OIL BASED FORMULATION OF *Andrographis paniculata* (Burm.f.) Nees AGAINST SUCKING PESTS OF CHILLI

by

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Abstract of the thesis

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DECLARATION

I, hereby declare that this thesis entitled **"OIL BASED FORMULATION OF *Andrographis paniculata* (Burm.f.) Nees AGAINST SUCKING PESTS OF CHILLI"** 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.

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Bhavyashree, K.

BHAVYASHREE K

Dedicated

To

My beloved parents

(ObalaReddy and Reddemma)

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LIST OF ABBREVATIONS AND SYMBOLS USED

a.i.	Active ingredient
et al.	And other co workers
@	At the rate of
BPF	Biopesticide formulation
Cm	Centimetre
CD	Critical difference
CRD	Completely Randomized Block Design
DAT	Days after treatment
DAP	Days after planting
EC	Emulsifiable Concentrate
FYM	Farmyard manure
Fig.	Figure
G	Gram
ha	Hectare
HAT	Hours after treatment
KAU	Kerala Agricultural University
kg ha^{-1}	Kilogram per hectare
L	Litre
LCI	Leaf curl index
mL	Millilitre
viz.	Namely

NBAIR	National Bureau of Agricultural Important Insect Resource
NS	Non significant
%	Per cent
PEA	Plant extract of *Andrographis paniculata*
ha^{-1}	Per hectare
Rpm	Revolutions per minute
sp. or spp..	Species (Singular and Plural)
SC	Suspension concentrate
i.e.	That is
T	Triton X-100
viz.,	Namely
WG	Wettable granules

Introduction

1. INTRODUCTION

Chilli (*Capsicum annuum* L.) is one of the most widely cultivated spice as well as a vegetable crop of Solanaceae family and is a rich sources of vitamins and minerals. India is a major producer, consumer and exporter of chilli. In India, chilli is grown in an area of 774.9 thousand hectares producing around 1492.10 thousand tonnes which accounts for 36 per cent of world production (Geetha and Selvarani, 2017).

Several insect-pests and other arthropods are known to attack the crop at its different stages of growth. Aphid (*Aphis gossypii* Glover, *Myzus persicae* Sulzer), thrips (*Scirtothirps dorsalis* Hood) and mites (*Polyphagotarsonemus latus* Banks) are major sucking pests infesting chilli crop. Leaf crinkling and curling symptoms caused by a complex of pests and disease is a serious problem faced by farmers throughout India. Sucking pests of chilli also act as important vectors of many viral diseases (Zehra *et al.*, 2017).

Due to the monoculture of chilli crop, the pest multiplication is so high that the farmers have to go for about five to six chemical sprays. Extensive and unsystematic use of chemical pesticides leads to the development of problems like destruction of natural enemies, pest resurgence, resistance build-up in insect pests, secondary pest outbreak and contamination of the environment (Joia *et al.,* 2001). This demands a search for safer alternatives, which are environmental friendly and economically viable. In this context, botanical insecticides are emerging as supplements and also as a replacement to chemical pesticides. Botanicals are natural plant products that belong to the so-called secondary metabolites, which include alkaloids, terpenoids, phenolics, and minor secondary chemicals (Mamun, 2011; Mamun and Ahmed, 2011; Khan and Ram, 2016).

Andrographis paniculata (Burm.f.) Nees is an herbaceous plant that belongs to Acanthaceae family native to India and Srilanka. *A. paniculata* contains diterpenoid lactones, flavonoids, paniculides, farnesols as its primary chemical constitutes leading to possess antimicrobial properties (Roy *et al.,* 2010),

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antimalarial properties (Rahman *et al*., 2014) and insecticidal properties (Singh *et al.,* 2014). Oils of plant origin namely castor, neem and pongamia which are receiving more attention, since they are non-edible, abundant, non-polluting and sustainable. They can be better alternatives to conventional insecticides and promising botanicals for pest management.

The individual botanicals are not able to control crop pests when the pest population is very high in the field conditions. In view of this, a need was felt to find a sound and reliable Biopesticide formulation (BPF) which could be applied even at the time of an epidemic, when insect pressure is high under field conditions. In this context, the present investigation was conducted to develop an effective biopesticide formulation for the management of sucking pest complex of chilli comprising of *S. dorsalis, A. gossypii*, and *P. latus* with following specific objectives.

1. To develop oil based ready to use formulations of *A. paniculata.*
2. Evaluation of different oil-based formulations of *A. paniculata* for the management of sucking pest complex of chilli under field conditions and also to fix the optimum dose.
3. Shelf-life studies of promising treatments.

Review of Literature

2. REVIEW OF LITERATURE

Chilli is an important vegetable cum spice crop and an indispensable one in the kitchen garden, being the major constituent of the daily diet in every household. About 51 insects and two mite species were found infesting chilli (Reddy and Puttaswamy, 1983). Among these, *Scirtothrips dorsalis, Bemisia tabaci* Genn, *Aphis gossypii, Amrasca biguttula biguttula* (Ishida) and *Polyphagotarsonemus latus,* were major sucking pests contributing 60 to 75 per cent yield loss in green chilli (Patel and Gupta, 1998). Meena *et al.* (2013) mentioned about varied factors responsible for the reduction in the chilli yield, among which, insect and mite pests are responsible for a significant reduction in both the quality and quantity of chilli production. Zehra *et al.* (2017) found that the chilli crop is known to attack by several insects and non-insect pests. They also reported that sucking pests of chilli along with the plant pathogenic viruses results in the most destructive syndrome like chilli leaf curl that causes huge loss to market produce.

The publications related to the sucking pests of chilli and their management, particularly the environmental sound measures employing botanical insecticides are reviewed here.

2.1 SUCKING PESTS OF CHILLI

A survey conducted by the Asian Vegetable Research and Development Centre (AVRDC) revealed that *A. gossypii, S. dorsalis,* and *P. latus* are the important sucking pests of chilli, which altogether resulted in yield loss 34.5 per cent (Ahmed *et al.*, 1987). Venkateshalu *et al.* (2009) reported a yield loss of over 50 per cent in case of a severe infestation of thrips and mites.

Farmers use higher doses and number of sprays of different chemical pesticides for the management of these pests that lead to many problems like pest resurgence, secondary pest outbreak, destruction of natural enemies and environmental pollution (Shivaprasad *et al.*, 2010).

2.1.1 *Aphis gossypii* (chilli aphid)

The aphid, *A. gossypii* (Homoptera: Aphididae), a cosmopolitan polyphagous sucking pest infesting over 900 plant species in the world (Blackman and Eastop, 2000); including agricultural and horticultural crops (Agarwala and Das, 2007).

Pest occurring in almost all parts of the world can survive up to 7,000 feet from MSL throughout the year on different host plants (Behura, 1963). Agarwala and Raychaudhari (1985) described the principle host plants of aphids are cotton, okra, potato, chilli, tomato, brinjal, papaya and cucurbitaceous crops. Both adults and nymphs damage the crop by sucking sap from tender plant parts resulting in wrinkled, yellow and stunted leaves. Indirectly it affects the crop by excreting honeydew that favours the growth of sooty mold that inhibits photosynthesis (Singh *et al.*, 2014).

M. persicae and *A. gossypii* are important vectors of the Cucumber Mosaic Virus (Simons, 1955). Hamman (1985) observed that aphids can deform and discolour leaves and fruits, stunt plant growth or even cause galls on the stem, roots and leaves. Alegbego (1986) observed that both nymphs and adults of aphids are responsible for the transmission of the pepper vein mottle virus. Leaf curling symptoms on the tender leaves are mainly due to sap-feeding (David and Kumaraswami, 1996). Saxena (1998) and Kumar (1999) reported that aphid infested chilli plants became weak, pale and stunted in growth with curled leaves. The flower buds became brittle and dropdown. Severely infected plants were affected in all their growth parameters.

2.1.2 *Scirtothrips dorsalis* (chilli thrips)

The chilli thrips *S. dorsalis* (Thysanoptera: Thripidae) is an important polyphagous pest with a wide range of host plants including fruits crops, various vegetable and ornamental crops in southern and eastern Asia, Africa and Oceania. Both nymphs and adults lacerate the leaf tissue and suck the oozing juice, sometimes even the buds and flowers are attacked. Tatara (1994) reported chilli thrips as an important pest of tea and chillies in India and referred to as "chilli thrips" or the Assam thrips. *S. dorsalis*, the small-sized (1-2 mm long), yellow coloured, narrow and flat-bodied insects with two pairs of fringed wings and are mostly seen on the upper surface of the leaves of the tender meristems (Seal and Kumar, 2010).

Mound and Palmer (1986) recorded the yellow tea thrips from Australia, New Guinea, Southeast Asia, Pakistan, India and Japan. Muraoka (1988) and Vasundaraja (1994) observed a speedy multiplication of chilli thrips in dry weather conditions causes about 30 to 50 per cent yield loss. Multiplication of thrips is found to be higher during dry weather periods and causes a yield loss of 30-50 per cent in south India (Varadharajan and Veeravel, 1995). The infestation of chilli thrips was observed from the seedling stage in the nursery to harvest stage in the field. Both nymphs and adults suck sap from the buds, leaves, flowers and fruits which leads to the development of the hardened stem and fruits. Presences of upward curling of leaves with wrinkles and leaves with minute white spots are important symptoms of chilli thrips (Mandi and Senapati, 2009). The curling of leaves followed by the raising of the interveinal area and the older leaves and petioles became enlarged with leaf margin show burnt appearance and stunted growth. In case of severe infestation bud and flower shedding was also noticed (Mondal and Mondal, 2012).

2.1.3 *Polyphagotarsonemus latus* (broad mite)

The broad mite, *P. latus* (Acari: Tarsonemidae) is a microscopic and tiny spider-like creature where adults are eight-legged and larvae are six-legged found in large numbers on the underside of leaves, covered with fine webs. It is a serious pest on most of the vegetable crops and ornamental plants in glass houses. Petiole elongation and clustering at the tip of branches of older and tender leaves of the plant are important characteristic symptoms of mite infestation. The yellow tea mites or broad mites are small-sized (0.1-0.2 mm long), slightly yellow coloured. Both nymphs and adults suck the sap and devitalize the plants (Butani, 1976; Venzon *et al.*, 2008).

The yield loss due to chilli mite may go up to 96.39 per cent (Borah, 1987) sometimes leading to complete failure of the crop itself (Kulkarni, 1992). Mite infestation, confined mostly to the lower surface of the leaves results in downward curling of leaves, elongation of the petiole and scarring of the stem and fruit skin in chillies ((Karmakar, 1997; Rai and Solanki, 2002). Feeding of *P. latus* caused different types of physical deformities like downward curling, thickening, brittleness and shortening, twisting and crumpling of young leaves, blackening and death of new growth. The midrib of young infested leaves bent in a zigzag fashion, the ventral surface become silvery, petiole of mature leaves elongated and the plant became stunted with rosette symptoms. Infestation at the flowering stage caused the falling of flower bud (Mondal and Mondal, 2012). Bhattacharjee and Rahman (2017) observed a yield loss of up to 96.39 per cent by mites infestation that leads to the complete failure of the chilli crop.

2.1.4 Chilli Leaf Curl Syndrome

Dhanraj and Seth (1968) noticed chilli leaf curl as the utmost check factor of chilli cultivation. Chilli leaf curl symptom frequently named as "Murda" was investigated to be caused by an infestation of *P. latus* and *S. dorsalis* (Amin, 1979).

Chilli leaf curl symptom called "Murda" is one of the most destructive syndromes affecting chilli in India and is considered to be caused by both mites and thrips (Puttarudraiah, 1959). The yield loss due to these two pests was estimated to the tune of 50 per cent (Ahmed *et al.,* 1987; Kandasamy *et al.*, 1990).

Kumar and Kumar (2017) stated that the leaf curl symptom was distinguished by swollen and thickened veins with crinkled and curled leaves. In later stages of infestation, the whole plant becomes visible bushy with fewer flower buds and stunted growth. Zehra *et al.* (2017) reported the distinctive symptoms of vein yellowing, yellow mosaic and leaf curl associated with the infection of begomo viruses. The reduction in a considerable number of flowers leads to a low fruit set.

In computation to the feeding by sucking pests, there is an increased spread and association of begomo viruses transmitted by them was also credited to the development of leaf curl symptoms (Venkatesh *et al.*, 1998).

2.2 MANAGEMENT OF SUCKING PESTS

Farmers usually go for a minimum of 12 to 15 rounds of the conventional insecticide sprays to manage the sucking pest of chilli. Application of chemical insecticides in this manner not only increases the cost of cultivation but often caused the development of resistance, flare back of the pest and pest induced resurgence. *S. dorsalis* and *P. latus* are major constraints in the chilli cultivation. Due to the monoculture of chilli in major growing areas, the pest build-up was so huge that the number of pesticide applications had increased over the years (Varghese and Mathew, 2013; Halder *et al.*, 2015).

Sahu *et al.* (2018) highlighted the need to evaluate the present status of insecticide resistance in chilli pests in addition to estimating newer insecticides with a novel mode of action both under field and laboratory conditions so to have the more desirable option at hand to reduce the present control failure and residue problems faced by the farmers.

2.2.1 Chemical Pesticides

Mandi and Senapati (2009) reported that acetamiprid and thiamethoxam was effective to minimize the thrips population 93.3 per cent and 89.93 per cent respectively. Varghees and Mathew (2013) reported that spiromesifen 45 SC at 100 g a.i. ha^{-1} and propargite 57 EC at 570 g a.i. ha^{-1} reduced mite population in chilli and acetamiprid 20 SP at 20 g a.i. ha^{-1} with spiromesifen 45 SC at 100g a.i. ha^{-1} reduced chilli thrips.

Kumar *et al.* (2017) revealed that thiamethoxam 25 WG at 0.005% is highly effective in reducing thrips population to 67.20 per cent in 3 days after spray. Samota *et al.* (2017) reported that the mean per cent reduction of thrips was found to be 80.79 due to thiamethoxam 25 WG at 0.025%.

ICAR-Indian Institute of Vegetable Research, Varanasi conducted field experiments to evaluate the efficacy of different newer molecules against *S. dorsalis* and *P. latus* infesting chilli wherein greatest reduction in thrips population was observed in fipronil (75.41 per cent) followed by spiromesifen (58.29 per cent) while the highest reduction in mite population was observed with chlorfenapyr at 1.5 mL L^{-1} followed by spiromesifen at 0.6 mL L^{-1} and fipronil at 0.35 g L^{-1} (Halder *et al.,* 2015).

2.2.2 Botanical Pesticides

The botanical pesticides have been used by man since from the time immemorial. These pesticides were highly effective against a wide range of insects and non-insect pests. The botanical pesticides are easily available, comparatively inexpensive and hence could they definitely push the use of chemical pesticides. With every new generation of chemical pesticides, there are a several number of plant-derived products in use and they are comprehensively and broadly called as 'Botanicals' and being emphasized at a recent time as the best possible ingredient of integrated pest management. The praiseworthy aspects and shortcomings of botanical pesticides in the plant protection framework have been broadly evaluated by several researchers (Morallo-Rejesus, 1987; Ayyangar and Nagasampagi, 1990; Benner, 1993; Paramar, 1993; Bhatnagar and Sharma, 1994; Isman, 1994).

Botanical insecticides are mostly complimented for managing insect pests of vegetables and fruit crops considering the synthetic organic pesticides are scandalous for causing residue problems on the crop yield. Plants are endowed with a wide potential to produce a wide range of allelochemicals that protect them from insect-pests. However, the production of phytochemicals has been reported to vary from plant to plant (Ahmad and Aqil, 2007). The phytochemicals produced from plants in response to insect pests attack, affect the feeding and ovipositional activity of insects on plants (Ramya *et al.*, 2008).

Plants are known to have a variety of secondary metabolites that are absolutely necessary for their growth and development and are indispensable in protection against predators and pathogens (Rosenthal, 1991). Isman (2000) revealed that secondary metabolites of plants are reported to have insecticidal, antifeedant, growth-regulating and repellent properties. Weinzierl (2000) highlightened the history of use of conventional pesticides such as neem, rotenone, sabadilla and pyrethrum.

The need to develop non-toxic, safe and biodegradable alternatives to synthetic insecticides has in recent years led to collaborative international efforts to develop new sources from the vast store of the chemical substances in plants (Olaifa *et al.*, 1987).

There is resumed curiosity in botanical pesticides and a large number of the phytochemicals such as pyrethrin (Casida, 1980), plant essential oils (Koul *et al.,* 2008; Schafer and Wink, 2009), azadirachtin (Khater, 2012), nicotine (El-Wakeil, 2013), ryanoids (Martina and Kristina, 2013) which have been developed as commercial botanical insecticides.

2.2.2.1 Bioefficacy of A. paniculata

A. paniculata is a shrub commonly referred as "Kalmegh" and was most commonly used as wonder drug in ayurvedic and traditional medicine and it is very famous for its clinical applications (Mishra *et al.,* 2007). *A. paniculata* contains many primary constituents, diterpenoid lactones (Andrographolides), paniculides, farnesols and flavonoids (Ramya *et al.,* 2011).

Singh *et al.* (2014) tested bioefficacy of different botanical pesticides *i.e. A. paniculata, Calotropis gigantean* (L.), *Catharanthus roseus* (L.), *Lantana camara* L., *Azadirachta indica* A. Juss. *Pongamia pinnata* L. and

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Cassia tora L. Among the botanical pesticides, *A. paniculata* decoction was more effective against thrips (3.73–5.01 thrips per leaf) and the efficacy was similar to 0.03% dimethoate. The highest yield was obtained in dimethoate (98.07 q ha^{-1}) and *A. paniculata* decoction spray (98.04 q ha^{-1}) as against the control plot (89.99 q ha^{-1}). Prema *et al.* (2018) revealed that leaf extract of *A. paniculata* 10 % was found to be effective against *Thrips palmi* Karny in cotton.

Kiruba and Thirunavukkarasu (2017) observed that leaf extract of *A. paniculata* causes 72.92 per cent deformities to *Earias vittella* (Fab.). Madihah *et al.* (2018) observed that andrographolide, an active compound of *A. paniculata* shown the highest antifeedant activity against *Plutella xylostella* (L.) larvae by disrupting the midgut histological structures. The results also showed that andrographolide significantly reduced the amylase, invertase, protease and trypsin activity, as well as the total protein concentration of larvae of *P. xylostella.*

Widiarta *et al.* (1997) reported that the crude extract of *A. paniculata* at 1600 ppm showed the highest reduction in the feeding activity of green rice leafhopper by the root immersion method and they also found the antifeedant activity of andrographolide was similar to the feeding deterrent activities of cartap and bensultap. Bernice (2000) observed that leaf extract of *A. paniculta* in combination with neem oil emulsion 2.5% and garlic at 20 g L^{-1} caused 40, 80 per cent deterrent effects on the aphids and epilachna bettle respectively. Suganthy and Sakthivel (2012) reported that 1% azadiracthin and 2% aqueous extract of *A. paniculata* showed a maximum reduction of pest population of aphids, thrips, leaf miners and defoliators infesting *Solanum nigrum* L. and also conserved more number of natural enemies like predatory coccinellids. According to Premalatha *et al.* (2018), aqueous extract of *A. paniculata* 10 % concentration caused 42.23 per cent mortality of mites under laboratory conditions three days after application.

The methanol extract of *A. paniculata* showed the highest antifeedant, growth-inhibitory and oviposition deterrent activity against larval and adult stages of the Bihar hairy caterpillar, *Spilarctia oblique* (Walker) (Tripathi *et al.*, 1999).

Ramya and Jayakumararaj (2009) observed that aqueous leaf extracts of *A. paniculata* at a concentration of 1000 ppm showed 72.8 per cent mortality of *Helicoverpa armigera* Hubner at 24 hours after application. Ramya *et al.* (2011) reported that crude methanol extract of *A. paniculata* caused 83.3 per cent larval mortality in *H. armigera*. As per the research findings of Vattikonda (2015) andrographolide, active compounds isolated from *A. paniculata* at a concentration of 200 ppm showed 80.05 and 83.60 per cent antifeedant activity against the fourth instar larvae of *Papilio demoleus* L. 24 and 48 hours after treatment respectively.

The methanol and ethyl acetate extracts of *A. paniculata* at the highest concentrations (1000 ppm) caused 72.01 and 67.69 per cent adult mortality of cowpea weevil, *Callosobruchus chinensis* L. respectively (Bright *et al.*, 2001). Lingampally *et al.* (2012) reported that topical application of andrographolide inhibits ovarian development which affects the fertility and reproductive potentiality of *Tribolium confusum* (Duval). Adekunle and Ayodele (2014) stated that aqueous leaf extract of *A. paniculata* caused 100 per cent mortality of *Callosobruchus maculatus* (Fabr.) at 96 hours after application.

Extracts of *A. paniculata* reduced to a great degree of reproductive capacity and survival of the malarial vector *Anopheles stephensi* Liston (Kuppusamy and Murugan, 2010). Elango *et al.* (2011) reported that hexane and chloroform extract of *A. paniculata* showed 100 per cent mortality of mosquitoes (*Anopheles subpictus* Grassi). Recent evidence suggests that combined effect of *A. paniculata* and *A. lineate* Nees at 150 ppm of solvent extracts of petroleum ether: aqueous (1:1) caused 100 per cent mortality to the larvae of *Culex quinquefasciatus* (Say.) and *Aedes aegypti* (Linn.) after 24 h of exposure (Renugadevi *et al.*, 2013).

2.2.2.2 Bioefficacy of Oils

2.2.2.2.1 Sunflower and Palm

Research on sunflower oil as a protectant of stored grain products has been conducted on *C. maculatus* (Pierrard, 1986) and *C. chinensis* (Khalequzzaman *et al.*, 2007).

Law-Ogbomo and Enobakhare (2006) reported that palm oil at 10 mL kg^{-1} grain caused 91 per cent mortality of *Sitophilus zeamais* (Mots.). Abulude (2007) stated that palm oil application in grainery provide good protection of grains against pulse beetles with the least or no ovipositional and emergence activity.

2.2.2.2.2 Castor

Castor bean plant, *Ricinus communis* L. belongs to the family Euphorbiaceae. The insecticidal activity of plant materials derived from castor is attributed to its major components of protein ricin and alkaloid ricinine. Studies of the various solvents extraction prepared from different parts of *R. communis* have been reported numerous bioactive phytochemical constituents like alkaloids, anthocyanins, flavonoids, phenolics, tannins, terpenoids (Alugah and Ibraheem, 2014).

Castor bean contains the alkaloid ricinin (Bigi *et al.,* 2004), fatty acids Ramos-López *et al.* (2010) and the polyphenolic molecule epicatechin (Zahir *et al.,* 2012) in their leaves which all have insecticidal properties.

The castor bean has shown great potential as a source of insecticidal molecules against several insect pests (Upasani *et al.*, 2003; Rahuman *et al.,* 2008; Elimam *et al.,* 2009; Zahir *et al.,* 2010a). Ricinine is a toxic alkaloid isolated from the leaves and fruits of *R. communis.* The toxic effects of ricinine on the leaf-cutting ant, *Atta sexdens rubropilosa* Forel has been observed. The treated ants showed symptoms of intoxication, such as reduction or stoppage of locomotion, followed by disorientation, non coordination and death (Rana *et al.*, 2012).

Ricinine exhibited insecticidal activity against green peach aphids, *M. persicae* (Olaifa *et al.,* 1991). The crude methanolic leaf extracts of *R. communis* had acaricidal and insecticidal activities against *Haemaphysalis bispinosa* Neumann and *Hippobosca maculata* Leach respectively (Zahir *et al.*, 2010b). Ethanolic leaf extracts of *R. communis* exhibited acaricidal activity against organophosphate and pyrethroid-resistant ticks, *Rhipicephalus microplus* Canestrini. The acaricidal activity may be due to the active constituents in the extract like quercetin, gallic acid, flavones and kaempferol (Ghosh *et al.*, 2013). Veena *et al.* (2017) reported that castor oil 2 mL L^{-1} caused 46.67, 56.67, 60, 76.76 per cent mortality of *P. latus* 24, 48, 72 and 96 hours after treatments (HAT) under laboratory conditions. Castor oil showed larvicidal and adulticidal activities against *A. aegypti* (Wamaket *et al.*, 2018).

The flavonoids isolated from aqueous leaf extract of *R. communis* showed excellent insecticidal, ovicidal and oviposition deterrent activities against stored grain pest, *C. chinensis* (Upasani *et al.*, 2003). Kodjo *et al.* (2011) stated that the application of 10% castor oil emulsion caused 51.41 percent mortality to the third instar of *P. xylostella* under field conditions. As per research findings of Harish *et al.* (2014) spraying of castor 5% caused 69.7 per cent mortality of *Caryedon serratus* (Olivier) 24 hours after application.

2.2.2.2.3 Neem

Neem based insecticides are obtained from the tree, *A. indica* belongs to the family, meliaceae (Siddiqui *et al.*, 2004).

The bitter principles of neem are mainly due to the presence of limonoids which is a group of tetranortriterpenoids of which azadirachtin is the important active compound used for pest management (Kumar *et al.*, 2003). More than 100 neem formulations were found to be used for pest management worldwide (Khater, 2012).

Neem oil was found highly effective botanical pesticide against *S. dorsalis* (Roa *et al.,* 1999), *P. latus* (Venzon *et al.,* 2008) and *A. gosssypii* (Pinto *et al.*, 2013).

Insecticidal activity of neem oil is due to repellent activity from treated plants and secondly due to antifeedant effect on the insect pests (Rajput *et al.,* 2003). Oviposition deterrence of neem oil was also observed in *Mussidia nigrivenella* Ragonot (Lepidoptera: Pyralidae) by (Agboka *et al.*, 2009).

Azadirachtin based insecticides persist only for about 4 to 8 days in the environment and therefore are immensely acceptable and suitable for eco-friendly management of insect pests (Schmutterer, 1990). Neem seed oil 2.5 or 5% with garlic at 20 g L^{-1} effectively controlled aphid, mite and jassid on bitter guard (KAU, 1996). As per research findings of Ali *et al.* (2002) application of Neem Seed Kernel Extract (NSKE 5%) found to be highly effective and superior to the chemical pesticides in controlling chilli mites and thrips. The mortality of aphids in treatments with neem oil can be credited due to the presence of azadirachtin, the tetranortriterpenoid limonoid, possessing pesticidal properties (Kumar *et al.*, 2003). According to Ghosh (2015), the botanical pesticide azadirachtin gave better results in suppressing *A. gossypii* (60.30 per cent).

Thamilvel (2009) observed that the application of neem oil + garlic emulsion 2 % was effective in controlling aphid. Kumar *et al.* (2010) reported that the application of neem oil (3.5%) was found to be highly effective in managing chilli aphid. Vinodhini and Malaikozhundan (2011) observed the application of neem oil 80 EC 3 mL L^{-1} showed 57.72 per cent reduction of *A. gossypii* at 4 days after treatment under field conditions.Vasantlal (2012) highlighted that neem oil (0.5%) found highly significant in reducing the thrips population in chilli. As per the research findings of Singh and Singh (2013) spraying of neem oil based formulation 0.03% resulted in a 33.77 per cent reduction in the mite population at one day after application. Kumar (2016) reported neem oil 2% was most effective against thrips as it recorded the lowest population (6.90 thrips per plant). Meena and Tayde (2017) stated that neem oil 2.5 mL L^{-1} reduces the population of *S. dorsalis* to 55.78 per cent. Sundaran (2018) reported that neem oil 2% gave 50 per cent mortality of aphids 24 hours after treatment.

Bernice (2000) reported that the application of neem oil and *Hyptis suaveolens* L. either alone or in combination were found to have high deterrent and toxic effects on aphids, brinjal shoot and fruit borer and epilachna beetle in the laboratory. Sreerag and Jayprakash (2014) reported that 1% formulation which contained 50 Ml neem oil, 30 mL surfactant and 20 mL cassava leaf extract found to be most effective biopesticide formulation against cowpea aphid, *Aphis craccivora* (Koch) and papaya mealybug, *Paracoccus marginatus* (Williams and Granara de).

Azam (1991) reported that the neem oil 1.0 and 1.25% caused more than 80 per cent mortality of the larvae and pupae of *Liriomyza trifolii* (Burgess). Ramesh and Ukey (2007) reported that neem oil 1% was effective in reducing leaf miner infestation in tomato. As per the research findings of Rahman *et al.* (2009) application of neem oil 4% showed the highest percentage reduction (70.44 per cent infested shoots per plant) of brinjal shoot and fruit borer. Experiments were conducted to assess the biological efficacy of neem oil against spiraling whitefly on brinjal. Neem oil 3% showed a significantly high mortality of 78.16 per cent in 10 days after treatment (Boopathi and Karuppuchamy, 2013).

Sontakke (1993) observed neem oil 1% spray gave good control of *Spodoptera.* Packiam and Ignacimuthu (2012) mentioned 0.6% concentration of formulation containing 85% neem oil + 15% emulsifier recorded 56.04 per cent antifeedant activity of *Spodoptera litura* (Fabricius) within 24 hours after treatment application. As per research findings of Harish *et al.* (2014) spraying of neem 5% caused 88.2 per cent mortality of *C. serratus* after 24 hours.

Neem oil 1.5% spray showed 100 per cent mortality to mustard aphid (Mani *et al.*, 1990). Neem oil at different concentrations has been reported to be effective against *B. tabaci* (Natarajan and Sundaramurthy, 1990; Rosaiah and

Reddy, 1996). Neem oil (5%) sprays were found to be effective in reducing the populations of the pest in chickpea (Rao and Srivastava, 1985; Siddappaji *et al.*, 1986 and Sinha, 1993).

2.2.2.1.5 Pongamia

Pongamia pinnata which belongs to the family Leguminosae is a rich source of flavonoids, chalcones, steroids and terpenoids. Pongam oil serves as defensive agents against insect pests (Pavela, 2004; Pavela *et al.*, 2005).

Rao and Dhingra (1997) observed karanjin, an active component isolated from pongamia seed oil showed juveno-mimetic activity in the larvae of *Tribolium castaneum* (Herbst). Kumar and Singh (2002) reported that the persistence of pongamia oil is greater than other botanical insecticides. Pongamia oil also shows a good synergistic effect with a number of chemical pesticides and also recorded greater biological activity. Increasing potential as a biopesticide is due to its antifeedant, oviposition deterrent, ovicidal, juvenile hormone activity that can be attributed by karanjin, the major flavonoid of the seed oil. Meera *et al.* (2003) highlighted active components of the karanjin group, extracted in water from pongamia oil cause toxic effects on *S. litura* larvae.

Reddy and Kumar (2006) highlighted pongamia oil 1% gave satisfactory control of *P. latus*. Pongamia oil at 1% concentration found to be highly effective in the management of chilli thrips (Vasanthalal, 2012). Kaur and Singh (2013) observed that pongamia soap 1% gave significantly better control of thrips. Meena and Tayde (2017) stated that pongamia oil 4% reduces the population of *S. dorsalis* to 55.64 per cent. Veena *et al.* (2017) reported that pongamia oil 2 mL L^{-1} caused 26.67, 36.67, 46.67 and 56.76 per cent mortality of *P. latus* 24, 48, 72 and 96 hours after treatments (HAT) under laboratory conditions.

Jothi *et al.* (1990) assessed the different oils of plant origin and their extracts against citrus aphids, based on the cost and effectiveness of treatments. They found pongamia seed extract (2%) and pongamia oil (1%) was effective for control of citrus aphid. Spraying of pongamia oil 80 EC 3 mL L^{-1} showed a 40.58

per cent reduction of *A. gossypii* three days after treatment under field conditions (Vinodhini and Malaikozhundan, 2011). Arya (2015) reported that oxuron a commercial botanical product comprising of neem oil and karanja oil was found to be highly effective against brinjal sucking pests. Sundaran (2018) also reported that oxuron was found to be effective against *A. gossypii.*

Packiam and Ignacimuthu (2012) mentioned 0.6% concentration of formulation containing 85% pongamia oil + 15% emulsifier recorded 51.06 per cent antifeedant activity in *S. litura* 24 hours after treatment application. PONNEEM a commercial botanical product comprising of neem oil and karanja oil in the ratio of (1:1) showed 58.16 per cent mortality against *H. armigera* (Packiam *et al.*, 2013). As per research findings of Harish *et al.* (2014) spraying of pongamia oil 5% caused 37.4 per cent mortality of *C. serratus* 24 hours after application. Stepanycheva *et al.* (2014) observed pongamia oil 1% did not have a negative influence on insect pollinators of hymenopterans, dipteran, lepidoptera, hemiptera and coleoptera.

Karanja oil (2%) was reported to prolong larval development and growth-inhibiting activity of *H. armigera* (Bajpai and Sehgal, 1994). As per the research findings of Rahman *et al.* (2009) pongamia oil 4% showed a maximum percentage reduction of brinjal shoot and fruit borer.

Materials and Methods

3. MATERIALS AND METHODS

The present investigation entitled "Oil based formulation of *Andrographis paniculata* (Burm.f.) Nees against sucking pests of chilli" was conducted at College of Agriculture, Vellayani during the period of 2017-2019. The objectives of the study were to develop oil based ready to use formulations of *A. paniculata*, evaluation of different oil based formulations of *A. paniculata* for the management of sucking pest complex of chilli under field conditions and to fix the optimum dose and also shelf life studies of promising formulations.

3.1 *IN VITRO* EVALUATION OF DIFFERENT FORMULATIONS OF *Andrographis paniculata*

3.1.1 Development of formulations

The basic components used for developing the formulations were

1. Plant extract of *A. paniculata*
2. Oils *viz.,* sunflower oil, palm oil, castor oil, neem oil and pongamia oil
3. Surfactants- Tween 60, Tween 20, Tween 80, Span 60, Span 20, Soap oil and Triton X-100.

3.1.1.1 Preparation of Plant Extract

Tender stems, leaves, flowers and roots of *A. paniculata* collected from Instructional farm at College of Agriculture, Vellayani, were washed thoroughly with clean water and chopped into small pieces for easy grinding (Plate 1). Fresh chopped plant material of *A. paniculata* (2.5 kg) was macerated in an electric grinder to get 1 litre of the plant extract. The extract obtained were first filtered using strainer to remove plant debris then again sieved through double layered muslin cloth to get a clear plant extract.

Plate 1: *Andrographis paniculata*

3.1.1.2 Preparation of oil based formulations of Andrographis paniculata

Different combinations of *A. paniculata* extract, oils and surfactants were tested in the laboratory for finding the suitable surfactant and their effective combination of Extract- oil- surfactant (EOS) as mentioned in Table 1.

Table1: Proportions of different combinations of Plant extract- Oil-Surfactant

Extract of *A. paniculata* (%)	Oil (%)	Surfactant (%)
50	25	25
50	30	20
60	20	20
40	40	20
60	30	10
70	20	10
65	25	10
72	20	8
75	20	5
85	10	5

Out of seven surfactants (Tween 60, Tween 20, Tween 80, Span 60, Span 20, Triton X-100 and Soap oil) used the best surfactant was selected based on the following criteria as stated by Spalton (1950).

1. The surfactant need to bring about a stable film at the interfacial tension between two immiscible liquids
2. It should be compatible with other ingredients of the formulation.
3. It must be non-irritant and non-toxic to mucous membranes and also for skin.
4. It should be able to maintain the required viscosity of the formulation.
5. It should not impart any colour or odour to the formulation.
6. The emulsifying agent should be stable to chemical degradation.
7. It should be economically affordable.

After mixing the components in the desired ratio, the formulations were kept in rotary shaker at 192 rpm for 30 minutes for proper mixing to get a better emulsion. Formulations after preparation were tested for blooming and emulsion stability test as stated by (BIS, 1997 and Allawzi *et al*, 2016).

3.1.2 Maintenance of stock culture of test organisms

Aphis gossypii

The aphid species were taxonomically confirmed with the service of Indian Council of Agricultural Research (ICAR), National Bureau of Agricultural Important Insect Resources (NBAIR), Bengaluru (Plate 2A). After species confirmation the *A. gossypii* colony were excised from infested plants and transferred to seedlings of chilli variety Vellayani Athulya which were obtained from the Instructional farm, College of Agriculture, Vellayani. Seedlings were transplanted to plastic cups of 200 mL filled with potting media containing sand, soil and farmyard manure in the ratio of 1:2:1 (Plate 3A). At two to three leaf stages, aphids were released into seedlings using camel paint brush. After inoculation, seedlings were maintained in rearing cage for multiplication.

Scirtothrips dorsalis

Scirtothrips dorsalis infested leaves were brought from field and inoculated on chilli seedlings at two to three leaves stages and maintained for multiplication (Plate 2B and 3B).

Polyphagotarsonemus latus

For rearing of *P. latus* also, the same methodology was followed as that *S. dorsalis* (Plate 2C and 3B).

Wingless form

Winged form

A. *Aphis gossypii*

B. *Scirtothrips dorsalis*

C. *Polyphagotarsonemus latus*

Plate 2: Sucking pest complex of chilli

A. Chilli plants raised for evaluation against aphids

B. Chilli plants raised for evaluation against thrips and mites

Plate 3: Maintenance of test insects

3.1.3 Bioassay Studies

3.1.3.1 Evaluation of Different Formulations of Andrographis paniculata (Higher dose)

3.1.3.1.1 Screening of different oil based formulations of A.paniculata

Screening of different oil based formulations of *A. paniculata* was carried out in laboratory using *A. gossypii* as test insect. Concentrations of 5, 10 and 20% of the following treatments were tested against the test insect. The treatments were applied using Potter Precision Laboratory Spray Tower (Plate 4). Twenty aphids were placed in each Petri dish and directly sprayed with 2 mL of formulations.

Design: CRD Treatments: 35 Replications: 3

T1: PEA (90%) + Triton X-100 (10%)

T2: PEA (70%) + sunflower oil (20%) + Triton X-100 (10%)

T3: PEA (70%) + palm oil (20%) + Triton X-100 (10%)

T4: PEA (70%) + castor oil (20%) + Triton X-100 (10%)

T5: PEA (70%) + neem oil (20%) + Triton X-100 (10%)

T6: PEA (70%) + pongamia oil (20%) + Triton X-100 (10%)

T7: Sunflower oil (20%) + Triton X-100 (10%)

T8: Palm oil (20%) + Triton X-100 (10%)

T9: Castor oil (20%) + Triton X-100 (10%)

T10: Neem oil (20%) + Triton X-100 (10%)

T11: Pongamia oil (20%) + Triton X-100 (10%)

T12: Triton X-100 (10%)

T13: Untreated control

(PEA- Plant extract of *A. paniculata*)

The treated insects were then transferred to Petri dishes containing chilli leaves as food. Three replications were maintained for each treatment. The numbers of dead aphids were counted at 24, 48 and 72 hours after treatment (HAT). The number of dead aphids was recorded and percentage mortality was

Plate 4: Potter Precision Spray Tower

calculated by using Abbott's formula (Abbot, 1925). The cumulative corrected percentage mortality was statistically analysed.

$$\text{Corrected per cent mortality} = \frac{\text{Mortality in treatment} - \text{mortality in control}}{100 - \text{Mortality in control}} \times 100$$

3.1.3.1.2 Evaluation of the selected formulations

The selected treatments from the above experiment 3.1.3.1.1 were evaluated at 5, 10 and 20% concentration against thrips and mites. Infested leaves with 20 thrips and mites were collected and kept in Petri dish and sprayed with Potter Precision Laboratory Spray Tower. Three replications were maintained for each treatment. The number of dead thrips and mites were counted at 24, 48 and 72 HAT application.

3.1.3.2 Evaluation of Different Formulations of Andrographis paniculata against A. gossypii (Lower dose)

Different concentrations of 1, 2, 3 and 4% of the following formulations selected from 3.1.3.1.1 were evaluated against aphids.

Design: CRD Treatments: 13 Replications: 3

T1: PEA (70%) + castor oil (20%) + Triton X-100 (10%)

T2: PEA (70%) + neem oil (20%) + Triton X-100 (10%)

T3: PEA (70%) + pongamia oil (20%) + Triton X-100 (10%)

T4: Untreated control

3.2 EVALUATION OF EFFECTIVE FORMULATIONS FOR FIXING THE DOSE

A pot culture experiment was conducted to evaluate the efficacy of selected treatments for the management of sucking pest complex of chilli under field conditions. Effective treatments from 3.1 were selected based on the laboratory studies.

Design: CRD Treatments: 30 Replications: 3

T1: PEA (70%) + castor oil (20%) + Triton X- 100 (10%)

T2: PEA (70%) + neem oil (20%) + Triton X- 100 (10%)

T3: PEA (70%) + pongamia oil (20%) + Triton X- 100 (10%)

(1, 2, 3, 4, 5, 7, 10, 15 and 20% concentrations of the above treatments)

T4: Thiamethoxam 25% WG 50 g a.i ha^{-1}

T5: Spiromesifen 22.9% SC 96 g a.i ha^{-1}

T6: Untreated control

Chilli seedlings of variety Vellayani Athulya was obtained from the Department of Olericultwere transplanted in grow bags (35 x 20 x 20 cm) filled with the potting mixture prepared with sand, soil and farmyard manure in 1:2:1 ratio (Plate 5). The crop was raised following the package of practices recommendations of Kerala Agricultural University (KAU, 2016).

A consistent population of sucking pests comprising of *S. dorsalis*, *A. gossypii* and *P. latus* were maintained in these plants avoiding plant protection interventions. After recording the pre treatment population of the sucking pests the first round of treatments were applied at 30 days after planting (DAP) in the vegetative stage of the crop. Treatments were applied to the entire plant using a hand sprayer ensuring coverage of both abaxial and adaxial surfaces of leaves. Post treatment population of sucking pests was recorded on 1, 3, 5 and 7 days after treatment (DAT). From each plant, one leaf each was selected from top, middle and bottom at random to assess the pest population. The count of thrips, aphids and mites was taken from both surfaces of the leaves using a hand lens and expressed as numbers per leaf.

Second round of treatments were applied in the reproductive stage of the crop at 60 DAP and the pest population observations were recorded.

Plate 5: Experimental layout

3.2.1 Damage Caused by Sucking Pests

The nature of damage of sucking pests was observed for each sucking pest *viz., S. dorsalis, A. gossypii* and *P. latus* by associating the symptoms of damage with the presence of pests on the crop.

3.2.1.1 Effect of Oil Based Formulation of A. paniculata on Sucking Pests Based on Leaf Curl Index

In order to assess the effect of treatments on the damage caused by sucking pests, the leaf curl index, an indicator of damage was worked out 10 days after each round of treatments *viz.,* 40 and 70 DAP respectively and again at the end of the crop period (100 DAP). The plants were scored visually for sucking pest damage in zero to four scale (Niles, 1980 and Desai *et al.*, 2006) (Table 2).

Table 2: Scoring of damage by sucking pest infestation in chilli

Score	Category	Symptom
0	No damage	No symptom
1	Less damage	1-25% leaves plant^{-1} show curling
2	Moderate damage	26-50% leaves plant^{-1} show curling
3	Heavy damage	51-75% leaves plant^{-1} show curling, malformation of growing points and reduction in plant height
4	Complete damage	> 75% leaves plant^{-1} show curling, damage of growing points, and drastic reduction in plant height, defoliation and severe malformation.

The leaf curl index was worked out using the formula

$$\text{Leaf curl index} = \sum \left\{ \frac{\text{Score x Number of plants in that score}}{\text{Total number of plants}} \right\}$$

3.2.2 Population Density of Natural Enemies, Pollinators and Neutrals

The number of natural enemies, pollinators and neutrals seen in the plants were counted and mean value were calculated one day before pre-treatment and 1, 3, 5 and 7 DAT.

3.2.3 Growth Parameters of Chilli Treated with Different Formulations

Growth and yield parameters of chilli crop at different stages recorded were given below.

a. Plant height (cm) at 40, 70 and 100 DAP
b. Number of Primary branches plant^{-1} at 40, 70 and 100 DAP
c. Fruit weight in g plant $^{-1}$

Height of the plant from the base to the tip of the upper branches were measured and expressed in centimeter (cm). Number of primary branches was taken into account. The weight of chilli fruits harvested at different intervals was recorded and cumulative yield was expressed as g plant $^{-1}$.

3.3 SHELF LIFE STUDIES OF PROMISING TREATMENTS

Shelf life studies of the promising formulations selected from 3.2 were carried at different intervals after preparation of the formulations given below.

i. Fresh preparation
ii. 15 days after preparation
iii. 30 days after preparation
iv. 60 days after preparation

After preparation, formulations were stored in amber coloured glass bottles and kept under room temperature for future applications. The effectiveness of the above mentioned formulations was studied in a pot culture experiment against.

3.4 STATISTICAL ANALYSIS

The data collected from the laboratory and field experiments were subjected to statistical analysis using WASP software (Panse and Sukhatme, 1967). Data were analysed using one way analysis of variance after subjected to angular and square root transformations appropriately.

Results

4. RESULTS

An experiment was conducted at College of Agriculture, Vellayani during 2017 to 2019 to develop oil based ready to use formulations of *Andrographis paniculata* and to evaluate different oil based formulations of *A. paniculata* for the management of chilli sucking pest complex. The data were analyzed statistically after proper transformation and important findings obtained from the present investigation are explained below.

4.1 *IN VITRO* EVALUATION OF DIFFERENT FORMULTION OF *Andrographis paniculata*

4.1.1 Development of Formulations

Different combinations of plant extract-oil-surfactant were tried and the ratio of 7:2:1 was found to be suitable combination with good miscibility and Triton X-100 as most suitable surfactant.

4.1.1.1 Efficacy of Higher Doses of Oil Based Formulation of A. paniculata

Different concentration (5, 10 and 20%) of oil based formulation of *A. paniculata* were evaluated against *A. gossypii*, *S. dorsalis* and *P. latus*

The data on the cumulative per cent mortality of aphids treated with treatments are presented (Table 3, 4 and 5).

Among various treatments evaluated, extract of *A. paniculata* + pongamia oil + Triton X-100 and extract of *A. paniculata* + neem oil + Triton X-100 at 5% concentration showed 100 per cent mortality which was found to be on par with 5% concentration of extract of *A. paniculata* + castor oil + Triton X-100 with 98.33 per cent mortality at 24 hours after treatment (HAT). This was followed by extract of *A. paniculata* + Triton X-100, neem oil + Triton X-100, pongamia oil + Triton X-100, extract of *A. paniculata* + sunflower oil + Triton X-100 and extract of *A. paniculata* + palm oil + Triton X-100 which were on par with each other. Triton X- 100 recorded least mortality (1.67%) after 24 HAT.

At 48 HAT, extract of *A. paniculata* + pongamia oil + Triton X-100, extract of *A. paniculata* + neem oil + Triton X-100, extract of *A. paniculata* + castor oil + Triton X-100, extract of *A. paniculata* + Triton X-100 and neem oil + Triton X-100 showed superiority over other treatments with 100 per cent mortality. Pongamia oil + Triton X-100 (88.33%), extract of *A. paniculata* + sunflower oil + Triton X-100 (93.33%) and extract of *A. paniculata* + palm oil + Triton X-100 (93.33%) were found to be on par with each other though inferior to the best treatments.

At 72 HAT, extract of *A. paniculata* + pongamia oil + Triton X-100, extract of *A. paniculata* + neem oil + Triton X-100, extract of *A. paniculata* + castor oil + Triton X-100, extract of *A. paniculata* + Triton X-100, neem oil + Triton X-100, extract of *A. paniculata* + sunflower oil + Triton X-100 and extract of *A. paniculata* + palm oil + Triton X-100, extract of *A. paniculata* + Triton X-100, neem oil + Triton, pongamia + Triton X-100 showed 100 per cent mortality which did not vary significantly from other treatments *viz.,* sunflower oil + Triton X-100, castor oil + Triton X-100 and palm oil + Triton X-100 with 96.67, 96.67 and 95.00 per cent mortality respectively.

At 10% concentration, castor, neem and pongamia based formulation and extact of *A. paniculata* + Triton X-100 recorded 100 per cent mortality at 24 HAT. This was followed by castor oil + Triton X-100 (95.00%), pongamia oil + Triton X-100 (95.00%), palm based formulation (91.67%), sunflower based formulation (90.00%), neem oil + Triton X-100 (95.00%), pongamia oil + Triton X-100 (95.00%), castor oil + Triton X-100 (86.67%), palm oil+ Triton X-100 (85.00%) and sunflower oil+ Triton X-100 (83.33%) were found to be on par with each other.

At 48 HAT, pongamia, neem and castor oil based formulation, extact of *A. paniculata* + Triton X-100, neem oil + Triton X-100, pongamia oil + Triton X-100 showed superiority over other treatments with 100 per cent mortality. Treatments with sunflower based formulation, palm based formulation, palm oil +

Table 3: Mortality of *Aphis gossypii* treated with oil based formulations of *Andrographis paniculata* (5% concentration)

Treatments	Mortality (%)		
	24 HAT	48 HAT	72 HAT
P E A (90%) + T (10%)	95.00 (79.33)^{b}	100.00 (89.35)^{a}	100.00 (89.35)^{a}
P E A (70%) + sunflower oil (20%) + T (10%)	73.33 (59.00)^{cd}	93.33 (75.24)^{cd}	100.00 (89.35)^{a}
P E A (70%) + palm oil (20%) + T (10%)	76.67 (61.15)^{cd}	93.33 (75.24)^{cd}	100.00 (89.35)^{a}
P E A (70%) + castor oil (20%) + T (10%)	98.33 (85.27)^{ab}	100.00 (89.35)^{a}	100.00 (89.35)^{a}
P E A (70%) + neem oil (20%) + T (10%)	100.00 (89.35)^{a}	100.00 (89.35)^{a}	100.00 (89.35)^{a}
P E A (70%) + pongamia oil (20%) + T (10%)	100.00 (89.35)^{a}	100.00 (89.35)^{a}	100.00 (89.35)^{a}
Sunflower oil (20%) + T (10%)	70 .00 (60.00)^{de}	88.33 (70 .12)^{d}	96.67 (81.17)^{ab}
Palm oil (20%) + T (10%)	56.67 (48.93)^{e}	88.33 (70 .12)^{d}	95.00 (79.33)^{b}
Castor oil (20%) + T (10%)	63.33 (52.91)^{de}	95.00 (79.33)^{bc}	96.67 (81.17)^{ab}
Neem oil (20%) + T (10%)	85.00 (67.71)^{c}	100.00 (89.35)^{a}	100.00 (89.35)^{a}
Pongamia oil (20%) + T (10%)	76.67 (61.15)^{cd}	98.33 (85.27)^{ab}	100.00 (89.35)^{a}
T (10%)	1.67 (4.73)^{f}	6.67 (14.76)^{e}	23.33 (28.85)^{c}
CD (0.05)	(9.654)	(6.450)	(6.665)

(Values in the parentheses are angular transformed)

PEA: Plant extract of *Andrographis paniculata* T: Triton X-100

HAT Hours after treatment

Table 4: Mortality of *Aphis gossypii* treated with oil based formulations of *Andrographis paniculata* (10% concentration)

Treatments	Mortality (%)		
	24 HAT	48 HAT	72 HAT
P E A (90%) + T (10%)	100.00 (89.35)[a]	100.00 (89.35)[a]	100.00 (89.35)[a]
P E A (70%) + sunflower oil (20%) + T (10%)	90.00 (72.53)[bc]	98.33(85.27)[ab]	100.00 (89.35)[a]
P E A (70%) + palm oil (20%) + T (10%)	91.67 (73.40)[bc]	96.67 (81.17)[bc]	100.00 (89.35)[a]
P E A (70%) + castor oil (20%) + T (10%)	100.00 (89.35)[a]	100.00 (89.35)[a]	100.00 (89.35)[a]
P E A (70%) + neem oil (20%) + T (10%)	100.00 (89.35)[a]	100.00 (89.35)[a]	100.00 (89.35)[a]
P E A (70%) + pongamia oil (20%) + T (10%)	100.00 (89.36)[a]	100.00 (89.35)[a]	100.00 (89.35)[a]
Sunflower oil (20%) + T (10%)	83.33 (65.96)[c]	90.00 (71.95)[d]	100.00 (89.35)[a]
Palm oil (20%) + T (10%)	85.00 (67.40)[c]	93.33 (75.24)[cd]	100.00 (89.35)[a]
Castor oil (20%) + T (10%)	86.67 (68.66)[c]	91.67 (73.40)[d]	100.00 (89.35)[a]
Neem oil (20%) + T (10%)	95.00 (79.33)[b]	100.00 (89.35)[a]	100.00 (89.35)[a]
Pongamia oil (20%) + T (10%)	95.00 (79.33) [b]	100.00 (89.35)[a]	100.00 (89.35)[a]
T (10%)	1.67 (4.73)[d]	6.67 (14.76)[e]	23.33 (28.85) [b]
CD (0.05)	(8.644)	(6.063)	(0.967)

(Values in the parentheses are angular transformed)

PEA: Plant extract of *Andrographis paniculata* T: Triton X-100

HAT Hours after treatment

Triton X-100 castor oil + Triton X-100 and Sunflower + Triton X-100 recorded 98.33, 96.67, 93.33, 91.67 and 90.00 per cent mortality respectively.

At 72 HAT, all treatments showed 100 per cent mortality which did not vary significantly from the other treatments.

At 24 HAT, 20% concentration castor, neem and pongamia formulation, extract of *A. paniculata* + Triton X-100, neem oil + Triton X-100 and pongamia oil + Triton X-100 recorded 100 per cent mortality. This was followed by castor oil + Triton X-100 (96.67%), extract of *A. paniculata* + sunflower oil + Triton X-100 (95.00%), extract of *A. paniculata* + palm oil + Triton X-100 (95.00%), palm oil + Triton X-100 (93.33%) and sunflower oil + Triton X-100 (91.67%) and effects of these treatments was statistically on par.

At 48 HAT and 72 HAT all treatments of 20% concentration, there was no significant difference found between treatments.

The three effective treatments (castor, neem and pongamia based formulations) with the 5, 10 and 20% concentration were tested against thrips and mites. 100 per cent mortality was recorded in all the treatments 24 HAT.

4.1.1.2 Efficacy of Lower Doses of Oil Based Formulation of *A. paniculata*

The data on the cumulative per cent mortality of aphids treated with treatments are present in Table 6.

In the observation recorded at 24 HAT, 4% concentration of pongamia oil based formulation recorded 100 per cent mortality were found to be superior over the other treatments and was on par with 4% concentration of neem based formulation of (98.88%), 4% concentration castor oil based formulation (96.67%). This was followed by 3% pongamia oil based formulation (95.00%), neem oil based formulation (93.33%) and castor oil based formulation (88.33%). The treatments with pongamia based formulation at 1, 2 and 3% concentration recorded 85.00, 88.33, 95.00 per cent mortality respectively. At concentrations of 1, 2 and 3%, neem based formulation recorded 83.33, 88.33 and 88.33 per cent

Table 5: Mortality of *Aphis gossypii* treated with oil based formulations of *Andrographis paniculata* (20% concentration)

Treatments	Mortality (%)		
	24 HAT	48 HAT	72 HAT
P E A (90%) + T (10%)	100.00 (89.35)^{a}	100.00 (89.35)^{a}	100.00 (89.35)^{a}
P E A (70%) + sunflower oil (20%) + T (10%)	95.00 (79.33)^{b}	100.00 (89.35)^{a}	100.00 (89.35)^{a}
P E A (70%) + palm oil (20%) + T (10%)	95.00 (79.33)^{b}	100.00 (89.35)^{a}	100.00 (89.35)^{a}
P E A (70%) + castor oil (20%) + T (10%)	100.00 (89.35)^{a}	100.00 (89.35)^{a}	100.00 (89.35)^{a}
P E A (70%) + neem oil (20%) + T (10%)	100.00 (89.35)^{a}	100.00 (89.35)^{a}	100.00 (89.35)^{a}
P E A (70%) + pongamia oil (20%) + T (10%)	100.00 (89.36)^{a}	100.00 (89.35)^{a}	100.00 (89.35)^{a}
Sunflower oil (20%) + T (10%)	91.67 (73.40)^{b}	100.00 (89.35)^{a}	100.00 (89.35)^{a}
Palm oil (20%) + T (10%)	93.33 (75.24)^{b}	100.00 (89.35)^{a}	100.00 (89.35)^{a}
Castor oil (20%) + T (10%)	96.67 (81.17)^{ab}	100.00 (89.35)^{a}	100.00 (89.35)^{a}
Neem oil (20%) + T (10%)	100.00 (89.35)^{a}	100.00 (89.35)^{a}	100.00 (89.35)^{a}
Pongamia oil (20%) + T (10%)	100.00 (89.35)^{a}	100.00 (89.35)^{a}	100.00 (89.35)^{a}
T (10%)	1.67 (4.73)^{c}	6.67 (14.76)^{b}	23.33 (28.85)^{b}
CD (0.05)	(8.231)	(1.403)	(0.967)

(Values in the parentheses are angular transformed)

PEA: Plant extract of *Andrographis paniculata* T: Triton X-100

HAT Hours after treatment

mortality respectively. Castor based formulation at 1, 2 and 3% concentrations showed 66.67, 83.33 and 88.33 per cent mortality respectively at 24 HAT.

At 48 HAT, 3 and 4% concentration pongamia based formulation and 4% concentration of neem based formulation recorded 100 per cent mortality and rest of the treatments were found to be on par with each other.

At 72 hours after spraying, treatments did not vary significantly. All treatments found to be highly effective against chilli aphid with per cent mortality values ranges between 95.00 to 100.00.

4.2 EVALUATION OF EFFECTIVE FORMULATION FOR FIXING THE DOSE.

Based on the laboratory evaluation three treatments were selected for further studies (Plate 6)

1. Plant extract of *A. paniculata* + castor oil + Triton X-100,
2. Plant extract of *A. paniculata* + neem oil + Triton X-100
3. Plant extract of *A. paniculata* + pongamia oil + Triton X-100

The above mentioned treatments were selected for further evaluation in field with thiamethoxam 25% WG and spiromesifen 22.9% SC as chemical check.

4.2.1 Effect of Oil Based Formulations of *A. paniculata* on the population of sucking pests in the Vegetative Stage of the Chilli Crop

Population of the sucking pests *viz.,* chilli thrips (*S. dorsalis*), aphid (*A. gossypii*) and yellow mites (*P. latus*) subsequent to the first round of application of treatments undertaken at 30 days after planting (DAP) were recorded at 1, 3, 5 and 7 days after treatment (DAT).

Plate 6: Formulations selected for field evaluation

T1: Plant extract of *A. paniculata* (70 %) + castor oil (20 %) + Triton x-100 (10 %)

T2: Plant extract of *A. paniculata* (70 %) + neem oil (20 %) + Triton x-100 (10 %)

T3: Plant extract of *A. paniculata* (70 %) + pongamia oil (20 %) + Triton x-100 (10 %)

Table 6: Mortality of *Aphis gossypii* treated with oil based formulations of *Andrographis paniculata* (Lower dose)

Treatments	Concentration (%)	Mortality (%)		
		24 HAT	48 HAT	72 HAT
P E A (70%) + castor oil (20%) + T (10%)	1	66.67 (54.83)^{e}	88.33 (70.12)^{b}	95.00 (77.08)
	2	83.33 (65.95)^{d}	91.67 (73.40)^{b}	96.67 (81.17)
	3	88.33 (70 .12)^{cd}	93.33 (75.24)^{b}	98.333 (85.27)
	4	96.67 (83.43)^{ab}	98.33 (85.27)^{a}	100.00 (89.36)
P E A (70%) + neem oil (20%) + T (10%)	1	83.33 (65.95)^{d}	88.33 (70.12)^{b}	96.67 (81.17)
	2	88.33 (70 .12)^{cd}	93.33 (75.24)^{b}	98.33 (85.27)
	3	93.33 (75.24)^{c}	98.33 (85.27)^{a}	100.00 (89.36)
	4	98.33(85.27)^{a}	100.00 (89.36)^{a}	100.00 (89.36)
P E A (70%) + pongamia oil (20%) + T (10%)	1	85.00 (67.21)^{d}	90.00 (71.57)^{b}	96.67 (81.17)
	2	88.33 (70 .12)^{cd}	93.33 (75.24)^{b}	98.33 (85.27)
	3	95.00 (77.08)^{bc}	100.00 (89.36)^{a}	100.00 (89.36)
	4	100.00 (89.36)^{a}	100.00 (89.36)^{a}	100.00 (89.36)
CD (0.05)		(7.162)	(6.033)	NS

(Values in the parentheses are angular transformed)

PEA: Plant extract of *Andrographis paniculata* T: Triton X-100

HAT Hours after treatment

4.2.1.1 Scirtothrips dorsalis (Chilli thrips)

The population of thrips prior to the application of treatments were found to be homogenous. Mean population of thrips at different intervals after treatment application are presented in the Table 7 and 8.

Significant reduction in the population of thrips over untreated check was observed in all treatments from 1 to 7 days after treatment. In case of higher doses *viz.,* 7, 10, 15 and 20% concentration of castor, neem and pongamia based formulation recorded no population of thrips and gave good control upto 5 days after treatment (DAT) and were found to be superior compared to chemical check thiamethoxam 25% WG and spiromesifen 22.9% SC.

In the case of lower dose, at 1 DAT significant lower population of thrips was recorded in treatments with 5% concentration of castor based formulation (0.55 per leaf), 4 and 5% concentration of neem based formulation 0.55 per leaf and 0.44 per leaf respectively, 5% concentration of pongamia based formulation (0.44 per leaf), thiamethoxam 25% WG (0.55 per leaf) and spiromesifen 22.9% SC (0.55 per leaf). All the above treatments were on par with each other. Thrips population was comparatively high in the untreated plants (10.33 per leaf).

At three DAT, the thrips population was statistically lower in plants sprayed with 5% concentration of pongamia based formulation (0.11 per leaf), 4% and 5% concentration of neem based formulation (0.22 per leaf), 5% concentration of castor based formulation (0.22 per leaf). These treatments were found superior to the chemical check thiamethoxam 25% WG (0.33 per leaf) and spiromesifen 22.9% SC (0.33 per leaf). All other treatments were significantly superior over the untreated control with 10.67 thrips per leaf.

At five DAT, there was no significant difference noticed between treatments, the thrips population remained lower in 5% concentration of pongamia based formulation (0.11 per leaf), 4 and 5% concentration of plant extract of neem based formulation (0.22 per leaf), 5% castor based formulation (0.11 per leaf),

Table 7: Effect of higher dose of formualtions on population of thrips after first spraying

Treatments	Dose (%)	Mean population (Number leaf $^{-1}$)*			
		1 DAT	3 DAT	5 DAT	7 DAT
Plant extract of *A. paniculata* (70%) + castor oil (20%) + Triton X-100 (10%)	7	0.11 $(0.77)^c$	0.00 $(0.70)^c$	0.00 $(0.70)^b$	0.00 $(0.70)^b$
	10	0.11 $(0.77)^c$	0.00 $(0.70)^c$	0.00 $(0.70)^b$	0.00 $(0.70)^b$
	15	0.00 $(0.70)^c$	0.00 $(0.70)^c$	0.11 $(0.77)^b$	0.11 $(0.77)^b$
	20	0.00 $(0.70)^c$	0.00 $(0.70)^c$	0.00 $(0.70)^b$	0.00 $(0.70)^b$
Plant extract of *A. paniculata* (70%) + neem oil (20%) + Triton X-100 (10%)	7	0.00 $(0.70)^c$	0.00 $(0.70)^c$	0.00 $(0.70)^b$	0.00 $(0.70)^b$
	10	0.00 $(0.70)^c$	0.00 $(0.70)^c$	0.00 $(0.70)^b$	0.00 $(0.70)^b$
	15	0.00 $(0.70)^c$	0.00 $(0.70)^c$	0.00 $(0.70)^b$	0.00 $(0.70)^b$
	20	0.00 $(0.70)^c$	0.00 $(0.70)^c$	0.00 $(0.70)^b$	0.00 $(0.70)^b$
Plant extract of *A. paniculata* (70%) + pongamia oil (20%) + Triton X-100 (10%)	7	0.00 $(0.70)^c$	0.00 $(0.70)^c$	0.00 $(0.70)^b$	0.11 $(0.77)^b$
	10	0.00 $(0.70)^c$	0.00 $(0.70)^c$	0.00 $(0.70)^b$	0.00 $(0.70)^b$
	15	0.00 $(0.70)^c$	0.00 $(0.70)^c$	0.00 $(0.70)^b$	0.00 $(0.70)^b$
	20	0.00 $(0.70)^c$	0.00 $(0.70)^c$	0.00 $(0.70)^b$	0.00 $(0.70)^b$
Thiamethoxam 25% WG	50 g a.i ha^{-1}	0.55 $(0.99)^b$	0.33 $(0.90)^b$	0.11 $(0.77)^b$	0.11 $(0.77)^b$
Spiromesifen 22.9% SC	96 g a.i ha^{-1}	0.55 $(0.99)^b$	0.33 $(0.90)^b$	0.83 $(0.22)^b$	0.22 $(0.84)^b$
Control		10.33 $(3.29)^a$	10.67 $(3.34)^a$	11.33 $(3.43)^a$	11.44 $(3.45)^a$
CD (0.05)		(0.214)	(0.116)	(0.126)	(0.138)

*Mean of 3 replications comprising 3 plants each (Values in the parentheses are square root transformed) DAT: Days after treatment

Table 8: Effect of lower dose of formulations on population of thrips after first spraying

Treatments	Dose (%)	Mean population (Number leaf $^{-1}$)*			
		I DAT	3 DAT	5 DAT	7 DAT
Plant extract of *A. paniculata* (70%) + castor oil (20%) + Triton X-100 (10%)	1	1.56 (1.35)^{bc}	0.89 (1.16)^{bc}	0.06 (1.03)^{b}	0.45 (0.96)^{b}
	2	1.56 (1.42)^{b}	1.11 (1.25)^{b}	0.44 (0.96)^{b}	0.44 (0.96)^{b}
	3	0.89 (1.17)^{bc}	0.33 (0.89)^{bc}	0.33 (0.89)^{b}	0.44 (0.96)^{b}
	4	0.78 (1.12)^{bc}	0.33 (0.89)^{bc}	0.22 (0.84)^{b}	0.22 (0.84)^{b}
	5	0.55 (0.99)^{bc}	0.22 (0.84)^{cd}	0.11 (0.77)^{b}	0.11 (0.77)^{b}
Plant extract of *A. paniculata* (70%) + neem oil (20%) + Triton X-100 (10%)	1	0.78 (1.12)^{bc}	0.78 (1.08)^{bc}	0.44 (0.96)^{b}	0.33 (0.89)^{b}
	2	1.00 (1.19)^{bc}	0.78 (0.96)^{bc}	0.11 (0.84)^{b}	0.22 (0.84)^{b}
	3	0.78 (1.21)^{bc}	0.78 (1.09)^{bc}	0.44 (0.89)^{b}	0.33 (0.89)^{b}
	4	0.55 (0.99)^{bc}	0.22 (0.99)^{bc}	0.22 (0.84)^{b}	0.22 (0.84)^{b}
	5	0.44 (0.95)^{c}	0.22 (0.84)^{cd}	0.22 (0.83)^{b}	0.11 (0.77)^{b}
Plant extract of *A. paniculata* (70%) + pongamia oil (20%) + Triton X-100 (10%)	1	0.78 (1.00)^{bc}	0.55 (1.02)^{bc}	0.33 (0.89)^{b}	0.22 (0.84)^{b}
	2	0.89 (1.16)^{bc}	0.44 (0.95)^{bc}	0.22 (0.84)^{b}	0.22 (0.84)^{b}
	3	0.78 (1.12)^{bc}	0.33 (0.89)^{bc}	0.33 (0.89)^{b}	0.33 (0.89)^{b}
	4	0.67 (1.05)^{bc}	0.55 (0.99)^{bc}	0.33 (0.89)^{b}	0.22 (0.84)^{b}
	5	0.44 (0.95)^{c}	0.11 (0.77)^{d}	0.11 (0.77)^{b}	0.11 (0.77)^{b}
Thiamethoxam 25% WG	50 g a.i ha^{-1}	0.55 (0.99)^{bc}	0.33 (0.89)^{bc}	0.11 (0.77)^{b}	0.11 (0.77)^{b}
Spiromesifen 22.9% SC	96 g a.i ha^{-1}	0.55 (0.99)^{bc}	0.33 (0.89)^{bc}	0.22 (0.83)^{b}	0.22 (0.83)^{b}
Control		10.33 (3.20)^{a}	10.67 (3.35)^{a}	11.33 (3.43)^{a}	11.44 (3.45)^{a}
CD (0.05)		(0.464)	(0.363)	(0.249)	(0.230)

*Mean of 3 replications comprising 3 plants each (Values in the parentheses are square root transformed) DAT: Days after treatment

thiamethoxam 25% WG (0.11 per leaf) and spiromesifen 22.9% SC (0.22 per leaf). Untreated plants recorded 11.33 thrips per leaf.

On the seventh day of spraying, the thrips population showed the same trend as in the fifth day where treatments with thiamethoxam 25% WG (0.11 per leaf), spiromesifen 22.9% SC (0.22 per leaf), 5% concentration of castor, neem and pongamia based formulations (0.11 per leaf) recorded low population of thrips. Rest of the treatments recorded thrips population ranging from 0.22 to 0.45 per leaf. Untreated plants recorded a population of 11.44 thrips per leaf.

4.2.1.2 Aphis gossypii (Chilli aphid)

The aphid population decreased slightly during the period of observation taken during first spray. Mean population of chilli aphid at different intervals after treatment application are presented in the Table 9 and 10.

Higher doses of 7, 10, 15 and 20% concentration of castor, neem and pongamia based formulation recorded no population of aphids and was found to be superior compared to chemical check thiamethoxam 25% WG and spiromesifen 22.9% SC.

At one DAT, 5% concentration of pongamia based formulation (5.11 per leaf), thiamethoxam 25% WG (5.89 per leaf) and spiromesifen 22.9% SC (5.55 per leaf) recorded lower aphids population and superior than other treatments. Highest population of aphids recorded in untreated control (24.67 per leaf).

On third DAT, aphid population remained lower in 2, 4 and 5% concentration of pongamia oil based formulation (4.44 , 4.33 and 4.45 aphids per leaf respectively) followed by 5 % concentration neem oil based formulation (4.22 per leaf) and castor oil based formulation at 4 and 5% concentration (4.33 and 4.45 per leaf respectively). All the above treatments found to be superior compared to the chemical check. All the treatments were significantly superior over the untreated control which showed a high population of 27.11 aphids per leaf.

Table 9: Effect of higher dose of formulations on population of aphid after first spraying

Treatments	Dose (%)	Mean population (Number leaf $^{-1}$)*			
		I DAT	3 DAT	5 DAT	7 DAT
Plant extract of *A. paniculata* (70%) + castor oil (20%) + Triton X-100 (10%)	7	1.33 (1.34)^{c}	0.44 (0.95)^{c}	0.11 (0.77)^{c}	0.11 (0.77)^{bc}
	10	0.67 (1.05)^{cd}	0.33 (0.88)^{cd}	0.00 (0.70)^{c}	0.00 (0.70)^{c}
	15	0.00 (0.70)^{e}	0.00 (0.70)^{d}	0.00 (0.70)^{c}	0.00 (0.70)^{c}
	20	0.00 (0.70)^{e}	0.00 (0.70)^{d}	0.00 (0.70)^{c}	0.00 (0.70)^{c}
Plant extract of *A. paniculata* (70%) + neem oil (20%) + Triton X-100 (10%)	7	0.56 (1.01)^{de}	0.11 (0.77)^{cd}	0.00 (0.70)^{c}	0.00 (0.70)^{c}
	10	0.22 (0.84)^{de}	0.00 (0.70)^{d}	0.00 (0.70)^{c}	0.00 (0.70)^{c}
	15	0.00 (0.70)^{e}	0.00 (0.70)^{d}	0.11 (0.77)^{c}	0.00 (0.70)^{c}
	20	0.00 (0.70)^{e}	0.00 (0.70)^{d}	0.00 (0.70)^{c}	0.00 (0.70)^{c}
Plant extract of *A. paniculata* (70%) + pongamia oil (20%) + Triton X-100 (10%)	7	0.22 (0.84)^{de}	0.11 (0.77)^{cd}	0.11 (0.77)^{c}	0.00 (0.70)^{c}
	10	0.11 (0.77)^{de}	0.11 (0.77)^{cd}	0.00 (0.70)^{c}	0.00 (0.70)^{c}
	15	0.00 (0.70)^{e}	0.00 (0.70)^{d}	0.00 (0.70)^{c}	0.00 (0.70)^{c}
	20	0.00 (0.70)^{cd}	0.00 (0.70)^{d}	0.00 (0.70)^{c}	0.00 (0.70)^{c}
Thiamethoxam 25% WG	50 g a.i ha^{-1}	5.89 (2.53)^{b}	5.11 (2.36)^{b}	0.77 (1.12)^{b}	0.44 (0.95)^{b}
Spiromesifen 22.9% SC	96 g a.i ha^{-1}	5.55 (2.45)^{b}	5.22 (2.39)^{b}	1.00 (1.18)^{b}	0.44 (0.95)^{b}
Control		24.67 (5.02)^{a}	27.11 (5.25)^{a}	31.22 (5.63)^{a}	35.22 (5.97)^{a}
CD (0.05)		(0.309)	(0.230)	(0.252)	(0.200)

*Mean of 3 replications comprising 3 plants each (Values in the parentheses are square root transformed) DAT: Days after treatment

Table 10: Effect of lower dose of formulations on population of aphids after first spraying

Treatments	Dose (%)	Mean population (Number leaf $^{-1}$)*			
		I DAT	3 DAT	5 DAT	7 DAT
Plant extract of *A. paniculata* (70%) + castor oil (20%) + Triton X-100 (10%)	1	11.22 (3.34)^{bc}	6.78 (2.50)^{b}	5.22 (2.38)^{b}	4.33 (2.10)^{b}
	2	11.11 (3.32)^{bcd}	5.89 (2.41)^{bc}	4.06 (2.14)^{bc}	2.22 (1.65)^{cde}
	3	13.00 (3.59)^{b}	5.45 (2.33)^{bcde}	3.83 (2.09)^{bcd}	2.89 (1.85)^{cd}
	4	8.33 (2.89)^{def}	4.45 (2.10)^{de}	3.50 (1.99)^{bcd}	3.06 (1.89)^{bc}
	5	7.00 (2.65)^{fgh}	4.33 (2.09)^{e}	2.83 (1.71)^{def}	0.78 (1.12)^{fg}
Plant extract of *A. paniculata* (70%) + neem oil (20%) + Triton X-100 (10%)	1	7.22 (2.68)^{fgh}	5.89 (2.43)^{bc}	3.89 (2.09)^{bcd}	2.67 (1.77)^{cd}
	2	9.78 (3.12)^{cde}	5.78 (2.41)^{bcd}	3.33 (1.95)^{cde}	2.44 (1.62)^{cd}
	3	7.34 (2.69)^{efgh}	5.11 (2.26)^{cde}	2.50 (1.73)^{def}	2.11 (1.35)^{cde}
	4	7.90 (2.78)^{efg}	4.78 (2.18)^{cde}	2.00 (1.56)^{efg}	1.33 (1.05)^{ef}
	5	9.78 (2.57)^{fgh}	4.22 (2.06)^{e}	1.78 (1.49)^{fgh}	0.67 (1.05)^{fg}
Plant extract of *A. paniculata* (70%) + pongamia oil (20%) + Triton X-100 (10%)	1	7.00 (3.12)^{cde}	5.22 (2.28)^{cde}	2.72 (1.781)^{cde}	1.89 (1.53)^{de}
	2	6.89 (2.64)^{fgh}	4.44 (2.11)^{e}	2.83 (1.81)^{cde}	2.00 (1.58)^{cde}
	3	6.67 (2.63)^{fgh}	5.11 (2.26)^{cde}	2.56 (1.74)^{cde}	1.89 (1.53)^{de}
	4	6.67 (2.58)^{fgh}	4.45 (2.10)^{de}	1.33 (1.35)^{ghi}	1.83 (1.52)^{de}
	5	5.11 (2.26)^{h}	4.33 (2.09)^{e}	1.11 (1.21)^{hi}	0.33 (0.88)^{g}
Thiamethoxam 25% WG	50 g a.i ha^{-1}	5.89 (2.42)^{gh}	5.11 (2.25)^{cde}	0.78 (1.12)^{i}	0.43 (0.95)^{g}
Spiromesifen 22.9% SC	96 g a.i ha^{-1}	5.55 (2.34)^{gh}	5.22 (2.28)^{cde}	1.00 (1.18)^{hi}	0.44 (0.95)^{g}
Control		24.67 (4.97)^{a}	27.11 (5.21)^{a}	31.22 (5.63)^{a}	35.22 (5.98)^{a}
CD (0.05)		(0.447)	(0.297)	(0.403)	(0.346)

*Mean of 3 replications comprising 3 plants each (Values in the parentheses are square root transformed) DAT: Days after treatment

The aphid population declined at fifth DAT. The population of aphids was significantly lower in the chemical check, thiamethoxam 25% WG (0.78 per leaf) and spiromesifen 22.9% SC (1.00 per leaf). The lowest population of aphids were recorded in 4 and 5% concentration of pongamia based formulation (1.33 per leaf) and (1.11 per leaf). Highest population of aphids recorded in untreated control plants (31.22 per leaf).

At seven DAT, lowest population of aphid were recorded in 5% concentration of pongamia based formulation (0.33 per leaf) which is found to be statistically similar with thiamethoxam 25% WG (0.43 per leaf) and spiromesifen 22.9% SC (0.44 per leaf). All the above treatments were on par with each other. The population of aphids was significantly low in the rest of the treatments than the untreated check which had the highest population of 35.22 per leaf.

4.2.1.3 Polyphagotarsonemus latus (Yellow mite)

The population of chilli thrips prior to the application of treatments were found to be homogenous. Mean population of chilli mites at different intervals after treatment are presented in Table 11 and 12.

Higher concentration (7, 10, 15 and 20%) of castor, neem and pongamia based formulation recorded no population of mite at 1 DAT, which shown 100 reduction in the population of mites upto 7 DAT and found to be superior compared to chemical check thiamethoxam 25% WG and spiromesifen 22.9% SC.

In case of lower doses, 5% concentration of pongamia based formulation treated plants exhibited significantly low mite population (5.11 per leaf) was observed one DAT, which is found to be on par with spiromesifen 22.9% SC (5.55 per leaf) and thiamethoxam 25% WG (5.89 per leaf). The other treatments were also found to be on par with other population ranging from 6.67 to 11.22 mites per leaf. The population of mites was significantly low in all the treatments than the untreated check which had the highest population of 28.33 mites per leaf.

Table 11: Effect of higher dose of formulations on population of mites after first spraying

Treatments	Dose (%)	Mean population (Number leaf $^{-1}$)*			
		I DAT	3 DAT	5 DAT	7 DAT
Plant extract of *A. paniculata* (70%) + castor oil (20%) + Triton X-100 (10%)	7	0.22 (0.83)^{c}	0.00 (0.70)^{d}	0.11 (0.77)^{c}	0.00 (0.70)^{d}
	10	0.00 (0.70)^{c}	0.00 (0.70)^{d}	0.00 (0.70)^{c}	0.11 (0.77)^{cd}
	15	0.00 (0.70)^{c}	0.00 (0.70)^{d}	0.00 (0.70)^{c}	0.00 (0.70)^{d}
	20	0.00 (0.70)^{c}	0.00 (0.70)^{d}	0.00 (0.70)^{c}	0.00 (0.70)^{d}
Plant extract of *A. paniculata* (70%) + neem oil (20%) + Triton X-100 (10%)	7	0.22 (0.84)^{c}	0.00 (0.70)^{d}	0.00 (0.70)^{c}	0.11 (0.77)^{cd}
	10	0.00 (0.70)^{c}	0.00 (0.70)^{d}	0.00 (0.70)^{c}	0.00 (0.70)^{d}
	15	0.00 (0.70)^{c}	0.00 (0.70)^{d}	0.00 (0.70)^{c}	0.00 (0.70)^{d}
	20	0.00 (0.70)^{c}	0.00 (0.70)^{d}	0.00 (0.70)^{c}	0.00 (0.70)^{d}
Plant extract of *A. paniculata* (70%) + pongamia oil (20%) + Triton X-100 (10%)	7	0.33 (0.88)^{c}	0.00 (0.70)^{d}	0.00 (0.70)^{c}	0.22 (0.84)^{bcd}
	10	0.00 (0.70)^{c}	0.00 (0.70)^{d}	0.00 (0.70)^{c}	0.00 (0.70)^{d}
	15	0.00 (0.70)^{c}	0.00 (0.70)^{d}	0.00 (0.70)^{c}	0.00 (0.70)^{d}
	20	0.00 (0.70)^{c}	0.00 (0.70)^{d}	0.00 (0.70)^{c}	0.00 (0.70)^{d}
Thiamethoxam 25% WG	50 g a.i ha^{-1}	5.68 (2.48)^{b}	2.67 (1.77)^{b}	1.11 (1.26)^{b}	0.61 (1.03)^{bc}
Spiromesifen 22.9% SC	96 g a.i ha^{-1}	4.89 (2.31)^{b}	2.00 (1.56)^{c}	0.78 (1.12)^{b}	0.67 (1.05)^{b}
Control		28.33 (5.36)^{a}	29.61 (5.49)^{a}	32.90 (5.79)^{a}	34.89 (5.94)^{a}
CD (0.05)		(0.252)	(0.158)	(0.133)	(0.264)

*Mean of 3 replications comprising 3 plants each (Values in the parentheses are square root transformed) DAT: Days after treatment

At three DAT, treatment with 5% concentration of pongamia oil based formulation (4.33 per leaf), 5% concentration of neem oil based formulation (4.22 per leaf) and 5% concentration of pongamia oil based formulation (4.22 per leaf) recorded significant low population of mite. Rest of the treatments were found to be on par with each other with mite population ranging from 4.45 to 6.78 mites per leaf. The population of mites was maximum in untreated plants (27.11 per leaf).

At five DAT, Spiromesifen 22.9% SC (0.78 per leaf) recorded lowest mite population which are significantly on par from the treatments, thiamethoxam 25% WG (1.00 per leaf) and 5% concentration of pongamia based formulation (1.11 per leaf). All treatments significantly differed from the untreated plants (31.22 mites per leaf).

The population of mites was significantly lower in 5% concentration of pongamia based formulation (0.33 per leaf), thiamethoxam 25% WG (0.43 per leaf) and spiromesifen 22.9% SC (0.44 per leaf), than all the treatments at seven DAT followed by neem and castor based formulation at 5% concentration with mite population of 0.67 and 0.78 per leaf respectively. All treatments significantly differed from the untreated plants (34.89 mites per leaf).

4.2.1 Effect of Oil Based Formulation of *A. paniculata* on the population of sucking pests in the Reproductive Stage of the Chilli Crop

Second round of application of treatments in the reproductive stage of the crop was given at 60 DAP and the population of the sucking pests were recorded at 1, 3, 5 and 7 days after treatment application.

4.2.2.1 Scirtothrips dorsalis (Chilli thrips)

The population of thrips prior to the treatment application were found to be uniform. Mean population of thrips at different intervals after application of the treatments are presented in Table 13. Significant reduction in the thrips population

Table 12: Effect of lower dose of formulations on population of mites after first spraying

Treatments	Dose (%)	Mean population (Number leaf $^{-1}$)*			
		I DAT	3 DAT	5 DAT	7 DAT
Plant extract of *A. paniculata* (70%) + castor oil (20%) + Triton X-100 (10%)	1	10.00 (3.16)^{a}	8.11 (2.85)^{b}	3.22 (1.76)^{bcd}	2.22 (1.65)^{b}
	2	7.67 (2.77)^{cd}	6.22 (2.49)^{cde}	3.90 (2.00)^{b}	1.89 (1.53)^{bc}
	3	7.56 (2.74)^{cde}	5.89 (2.42)^{cde}	3.55 (1.88)^{bc}	1.67 (1.46)^{bcd}
	4	7.11 (2.66)^{def}	5.67 (2.37)^{cdef}	2.22 (1.48)^{cdef}	1.45 (1.39)^{bcde}
	5	6.67 (2.58)^{defg}	4.45 (2.09)^{fgh}	1.78 (1.32)^{defg}	0.78 (1.10)^{def}
Plant extract of *A. paniculata* (70%) + neem oil (20%) + Triton X-100 (10%)	1	8.89 (2.98)^{bc}	6.44 (2.53)^{cd}	3.22 (1.76)^{bcd}	1.11 (1.26)^{cdef}
	2	7.67 (2.77)^{cd}	6.45 (2.54)^{cd}	2.67 (1.60)^{bcde}	1.45 (1.39)^{bcde}
	3	7.45 (2.72)^{cde}	4.89 (2.21)^{efg}	2.44 (1.55)^{bcde}	1.25 (1.32)^{bcdef}
	4	7.56 (2.74)^{cde}	4.45 (2.11)^{fgh}	2.33 (1.48)^{cdef}	1.14 (1.28)^{cdef}
	5	6.22 (2.49)^{efg}	4.22 (2.06)^{gh}	1.33 (1.13)^{efg}	1.11 (1.26)^{cdef}
Plant extract of *A. paniculata* (70%) + pongamia oil (20%) + Triton X-100 (10%)	1	7.67 (2.76)^{cde}	6.56 (2.56)^{bc}	3.44 (1.84)^{bc}	1.67 (1.46)^{bcd}
	2	7.56 (2.54)^{cde}	5.89 (2.420)^{cde}	2.89 (1.63)^{bcd}	1.58 (1.43)^{bcd}
	3	6.45 (2.54)^{defg}	5.11 (2.25)^{defg}	2.67 (1.62)^{bcd}	1.25 (1.31)^{bcdef}
	4	5.89 (2.42)^{fgh}	3.44 (1.84)^{hi}	2.11 (1.41)^{cdef}	0.92 (1.18)^{cdef}
	5	5.89 (2.42)^{fgh}	2.78 (1.650)^{ij}	2.33 (1.52)^{bcde}	0.58 (1.02)^{f}
Thiamethoxam 25%WG	50 g a.i ha^{-1}	5.67 (2.37)^{gh}	2.67 (1.62)^{ij}	1.11 (1.04)^{fg}	0.61 (1.02)^{ef}
Spiromesifen 22.9% SC	96 g a.i ha^{-1}	4.89 (2.20)^{h}	2.00 (1.38)^{j}	0.78 (0.88)^{g}	0.67 (1.05)^{ef}
Control		28.33 (5.32)^{a}	29.61 (5.44)^{a}	32.90 (5.74)^{a}	34.89 (5.96)^{a}
CD (0.05)		(0.268)	(0.303)	(0.481)	(0.373)

*Mean of 3 replications comprising 3 plants each (Values in the parentheses are square root transformed) DAT: Days after treatment

over untreated check was observed in all the treatments from 1 to 7 days after treatment.

Significant lower population of thrips was recorded in chemical check of spiromesifen 22.9% SC (0.00 per leaf) and thiamethoxam 25% WG (0.44 per leaf) at 1 DAT. Rest of the treatments recorded thrips population ranging from 0.78 to 1.56 thrips per leaf though inferior to the chemical check. The untreated plants exhibited significantly higher population of 10.45 thrips per leaf.

On third DAT, thiamethoxam 25% WG and spiromesifen 22.9% SC were recorded 0.33 per leaf showed superiority over other treatments followed by pongamia and neem based formulation at 5% concentration with mean population 0.44 and 0.33 thrips per leaf followed by castor based formulation at 4 and 5% concentration with mean population of 0.44 thrips per leaf. Rest of the treatments recorded thrips population ranging from 0.55 to 1.11 thrips per leaf. The untreated plants recorded a population of 10.89 thrips per leaf.

On fifth DAT, spiromesifen 22.9% SC and thiamethoxam 25% WG recorded 0.00 thrips per leaf followed by 5% concentration of pongamia and neem based formulation (0.22 per leaf). The other treatments were also found to be on par with other population ranging from 0.33 to 0.56 thrips per leaf. Untreated plants recorded 11.44 thrips per leaf.

At seven DAT, significantly lower population of thrips was recorded in spiromesifen 22.9% SC (0.00 per leaf) followed by thiamethoxam 25% WG (0.00 per leaf), 4 and 5% concentration of pongamia and neem based formulation with mean population of 0.11 thrips per leaf. Rest of the treatments found to be on par with each other with thrips population ranging from 0.22 to 0.56 per leaf. The population in untreated check during the same period was 11.44 thrips per leaf.

4.2.2.2 Aphis gossypii (Chilli aphid)

Mean population of chilli aphids at different intervals after spraying are presented in Table 14.

Table 13: Effect of formulations on population of thrips after second spraying

Treatments	Dose (%)	Mean population (Number leaf $^{-1}$)*			
		I DAT	3 DAT	5 DAT	7 DAT
Plant extract of *A. paniculata* (70%) + castor oil (20%) + Triton X-100 (10%)	1	1.44 (1.38)^{b}	0.89 (1.17)^{bcd}	0.56 (1.03)^{bc}	0.44 (0.97)^{bc}
	2	1.33 (1.35)^{b}	0.67 (1.07)^{bcde}	0.44 (0.97)^{bc}	0.33 (0.91)^{bcd}
	3	1.22 (1.30)^{b}	0.67 (1.07)^{bcde}	0.33 (0.90)^{cd}	0.22 (0.84)^{bcd}
	4	0.78 (1.12)^{bc}	0.44 (0.97)^{de}	0.33 (0.91)^{cd}	0.22 (0.83)^{bcd}
	5	0.78 (1.12)^{bc}	0.44 (0.97)^{de}	0.33 (0.91)^{cd}	0.22 (0.84)^{bcd}
Plant extract of *A. paniculata* (70%) + neem oil (20%) + Triton X-100 (10%)	1	1.56 (1.42)^{b}	0.78 (1.12)^{bcde}	0.56 (1.03)^{bc}	0.33 (0.91)^{bcd}
	2	1.33 (1.35)^{b}	0.67 (1.07)^{bcde}	0.55 (1.02)^{bc}	0.22 (0.84 ^{bcd}
	3	1.11 (1.26)^{bc}	0.67 (1.07)^{bcde}	0.33 (0.90)^{cd}	0.22 (0.84)^{bcd}
	4	0.89 (1.17)^{bc}	0.55 (1.02)^{cde}	0.33 (0.90)^{cd}	0.11 (0.77)^{cd}
	5	0.78 (1.10)^{bc}	0.33 (0.90)^{ef}	0.22 (0.83)^{cd}	0.11 (0.77)^{cd}
Plant extract of *A. paniculata* (70%) + pongamia oil (20%) + Triton X-100 (10%)	1	1.44 (1.38)^{b}	1.11 (1.26)^{b}	0.89 (1.17)^{b}	0.56 (1.01)^{b}
	2	1.22 (1.31)^{b}	0.78 (1.13)^{bcde}	0.44 (0.97)^{bc}	0.33 (0.91)^{bcd}
	3	1.22 (1.30)^{b}	1.11 (1.25)^{bc}	0.44 (0.97)^{bc}	0.22 (0.84)^{bcd}
	4	1.33 (1.35)^{b}	1.00 (1.22)^{bc}	0.44 (0.97)^{bc}	0.11 (0.77)^{cd}
	5	0.78 (1.08)^{bc}	0.44 (0.97)^{de}	0.22 (0.84)^{cd}	0.11 (0.77)^{cd}
Thiamethoxam 25% WG	50 g a.i ha^{-1}	0.44 (0.92)^{cd}	0.33 (0.90)^{ef}	0.00 (0.70)^{d}	0.00 (0.70)^{d}
Spiromesifen 22.9% SC	96 g a.i ha^{-1}	0.00 (0.70)^{d}	0.33 (0.70)^{f}	0.00 (0.70)^{d}	0.00 (0.70)^{d}
Control		10.45 (3.30)^{a}	10.89 (3.38)^{a}	11.44 (3.45)^{a}	11.44 (3.46)^{a}
CD (0.05)		(0.356)	(0.241)	(0.217)	(0.215)

*Mean of 3 replications comprising 3 plants each (Values in the parentheses are square root transformed) DAT: Days after treatment

At one DAT, spiromesifen 22.9% SC (2.33 per leaf), thiamethoxam 25% WG (4.00 per leaf) treated plants exhibited significant low aphid population followed by 3 and 5% concentration of neem based formulation with (6.67 and 6.33 per leaf respectively), pongamia and castor based formulation at 5% concentration with 7.33 and 7.44 per leaf respectively. Aphid population ranged from 7.78 to 10.33 per leaf in all other treatments except untreated plants which had a higher population of 21.44 per leaf.

Significant superiority of the treatments over untreated control (26.00 per leaf) was evident at three DAT. Lowest aphid population of (2.00 per leaf) was recorded in plants treated with spiromesifen 22.9% (0.33 per leaf) followed by 5% concentration of castor oil based formulation recorded 2.00 per leaf. Aphid population significantly reduced in all other treatments values ranges from 2.33 to 5.33 aphids per leaf.

On five DAT, plants that received various treatments harboured significantly lower population of aphid than that in untreated plants (34.33 per leaf). The lowest mean population was observed in spiromesifen 22.9% (0.11 per leaf) which is found to be on par with thiamethoxam 25% WG (0.78 per leaf) and 5% concentration of castor based formulation (1.22 per leaf). Rest of the treatments also recorded significant reduction in the aphid population. Untreated plants recorded aphid population of 34.33 aphids per leaf.

Significant difference in the mean population of aphid between treated and untreated plots (45.00 per leaf) was observed on seven days after treatment application. Among the treated plants, spiromesifen 22.9% (0.00 per leaf) contained the no population, which are on par with that in the 5% concentration pongamia based formulation and thiamethoxam recorded 0.33 per leaf followed by 5% concentration of neem and castor formulation with 0.44 per leaf. Aphid population significantly reduced in all other treatments values ranges from 1.00 to 2.67 aphids per leaf.

Table 14: Effect of formulations on population of aphids after second spraying

Treatments	Dose (%)	Mean population (Number leaf $^{-1}$)*			
		I DAT	3 DAT	5 DAT	7 DAT
Plant extract of *A. paniculata* (70%) + castor oil (20%) + Triton X-100 (10%)	1	9.11 (3.00)^{bc}	5.00 (2.34)^{b}	4.00 (2.11)bc	2.67 (1.74)^{b}
	2	8.00 (2.81)^{bcd}	4.56 (2.24)^{bc}	3.17 (1.91)^{bcde}	1.67 (1.44)^{bc}
	3	8.33 (2.89)^{bcd}	3.67 (2.01)^{bcd}	1.44 (1.37)^{defg}	0.44 (0.95)^{cd}
	4	8.00 (2.83)^{bcd}	3.11 (1.87)^{bcd}	1.67 (1.44)^{cdefg}	1.00 (1.18)^{bcd}
	5	7.44 (2.72)^{cd}	2.00 (1.56)^{d}	1.22 (1.23)^{efg}	0.44 (0.95)^{cd}
Plant extract of *A. paniculata* (70%) + neem oil (20%) + Triton X-100 (10%)	1	10.33 (3.22)^{b}	4.67 (2.25)^{bc}	3.55 (1.98)^{bcd}	2.28 (1.65)^{b}
	2	8.00 (2.83)^{bcd}	4.00 (2.11)^{bcd}	3.67 (2.00)^{bcd}	2.17 (1.61)^{b}
	3	6.67 (2.58)^{d}	3.67 (2.03)^{bcd}	3.11 (1.86)^{bcde}	1.67 (1.44)^{bc}
	4	7.22 (2.69)^{cd}	3.67 (2.02)^{bcd}	2.67 (1.71)^{bcdef}	1.11 (1.24)^{bcd}
	5	6.333 (2.52)^{d}	3.22 (1.92)^{bcd}	2.00 (156)^{bcdef}	0.44 (0.95)^{cd}
Plant extract of *A. paniculata* (70%) + pongamia oil (20%) + Triton X-100 (10%)	1	10.00 (3.16)^{b}	5.33 (2.39)^{b}	4.22 (2.14)^{b}	1.55 (1.36)^{bc}
	2	8.67 (2.93)^{bcd}	5.11 (2.35)^{b}	3.78 (2.04)^{bcd}	2.00 (1.56)^{b}
	3	8.44 (2.91)^{bcd}	4.67 (2.23)^{bc}	3.00 (1.82)^{bcde}	1.00 (1.18)^{bcd}
	4	7.78 (2.78)^{bcd}	3.89 (2.04)^{bcd}	3.00 (1.84)^{bcde}	1.44 (1.38)^{bc}
	5	7.33 (2.71)^{cd}	2.67 (1.74)^{bcd}	1.78 (1.49)^{bcdef}	0.33 (0.88)^{cd}
Thiamethoxam 25% WG	50 g a.i ha^{-1}	4.00 (1.89)^{e}	2.33 (1.64)^{cd}	0.78 (1.06)^{fg}	0.33 (0.88)^{cd}
Spiromesifen 22.9% SC	96 g a.i ha^{-1}	2.33 (1.52)^{e}	0.33 (0.88)^{e}	0.11 (1.77)^{g}	0.00 (0.70)^{d}
Control		21.44 (4.63)^{a}	26.00 (5.15)^{a}	34.33 (5.89)^{a}	45.00 (6.74)^{a}
CD (0.05)		(0.427)	(0.643)	(0.694)	(0.595)

*Mean of 3 replications comprising 3 plants each (Values in the parentheses are square root transformed) DAT: Days after treatment

4.2.2.3 Polyphagotarsonemus latus (Yellow mite)

The pretreatment population of mites was not significant. Mean population of chilli mites at different intervals after treatments are presented in Table 15.

On first DAT, there was significant difference between treated and untreated plants (21.46 per leaf). Thiamethoxam 25% WG and spiromesifen 22.9% SC treated plants recorded lowest mite population of 3.67 per leaf which were statistically similar to that in 3, 4 and 5% pongamia oil based formulation with 4.00, 4.33 and 4.00 per leaf respectively, followed by 4 and 5% concentration neem oil based formulation recorded 4.33 and 4.00 mites per leaf.

Significant difference in the mean population of aphid between treated and untreated plots (24.11 per leaf) was observed on three days after treatment application. The lowest population of mite (2.00 per leaf) was recorded in thiamethoxam 25% WG treated plants which were found to be on par with spiromesifen 22.9% SC (2.22 per leaf), 4 and 5% concentration of pongamia oil based formulation (2.33 per leaf) and 4 and 5% concentration of neem based formulation (2.67 per leaf). Mite population reduced in all the other treatments also and whose mean population ranges from 3.67 to 6.11 per leaf.

Spiromesifen 22.9% SC recorded lowest population of mites (0.67 per leaf) on five DAT followed by thiamethoxam 25% WG (1.11 per leaf) and 5% concentration of pongamia based formulation (1.33 per leaf). Mite population ranged from 1.92 to 4.22 per leaf in all other treatments except in untreated control (29.11 per leaf).

At seven DAT, spiromesifen 22.9% SC treated plants had no population of mites followed by thiamethoxam 25% WG, 5 % concentration of pongamia based formulation and 3, 4 and 5% concentration of neem oil based formulation recorded mean population of 0.11, 0.55, 0.58, 0.58 and 0.56 mites respectively. Rest of the treatments also recorded significant reduction of mite population ranging from 0.83 to 2.56 per leaf. Untreated plants recorded mite population of 33.78 per leaf.

Table 15: Effect of formulations on population of mites after second spraying

Treatments	Dose (%)	Mean population (Number leaf $^{-1}$)*			
		I DAT	3 DAT	5 DAT	7 DAT
Plant extract of *A. paniculata* (70%) + castor oil (20%) + Triton X-100 (10%)	1	8.89 (2.98)^{b}	6.11 (2.46)^{bc}	3.89 (2.09)^{bc}	2.56 (1.74)^{b}
	2	8.22 (2.87)^{bc}	6.44 (2.53)^{b}	3.44 (1.96)^{bcd}	2.33 (1.64)^{bc}
	3	6.11 (2.47)^{bcde}	5.78 (2.40)^{bcde}	3.44 (1.96)^{bcd}	2.33 (1.64)^{bc}
	4	5.67 (2.38)^{cdef}	5.00 (2.22)^{bdce}	3.89 (2.09)^{bc}	1.58 (1.43)^{bcde}
	5	5.56 (2.35)^{cdef}	4.00 (1.98)^{bcdefg}	1.67 (1.46)^{defgh}	0.890 (1.14)^{def}
Plant extract of *A. paniculata* (70%) + neem oil (20%) + Triton X-100 (10%)	1	7.00 (2.63)^{bcd}	6.00 (2.44)^{bcd}	4.22 (2.17)^{b}	2.00 (1.56)^{bcd}
	2	5.78 (2.38)^{cdef}	5.11 (2.25)^{bcde}	3.89 (2.07)^{bc}	1.33 (1.35)^{bcde}
	3	5.00 (2.16)^{def}	3.56 (1.85)^{defgh}	3.11 (1.85)^{bcde}	0.58 (1.02)^{ef}
	4	4.33 (2.07)^{ef}	2.67 (1.61)^{gh}	2.33 (1.64)^{bcde}	0.58 (1.02)^{ef}
	5	4.00 (1.99)^{ef}	2.67 (1.61)^{fgh}	1.33 (1.35)^{efgh}	0.56 (0.96)^{ef}
Plant extract of *A. paniculata* (70%) + pongamia oil (20%) + Triton X-100 (10%)	1	5.67 (2.38)^{cdef}	4.56 (2.11)^{bcdef}	2.89 (1.84)^{bcdef}	2.00 (1.56)^{bcd}
	2	5.67 (2.38)^{cdef}	3.78 (1.91)^{cdefgh}	2.00 (1.56)^{cdefgh}	0.83 (1.16)^{cdef}
	3	4.00 (1.96)^{ef}	3.67 (1.88)^{defgh}	2.22 (1.65)^{bcdefg}	1.36 (1.36)^{bcde}
	4	4.33 (2.08)^{ef}	2.33 (1.47)^{gh}	1.92 (1.52)^{cdefgh}	0.92 (1.13)^{def}
	5	4.00 (1.98)^{ef}	2.33 (1.47)^{gh}	1.33 (1.27)^{fgh}	0.55 (0.99)^{ef}
Thiamethoxam 25% WG	50 g a.i ha^{-1}	3.67 (1.90)^{f}	2.00 (1.38)^{h}	1.11 (1.22)^{gh}	0.11 (0.77)^{f}
Spiromesifen 22.9% SC	96 g a.i ha^{-1}	3.67 (1.88)^{f}	2.22 (1.48)^{gh}	0.67 (1.05)^{h}	0.00 (0.70)^{f}
Control		21.46 (4.64)^{a}	24.11 (4.90)^{a}	29.11 (5.44)^{a}	33.78 (5.85)^{a}
CD (0.05)		(0.538)	(0.566)	(0.573)	(0.495)

*Mean of 3 replications comprising 3 plants each (Values in the parentheses are square root transformed) DAT: Days after treatment

4.2.3 Damage Caused by Sucking pests

4.2.3.1 Scirtothrips dorsalis (Chilli thrips)

Thrips were observed on both abaxial and adaxial surfaces of leaves particularly on the upper strata of the plant. The feeding resulted in curling and cupping of the leaves with pronounced crinkling (Plate 7). The symptoms caused on the tender tissues resulted in the malformation and shrivelling of leaves, buds and fruits. The leaves showed rolling up symptoms with raised interveinal area. In severe cases the buds became brittle and dropped down.

4.2.3.2 Aphis gossypii (Chilli aphid)

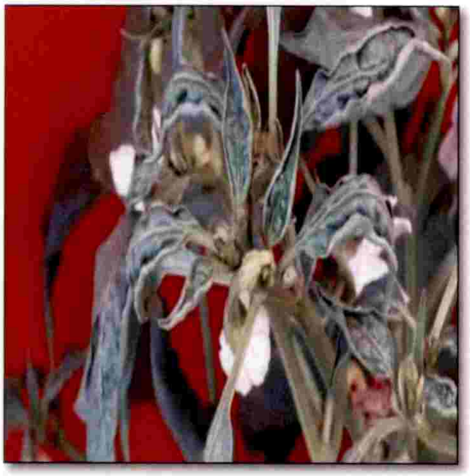
Aphids were mostly observed on the lower side of leaves, tender shoots and flower stalks (Plate 8). Feeding mainly resulted in stunted plants with discoloured and deformed leaves. The aphids were found to suck the cell sap and excrete honey dew on which black sooty mould develops, which retard the plant growth.

4.2.3.3 Polyphagotarsonemus latus (Yellow mite)

Mites were observed on both sides of the middle and upper leaves of chilli plants. They were also found on the fruits. A first symptom of damage was observed on the tender shoots and leaves. The feeding by mites resulted in development of shiny spots on lower surface of leaves. On later stage the leaves showed downward curling, elongation and narrowing. The leaf size also get reduced (Plate 9). The infected leaves also became thickened and leathery.

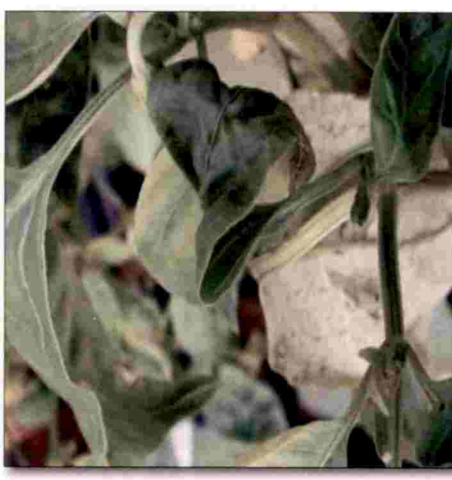
4.2.3.4 Combined Infestation of Sucking Pests

The combined infestation by sucking pests showed symptoms of leaf crinkling, curling, thickening and swelling of veins. In severe cases, the plants exhibited stunted growth resulting in a bushy stature (Plate 10). Also flower drying and withering were also found to be very high.



A. Upward curling of leaves

B. Crinkling of leaves

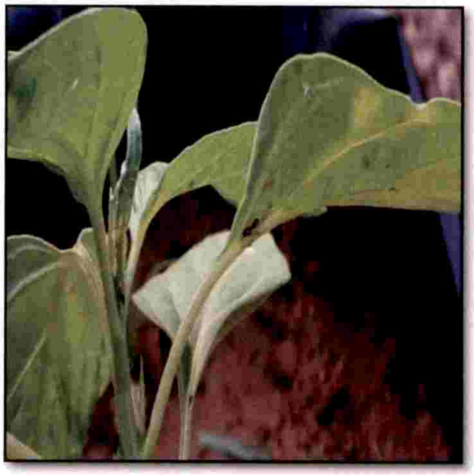


C. Curling of leaves

D. Cupping of leaves

Plate 7: Symptoms of damage by *Scirtothrips dorsalis*

A. Infestation on shoots and flowers

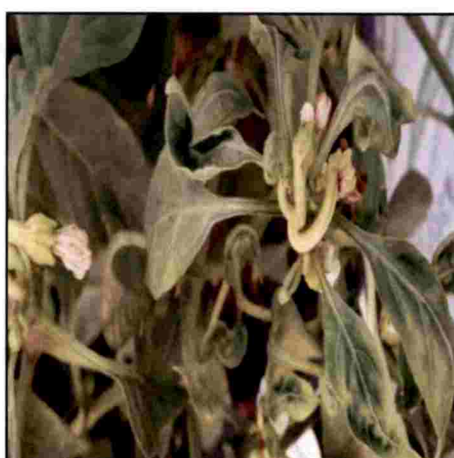


B. Infestation on leaves

Plate 8: Infestation of *Aphis gossypii* in chilli

A. Downward curling of leaves

B. Elongation of petiole



C. Dried flowers due to mite infestation

Plate 9: Symptoms of damage by *Polyphagotarsonemus latus*

A. Bushy stature of plant

B. Stunted growth of plant

C. Crinkling and curling of leaves

D. Thickening and swelling of veins

Plate 10: Symptoms of damage by sucking pest complex

4.2.4 Effect of Oil based formulations of *A. paniculata* on Damage by Sucking Pests (Leaf Curl Index)

The effectiveness of oil based formulations of *A. paniculata* on the intensity of damage was assessed by working out by using leaf curl index (LCI) as indicator at 40 DAP (10 DAT), 70 DAP (10 DAT), 100 DAP (end of the crop). The results are presented in the Table 16.

The application of various treatments did not exhibit significant difference in the damage by sucking pests based on the five grades of leaf damage at 40 DAP. Lowest LCI was recorded in thiamethoxam 25% WG (0.47) sprayed chilli plants and were found to be statistically on par. The rest of the treatments had a mean leaf curl index ranging from 0.52 to 0.78 with less than 25% leaves exhibiting symptoms of damage.

At 70 DAP, the damage caused by sucking pests becomes pronounced in all the treatments. There was no significant difference in the score of leaf curl index among the different treatments. All treatments recorded LCI of 1.13 to 1.67 whereas untreated plants recorded a mean LCI of 2.07.

At the end of the crop (100 DAP), the damage caused by sucking pests increased in all the treatments, but lowest leaf curl index was noticed in 5% concentration of pongamia oil based formulation (2.00), thiamethoxam 25% WG (2.00) and spiromesifen 22.9% SC (2.07). Leaf curl index of 2.07 to 2.33 was observed in other treatments which showed significant difference from that of untreated control (3.20).

4.2.5 Safety Evaluation of Oil based formulations of *A. paniculata* on Natural Enemies, Pollinators and Neutrals in Chilli Ecosystem.

The results of evaluation of oil based formulation of *A. paniculata* on the safety of natural enemies of pests in chilli ecosystem are furnished in Table 17 to 22. The count of predators in the field, coccinellids, spiders, pollinators and neutrals per plant were taken 1, 3, 5 and 7 days after spraying.

Table 16: Leaf curl index in chilli at different intervals after treatment

Treatments	Dose (%)	40 DAP*	70 DAP**	100 DAP***
Plant extract of *A. paniculata* (70%) + castor oil (20%) + Triton X-100 (10%)	1	0.78	1.67	2.33
	2	0.78	1.40	2.27
	3	0.78	1.53	2.27
	4	0.63	1.33	2.20
	5	0.53	1.40	2.13
Plant extract of *A. paniculata* (70%) + neem oil (20%) + Triton X-100 (10%)	1	0.77	1.60	2.33
	2	0.78	1.53	2.27
	3	0.75	1.47	2.20
	4	0.52	1.27	2.27
	5	0.53	1.33	2.13
Plant extract of *A. paniculata* (70%) + pongamia oil (20%) + Triton X-100 (10 %)	1	0.65	1.67	2.20
	2	0.67	1.47	2.27
	3	0.63	1.20	2.13
	4	0.53	1.20	2.13
	5	0.53	1.13	2.00
Thiamethoxam 25% WG	50 g a.i ha^{-1}	0.47	1.27	2.00
Spiromesifen 22.9% SC	96 g a.i ha^{-1}	0.53	1.20	2.07
Control		0.93	2.07	3.20
CD (0.05)		NS	NS	0.361

* 10 days after first spraying ** 10 days after second spraying *** At the end of the crop

DAP: Days after planting

4.2.5.1 Coccinellid beetles

The population of coccinellid beetles *viz., Chilomenus sexmaculata, Coccinella transversalis, Chilocorus* sp., *Pharoscymnus* sp., *Pseudaspidimerus* sp. and *Brumoides* sp. encountered in the chilli ecosystem are funished (Plate 11) in Table 17 and 18.

At first spraying, population of coccinellid beetless increased significantly in all treatments, analysis of data revealed that, all though the field population did not vary much among the treatments (Table 17). The count varied from 2.07 to 2.47 per 5 plants as against chemical check thiamethoxam 25% WG (0.00 to 0.33 per 5 plants) and spiromesifen 22.9% SC (0.67 to 1.87 per 5 plants). Untreated control recorded maximum number of coccinellids (2.33 to 3.33 per 5 plants).

At second spraying also the mean population of coccinellid beetles did not vary much among the treatments as against chemical check thiamethoxam 25% WG and spiromesifen 22.9% SC (Table 18). The population of coccinellid beetle ranged from 1.20 to 2.20 per 5 plants in all treatments except chemical check thiamethoxam 25% WG and spiromesifen 22.9% SC which had a significant lower population of (0.00 to 0.33 per 5 plants) and (1.00 to 1.07 per 5 plants) respectively. Untreated control plants recorded good number of coccinellids (1.73 to 2.40 per 5 plants).

4.2.5.2 Spiders

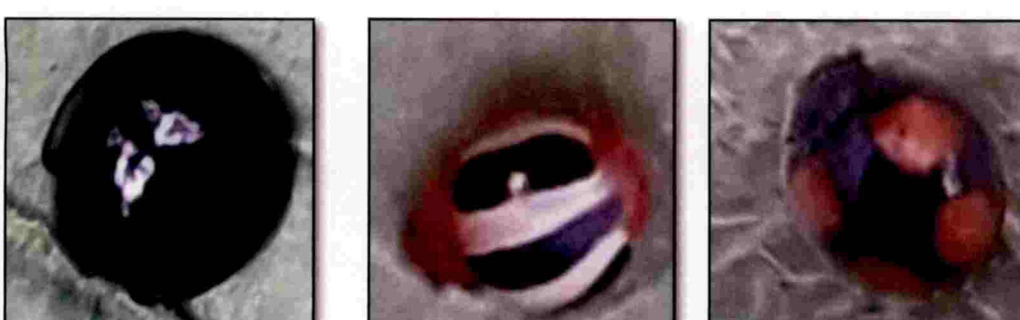
The population of predatory spiders encountered in the chilli ecosystem are furnished in Table 19 and 20. Important spiders *viz., Camaricus formosus, Oxyopes* sp., *Chrysilla* sp., *Tetragnatha* sp., *Phintella* sp., *Telamonia* sp. and *Camaricus* sp. observed in the chilli ecosystem (Plate 12) .

The mean population of spiders did not vary among treatments after first, third, fifth and seventh day after first spraying (Table 19).

Significant higher number of spiders was recorded in all treatments with mean population of 1.00 to 1.40 per 5 plants. The lowest population of spiders

Coccinella transversalis

Chilomenus sexmaculata



Chilocorus sp. *Brumoides* sp. *Pharoscymnus* sp.

Plate 11: Coccinellid beetles recorded in chilli ecosystem

Oxyopes sp.

Thomisus sp.

Tetragnatha sp.

Oxyopes sp.

Camaricus sp.

Chrysilla sp.

Phintella sp.

Telamonia sp.

Unidentified

Plate 12: Spiders recorded in chilli ecosystem

Table 17: Population of coccinellid beetles in chilli ecosystem after first spraying

Treatments	Dose (%)	Mean population of coccinellid beetles per five plants			
		1 DAT	3 DAT	5 DAT	7 DAT
Plant extract of *A. paniculata* (70%) + castor oil (20%) + Triton X-100 (10%)	1	2.07	2.20	2.20	2.27
	2	2.13	2.13	2.20	2.20
	3	2.07	2.13	2.27	2.33
	4	2.20	2.27	2.33	2.33
	5	2.33	2.27	2.33	2.33
Plant extract of *A. paniculata* (70%) + neem oil (20%) + Triton X-100 (10%)	1	2.40	2.40	2.40	2.47
	2	2.13	2.20	2.27	2.27
	3	2.40	2.40	2.47	2.47
	4	2.27	2.27	2.33	2.40
	5	2.13	2.13	2.13	2.13
Plant extract of *A. paniculata* (70%) + pongamia oil (20%) + Triton X-100 (10%)	1	2.40	2.47	2.47	2.47
	2	2.33	2.33	2.33	2.33
	3	2.40	2.47	2.40	2.40
	4	2.13	2.20	2.27	2.27
	5	2.13	2.20	2.27	2.27
Thiamethoxam 25% WG	50 g a.i ha^{-1}	0.33	0.27	0.00	0.33
Spiromesifen 22.9% SC	96 g a.i ha^{-1}	1.87	0.93	0.67	1.07
Control		2.33	2.93	3.13	3.33
CD (0.05)		0.517	0.623	0.603	0.615

DAT: Days after treatment

Table 18: Population of coccinellid beetles in chilli ecosystem after second spraying

Treatments	Dose (%)	Mean population of coccinellid beetles per five plants			
		1 DAT	3 DAT	5 DAT	7 DAT
Plant extract of *A. paniculata* (70%) + castor oil (20%) + Triton X-100 (10)	1	1.53	1.87	1.67	1.87
	2	1.53	1.73	1.93	1.93
	3	1.33	1.40	1.87	1.93
	4	1.27	1.27	1.93	2.07
	5	1.33	1.47	1.87	1.93
Plant extract of *A. paniculata* (70%) + neem oil (20%) + Triton X-100 (10%)	1	1.53	1.60	1.80	1.93
	2	1.27	1.33	1.93	2.07
	3	1.27	1.40	1.80	2.13
	4	1.20	1.33	1.87	2.07
	5	1.40	1.47	1.87	1.93
Plant extract of *A. paniculata* (70%) + pongamia oil (20%) + Triton X-100 (10 %)	1	1.20	1.33	2.00	2.13
	2	1.40	1.53	1.93	2.07
	3	1.33	1.40	2.07	2.13
	4	1.27	1.33	2.20	2.20
	5	1.40	1.40	1.93	2.00
Thiamethoxam 25% WG	50 g a.i ha^{-1}	0.00	0.00	0.00	0.33
Spiromesifen 22.9% SC	96 g a.i ha^{-1}	1.07	1.00	1.07	1.00
Control		1.73	2.07	2.27	2.40
CD (0.05)		0.361	0.285	0.439	0.400

DAT: Days after treatment

Table 19: Population of spiders in chilli ecosystem after first spraying

Treatments	Dose (%)	Mean population of spiders per five plants			
		1 DAT	3 DAT	5 DAT	7 DAT
Plant extract of *A. paniculata* (70%) + castor oil (20%) + Triton X-100 (10%)	1	1.07	1.20	1.33	1.40
	2	1.00	1.20	1.27	1.27
	3	1.07	1.27	1.27	1.33
	4	1.00	1.13	1.27	1.27
	5	1.07	1.13	1.20	1.40
Plant extract of *A. paniculata* (70%) + neem oil (20%) + Triton X-100 (10%)	1	1.00	1.13	1.13	1.20
	2	1.07	1.27	1.27	1.27
	3	1.07	1.13	1.20	1.27
	4	1.13	1.27	1.27	1.40
	5	1.07	1.07	1.13	1.27
Plant extract of *A. paniculata* (70%) + pongamia oil (20%) + Triton X-100 (10%)	1	1.07	1.20	1.27	1.40
	2	1.07	1.20	1.33	1.40
	3	1.00	1.13	1.27	1.33
	4	1.00	1.20	1.27	1.40
	5	1.13	1.27	1.27	1.33
Thiamethoxam 25% WG	50 g a.i ha^{-1}	0.27	0.00	0.00	0.00
Spiromesifen 22.9% SC	96 g a.i ha^{-1}	0.87	0.73	1.00	1.07
Control		1.13	1.33	1.40	1.80
CD (0.05)		0.329	0.320	0.213	0.312

DAT: Days after treatment

were encountered in thiamethoxam 25 % WG (0.00 to 0.27) and spiromesifen 22.9 % SC (0.73 to 1.07) spiders per 5 plants. Untreated control plants (1.13 to 1.80 per 5 plants) recorded maximum population of spiders.

The population of spiders increased significantly after second spraying. The population of spider count did not vary much after first, third, fifth and seventh days after second spraying (Table 20).

The lowest population of spiders were observed in thiamethoxam 25% WG (0.00 to 0.33) and spiromesifen 22.9% SC (0.67 to 1.33) spiders per 5 plants. Rest of the treatments showed significant high population of spiders (2.27 to 2.60 per 5 plants) which were found on par with each other. Untreated plants recorded spider population of 2.47 to 3.27 per five plants.

4.2.5.3 Pollinators and Neutrals

The population of pollinators includes *Nomia* sp., *Halictus* sp., *Lasioglossum* sp. and *Tetragonula* sp. and neutrals *viz.,* fly beetle, tortoise beetle, coreid bug and grasshopper recorded in the chilli ecosystem.The population of pollinators and neutrals were high in the chilli ecosystem compared to the spiders and coccinellid beetles (Table 21 and 22). At different intervals after spraying, the population of pollinators and neutrals were found to be on par with each other.

At first spraying, population of pollinators and neutrals recorded at different intervals after first spraying was 2.00 to 2.60 per 5 plants. The lowest population was reported in thiamethoxam 25% WG (0.33 to 0.67) and spiromesifen 22.9% SC (1.60 to 1.87) per five plants. Plants in the untreated control recorded highest number of pollinators and neutrals with mean population of 2.87 to 3.40 per five plants.

Analysis of data obtained after second spraying of treatments revealed that pronounced population of pollinators and neutral presented in Table 22. The mean population of pollinators and neutrals recorded at different intervals after spraying was 4.20 to 5.07 per 5 plants as against chemical check thiamethoxam 25% WG

Table 20: Population of spiders in chilli ecosystem after second spraying

Treatments	Dose (%)	Mean population of Spiders per five plants			
		1 DAT	3 DAT	5 DAT	7 DAT
Plant extract of *A. paniculata* (70%) + castor oil (20%) + Triton X-100 (10%)	1	2.27	2.33	2.47	2.47
	2	2.33	2.40	2.40	2.60
	3	2.27	2.33	2.47	2.33
	4	2.27	2.40	2.47	2.33
	5	2.27	2.27	2.47	2.33
Plant extract of *A. paniculata* (70%) + neem oil (20%) + Triton X-100 (10%)	1	2.33	2.40	2.47	2.53
	2	2.33	2.47	2.53	2.47
	3	2.33	2.33	2.47	2.33
	4	2.40	2.47	2.40	2.40
	5	2.13	2.27	2.40	2.33
Plant extract of *A. paniculata* (70%) + pongamia oil (20%) + Triton X-100 (10%)	1	2.27	2.40	2.47	2.47
	2	2.27	2.33	2.40	2.40
	3	2.33	2.47	2.47	2.33
	4	2.40	2.40	2.47	2.47
	5	2.40	2.47	2.53	2.27
Thiamethoxam 25% WG	50 g a.i ha^{-1}	0.00	0.00	0.33	0.00
Spiromesifen 22.9% SC	96 g a.i ha^{-1}	0.67	0.80	1.33	0.73
Control		2.47	2.67	3.07	3.27
CD (0.05)		0.545	0.606	0.556	0.627

DAT: Days after treatment

Table 21: Population of pollinators and neutrals in chilli ecosystem after first spraying

Treatments	Dose (%)	Mean population of pollinators and neutrals per five plants			
		1 DAT	3 DAT	5 DAT	7 DAT
Plant extract of *A. paniculata* (70%) + castor oil (20%) + Triton X-100 (10%)	1	2.00	2.20	2.27	2.53
	2	2.00	2.20	2.27	2.60
	3	2.07	2.27	2.47	2.53
	4	2.13	2.13	2.27	2.53
	5	2.00	2.33	2.33	2.47
Plant extract of *A. paniculata* (70%) + neem oil (20%) + Triton X-100 (10%)	1	2.07	2.13	2.53	2.33
	2	2.13	2.20	2.33	2.53
	3	2.07	2.13	2.40	2.53
	4	2.13	2.20	2.40	2.47
	5	2.07	2.20	2.47	2.60
Plant extract of *A. paniculata* (70%) + pongamia oil (20%) + Triton X-100 (10%)	1	2.13	2.13	2.47	2.53
	2	2.07	2.07	2.53	2.47
	3	2.20	2.07	2.40	2.53
	4	2.33	2.13	2.40	2.53
	5	2.27	2.20	2.40	2.53
Thiamethoxam 25% WG	50 g a.i ha^{-1}	0.33	0.33	0.67	0.33
Spiromesifen 22.9% SC	96 g a.i ha^{-1}	1.60	1.67	1.53	1.87
Control		3.20	2.87	3.13	3.40
CD (0.05)		0.524	0.508	0.552	0.562

DAT: Days after treatment

Table 22: Population of pollinators and neutrals in chilli ecosystem after second spraying

Treatments	Dose (%)	Mean population of pollinators and neutrals per five plants			
		1 DAT	3 DAT	5 DAT	7 DAT
Plant extract of *A. paniculata* (70%) + castor oil (20%) + Triton X-100 (10%)	1	4.00	5.20	5.33	6.20
	2	4.27	4.87	4.93	6.40
	3	4.20	5.00	5.73	6.27
	4	4.33	5.40	5.53	6.20
	5	4.33	5.33	6.20	6.40
Plant extract of *A. paniculata* (70%) + neem oil (20%) + Triton X-100 (10%)	1	4.33	5.20	6.13	6.33
	2	4.47	5.20	6.13	6.53
	3	4.33	4.93	6.07	6.60
	4	4.33	5.07	5.73	6.67
	5	4.33	5.40	5.73	6.67
Plant extract of *A. paniculata* (70%) + pongamia oil (20%) + Triton X-100 (10%)	1	4.47	5.13	5.73	7.00
	2	4.40	5.67	5.93	6.53
	3	4.67	5.20	6.27	6.87
	4	4.53	5.07	6.07	6.47
	5	5.13	6.00	6.40	7.40
Thiamethoxam 25% WG	50 g a.i ha^{-1}	1.00	0.67	1.00	1.00
Spiromesifen 22.9% SC	96 g a.i ha^{-1}	3.87	4.00	3.87	4.20
Control		6.47	7.07	7.33	7.47
CD (0.05)		0.943	1.308	1.155	1.338

DAT: Days after treatment

(0.67 to 1.00) and spiromesifen (3.87 to 4.20) per 5 plants. Untreated plants recorded highest number of pollinators and neutrals with 6.47 to 7.47 per five plants.

4.2.3 Biometric Observations of Chilli Plants Sprayed with Oil Based formulations of *A. paniculata.*

The influence of formulations on plant height, no of branches per plant and fruit yield per plant at different intervals of spraying are presented in Table 23 and 24.

4.2.3.1 Plant height

At 40 DAP i.e., 10 days after application of treatments in the vegetative phase there was no significant difference in the plant height among the different treatments.

At 70 DAP, 4% concentration castor oil based formulation recorded highest plant height of 48.12 cm. Rest of the treatments was found to be on par with each other. The lowest plant height was recorded in untreated plants (32.71 cm).

At 100 DAP also there was no significant difference in the plant height among the different treatments.

4.2.3.2 Number of primary branches

At 40 DAP i.e., 10 days after application of treatments in the vegetative phase, there was no significant difference in the number of branches among the different treatments.

At 70 and 100 DAP, there was no significant difference in the number of branches among the different treatments (Table 24).

Table 23: Effect of formulations on plant height at different intervals after transplanting

Treatments	Dose (%)	Plant height (cm)		
		40 DAP	70 DAP	100 DAP
Plant extract of *A. paniculata* (70%) + castor oil (20%) + Triton X-100 (10%)	1	35.62	43.11	47.78
	2	37.08	40.22	44.89
	3	35.11	39.00	45.88
	4	38.70	48.12	53.22
	5	37.17	47.86	56.11
Plant extract of *A. paniculata* (70%) + neem oil (20%) + Triton X-100 (10%)	1	37.03	41.91	51.22
	2	36.29	42.44	47.34
	3	36.70	42.70	52.42
	4	40.05	40.78	50.28
	5	37.38	47.74	53.62
Plant extract of *A. paniculata* (70%) + pongamia oil (20%) + Triton X-100 (10%)	1	40.11	45.28	52.50
	2	38.82	41.17	47.50
	3	38.78	43.96	52.04
	4	39.40	43.17	51.18
	5	39.53	47.40	53.11
Thiamethoxam 25% WG	50 g a.i ha^{-1}	37.72	41.93	50.11
Spiromesifen 22.9% SC	96 g a.i ha^{-1}	34.95	38.37	49.55
Control		31.71	32.71	44.89
CD (0.05)		NS	6.877	NS

DAP: Days after planting

Table 24: Effect of formulations on primary branches and yield of chilli

Treatments	Dose (%)	No. of primary branches			Yield (g plant^{-1})
		40 DAP	70 DAP	100 DAP	
Plant extract of *A. paniculata* (70%) + castor oil (20%) + Triton X-100 (10%)	1	8.22	9.56	10.00	333.44
	2	8.11	8.67	9.22	204.96
	3	8.22	9.56	9.78	242.83
	4	8.44	9.56	9.56	259.92
	5	7.67	9.44	10.00	258.76
Plant extract of *A. paniculata* (70%) + neem oil (20%) + Triton X-100 (10%)	1	8.89	9.22	9.67	335.88
	2	7.89	9.44	10.00	228.16
	3	8.33	10.11	10.44	286.38
	4	8.00	9.33	9.78	230.02
	5	7.89	9.11	9.33	317.91
Plant extract of *A. paniculata* (70%) + pongamia oil (20%) + Triton X-100 (10%)	1	8.67	9.33	9.67	260.92
	2	8.67	9.00	9.56	257.49
	3	8.22	9.67	10.00	251.49
	4	8.67	10.44	10.67	230.33
	5	8.33	9.56	10.00	380.74
Thiamethoxam 25% WG	50 g a.i ha^{-1}	8.00	8.89	9.11	259.56
Spiromesifen 22.9% SC	96 g a.i ha^{-1}	8.11	9.56	10.33	298.56
Control		8.67	8.78	9.33	179.85
CD (0.05)		NS	NS	NS	NS

DAP: Days after planting

4.2.3.3 Yield

The yield obtained during the crop period was not influenced by the treatments. Highest yield of 380.74 g $plant^{-1}$ was obtained from the plants treated with 5 % concentration of pongamia oil based formulation (Table 24).

4.3 SHELF LIFE STUDIES OF PROMISING TREATMENTS

The population of chilli aphids prior to the application of treatments were found to be non-significant. Mean population of chilli aphids at different intervals after treatment application are presented in Table 25.

Throughout the experimental period, the population of aphid did not vary significantly among the treatments. Shelf life studies revealed that pongamia based formulation found to be highly effective even upto 60 days after preparation against chilli aphid.

Table 25: Effect of pongamia based formulation of *Andrographis paniculata* on chilli aphid at different intervals after preparation

Treatments	Dose (%)	Mean population (Number leaf $^{-1}$)*			
		I DAT	3 DAT	5 DAT	7 DAT
Fresh preparation	5	1.00 (1.18)	0.22 (0.84)	0.00 (0.70)	0.11 (0.77)
	7	0.78 (1.06)	0.00 (0.70)	0.00 (0.70)	0.00 (0.70)
15 days after preparation	5	0.89 (1.07)	0.33 (0.88)	0.22 (0.84)	0.11 (0.77)
	7	0.22 (0.84)	0.00 (0.70)	0.00 (0.70)	0.00 (0.70)
30 days after preparation	5	1.11 (1.24)	0.11 (0.77)	0.33 (0.90)	0.11 (0.77)
	7	0.11 (0.77)	0.00 (0.70)	0.00 (0.70)	0.00 (0.70)
60 days after preparation	5	1.00 (1.14)	0.44 (0.95)	0.11 (0.70)	0.00 (0.70)
	7	0.22 (0.84)	0.00 (0.70)	0.00 (0.70)	0.00 (0.70)
CD (0.05)		NS	NS	NS	NS

*Mean of 3 replications comprising 3 plants each (Values in the parentheses are square root transformed) DAT: Days after treatment

Discussion

5. DISCUSSION

Unsystematic use of chemical insecticides coupled with monoculture of crops and the global climate change scenario have emanate in major reposition of pests from fruit or leaf eating caterpillars to sucking pests in many crop ecosystems. In chilli, sucking pest complex are often a barrier for productivity and heavy dependence on chemical pesticides to manage these pests resulted in various environmental and health hazards. This necessitates evolving new botanical formulations which are environment friendly and economically viable. Yet, some of the botanical pesticides were found less effective when the pest population is very high in the field conditions. Nowadays studies are concentrated on the development of formulations containing more than one plant extract, which often possesses more insecticidal potential due to synergistic action. Among the various biopesticide formulations, emulsifiable concentrate (EC) are more preferred by farmers because of its high biological activity, easiness in handling and good storage stability (Alan, 2008; Vanitha, 2010; Prajapati *et al.,* 2014). In this backdrop, the present investigation was conducted as a preliminary step to develop an eco-friendly bio pesticide formulation using extract of *Andrographis paniculata* and oils *viz.*, sunflower oil, palm oil, castor oil, neem oil and pongamia oil for tackling sucking pest complex of chilli.

5.1 *IN VITRO* EVALUATION OF DIFFERENT FORMULTION OF *Andrographis paniculata*

The present investigation was focused on the development of oil based formulations of *A. paniculata.* From the formulation trials conducted in the laboratory the best ratio of plant extract-oil-surfactant was found to be 7:2:1.

Triton X-100 at 10% concentration having 13.4 hydrophile-lipophile balance (HLB), was selected as the best surfactant with good emulsification properties for formulation development. Studies conducted by Foy (1992) and Knowles (2008) revealed that the total concentration of the surfactant in the EC formulation was usually 5-10%. They also stated that HLB value ranging between 8 and 18 was found to provide good oil-in-water emulsion.

Five different formulations were developed in the laboratory using *A. paniculata* extract, oils such as sunflower oil, palm oil, castor oil, neem oil and pongamia oil and the surfactant, Triton X-100 in the ratio of 7:2:1. These formulations were selected based on their performance in blooming test and emulsion stability test (BIS, 1997; Allawzi *et al*, 2016).

In vitro evaluation of different oil based formulations of *A. paniculata* at 5, 10 and 20% concentrations showed 90 to 100 per cent mortality against *Aphis gossypii*. Among the five oil based formulations of *A. paniculata* tested, pongamia and neem oil based formulation at 5% concentration found to be superior and exhibited 100 per cent mortality and was equally effective as 5% concentration of castor oil based formulation with 98.33 per cent mortality at 24 HAT. In general, mortality tends to increase with increasing concentration of formulations to all stages of sucking pests of chilli.

Lower concentrations (1, 2, 3 and 4%) of pongamia, neem and castor oil based formulations of *A. paniculata* were tested against chilli aphid and results revealed that 1% pongamia oil based formulation was significantly superior with 85.00 per cent mortality at 24 HAT. This was found in line with the study of Stepanycheva *et al.* (2014). They standardized the bioformulation containing pongamia oil, *Sapindus saponaria* extract and Tween in the ratio of 8: 1: 1 at 3% concentration was effective against green peach aphid causing 95.00 per cent mortality. Bioefficacy of combinations of pongamia oil and other plant extracts was less investigated and studies were concentrated more on the insecticidal properties of pongamia oil alone.

The higher per cent mortality recorded in pongamia oil based formulation may be due to the pesticidal property of pongamia oil which was in accordance with the study of Kumar and Singh (2002). They concluded that flavonoids, chalcones, steroids and terpenoids were responsible for insecticidal activity of pongamia oil. Further the toxicity of pongamia oil was also documented against *Polyphagotasonemus latus* by Reddy and Kumar (2006) and Veena *et al.* (2017), *Scirtothrips dorsalis* by Meena and Tayde (2017) and *A. gossypii* by Vinodhini and Malaikozhundan (2011) at concentration ranging from 1- 4%.

In the present study neem oil based formulation at 1% concentration was found to be effective against *A. gossypii* causing mortality of 83.33 per cent at 24 HAT. Sreerag and Jayprakash (2014) reported that 1% concentration of neem based formulation containing 50 mL neem oil, 30 mL surfactant and 20 mL cassava leaf extract was effective against cowpea aphid, *Aphis craccivora* and papaya mealy bug, *Paracoccus marginatus*. The mortality might be credited to the active ingredient in neem namely azadirachtin, the tetranortriterpenoid limonoid, having the insecticidal properties (Kumar, 2016).

At 1% castor based formulation exhibited 66.67 per cent mortality at 24 HAT against *A. gossypii*. The insecticidal activity of castor oil was explained by Alugah and Ibraheem (2014) as the toxicity may be due to protein, alkaloid, anthocyanins, flavonoids, phenolics, tannins and terpenoids present in castor oil. The role of castor oil in enhancing mortality of aphid was confirmed by the findings of Harish *et al.* (2014); Veena *et al.* (2017); Wamaket *et al.* (2018). The previous studies on the castor based formulations are very meagre.

In the present investigation, combination of *A. paniculata* extract and oils showed synergistic effect against aphids compared to plant extract and oils alone. The synergistic effect of pongamia oil in the present study was supported by the findings of Kumar and Singh (2002). They observed that pongamia oil based formulation gave good synergistic effect with other botanical insecticides and also had good emulsion stability. The insecticidal properties of *A. paniculata* can be due to the presence of diterpenoid lactones (andrographolides), paniculides, farnesols and flavonoids (Ramya *et al.,* 2011). The pesticidal action of *A. paniculata* observed in the present study was substantiated by the findings of

Suganthy and Sakthivel (2012); Singh *et al.* (2014); Madihah *et al.* (2018) and Prema *et al.* (2018).

In general, mode of action of oils is yet to be confirmed. But they are known to produce mortality by suffocation as per the studies of Don-Pedro (1989) and in some instances, they can also act as antifeedants or insect growth regulators (IRGs) by affecting metamorphosis of insects as per the findings of Weaver and Subramanyam (2000).

For further confirmation on the relative efficacy of the formulations (castor, neem and pongamia based formulations), the three selected formulations were screened in the field.

5.2 EVALUATION OF EFFECTIVE FORMULATION FOR FIXING THE DOSE

Field evaluation is a pre-eminent mechanism for realistic verification of the findings obtained in laboratory experiments. The promising results obtained in laboratory analysis may not replicate in field situations due to numerous biotic and abiotic stress existing in open field condition. Hence promising treatments were selected from *in vitro* studies was tested under field condition to compare their field efficacy. Field evaluation conducted using the effective formulations *viz.,* castor, neem and pongamia oil based formulations along with thiamethoxam 25% WG and spiromesifen 22.9% SC as the chemical check. The pot culture experiment was conducted using chilli variety, Vellayani Athulya. Treatments were applied two times, first at vegetative stage phase (30 days after planting) and the second at the reproductive phase (60 days after planting).

Higher doses (7, 10, 15 and 20%) and lower doses (1, 2, 3, 4 and 5%) of castor, neem and pongamia based formulation were tested against *A. gossypii*, *S. dorsalis* and *P. latus*. The population of thrips, aphids and mites were found to be significantly lower in higher dose of formulations and they were found to be superior compared to chemical insecticides thiamethoxam 25% WG and spiromesifen 22.9% SC at the vegetative stage of the crop. In case of lower doses, castor, neem and pongamia based formulations were on par with chemical check thiamethoxam 25% WG and spiromesifen 22.9% SC in tackling chilli thrips, aphids and mite population.

In the field trial, during first spraying, among the three formulations (pongamia, neem and castor based formulations) evaluated, maximum reduction in thrips population (98.97 per cent) over untreated control was noticed in pongamia based formulation at 5% concentration and it was followed by 5% concentration of neem and castor based formulations (97.94 per cent) at 3 DAT (Fig. 2). With respect to aphids, a per cent reduction of 79.29, 84.03 and 96.44 over control was observed in pongamia based formulation at 1, 3 and 5 DAT respectively (Fig. 1, 2 and 3). Pongamia based formulation at 5% concentration was found to be equally effective as spiromesifen 22.9% SC in controlling mite, *P. latus* in chilli. Per cent reduction over control was 90.16 at 3 DAT and 98.34 at 7 DAT. Neem and castor based formulation ranked second resulting in 95.96 and 94.59 per cent reduction, respectively at 5 DAT, 96.82 and 97.76 per cent, respectively at 7 DAT (Fig. 2, 3 and 4).

Second round of application was carried with lower doses of formulations, since from the first spray it was evident that all higher doses were found highly effective and superior compared to chemical check. The results showed that, the best formulation for reducing the *S. dorsalis* was pongamia based formulation at 5% concentration with a population reduction of 92.54, 95.96 and 98.08 per cent over untreated control on first, third and fifth day after spraying respectively (Fig. 5, 6 and 7). The highest population reduction of aphids was recorded in pongamia based formulation (99.27 per cent) and neem and castor based formulation (99.02 per cent) at 5% concentration. Significant reduction in the population of mites (98.34 per cent) over control was observed at seven days after spraying (Fig. 8) in plants sprayed with 5% concentration of pongamia based formulation and were on par with chemical checks thiamethoxam 25% WG and spiromesifen 22.9% SC.

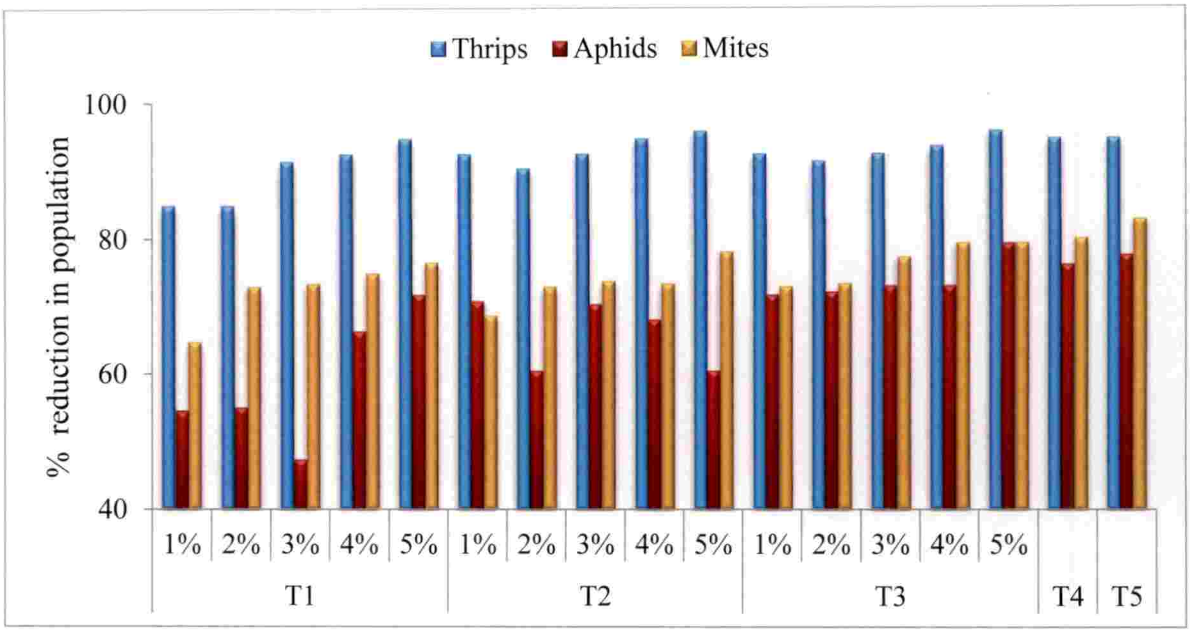


Fig. 1: Per cent reduction in the population of chilli sucking pests at 1day after first spraying

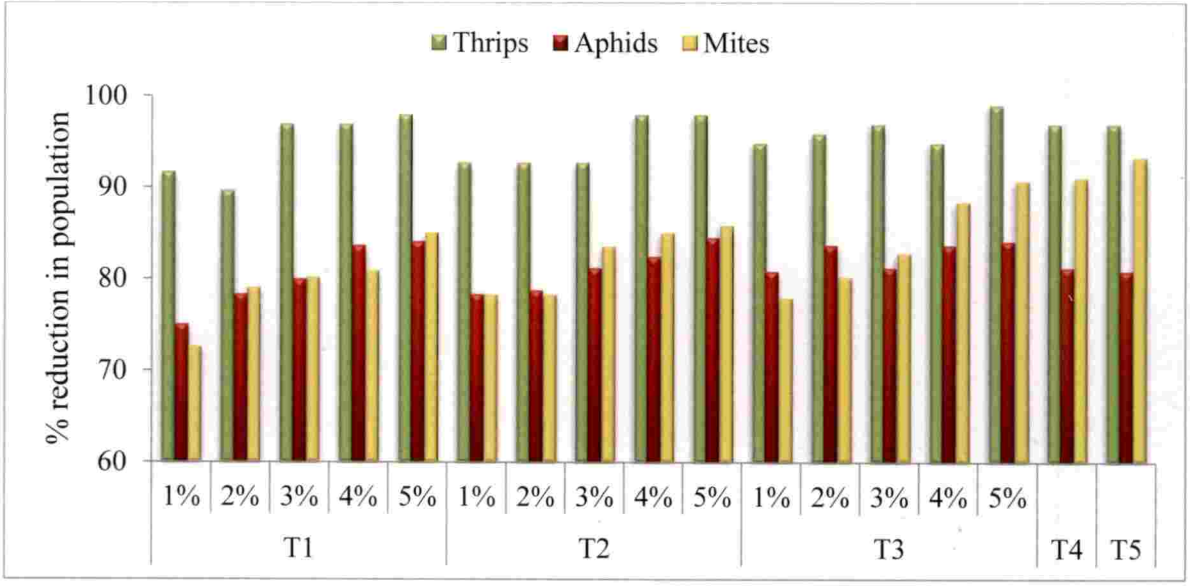


Fig. 2: Per cent reduction in the population of chilli sucking pests at 3 days after first spraying

T1 - Plant extract of *A. paniculata* (70 %) + castor oil (20 %) + Triton X-100 (10 %)

T2 - Plant extract of *A. paniculata* (70 %) + neem oil (20 %) + Triton X-100 (10 %)

T3 - Plant extract of *A. paniculata* (70 %) + pongamia oil (20 %) + Triton X-100 (10 %)

T4 - Thiamethoxam 25 % WG

T5 - Spiromesifen 22.9 % SC

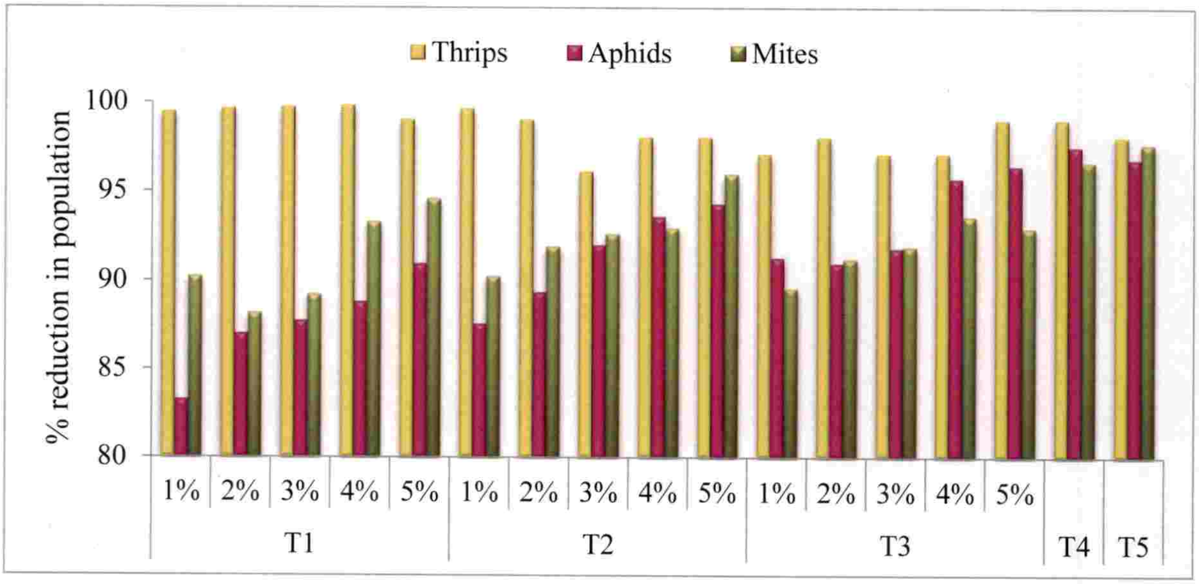


Fig. 3: Per cent reduction in the population of chilli sucking pests at 5 days after first spraying

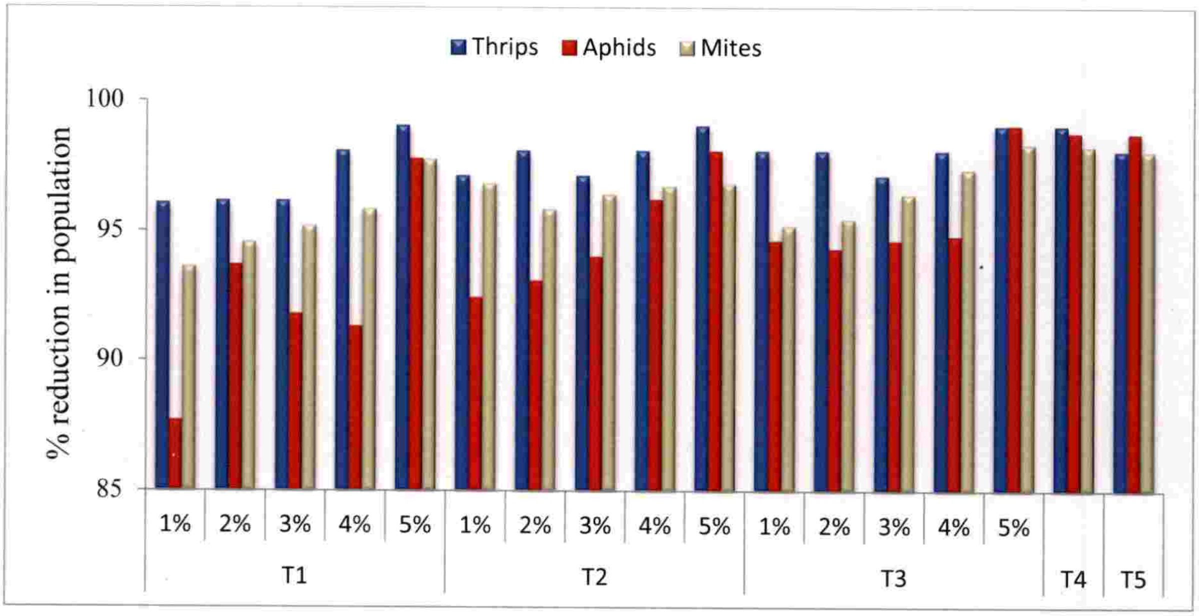


Fig. 4 Per cent reduction in the population of chilli sucking pests at 7 days after first spraying

T1 - Plant extract of *A. paniculata* (70 %) + castor oil (20 %) + Triton X-100 (10 %)

T2 - Plant extract of *A. paniculata* (70 %) + neem oil (20 %) + Triton X-100 (10 %)

T3 - Plant extract of *A. paniculata* (70 %) + pongamia oil (20 %) + Triton X-100 (10 %)

T4 - Thiamethoxam 25 % WG

T5 - Spiromesifen 22.9 % SC

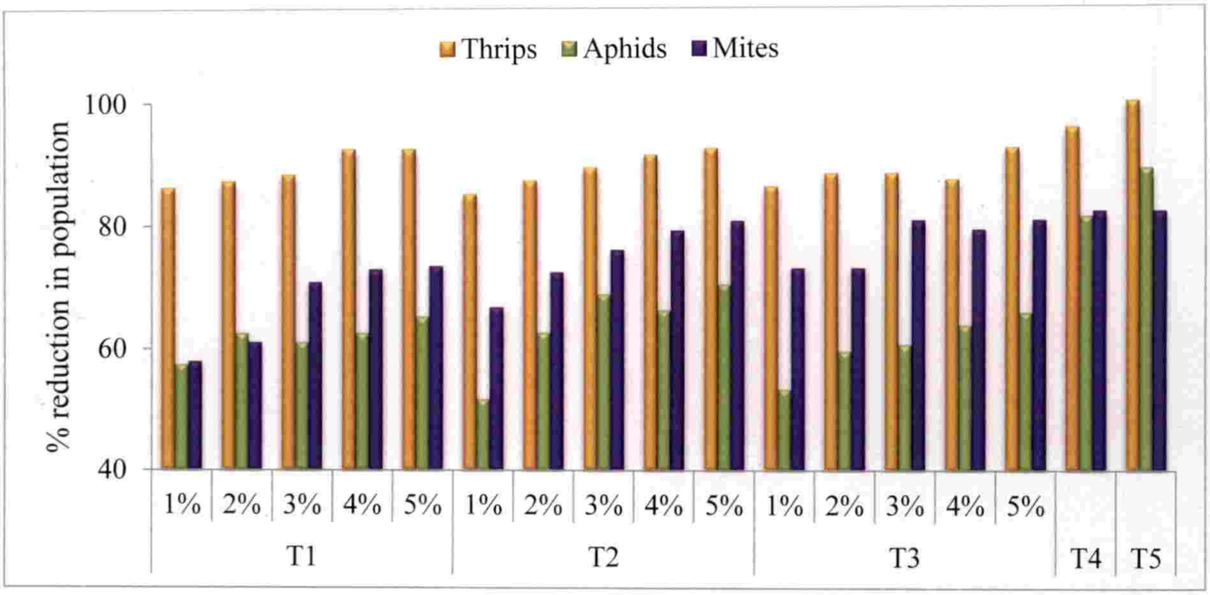


Fig. 5: Per cent reduction in the population of chilli sucking pests at 1day after second spraying

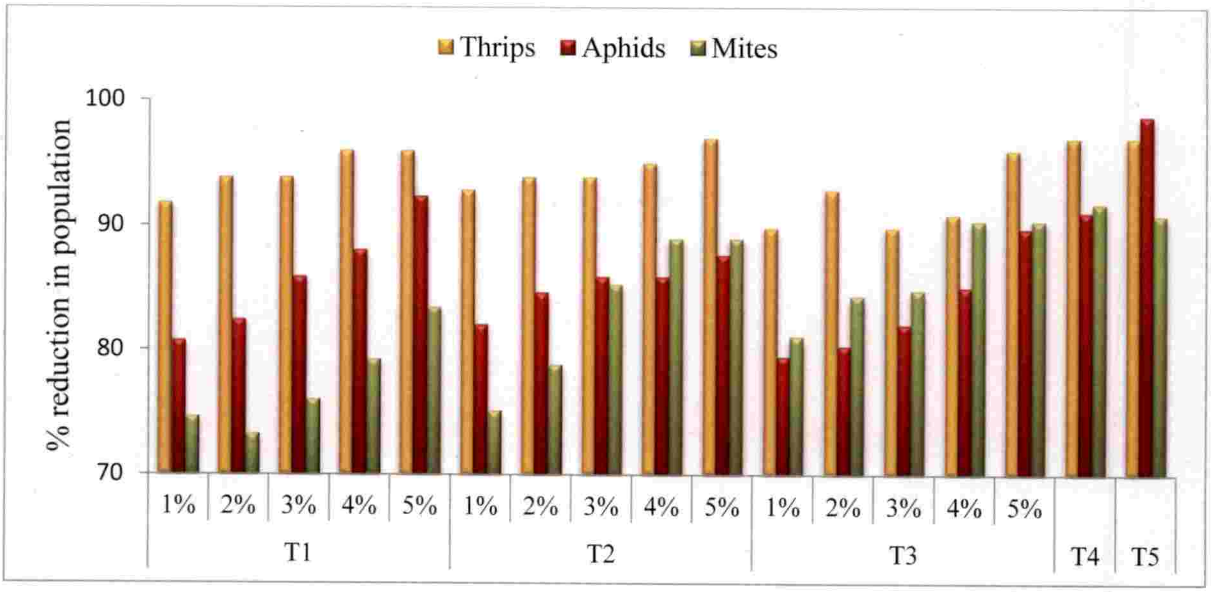


Fig. 6: Per cent reduction in the population of chilli sucking pests at 3 days after second spraying

T1 - Plant extract of *A. paniculata* (70 %) + castor oil (20 %) + Triton X-100 (10 %)

T2 - Plant extract of *A. paniculata* (70 %) + neem oil (20 %) + Triton X-100 (10 %)

T3 - Plant extract of *A. paniculata* (70 %) + pongamia oil (20 %) + Triton X-100 (10 %)

T4 - Thiamethoxam 25 % WG

T5 - Spiromesifen 22.9 % SC

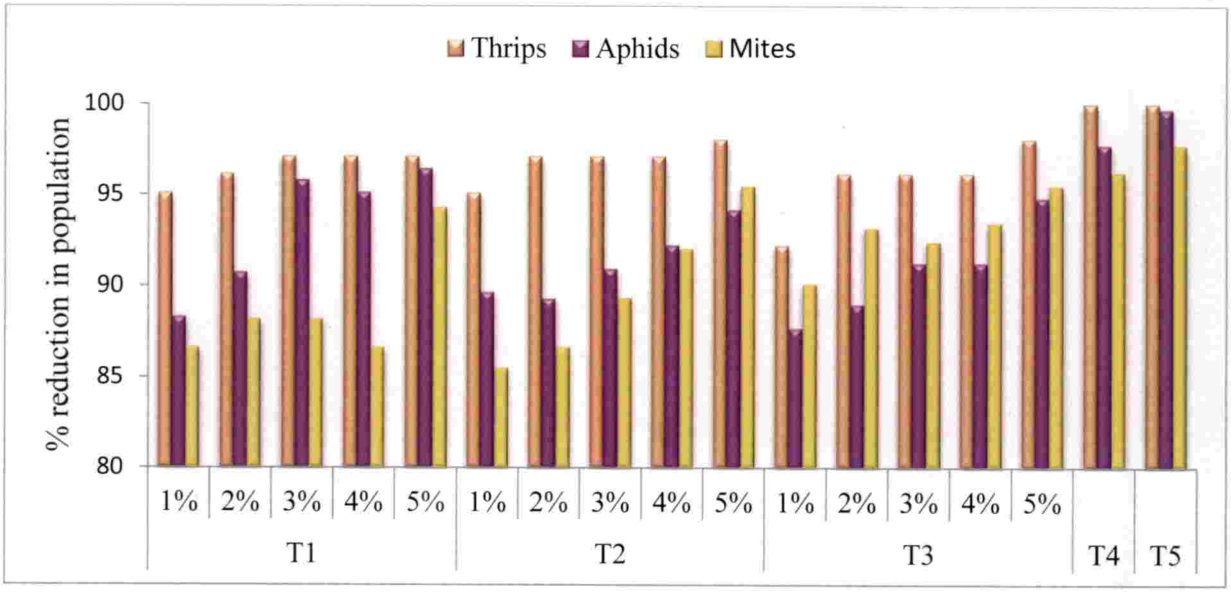


Fig. 7: Per cent reduction in the population of chilli sucking pests at 5 days after second spraying

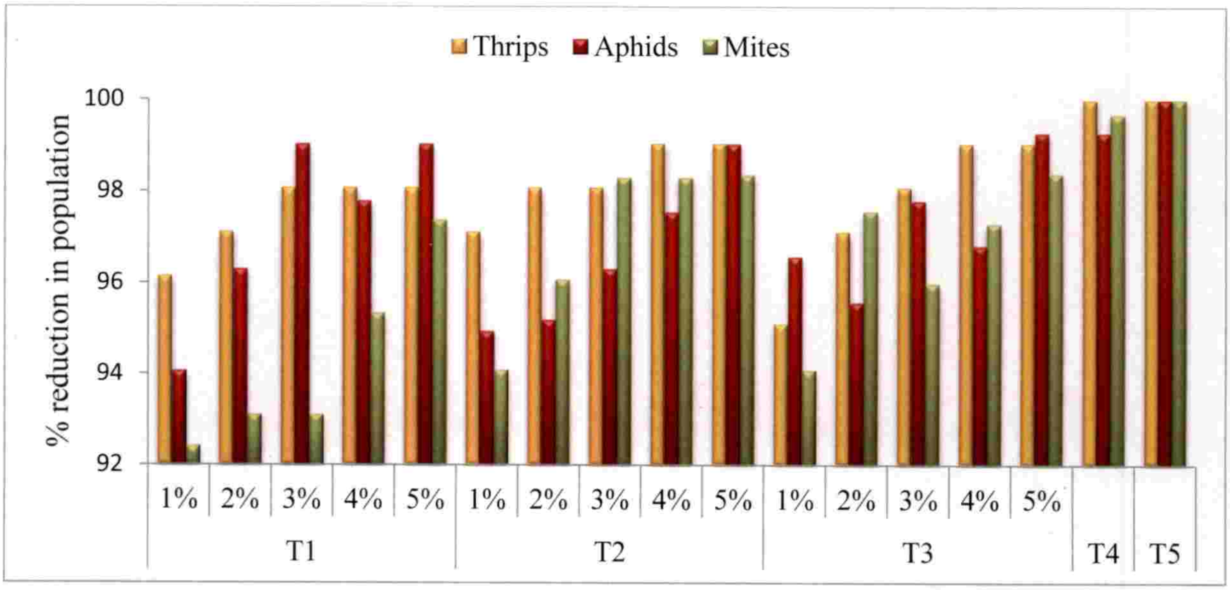


Fig. 8: Per cent reduction in the population of chilli sucking pests at 7 days after second spraying

T1 - Plant extract of *A. paniculata* (70 %) + castor oil (20 %) + Triton X-100 (10 %)

T2 - Plant extract of *A. paniculata* (70 %) + neem oil (20 %) + Triton X-100 (10 %)

T3 - Plant extract of *A. paniculata* (70 %) + pongamia oil (20 %) + Triton X-100 (10 %)

T4 - Thiamethoxam 25 % WG

T5 - Spiromesifen 22.9 % SC

From the first and second spraying, maximum reduction in sucking pest complex of chilli was brought about by pongamia oil based formulation of *A. paniculata*. Thus it can be concluded that pongamia oil based formulation at 5% concentration was found to be effective in managing chilli sucking pest complex and was equally effective as chemical insecticides thiamethoxam 25% WG and spiromesifen 22.9% SC.

Literature pertaining to development of oil based formulations of *A. paniculata* is meagre. Bernice (2000) reported that leaf extract of *A. paniculta* in combination with neem oil emulsion 2.5% and garlic at 2% possess deterrent effects on aphids and epilachna beetle.

Lowest leaf curl index (LCI) was recorded in 5% concentration of pongamia oil based formulation. The treatments with castor and neem based formulations were also effective in reducing the damage. Chakraborty and Nath (2015) reported that neem oil was found to be effective in reducing LCI of chilli. The efficiency of botanicals for the management of chilli leaf curl was reported by Ragupathi and Veeraragavathatham (2002); Venzon *et al.* (2006); Susheel *et al.* (2010) ; Asare-Bediako *et al.* (2014).

In addition to pest management, all bio pesticide formulations recorded significantly higher population of natural enemies, pollinators and neutrals as against chemical insecticides thiamethoxam 25% WG and spiromesifen 22.9% SC. As per the research findings of Sujay *et al.* (2015) the pesticides from biological origin might be relatively less harmful to the natural enemies than conventional chemical pesticides.

Safety of neem based pesticides to predatory fauna of aphids was also reported in vegetable ecosystem by Gowri *et al.* (2002); Patel *et al.* (2003) and Thamilvel (2009). Suganthy and Sakthivel (2012) observed that application of 1% azadiracthin and 2% aqueous extract of *A. paniculata* conserved more number of natural enemies. Stepanycheva *et al.* (2014) observed pongamia oil 1% did not have negative impact on insect pollinators *viz.*, hymenoptera, diptera, lepidoptera, hemiptera and coleoptera.

In the present study, there was no significant difference observed between treatments in biometric parameters *viz.*, plant height, number of primary branches and yield. Reduction in the overall yield might be due to the presence of high population of the sucking pests in the initial crop phase that have hindered the plants from expressing the effect of treatments in the later phase of the crop. Vichitbandha and Chandrapatya (2011) reported that more than 50 per cent damage caused by sucking pest resulted in retarded growth and yield loss in chilli.

5.3 SHELF LIFE STUDIES OF PROMISING TREATMENTS

The current investigation revealed that 5 and 7% of pongamia based formulations were found to be effective upto 60 days after preparation against chilli aphid. The prolonged shelf life of the formulation can be credited to the antimicrobial properties of *A. paniculata* as reported by Roy *et al.* (2010).

From the foregoing results it is abvious that an effective biopesticide formulation to chilli sucking pest complex can be successfully be formulated by using extract of *A. paniculata*, pongamia oil and Triton X-100 in the ratio of 7:2:1. The field application of this formulation at 5% concentration proved to be effective in the management of sucking pest complex in chilli and was found safe to natural enemies, pollinators and neutrals and with a shelf life of 60 days. In future, studies on the efficacy of these formulations against sucking pests of other crops especially vegetables may be carried out.

Summary

6. SUMMARY

Chilli (*Capsicum annuum* L.) is one of the important spice and solanaceous vegetable crops grown in India. Over the years, insect pests attack has been found as one of the major biotic constraints of vegetable production across the country. Sucking pest complex comprising of thrips, aphids and mites are one of the major constraints in chilli production. Unsystematic use of chemical insecticides resorted by the farmers to tackle this menance is having serious economical and ecological consequences warranting development of alternate eco-friendly pest management tactics.

Plants are known to have a variety of secondary metabolites that are absolutely necessary for their growth and development and are indispensable in protection against pests and pathogens. Plants derived secondary metabolites plays an important role in minimizing insect damage on crop plants. *Andrographis paniculata*, herbaceous plant which belongs to Acanthaceae family is a potential insecticide of plant origin. Oils of plant origin namely castor, neem and pongamia which are non-edible, abundant and readily available can be better alternatives to chemical pesticides for management of sucking pest complex of chilli. The botanical pesticides were found less effective when the pest population is very high in the field conditions. Nowadays studies are concentrated on the development of formulations based on more than one plant extract, which often possesses more insecticidal potential due to the action of synergism.

With this background, the present investigation entitled "Oil based formulation of *Andrographis paniculata* (Burm.f.) Nees against sucking pests of chilli" was conducted during period 2017-2019, in the Department of Agricultural Entomology, College of Agriculture, Vellayani with an objective to develop oil based ready to use formulations of *A. paniculata* and to study the shelf life and to fix the optimum dose for the management of chilli sucking pest complex comprising of thrips (*S. dorsalis*), aphids (*A. gossypii*) and mites (*P. latus*).

Different combination of extract of *A. paniculata*, oils and surfactants were tested in the laboratory for finding the suitable surfactant and their effective combination. From prelimnary experiment extract of *A. paniculata*, oils *viz.,* sunflower oil, palm oil, castor oil, neem oil and pongamia oil and the surfactant Triton X-100 was selected in the ratio of 7:2:1 based on their performance in blooming and emulsion stability test. Laboratory evaluation of various concentrations (5, 10, and 20%) of different oil based combinations of *A. paniculata* were done using aphids, thrips and mites as test insects.

Results of the laboratory experiment revealed that pongamia and neem based formulation at 5% concentration was sufficient for 100 per cent mortality of aphids at 24 hours after treatment (HAT) and it was statistically on par with 5% concentration of castor based formulation. The above mentioned treatments gave 100% mortality against thrips and mites also. Lower concentrations (1, 2, 3 and 4%) of the castor, neem and pongamia based formulation were selected for the further evaluation against aphids.

It was found that pongamia oil based combination at 4% gave 100 per cent mortality at 24 HAT which was on par with neem and castor based formulation with 98.33 and 96.67 per cent mortality respectively. The next best treatments were 3% concentration of pongamia, neem and castor based formulations (95.00, 93.33 and 88.33 per cent mortality respectively).

A pot culture experiment was carried out in chilli variety Vellayani Athulya with the selected three effective treatments (pongamia, neem and castor based formulation of *A. paniculata*) to assess the field efficacy against sucking pest complex. Different concentrations (1, 2, 3, 4, 5, 7, 10, 15 and 20%) of the above selected treatments were evaluated with thiamethoxam 25% WG and spiromesifen 22.9% SC as chemical check. Two rounds of spraying *viz.*, 30 days after planting (DAP) and 60 DAP of the crop were undertaken.

In pot culture experiment lowest population of chilli aphids, thrips and mites were recorded at 5% concentration of extract of *A. paniculata* + pongamia oil + Triton X- 100 sprayed chilli plants and the effects were on par with chemical check thiamethoxam 25% WG and spiromesifen 22.9% SC

After first round of application of treatments in the vegetative stage of the crop, per cent reduction in the thrips population of 98.97, 97.94 and 97.94 over control was recorded in 5% concentration of pongamia, neem and castor based formulation respectively at 3 days after treatment (DAT). Upto seven DAT these treatments were equally effective as chemical insecticides thiamethoxam 25% WG and spiromesifen 22.9% SC. The population of aphids was found to be least in the treatments with 5% concentration of pongamia based formulation at 3 and 5 DAT which did not vary significantly with neem and castor based formulation at 5% concentration and these treatments were also on par with chemical check thiamethoxam 25% WG and spiromesifen 22.9% SC. It was observed that there was significant reduction in the mites population in pongamia based formulation at 5% concentration which recorded 92.92 over control at 5 DAT.

At second spraying, 5% concentration of castor, neem and pongamia based formulation were found to be superior in managing chilli thrips and as effective as chemical check thiamethoxam 25% WG and spiromesifen 22.9% SC in the reproductive phase of the crop. At 3 DAT, castor, neem and pongamia based formulation had low population of 0.44. 0.33 and 0.44 thrips leaf^{-1} at 5% concentration which were on par with chemical check. The aphid population were controlled effectively by 5% concentration of pongamia based formulation upto seven DAT. Pongamia formulation at 5% concentration gave good control upto seven DAT with 0.33 aphids leaf^{-1} as against 45.00 aphids leaf^{-1} in control. Neem and castor based formulation at 5% concentration were found to be the next effective treatments against chilli aphids. At 3 DAT, pongamia and neem based formulation showed 90.34 and 88.93 per cent reduction in the mite population respectively over control at 5% concentration and were found to statistically on par with chemical check.

Pongamia based formulation at 5% concentration significantly reduced damage by sucking pests as evidenced by lesser value (2.00) of leaf curl index at 100 days after planting. Ponagamia (3 and 4% concentration); neem and castor based formulation at 5% concentration was also found to reduce the leaf curl index (2.13) though inferior to the above treatment.

Higher number of natural enemies including coccinellid beetles and spiders; pollinators and neutrals were recorded in all treatments compared to thiamethoxam 25% WG and spiromesifen 22.9% SC at different intervals after treatments application. It can be concluded that pongamia neem and castor bio pesticide formulations of *A. paniculata* were safe to natural enemies, pollinators and neutrals.

The highest yield of 380.74 g^{-1} plant was obtained in 5% concentration of pongamia based formulation but treatments did not vary significantly. All treated plants exhibited improvement in growth attributes like plant height, number of primary branches and yield as against untreated control.

Shelf life studies of the promising treatments (plant extract of *A. paniculata* + pongamia oil + Triton X-100) selected from the field experiment was carried out by spraying the developed formulation at different intervals after preparation (fresh, 15, 30 and 60 days after preparation) against chilli aphid. From the statistical analysis of data it was observed that the pongamia based formulation was found to be effective even upto 60 days after preparation. Prolonged shelf life of the formulation may be due to antimicrobial properties of *A. paniculata*.

From the above results it can be concluded that pongamia based formulation of *A. paniculata* at 5% concentration was found to be highly effective in managing sucking pest complex of chilli along with conserving significant high population of natural enemies including cocinellid beetles and spiders; pollinators and neutrals.

The sailent findings of the investigation are

- Plant extract oil surfactant combination in the ratio of 7:2:1 was found to be suitable combination with good miscibility and Triton X-100 as most suitable surfactant.
- Pongamia based formulation of *A. paniculata* at 4% concentration caused 100 per cent mortality of chilli aphid 24 hours of treatment under laboratory condition.
- Pongamia, neem and castor based formulation of *A. paniculata* applied at dose of 5% concentration, could be effectively control the sucking pest complex of chilli.
- Pongamia based biopesticide formulation (5%) is effective for the management of chilli thrips, aphids and mites, with highest yield of 380.74g plant^{-1}.
- The Bio pesticide formulations of castor, neem and pongamia did not affect the population of natural enemies; pollinators and neutrals while thiamethoxam 25% WG and spiromesifen 22.9% SC reduced their population significantly at different intervals after application.
- From shelf life studies it was observed that pongamia based formulation of *A. paniculata* was found to be effective bio pesticide formulation even upto 60 days after preparation.
- In conclusion, Bio pesticide formulation with *A. paniculata*, pongamia oil and Triton X-100 in the ratio of 7:2:1 at 5% concentration is effective against sucking pest of chilli without affecting natural enemies, pollinators and neutrals.

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OIL BASED FORMULATION OF *Andrographis paniculata* (Burm.f.) Nees AGAINST SUCKING PESTS OF CHILLI

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ABSTRACT

The study entitled "Oil based formulation of *Andrographis paniculata* (Burm.f.) Nees against sucking pests of chilli" was conducted during 2017-2019, in the Department of Agricultural Entomology, College of Agriculture, Vellayani with objectives to develop oil based ready to use formulation of *A. paniculata,* to study the shelf life and to fix optimum dose for the management of the sucking pest complex of thrips (*Scirtothrips dorsalis* Hood), aphids (*Aphis gossypii* Glover) and mites (*Polyphagotarsonemus latus* Banks) in chilli.

Different combinations of extract of *A. paniculata*, oils and surfactants were tested in the laboratory for finding the suitable surfactant and their effective combination. Extract oil surfactant combination (EOSC) in the ratio of 7:2:1 was found to be the suitable combination with good miscibility and Triton X-100 as most suitable surfactant. Laboratory evaluation of various concentrations (5, 10 and 20%) of the different oil based combinations with EOSC ratio 7:2:1 was done using aphids, thrips and mites as test insects.

Results of the laboratory experiment revealed that extract of *A. paniculata* + neem oil + Triton X-100 and extract of *A. paniculata* + pongamia oil + Triton X-100 at 5% concentration was sufficient for 100 per cent mortality of aphids at 24 hours after treatment (HAT) and it was statistically on par with 5% concentration of extract of *A. paniculata* + castor oil + Triton X-100. The above mentioned treatments gave 100 per cent mortality against thrips and mites also. Lower concentrations (1, 2, 3 and 4%) of the above mentioned three treatments were selected for further evaluation against aphids. It was found that pongamia oil based combination at 4% gave 100 per cent mortality at 24 HAT.

A pot culture experiment was carried out in chilli variety Vellayani Athulya with the selected three effective treatments to assess the field efficacy against sucking pest complex. Different concentrations (1, 2, 3, 4, 5, 7, 10, 15 and 20%) of the above selected treatments were evaluated with thiamethoxam 25% WG and

spiromesifen 22.9% SC as chemical check. Two rounds of spraying *viz*., 30 and 60 days after planting (DAP) of the crop were undertaken.

In pot culture experiment lowest population of chilli aphids, thrips and mites were recorded at 5% concentration of extract of *A. paniculata* + pongamia oil + Triton X- 100 sprayed chilli plants and the effects were on par with chemical check thiamethoxam 25% WG and spiromesifen 22.9% SC.

The per cent reduction in the thrips population was 98.97, 97.94 and 97.94 over control at 5% concentration of pongamia, neem and castor based formulation respectively at 3 days after treatment (DAT) in vegetative stage of chilli. The population of aphids was found to be least in the treatments with 5% concentration of pongamia based formulation at 3 and 5 DAT which did not vary significantly with neem and castor based formulation at 5% concentration and these treatments were also on par with chemical check thiamethoxam 25% WG and spiromesifen 22.9% SC. It was observed that there was significant reduction in the mites population in pongamia based formulation at 5% concentration which recorded 90.16 per cent over control at 3 DAT.

At second spraying, 5% concentration of castor, neem and pongamia based formulation were found to be superior in managing chilli thrips and as effective as chemical check thiamethoxam 25% WG and spiromesifen 22.9% SC in the reproductive phase of the crop. At 3 DAS, castor, neem and pongamia based formulation had low population of 0.44. 0.33 and 0.44 thrips leaf^{-1} at 5% concentration which were on par with chemical check. The aphid population were controlled effectively by 5% concentration of pongamia based formulation upto seven DAT. Pongamia formulation at 5% concentration gave good control upto seven DAT with 0.33 aphids leaf^{-1} as against 45.00 aphids leaf^{-1} in control. Neem and castor based formulation at 5% concentration were found to be the next effective treatments against chilli aphids. At 3 DAT, pongamia and neem based formulation showed 90.34 and 88.93 per cent reduction in the mite population respectively over control at 5% concentration and were found to statistically on par with chemical check.

Significant difference in leaf curl index was recorded 100 days after planting in treatments compared to control. Pongamia oil based combination at 5% concentration recorded lowest leaf curl index value (2.00) as against 3.20 in control.

Higher number of natural enemies including coccinellid beetles and spiders; pollinators and neutrals were recorded in all treatments compared to thiamethoxam 25% WG and spiromesifen 22.9% SC.

Shelf life studies of pongamia based formulation revealed that the bio pesticide formulation is effective upto 60 days after preparation.

From the study it can be concluded that Triton X-100 is the best surfactant for the development of oil based formulation of *A. paniculata.* The treatment with extract of *A. paniculata* + pongamia oil + Triton X-100 at 5% concentration found to be effective against sucking pest complex with lowest leaf curl index. Shelf life studies were revealed that 5% concentration of pongamia oil based formulation was highly effective upto 60 days after preparation. It can be recommended as an eco-friendly bio pesticide formulation for the management of sucking pest complex in chilli.