BOTANICAL-CHEMICAL PESTICIDE COMBINATIONS FOR MANAGING COWPEA APHID *Aphis craccivora* Koch

by

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THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"BOTANICAL-CHEMICAL PESTICIDE COMBINATIONS FOR MANAGING COWPEA APHID *Aphis craccivora* Koch"** is a bonafide record of research work done by me during the course of research and that 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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CERTIFICATE

Certified that this thesis entitled **"BOTANICAL-CHEMICAL PESTICIDE COMBINATIONS FOR MANAGING COWPEA APHID *Aphis craccivora* Koch"** is a record of research work done independently by Ms. Janu S. Nair (2020-11-154) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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Janu S Nair

CONTENTS

LIST OF TABLES

LIST OF PLATES

LIST OF FIGURES

LIST OF ABBREVIATIONS

a.i	Active ingredient
CD	Critical Difference
CRD	Completely Randomised Design
DAP	Days after planting
DAT	Days After Treatment
et al.	And others
Fig.	Figure
g	Gram
h	Hours
HAT	Hours After Treatment
KAU	Kerala Agricultural University
L	Litre
m^{-2}	Per meter square
mg	Milligram
mL	Millilitre
mL^{-1}	Per milliliter
RBD	Randomised Block Design
rpm	Revolutions per minute
SE	Standard error
sp. or spp.	Species (singular and plural)
viz.	Videlicet (Latin); Namely
%	Percentage
v/v	Volume by volume

Introduction

1. INTRODUCTION

Cowpea *Vigna unguiculata* L. is grown as pulse crop, fodder crop, catch crop, mulch crop, and green manure crop (Giridhar *et al.*,2020). India is the largest producer and consumer of pulses in the world. The production of pulses in India is 23.15 million tonnes during the period 2019-20 (DACFW, 2021).

Several insect-pests and other arthropods are known to attack the crop at its different stages of growth. As many as 21 insect pests of different groups are recorded damaging the cowpea crop from germination to maturity. The important insect species attacking cowpea crop are : pea aphid, *Aphis craccivora* Koch, mealy bug, *Ferrisia virgata* Cockerell; pod bug, *Riptortus pedestris* Fabricius; fulgorid bug, *Eurybrachys tomentosa* Fabricius; thrips, *Ayyaria chaetophora* Karny; spotted red mite, *Tetranychus truncatus* Ehara and foliage feeders *viz*., pod borer, *Lampides boeticus* Linnaeus; tobacco caterpillar, Spodoptera litura Fabricius; leaf beetle *Pagria flavopustulata* Baly; American serpentine leaf miner, *Liriomyza trifolii* Burgess resulting in yield losses (Thamilarasi, 2016) .

The cowpea aphid, *A craccivora* is the most serious pest of this crop causing 20 to 40 per cent yield loss (Singh and Allen, 1980). Both nymphs and adults cause damage by sucking cell sap from leaves, petioles, tender stems, inflorescence and pods. This pest also excretes honeydew (a sugar-rich substance) which accelerates the development of the fungi *Capnodium* spp. there by reducing the photosynthetically active area of the plant and lead to leaf shedding (Ambarish *et al.,* 2017). They also act as vectors of several viral diseases like cowpea mosaic and papaya mosaic leading to early death of plants. Saliva toxins released during feeding result in phytotoxicity. The aphid causes both qualitative and quantitative losses in cowpea.

Because it is a polyphagous species with a high reproductive potential and capacity for infestation (Kataria and Kumar, 2012), its control has faced several difficulties. Synthetic insecticides like thiamethoxam, cypermethrin, alphacypermethrin, deltamethrin and lambda cyhalothrin have served as effective control measure for several sucking pests like aphids. But according to Matsuura and Nakamura (2014) the problem associated with the application of such chemicals is that aphid populations, constantly exposed to these insecticides, have become resistant to these synthetic insecticides and the need for further pesticide application. This initiates the difficulty of constant application of synthetic insecticides (Herron and Wilson, 2017).

Synthetic insecticides are used to protect the crop from these noxious pests and use of insecticides during the flowering stage may lead to accumulation of residues in the pods. Farmers' resort to spraying various insecticides with short intervals resulted in insecticide resistance, secondary pest outbreak and pest resurgence, destruction of natural enemies and environmental pollution. This has necessitated the search for alternative control measures that are eco-friendly and pose no health and environmental threat. The use of plant extracts and various botanicals in insect pest management is not only useful for suppression of pest population but also helps to maintain a sound ecological balance. Botanical alone is not able to control pests when the pest population is very high in the field and farmers usually prefer very high doses of chemical pesticides for managing these pests.

It is known that combinations of different products can promote greater toxicity to insects, since a compound can potentiate the action of another active ingredient by weakening the insect detoxification system, acting on the inhibition of P450 enzymes and esterases (Bailen *et al.*, 2013; Khan *et al*., 2013). Another point that should be considered is that insecticide resistance develops slowly when essential oil-based products are used, due to the diversity of active compounds that characterize the products (Fazolin *et al*., 2016).

The use of plant derivatives as an alternative to chemical insecticides has been studied throughout the world from long time and found effective not only economically and ecologically safe, but also free from residual and resurgence problems. Many of the botanicals have been explored for their broad spectrum activity.

Neem tree, *Azadiracta indica* A. Juss, (Meliaceae) is an important source of 99 biologically active compounds and most of these compounds showed antifeedant, ovicidal, larvicidal and oviposition deterrent activity against a number of insects (Schumutterer, 1990; Isman, 2006; Locantoni *et al*., 2006; Dua *et al*., 2009; Stanley *et al*., 2014).

Pungam oil possesses toxic components such as glabrin, karajn, karajae and pongoglabrone, which are effective against insect pests of stored grains, field and plantation crops (Packiam and Ignacimuthu, 2012). *Andrographis paniculata* Burm. f. is found efficient in reducing the activities of insect pests attacking the cowpea and encouraged the cowpea plant to have more leaves, growth and flowering in comparison with untreated plants.

The combination of natural and synthetic products and their variable combinations can deliver comparable or greater pest toxicity while reducing the necessary dose of the synthetic molecules, thus maintaining its effectiveness. Numerous plant extracts may work in harmony with common pesticides. Scientists began to pay attention to plant-based synergists which include terpenes, phenolics, alkaloids, essential oils and several other secondary metabolites (Lichtenstein *et al*., 1974).

Botanical and chemical pesticide combinations can be an important tool to be developed and used in integrated pest management, specifically to manage insecticide resistance management. Furthermore, it may reduce the environmental impact of pesticide use.

The present study entitled botanical-chemical pesticide combinations for managing cowpea aphid *Aphis craccivora* Koch is intended to minimize the use of chemicals by combining them with different botanical pesticides.

Review of literature

2. REVIEW OF LITERATURE

Cowpea *Vigna unguiculata* L. belongs to the family of Fabaceae. The plant is a herbaceous legume showing considerable adaptation to warm climates with adequate rainfall and is cultivated across Southeast Asia, Africa, Southern United States and Latin America (Jayathilake *et al.*, 2018). Cowpea is an important pulse crop cultivated in arid and semi-arid regions of the world (Deepika *et al.*, 2020).

The peculiar features of the crop such as high protein content, nitrogen-fixing ability, drought tolerance, and adaptability to challenging environments make cowpea, a promising climate-resilient food legume of the 21st century (Tripathi, 2019). Ketema (2021) highlighted that although beans are the primary focus of the cowpea plant, in some parts of the world, flowers and leaves are also considered edibles.

In developing countries, cowpea provides food for millions of people, with an annual worldwide production of about 4.5 million metric tons (Animasaun, 2015). India, the largest producer and consumer of pulses in the world, recorded 23.15 million tonnes of pulse production during 2019-20 and the projected demand by the year 2030 is 35 million tonnes (DACFW, 2021; Farmer Portal, 2018). The major abiotic constraints in the production of cowpea are the attack by various pests and diseases.

Cowpea is attacked by many insect species, among which the cowpea aphid *Aphis craccivora* Koch is of major importance. *A. craccivora* is a sucking pest, feeding the plant sap from the growing points of plants and developing pods, this feeding causes considerable damage to the plant and leads to economic losses (El-Zoghby, 2022).

To control such prolifically breeding pest, various management measures are used, among those the most reliable method followed is the use of synthetic chemicals. The irrational use of synthetic chemicals exerts many drawbacks such as pest resurgence, outbreaks of secondary pests, phytotoxicity and residues in foods and feeds, killing beneficial organisms and creating an ecological imbalance (Ashamo, 2004).

This necessitated the need to develop alternate management measures which are environment friendly and pose no threat to the ecology. The use of botanicals and plant extracts to control pests and its integration with chemical pesticides is emerging as a sustainable method of crop management. The various publications related to the cowpea aphid *A. craccivora* and their management, combining botanicals with chemical pesticides and their efficacy and environmental impact are reviewed here.

2.1 PESTS OF COWPEA

Insect pests are thought to be the main cause of the considerable reduction in pulse grain production. In India, over 150 insect species are known to damage pulse crops, with about 25 species being particularly harmful (Srivastava, 1964). A diversity of insect species attacks almost every part of the cowpea plant.

Thamilarasi (2016) reported the following pests associated with cowpea which includes sucking pests *viz.*, pea aphid, *Aphis craccivora* (Koch), mealy bug, *Ferrisia virgata* (Cockerell), pod bug, *Riptortus pedestris* (Fabricius), fulgorid bug, *Eurybrachys tomentosa* (Fabricius), thrips, *Ayyaria chaetophora* (Karny), spotted red mite, *Tetranychus truncatus* (Ehara) and leaf feeders *viz.*, pod borer, *Lampides boeticus* (Linnaeus), tobacco caterpillar, *Spodoptera litura* (Fabricius), leaf beetle *Pagria flavopustulata* (Baly), American serpentine leaf miner, *Liriomyza trifolii* (Burgess) and girdle beetle, *Oberiopsis brevis* (Gahan) are the pests of cowpea under polyhouse.

Insect pest attack and their damage are noticed at all growth stages and this leads to yield loss up to 70 per cent. The heavy incidence of pests is a major limiting factor in cowpea production (Edema and Adipala, 1996).

The cowpea aphid is the major insect pest that severely harms cowpea at all stages of growth (Jackai and Daoust, 1986). Reasonable grain production cannot be attained without their control (Suh *et al.*, 1986).

2.1.1 Cowpea Aphid *Aphis craccivora* Koch

According to Obopile and Ositile (2010) cowpea aphid, *A. craccivora* is a devastating pest of cowpea causing damage by sucking sap from the tender parts of the plants from the young seedling stage to pod bearing stage. Cowpea aphid serves as an important pest of cowpea in most tropical regions. The incidence and attack of cowpea aphid are seen in almost all states of India. They cause significant damage by acting as a vector for several viral diseases.

The pest even causes significant yield losses in other legume crops including alfalfa, beans, chickpea, lentils, lupins and peanuts. In the tropics, *A. craccivora* spends the dry and winter season on wild host species such as the *Medicago* sp., *Melilotus* sp., *Trifolium* sp., *Euphorbia* sp. and *Boerhaavia* sp. (Kamphuis *et al.,* 2012).

The damage caused to the host is by both adults and nymphs of *A. craccivora*. The feeding habit is of sucking the plant sap from the phloem of the tender shoots, inflorescence, leaves and tender pods; which leads to the drying up of plant parts, stunting, malformation and loss of vigour in the plant. Heavy feeding eventually kills the young seedlings (Umaru *et al*., 2003).

The adults are shiny black or dark brown in colour and of variable size of 1.5 to 2 mm. The paired antennae are present and are two-thirds as long as the body. They are wingless with a dusty brown colour body and fairly rounded in shape (Wightman *et al.*, 1990).

According to Ofuya (1997) the alate forms disperse once the rain starts and colonise the host plants and are mostly responsible for the finding of new host plants. The insect passes through four nymphal stages before reaching the adult stage. Under favourable conditions and abundant food supply, the apterous adult females are produced parthenogenetically, whereas when the situations are unfavorable with a shortage of food and overcrowding occurs this leads to the production of alate adults.

They cause significant economic damage either directly by sucking sap from leaves, pods, and other tender aerial tissues, or indirectly through transmission of major viruses like the faba bean necrotic yellows virus (FBNYV) and the bean leaf roll virus (BLRV) (Laamari *et al*., 2008). It spreads at least 14 viruses that affect legumes. Additionally, they release honeydew, which promotes the development of the fungus known as sooty mould and prevents plants from photosynthesis (Trivedi and Singh, 2014).

2.2 NATURAL ENEMIES

According to Jackai (1982), who conducted an extensive study on the ecology of pests and natural enemies of cowpea states that natural enemies play a key role in reducing the potential of pest population surges, and in a monocropping system of cowpea, the population of natural enemies may not be sufficient to suppress a large number of pest populations. The biology and population dynamics of the pest and natural enemies differ largely due to variations in the agroclimatic conditions that prevail over each region.

Niba (2011) highlighted that ladybird beetles (Coleoptera: Coccinellidae, 50%), Wasps (Hymenoptera: Vespidae, 28%), Assassin bugs (Hemiptera: Reduviidae, 18%) and spiders (Arachnida, 11%) were the most prevalent arthropod natural enemy populations recorded from the cowpea experimental plot during vegetative to maturity stages.

The majority of the species of specialised aphidophagous predators belonged to the lacewing (Chrysopidae: Neuroptera) and coccinellid (Coccinellidae: Coleoptera). Lacewings only act as predators during their larval stage, whereas coccinellids are active predators in both the larval and adult stages (Caballero-López *et al*., 2012). Omkar and Bind (2004) stated that predaceous coccinellids are a major factor in the natural control of the *A. craccivora*. Voracious and aphidophagous coccinellids *such as Cheilomenes sexmaculata* (Fabricius), *Coccinella transversalis* Fabricius and *Propylea dissecta* (Mulsant) are found abundant in the cowpea fields of India infested with the aphids, *A. craccivora* Koch.

2.3 MANAGEMENT OF COWPEA APHID

The commonly used measure against the management of aphids is chemical insecticides as they provide the desired control of the aphid population in a short period of time. Many insecticides have been evaluated and recommended for effective aphid control.

According to Patil *et al.* (2018) over the years, conventional traditional chemicals have become resistant and ineffective to control the increasing pest population. Selective insecticides like neonicotinoid insecticides were introduced to overcome the disadvantages of conventional insecticides and they act on the central nervous system and bind at a specific site *viz*, the postsynaptic nicotinic acetylcholine receptor leading hyperexcitation of nerves which eventually paralyse and kill the insect.

The bioassay study conducted by Saleh *et al.* (2016) showed that *A. craccivora* population for 12 generations in consecutive selection with selected strains had developed 48 fold resistance against thiamethoxam. This resistant strain also showed cross-resistance to the tested neonicotinoid (acetamiprid), carbamates (pirimicarb and carbosulfan) and organophosphorus (malathion, fenitrothion and chlorpyrifos-methyl). Such studies propose the need for the development of newer management strategies incorporating less amount of chemicals and more botanicals for pest management.

2.3.1 Efficacy of Botanicals Against Cowpea Aphid

Adeyemi (2010) highlighted that Greeks were the first to record the use of plants as biopesticides against biting insects, and this practice is still widely used today. Prior to the discovery of synthetic pesticides, farmers around the world could only manage pests with plant-based or plant-derived products.

Plant-derived essential oils and various plant products can be employed as active ingredients in novel botanical pesticides because they are usually regarded as harmless for the environment and human health (Ping *et al*., 2001).

Walia and Koul (2008) stated that there are over 6000 plant species that posses various insecticidal properties and most of which are exploited by the farmers in developing countries.

Mohapatra *et al.* (2021) commented that plant-based insecticides are widely used and recognized as natural pesticides, they protect crop plants, as well as the environment from pesticide pollution. The use of botanicals as pesticides was found to possess many repellent and toxic capacities for various pests including aphids (Gupta and Dikshit, 2010).

Ikbal and Pavela (2019) observed that plants can be protected against pests using botanical insecticides, which are based on the insecticidal properties of secondary plant metabolites. The metabolites also serve as a toxic defensive mechanism that deters the reproduction and other processes of invading pests.

It has been observed that many plant derivatives and essential oils are beneficial against *A. craccivora* (Aziz *et al*., 2015). Many such plant products which include botanical oils of *Azadirachta indica* (neem), *Pongamia pinnata* L. (karanja) and plant extracts of *Andrographis paniculata* (Burm.f.) are been reported as effective for the management of aphids (Aziz *et al*., 2018; Bhavyasree, 2019).

A study conducted by Khan *et al.* (2017) stated that the potential botanical insecticides could adapt well to integrated pest management programs toward controlling aphids. Plant derivatives of *Daphne mucronata* R., *Tagetes minuta* L., *Calotropis procera* L., *Boenninghausenia albiflora* R., *Eucalyptus sideroxylon* C., *Cinnamomum camphora* S. and *Isodon rugosus* W. will be safer than the traditional pesticides currently used to control aphids as they have already been employed for various medicinal uses traditionally.

In addition, plant-derived insecticides include a wide range of chemical compounds that act together to affect both physiological and behavioral processes, in contrast to conventional insecticides that are based on a single active ingredient. Therefore, it is less probable that pests will develop a resistance to these compounds (Saxena, 1987).

2.3.1.1 Bioefficacy of pongamia oil

Pongamia pinnata (L.) Pierre is a tree native to Southeast Asia. The tree is commonly known as Karanja, found all over India and belongs to the family Fabaceae. It is a medium-sized glabrous, perennial tree with imparipinnate leaves and pinkish-white blooms. It can withstand drought and salinity very well (Kirtikar and Basu, 1984).

According to Sangwan *et al.* (2010), *P. pinnata* seeds contain about 40 per cent of oil. The seed cake and the brown oil that was extracted from the tree have been used as biopesticides and repellents. This plant also has curative properties in its roots, bark, leaves, flowers and seeds.

Karanjin, pongamol and glabrin are compounds found within the seeds. Additionally, phytochemistry studies on this plant have revealed the presence of furanoflavones, furanoflavonols, chromenoflavones, flavones, furanodiketones and flavonoid glucosides. Pongamia is a rich source of flavonoids, some of which have biological activity. In pongamia oil, the secondary metabolites flavonoids, chalcones, steroids, and terpenoids act as insect deterrents (Pavela, 2007).

Due to its antifeedant, oviposition deterrent, ovicidal, roachicidal, juvenile hormone activity and insecticidal capabilities against a variety of pests, pongamia oil also exhibits a good synergistic impact with a number of conventional pesticides, increasing its potential as a biopesticide (Kumar and Singh, 2002).

As per the study conducted by Parmar and Gulati (1969), pure karanjin, the defatted seed cace, and ethanolic extracts exhibited insecticidal action against the mustard aphid (*Lipaphis erymsimi* Kalt.). According to Pavela, (2007) *P. pinnata* extracts were found to have antifeedant properties toward numerous insect pests of diverse crops. When applied at 1.0% (v/v), has a well-known high egg-laying deterrent action against several insect pests.

A study conducted by Sajay *et al.* (2020) in the management of cowpea aphid, *A. craccivora* revealed that the highest efficacy without phytotoxicity was demonstrated by pongamia oil soap at 2%, followed by 1% and 0.6 % neem oil soap. Pongamia extracts are one of the ingredients in several commercially marketed insecticides, including Plexin, Karrich, Salotrap, RD-RepelinTM, and RD-9 Repelin TM, that are used to control a variety of insect pests.

2.3.1.2 Bioefficacy of neem oil

Azadirachta indica is native to South Asia; however, the tree has spread globally along the tropical belt and is widely available in India. Also known as margosa or Indian lilac, is a plant from the Meliaceae family. The seed consists of a shell surrounding one to three kernels, each of which contains azadirachtin and its analogues as well as several associated triterpenoids which include salannin, nimbin and 3-tigloyl-azadirachtin (Nisbet, 2000; Das *et al.*,2008). *A. indica* can be used as an effective pesticide (Hussain *et al*., 1996).

Botanicals from neem contain Azadiractin as a main component which can reduce pest infestation in cowpea plants and repel them (Selvasundaram and Muraleedharan, 1999; Lale and Kabeh, 2004). Various studies have proved that neem products including neem oil are effective in controlling sucking pests including aphids (Roy and Gurusubramanian, 2011; Sakthivel *et al*., 2011 ; Sreerag and Jayaprakas, 2015).

According to Osman and Port (1990), neem is systemically active, works at low concentrations, is barely hazardous to mammals and degrades easily in the environment. Neem-based insecticides have been reported as effective in managing the aphid population and are also viable for inclusion in integrated pest management.

Halder and Banik (2013) stated that the active element azadirachtin a complex tetranortriterpenoid limonoid is found in many plant parts, including the leaves, seeds, and bark, of the neem plant, and it can be used to manage plant diseases and insect pests. Neem extracts can inhibit insects from feeding, regulate their growth and restrict insect growth regulators from being produced. When applied to the root region, neem-based products with no residue on crops can have systemic effects. Azadirachtin has a low mammalian toxicity with an LD_{50} greater than 5000 mg/kg for rats, making it likely to be harmless to mammals, fish and pollinators.

An experiment conducted by Rabbi (2021) included seven treatments *viz*, neem seed extract, neem oil, mahogany seed extract, black pepper extract, garlic extract, a tobacco extract, and untreated control to study their effect on the seed quality of the country bean, *Lablab purpureus* L. The results infer that during the early, mid, and late pod development stage minimum incidence of aphid were 2.49, 2.23, and 4.27, respectively whereas in pod, population 5.97, 7.89 and 8.54, respectively was observed in the plots with neem oil.

A study was conducted by Halder *et al.* (2013) to analyse the median lethal time (LT_{50}) of various entomopathogens and neem oil alone against important sucking pests of vegetables and their 1:1 combinations with neem oil. The results on *A. craccivora* and *L. erysimi* indicated that neem oil (5%) was found to be the most efficient biopesticide in preventing aphids from infesting crops, and its median lethal time (LT_{50})

was 60.88 h. Whereas *Verticillium lecanii* Zimm., *Beauveria bassiana* Bals., and *Metarhizium anisopliae* Metschn. had the lowest LT_{50} values among the entomopathogens (66.54 h, 79.40 h, and 82.19 h, respectively). However, when these bioagents were combined with neem oil at a 1:1 ratio, all of the entomopathogens not only showed compatibility but also indicated synergism with neem oil. The apparent additive, synergistic, and/or stabilising effects of neem oil were linked to the observed increase in the activity of neem oil and entomopathogenic fungal combinations.

An experiment was conducted by Baidoo *et al.* (2012) to evaluate the effectiveness of two neem formulations, aqueous neem kernel extract (ANKE) and neem kernel powder (NKP) for the management of cowpea aphid, *A. craccivora,* and the effect on its predator *Harmonia axyridis* Pallas. The results of the study revealed that the population of *A. craccivora* on ANKE and NKP-treated plots (6.8 per plant and 9.8 per plant respectively) were lower than the untreated control plot (24.8 per plant). Whereas the population of *H. axyridis* was highest in the control plot (5.2 per plant) and the plants treated with ANKE and NKP harbored 4.0 per plant and 4.1 per plant respectively, which was higher than the population in chemical check (2.0 per plant) treated with active ingredient lambda cyhalothrin.

2.3.1.3 Bio efficacy of Andrographis paniculata (Burm.)

Andrographis paniculata Burm. belongs to the Acanthaceae family and is a medicinal plant that tastes extremely bitter. It is commonly known as the King of Bitters or Rice Bitters or Kalmegh is an annual, branched, herbaceous plant growing up to a height of 30-110 cm in moist shady regions with simple, opposite and lanceolate leaves. The plant grows abundantly in South-East Asia and is native to Taiwan, Mainland China and India (Chopra *et al*., 1956).

Over 20 diterpenoids and over 10 flavonoids have been reported to be active chemicals extracted with ethanol or methanol from the entire plant, leaf and stem of *A. paniculata*. The main diterpenoid in *A. paniculata* is andrographolide ($C_{20}H_{30}O_5$), which accounts for 4%, 0.8–1.2% and 0.5–6% in dried whole plant, stem and leaf extracts, respectively. Deoxyandrographolide, neoandrographolide, 14-deoxy-11,12-

didehydroandrographide and isoandrographolide are the other primary diterpenoids (Mandal *et al.,* 2001; Rao *et al*., 2004; Chao *et al.*, 2009)

A study conducted by Obadofin *et al.* (2018) revealed that extracts of *A. paniculata* reduced the activities of insect pests attacking cowpea and encouraged the cowpea plant to have more leaves, growth and flowering in comparison with untreated plants.

Suganthy and Sakthivel (2013) conducted an experiment in studying the efficacy of botanicals *viz, A. paniculata* extracts 2 % , neem seed kernel extract 5 %, aqueous extract of *Vitex negundo* L. 2 %, azadirachtin 1%, pongamia oil 3 mL/litre, mineral oil 3 mL/litre, with chemical check profenophos 2 mL/litre and untreated control against major pests (aphids, thrips, leaf miners and defoliators) infesting black nightshade *Solanum nigrum* Linn. In thrips, *Thrips tabaci* Lindeman at seven days after treatment, *A. paniculata* recorded maximum reduction (0.3 thrips/plant) followed by NSKE and mineral oil (0.5 thrips/plant) when compared with the pre-count ranging from 8.1 to 9.7 thrips/plant. Similarly in defoliators (*Spodoptera litura* Fabr., *Henosepilachna vigintioctopunctata* Fabr., *Plusia peponis* F.), at seven days after treatment, highest reduction in the defoliation percentage was recorded in the standard check (no damage) followed by *A. paniculata* (0.9 %), neem oil (1.0 %) and *V. negundo* (1.1 %). *A. paniculata* extracts 2 % was also found significant in reducing the population of *A. craccivora* at a rate of 6.3 aphids per plant when compared with 39.5 per plant in control plot at 14 days after treatment.

A. paniculata, Catharanthus roseus (L.), *Calotropis gigantea* (L.), *Lantana camara* L., *A. indica*, *P. pinnata* and *Cassia tora* L. were examined for their bio efficacy by Singh *et al.* (2014). *A. paniculata* decoction was the most effective botanical insecticide against thrips (3.73-5.01 thrips per leaf), and its performance was comparable to that of 0.03% dimethoate. In comparison to the control plot (89.99 q ha^{-1}), the maximum yields were obtained using dimethoate (98.07 q ha^{-1}) and *A. paniculata* decoction spray (98.04 q ha^{-1}).

In a pot culture experiment conducted by Bhavyasree (2018), the lowest population of chilli aphids, mites and thrips were observed when *A. paniculata* extract, pongamia oil, and triton X-100 were sprayed on the plants. These results were comparable to thiamethoxam 25% WG (50 g a.i ha^{-1}) and spiromesifen 22.9% SC (96 g a.i ha^{-1}).

According to Bernice (2000), combining *A. paniculata* leaf extract with 2.5% neem oil emulsion and 20 g L^{-1} of garlic had deterrent effect of 40% and 80% on aphids and epilachna beetles in the brinjal .

2.3.2 Efficacy of Chemicals

Generally, aphid control heavily relies on the use of synthetic insecticides such as carbamates, organophosphates and pyrethroids, which led to aphid resistance to these insecticides therefore, another group of insecticides is required to be used for aphid management. One of these insecticides is the neonicotinoid group including; imidacloprid, acetamiprid and thiamethoxam, which have been used globally over the last decade because of their high impact against a wide range of dangerous aphid species (Jeschke *et al*., 2011).

Neonicotinoid insecticides are some of the most efficient pesticides used in the world for the prevention and control of sucking insect pests such aphids, whiteflies, leafhoppers, planthoppers, thrips, several micro-lepidoptera and a number of coleopteran pests. Due to their physicochemical characteristics, they can be applied in a variety of ways, including foliar, seed treatment, soil drench and stem application (Liu *et al*., 2011).

Due to the indiscriminate use of non-selective synthetic molecules and the resulting resistance problem in aphids and borers with higher natural enemy mortality, a new modern era of employing combinations of new molecules with different modes of action for sustainable management of these pests has emerged (Sharah and Ali, 2008).

Yadav *et al*. (2015) evaluated the effectiveness of ten insecticides and bioagents against the leaf hopper, *Empoasca motti* Pruthi, whitefly, *Bemisia tabaci* Genn, and aphid, *A. craccivora* of cluster bean, *Cyamopsis tetragonoloba* (Linn.), and found that dimethoate (0.03%), thiamethoxam (0.025%), and imidacloprid (0.005%) were most efficient .Whereas, profenophos (0.05%), acephate (0.037%), and lambda-cyhalothrin (0.008%) were ranked in the middle; however, novaluron (0.02%), diflubenzuron (0.05%), *Metarrhizium anisopliae* Metschn. (2 x10^7 spores) and NSKE (5.0%) were seen as the least effective.

Vegetables and fruits with little to no pesticide use are in high demand. Additionally, the scale of the global vegetable trade has increased the need for environmentally sustainable insect control.

2.3.2.1 Efficacy of thiamethoxam

The first commercially available thianicotinyl subclass of neonicotinoid pesticide is thiamethoxam. By attaching to nicotinic acetylcholine receptors, thiamethoxam exerts its action (Wiesner and Kayser ,2000). Neonicotinoids are chemically similar to nicotine and epibatidine, two naturally occurring substances that are known to be powerful agonists of nicotinic receptors in both insects and vertebrates. However, neonicotinoids are rather selective for insect receptors as opposed to vertebrate receptors as a result of their unique structural properties, which is a great benefit for application in crop protection and public hygiene (Wellman *et al*., 2004).

Thiamethoxam displays great systemic properties and offers excellent control of a variety of commercially significant pests, including several lepidopteran species and aphids, jassids, whiteflies, thrips, rice hoppers, beetles and whiteflies. Additionally, it has been shown to have a potent preventive effect on the spread of several viruses. Both foliar/soil treatments and seed treatment for usage in the majority of agricultural crops worldwide are developed for thiamethoxam (Torres *et al*.,2003).

This novel pesticide is well-suited for modern integrated pest management programmes in many agricultural systems because of its low usage rates, variable application methods, good efficacy, long-lasting residual activity and favourable safety profile (Maienfisch *et al*., 2001).

An experiment conducted by Abd-Ella, (2014) in *A. craccivora*, a field strain of the cowpea aphid, was exposed to various neonicotinoid insecticides to assess their persistence and toxicity. Thiamethoxam, acetamiprid and imidacloprid had the highest aphidicidal activity according to the toxicity index, with LC_{50} of 0.60, 0.71, and 1.16 mgL^{-1}, respectively, whereas dinotefuran had the lowest LC_{50} of 23.41 mgL^{-1}. According to the pesticides' residual effects, the LT_{50} for acetamiprid, imidacloprid, thiamethoxam and dinotefuran, respectively, was 5.8, 6.2, 6.95, and 4.2 days. According to the report findings, both in the field and in the lab, neonicotinoid pesticides were quite effective against cowpea aphid.

2.3.3 Botanical-Chemical Pesticide Combinations

In 1974, scientists began to pay attention to plant-based synergists. These plant extracts include terpenes, phenolics, alkaloids, essential oils and several other secondary metabolites (Lichtenstein *et al*., 1974).

Kaleem *et al.* (2022) stated that excessive insecticide use has led to pest resurgence and insect pest resistance. Synergists that act as inhibitors of detoxifying enzymes can provide a unique approach to resistance management to address this issue. Plant-based and RNAi-based synergists are significantly safer and simpler to produce against insects due to issues with chemical synergists. Numerous plant extracts may work in harmony with common pesticides.

There are numerous reports of using botanical pesticides in place of chemical pesticides, which are essentially detrimental for the ecosystem. *Tribolium castaneum* H., a pest of stored products, was found to be more sensitive to pongamia oil or citronella oil combined with deltamethrin (Sridevi and Dhingra, 1997). Bioassay studies were carried out by Hassan (2020) to evaluate the combined effects of spinosad and sweet almond oil at different concentrations against the adults of *Oryzaephilus surinamensis* L. Spinosad and sweet *al*mond oil, mixed at LC_{20} spinosad + LC_{20} sweet almond, were the most effective against *O. surinamensis* when compared to other combinations.

An experiment conducted by Lichtenstein *et al*. (1974) in dill plants (*Anethurn graueolus* L.) indicates that certain compounds isolated from the plant (d-carvone, myristicin, apiol and its isomer, dill-apiol) when combined at a sublethal dose increased the toxicicty of chemicals (carbaryl, carbofuran and parathion) towards insects.

Singhamony *et al.* (1983) inferred that adding the oil of *P. glabra* and its constituents, karanjin and pongamol, to synthetic insecticides such as isolan, pyrolan, carbaryl, endrin, or heptachlor can significantly increase their toxicity against adult house fly (*Musca domestica* L.) and the cotton stainer, *Dysdercus cingulatus* F.

When combined with 4% aqueous neem leaf extract, pesticide (profenfos 1ml $Litre^{-1}$) effectiveness in suppressing *Plutella xylostella* L. was reported to improve (Facknath, 1993). When monocrotophos 0.05% and annona seed extract (1%) were combined, *Spodoptera litura* F. *invitro* mortality increased to the highest level (Boreddy and Chitra, 2001). Similarly experiment conducted by Loganathan *et al*. (2003) states that indoxacarb and pongamia oil (5%) together have successful performance against *S. litura* .

Sesamum indicum L., *Millettia pinnata* L., *A. indica* L. and *Pelargonium citrosum* L. are case studies of plants whose vegetable oils can effectively increase the toxicity of pyrethroids to a greater extent. Synthetic synergists like piperonyl butoxide and diethyl maleate also increase the toxicity of pyrethroids against beetles (Sridevi and Dhingra, 1996).

In a study conducted by Flanery (2011), included the experiments to evaluate the efficacy of combining Agroneem Plus® and thiamethoxam on diamondback moths, *P. xylostella* infesting collard greens, *Brassica oleracea* L . The results of the study shows that the combination demonstrated the full spectrum of specified interactions, including antagonistic, additive and synergistic effects. It also reports that the potential synergy observed was more effective than thiamethoxam at one by fourth the recommended rate and Agroneem Plus® at double the recommended rate.

Materials and methods

3. MATERIALS AND METHODS

The field experiments and laboratory studies in the present investigation were carried out at the Department of Agricultural Entomology and at the Instructional farm of the College of Agriculture, Vellayani during the period 2020 to 2022. The objectives of the study were to evaluate the effect of botanical-chemical pesticide combinations for managing cowpea aphid *Aphis craccivora* in cowpea. The materials utilized and methods followed for conducting the investigation are described in this chapter.

3.1 *IN-VITRO* EVALUATION OF BOTANICAL CHEMICAL PESTICIDE COMBINATIONS AGAINST COWPEA APHID *A. craccivora*

3.1.1 Development of Formulations

The basic components used for developing the formulations were

1. Oils - neem oil and pongamia oil
2. Plant extract of *Andrographis paniculata* (Burm.f.)
3. Thiamethoxam 25 WG
4. Surfactant - Triton X-100

3.1.1.1 Preparation of neem oil emulsion

2 % neem oil emulsion was obtained by mixing 2 mL neem oil with 1 mL of triton X-100 and the solution is made upto one litre by adding water.

3.1.1.2 Preparation of pongamia oil emulsion

2 % pongamia oil emulsion was obtained by mixing 2 mL pongamia oil with 1 mL of Triton X-100 and the solution is made upto one litre by adding water.

3.1.1.3 Preparation of plant extract

A. paniculata (2.5 kg) was collected from the College of Agriculture, Vellayani premises. The leaves, flowers, tender shoots and roots were chopped into an approximate size of 0.5 - 1.00 cm and washed in clean water. The chopped plant parts were macerated thoroughly in an electric grinder without adding water to obtain plant extract. The obtained plant extract was strained using a filter to remove the debris followed by sieving through a double layered muslin cloth. Pongamia oil, triton-X-100 and *A. paniculata* plant extract were combined in 7:2:1 ratio and spin at 192 rpm for 30 minutes to ensure thorough mixing (Bhavyasree, 2019). The final formulation was stored in a refrigerator for later use.

3.1.1.4 Preparation of thiamethoxam solution

0.2, 0.01 and 0.005 % thiamethoxam 25 WG solutions were prepared by dissolving 0.2, 0.1 g and 0.05 g of thiamethoxam 25 WG in one litre of water with constant stirring.

3.1.1.5 Preparation of botanical-chemical pesticide combinations

Different combinations of treatments (Thiamethoxam 25 WG, *A. paniculata* extract, oils and surfactant) were mixed in the desired concentration. One litre of each combination was prepared by mixing an equal volume (500 mL) of the mentioned concentration of thiamethoxam with 500 ml of corresponding botanicals (*A. paniculata* extract, Pongamia oil emulsion and neem oil emulsion) and properly mixed to obtain stable combinations. The final combinations were evaluated for the blooming and stability test (BIS, 1997; Allawzi *et al*., 2016).

3.1.2 Maintenance of Stock Culture of Test Organism, *Aphis craccivora*

The aphid species were collected from cowpea fields in the College of Agriculture, Vellayani. After species confirmation, the *A. craccivora* colonies were excised from infested plants and transferred to seedlings of cowpea variety Anaswara which were obtained from the Instructional Farm, College of Agriculture, Vellayani. Plastic cups of 200 mL were filled with potting mixture consisting of sand, soil and coir pith compost in the ratio of 1:2:1. Seedlings at two to three leaf stages were transplanted to such cups and they were inoculated with gravid female aphids using a camel hair brush. The aphids were allowed to multiply in the rearing cage after inoculation (Plate 1).

3.1.3 Screening of Different Botanical-Chemical Pesticide Combinations

Screening of different botanical-chemical pesticide combinations was carried out in the laboratory using *A. craccivora* (Plate 2) as the test insect. The treatments (Plate 3 B) were applied using a hand sprayer. Thirty aphids aggregating around

A. Insect proof cage

B. Inoculation of gravid females to seedlings using camel hair brush

Plate 1. Maintaining stock culture of *Aphis craccivora* for *in vitro* evaluation

A. Adult

B. Nymph

Plate 2. Adult and nymph of *Aphis craccivora*

healthy, fresh stem portions were placed in each petridish (Plate 3 B) and directly sprayed with 2 mL of spray solution.

Design-CRD Treatments-14 Replication -3

Treatments

T1: Neem oil emulsion 2%+Thiamethoxam 0.02%

T2: Neem oil emulsion 2%+ Thiamethoxam 0.01%

T3: Neem oil emulsion2%+Thiamethoxam 0.005%

T4: Pongamia oil emulsion 2%+Thiamethoxam 0.02%

T5: Pongamia oil emulsion 2%+ Thiamethoxam 0.01%

T6: Pongamia oil emulsion 2%+Thiamethoxam 0.005%

T7: *Andrographis* formulation 5 % (Bhavyasree, 2019) +Thiamethoxam 0.02%

T8: *Andrographis* formulation5 % (Bhavyasree, 2019) +Thiamethoxam 0.01%

T9: *Andrographis* formulation5 % (Bhavyasree, 2019) +Thiamethoxam 0.005%

T10: Neem oil emulsion 2%

T11: Pongamia oil emulsion 2%

T12: Andrographis formulation5%

T13: Thiamethoxam 0.02%

T14: Untreated control

The number of dead aphids were counted at 12, 24 and 48 hours after treatment (HAT). Petri dish with aphid aggregated stem were sprayed with water to serve as control. The aphids which did not respond for the fine prick made by the camel hair brush were considered dead. The number of dead aphids was recorded and the percentage mortality was calculated by using Abbott's formula (Abbot, 1925). The cumulative corrected percentage mortality of aphids was statistically analysed.

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

3.2 FIELD EVALUATION OF EFFECTIVE BOTANICAL-CHEMICAL COMBINATIONS

A field experiment was conducted to evaluate the efficacy of selected treatments for the management of cowpea aphid *A. craccivora* in cowpea under field conditions.

Effective treatments were selected based on the laboratory studies. The best three treatments from *in vitro* evaluation were tested for studying their field level efficacy on target pest and its effect on natural enemies.

Design - RBD Treatments – 4 Replication - 5

3.2.1 Raising of Crop

Semi- trailing variety Anaswara were procured from Department of Vegetable science, College of Agriculture, Vellayani, and were soaked overnight and sowed in the field. The size of each plot was 3m×3m (Plate 4). A spacing of 45cm between rows and 30cm between plants was given. The crop was maintained as per the package of practices recommendations (KAU, 2016).

3.2.2 Application of Spray Solution

The botanical-chemical pesticide combinations were freshly prepared at the experiment site just prior to spraying. The required quantity of insecticide per plot was thoroughly mixed in water and stirred well before spraying. The mixture was stirred frequently during the time of spray. The spraying operations were performed in the evening hours.

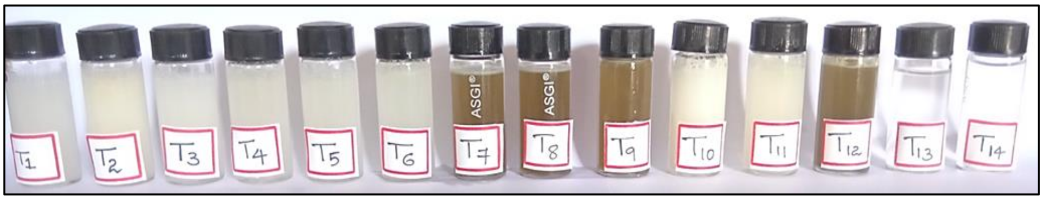
All the treatments were applied using a knapsack sprayer. Three sets of sprays were applied, where the first spray was undertaken at 15 DAP (days after planting), second spray was given at 35 DAP and the third spray at 55 DAP. The precount of aphids and natural enemies were documented prior to spraying. Post treatment counts were recorded at 1, 3, 5 and 7 days after each spraying.

3.2.3 Sampling and Collection of Experiment Data

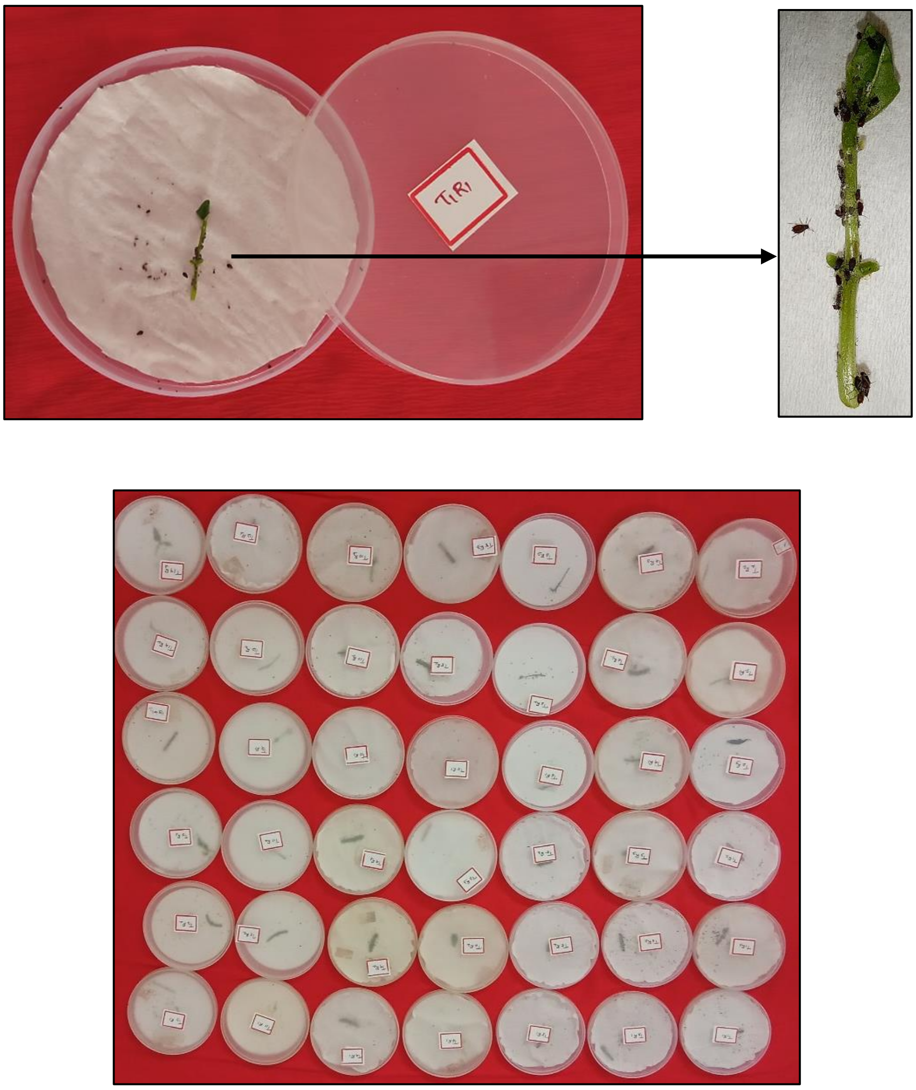
Ten observational plants were selected randomly from the experimental plots by leaving the border rows and tagged for recording the observations on the infestation of pests and natural enemies. Observations were taken during the early hours of the day.

3.2.3.1 Population of cowpea aphid

Observations on population density prior to spraying and post treatment at 1,3,5,7 day by counting the cowpea aphids present in five centimetre shoot length from the tender growing points of each observational plant (Bindu,1997)



A. Prepared botanical chemical combinations for *invitro* evaluation



B. Screening of different botanical-chemical pesticide combinations

Plate 3. *In vitro* evaluation of various treatments

Experimental plots

Tagged experimental plants

Plate 4. Experimental field

3.2.3.2 Population of pod bugs

Infestations were assessed by counting all bug species and stages (beyond the second nymphal instar) on the two central rows of each plot. The pods, flowers, leaves and stem were closely inspected for pod bug nymphs and adults. (Afun *et al.*, 1991).

3.2.3.3 Natural enemies

Natural enemies *viz.*, lacewings, syrphid flies, spiders and coccinellids were counted by visual counting mean values were calculated one day before treatment and 1, 3, 5 and 7 DAS (Days After Spraying) (Jat and Rana, 2018).

3.2.4 Phytotoxicity Studies

The botanical chemical combinations were sprayed over the cowpea seedlings and their corresponding observations for symptoms like yellowing, epinasty, hyponasty, scorching and necrosis were carried out. The CIBRC (Central insecticides board and registration committee) prescribed grades were used to scale injury symptoms every 1, 3, 5 and 7 days of interval.

Table 1. Percentage of phytotoxicity based on CIBRC Grade

Percentage of phytotoxicity	CIBRC Grade
No phytotoxicity	0
1-10	1
11-20	2
21-30	3
31-40	4
41-50	5
51-60	6
61-70	7
71-80	8
81-90	9
91-100	10

3.3 STATISTICAL ANALYSIS

The data collected from the laboratory and field experiments were subjected to statistical analysis using KAU - GRAPES (Gopinath *et al*., 2021). Data were analysed after subjected to arc sine and square root transformations appropriately.

Results

4. RESULTS

Study was conducted at College of Agriculture, Vellayani during 2020 to 2022 to evaluate the efficacy of various botanical-chemical pesticide combinations at different concentrations for the management of cowpea aphid *A. craccivora*. Laboratory studies were conducted to evaluate the efficacy of various treatment combinations and best three from these were selected for the field studies. For ensuring the quality of the produce harvest time residue were tested at Pesticide Residue Research and Analytical Laboratory, College of Agriculture, Vellayani. The data were analysed statistically and important experimental findings were explained below.

4.1 *IN-VITRO* EVALUATION OF BOTANICAL-CHEMICAL PESTICIDE COMBINATIONS AGAINST COWPEA APHID *A. craccivora*

4.1.1 Screening of Botanical-Chemical Pesticide Combinations

Mortality of *A. craccivora* in response to application of various treatments were depicted in Table 2. The highest mortality (68.89%) was observed in the treatment thiamethoxam 0.02% at 12 hours after treatment (HAT) which showed significant difference from all other treatments. Next best treatment was pongamia oil emulsion 2% + thiamethoxam 0.02% with 60 per cent mortality which also recorded significant variation from other treatments. This was followed by the treatments nem oil emulsion 2% + thiamethoxam 0.02% (47.76 per cent mortality) which was on par with pongamia oil emulsion 2% + thiamethoxam 0.02% (43.33 per cent mortality). Effect of neem oil emulsion 2% + thiamethoxam 0.01% (42.22 per cent mortality) was on par with the treatment pongamia oil emulsion 2% + thiamethoxam 0.02% (43.33 per cent mortality). Whereas *Andrographis* formulation 5% + thiamethoxam 0.02% showed a mortality of 36.67 per cent.

At 24 HAT, Thiamethoxam 0.02% recorded highest mortality (88.89%), which was followed by pongamia oil emulsion 2% +thiamethoxam 0.02% with 76.67 per cent and neem oil emulsion 2% + thiamethoxam 0.02% with 70 per cent mortality. The treatment pongamia oil emulsion 2% + thiamethoxam 0.01% showed a mortality of 61.11 per cent, followed by neem oil emulsion 2% + thiamethoxam 0.01% with 53.33

per cent mortality and pongamia oil emulsion 2% + thiamethoxam 0.005% with 51.11 per cent mortality and were statistically on par with each other.

At 48 HAT, thiamethoxam 0.02% showed 99 per cent mortality, which was followed by pongamia oil emulsion 2% + thiamethoxam 0.02% (90.44 per cent) and neem oil emulsion 2% + thiamethoxam 0.02% (81.89 per cent). The treatment pongamia oil emulsion 2% + thiamethoxam 0.01% showed a mortality of 73.33 per cent. The effect of treatments, pongamia oil emulsion 2% (63.56 per cent mortality), Neem oil emulsion 2% + thiamethoxam 0.01% (63.33 per cent mortality) and pongamia oil emulsion 2% + thiamethoxam 0.005% (62.33 per cent mortality) were on par.

4.2 FIELD EVALUATION OF EFFECTIVE BOTANICAL – CHEMICAL FORMULATION

Based on the laboratory studies following treatments were selected for field evaluation

1. Pongamia oil emulsion 2% +Thiamethoxam 0.02%

2. Neem oil emulsion 2% + Thiamethoxam 0.02%

3. Thiamethoxam 0.02%

4.2.1 Effect of Botanical -Chemical Combinations on the Population of *A. craccivora*

Population of *A. craccivora* (Plate 5) subsequent to the first round of application of treatments at 15 days after planting (DAP) were recorded at 1, 3, 5 and 7 days after treatment (DAT).

The population of aphids prior to the application of treatments were found to be homogenous and statistically non-significant. Mean population of aphids at different intervals after the application of treatment are presented in the Table 3.

After first spraying, significant reduction in the population of aphids over untreated control was observed in all treatments from one to seven days after treatment. In case of pongamia oil emulsion 2% + thiamethoxam 0.02% and neem oil emulsion 2% + thiamethoxam 0.02% recorded fewer population of aphids and gave good control

A. Infestation on underside of the leaves

B. Infestation on shoots

C. Infestation on growing points

D.Infestation on pods

Plate 5. Infestation of *Aphis craccivora* in untreated control plants

Table 2. Mortality of *A. craccivora* treated with various botanical-chemical pesticide combination

Treatments	Mortality (%)		
	12 HAT	24 HAT	48 HAT
Neem oil emulsion 2% + Thiamethoxam 0.02%	47.76 (43.73)[c]	70.00 (56.81)[c]	81.89 (64.90)[c]
Neem oil emulsion 2% + Thiamethoxam 0.01%	42.22 (40.52)[d]	53.33 (46.92)[e]	63.33 (52.14)[e]
Neem oil emulsion 2% + Thiamethoxam 0.005%	32.22 (34.58)[f]	43.33 (41.16)[f]	52.56 (46.46)[f]
Pongamia oil emulsion 2% +Thiamethoxam 0.02%	60.00 (50.78)[b]	76.67 (61.12)[b]	90.44 (72.04)[b]
Pongamia oil emulsion 2% + Thiamethoxam 0.01%	43.33 (41.12)[cd]	61.11(51.42)[d]	73.33 (59.05)[d]
Pongamia oil emulsion 2% + Thiamethoxam 0.005%	35.55 (36.58)[ef]	51.11(45.63)[e]	62.33 (52.15)[e]
Andrographis formulation 5% (Bhavyasree, 2019) + Thiamethoxam 0.02%	36.67 (37.25)[e]	41.11(39.87)[f]	48.89 (44.36)[fg]
Andrographis formulation 5% (Bhavyasree, 2019) + Thiamethoxam 0.01%	27.78 (31.79)[g]	34.446(33.87)[g]	44.00 (41.55)[gh]
Andrographis formulation 5% (Bhavyasree, 2019) + Thiamethoxam 0.005%	24.44 (29.62)[gh]	30.00(33.21)[h]	42.78 (40.84)[h]
Neem oil emulsion 2%	20.00 (26.56)[i]	30.00(33.18)[h]	51.33 (45.76)[f]
Pongamia Oil emulsion 2%	23.33 (28.84)[hi]	42.22(40.52)[f]	63.56 (52.87)[e]
Andrographis formulation 5%	11.11 (19.42)[j]	15.56 (23.20)[i]	33.00 (35.04)[i]
Thiamethoxam 0.02%	68.89 (56.11)[a]	88.89 (70.57)[a]	99.00 (84.26)[a]
CD (0.05)	(2.575)	(2.511)	(3.233)
SE(m)	0.889	0.867	1.116

Values in the parenthesis are arc sine transformed, HAT- hours after treatment

Table 3. Effect of different treatments on population of cowpea aphids *Aphis craccivora*

Treatments	First spray (15 days after sowing)				Second spray (35 days after sowing)				Third spray (55 days after sowing)			
	Mean population of aphid per plant				Mean population of aphid per plant				Mean population of aphid per plant			
	I DAT	3 DAT	5 DAT	7 DAT	I DAT	3 DAT	5 DAT	7 DAT	I DAT	3 DAT	5 DAT	7 DAT
Thiamethoxam 0.02%	3.64 (2.01)^{bc}	0.48 (0.96)^{c}	1.02 (1.16)^{b}	2.82 (1.81)^{b}	8.90 (3.06)^{bc}	3.62 (2.02)^{b}	1.38 (1.34)^{b}	2.22 (1.63)^{b}	10.88 (3.36)^{c}	5.38 (2.42)^{b}	2.22 (1.62)^{b}	3.52 (1.99)^{b}
Pongamia oil emulsion 2% + Thiamethoxam 0.02%	2.74 (1.79)^{c}	0.22 (0.83)^{c}	0.00 (0.71)^{c}	1.36 (1.32)^{c}	7.94 (2.90)^{c}	2.26 (1.63)^{c}	0.38 (0.90)^{b}	0.60 (0.99)^{c}	12.42 (3.59)^{c}	1.34 (1.28)^{c}	1.40 (1.37)^{c}	0.44 (0.89)c
Neem oil emulsion 2%+Thiamethoxam 0.02%	4.88 (2.31)^{b}	1.46 (1.39)^{b}	1.62 (1.39)^{b}	1.94 (1.54)^{bc}	10.02 (3.24)^{b}	4.14 (2.15)^{b}	1.38 (1.29)^{b}	1.38 (1.28)^{bc}	14.5 (3.86)^{b}	2.00 (1.51)^{c}	2.12 (1.60)^{bc}	1.26 (1.25)^{c}
Control	17.80 (4.27)^{a}	20.48 (4.58)^{a}	22.36 (4.77)^{a}	22.72 (4.82)^{a}	45.72 (6.79)^{a}	53.60 (7.35)^{a}	57.36 (7.61)^{a}	57.60 (7.62)^{a}	54.14 (7.39)^{a}	59.88 (7.77)^{a}	63.82 (8.01)^{a}	64.58 (8.07)^{a}
CD (0.05)	(0.329)	(0.256)	(0.399)	(0.340)	(0.199)	(0.366)	(0.480)	(0.477)	(0.232)	(0.521)	(0.237)	(0.513)
SEM	0.106	0.082	0.128	0.109	0.064	0.118	0.154	0.153	0.075	0.167	0.076	0.165

Mean of 5 replications comprising 10 plants each (Values in the parentheses are square root transformed)   DAT: Days after treatment

up to 7 days after treatment (DAT) and were found to be superior compared to chemical check thiamethoxam 0.02%.

At 1 DAT, the aphid population was statistically lower in plants sprayed with pongamia oil emulsion 2% + thiamethoxam 0.02% (2.74 per plant) and found to be on par with chemical check thiamethoxam 0.02% (3.64 per plant). Neem oil emulsion 2% + thiamethoxam 0.02% (4.88 per plant) and thiamethoxam 0.02% (3.64 per plant) were also statistically on par with each other. The treatments were significantly superior to the untreated control with an aphid count of 17.80 per plant.

At 3 DAT, the aphids population was statistically lower in plants sprayed with pongamia oil emulsion 2% + thiamethoxam 0.02% (0.22 per plant) and found to be on par with chemical check thiamethoxam 0.02% (0.48 per plant). The treatment neem oil emulsion 2% + thiamethoxam 0.02% showed population of 1.46 aphids per plant and it is significantly lower compared to the untreated control with 20.48 per plant.

At 5 DAT, the plants treated with pongamia oil emulsion 2% + thiamethoxam 0.02% did not record any aphid population, and is significantly superior to other treatments. The effect of treatments neem oil emulsion 2% + thiamethoxam 0.02% (1.62 per plant) and thiamethoxam 0.02% (1.02 per plant) were also statistically on par with each other. The treatments were significantly superior to the untreated control (22.36 aphids per plant.)

At 7 DAT, the population of aphids in plants treated with pongamia oil emulsion 2% + thiamethoxam 0.02% (1.36 per plant) were significantly lower than the chemical check thiamethoxam 0.02% (2.82per plant) and statistically on par with neem oil emulsion 2% + thiamethoxam 0.02% (1.94 per plant). All the treatments were superior to untreated control with a population of 22.72 per plant.

One day after second spraying (35 DAP), all the treatments showed significant variation from the untreated control and the population of aphids in the plots treated with pongamia oil emulsion 2% + thiamethoxam 0.02% recorded the lowest (7.94 per plant) and it was on par with effect of the treatment thiamethoxam 0.02% (8.90per plant). Treatment effect of neem oil emulsion 2% + thiamethoxam 0.02% (10.02aphids per plant) were also found on par with the treatment thiamethoxam 0.02% but were significantly different from the effect of pongamia oil emulsion 2% + thiamethoxam 0.02%. Whereas the population in the control plots were 45.72 aphids per plant.

At 3 DAT, all the treatments recorded significantly lower populations when compared to untreated control. The treatment pongamia oil emulsion 2% + thiamethoxam 0.02% recorded minimum aphid population per plant (2.26) followed by thiamethoxam 0.02% (3.62) and neem oil emulsion 2% + thiamethoxam 0.02% (4.14) respectively. In the control plot the population of aphid were significantly higher *i.e.* 53.60 per plant. At 5 DAT, the effect of treatments thiamethoxam 0.02% (1.38 per plant), pongamia oil emulsion 2% + thiamethoxam 0.02% (0.38 per plant) and neem oil emulsion 2% + thiamethoxam 0.02% (1.38 per plant) were statistically on par and recorded minimum aphid population compared to untreated control. (57.36 per plant).

At 7 DAT, all the treatments recorded significant variation from the untreated control and the treatment pongamia oil emulsion 2% + thiamethoxam 0.02% showed minimum aphid population (0.60 per plant) and was significantly superior when compared to other treatments. Next best treatment was neem oil emulsion 2% + thiamethoxam 0.02% (1.38 per plant) and its effect was statistically on par with the treatment thiamethoxam 0.02% (2.22 per plant). The population of aphids in the untreated control plots was 57.60 per plant

First day after the third spraying (55 DAP), the treatments thiamethoxam 0.02% (10.88 per plant) and pongamia oil emulsion 2% + thiamethoxam 0.02% (12.42 per plant) were superior in managing the aphid population and statistically on par with each other. This was followed by neem oil emulsion 2% + thiamethoxam 0.02% with a population of 14.5 per plant aphids. The control plot (54.14 per plant) recorded a significantly higher population of aphids.

At 3 DAT, the population of aphids were lower in the plots treated with pongamia oil emulsion 2% + thiamethoxam 0.02% (1.34 per plant) and neem oil emulsion 2% + thiamethoxam 0.02% (2.00 per plant). This was followed by thiamethoxam 0.02% with 5.38 aphids per plant.

At 5 DAT, pongamia oil emulsion 2% + thiamethoxam 0.02% recorded a mean population of 1.40 per plant which is on par with the effect the treatment neem oil emulsion 2% + thiamethoxam 0.02% (2.12 per plant) . The treatment neem oil emulsion 2% + thiamethoxam 0.02% (2.12 per plant) was statistically on par with the effect of thiamethoxam 0.02% (2.22 per plant) and all the treatments recorded significantly lower population of aphids per plant when compared to untreated control. (63.82 per plant).

At 7 DAT, the lowest population of aphids were recorded in the plots treated with pongamia oil emulsion 2% + thiamethoxam 0.02% (0.44 per plant) and neem oil emulsion 2% + thiamethoxam 0.02% (1.26 per plant) and statistically on par with each other; they were superior to the treatment thiamethoxam 0.02% (3.52 per plant) in reducing the population of aphids. The population were significantly higher in the plants of untreated control plot (64.58 per plant).

4.2.2 Effect of Botanical -Chemical Combinations on the Population of Pod Bugs *Riptortus pedestris*

Effect of different treatments on the population of *R. pedestris* (Plate 6 A) were studied after third spray schedule (55 DAP) and the mean population were recorded at 1,3,5 and 7 DAT (Table 4). During the first day after treatment application effect of all treatments were found on par and recorded 0.08 , 0.02 and 0.04 numbers for treatments thiamethoxam 0.02%, pongamia oil emulsion 2% + thiamethoxam 0.02% and neem oil emulsion 2% + thiamethoxam 0.02% respectively. Untreated control recorded a mean population of 4.22 per plant.

There were no incidence of pod bug in plots treated with pongamia oil emulsion 2% + thiamethoxam 0.02% and neem oil emulsion 2% + thiamethoxam 0.02% at three DAT. Whereas treatment thiamethoxam 0.02% recorded a mean population of 0.8. All these treatments were found to be effective in managing pod bugs when compared to untreated plot which recorded 4.33 pod bugs per plant.

At 7 DAT, pongamia oil emulsion 2% + thiamethoxam 0.02% recorded the lowest population (0.48 per plant) which is on par with neem oil emulsion 2% + thiamethoxam 0.02% (0.58 per plant). Untreated control plots recorded the mean population of 4.84 per plant.

4.2.3 Evaluation of Botanical Chemical Combinations on Natural Enemies in Cowpea Ecosystem

The results of evaluation of botanical chemical combinations on the safety of natural enemies of pests in cowpea ecosystem are furnished in Table 5 to 9. The count of predators in the field *viz,* coccinellids, spiders, brown lacewings and syrphids per plant were taken 1, 3, 5 and 7 days after spraying.

4.2.3.1 Coccinellid larvae and adults

The population of coccinellid beetles *viz*., *Chilomenus sexmaculata* F., *Coccinella transversalis* F. and *Pseudaspidimerus trinotataus* T. (Plate 7) were encountered in the cowpea ecosystem are furnished in tables 5 and 6.

4.2.3.1.1 Coccinellid larvae

The population of coccinellid larvae prior to the application of treatments were found to be homogenous and statistically non-significant. Mean population of coccinellid larvae at different intervals after treatment are presented in Table 5.

There were no coccinellid larvae in plots treated with Thiamethoxam 0.02%, after all the three spray schedule given at 15, 35 and 55 days.

After first spray, highest population of coccinellid larvae were recorded in untreated control which was followed by pongamia oil emulsion 2% + thiamethoxam 0.02%, treated plots at 5 DAT and 7 DAT. Treatments pongamia oil emulsion 2% + thiamethoxam 0.02% recorded mean population of 0.08 and neem oil emulsion 2%+ thiamethoxam 0.02% recorded 0.06 per plant at 7 DAT.

After second spraying, pongamia oil emulsion 2% + thiamethoxam 0.02% recorded 0.22 followed by neem oil emulsion 2% + thiamethoxam 0.02% (0.1 per plant) at 7 DAT. Control plots recorded a mean population of 3.6 larvae per plant.

At third spraying, 7 DAT the pongamia oil emulsion 2% + thiamethoxam 0.02% recorded a mean population of 0.26 which was followed by neem oil emulsion 2% + thiamethoxam 0.02% (0.12 per plant). Highest population was recorded in untreated control (5.86 per plant). And it was noticed that the population of coccinellid larvae


A. Infestation of pod bugs

C. Damaged pods

Plate 6. Infestation of *Riptortus pedestris*

A. Adults and grubs of *Cheilomenes sexmaculata*

B. *Coccinella transversalis*

C. *Pseudaspidimerus trinotataus*

Plate 7. Coccinellid beetles and grubs recorded in cowpea ecosystem

Table 4. Effect of different treatments on pod bugs *Riptortus pedestris*

Treatments	Third spray (55 days after sowing)			
	Mean population of pod bugs per plant			
	I DAT	3 DAT	5 DAT	7 DAT
Thiamethoxam 0.02%	0.08 (0.76)[b]	0.08 (0.76)[b]	0.20 (0.83)[b]	1.08 (1.25)[b]
Pongamia oil emulsion 2%+Thiamethoxam 0.02%	0.02 (0.72)[b]	0 (0.71)[c]	0.14 (0.79)[b]	0.48 (0.98)[c]
Neem oil emulsion 2%+Thiamethoxam 0.02%	0.04 (0.73)[b]	0 (0.71)[c]	0.22 (0.84)[b]	0.58 (1.04)[c]
Control	4.22 (2.17)[a]	4.32 (2.19)[a]	4.48 (2.23)[a]	4.84 (2.31)[a]
CD (0.05)	(0.053)	(0.051)	(0.086)	(0.072)
SEM	0.017	0.016	0.028	0.023

Mean of 5 replications comprising 10 plants each (Values in the parentheses are square root transformed) DAT: Days after treatment

Table 5. Effect of treatments on coccinellid grubs in cowpea ecosystem

Treatments	First spray (15 days after sowing)				Second spray (35 days after sowing)				Third spray (55 days after sowing)			
	Mean population of grub per plant				Mean population of grub per plant				Mean population of grub per plant			
	I DAT	3 DAT	5 DAT	7 DAT	I DAT	3 DAT	5 DAT	7 DAT	I DAT	3 DAT	5 DAT	7 DAT
Thiamethoxam 0.02%	0 (0.71)[b]	0 (0.71)[b]	0 (0.71)[b]	0 (0.71)[b]	0 (0.71)[b]	0 (0.71)[b]	0 (0.71)[c]	0 (0.71)[c]	0 (0.71)[b]	0 (0.71)[b]	0 (0.71)[c]	0 (0.71)[d]
Pongamia oil emulsion 2%+Thiamethoxam 0.02%	0 (0.71)[b]	0 (0.71)[b]	0.04 (0.73)[b]	0.08 (0.76)[b]	0 (0.71)[b]	0.02 (0.72)[b]	0.16 (0.81)[b]	0.22 (0.84)[b]	0 (0.71)[b]	0 (0.71)[b]	0.14 (0.79)[b]	0.26 (0.87)[b]
Neem oil emulsion 2%+Thiamethoxam 0.02%	0 (0.71)[b]	0 (0.71)[b]	0.02 (0.72)[b]	0.06 (0.74)[b]	0 (0.71)[b]	0 (0.71)[b]	0.06 (0.75)[bc]	0.10 (0.77)[bc]	0 (0.71)[b]	0 (0.71)[b]	0.08 (0.76)[bc]	0.12 (0.78)[c]
Control	2.40 (1.70)[a]	2.68 (1.78)[a]	2.86 (1.83)[a]	3.06 (1.88)[a]	3.26 (1.93)[a]	3.44 (1.98)[a]	3.50 (2.0)[a]	3.60 (2.02)[a]	5.48 (2.44)[a]	5.62 (2.47)[a]	5.72 (2.49)[a]	5.86 (2.52)[a]
CD (0.05)	(0.060)	(0.070)	(0.078)	(0.067)	(0.049)	(0.031)	(0.076)	(0.099)	(0.029)	(0.032)	(0.072)	(0.066)
SEM	0.019	0.022	0.025	0.021	0.016	0.014	0.024	0.032	0.009	0.010	0.023	0.021

Mean of 5 replications comprising 10 plants each (Values in the parentheses are square root transformed) DAT: Days after treatment

were gradually progressing from 2.4 to 5.86 in control plots. In all the three spray schedules population of coccinellid larvae were not recorded 1 DAT.

4.2.3.1.2 Coccinellid adults

The population of coccinellid adults prior to the application of treatments were found to be homogenous and statistically non-significant. The mean population of coccinellid adults at different intervals after treatment are presented in Table 6.

After first spraying, population of coccinellid adults were not recorded in plants treated with thiamethoxam 0.02% at 1 DAT. Whereas significant population of coccinellid beetles were seen in plants treated with neem oil emulsion 2% + thiamethoxam 0.02% (0.36 per plant) and pongamia oil emulsion 2% + thiamethoxam 0.02% (0.28 per plant), which were statistically on par .The control plots showed a population of 1.66 adults per plant.

At 3 DAT the coccinellid adult population was highest in the untreated control plots (1.68 per plant), which was statistically on par with pongamia oil emulsion 2% + thiamethoxam 0.02% (1.08 per plant). The lowest population of coccinellid adults was reported from plots treated with thiamethoxam 0.02% (0.36 per plant) being statistically on par with neem oil emulsion 2% + thiamethoxam 0.02% (0.76 per plant).

In 5 DAT the population of coccinellid adults were statistically on par. Whereas the control plots recorded a significant population (2.60 per plant).

At 7 DAT, the highest population of coccinellid adults were recorded in the untreated control plots (2.12 per plant), which was found statistically on par with neem oil emulsion 2% + thiamethoxam 0.02% (1.52 per plant) and pongamia oil emulsion 2% + thiamethoxam 0.02% (1.96 per plant). The population of beetles were lowest in the plants treated with Thiamethoxam 0.02% (1.26 per plant).

At second spray, the least population of coccinellid beetles were recorded in the plants treated with thiamethoxam 0.02% from 1 DAT to 7 DAT. At 1 DAT, the plants treated with neem oil emulsion 2%+ thiamethoxam 0.02% (0.2 per plant) were statistically on par with pongamia oil emulsion 2%+ thiamethoxam 0.02% (0.24 per plant) and thiamethoxam 0.02% (0 per plant). The plants in untreated plots recorded population of 2.48 per plant.

At 3 DAT, 5 DAT and 7 DAT, the plants treated with thiamethoxam 0.02% recorded lower coccinellid beetle population and was statistically inferior to other treatments. And the plants treated with neem oil emulsion 2% + thiamethoxam 0.02% (2.26 per plant) and pongamia oil emulsion 2% + thiamethoxam 0.02% (2.22 per plant) showed superior beetle population over thiamethoxam 0.02% and were statistically on par.

At third spray, the plants treated with thiamethoxam 0.02% recorded least population of coccinellid beetles from 1 DAT to 7 DAT when compared with other treatments and untreated control.

1 DAT , the untreated plants in control plot showed a significant population of 3.14 per plant which was followed by pongamia oil emulsion 2% + thiamethoxam 0.02% (0.4 per plant).The treatments neem oil emulsion 2% + thiamethoxam 0.02% (0.84 per plant) were statistically on par with thiamethoxam 0.02% (0 per plant) and pongamia oil emulsion 2% + thiamethoxam 0.02% (0.4 per plant).

In 3 DAT and 5 DAT , the population of beetles were significantly lower in plants treated with thiamethoxam 0.02% compared to other treatments , while the treatments neem oil emulsion 2% + thiamethoxam 0.02% and pongamia oil emulsion 2% + thiamethoxam 0.02% were statistically on par with each other. The population in plants in the untreated plot showed steady increase in population of coccinellid beetles.

7 DAT , the population of coccinellid beetles in all the treatments were significantly different from each other where the plants treated with thiamethoxam 0.02% recorded least number of beetles that is , 1.84 per plant .Whereas the plants treated with pongamia oil emulsion 2% + thiamethoxam 0.02% recorded a population of 2.72 per plant and neem oil emulsion 2% + thiamethoxam 0.02% recorded 2.32 per plant. The plants in untreated control recorded population of 3.80 per plant.

Table 6. Effect of treatments on coccinellid adults in cowpea ecosystem

Treatments	First spray (15 days after sowing)				Second spray (35 days after sowing)				Third spray (55 days after sowing)			
	Mean population of coccinellid adult/plant				Mean population of coccinellid adult/plant				Mean population of coccinellid adult/plant			
	I DAT	3 DAT	5 DAT	7 DAT	I DAT	3 DAT	5 DAT	7 DAT	I DAT	3 DAT	5 DAT	7 DAT
Thiamethoxam 0.02%	0 (0.71)[c]	0.36 (0.92)[c]	0.56 (0.99)[b]	1.26 (1.32)[b]	0 (0.71)[c]	0.56 (0.98)[c]	0.52 (0.98)[c]	0.70 (1.05)[c]	0 (0.71)[c]	0.46 (0.95)[c]	0.96 (1.12)[c]	1.84 (1.53)[d]
Pongamia oil emulsion 2%+Thiamethoxam 0.02%	0.28 (0.88)[b]	1.08 (1.25)[ab]	1.24 (1.31)[b]	1.96 (1.56)[a]	0.24 (0.85)[b]	1.54 (1.43)[b]	2.02 (1.58)[b]	2.22 (1.65)[b]	0.40 (0.94)[b]	1.68 (1.48)[b]	2.18 (1.63)[b]	2.72 (1.79)[b]
Neem oil emulsion 2%+Thiamethoxam 0.02%	0.36 (0.93)[b]	0.76 (1.11)[bc]	1.20 (1.27)[b]	1.52 (1.41)[ab]	0.20 (0.83)[bc]	1.44 (1.38)[b]	1.92 (1.55)[b]	2.26 (1.66)[b]	0.22 (0.84)[bc]	1.58 (1.44)[b]	2.02 (1.58)[b]	2.32 (1.67)[c]
Control	1.66 (1.47)[a]	1.68 (1.46)[a]	2.60 (1.76)[a]	2.12 (1.61)[a]	2.48 (1.72)[a]	2.64 (1.77)[a]	2.72 (1.79)[a]	3.10 (1.89)[a]	3.14 (1.91)[a]	3.08 (1.89)[a]	3.36 (1.96)[a]	3.80 (2.07)[a]
CD (0.05)	(0.115)	(0.255)	(0.342)	(0.212)	(0.132)	(0.270)	(0.197)	(0.223)	(0.140)	(0.189)	(0.183)	(0.110)
SE(m)	0.037	0.116	0.110	0.068	0.060	0.087	0.063	0.072	0.045	0.061	0.059	0.036

Mean of 5 replications comprising 10 plants each (Values in the parentheses are square root transformed) DAT: Days after treatment

4.2.3.2 Syrphid maggots

The population of syrphid maggots (Plate 8 B) prior to the application of treatments were found to be homogenous and statistically non-significant. Mean population of coccinellid larvae at different intervals after treatment are presented in Table 7.

After the application first spray, the population of maggots were not seen in plants with thiamethoxam 0.02%, neem oil emulsion 2% + thiamethoxam 0.02% and pongamia oil emulsion 2% + thiamethoxam 0.02% till 7 DAT. Whereas the population of maggots in control plot showed an increase of 0.1 per plant to 0.24 per plant.

At second spray, the population of maggots in the plants with thiamethoxam 0.02%, neem oil emulsion 2% + thiamethoxam 0.02% and pongamia oil emulsion 2%+ thiamethoxam 0.02% were not recorded in 1 DAT and 3 DAT.

At 5 DAT the population of syrphid maggots were not recorded in plants treated with thiamethoxam 0.02%, whereas the plants treated with neem oil emulsion 2 %+ thiamethoxam 0.02% (0.56 per plant) and pongamia oil emulsion 2% + thiamethoxam 0.02% (1.02 per plant) were statistically on par. The untreated plants in control plot showed a significant population of 5.96 per plant.

At 7 DAT, the trend of syrphid population was similar to that of 5 DAT, and the treatments neem oil emulsion 2% + thiamethoxam 0.02% (0.8 per plant) and pongamia oil emulsion 2% + thiamethoxam 0.02% (1.3 per plant) were statistically on par. The plants treated with thiamethoxam 0.02% had a syrphid maggot population of 0.2 per plant and whereas the untreated control plot had a population of 6.16 per plant.

After third spray, 1 DAT, the treatment plots, did not show any syrphid maggot population when compared with 6.16 per plant population in the untreated control.

Three DAT, the population of syrphids in all the treatments were significantly different . The higher population of syrphids were seen in the untreated control plot (7.40 per plant), followed by pongamia oil emulsion 2% + thiamethoxam 0.02% (0.38 per plant) and neem oil emulsion 2% + thiamethoxam 0.02% (0.28 per plant). The plants treated with chemical check thiamethoxam 0.02% had no visible population of syrphids.

At 5 DAT and 7 DAT the population of syrphid maggots were statistically on par in plants treated with pongamia oil emulsion 2% + thiamethoxam 0.02% (1.54 per plant and 2.1 per plant respectively) and neem oil emulsion 2% + thiamethoxam 0.02% (1.56 per plant and 4.0 per plant respectively), whereas the population in plots treated with thiamethoxam 0.02% were statistically inferior (0.04 per plant and 0.22 per plant respectively). The untreated plants in control plot showed a significant population progress of 7.70 per plant at 5 DAT and 8.06 per plant 7 DAT.

4.2.3.3 Neuropteran predators

Brown lacewing larvae (Haemerobidae) were noticed as a predominant neuropteran predator for *A.craccivora* in cowpea ecosystem. The population of neuropteran predators (Plate 8 A) prior to the application of treatments were found to be homogenous and statistically non-significant. Mean population of larvae at different intervals after treatment are presented in Table 8.

After the application of first spray, the population of brown lacewing larvae were not recorded from 1 DAT to 7 DAT in treatment plots. Whereas the population of larvae in untreated control plants showed an increase of 0.06 per plant in 1 DAT to 0.16 per plant in 7 DAT.

After the application of second spray, in the 1 DAT and 3 DAT the population of larvae were not noticed in the treatments plots. The population in untreated control progressed from 1.54 per plant in 1 DAT to 1.60 per plant in 3 DAT.

At 5 DAT, the population of lacewings larvae were not recorded in plants treated with thiamethoxam 0.02%. And the treatments pongamia oil emulsion 2% + thiamethoxam 0.02% (0.12 per plant) and neem oil emulsion 2% + thiamethoxam 0.02% (0.04 per plant) were statistically on par with each other. The untreated control plot had a grub population of 1.84 per plant.

At 7 DAT , the treatment pongamia oil emulsion 2% + thiamethoxam 0.02% recorded a population of 0.16 per plant. The grub population were not recorded in plants

A. Lacewing grubs observed in field

B. Syrphid maggots observed in cowpea field

Plate 8. Syrphid and neuropteran predators recorded in cowpea ecosystem

Table 7. Effect of treatments on syrphid maggots in cowpea ecosystem

Treatments	First spray (15 days after sowing)				Second spray (35 days after sowing)				Third spray (55 days after sowing)			
	Mean population of syrphid per plant				Mean population of syrphid per plant				Mean population of syrphid per plant			
	I DAT	3 DAT	5 DAT	7 DAT	I DAT	3 DAT	5 DAT	7 DAT	I DAT	3 DAT	5 DAT	7 DAT
Thiamethoxam 0.02%	0 (0.71)^{b}	0 (0.71)^{b}	0 (0.71)^{b}	0 (0.71)^{b}	0 (0.71)^{b}	0 (0.71)^{b}	0 (0.71)^{c}	0.20 (0.83)^{c}	0 (0.71)^{b}	0 (0.71)^{d}	0.04 (0.73)^{c}	0.22 (0.84)^{c}
Pongamia oil emulsion 2%+Thiamethoxam 0.02%	0 (0.71)^{b}	0 (0.71)^{b}	0 (0.71)^{b}	0 (0.72)^{b}	0 (0.71)^{b}	0 (0.71)^{b}	1.02 (1.22)^{b}	1.3 (1.33)^{b}	0 (0.71)^{b}	0.38 (0.93)^{b}	1.54 (1.41)^{b}	2.10 (1.60)^{b}
Neem oil emulsion 2%+Thiamethoxam 0.02%	0 (0.71)^{b}	0 (0.71)^{b}	0 (0.71)^{b}	0 (0.71)^{b}	0 (0.71)^{b}	0 (0.71)^{b}	0.56 (0.99)^{b}	0.8 (1.12)^{b}	0 (0.71)^{b}	0.28 (0.88)^{c}	1.56 (1.43)^{b}	4.0 (1.95)^{b}
Control	0.10 (0.77)^{a}	0.16 (0.81)^{a}	0.20 (0.84)^{a}	0.24 (0.86)^{a}	5.68 (2.58)^{a}	5.70 (2.56)^{a}	5.96 (2.58)^{a}	6.16 (2.61)^{a}	7.28 (2.79)^{a}	7.40 (2.81)^{a}	7.70 (2.86)^{a}	8.06 (2.93)^{a}
CD (0.05)	(0.032)	(0.023)	(0.042)	(0.046)	(0.034)	(0.028)	(0.285)	(0.266)	(0.033)	(0.050)	(0.205)	(0.733)
SE(m)	(0.01)	0.007	0.014	0.021	0.011	0.009	0.091	0.085	0.011	0.016	0.066	0.236

Mean of 5 replications comprising 10 plants each (Values in the parentheses are square root transformed) DAT: Days after treatment

Table 8. Effect of treatments on brown lacewings in cowpea ecosystem

Treatments	First spray (15 days after sowing)				Second spray (35 days after sowing)				Third spray (55 days after sowing)			
	Mean population of lacewing larvae/plant				Mean population of lacewing larvae/plant				Mean population of lacewing larvae/plant			
	I DAT	3 DAT	5 DAT	7 DAT	I DAT	3 DAT	5 DAT	7 DAT	I DAT	3 DAT	5 DAT	7 DAT
Thiamethoxam 0.02%	0 (0.71)[b]	0 (0.71)[b]	0 (0.71)[b]	0 (0.71)[b]	0 (0.71)[b]	0 (0.71)[b]	0 (0.71)[b]	0 (0.71)[c]	0 (0.71)[b]	0 (0.71)[b]	0 (0.71)[b]	0 (0.71)[c]
Pongamia oil emulsion 2%+Thiamethoxam 0.02%	0 (0.71)[b]	0 (0.71)[b]	0 (0.71)[b]	0 (0.71)[b]	0 (0.71)[b]	0 (0.71)[b]	0.12 (0.78)[b]	0.16 (0.81)[b]	0 (0.71)[b]	0 (0.71)[b]	0.04 (0.73)[b]	0.16 (0.81)[b]
Neem oil emulsion 2%+Thiamethoxam 0.02%	0 (0.71)[b]	0 (0.71)[b]	0 (0.71)[b]	0 (0.71)[b]	0 (0.71)[b]	0 (0.71)[b]	0.04 (0.73)[b]	0.10 (0.77)[bc]	0 (0.71)[b]	0 (0.71)[b]	0.06 (0.75)[b]	0.14 (0.79)[b]
Control	0.06 (0.75)[a]	0.08 (0.76)[a]	0.12 (0.78)[a]	0.16 (0.81)[a]	1.54 (1.42)[a]	1.60 (1.45)[a]	1.84 (1.53)[a]	2.14 (1.62)[a]	2.32 (1.68)[a]	2.36 (1.68)[a]	2.58 (1.75)[a]	2.72 (1.79)[a]
CD (0.05)	(0.027)	(0.038)	(0.058)	(0.023)	(0.064)	(0.060)	(0.084)	(0.076)	(0.055)	(0.057)	(0.056)	(0.070)
SE(m)	0.009	0.0017	0.019	0.007	0.02	0.019	0.027	0.025	0.018	0.018	0.018	0.022

Mean of 5 replications comprising 10 plants each (Values in the parentheses are square root transformed) DAT: Days after treatment

treated with thiamethoxam 0.02% and were statistically on par with neem oil emulsion 2% + thiamethoxam 0.02% (0.1 per plant). The control plot had a significantly different grub population of 2.14 per plant.

After third spray at 1 DAT and 3 DAT the population of lacewing larvae were not recorded from the treatment plots, whereas significant population was present in control plot (2.32 per plant and 2.36 per plant respectively).

At 5 DAT, the plants treated with neem oil emulsion 2%+ thiamethoxam 0.02% (0.06 per plant) and pongamia oil emulsion 2%+ thiamethoxam 0.02% (0.04 per plant) and were statistically on par with each other. The plots of thiamethoxam 0.02% did not record any population of larvae, whereas the untreated plants were seen with 2.58 per plant grub population.

At 7 DAT, the population of larvae were statistically on par in plants treated with pongamia oil emulsion 2% + thiamethoxam 0.02% (0.16 per plant) and neem oil emulsion 2% + thiamethoxam 0.02% (0.14 per plant). The population of larvae were 2.72 per plant in the untreated control whereas the plants treated with the chemical check thiamethoxam 0.02% did not record any population of larvae.

4.2.3.4 Spiders

The population of spiders *viz*, *Oxyopes javanus, Pardosa sumathrana, Carrhotus viduus*, and few others belonging to the genera *Oxyopes* sp. and *Pardosa* sp. were encountered in the cowpea ecosystem are furnished (Plate 9). The population of spiders prior to the application of treatments were found to be homogenous and statistically non-significant. Mean population of coccinellid larvae at different intervals after treatment are presented in Table 9.

Post application of first spray, 1 DAT the population of spiders were statistically on par in the treatment plots neem oil emulsion 2% + thiamethoxam 0.02% (0.08 per pant) and pongamia oil emulsion 2% + thiamethoxam 0.02% (0.04 per plant), whereas no spiders were observed in the plants treated with thiamethoxam 0.02%. The population of spiders in untreated control plot were 0.28 per plant.

3 DAT, the population of spiders was highest in the untreated control (0.38 per plant) and found statistically on par with pongamia oil emulsion 2% + thiamethoxam 0.02% (0.28 per plant). The treatment neem oil emulsion 2%+ thiamethoxam 0.02% (0.22 per plant) was found statistically on par with Thiamethoxam 0.02% (0.12 per plant).

5 DAT, the population of spiders were highest in the untreated control (0.48 per plant), which was statistically on par with pongamia oil emulsion 2% + thiamethoxam 0.02% (0.36 per plant) and neem oil emulsion 2% + thiamethoxam 0.02% (0.38 per plant). The population were significantly lower in plants treated with thiamethoxam 0.02% (0.24 per plant).

7 DAT, the population of spiders were on par on plots treated with pongamia oil emulsion 2% + thiamethoxam 0.02% (0.48 per plant) and neem oil emulsion 2% + thiamethoxam 0.02% (0.56 per plant). In the untreated control plots, the population of spiders were 0.76 per plant whereas the population in the chemical check plots thiamethoxam 0.02% (0.28).

After the application of second spray, at 1 DAT the population of spiders were on par in the treatment plots. The plants in the control plot with untreated plants had a population of 0.60 per plant.

At 3 DAT , the plants treated with pongamia oil emulsion 2% + thiamethoxam 0.02% (0.28 per plant), neem oil emulsion 2% + thiamethoxam 0.02% (0.24 per plant) were statistically on par and superior to thiamethoxam 0.02% (0.04 per plant). Whereas the population in control plots were highest and recorded 0.66 per plant. The similar trend was followed in the 5 DAT and 7 DAT.

At third spray, at 1 DAT the population of spiders were statistically on par in the treatment plots and the treatment thiamethoxam 0.02% recorded no spider population. Whereas the population of spiders in the control plot were 1.34 per plant. The similar trend was observed at 3 DAT.

At 5 DAT, the population of spiders in plants treated with neem oil emulsion 2% + thiamethoxam 0.02% were recorded as 0.32 per plant and were statistically on

Oxyopes javanus *Oxyopes sp*

Carrhotus viduus *Lycosa sp*

Pardosa sumathrana *Pardosa sp*

Plate 9. Spiders recorded in cowpea ecosystem

Table 9. Effect of treatments on spiders in cowpea ecosystem

Treatments	First spray (15 days after sowing)				Second spray (35 days after sowing)				Third spray (55 days after sowing)			
	Mean population of spider per plant				Mean population of spider per plant				Mean population of spider per plant			
	I DAT	3 DAT	5 DAT	7 DAT	I DAT	3 DAT	5 DAT	7 DAT	I DAT	3 DAT	5 DAT	7 DAT
Thiamethoxam 0.02%	0.00 (0.71)^{b}	0.12 (0.78)^{c}	0.24 (0.85)^{b}	0.28 (0.88)^{c}	0.00 (0.71)^{b}	0.04 (0.73)^{c}	0.16 (0.82)^{c}	0.30 (0.89)^{c}	0.00 (0.71)^{b}	0.06 (0.75)^{b}	0.20 (0.83)^{c}	0.24 (0.86)^{c}
Pongamia oil emulsion 2%+Thiamethoxam 0.02%	0.04 (0.73)^{b}	0.28 (0.88)^{ab}	0.36 (0.93)^{ab}	0.48 (0.98)^{b}	0.06 (0.75)^{b}	0.28 (0.88)^{b}	0.40 (0.95)^{b}	0.54 (1.01)^{b}	0.06 (0.75)^{b}	0.16 (0.81)^{b}	0.44 (0.97)^{b}	0.62 (1.05)^{b}
Neem oil emulsion 2%+Thiamethoxam 0.02%	0.08 (0.76)^{b}	0.22 (0.85)^{bc}	0.38 (0.94)^{a}	0.56 (1.02)^{b}	0.10 (0.77)^{b}	0.24 (0.86)^{b}	0.32 (0.91)^{b}	0.56 (1.02)^{b}	0.08 (0.76)^{b}	0.18 (0.82)^{b}	0.32 (0.91)^{bc}	0.50 (0.99)^{b}
Control	0.28 (0.88)^{a}	0.38 (0.94)^{a}	0.48 (0.99)^{a}	0.76 (1.12)^{a}	0.60 (1.05)^{a}	0.66 (1.07)^{a}	0.70 (1.09)^{a}	0.92 (1.12)^{a}	1.34 (1.35)^{a}	1.26 (1.31)^{a}	1.60 (1.44)^{a}	1.74 (1.49)^{a}
CD (0.05)	(0.057)	(0.083)	(0.075)	(0.061)	(0.067)	(0.043)	(0.062)	(0.061)	(0.128)	(0.138)	(0.109)	(0.122)
SE(m)	0.018	0.027	0.024	0.019	0.021	0.014	0.02	0.028	0.041	0.044	0.035	0.039

Mean of 5 replications comprising 10 plants each (Values in the parentheses are square root transformed) DAT: Days after treatment

par with thiamethoxam 0.02% (0.20 per plant) and pongamia oil emulsion 2% + thiamethoxam 0.02% (0.44 per plant). The population in the untreated control were recorded as 1.60 per plant.

At 7 DAT, the population of spiders were seen statistically on par in the treatment plots of pongamia oil emulsion 2% + thiamethoxam 0.02% (0.62 per plant) and neem oil emulsion 2% + thiamethoxam 0.02% (0.50 per plant). The population in the untreated plots were superior (1.74 per plant) whereas the least population were recorded in the plots treated with the chemical check thiamethoxam 0.02% (0.24 per plant).

4.2.4 Observations of Cowpea Yield with Response of Botanical Chemical Combinations

4.2.4.1 Yield

The pod yield in all the treatment plots were significantly different (Table 10). The highest pod weight (854 g plot^{-1}) was obtained from the plants treated with pongamia oil emulsion 2% + thiamethoxam 0.02% which was statistically superior to all other treatments. This was followed by neem oil emulsion 2% + thiamethoxam 0.02% (776 g plot^{-}1) and thiamethoxam 0.02% (718 g plot^{-1}). Untreated plants recorded lowest pod weight of 380 g plot$^{1.}$

4.2.5 Phytotoxicity

The effects of the botanical chemical combinations for phytotoxicity in cowpea plants were evaluated and observed for symptoms like yellowing, scorching, necrosis, epinasty and hyponasty. The results of the study shows that the treatments applied does not elucidate any symptoms of phytotoxicity.

4.2.6 Estimation of Harvest Time Residue

Samples collected from the different plots 5 days after the application of treatments were subjected to residue analysis at the Pesticide Residue Research and Analytical Laboratory, College of Agriculture, Vellayani. Pesticide residue were below the limit of quantification (0.1 mg kg^{-1}) in all the samples from different treatment (Table 11).

Table 10. Effect of different treatments on the yield (gram $plot^{-1}$)

Treatment	yield (gram $plot^{-1}$)
Thiamethoxam 0.02%	(718)[c]
Pongamia oil emulsion 2%+Thiamethoxam 0.02%	(854)[a]
Neem oil emulsion 2%+Thiamethoxam 0.02%	(776)[b]
Control	(380)[d]
CD (0.05)	(28.058)
SE(m)	12.878

Table 11. Estimation of harvest time residue

S.no	Treatments	Sample ID	Molecule	Concentration (ppm)
1	Thiamethoxam 0.02%	V 10548 CP	Thiamethoxam	<LOQ
2	Pongamia oil emulsion 2%+Thiamethoxam 0.02%	V 10549 CP	Thiamethoxam	<LOQ
3	Neem oil emulsion 2%+Thiamethoxam 0.02%	V 10550 CP	Thiamethoxam	<LOQ
4	Control	V 10551 CP	Thiamethoxam	<LOQ

<LOQ – limit of quantification (0.1 mg/kg)

Discussion

5. DISCUSSION

The irrational use of pesticides, monoculture, improper management strategies have played a major role in the rapid increase of sucking pest population in many cropping ecosystems. Sole reliance on chemical pesticides for pest control can possess a threat to sustainable agriculture productivity and lethal effects on the non-target organisms. The indiscriminate use of pesticides also caters to high costs and increased health hazards to both users and consumers. The constant exposure to systemic chemicals induces a greater probability of sucking pests like aphids in developing resistance.

The indiscriminate use of chemical pesticides along with low yield led to a search of novel management strategies to improve yield with less chemical insecticide input and incorporation of plant-based insecticides. Many botanicals have proved to be effective against various sucking pests such as the cowpea aphid *A.craccivora.*Yet when the population is in large numbers the botanicals may be ineffective to bring down the population, in such cases a combination of botanicals with systemic chemicals can be effective. This highlights the need to reduce sole reliance on chemicals by combining them with natural products like extracts and oils of plant origin. The combination of chemical and botanical pesticides helps in reducing the quantity of chemical pesticides, without reducing the effectiveness of pest management.

The present investigation is intended to conduct a study in evaluating the effect of botanical chemical pesticide combinations in the management of cowpea aphid *A.craccivora* in cowpea ecosystem using botanicals such as pongamia oil, Neem oil, and *Andrographis paniculata* extracts in combination with various concentration of Thiamethoxam.

5.1 IN VITRO EVALUATION OF DIFFERENT COMBINATION OF BOTANICAL CHEMICAL COMBINATION AGAINST *A.craccivora*

The present investigation emphasized studying the efficacy of botanical-chemical pesticide combinations in the management of cowpea aphid *A.craccivora.*

Equal volumes of chemical solution and botanical oil emulsion or extract were mixed to obtain a combination of botanical–chemical pesticides. During the combination of two components, it was observed that the thiamethoxam was readily miscible with the botanical components to obtain a stable combination mixture. This observation is in agreement with the studies of Sridevi and Dhingra (1997), Marques *et al.* (2019) and Hassan (2020) who reported that the combination of various botanical oils such as neem oil, pongamia oil, almond oil and basil oil was compatible and stable when mixed with various synthetic chemical pesticides.

It was found that the combination of pongamia oil emulsion 2% + thiamethoxam 0.02% and neem oil emulsion 2% + thiamethoxam 0.02% were efficient in managing aphids with a percentage mortality of 90.44 and 81.89 respectively after 48 h of treatment. This was found in conformity with the study of Fazolin *et al. (*2016) who evaluated the combination of botanical essential oil (*Piper aduncum* L.) with synthetic pyrethroids (cypermethrin, zeta-cypermethrin, permethrin, and esfenvalerate) and obtained a synergistic reaction and significant reduction in fall army worm population.

In the present study, pongamia oil emulsion 2% + thiamethoxam 0.02% were superior in terms of per cent mortality of aphids when compared to other treatments. The synergistic effect of pongamia oil was supported by Singhamony *et al.* (1983) whose study revealed that combination of Pongamia oil and its constituents like karanjin and pongamol, to synthetic insecticides such as isolan, pyrolan, carbaryl, endrin, or heptachlor can significantly increase their toxicity against major sucking pest of cotton, the cotton stainer, *D. cingulatus*. A study conducted by Sridevi and Dhingra (1997), infers that the pest of stored products *Tribolium castaneum* H. was found more sensitive to the combination product of Pongamia oil with deltamethrin than their individual effects. The insecticidal activity of pongamia oil emulsion 2% + thiamethoxam 0.02% can be validated by other findings of Loganathan *et al.* (2003), Walia *et al.* 2017) and Pavela (2007).

The combination of neem oil emulsion 2% + thiamethoxam 0.02% reported 81.89 per cent mortality of *A.craccivora* at 48 h post-treatment in the current investigation which was in accordance with a study conducted by Flanery (2011), who concluded that the effect of combining neem based products (AgroNeem Plus®) with thiamethoxam (0.25 - 2 times label rate) on diamondback moths, *P. xylostella* exhibited a broad spectrum of interactions which includes antagonistic, additive, and synergistic effects. According to a study by Radhika and Sahayaraj (2014), combination of monocrotophos (0.03%) with neem oil gave maximum mortality of *S. litura* larvae under controlled laboratory conditions. Further, the synergistic effect of neem oil along with chemical pesticides were confirmed by the findings of Rao and Dhingra (2000), who observed that in locations where fenvalerate resistance was recorded, the combination of fenvalerate and neem oil could significantly outperform fenvalerate alone in controlling *S. litura* larvae.

In the current research work the combination of *Andrographis* formulation 5 % + thiamethoxam 0.02%, reported 48.89 per cent mortality of *A.craccivora* when recorded at 48 h after treatment application; which was statistically superior than the sole effect of *Andrographis* formulation 5% (33 per cent). The findings of Kumar and Singh (2002) validated the synergistic impact of pongamia oil in the current investigation. They found that formulations based on pongamia oil had good emulsion stability and provided good synergistic effects with other botanical insecticides. The insecticidal efficacy of *A. paniculata* in combination with thiamethoxam observed in the present study can be substantiated by the findings of Singh *et al.* (2014), Madihah *et al.* (2018) and Prema *et al.* (2018) who evaluated the insecticidal properties of *A. paniculata.*

The synergistic effect of the combination between botanicals and thiamethoxam was well supported by the findings of Marques *et al.* (2019). They found that the combination of *O. basilicum* essential oil with thiamethoxam resulted in the efficient management of *A. gossypii*. The high mortality attributed to the combination of botanical chemical pesticides may be credited to the synergistic action of the neonicotinoid thiamethoxam, an activator of nicotinic acetylcholine receptors in the postsynaptic cleft along with the *O. basilicum* essential oil which inhibits acetylcholinesterase.

5.2 FIELD EVALUATION OF EFFECTIVE BOTANICAL-CHEMICAL COMBINATIONS

The effective approach for authentically validating the results of laboratory experiments is field evaluation. In order to compare their field efficacy, effective treatments were selected from *in vitro* experiments and tested in the field. Field evaluation was conducted using the selected best treatments *viz*., pongamia oil emulsion 2% + thiamethoxam 0.02% and neem oil emulsion 2% + thiamethoxam 0.02% and thiamethoxam 0.02% as the chemical check. Even though the chemical check thiamethoxam 0.02% recorded fastest and highest mortality rate in *in vitro* studies, in field situations its combination with oils showed better performance. This may be due to the enhanced biotic (natural enemy population) and abiotic stress factors.

During the first round of spraying in the field trial, among the two botanical-chemical combinations evaluated, minimum population of aphids , when compared with the untreated control, was observed in the pongamia oil emulsion 2% + thiamethoxam 0.02% with no record of aphids followed by, neem oil emulsion 2% + thiamethoxam 0.02% (1.62 aphids per plant) and thiamethoxam 0.02% (1.02 aphids per plant) which was statistically on par with each other at 5 DAT. Pongamia oil emulsion 2% + thiamethoxam 0.02% (1.36 per plant) was on par with neem oil emulsion 2% + thiamethoxam 0.02% (1.94 aphids per plant) and proved efficient in reducing the aphid population at 7 DAT.

The results of the second round of spray also substantiate the results obtained during the initial spray, where the first and seventh day after the treatment, the combination of pongamia oil emulsion 2% + thiamethoxam 0.02% (7.94 and 0.60 per plant respectively) was superior over other tested treatments. The treatment, neem oil emulsion 2% + thiamethoxam 0.02% (4.14,1.38 and 1.38 per plant respectively) was found statistically on par with pongamia oil emulsion 2% + thiamethoxam 0.02% (2.26, 0.38, and 0.60 per plant respectively) during 3 DAT, 5 DAT and 7 DAT.

The third round of application indicates that the maximum reduction in aphid population was brought by pongamia oil emulsion 2% + thiamethoxam 0.02% (97.37 per cent) and it was followed by neem oil emulsion 2% + thiamethoxam 0.02% (91.81

per cent) when compared with the untreated control at 7 DAT. The least population of aphids during 1 DAT, 3 DAT, 5DAT and 7 DAT were recorded in the plants treated with pongamia oil emulsion 2% + thiamethoxam 0.02% (12.42, 1.34, 1.40, and 0.44 per plant respectively). The aphid population in neem oil emulsion 2% + thiamethoxam 0.02% (2.00 and 1.26 per plant respectively) was found statistically on par with the effects of pongamia oil emulsion 2% + thiamethoxam 0.02% (1.34 and 0.44 per plant respectively) during the 3DAT and 7 DAT.

The highest percentage reduction in the *A. craccivora* population seven days after third spray were obtained in the treatment pongamia oil emulsion 2% + thiamethoxam 0.02% (97.37 per cent) followed by neem oil emulsion 2% + thiamethoxam 0.02% (91.81 per cent) , whereas plots treated with thiamethoxam 0.02% recorded 77.31 per cent (Fig. 1).

The comparatively lower population of aphids found in the plots treated with botanical chemical combinations may be due to the simultaneous increase in the natural enemy population in those plots and synergistic action between the chemical and botanical pesticides. The increased natural enemy population might have induced abiotic stress leading to the natural control of aphids to some extent. This can be substantiated by the findings of study conducted by Baidoo *et al.* (2012), which evaluated the effectiveness of neem formulations (aqueous neem kernel extract (ANKE) and neem kernel powder (NKP) on *A. craccivora* and its natural enemy *Harmonia axyridis* Pallas. The result of the study states that the population of the natural enemy was greater in ANKE (4.0 per plant) and NKP (4.1 per plant) treated plants compared with the chemical check (2.0 per plant).

The various combination of essential oils with neonicotinoids and their mode of action have been already been demonstrated to control other aphid species such as, *Myzus persicae* Sulzer treated with essential oils from *Lavandula angustifolia* M. (lavender) and *Thymus vulgaris* L. (thyme) in combination with imidacloprid (Faraone *et al.*, 2015) similarly, *Aphis gossypii* G *treated with combination of* essential oil of *Ocimum basilicum* L.(0-60 nano litre insect^{-1}) and thiamethoxam (0-50 nano gram insect^{-1}) were evaluated for their insecticidal activity and synergism (Marques *et al.*, 2019). A study conducted by Faraone *et al.* (2015), identified that the dose of neonicotinoids can be reduced when mixed with major essential oils and this also confirms the synergistic relationship between them.

There is insufficient literature pertaining to the efficacy of combination of neem oil and pongamia oil with thiamethoxam in the management of *A. craccivora.* Neem oil in combination with triazophos (EC 40%), acephate (EC 75%), monocrotophos (EC 36%) resulted significant reduction of *Dialeuroporo decempuncta* attacking mulberry. The highest population reduction was obtained in neem oil (EC 0.03%) + triazophos (EC 40%) with 77.35 per cent (Bandyopadhyay and Kumar, 2000).

The effect of treatments on the population of pod bugs, *R. pedestris* was observed during the third round of spraying. Significant reduction in the population of pod bugs were observed in the treatments pongamia oil emulsion 2% + thiamethoxam 0.02% and neem oil emulsion 2% + thiamethoxam 0.02%, and there was no record of pod bugs in these treatments on 3 DAT. After seven days of treatment, the highest percentage reduction of pod bugs were reported from the plants treated with pongamia oil emulsion 2% + thiamethoxam 0.02% (0.48 per plant and 87.5 per cent reduction) and neem oil emulsion 2% + thiamethoxam 0.02% (0.58 per plant and 84.89 per cent reduction) whereas thiamethoxam 0.02% sprayed plots recorded 71.72 per cent (Fig 2).

A study conducted by Oparaeke *et al* (2005) reveals that the combination of various botanicals (leaf extract mixtures of *Azadirachta indica* A. Juss and *Eucalyptus citriodora* Pers.) were found efficient in reducing the population of cowpea pod bugs with a significantly lower percentage of pod damage. Hence the reduction in pod bugs in plants treated with pesticide combination can be associated with the complementary roles played by individual pesticides.

From the first, second and third spraying, the maximum reduction in aphids and pod bugs in the cowpea ecosystem was brought by pongamia oil emulsion 2% + thiamethoxam 0.02%, followed by neem oil emulsion 2% + thiamethoxam 0.02%. Thus, it can be concluded that the combination of pongamia oil 2% or Neem oil 2 % with thiamethoxam 0.02% was found more effective than the sole use of thiamethoxam 0.02% in managing two major sucking pests *viz* aphids *A. craccivora* and pod bugs *R. pedestris* encountered in cowpea ecosystem.

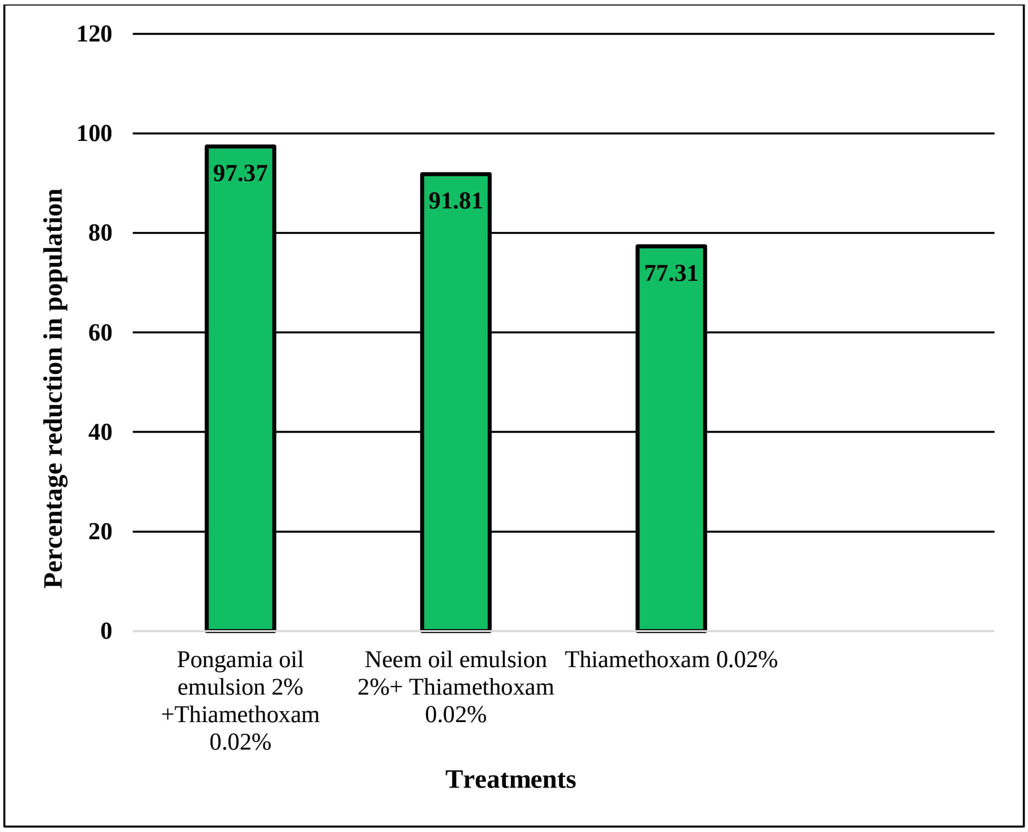


Fig 1: Percentage reduction of *Aphis craccivora* seven days after third spray

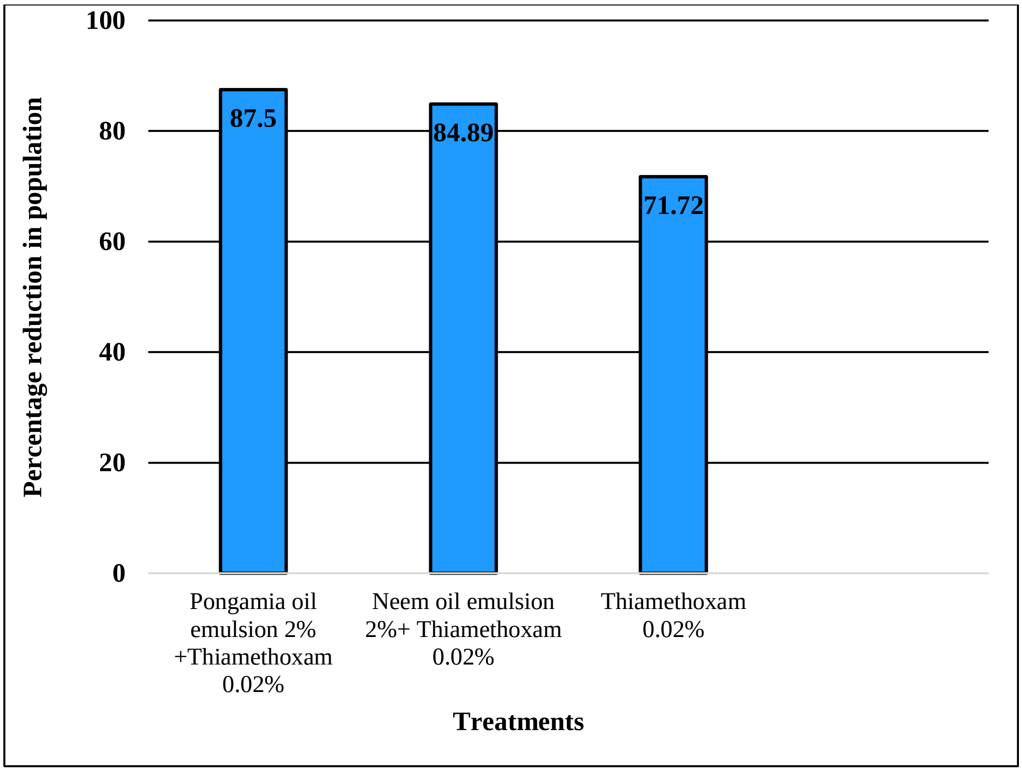


Fig 2: Percentage reduction of *Riptortus pedestris* seven days after third spray

In addition to pest management, all combinations revealed noticeably greater natural enemy populations when compared to chemical control (thiamethoxam). The population of coccinellids, lacewings, spiders and syrphids were significantly higher in plants treated with pongamia oil emulsion 2% + thiamethoxam 0.02% and neem oil emulsion 2% + thiamethoxam 0.02% compared to the population in chemical check plots. Seven days after the third spray, the population of coccinellids (2.98 per plant), syrphids (2.1 per plant), lacewings (0.16 per plant) and spiders (0.54 per plant) were highest in plots treated with pongamia oil emulsion 2% + thiamethoxam 0.02%. Whereas the lowest population of natural enemies *viz,* coccinellids (1.84 per plant), syrphids (0.22 per plant), lacewings (0 per plant) and spiders (0.32 per plant) were observed in plots treated with thiamethoxam 0.02% (Fig. 3). From this finding it can be inferred that the comparatively higher population of natural enemies in the treatments pongamia oil emulsion 2% + thiamethoxam 0.02% and neem oil emulsion 2% + thiamethoxam 0.02% can act as a complimentary factor in bringing down aphid population through natural control, also helps to maintain a sustainable ecosystem. A study conducted by Golvankar *et al.* (2019) recorded that natural enemies in cowpea ecosystem such as lady beetles, *Coccinella septempunctata* L. and *Cheilomenas sexmaculata* F. and spiders population were significant from 4 th to 11^{th} week after treatment Azadirachtin 50000 ppm and was at the peak on the 7^{th} week.

The present study is in accordance with the research findings of Jeevitha (2020) on population statistics of coccinellids, syrphids and green lacewings which revealed that significantly higher population of natural enemies *viz* coccinellids, syrphids and green lacewing were recorded in the plots treated with Pongamia oil soap whereas Thiamethoxam recorded no population of up to the fifth day of spray. Similar findings were observed by Baidoo *et al.* (2012) in a study conducted on *A. craccivora* and its natural enemy *Harmonia axyridis* Pallas using neem based products in comparison with chemical pesticides.

The yield obtained was highest in the plots treated with pongamia oil emulsion 2% + thiamethoxam 0.02% (854 g $plot^{-1}$) followed by neem oil emulsion 2% + thiamethoxam 0.02% (776 g $plot^{-1}$). The yield in the chemical check plot was recorded as 718 g $plot^{-1}$, whereas the lowest yield was recorded in control plot (380 g $plot^{-1}$).This may be due to the synergistic effect of these botanical oils and increased activity of natural enemies in the botanical chemical combination treated plots when compared to the chemical alone treated plots. Even though the natural enemies population is high in the control plots, the yield obtained from these plots were comparatively low may be due to the increased pest population in control plots which was always above the economic threshold level.

From the current study, it can be concluded that the negative effects of thiamethoxam towards natural enemies can be overcome by combining it with botanicals like pongamia oil 2% or neem oil 2%. It was found that these botanicals may acts as synergists when combining with thiamethoxam and also beneficial to the natural enemies population in cowpea ecosystem. Besides reducing the accumulation of chemical residues with the repeated application of chemical pesticides, it will helps in maintaining the quality and quantity of harvested produce and also conserve the balance of the ecosystem by maintaining the natural enemy population.

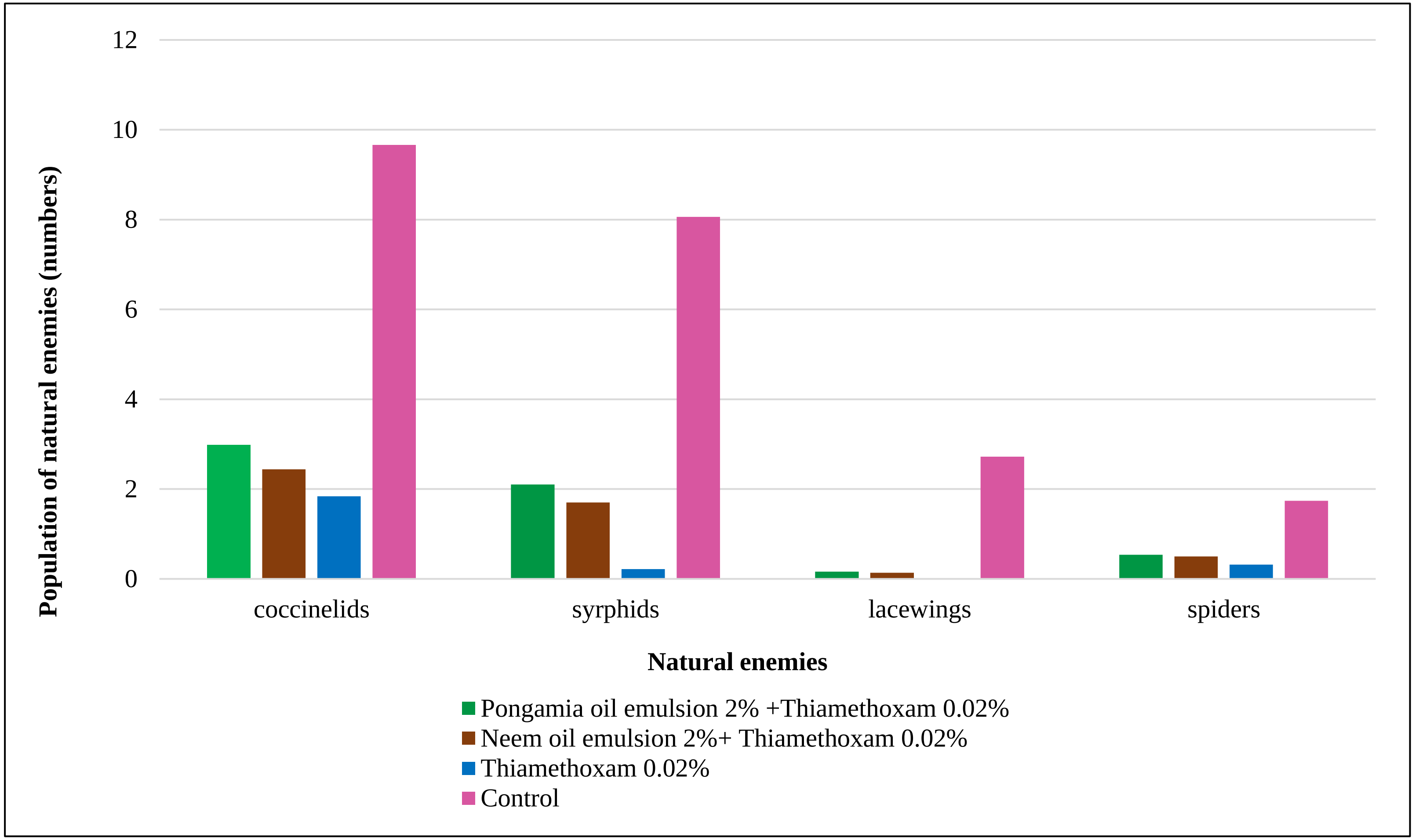


Fig 3: Population of natural enemies seven days after third spray

Summary

6. SUMMARY

Cowpea *Vigna unguiculata* L. is one of the important vegetable, pulse, and fodder crops grown in India. Insect pest attacks have been identified as one of the main biotic constraints on the production of vegetables across the country over time. One of the main obstacles to the growth and development of cowpea is the sucking pests.

Cowpea aphid *Aphis craccivora* is a major sucking pest of cowpea causing considerable economic damage. The adults and nymphs feed by sucking sap from the phloem of the tender shoots, inflorescence, leaves, and tender pods leading to the drying of plant parts, stunting, malformation, and loss of vigour in the plant. They also act as vector for transmitting several viral diseases and cause indirect economic damage.

Aphids multiply at a faster rate due to the parthenogenetic reproductive ability and prevailing monocropping ecosystem. Farmers adopt the use of broad-spectrum and synthetic pesticides for the immediate control of pests in fields. Extensive use of traditional chemicals induced resistance and turned ineffective to manage the emerging pest population over years of repeated usage.

Neonicotinoid insecticides were introduced to overcome the demerits of conventional insecticides and various studies confirmed their efficacy in managing various sucking pests including aphids. However, the repeated application of neonicotinoids increased the threat of resistance development in various target pests, additionally they also negatively affected the natural enemy population in the ecosystem and hindered the natural control of pests. Thus, researchers are focused on reducing the use chemical pesticides by incorporating natural or plant-based pesticides in the spray schedule.

With this backdrop, the current study entitled "Botanical-chemical pesticide combinations for managing cowpea aphid *Aphis craccivora* Koch" was conducted during the period 2020-2022, Department of Agricultural Entomology, College of Agriculture, Vellayani with an objective to study the efficacy of combining botanical and chemical pesticide solutions against *A. craccivora* and natural enemies in a cowpea ecosystem.

The present study comprised *in vitro* and field evaluation of botanical-chemical pesticide combinations. Different combinations were evaluated in the laboratory to choose three best treatments for further evaluation in the field.

Findings from the laboratory study records that after 24 hour of treatment, the highest mortality was reported by Thiamethoxam0.02% (88.89 per cent), followed by Pongamia oil emulsion 2% +Thiamethoxam 0.02% (76.67 per cent) and Neem oil emulsion 2% + Thiamethoxam 0.02% (70 per cent). A similar trend was observed for data collected at 24 hour and 48 hour post treatment. At the end of 48 hour the treatments showed significant results, where Thiamethoxam 0.02% recorded the highest mortality (99 per cent), followed by Pongamia oil emulsion 2% +Thiamethoxam 0.02% (90.44 per cent) and Neem oil emulsion 2% + Thiamethoxam 0.02% (81.89 per cent). From the in-vitro study, three treatments namely Thiamethoxam 0.02%, Pongamia oil emulsion 2% + Thiamethoxam 0.02% and Neem oil emulsion 2% + Thiamethoxam 0.02% were found superior, thus chosen for field evaluation.

Field experiment was carried out in cowpea variety Anaswara with the three selected treatments to assess the field efficacy against *A. craccivora* and its effect on the population of natural enemies in the cowpea ecosystem. A consistent population of pests and natural enemies was maintained in the field by avoiding plant protection measures.

Three rounds of treatment sprays were applied after documenting the precount of pests and natural enemies at 15, 35 and 55 DAS for field evaluation and data were recorded at 1,3,5 and 7 DAT.

Seven days after the first spray, the treatments Pongamia oil emulsion 2% + Thiamethoxam 0.02% (1.36 per plant) showed a lower population of aphid *A. craccivora* when compared with the chemical check and control. The population of aphids in the plants treated with Neem oil emulsion 2% + Thiamethoxam 0.02% (1.94 per plant) was found statistically on par with Pongamia oil emulsion 2% +Thiamethoxam 0.02% (1.36 per plant) and Thiamethoxam 0.02% (2.82 per plant). A similar trend was followed 7 DAT of the second spray.

After the application of the third spray, superior performance was showcased by treatments Pongamia oil emulsion 2% + Thiamethoxam 0.02% (0.44 per plant) and

Neem oil emulsion 2% + Thiamethoxam 0.02% (1.26 per plant) in reducing the aphid population and were statistically on par with each other at 7 DAT.

Additionally, pod bugs *R. pedestris* were observed as another major sucking pest 50 DAP. The treatments Pongamia oil emulsion 2% + Thiamethoxam 0.02% and Neem oil emulsion 2% + Thiamethoxam 0.02% were reported superior in reducing the pod bug population with 0.48 and 0.58 per plant population respectively at 7 DAT of third spray.

Results of the field experiment revealed that Pongamia oil emulsion 2% + Thiamethoxam 0.02% recorded the highest percentage reduction in the population of *A. craccivora* (97.37 per cent) and *R. pedestris* (87.5 per cent).

The population of natural enemies including coccinellids, syrphids, lacewings and spiders were conserved in the plots treated with botanical chemical combinations when compared with the sole application of thiamethoxam (chemical check). The maximum population of natural enemies were recorded in the control plot and minimum in the chemical check.

The treatments showed significant variation in yield. The highest yield in terms of fresh pod weight of 854 g plot^{-1} was obtained by Pongamia oil emulsion 2% + Thiamethoxam 0.02% followed by Neem oil emulsion 2% + Thiamethoxam 0.02% with 776 g plot^{-1} which were comparatively superior than the sole spray of Thiamethoxam 0.02% (718 g plot^{-1}).

Studies on phytotoxicity revealed no symptoms of scorching, necrosis, epinasty, yellowing and hyponasty. The Central Insecticides Board and Registration Committee's (CIBRC) protocol was followed while grading the observations for phytotoxic symptoms. Results conclude that the evaluated treatments exhibited no phytotoxic response.

The salient findings of the investigation are:

- The combination of botanicals like Neem oil, Pongamia oil and *Andrographis paniculata* extracts with chemical pesticides were found miscible and compactable with each other to produce a stable treatment solution.
- Under laboratory evaluation, the treatments Thiamethoxam 0.02%, Pongamia oil emulsion 2% + Thiamethoxam 0.02% and Neem oil emulsion 2% +

Thiamethoxam 0.02% were found superior to others in terms of per cent mortality of aphids.

- During field evaluation, the treatments Pongamia oil emulsion 2% + Thiamethoxam 0.02% and Neem oil emulsion 2% + Thiamethoxam 0.02% were efficient by showing higher per cent reduction in the population of cowpea aphids and pod bugs in cowpea ecosystem.
- Highest population of natural enemies was recorded in the control plot and lowest in the chemical check, whereas the plots treated with botanical – chemical combinations harboured comparatively significant natural enemy populations.
- No phytotoxicity symptoms were recorded in the cowpea field during the evaluation of treatments.
- The botanicals such as pongamia oil and neem oil can be effectively combined with thiamethoxam to control sucking pests such as *A. craccivora* and *R. pedestris* due to the possible synergistic action of botanicals with chemical pesticides. This combination can promote the population of natural enemies, thereby encouraging natural control along with reducing the quantity of chemical pesticides and quality of environment.

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BOTANICAL-CHEMICAL PESTICIDE COMBINATIONS FOR MANAGING COWPEA APHID *Aphis craccivora* Koch

by

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ABSTRACT

The present investigation on "Botanical-chemical pesticide combinations for managing cowpea aphid *Aphis craccivora* Koch" was conducted at the Department of Agricultural Entomology, College of Agriculture, Vellayani during 2020 to 2022 with an objective to study the effect of botanical-chemical pesticide combinations for managing cowpea aphid *Aphis craccivora* in cowpea.

Fourteen treatments namely Neem oil emulsion 2%+ Thiamethoxam 0.02%, Neem oil emulsion 2%+ Thiamethoxam 0.01%, Neem oil emulsion2%+ Thiamethoxam 0.005%, Pongamia oil emulsion 2%+Thiamethoxam 0.02%, Pongamia oil emulsion 2%+ Thiamethoxam 0.01%, Pongamia oil emulsion 2%+Thiamethoxam 0.005%, Andrographis formulation 5 % (Bhavyasree, 2019) +Thiamethoxam 0.02%, Andrographis formulation 5 % (Bhavyasree, 2019) +Thiamethoxam 0.01%, Andrographis formulation 5 % (Bhavyasree, 2019) +Thiamethoxam 0.005%, Neem oil emulsion 2%, Pongamia Oil emulsion 2%, Andrographis formulation 5% , Thiamethoxam 0.02% and Untreated control were evaluated against *A. craccivora* with three replications maintained under laboratory conditions. The mortality of the test insect was recorded at 12, 24 and 48 h after treatment and the data were statistically analysed.

After 24 h of treatment, the highest mortality was shown by Thiamethoxam 0.02% (88.89 per cent), followed by Pongamia oil emulsion 2% +Thiamethoxam 0.02% (76.67 per cent) and Neem oil emulsion 2% + Thiamethoxam 0.02% (70 per cent). After 48h of treatment, same trend was observed and Thiamethoxam 0.02% recorded highest mortality (99 per cent), followed by Pongamia oil emulsion 2% +Thiamethoxam 0.02% (90.44 per cent) and Neem oil emulsion 2% + Thiamethoxam 0.02% (81.89 per cent). Based on the *in-vitro* study, three treatments were chosen for field evaluation namely Pongamia oil emulsion 2% + Thiamethoxam 0.02%, Neem oil emulsion 2% + Thiamethoxam 0.02% and Thiamethoxam 0.02%.

Three prophylactic sprays were given at 15, 35 and 55 days after sowing for field evaluation and data were recorded at 1,3,5 and 7 days after treatment. The field data were evaluated using the 2 Way Analysis of Covariance (ANCOVA). The treatments Pongamia oil emulsion 2% + Thiamethoxam 0.02% and Neem oil emulsion

2% + Thiamethoxam 0.02% showed significantly lower population of aphid *A. craccivora* when compared with the chemical check and control. Seven days after first spray, the mean population of aphids per plant were significantly lower in the plots treated with Pongamia oil emulsion 2% + Thiamethoxam 0.02% (1.36 per plant) followed by the Neem oil emulsion 2%+ Thiamethoxam 0.02% (1.94 per plant) and both the treatments exhibited a steady decline in the aphid population when compared with control. The similar trend was followed in the second spray (35 days after sowing) and third spray (55 days after sowing). Testing the effectiveness of these treatments against pod bugs, *Riptortus pedestris,* the results were similar to that of *A. craccivora* population. The effects on the natural enemies *viz,* coccinellid (adult and larvae), brown lacewings, spiders and syrphids were recorded. The analysed data showed that the plots treated with Pongamia oil emulsion 2% + Thiamethoxam 0.02% and Neem oil emulsion 2% + Thiamethoxam 0.02% harboured significantly higher population of natural enemies when compared with the standard chemical check. Symptoms like yellowing, scorching, necrosis, epinasty and hyponasty were observed for phytotoxicity studies and the above treatments did not exhibit any form of phytotoxicity.

All the treatments exhibited significant variation in fresh pod weight. The highest yield was recorded in the plots treated with Pongamia oil emulsion 2%+Thiamethoxam 0.02% (854 g/plot), which was followed by Neem oil emulsion 2%+Thiamethoxam 0.02% (776 g/plot). Traces of chemical residue (0.011ppm) were detected in chemical check (Thiamethoxam 0.02%), but it is below the limit of quantification (< LOQ), whereas the plots treated with Pongamia oil emulsion 2% + Thiamethoxam 0.02% and Neem oil emulsion 2% + Thiamethoxam 0.02%, did not detect any residue.

From the study, it can be concluded that the combination of Pongamia oil emulsion 2% + Thiamethoxam 0.02% and Neem oil emulsion 2% + Thiamethoxam 0.02%, were effective in controlling aphid and pod bug population and they also supported the population of natural enemies when compared to chemical check (Thiamethoxam 0.02%). The chemical-botanical combinations supported good yield of cowpea and also reported thiamethoxam residue below limit of quantification.

സംഗ്രഹം

രാസ കീടനാശിനികളുടെ അളവ് കുറച്ച് പ്രവർത്തനക്ഷമത കൂട്ടുന്നതിനായി സസ്യജന്യ കീടനാശിനികളെ വിവിധ അനുപാതത്തിൽ കൂട്ടിച്ചേർത്ത് പയർ ചെടികളിൽ പ്രയോഗിച്ച് മുഞ്ഞകളെ നിയന്ത്രിക്കുന്നതിനുള്ള പഠനം 2020-22 കാലയളവിൽ വെള്ളയാണി കാർഷിക കോളേജിലെ എന്റെമോളജി വിഭാഗത്തിൽ വച്ച് നടത്തുകയുണ്ടായി. പരീക്ഷണം നടത്തിയ സസ്യജന്യ കീടനാശിനികളുടെ വിവിധ അനുപാതം താഴെക്കൊടുത്തിരിക്കുന്നു.

വേപ്പെണ്ണ എമൽഷൻ 2% + തയോമെത്തോക്സാം 0.02%, വേപ്പെണ്ണ എമൽഷൻ 2% + തയോമെത്തോക്സാം 0.01%, വേപ്പെണ്ണ എമൽഷൻ 2% + തയോമെത്തോക്സാം 0.005%, പൊങ്കാമിയ എണ്ണ എമൽഷൻ 2% + തയോമെത്തോക്സാം 0.02%, പൊങ്കാമിയ എണ്ണ എമൽഷൻ 2% + തയോമെത്തോക്സാം 0.01%, പൊങ്കാമിയ എണ്ണ എമൽഷൻ 2% + തയോമെത്തോക്സാം 0.005%, കിരിയാത്ത് ഫോർമുലേഷൻ 5% (ഭവ്യശ്രീ, 2019) + തയോമെത്തോക്സാം 0.02%, കിരിയാത്ത് ഫോർമുലേഷൻ 5% (ഭവ്യശ്രീ, 2019) + തയോമെത്തോക്സാം 0.01%, കിരിയാത്ത് ഫോർമുലേഷൻ 5% (ഭവ്യശ്രീ, 2019) + തയോമെത്തോക്സാം 0.005%, വേപ്പെണ്ണ എമൽഷൻ 2%, പൊങ്കാമിയ എണ്ണ എമൽഷൻ 2%, കിരിയാത്ത് ഫോർമുലേഷൻ 5% (ഭവ്യശ്രീ, 2019), തയോമെത്തോക്സാം 0.02%.

മുഞ്ഞകളെ നിയന്ത്രിക്കുന്നതിനുള്ള ഈ പരീക്ഷണങ്ങളുടെ പ്രവർത്തനക്ഷമത 12, 24, 48 മണിക്കൂറുകളിൽ രേഖപ്പെടുത്തി. മുഞ്ഞകളുടെ ഏറ്റവും കൂടിയ മരണനിരക്ക് (90.44%) 48-മണിക്കൂറിൽ തയോമെത്തോക്സാം (0.02%) + പൊങ്കാമിയ എണ്ണ എമൽഷൻ (2%) രേഖപ്പെടുത്തി. തുടർന്ന് ഇതേ കീടനാശിനി തന്നെ വേപ്പെണ്ണ എമൽഷനുമായി 2% വീര്യത്തിൽ സംയോജിപ്പിച്ചപ്പോൾ (81.89%) മുഞ്ഞകളുടെ മരണ നിരക്ക് രേഖപ്പെടുത്തി.

ലബോറട്ടറിയിൽ നടത്തിയ ഈ പഠനത്തിലെ മികച്ച രാസസസ്യജന്യ കീടനാശിനി സംയോജന അനുപാതം കൃഷിയിടങ്ങളിൽ പരീക്ഷണം നടത്തി. വിത്തു വിതച്ച് 15, 35, 55 ദിവസങ്ങളിൽ തയോമെത്തോക്സാം 0.02% + പൊങ്കാമിയ എണ്ണ എമൽഷൻ 2% സംയോജന അനുപാതം, തയോമെത്തോക്സാം 0.02% + വേപ്പെണ്ണ എമൽഷൻ 2% സംയോജന അനുപാതം എന്നിവ ചെടികളിൽ തളിച്ചു. ശേഷം 1, 3, 5, 7 ദിവസങ്ങളിൽ ഉള്ള കീടങ്ങളുടെയും മിത്ര പ്രാണികളുടെയും എണ്ണംരേഖപ്പെടുത്തി. ഇവയുടെ പ്രവർത്തനക്ഷമത തയോമെത്തോക്സാം 0.02%-മായി താരതമ്യം ചെയ്തപ്പോൾ മുഞ്ഞകളെയും, ചാഴികളെയും നിയന്ത്രിക്കുന്നതിന് തയോമെത്തോക്സാമിന്റെ പൊങ്കാമിയ എണ്ണയുമായുള്ള 2% വീര്യത്തിലുള്ള സംയോജിത അനുപാതം വളരെ ഫലപ്രദമാണെന്ന് കണ്ടു. തയോമെത്തോക്സാമിന്റെ വേപ്പെണ്ണയും ആയുള്ള 2% വീര്യത്തിലുള്ള സംയോജിത അനുപാതവും ഫലപ്രദമാണെന്ന് കണ്ടു.

രാസകീടനാശിനി യുമായി താരതമ്യം പഠനം നടത്തിയപ്പോൾ രാസ-സസ്യജന്യ കീടനാശിനി മിശ്രിതം മിത്ര പ്രാണികൾക്ക് സുരക്ഷിതം ആണെന്ന് കണ്ടെത്തി. രാസ-സസ്യജന്യ കീടനാശിനി മിശ്രിതം ചെടികളിൽ യാതൊരു വിധത്തിലുള്ള ദോഷഫലങ്ങൾ ഉണ്ടാക്കുന്നില്ല എന്നും തെളിഞ്ഞു. ഏറ്റവും കൂടുതൽ വിളവ് രേഖപ്പെടുത്തിയ തയോമെത്തോക്സാം 0.02% + പൊങ്കാമിയ എണ്ണ എമൽഷൻ 2% മിശ്രിതം ആണ് (854 ഗ്രാം/പ്ലോട്ട്). വിഷാംശ അവശിഷ്ട പരിശോധനയിൽ രാസസസ്യജന്യ കീടനാശിനി മിശ്രിതങ്ങൾ തളിച്ച പയറുകളിൽ വിഷാംശ അവശിഷ്ടം തീരെയില്ല എന്നും കണ്ടു.

ഈ പഠനത്തിൽ നിന്നും തയോമെത്തോക്സാം 0.02% + പൊങ്കാമിയ എണ്ണ എമൽഷൻ 2% മിശ്രിതവും തയോമെത്തോക്സാം 0.02 % + വേപ്പെണ്ണ എമൽഷൻ 2% മിശ്രിതവും പയറിലെ മുഞ്ഞകളയും ചാഴികളെയും നിയന്ത്രിക്കുന്നതിന് ഫലപ്രദമാണെന്ന് തെളിഞ്ഞു. ഇതോടൊപ്പം തന്നെ മിത്ര പ്രാണികൾക്കും സുരക്ഷിതം ആണെന്ന് തെളിഞ്ഞു.