival of coccinellids with 11.33 to 28.33% whereas control recorded 33.66% respectively. Basappa (2007) also reported the safety of biopesticides including pongamia oil with 8.88 to 22.21% adult mortality in *Cheilomenes sexmaculata* while synthetic chemicals showed 42.22 to 84.44% mortality.

Stephanycheva *et al*. (2014) reported the biosafety of pongamia oil on dipterans (Syrphidae and Muscidae).

5.2.7.3. Relative abundance of Hemipteran predators and Hymenopteran parasitoids during field evaluation of pongamia oil soap from November 2019 to May 2020

There was no significant population reduction in Hemipteran predators and Hymenopteran parasitoids in the first spray. Maximum population of 3.33/plant was recorded by pongamia oil soap 0.6% on fourteenth day of first spray. During second spray highest population was recorded in pongamia oil soap @ 0.6% followed by neem oil soap @ 0.6% and 1, 2 and 3% of pongamia oil soap. The results can be supported by the study conducted by Basappa (2007) which revealed that highest adult emergence of egg parasitoid, *Trichogramma chilonis* was recorded in NSKE 5% followed by neem oil @ 2%, pongamia seed extract @ 5% and pongamia oil @ 2% treated eggs with 82.66%, 79.33%, 74.00% and 70.66% adult emergence respectively under laboratory condition. Naik and Chakravarthy (2013) reported the biosafety of pongamia oil when treated against tea mosquito bug and it showed no toxicity against red ant, *Oecophylla smaragdina*. Stephanycheva *et al*. (2014) reported that 1% pongamia oil treated plants had no negative impact on pollinating hymenopterans such as *Apis florea* and *A. dorsata.* Hymenopteran bee activity was reported by Patidar (2007) who recorded the bee numbers after and before the treatment application. Before and two days after treatment application, the karanj oil @ 0.5% witnessed 27.2 and 26.4 bees at the same time 33.0 to 16.2 bees were observed before and after treatment in chemicals treated plots respectively. These two studies confirm the biosafety of pongamia oil against hymenopterans.

Chlorantraniliprole and thiamethoxam found to be moderate toxic to these natural enemies which showed less population when compared to the other treatments. Minimum population of Hemipteran predators and Hymenopteran parasitoids were recorded on fifth day of first spray by chlorantraniliprole (0.67/plant) and first and third day of second spray by thiamethoxam (0.00/plant).

Toxicity of chlorantraniliprole and thiamethoxam was reported by Nagrare *et al*. (2016) also. In their study thiamethoxam, chlorantraniliprole, indoxocarb and flonicamid were reported to be highly toxic to the nymphal solitary parasitoid of cotton mealybug (*Phenacoccus solenopsis*) *Aenasius bambawalei* which recorded 100% mortality on 96 h after treatment under laboratory condition. In the same study, neem oil (1500 ppm) @ 2.5L/ha recorded 66.66% mortality of *A. bambawalei* on 96 h after treatment. Wang *et al*. (2008) reported that among all the fourteen insecticides tested 100% mortality of egg parasitoid of rice planthopper (*Anagrus nilaparvatae*) was recorded by dichlorvos after 2 h of treatment itself with high oral toxicity. The second most toxic chemicals were Isoprocarb, imidacloprid and thiamethoxam which killed all the wasps at 4 h of treatment.

5.2.7.4. Relative abundance of mite predators during field evaluation of pongamia oil soap from November 2019 to May 2020

Data on red spider mite predators such as rove beetle, *Oligotus* and predatory gall midge, *Feltiella acarisuga* revealed that pongamia oil soap treated plants recorded relatively higher population of mite predators when compared to even untreated control plot. However, richness of mite predators was high in soap solution 0.5% (35.67/plant) treated plots followed by pongamia oil soap @ 0.6% (20.00/plant), pongamia oil soap @ 1% (19.67/plant), pongamia oil soap @ 2% (18.00/plant), neem oil soap 0.6% (12.33/plant), pongamia oil soap @ 3% (11.33) and control on 14^{th} day of spray application. Least population of mite predators was observed by thiamethoxam even at 14^{th} day of spray (8.00/plant). On immediate day after spray application, the population was less and it was increased in the subsequent days to reach highest on fourteenth day.

Previous studies on the impact of pongamia treatment with mite predators was not available in the literatures hence the results on mite predator's population is compared with neem product. Side effects of application of botanical insecticides on mite predator, *Amblyseius andersoni* was reported by Castasnoli *et al*. (2002). Various types of laboratory (direct toxicity on eggs, direct toxicity on females, semi-field tests, residual toxicity on protonymphs and residual toxicity on females) and field test were carried out. The eggs were not affected by biopiren plus (pyrethrins 8 EC) (92.31% hatching) and neemazal 10 EC (98.73% hatching) after the treatment. Only 14.01%

toxicity was recorded on females by neemazal while others showed 100%. Survival percentage of protonymphs was 51.33% and death was 0.00 by neemazal treatment.

Pozzebon *et al.* (2011) reported that total toxicity effect of thiamethoxam by different exposure routes on *Phytoseiulus persimilis*. He observed that total toxicity effect of thiamethoxam by all different routes of exposure was more than 90% on *Phytoseiulus persimilis*. However, he also stated that topical exposure might resulted in low mortality while residual exposure caused high mortality. In contrast, Jamil *et al*. (2014) reported that neonicotinoids were slightly toxic to *Neoseiulus fallacis* and Bostanian *et al*. (2010) stated that neonicotinoids were moderately to highly toxic to *Galendromus occidentalis* and *N. fallacis*.

5.3. BIOMETRIC OBSERVATIONS

5.3.1. Length of fruits

To study the influence of different treatments on biometrics of brinjal plants, length of fruits was measured at each harvest and the mean length was compared between treatments. Maximum fruit length was recorded by 3% pongamia oil soap (8.53 cm) and standard check (8.49 cm) treated plants which indicates its efficacy in controlling the fruit and shoot borer incidence which causes the fruit malformation and deformed fruits. However, all the treatments were superior in mean fruit length over control except soap solution 0.5%. Pongamia oil soap @ 1%, neem oil soap 0.6% and pongamia oil soap @ 0.6% were statistically similar in results and found to be on par with 2% pongamia oil soap. All the botanical treatments were statistically equal except pongamia oil soap @ 3% in mean length which indicates that slight concentration change in botanicals may not affect the biometric parameters.

5.4. YIELD ATTRIBUTES OF BRINJAL

From the ten harvests obtained during field evaluation, standard check recorded highest total fresh yield of 2156.64g/plant over control (1482.68g/plant) which recorded the lowest yield. Next best yield was showed in pongamia oil soap @ 3% treated plot which was best yield among botanical treatments. However, when compared to control and soap solution, all the treatments were superior significantly.

Highest marketable yield was also recorded by standard check (2058.44g/plant) followed by pongamia oil soap @ 3% (1919.04g/plant) > pongamia oil soap @ 2% (1809.02g/plant) > pongamia oil soap @ 1% (1661.29g/plant) > pongamia oil soap @ 0.6% (1507.75g/plant) neem oil soap 0.6% (1436.80g /plant) in a sequence. Control and soap solution 0.5% were low in marketable yield with 1257.28 and 1374.70g/plant respectively. Maximum yield obtained in standard check treated plants might be due to the higher reduction in the fruit and shoot borer infestation.

Management of borers resulted in high marketable yield because of the low ratio of malformed fruits to the undamaged fruits. Also, if the Epilachna damage and leafhoppers population are low, healthy foliage will produce abundant photosynthates which in turn contributes for the higher economic yield. Patra *et al.* (2016) reported that higher efficiency of chlorantraniliprole 18.5 SC in reducing fruit and shoot borer infestation had resulted in highest marketable yield (147.56q/ha) in brinjal followed by flubendiamide (140.45q/ha). Shaikh and Patel (2012) reported that highest yield of 350.57q/ha recorded by diafenthiuron in brinjal followed by thiamethoxam (342.34q/ha) due to its persistent action against sucking pests. Pongamia oil soap @ 3 per cent gave the highest efficacy against fruit and shoot borer, leafhoppers, Epilachna, aphids, mites and whiteflies and in turn highest marketable yield among botanicals. So, the highest concentration of pongamia oil soap @ 3% may secure higher marketable yield in brinjal by protecting the crop from pest infestation and can be a good biopesticide in either integrated pest management and organic agriculture.

5.5. ECONOMIC ATTRIBUTES

Standard check - chlorantraniliprole 18.5 SC @ 3 mL/10L and/or thiamethoxam 25 WG @ 2g/10L proved to be the superior treatment in cost benefit ratio followed by pongamia oil soap @ 3 per cent, pongamia oil soap @ 2 per cent, pongamia oil soap @ 1 per cent, pongamia oil soap @ 0.6 per cent and neem oil soap 0.6 per cent. Similar statement was given by Tripura *et al*. (2017) where chlorantraniliprole recorded higher yield in brinjal followed by spinosad, chlorfenapyr, chlorpyriphos and indoxacarb followed by biopesticides including neem oil.

5.6. PHYTOTOXICITY SYMPTOMS

Pongamia oil soap @ 3% showed phytotoxic symptom after 2^{nd} and 3^{rd} spray. When compared to aqueous extracts, oil formulations are generally showing phytotoxic symptom on leaves (Chianella and Rovesti, 1992). Cobbinah and Osei-Owusu (1988) stated that 10 and 20% neem emulsions were phytotoxic in brinjal.

Summary

6. SUMMARY

Brinjal crop is more vulnerable to pest attack throughout the cultivation period and the continuous usage of chemical insecticides for managing these pests may result in residue in food chain, loss of biodiversity in the field, environmental pollution etc. So, evaluating less toxic chemical insecticides and also the alternative biopesticides to use in vegetable crops is imperative nowadays. The study entitled ‘Pongamia oil soap for the management of major pests of brinjal (*Solanum melongena* L.)’ with the objective of evaluating the efficacy of pongamia oil soap at four different concentrations in the management of important pests of brinjal such as brinjal fruit and shoot borer, leafhoppers, Epilachna beetles, aphids, mites and whiteflies and also to test their influence on the population of natural enemies was carried out.

Antifeedant and growth retardation properties of pongamia oil soap were evaluated by the laboratory bioassay conducted in the Department of Agricultural Entomology, College of Agriculture, Padannakkad (2019-20). Fourth instar grubs of Epilachna beetles (*Epilachna dodecastigma*) were used in the feeding deterrency study and the growth retardation study was started in the first instar grubs. Seven different treatments including pongamia oil soap @ 3% (T_1), pongamia oil soap @ 2% (T_2), pongamia oil soap @ 1% (T_3), pongamia oil soap @ 0.6% (T_4), soap solution @ 0.5% (T_5), water spray (T_6) and control (T_7) were imposed on the test organism (Epilachna grubs) under completely randomised design (CRD) by three replications.

Field experimentation was carried out on KAU released brinjal variety ‘Surya’ under randomised block design (RBD) with eight treatments and three replications at Instructional farm, Karuvachery, Padannakkad during November 2019 to May 2020. Chlorantraniliprole 18.5 SC 3 mL/10L (Spray I and III) & Thiamethoxam 25 WG 2g/10L (Spray II) (T_1); pongamia oil soap @ 3% (T_2); pongamia oil soap @ 2% (T_3); pongamia oil soap @ 1% (T_4); pongamia oil soap @ 0.6% (T_5); neem oil soap @ 0.6% (T_6); soap solution @ 0.5% (t_7) and control (T_8) were the eight different treatments imposed at field study.

The crop was given with three number of sprays during the course of study period. Observations for the damage symptoms caused by fruit and shoot borer and Epilachna beetles were made at one day before spray, 7 and 14 days after treatment. For the sucking pests and natural enemies, the count was made on one day before to treatment, 1, 3, 5, 7 and 14 days after treatment.

The salient findings of the present investigation are following;

Among the different treatments tested, 3% pongamia oil soap was superior in antifeedant activity with maximum feeding deterrency against Epilachna grubs at fourth instar due to its high concentration of active components *viz.*, pongamol, karanjin, pongapin etc.

Maximum of 100 per cent growth retardation (0.00 RGI) was shown by 3% pongamia oil in which all the grubs released on the treated leaves were died at first instar itself. The reason might be the more antifeedant activity of pongamia at higher concentration of 3% which also repelled the grubs to feed on treated leaves. None of the above-mentioned properties (antifeedant/repellent/growth retardation properties) was exhibited by soap solution 0.5% when tested on Epilachna grubs.

Pongamia oil soap @ 3% and 2% effectively reduced the fruit infestation by fruit and shoot borer during all the three sprays because of its high repellent, antifeedant, oviposition deterrence and ovicidal activity expressed against FSB. Minimum fruit damage was exhibited on seventh day after application then the efficacy was declined on fourteenth day.

During first and second spray, the leafhopper incidence was effectively controlled by the application of pongamia oil soap @ 3%. Maximum reduction in leafhopper population was on immediate day after spray then gradually the population increased in the subsequent observations.

Pongamia oil soap @ 3% was the most effective one in reducing the Epilachna incidence. Leaf damage caused by Epilachna grubs and adult beetles was effectively lowered by 3% soap and the maximum reduction was on seventh day of all the three sprays and the effectiveness remained high up to fourteen day even.

Aphid colonies were significantly eliminated from 3% pongamia oil soap treated plants. Maximum population reduction was recorded on one day after treatment and started increasing after that up to fourteenth day during all the three sprays.

Pongamia oil soap was effective against red spider mites also and the superior efficacy was recorded in 3% soap. This was immediately followed by pongamia oil soap @ 2%, 1% and 0.6%. Effectiveness of the pongamia oil soap at all concentrations found to be high on first day of treatment and then reducing from third day gradually.

Pongamia oil soap @ 3% was equally effective as thiamethoxam in reducing the population density of whiteflies followed by 2, 1 and 0.6% pongamia oil soap. Maximum efficacy was observed by first day of application and by fourteenth day the population was raised slightly.

Natural enemies' fauna of brinjal crop was categorised into four (1. spiders, 2. Coccinellids, syrphids and green lacewings, 3. Hemipteran predators and hymenopteran parasitoids and 4. Predators of red spider mites) and recorded their richness in pongamia oil soap treated plants. Overall, the spider (general predator) population recorded maximum under soap solution @ 0.5% and pongamia oil soap @ 0.6% treatments over untreated control which in turn proves the safety of pongamia soap on spiders. Relative abundance of coccinellids, syrphids and lacewings was maximum in control plot however, all the concentrations of pongamia oil soap was statistically at par with control in coccinellids, syrphids and lacewings population.

Population of hemipteran predators and hymenopteran parasitoids was found to be highest in untreated control plot. Here also, all the other treatments were on par with control in hemipteran predators and hymenopteran parasitoids population except thiamethoxam treated plants. Relative abundance of predatory gall midges and rove beetles (predators of red spider mites) in pongamia oil soap treated plants was statistically at par with control plot although soap solution @ 0.5% recorded the highest population.

Fruit length of brinjal was maximum in standard check treatment which was immediately followed by pongamia oil soap @ 3% due to the minimum incidence of fruit and shoot borer. Pongamia oil soap @ 3% treated plants recorded highest fresh and marketable yield after standard check followed by pongamia oil soap @ 2, 1, 0.6% and neem oil soap @ 0.6%. Benefit Cost ratio was also superior in standard check followed by 3, 2, 1, 0.6% pongamia oil soap and 0.6% neem oil soap over control.

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Abstract

PONGAMIA OIL SOAP FOR THE MANAGEMENT OF MAJOR PESTS OF BRINJAL (*Solanum melongena* L.)

by

JEEVITHA P

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ABSTRACT

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ABSTRACT

Brinjal is highly nutritious and most demanding vegetable in India as it can be grown throughout the year. The crop is prone to various pest incidence which is considered to be the major yield limiting factor. The un-scientific, irrational and over use of chemical insecticides in vegetables crops lead to many negative sequences. Hence the present research work ‘Pongamia oil soap for the management of major pests of brinjal (*Solanum melongena* L.)’ was undertaken during 2019-20 with the aim of evaluating the potential of a new product pongamia oil soap at four different concentrations on major brinjal pests *viz.*, fruit and shoot borer (FSB), leafhopper, hadda beetle, aphids, red spider mites and brinjal whiteflies. The influence on natural enemies was also recorded.

Laboratory experiment on evaluation of pongamia oil soap was carried out at Department of Agricultural Entomology, College of Agriculture, Padannakkad during 2019-20 for the antifeedant and growth retardation property against Epilachna grubs (*Epilachna dodecastigma*). Fourth instar grubs and first instar grubs were used to study the feeding deterrence index (FDI) and growth retardation index (GI and RGI) with seven treatments: Pongamia oil soap @ 3% (T_1), Pongamia oil soap @ 2% (T_2), Pongamia oil soap @ 1% (T_3), Pongamia oil soap @ 0.6% (T_4), Soap solution @ 0.5% (T_5), Water spray (T_6) and Control (T_7) under Completely Randomised Design (CRD) with three replications.

Hundred per cent antifeedant activity on fourth instar grubs of Epilachna was observed under pongamia oil soap 3 per cent treatment. Maximum growth retardation property also observed by 3% pongamia oil soap (RGI of 0.00) which caused death of grubs at first instar itself among the different treatments. It was followed by pongamia oil soap 2%, 1%, 0.6% with 94.35, 92.07 and 90.48% FDI and 0.08, 0.16 and 0.32 RGI respectively.

Field evaluation of pongamia oil soap was carried out at Instructional farm II, Karuvachery, CoA, Padannakkad under Randomised Block Design (RBD) with eight treatments and three replications on Surya variety. The treatments imposed in field study were: Chlorantraniliprole 18.5 SC @ 3 mL/10L (Spray I and III) &

Thiamethoxam 25 WG @ 2g/10L (Spray II) (T_1); Pongamia oil soap @ 3% (T_2); Pongamia oil soap @ 2% (T_3); Pongamia oil soap @ 1% (T_4); Pongamia oil soap @ 0.6% (T_5); Neem oil soap @ 0.6% (T_6); Soap solution @ 0.5% (T_7) and Control (T_8). Observations for the damage symptoms caused by FSB and hadda beetles were made at 1 DBT, 7 and 14 DAT. For the sucking insect and mite pests, count was made on 1 DBT, 1, 3, 5, 7 and 14 DAT. Totally three sprays were given during *rabi* season 2019-20.

Fruit infestation caused by fruit and shoot borer was effectively reduced by pongamia oil soap @ 3% and @ 2% during all the three sprays. Minimum fruit damage was observed on seventh day after spray (12.94% on 7 days after third spray) by 3% pongamia oil soap followed by chlorantraniliprole. The efficacy of chlorantraniliprole was persisted up to 14 DAS while efficacy of pongamia soap reduced gradually. The leafhopper incidence was effectively controlled by the application of pongamia oil soap @ 3% during first and second spray. Maximum reduction in leafhopper population was recorded by thiamethoxam followed by pongamia oil soap (3%, 2%, 1% and 0.6%) and neem oil soap.

Among botanicals, pongamia oil soap @ 3% was the most effective treatment against hadda beetle incidence followed by chlorantraniliprole and thiamethoxam. Maximum efficacy by pongamia oil soap was observed on 7DAS and it was reduced on 14 DAS. Neem oil soap and pongamia oil soap at 0.6% were statistically on par with each other except during first spray. Aphid colonies were significantly reduced in 3% pongamia oil soap followed by thiamethoxam, 2%, 1% and 0.6% pongamia oil soap. Maximum population reduction was recorded on one day after treatment.

Pongamia oil soap @ 3% was the superior treatment against red spider mites which was immediately followed by pongamia oil soap @ 2%, 1% and 0.6%. Pongamia oil soap 3% was equally effective as thiamethoxam in reducing the population density of whiteflies then the lower doses tested and neem oil soap @ 0.6%.

Effectiveness of the pongamia oil soap was reduced with time and lower concentrations. Soap solution @ 0.5% didn’t affect any pest incidence.

Spider population recorded maximum in pongamia oil soap @ 0.6% treated plants over control while pongamia oil soap was statistically at par with control in coccinellids, syrphids and lacewings count at all the concentrations. Hemipteran predators and hymenopteran parasitoids count recorded highest in control plot and all other treatments found to be at par with control except thiamethoxam. Pongamia oil soap (3, 2, 1 and 0.6%) was at par with control in predatory mite population.

Average fruit length was high in pongamia oil soap @ 3% treated plants (8.53 cm) followed by standard check (8.49 cm), pongamia oil soap @ 2%, 1% and 0.6% and neem oil soap @ 0.6%. Standard check recorded highest fresh and marketable yield over control followed by pongamia oil soap @ 3%. Benefit Cost ratio was also high in standard check followed by 3% pongamia oil soap as compared to control plot showing its potential to be a good biopesticide and IPM component in brinjal cultivation.