MANAGEMENT OF SUCKING PEST COMPLEX IN CHILLI USING BOTANICAL AND MICROBIAL PESTICIDES

by

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THESIS

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DECLARATION

I, hereby declare that this thesis, entitled **"MANAGEMENT OF SUCKING PEST COMPLEX IN CHILLI USING BOTANICAL AND MICROBIAL PESTICIDES"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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EXTERNAL EXAMINER

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PRIYATHA SUNDARAN C.

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LIST OF ABBREVIATIONS AND SYMBOLS USED

a.i.	Active ingredient
et al.	And other co workers
@	At the rate of
cm	Centimetre
CD	Critical difference
CFU	Colony-forming unit
CNSL	Cashew nut shell liquid
DAP	Days after planting
DAT	Days after treatment
^{o}C	Degree Celsius
Fig.	Figure
g	Gram
h	Hour
ha	Hectare
HAT	Hours after treatment
kg	Kilogram
kg ha^{-1}	Kilogram per hectare
LAI	Leaf area index
m	Metre

mm	Millimetre
viz.	Namely
NS	Non significant
No.	Number
%	Per cent
ha^{-1}	Per hectare
CRD	Completely Randomized Block Design
RH	Relative humidity
SE	Standard error
sp or spp	Species (Singular and Plural)
SP	Soluble powder
SL	Soluble liquid
mL	Milliliter
m^2	Square metre
i.e.	That is
WG	Wettable granule

INTRODUCTION

1. INTRODUCTION

Chilli (*Capsicum annuum* Linn.) is one of the major commercial crops used as spice, condiment, vegetable, sauce, pickle and medicine. Besides large scale commercial cultivation, chilli is also an indispensable crop in kitchen garden, being an ingredient in most curries and dishes. Chilli occupies the first position among the spices produced in India, with a production share of 30 per cent under main spices in India (Singh *et al.*, 2017). In India, chilli is cultivated in an area of 774.9 thousand hectares producing 1492.10 thousand tonnes which accounts to 36 per cent of world production (Geetha and Selvarani, 2017) of which 70 per cent is consumed domestically.

Chilli is exported in the form of dry chilli, chilli powder and oleoresins. The share of chilli in total spice export earning of India is 25 per cent that fetches 375 million US dollars (Balaji and Paltasingh, 2014; Pednekar, 2015). Although the crop has got great export potential, low productivity limits the full exploitation.

The ravages by pests drastically reduce chilli productivity. Leaf curl is one of the most destructive problem in chilli causing abaxial and adaxial curling of leaves along with puckering and swelling of veins (Mishra *et al.,* 1963). This malady is caused by infestation of sucking pest complex and the infection of begomoviruses (Zehra *et al.*, 2017). The sucking pest complex comprising of chilli thrips (*Scirtothrips dorsalis* Hood), aphids (*Aphis gossypii* Glover) and yellow mites (*Polyphagotarsonemus latus* Banks) desap the plants causing curling, distortion and discoloration of leaves, leading to stunted growth.

The infestation results in yield loss ranging from 50-96.39 per cent (Ahmed *et al.*, 1987; Borah, 1987) besides acting as vectors of many diseases. Due to their small size, these sucking pests remain unnoticed in the fields and are detected only when they have multiplied in number and caused serious damage to plants. Favourable dry weather situation leads to heavy population build up of sucking pests causing severe yield losses.

Different strategies are being practiced to control the sucking pests, among which chemical control is the most widely used one. Due to the monoculture of chilli, the pest build up is so high that the farmers have to go for about five to six chemical sprays (Khan and Ram, 2016).

Over use of pesticide leads to the development of undesirable problems like destruction of natural enemies, pest resurgence and environmental contamination. Continuous and indiscriminate use of chemical insecticides has been found to be ecologically unsafe resulting in accumulation of pesticide residue on fruits. The presence of pesticide residues in chillies (Joia *et al.,* 2001) has been a concern for export of chillies to developed countries.

The failure of insecticide control strategies coupled with the chances of leaving high pesticide residues warrants development of alternate eco-friendly management measures. Plant origin insecticides and microbial pesticides are emerging as supplements, if not replacements to chemical pesticides, particularly in kitchen garden. Botanical insecticides are comparatively easily degradable, least toxic to natural enemies, pollinators, mammals and safer for the environment. Many commercial pesticides of botanical origin such as pyrethrin, azadirachtin, nicotine, ryanoids are in use for pest management (Martina and Kristina, 2013; Iqbal *et al.,* 2015).

The cashew plant (*Anacardium occidentale* L.) produce phenolic compounds like anacardic acid and cardol which are used as defence against insect pests (Venmalar and Nagaveni, 2005). The nut shell of cashew is a rich source of these compounds. The nut of cashew has a shell of about 1/8 inch thickness with a honey comb structure which has a high concentration of these chemicals. The dark reddish brown viscous liquid exuding from the shells during cashew processing known as the Cashew Nut Shell Liquid (CNSL) is a by-product of cashew industry available in quantity at minimal cost. The CNSL has been reported to have insecticidal properties (Mahapatro, 2011) and has the potential to be developed as a botanical insecticide.

Biological control measures particularly microbial control are now receiving more attention, since they are non polluting and sustainable. Fungal pathogens are the most promising microbial agent for the management of pests with sucking mouth parts since they are capable of infecting them through the cuticle (Rabindra and Ramanujam, 2007).

Species of hyphomycetes fungi such as *Beauveria bassiana* (Balsamo) Vullemin (Arthurs *et al.*, 2013), *Metarhizium anisopliae* (Metchnikoff) Sorokin (Jandricic *et al.*, 2014), *Lecanicillium lecanii* (Zimmermann) Viegas (Lokesh, 2014) and *Lecanicillium saksenae* (Kuṣhwaha) Kurihara and Sukarno (Rani *et al.*, 2015) have been reported to be effective against sucking pests.

The present study was undertaken to evolve an eco-friendly management strategy against sucking pest complex of chilli comprising of thrips (*S. dorsalis*), aphids (*A. gossypii*) and mites (*P. latus*) using botanical and microbial pesticides with the following objectives.

- Evaluation of botanical and microbial pesticides against *A. gossypii* under laboratory conditions
- *In vitro* assessment of compatibility of botanical and microbial agents
- Management of sucking pest complex of chilli using effective botanical and microbial pesticides

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Chilli is an important spice crop and an indispensable one in kitchen garden being the major constituent of daily diet in every households. Chilli was introduced to India, Indonesia and other parts of Asia by the Portuguese traders around 450-500 years ago (Berke and Shieh, 2000). India is the largest producer and exporter of chilli in the world with an annual production of 1492.10 thousand tonnes from an area of 774.9 thousand hectares (Geetha and Selvarani, 2017).

The chilli crop is attacked by large number of insect and non insect pests. Reddy and Puttaswamy (1984) recorded 57 pests in chilli, of which thrips (*Scirtothrips dorsalis*), aphids (*Aphis gossypii*) and mites (*Polyphagotarsonemus latus*) are the major ones that substantially reduce the yield (Berke and Shieh, 2000). The sucking pests along with the plant pathogenic viruses result in the most destructive syndrome, the chilli leaf curl that cause upto 100 per cent loss of marketable produce (Zehra *et al*., 2017).

The literature pertaining to the sucking pests of chilli and their management, particularly the eco-friendly measures employing botanical and microbial pesticides are reviewed here.

2.1 SUCKING PESTS OF CHILLI

A survey conducted by Asian Vegetable Research and Development Centre (AVRDC) in Asia revealed that thrips (*S. dorsalis*), aphids (*A. gossypii*) and mites (*P. latus*) are the major pests of chilli which together resulted a yield loss of 34.5 per cent (Ahmed *et al*., 1987). Venkateshalu *et al*. (2009) reported a yield loss of over 50 per cent in case of severe infestation of thrips and mites. Farmers use higher doses and more number of sprays of different insecticides for the control of these pests that lead to many undesirable problems like pest resurgence, destruction of natural enemies and environmental pollution (Shivaprasad *et al.,* 2010).

2.1.1 Chilli thrips (*S. dorsalis*)

The yellow tea thrips (*S. dorsalis*) was recorded from Pakistan, India, Southeast Asia, New Guinea, Australia and Japan (Mound and Palmer, 1986). Muraoka (1988) recorded the occurance of chilli thrips on 50 host plants. It was reported as an important pest of tea and chillies in India, and referred to as "chilli thrips" or the "assam thrips" (Tatara, 1994). Vasundarajan (1994) reported severe economic loss by thrips in several crops including vegetables and ornamentals and observed a faster rate of multiplication of thrips in dry weather conditions causing a yield loss of 30 to 50 per cent. *S. dorsalis*, the small sized (1–2 mm long), yellow coloured, narrow and flat bodied insects with two pairs of fringed wings are mostly recorded on the upper surface of the leaves of tender meristems (Seal and Kumar, 2010).

In chilli, thrips infestation was observed from the seedling stage in the nursery to the harvesting stage in the field. Both the adults and nymphs suck sap from the leaves, buds, flowers and fruits which resulted in hardened stem and fruits. The leaves had minute white spots and showed upward curling of leaves with wrinkles (Mandi and Senapati, 2009). The curling of the leaves was followed by the raising of interveinal area. The older leaves and petioles became elongated and the leaf margin show burnt appearance with stunted growth. Bud and flower shedding was noticed in severe cases (Mondal and Mondal, 2012).

2.1.2 Chilli aphids (*A. gossypii*)

The aphid, *A. gossypii* (Homoptera: Aphididae), the polyphagous sap sucking insect was found on over 900 plant species in the world (Blackman and Eastop, 2000) including several agricultural and horticultural crops (Agarwala and Das, 2007) *viz.*, okra, cotton, potato, tomato, chilli and cucurbits (Singh *et al.,* 2014). Both adults and nymphs result in direct damage by sucking sap from tender plant parts resulting in wrinkled, yellow and stunted leaves. Indirectly it also affects the crop by excreting honeydew that favour the growth of sooty mould that inhibit photosynthesis, and transmission of plant viruses (Singh *et al.*, 2014).

Aphid infested chilli plants became weak, pale and stunted in growth with curled leaves. The flower buds became brittle and drop down. Severely infested plants were affected in all their growth parameters (Kumar, 1999).

Simons (1955) reported *A. gossypii* and *M. persicae* as vectors of Cucumber Mosaic Virus. Both nymphs and adults of aphids transmit pepper vein mottle virus (Alegbego, 1986).

2.1.3 Yellow mite (*P. latus*)

Mites or acarids are tiny, spider-like creatures where the adults are eight legged and the larvae are six legged. The yellow tea mites or broad mites (*P. latus*) are slightly yellow coloured, small sized (0.1–0.2 mm long), round, sac-like unsegmented organism that infests many crops *viz.*, pepper, cucumber and egg plants (Gerson, 1992). *P. latus* is also known as muranai mites (TNAU, 2016).

Because of their small size, presence of *P. latus* were not initially noticed in crops, but will be detected only when plants begin to show damage symptoms (Venzon *et al.,* 2008).

Mites injure the plants by piercing cells of leaves, petioles and tender twigs and feed on the sap that oozes out of the wound (Waterhouse and Norris, 1987). The population build up was usually observed during dry weather conditions. Mite infestation, confined mostly to the lower surface of the leaves results in downward curling of leaves, elongation of the petiole and scarring of stem and fruit skin in chillies (Rai and Solanki, 2002). Narrowing of leaves along with elongated petiole results in the characteristic rat tail symptom (Chinniah *et al.*, 2016). The infested leaves appear shiny with silvery lining and small sized leaves are produced in severely infested plants.

The infestation was also found on fruits causing silvery and shiny appearance in early stages that became cracked and deformed in the later stages. The buds were found aborted and flowers distorted (Gerson, 1992; Mondal and Mondal, 2012). Bhattacharjee and Rahman (2017) observed an yield loss upto 96.39 per cent by mites that lead to the complete failure of the crop.

2.1.4 Chilli Leaf Curl Syndrome

Chilli leaf curl was observed as the major limiting factor of chilli cultivation (Dhanraj and Seth, 1968). Chilli leaf curl syndrome commonly called as "murda" was reported to be caused by infestation of thrips (*S. dorsalis*) and mites (*P. latus*) (Amin, 1979).

The leaf curl syndrome was characterised by curled leaves, thickened and swollened veins. In advanced stages the whole plant appeared bushy with stunted growth and fewer flowers (Kumar and Kumar, 2017). Flowering was also found to be less in such plants leading to low fruit set.

In addition to the feeding of sucking pests, the association of begomoviruses transmitted by them were also attributed to the development of the leaf curl syndrome (Venkatesh *et al.*, 1998).

Brown *et al.* (1995) reported the transmission of begomovirus in a persistent manner by whiteflies, *Bemisia tabaci* (Gennadius) also. Zehra *et al.* (2017) recognized the distinctive symptoms of vein yellowing, yellow mosaic and leaf curl associated with the infection of begomoviruses.

Niles (1980) developed a scoring technique comprising of five scores (0 to 4) for assessing spider mite damage in cotton. Desai *et al.* (2006) used this scoring technique with modifications to score leaf curl damage caused by *P. latus* in chilli.

2.2 MANAGEMENT OF SUCKING PESTS

To manage the sucking pests, usually Indian farmers apply minimum of 12 to 15 rounds of the conventional pesticide sprays. This not only increased the cost of cultivation but often caused development of resistance, pesticide induced resurgence and secondary pest outbreak. Due to monoculture of chilli in major growing areas, the pest build up was so large that the number of insecticidal applications had increased over the years (Varghese and Mathew, 2013; Halder *et al.*, 2015).

Sahu *et al.* (2018) emphasized the need to estimate the current status of insecticide resistance in chilli pests besides evaluating newer insecticides with novel mode of action both under laboratory and field conditions so as to have better option at hand to mitigate the present control failures and residue problems faced by the farming community.

2.2.1 Chemical Pesticides

Acetamiprid 20 SP @ 80 and 40 g a.i. ha^{-1} was found effective in reducing the sucking pests of chilli followed by acetamipriid 20 SP @ 20 g a.i. ha^{-1} (Jayewar *et al.*, 2003). Sarangi and Panda (2004) reported the efficacy of imidacloprid as seedling root dip in reducing thrips population in chilli. In a field experimemt conducted by Singh *et al.* (2005), imidacloprid 17.8 SL (200 mL ha^{-1}) was found to be the most effective one against *S. dorsalis* and *A. gossypii* in chilli cv Pusa Sadabahar.

According to Seal *et al.* (2006), chlorfenapyr (731 mL ha^{-1}) was the most effective insecticide in reducing the densities of *S. dorsalis* adults and larvae followed by spinosad (511 mL ha^{-1}) and imidacloprid (274 mL ha^{-1}). Fipronil 0.01 % and triazophos 0.08 % were also found to be effective against chilli thrips followed by profenofos 0.10 %, ethion 0.10 % and cypermethrin 0.0012 % (Mahalingappa *et al.*, 2008). Ghosh *et al.* (2009) reported the maximum reduction of curly leaves of chilli in thiamethoxam treated plants followed by chemicals acetamiprid, fipronil, clothianidin and oxydemeton-methyl. The chemical control of sucking pests in chilli evaluated by Varghese and Mathew (2013) revealed lower population of chilli thrips in plants treated with acetamiprid 20 SP at 20 g a.i. ha^{-1} along with spiromesifen 45 SC at 100 g a.i. ha^{-1} while spiromesifen 45 SC at 100 g a.i. ha^{-1} and propargite 57 EC at 570 g a.i. ha^{-1} were found to be effective in reducing chilli mite population.

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

2.2.2 Botanical Pesticides

Plants synthesise a variety of secondary matabolites that are not essential for their growth and development but are important in protection against predators and pathogens (Rosenthal, 1991; Schafer and Wink, 2009).

Plant secondary metabolites are reported to have insecticidal, repellant, anti-feedant and growth regulatory properties (Isman, 2000). Botanical insecticides with long history of traditional use include pyrethrum, neem, rotenone and sabadilla (Weinzierl, 2000).

There is renewed interest in botanical insecticides and many phytochemicals such as pyrethrin (Casida, 1980), plant essential oils (Koul *et al*., 2008), azadirachtin (Khater, 2012), nicotine (El-Wakeil, 2013), ryanoids (Martina and Kristina, 2013) have been developed as commercial botanical pesticides.

2.2.2.1 Neem

Neem based insecticides are derived from the tropical tree, *Azadirachta indica* A. Juss. in the family meliaceae (Siddiqui *et al.*, 2004).

The bitter taste of neem is due to the presence of the limonoids which is a group of tetranortriterpenoids of which azadirachtin is the most active compound useful for pest management (Kumar *et al.,* 2003). More than 100 neem formulations are used worldwide as pesticides (Khater, 2012).

Neem oil was reported as an effective botanical pesticide against *S. dorsalis* (Rao *et al.*, 1999), *P. latus* (Venzon *et al.*, 2008) and *A. gossypii* (Pinto *et al.*, 2013).

Neem Seed Kernel Extract (NSKE 5%) application was found to be effective and superior to chemical insecticides in controlling thrips and aphids in chillies (Ali *et al.*, 2002).

Azadirachtin insecticides persists only for 4 to 8 days in the environment and hence are highly suitable for eco-friendly management of pests (Schmutterer, 1990). The population growth of chilli mites was found reduced with increased concentration (higher than 0.13 g a. i. L^{-1}) of neem seed kernel extract (Venzon *et al.*, 2008). The cotton aphid population was also found to be effectively reduced by neem seed kernel extract that caused population reduction of 33.77 to 36.32 per cent (Vinodhini and Malaikozhundan, 2011). According to Ghosh (2015), the botanical insecticide azadirachtin gave better result in suppressing *A. gossypii* population (60.30 %). Neem oil (2.5 mL L^{-1}) and NSKE (5%) was found to cause 55.64 and 50.03 per cent reduction in the population of *S. dorsalis* in chilli (Meena and Tayde, 2017).

2.2.2.1.1 Oxuron

Oxuron, a commercially available organic plant product containing karanja oil (0.25 %) and neem oil (0.20 %) @ 5 mL $L^{-1}$is reported to reduce the population of sucking pests *viz.*, *Amrasca biguttula biguttula* (Ishida), *A. gossypii*, *B. tabaci*, *Tetranychus* sp in brinjal (Arya, 2015). Mohan and Anitha (2017) observed that oxuron 0.5 % was less effective against american serpentine leaf miner (*Liriomyza trifolii* (Burgess)) on tomato with a leaf damage of 23.10 per cent in comparison with chlorantraniliprole 0.006 % and NSKE 5 % with a leaf damage of 9.95 and 19.15 per cent respectively at 10 days after spraying.

2.2.2.2 Cashew Nut Shell Liquid (CNSL)

The need to develop non-toxic, safe and biodegradable alternatives to synthetic insecticides has in recent years led to concerted international efforts to develop new sources from the vast store of chemical substance in plants (Olaifa *et al.*, 1987). The nut of cashew has a shell of about 1/8 inch thickness with a honey comb structure which contains a dark reddish brown viscous liquid known as the cashew nut shell liquid constituting 15 per cent of the gross weight of nuts (Azam-Ali and Judge, 2001). CNSL obtained by extraction in oils or in solvent or by mechanical expulsion from the shells consists chiefly of naturally produced phenolic compounds, anacardic acid (about 90 %) and cardol (about 10 %) (Venmalar and Nagaveni, 2005). The technical CNSL obtained from the cashew industry contains 52 per cent cardanol, 10 per cent cardol and 30 per cent polymeric material as the anacardic acid get decarboxylated to cardanol in high temperature during processing (Shabtay, 2017).

CNSL is used for the manufacture of many industrial products including polymeric resins. In its natural form CNSL has the potential to be used as an insecticide, fungicide and bactericide (Olotuah and Ofuya, 2010).

Asogwa *et al.* (2007) recorded 100 per cent mortality of termites at 90th minute for the soldier caste at 60th minute for the workers caste when treated with

CNSL at concentration 6, 8 and 10 %. John *et al.* (2008) highlighted the efficacy of CNSL @ 5- 25 % (with 100 % mortality) against root grub (*Leucopholis coneophora* Bur.), a major pest in coconut and arecanut growing regions. Efficacy of ethanolic extract of CNSL (1 %) in protecting cowpea from the pests *Aphis craccivora* and *Maruca testulalis* (Geyer) was reported by Olotuah and Ofuya (2010). Mahapatro (2011) reported the insecticidal activity of CNSL by stomach poisoning in diet incorporation, while it had no contact toxicity by direct spray method. He evaluated the activity of CNSL (1 %) on *Helicoverpa armigera* (Heliar) and *Spilarctia oblique* (Walker), important lepidopteran pests, by 'artificial diet surface incorporation' method in 'no-choice' assay. The hydrogenated CNSL was found to be more active than CNSL against *H. armigera* with 75 per cent mortality till pupation as against 43.8 per cent in CNSL.

2.2.3 Microbial Pesticides

Naturally occurring entomopathogenic microorganisms particularly bacteria, viruses and fungi are employed as biocontrol agents of insect pests primarily from the perspective of safety to non target organisms (Ignoffo, 1978). Sucking pests are more prone to infection by entomopathogenic fungi since the piercing and sucking mouth parts of them preclude the entry of bacterial and viral pathogens (Tanada and Kaya, 1993). Fungal pathogens can directly infect insects through the cuticle and do not require ingestion and hence are more suited against sucking pests (Rabindra and Ramanujam, 2007).

2.2.3.1 Entomopathogenic Fungi

Entomopathogenic fungi are important natural regulators of insect populations and have potential as microbial insecticide against diverse insect pests in agriculture. Last three decades has seen tremendous increase in usage of entomopathogenic fungi in pest management. Nearly 750 species of fungi were recorded to be pathogens of pests (Rabindra and Ramanujam, 2007).

Species of hyphomycetes demonstrate activity against a broad range of insect pests and are the main contenders for the use against homopterous pest insects. Several species *viz*., *B. bassiana*, *M. anisopliae*, *L. lecanii*, *Paecilomyces fumosoroseus* (Wize) Brown and Smith, *Metarhizium flavoviridae* Gams and Rozsypal, *Nomuraea rileyi* (Farlow) Samson and *Aschersonia aleyrodis* Webber are in use or development (Lacey *et al*., 2001).

2.2.3.1.1 Beauveria bassiana

B. bassiana belongs to the sub class Hyphomycetes of Deutromycetes. It is a well-known entomopathogen of Coleopteran, Hemipteran, and Lepidopteran insects. Inglis *et al*. (2001) reported the presence of the fungus naturally in more than 700 species of hosts. The infectivity of *B. bassiana* to insects were reported from different parts of India (Vimala and Hari, 2009; Sudharma and Archana, 2009). *B. bassiana* isolates obtained from several insects were found to be pathogenic to the nymphs of *A. gossypii* by Herlinda (2010).

Saranya *et al*. (2010) observed 96.66 per cent mortality of *A. craccivora* by *B. bassiana* at the concentration 10^8 spores mL^{-1}. Selvaraj and Kaushik (2014) conducted bioassay studies of *B. bassiana* against *A. craccivora* on fenugreek under greenhouse conditions in which mortality of 43.50 per cent at highest concentration (1×10^{10} spores mL^{-1}) and 20.85 per cent at lowest concentration (1×10^{4} spores mL^{-1}) were obtained one day after treatment.

A population reduction of thrips *S. dorsalis* ranging from 81 to 94 per cent was recorded in greenhouse cages with three applications of *B. bassiana* (Arthurs *et al*., 2013).

In a study conducted by Nugroho and Ibrahim (2007) with three fungi against the chilli mite, *B. bassiana* (8bGc) was the most efficient one followed by *P. fumosoroseus* (PfPp) and *M. anisopliae* (MaPs). Sangeetha (2013) reported that application of *B. bassiana* (Bb101) @ 10^8 spores mL^{-1} caused 45.66 per cent reduction of mite population over control.

Mascarin *et al.* (2013) reported the virulence of *B. bassiana* @ 10^7 conidia mL^{-1} against whitefly nymphs with 71-86 per cent mortality in 8 days. Though most of the eggs hatched after the treatment, 40-70 per cent of nymphs hatched were infected due to their indirect exposure to conidia on the leaves.

2.2.3.1.2 Metarhizium anisopliae

The bioefficacy of *M. anisopliae* was evaluated against seven common insect pests of Tamil Nadu, India including *A. craccivora* by dermal toxicity tests and was found effective (Sahayaraj and Borgio, 2010). Mortality of 73-77 per cent by *M. anisopliae* on aphids (*A. gossypii*) was reported by Hundessa (2016).

The results of the study by Wekesa *et al.* (2006) showed that *B. bassiana* isolate GPK and *M. anisopliae* isolate ICIPE 78 are capable of causing significant mortality in eggs and motile stages of *Tetranychus evansi* (Baker and Pritchard) among which eggs and adults were found more susceptible. In the study conducted by Maketon *et al.* (2008) using 12 entomopathogenic fungi for controlling broad mite (*P. latus*) of mulberry, *M. anisopliae* CKM-048 was identified as the most virulent strain infecting both larvae and adults.

According to Seal and Kumar (2010), treatments of *M. anisopliae* and *B. bassiana* significantly reduced populations of chilli thrips and were comparable to spinosad which provided excellent control.

2.2.3.1.3 Lecanicillium lecanii

The genus *Lecanicillium*, previously named as *Verticillium* has been reclassified by Zare and Gams (2001), based on morphological and molecular characters. It is one of the most important and common entomogenous Hyphomycetes that infects on Diptera, Homoptera, Hymenoptera, Lepidoptera and mites.

Among the common entomopathogens, *L. lecanii* has been extensively exploited worldwide for the management of sucking pests (Rabindra and Ramanujam, 2007).

The high virulence of *L. lecanii* to the aphids *M. persicae, A. gossypii* and *Brevicoryne brassicae* Linnaeus was ascertained by Alavo *et al*. (2002) in which 90 and 82 per cent mortality of *A. gossypii* for the isolates, V24 and VI8 @ 10^8 spores mL^{-1} was observed.

Nirmala *et al*. (2006) tested the pathogenicity of the isolates of *L. lecani* on *A. gossypii* by detached leaf bioassay technique and observed pathogenicity at a concentration of 10^7 spores mL^{-1}. Vu *et al*. (2007) reported high virulence of *L. lecanii* to *A. gossypii* (100 % mortality) at 25 °C and 75 per cent relative humidity. According to Gurulingappa *et al*. (2011), exposure to *L. lecanii* significantly reduced the rate and period of reproduction of *A. gossypii*. As conidial concentration increased, aphid reproduction declined significantly. The total fecundity varied from 8-26 in aphids exposed to *L. lecanii* as against 44 in control. Mortality of 24- 82 per cent was also observed in treated aphids. Lokesh (2014) reported *L. lecanii* pathogenic to *A. gossypii* causing complete mortality at 48 hours after treatment (HAT) with thread like mycelia outgrowths emerging from the cadavers. He also reported its pathogenicity to *S. dorsalis* and *P. latus* with more or less similar symptoms.

L. lecanii 0.0069 per cent was observed as the most promising microbial treatment for management of *S. dorsalis* in chilli causing 91.60 per cent population reduction at 14 days after spraying (Shirish, 2010).

2.2.3.1.4 Lecanicillium saksenae

L. saksenae was first described by Kushwaha (1980) as a keratin degrader and later Sukarno *et al*. (2009) isolated it from soil dwelling arthropods of Kalimantan province of Indonesia. Rani *et al*. (2015) isolated an indigenous strain of *L. saksenae* from Vellayani soils and reported it to be a potent pathogen against several homopterans *viz., A. craccivora, A. gossypii, B. tabaci, A. biguttula biguttula* and *Coccidohystrix insolita* Green. It was found that conidial suspension of *L. saksenae* at 6.98 x 10^7 spores mL^{-1} caused 100 per cent mortality to *A. craccivora* within 24 hours. Jasmy (2016) reported the pathogenicity of *L. saksenae* to *A. craccivora, C. insolia, B. tabaci, A. biguttula biguttula* and *Leptocorisa acuta* (Thunberg) causing 100 per cent mortality within 72 HAT when treated with spore suspension @ 10^7spores mL^{-1}.

2.2.3.1.5 Other Pathogens

Nugroho and Ibrahim (2004) reported 50 per cent mortality of *P. latus* treated with *P. fumosoroseus* @ 3.23 x 10^6 conidia mL^{-1}. *Fusarium* spp. was identified as a potential biocontrol agent of thrips and mites in chilli (Mikunthan and Manjunatha, 2006). Kim *et al.* (2010) reported that the commercial mycopesticide, Vertalec based on *L. longisporum* provided complete control of *A. gossypii* 16 days after inoculation. Saranya *et al.* (2010) recorded the effectiveness of *H. thopmsonii* against *A. craccivora* causing 100 per cent mortality. Chinnaiah *et al.* (2016) reported the efficacy of seed treatment with *P. fluorescens* @ 10 g kg^{-1} of seed along with application of *H. thompsonii* @ 1 x 10^{-8} CFU mL^{-1} for chilli mite management.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The efficacy of botanical and microbial pesticides were evaluated under laboratory conditions in the Department of Entomology, College of Agriculture using *A. gossypii* as test insect. The effective treatments were later evaluated against sucking pest complex of chilli in pot culture experiment carried out in the Instructional farm, Vellayani during 2016-18.

3.1 EVALUATION OF EFFICACY OF BOTANICAL PESTICIDES

Emulsions of three botanical pesticides, cashew nut shell liquid (CNSL), neem seed kernel extract (NSKE) and neem oil along with commercial botanical insecticide oxuron, and chemical insecticide thiamethoxam were evaluated under laboratory conditions using *Aphis gossypii* as test insect in completely randomized block design with three replications.

3.1.1 Preparation of Botanical Pesticides

Emulsions of botanicals were prepared using vegetable soap as emulsifier.

3.1.1.1 Soap Solution

Six grams of ordinary bar soap was sliced into small pieces and dissolved in 100 mL of luke warm water and was used for the preparation of one litre of various emulsions.

3.1.1.2 Cashew Nut Shell Liquid Emulsion

Cashew nut shell liquid (CNSL), a by-product of cashew industry was procured from Mahatma cashew exports, Kollam district. Five different concentrations of cashew nut shell liquid (0.025, 0.05, 0.075, 0.1 and 0.2 %) were prepared. 250, 500, 750, 1000 and 2000 μL of CNSL were mixed with 100 mL of soap solution (3.1.1.1) under constant agitation. The final volume was made upto 1000 mL by adding required quantity of water.

3.1.1.3 Neem Seed Kernel Extract Emulsion (5%)

For preparing 5 % NSKE, 50 g of coarse neem seed powder was tied in a muslin cloth and soaked in 500 mL of water for 24 hours (h). The muslin cloth containing the material was squeezed to release the extract completely. The extract was then mixed with 100 mL soap solution (3.1.1.1) under constant agitation and final volume was made upto 1000 mL by adding water.

3.1.1.4 Neem Oil Emulsion (2 %)

For the preparation of 1 L neem oil emulsion, 20 mL of neem oil was added to 100 mL soap solution prepared as in 3.1.1.1 and made upto 1000 mL under constant agitation.

3.1.2 Maintenance of Test Insects

The test insects (*A. gossypii*) were reared on chilli plants. Seedlings of chilli *Capsicum annuum* variety Jwalamukhi obtained from Instructional farm, College of Agriculture, Vellayani were planted in grow bags. Aphids were collected from the field and released into these plants (Plate 1) and protected using cylindrical polyester cages having cloth lined ventilations. The population thus maintained served as source of aphids for further studies. The gravid females were collected from the population and transferred to new plants and the second instar nymphs were collected carefully using a camel hair brush and used for the experiment.

Chilli seeds were sown in a paper cup of 150 mL filled with potting media containing sand, soil and farmyard manure in the ratio 1:2:1. At three to four leaf stage, 50 second instar nymphs that showed movement were transferred to the seedlings using a camel hair brush. A white paper was kept at the base of the seedlings. The following treatments were applied

Plate 1a: Collection and releasing aphids to chilli plant

Plate 1b: Nymphs of *A. gossypii*

Plate 1: Maintenance of test insects

T1: CNSL emulsion 0.025 %

T2: CNSL emulsion 0.05 %

T3: CNSL emulsion 0.075 %

T4: CNSL emulsion 0.1 %

T5: CNSL emulsion 0.2 %

T6: Neem seed kernel extract emulsion 5%

T7: Neem oil emulsion 2 %

T8: Oxuron@ 5 mL L^{-1}(Neem oil 0.20 % + Karanja 0.25%)

T9: Thiamethoxam 0.015 %

The treatments were applied using atomizer ensuring uniform coverage of the seedlings. The plants sprayed with distilled water served as untreated check. These seedlings with aphids were then covered with a transparent cup having pinholes. Three replications were maintained for each treatment. The number of dead aphids were counted at 24, 48 and 72 hours after treatment (HAT). The treatment mortality was corrected with mortality in untreated check (Abbot, 1925) using the formula

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

The cumulative corrected percentage mortality was statistically analysed.

3.2 EVALUATION OF EFFICACY OF MICROBIAL AGENTS

Beauveria bassiana (Bb5a), *Metarhizium anisopliae* (Ma4) and *Lecanicillium lecanii* (Ll8) obtained from National Bureau of Agriculturally Important Insects (NBAII), Benagaluru and maintained at the Biocontrol Laboratory for Crop Pest Management, College of Agriculture, Vellayani and

Lecanicillium saksenae (Ls Vs 1-7714) isolated from Vellayani soils at biocontrol laboratory, College of Agriculture, Vellayani (Rani *et al*., 2015) were used for the present investigation.

3.2.1 Maintenance of Fungal Culture and Preparation of Spore Suspension

Pure cultures of *B. bassiana, M. anisopliae, L. lecanii* and *L. saksenae* were maintained in potato dextrose agar (PDA) slants. The spore suspensions prepared from PDA slants were spreadplated on PDA in Petri dishes and incubated at room temperature.

The spore suspension for application were prepared by aseptically pouring 10 mL of sterile distilled water into heavily sporulating 14 day old culture grown on PDA in Petri dishes. After shaking the plates resultant spore suspension was aseptically transferred to 30 mL screw cap vials. Spore concentrations were determined using a double ruled Neubauer's haemocytometer in a Motic BA 210 compound microscope. The required concentration of the spore suspensions were prepared by adding sterile distilled water.

The following treatments were applied

T1: *Beauveria bassiana* (Bb5a) @ 10^8 spores mL^{-1}

T2: *Metarhizium anisopliae* (Ma4) @ 10^8 spores mL^{-1}

T3: *Lecanicillium lecanii* (Vl8) @ 10^7 spores mL^{-1}

T4: *Lecanicillium saksenae* (Ls Vs 1-7714) @ 10^7 spores mL^{-1}

T5: Thiamethoxam 0.015 %

The treatments were applied on to chilli seedlings harboring 50 numbers of second instar nymphs as detailed in 3.1.2 using an atomizer ensuring uniform coverage. The plants sprayed with distilled water served as untreated check. Each treatment was replicated four times. The treated insects were observed for mortality at 24, 48 and 72 HAT. For confirmation of mortality by mycosis, the cadavers were placed on moist filter paper in petri plates and examined under microscope. Percentage mortality was corrected (Abbot, 1925) and cumulative percentage mortality was statistically analysed after necessary transformations.

3.3 COMPATIBILITY OF BOTANICAL AND MICROBIAL AGENTS

The compatibility of effective botanical (CNSL 0.2 %) with microbial agents (*B. bassiana, M. anisopliae*, *L. lecanii* and *L. saksenae*) was studied by disc diffusion technique in PDA plates.

Filter paper were made into small circular pieces of 5 mm diameter and sterilized by autoclaving. CNSL emulsion 0.2 % (25 mL) prepared as in 3.1.1.2 was sterilized by passing through bacteriological filter (0.25 microns) and collected in sterile 30 mL tubes in a laminar air flow chamber.

PDA medium (100 mL) was sterilized in conical flasks and was poured into nine cm diameter sterile Petri dishes and allowed to solidify in a laminar air flow chamber. Four filter paper discs dipped in the filtered CNSL emulsion 0.2 % for 2 minutes were transferred to PDA plates at 2.25 cm equidistant from the centre. An agar disc with mycelium of the respective fungi was cut from the periphery of 10 day old colony using a 5 mm diameter cork borer and transferred asceptically to the centre of these Petri plates. Control plates were maintained with filter paper discs dipped in sterile distilled water. The plates were sealed with parafilm and incubated at room temperature for 21 days to allow maximum growth.

3.3.1 Assessment of Radial Growth

The diameter of the growing culture in each petri plate was measured when the fungal growth in control reached the filter paper bits kept at four sides equidistantly from the centre. The data was further expressed as percentage inhibition of radial growth (Hokkanen and Kotiluoto, 1992).

X =Y-Z/Y x 100

where, X- percentage of growth inhibition

Y- radial growth of fungus in untreated check (control)

Z- radial growth of fungus in treatment

Percentage inhibition were rated using Hassan's classification scheme (Hassan, 1989) as follows

1- Harmless (< 50 % growth inhibition)
2- Slightly harmful (50-79 % growth inhibition)
3- Moderately harmful (80-90 % growth inhibition)
4- Harmful (>90 % growth inhibition)

3.4 MANAGEMENT OF SUCKING PEST COMPLEX (POT CULTURE EXPERIMENT)

Pot culture experiment was conducted to evaluate the field efficacy of botanical and microbial agents for the management of sucking pest complex of chilli under field conditions. Effective botanical from 3.1 and microbial agents from 3.2 and their combination selected based on the laboratory studies were evaluated.

Design : CRD

Replication : 3

Treatments : 8

T1: CNSL emulsion 0.075 %

T2 : CNSL emulsion 0.2 %

T3 : Neem oil emulsion 2 %

T4 : Oxuron @ 5 mL L^{-1} (Neem oil 0.20 % + Karanja 0.25%)

T5 : *Lecanicillium lecanii* @ 10^7 spores mL^{-1} (Vl8) @ 10^7 spores mL^{-1}

T6 : Combination of *L. lecanii* and CNSL emulsion 0.2 %

T7 : Thiamethoxam 0.015 % (Actara 25 WG)

T8 : Untreated

Chilli seedlings of variety Jwalamukhi, raised in pro trays were transplanted in grow bags (35 x 20 x 20 cm) filled with the potting mixture prepared with sand, soil and farmyard manure in 1:2:1 ratio. The crop was raised following KAU package of practices recommendations (KAU, 2016). A consistent population of sucking pests comprising of thrips (*S. dorsalis*), aphids (*A. gossypii*) and mites (*P. latus*) was maintained in these plants avoiding plant protection interventions. The first round of treatments were applied 30 days after planting in the vegetative stage of the crop, after recording the pre treatment population of the sucking pests. The emulsions of botanical and microbial pesticides were prepared as specified in 3.1.1 and 3.2.1 respectively. For the combined application, spore suspensions of *L. lecanii* was added to CNSL 0.2 % and standardized to 10^7 spores mL^{-1}. Treatments were applied to the entire plant using a hand sprayer ensuring coverage of both abaxial and adaxial surfaces of leaves. Post treatment population of sucking pests was observed on 1, 3, 5, 7 and 14 days after spraying, as detailed below.

From each replication, one leaf each was selected from top, middle and bottom at random to assess the pest population as shown in Plate 2. The count of thrips, aphids and mites was taken from both surfaces of the leaves using a hand lens and expressed as numbers per leaf.

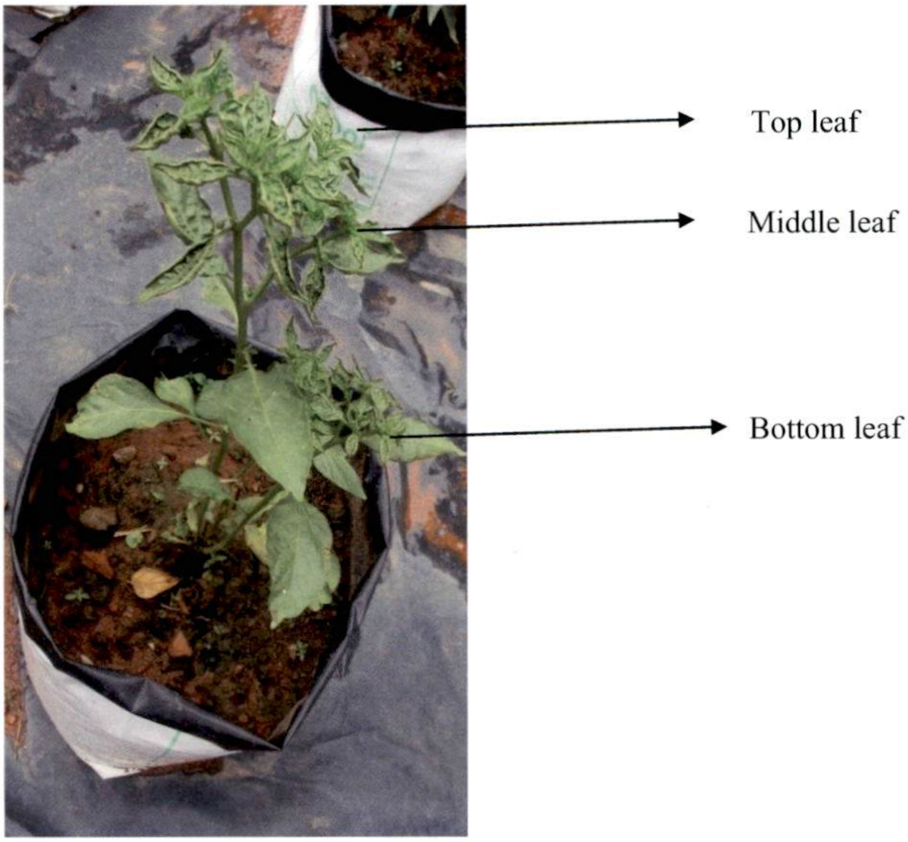


Plate 2 : Sampling in the field for sucking pests

The final population adjusted with the pre treatment population was subjected to statistical analysis. Second round of treatments were applied in the reproductive stage of the crop at 60 days after planting and the pest population observations were recorded as above.

3.4.1 Damage Caused by Sucking Pests

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

3.4.1.1 Effect of Treatments on Damage by Sucking Pests Based on Leaf Curl Index

In order to assess the effect of treatments on the damage caused by sucking pests, the leaf curl index, an indicator of damage was worked out 10 days after each round of treatments (40 DAP and 70 DAP respectively) and again at the end of the crop period (90 DAP). The plants were scored visually for sucking pest damage in zero to four scale (Niles, 1980) (Table 1).

Table 1: Scoring of damage by sucking pest infestation in chilli

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

4	Complete damage	>75 % leaves plant^{-1} show curling, damage of growing points, and drastic reduction in plant height, defoliation and severe malformation.

The leaf curl index was worked out using the formula

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

3.5 GROWTH PARAMETERS OF CHILLI TREATED WITH DIFFERENT PESTICIDES

The following biometric observations of plants that received different treatments (3.4) in the pot culture experiment were recorded to understand the growth of the plant, damage by the pest complex and any other possible effects of treatments.

3.5.1 Shoot Length

The length of the shoot was measured using measuring scale and mean length was worked out and expressed in centimeter. Observations were recorded at 40, 70 and 90 days after planting (DAP).

3.5.2 Number of Leaves

The total number of leaves were counted and expressed as number of leaves plant^{-1}. The observations were recorded at 40, 70 and 90 DAP.

3.5.3 Number of Branches

The total number of branches arising from the stem were counted at 90 DAP and its mean values were recorded.

3.5.4 Collar Girth

The girth of the collar region of the stem was taken at 90 DAP by measuring the circumference of the collar region using a thread and measuring scale. Mean girth was calculated and expressed in centimeter.

3.5.5 Root Length

The length of root was measured from the base of plant to the growing tip of the root after uprooting the plants at 90 DAP. The mean values were worked out and expressed in centimeter.

3.5.6 Fresh Weight of Shoot

The plants from the plot was uprooted and fresh weight of the above ground portion was recorded and expressed as g plant^{-1}. The observations were recorded at 90 days after planting.

3.5.7 Dry Weight of Shoot

Above ground portion of the samples (3.5.6) were packed with proper labeling. The samples were dried to consistent weight in a hot air oven at temperature of 70 ±5°C. Total dry weight was expressed as g plant^{-1}.

3.5.8 Fresh Weight of Root

The weight of the roots after uprooting the plants (90 DAP) were recorded and mean value is worked out. The fresh weight of root is expressed as g plant^{-1}.

3.5.9 Dry Weight of Root

Fresh root samples (3.5.8) were dried in hot air oven at 70 ±5°C until consistent weight was obtained. The dry weight of the root was expressed as g plant^{-1}.

3.5.10. Yield

The weight of chilli fruits harvested at various intervals were recorded and cumulative yield is expressed as g plant^{-1}.

3.6 STATISTICAL ANALYSIS

Data of each experiment were analyzed with the help of suitable analytical methods. Data on per cent mortality and mean population of pests in field were analyzed by one way analysis of variance after arc sin and square root transformation, respectively.

RESULTS

4. RESULTS

4.1 EVALUATION OF EFFICACY OF BOTANICAL PESTICIDES

Three botanical insecticides *viz*, cashew nut shell liquid, neem oil and oxuron at different concentrations were evaluated against *A. gossypii*. The mortality of aphids treated with different botanical pesticides were corrected with mortality in untreated check using Abbot's formula and the cumulative corrected percentage mortality at 24, 48 and 72 hours after treatment (HAT) are presented in Table 2.

Among the various treatments evaluated, the chemical check thiamethoxam 0.015 %, CNSL 0.2 % and neem oil 2 % recorded 66.67, 64 and 58 per cent mortality, respectively of chilli aphid and were superior to all other treatments at 24 HAT. This was followed by oxuron 5 mL L^{-1}, CNSL 0.1 %, CNSL 0.075 %, NSKE 5 % and CNSL 0.05 % with per cent mortality of 49.33, 47.33, 47.33, 41.33 and 42, respectively which were on par with each other. CNSL 0.025 % recorded least mortality (24.67 %) after 24 hours.

At 48 HAT, CNSL 0.2 %, CNSL 0.075 %, thiamethoxam 0.015 %, CNSL 0.1 % and oxuron 5 mL L^{-1} showed superiority over other treatments with mortality of 92.67, 88.67, 86.67, 86 and 85.33 per cent respectively. CNSL 0.05 % (80.33 %), CNSL 0.025 % (80.67 %), neem oil 2 % (79.33 %) and NSKE 5 % (76 %) were found to be on par with each other though inferior to the best treatments.

At 72 HAT, thiamethoxam 0.015 %, oxuron 5 mL L^{-1}, CNSL 0.2 % and CNSL 0.1 % showed 100 per cent mortality which did not vary significantly from the other treatments *viz.,* CNSL 0.075 %, CNSL 0.05 %, CNSL 0.025 %, neem oil 2 % and NSKE 5 % with 99.33, 98.67, 98, 98 and 97.33 per cent mortality, respectively.

Table 2: Corrected cumulative per cent mortality of *Aphis gossypii* treated with different botanical pesticides*

Treatments	Per cent mortality**		
	24 HAT	48 HAT	72 HAT
CNSL 0.025 %	24.67 (29.60)^{d}	80.67 (64.17)^{bc}	98.00 (83.34)
CNSL 0.05 %	42.00 (40.39)^{c}	80.33 (64.18)^{bc}	98.67 (85.96)
CNSL 0.075 %	47.33 (43.46)^{c}	88.67 (70.94)^{ab}	99.33 (87.09)
CNSL 0.1 %	47.33 (43.46)^{bc}	86.00(68.44)^{abc}	100.00 (89.71)
CNSL 0.2 %	64.00 (53.15)^{a}	92.67 (74.40) ^{a}	100.00 (89.71)
NSKE 5 %	41.33 (39.97)^{c}	76.00 (60.70) ^{cd}	97.33 (82.46)
Neem oil emulsion 2 %	58.00 (49.83)^{ab}	79.33 (63.24)^{bc}	98.00 (83.34)
Oxuron 5 mL L^{-1}	49.33 (44.61)^{bc}	85.33 (67.67)^{abc}	100.00 (89.71)
Thiamethoxam 0.015 %	66.67 (54.73)^{a}	86.67 (69.44)^{abc}	100.00 (89.71)
CD(0.05)	8.440	9.296	NS

*Corrected with Abbot's formula over control

**Mean of 3 replications comprising 50 aphids each (Values in the parentheses are angular transformed values)

HAT: Hours After Treatment

4.2 EVALUATION OF EFFICACY OF MICROBIAL AGENTS

All microbial agents *viz*., *B. bassiana, M. anisopliae*, *L. lecanii* and *L. saksenae* evaluated were found to be infective to *A. gossypii*. The following symptoms were exhibited by different fungi.

4.2.1 Symptoms of Infection

4.2.1.1 B. bassiana

Initially the treated aphids were active, later they became sluggish. Mycelial growth was observed between 24-48 h after the death. The cadavers were completely covered with white mycelial growth of the fungus.

4.2.1.2 M. anisopliae

The white mycelial outgrowth of the fungus on the cadaver was observed within 48 h after death. Upon sporulation, the colour turned to greenish black.

4.2.1.3 L. lecanii and *L. saksenae*

Similar symptoms of infection were observed in aphids treated with *L. lecanii* and *L. saksenae*. The aphids treated were active initially and mortality was observed at 24 HAT. White mycelial growth was observed on cadavers 72 h after death.

4.2.2 Mortality on *A. gossypii*

The data on the cumulative per cent mortality of aphids treated with microbials are presented in Table 3. In the observation recorded at 24 HAT, *L. saksenae* and *L. lecanii* with 55 and 54.5 per cent mortality respectively were found superior over other treatments and was on par with chemical check thiamethoxam 0.015 % with 63 per cent mortality. *B. bassiana* @ 10^8 spores mL^{-1} and *M. anisopliae* @ 10^8 spores mL^{-1} treatments exhibited 35.50 and 31 per cent mortality respectively that were on par with each other.

Table 3 : Corrected cumulative per cent mortality of *Aphis gossypii* treated with different microbial agents*

Treatments	Per cent mortality**		
	24 HAT	48 HAT	72 HAT
B. bassiana @ 10^8 spores mL^{-1}	35.50 (36.33)^{b}	73.50 (59.42)^{bc}	92.00 (73.83)^{b}
M. anisopliae @ 10^8 spores mL^{-1}	31.00 (33.78)^{b}	71.00 (57.44)^{c}	92.50 (76.14)^{b}
L. lecanii@ 10^7 spores mL^{-1}	54.50 (47.59)^{a}	87.50 (70.12)^{a}	100.00 (89.71)^{a}
L. saksenae @ 10^7 spores mL^{-1}	55.00 (47.87)^{a}	85.50 (68.31)^{ab}	100.00 (89.71)^{a}
Thiamethoxam 0.015 %	63.00 (52.58)^{a}	87.00 (69.62)^{a}	100.00 (89.71)^{a}
CD (0.05)	5.933	9.169	6.100

*Corrected with Abbot's formula over control

**Mean of 3 replications comprising 50 aphids each (Values in the parentheses are angular transformed values)

HAT : Hours After Treatment

At 48 HAT, 87.50 per cent mortality was recorded with *L. lecanii* @ 10^7 spores mL^{-1} which was at par with thiamethoxam 0.015 % (87.00 %) and *L. saksenae* @ 10^7 spores mL^{-1} (85.50 %). *B. bassiana* @ 10^8 spores mL^{-1} and *M. anisopliae* @ 10^8 spores mL^{-1} with 73.50 and 71 per cent mortality respectively followed the above treatments in their efficacy against aphids.

Complete mortality was observed in treatments with *L. saksenae* @ 10^7 spores mL^{-1}, *L. lecanii* @ 10^7 spores mL^{-1} and thiamethoxam 0.015 % at 72 HAT and were found to be significantly superior to *M. anisopliae* @ 10^8 spores mL^{-1} and *B. bassiana* @ 10^8 spores mL^{-1} with 92.50 and 92 per cent mortality respectively.

4.3 COMPATIBILITY OF BOTANICAL AND MICROBIAL AGENTS

After 21 days of incubation, the mean radial growth of microbial agents, *B. bassiana*, *M. anisopliae*, *L. lecanii* and *L. saksenae* in control was 3.23, 4.7, 3.3 and 3.73 cm respectively as against 1.13, 1.7, 1.28 and 1.47 cm respectively observed in presence of CNSL 0.2 % (Plate 3). The percentage growth inhibition was scored by Hassan's classification scheme by recording the radial growth of fungus in control as well as in the CNSL treated medium. CNSL was found to be slightly harmful (score 2) to the growth of the fungi with a growth inhibition of 65.01, 63.8, 61.21 and 60.58 per cent recorded in *B. bassiana*, *M. anisopliae*, *L. lecanii* and *L. saksenae* respectively (Table 4).

4.4 MANAGEMENT OF SUCKING PEST COMPLEX (POT CULTURE EXPERIMENT)

Based on the laboratory evaluation, the botanical insecticides *viz*., CNSL 0.075 %, CNSL 0.2 %, neem oil 2 %, oxuron 5 mL L^{-1} were selected for further studies. Among the microbials, *L. lecanii* @ 10^7 spores mL^{-1} was selected for the study as it was the most popularly used species against sucking pests, though *L. saksenae* @ 10^7 spores mL^{-1} was also effective. The combination of CNSL

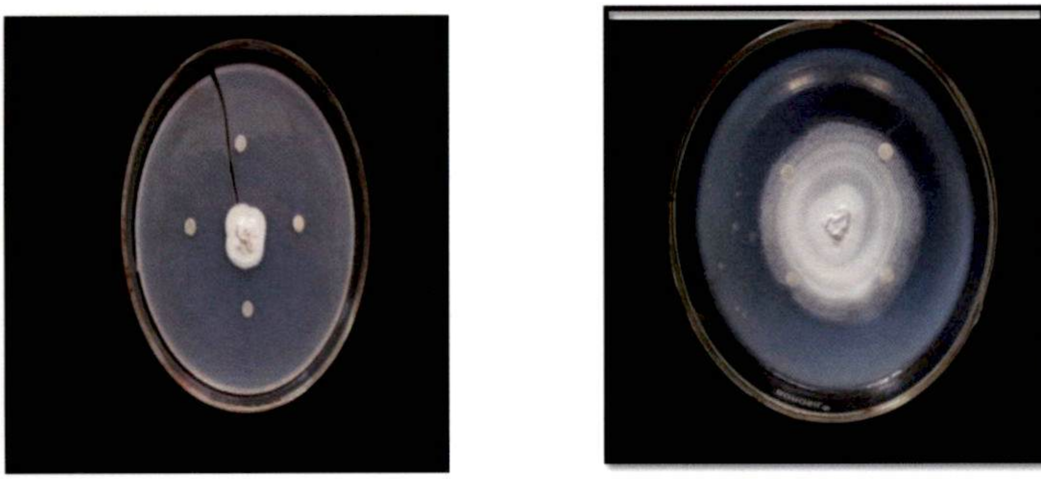


Plate 3 a: *L. lecanii* + CNSL 0.2 % and control

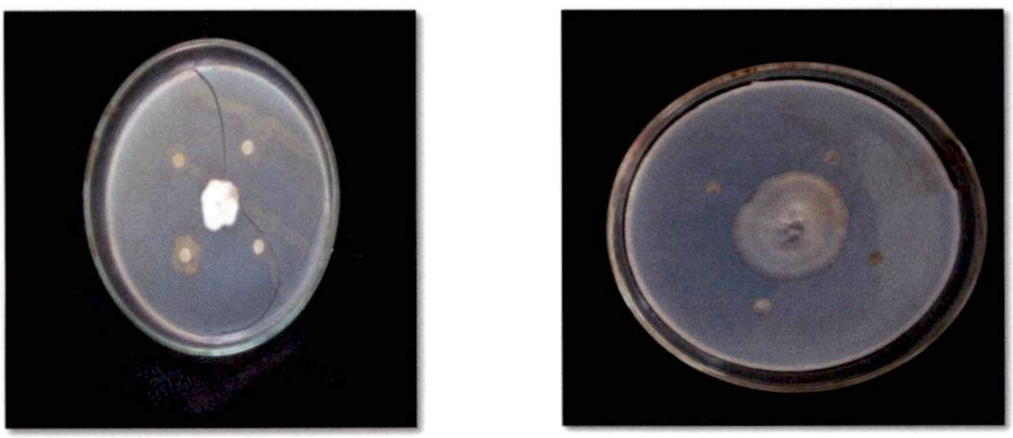


Plate 3 b: *L. saksenae* + CNSL 0.2 % and control

Plate 3: *In vitro* assessment of compatibility of botanical and microbial agents

Table 4: Compatibility of microbial agents and CNSL 0.2 %

Treatments	Radial growth of fungus in treated medium (cm)	Radial growth of fungus in control (cm)	Per cent growth inhibition (%)
B. bassiana	1.13	3.23	65.01
M. anisopleae	1.70	4.70	63.80
L. lecanii	1.28	3.30	61.21
L. saksenae	1.47	3.73	60.58

Scoring by Hassan's classification scheme (Hassan, 1989)

1- Harmless (< 50 % growth inhibition)

2- Slightly harmful (50-79 %)

3- Moderately harmful (80-90 %)

4- Harmful (>90 %)

0.2 % + *L. lecanii* (10^7 spores mL^{-1}) were also selected for further evaluation in field with thiamethoxam 0.015 % as chemical check.

4.4.1 Population of Sucking Pest After Treatment in the Vegetative Stage of the Crop

Population of the sucking pests *viz*., chilli thrips (*Scirtothrips dorsalis* Hood), aphid (*Aphis gossypii* Glover) and yellow mites (*Polyphagottarsonemus latus* Banks) subsequent to the first round of application of treatments undertaken at 30 DAP were recorded at 1, 3, 5, 7 and 14 days after treatment.

4.4.1.1 Chilli thrips S. dorsalis

Mean population of chilli thrips adjusted with the pre treatment count are presented in Table 5.

At one day after treatment (DAT), population of thrips was significantly lower in the combination of CNSL 0.2 % + *L. lecanii* (10^7 spores mL^{-1}) (0.21 $leaf^{-1}$) than all other treatments. The treatments CNSL 0.2 % (0.39 $leaf^{-1}$), CNSL 0.075 % (0.41 $leaf^{-1}$), *L. lecanii* @ 10^7 spores mL^{-1} (0.42 $leaf^{-1}$), oxuron 5 mL L^{-1} (0.65/leaf) and neem oil 2 % (0.78 $leaf^{-1}$) were found to manage thrips as effectively as the chemical thiamethoxam 0.015 %, though inferior to CNSL 0.2 % + *L. lecanii* (10^7 spores mL^{-1}). All the above treatments were on par with each other. Thrips population was comparatively high in the untreated plants (3.69 $leaf^{-1}$).

At three days after treatment, the thrips population was statistically lower in the combination CNSL 0.2 % + *L. lecanii* (10^7 spores mL^{-1}) (0.001 $leaf^{-1}$), CNSL 0.075 % (0.04 $leaf^{-1}$), thiamethoxam 0.015 % (0.12 $leaf^{-1}$), CNSL 0.2 % (0.31 $leaf^{-1}$) and *L. lecanii* @ 10^7 spores mL^{-1} (0.34 $leaf^{-1}$) which were on par with each other. Treatment with neem oil 2 % and oxuron 5 mL L^{-1} were less effective with population of 0.91 and 1.43 thrips $leaf^{-1}$ respectively. All the treatments were significantly superior over the untreated plants with 3.07 thrips $leaf^{-1}$.

Table 5 : Mean population of chilli thrips at different intervals after first spraying**

Treatment	Adjusted mean population (Number leaf^{-1})*				
	1 DAT	3 DAT	5 DAT	7 DAT	14 DAT
CNSL 0.075 %	0.41 (0.88)^{b}	0.04 (0.64)^{d}	0.55 (0.96)^{b}	0.76 (1.06)^{b}	0.37 (0.86)^{d}
CNSL 0.2 %	0.39 (0.87)^{b}	0.31 (0.82)^{cd}	0.36 (0.85)^{b}	0.55 (0.96)^{b}	1.31 (1.29)^{c}
Neem oil emulsion 2 %	0.78 (1.07)^{b}	0.91 (1.13)^{bc}	0.59 (0.98)^{b}	0.47` (0.92)^{b}	1.00 (1.17)^{cd}
Oxuron 5 mL L^{-1}	0.65 (1.01)^{b}	1.43 (1.34)^{b}	0.55 (0.96)^{b}	0.73 (1.05)^{b}	2.85 (1.79)^{b}
L. lecanii@ 10^7 spores mL^{-1}	0.42 (0.89)^{b}	0.34 (0.84)^{cd}	0.38 (0.87)^{b}	0.47 (0.92)^{b}	1.48 (1.36)^{c}
L. lecanii+ CNSL 0.2 %	0.21 (0.76)^{c}	0.001 (0.61)^{d}	0.54 (0.95)^{b}	0.58 (0.97)^{b}	1.71 (1.44)^{bc}
Thiamethoxam 0.015%	0.36 (0.86)^{b}	0.12 (0.71)^{d}	0.31 (0.82)^{b}	0.18 (0.74)^{c}	0.28 (0.81)^{d}
Control	3.69 (2.01)^{a}	3.07 (1.86)^{a}	4.63 (2.23)^{a}	4.17 (2.13)^{a}	4.86 (2.28)^{a}
SE(m)	0.061	0.088	0.059	0.069	0.098
CD (0.05)	0.231	0.336	0.223	0.267	0.370

*Mean population adjusted with pre treatment count

**Mean of 3 replications comprising 2 plants each (Values in the parentheses are square root transformed)

DAT: Days After Treatment

After five days, the thrips population increased slightly and in all treatments except untreated check and were found to be equally effective in containing the population which ranged from 0.31 to 0.59 thrips leaf^{-1}. The population in untreated check during the same period was 4.63 thrips leaf^{-1}.

Thiamethoxam 0.015 % maintained the lowest thrips population (0.18 leaf^{-1}) and was found to be superior than all other treatments at 7 DAT. The *L. lecanii* @ 10^7 spores mL^{-1}, neem oil 2 %, the combination of CNSL 0.2 % + *L. lecanii* (10^7 spores mL^{-1}), CNSL 0.2 %, oxuron 5 mL L^{-1}, CNSL 0.075 % had thrips population ranging from 0.47 to 0.76 leaf^{-1}. All these treatments were found on par with each other and were found superior to untreated plants (4.17 leaf^{-1}).

At 14 DAT, thiamethoxam 0.015 % (0.28 leaf^{-1}) and CNSL 0.075 % (0.37 leaf^{-1}) recorded lower thrips population and were superior than other treatments. These were followed by neem oil 2 % (1.00 leaf^{-1}), CNSL 0.2 % (1.31 leaf^{-1}) and *L. lecanii* @ 10^7 spores mL^{-1} (1.48 leaf^{-1}). Highest population of thrips was recorded in untreated plants (4.86 leaf^{-1}).

4.4.1.2 Chilli aphid A. gossypii

No aphid population was found to establish in the crop during the vegetative phase. High population of thrips and mites hindered successful establishment of aphid colonies.

4.4.1.3 Yellow mite P. latus

Mean adjusted population of chilli mites at different intervals after treatment are presented in Table 6.

Thiamethoxam 0.015 % treated plants exhibited significantly low mite population (0.65 leaf^{-1}) than all other treatments at one DAT indicating its quick action. The other treatments with botanicals and microbial agents were found to be on par with each other with population ranging from 1.01 to 1.62 mites leaf^{-1}.

Table 6: Mean population of chilli mites at different intervals after first spraying**

Treatment	Adjusted mean population (Number leaf^{-1}) *				
	1 DAT	3 DAT	5 DAT	7 DAT	14 DAT
CNSL 0.075 %	1.28 (1.28)^{bc}	0.53 (0.95)^{c}	0.35 (0.85)^{cd}	0.49 (0.93)^{bcd}	2.03 (1.55)^{c}
CNSL 0.2 %	1.62 (1.41)^{b}	1.02 (1.18)^{bc}	0.32 (0.83)^{d}	0.34 (0.84)^{d}	1.97 (1.53)^{cd}
Neem oil emulsion 2 %	1.44 (1.34)^{b}	1.06 (1.19)^{bc}	0.69 (1.03)^{bc}	0.61 (0.99)^{bcd}	1.89 (1.50)^{cd}
Oxuron 5 mL L^{-1}	1.28 (1.29)^{bc}	1.32 (1.30)^{b}	0.84 (1.10)^{b}	0.77 (1.07$^{)b}$	3.15 (1.87)^{b}
L. lecanii@ 10^7 spores mL^{-1}	1.01 (1.17)^{c}	0.75 (1.06)^{bc}	0.64 (1.01)^{bcd}	0.43 (0.90)^{cd}	1.44 (1.35)^{cd}
L. lecanii+ CNSL 0.2 %	1.53 (1.38)^{b}	0.42 (0.89)^{c}	0.29 (0.82)^{d}	0.73 (1.05)^{bc}	1.39 (1.33)^{d}
Thiamethoxam 0.015%	0.65 (1.01)^{d}	0.17 (0.73)^{d}	0.08 (0.67)^{e}	0.15 (0.72)^{e}	1.22 (1.26)^{e}
Control	3.56 (1.98)^{a}	3.73 (2.02)^{a}	3.82 (2.04)^{a}	4.6 2(2.23)^{a}	4.70 (2.25)^{a}
SE(m)	0.039	0.077	0.052	0.042	0.058
CD (0.05)	0.147	0.289	0.193	0.158	0.216

*Mean population adjusted with pre treatment count

**Mean of 3 replications comprising 2 plants each (Values in the parentheses are square root transformed)

DAT: Days After Treatment

The population of mites was significantly low in all the treatments than the untreated check which had the highest population of 3.56 mites leaf^{-1}.

At three days after spraying, treatments with thiamethoxam 0.015 % (0.17 leaf^{-1}), combination of CNSL 0.2 % + *L. lecanii* (10^7 spores mL^{-1}) (0.42 leaf^{-1}) and CNSL 0.075 % (0.53 leaf^{-1}) were found to be significantly superior with low mite population. These were followed by *L. lecanii* @ 10^7 spores mL^{-1} (0.75 leaf^{-1}), CNSL 0.2 % (1.02 leaf^{-1}), neem oil 2 % (1.06 leaf^{-1}) and oxuron 5 mL L^{-1} (1.32 leaf^{-1}). The population was maximum in untreated plants (3.73 leaf^{-1}).

At five DAT, the combination of CNSL 0.2 % + *L. lecanii* (10^7 spores mL^{-1}) (0.29 leaf^{-1}) recorded lowest mite population which did not vary significantly from the treatments CNSL 0.2 % (0.32 leaf^{-1}) and CNSL 0.075 % (0.35 leaf^{-1}) and the chemical check thiamethoxam 0.015 % (0.08 leaf^{-1}). *L. lecanii* @ 10^7 spores mL^{-1} (0.64 leaf^{-1}), neem oil 2 % (0.69 leaf^{-1}) and oxuron 5 mL L^{-1} (0.84 leaf^{-1}) followed these treatments. All the treatments significantly differed from the untreated plants (3.82 mites leaf^{-1}).

The population of mites was significantly lower (0.15 leaf^{-1}) in chemical check than all other treatments at seven days after treatment followed by CNSL 0.2% and *L. lecanii* @ 10^7 spores mL^{-1} recording mite population of 0.34 and 0.43 leaf^{-1} respectively. Among the treatments, highest mite population was recorded in oxuron 5 mL L^{-1} (0.77 leaf^{-1}).

An increase in population of mites was observed in all treatments at the 14 DAT among which the combination of CNSL 0.2 % + *L. lecanii* (10^7 spores mL^{-1}) (1.39 leaf^{-1}) recorded lowest mite population which was on par with chemical check thiamethoxam 0.015 % (1.22 leaf^{-1}). CNSL 0.075, CNSL 0.2 %, neem oil 2 % and *L. lecanii* @ 10^7 spores mL^{-1} were found to be superior than oxuron 5 mL L^{-1} and untreated check.

4.4.2 Population of Sucking Pest after Treatment in the Reproductive Stage of the Crop

Second round of application of treatments in the reproductive stage of the crop was given at 60 DAP and the population of the sucking pests were recorded at 1, 3, 5, 7 and 14 days after treatment.

4.4.2.1 Chilli thrips S. dorsalis

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

Significant reduction in the population of thrips over untreated check was observed in all treatments from 1 to 14 days after treatment. Significantly lower population of thrips was recorded in CNSL 0.2 % (0.33 leaf^{-1}), thiamethoxam 0.015 % (0.5 leaf^{-1}) and the combination of CNSL 0.2 % + *L. lecanii* (10^7 spores mL^{-1}) (0.77 leaf^{-1}) at 1 DAT and were found to be on par with each other. These were followed by CNSL 0.075 % (0.97 leaf^{-1}), *L. lecanii* @ 10^7 spores mL^{-1} (1.03 leaf^{-1}), neem oil 2 % (1.2 leaf^{-1}) and oxuron 5 mL L^{-1} (1.33 leaf^{-1}).

CNSL 0.2 % (0.27 leaf^{-1}), thiamethoxam 0.015 % (0.37 leaf^{-1}) and *L. lecanii* @ 10^7 spores mL^{-1} (0.4 leaf^{-1}) showed low thrips population on third day after treatment. The combination of CNSL 0.2 % + *L. lecanii* (10^7 spores mL^{-1}) (0.8 leaf^{-1}) was the next effective treatment. Neem oil 2 % (0.97 leaf^{-1}), CNSL 0.075 % (1.07 leaf^{-1}) and oxuron 5 mL L^{-1} (1.23 leaf^{-1}) treated plants had comparatively higher population of thrips though superior over untreated plants (4.53 leaf^{-1}).

After five days, the thrips population remained lower in thiamethoxam 0.015 % (0.13 leaf^{-1}). Rest of the treatments recorded thrips population ranging

Table 7: Mean population of chilli thrips at different intervals after second spraying

Treatment	Mean population (Number leaf^{-1}) *				
	1 DAT	3 DAT	5 DAT	7 DAT	14 DAT
CNSL 0.075 %	0.97 (0.97)^{bc}	1.07 (1.03)^{bc}	0.60 (1.05)^{b}	0.53 (1.01)^{c}	1.57 (1.25)^{bc}
CNSL 0.2 %	0.33 (0.57)^{d}	0.27 (0.51)^{d}	0.37 (0.93)^{bc}	0.30 (0.89)^{cd}	1.27 (1.11)^{c}
Neem oil emulsion 2%	1.20 (1.08)^{bc}	0.97 (0.98)^{bc}	0.73 (1.08)^{b}	0.63 (1.05)^{c}	2.23 (1.49)^{b}
Oxuron 5 mL L^{-1}	1.33 (1.14)^{b}	1.23 (1.11)^{b}	0.80 (1.13)^{b}	1.10 (1.26)^{b}	2.27 (1.50)^{b}
L. lecanii@ 10^7 spores mL^{-1}	1.03 (1.01)^{bc}	0.40 (0.62)^{d}	0.33 (0.91)^{bc}	0.37 (0.93)^{cd}	1.23 (1.08)^{c}
L. lecanii+ CNSL 0.2 %	0.77 (0.85)^{cd}	0.80 (0.89)^{c}	0.60 (1.05)^{b}	0.57 (1.03)^{c}	1.23 (1.11)^{c}
Thiamethoxam 0.015%	0.50 (0.67)^{d}	0.37 (0.59)^{d}	0.13 (0.78)^{c}	0.17 (0.81)^{d}	1.17 (1.08)^{c}
Control	4.53 (2.12)^{a}	4.53 (2.13)^{a}	4.43 (2.22)^{a}	4.43 (2.22)^{a}	4.50 (2.12)^{a}
SE(m)	0.079	0.049	0.063	0.047	0.074
CD (0.05)	0.287	0.181	0.230	0.177	0.274

*Mean of 3 replications comprising 2 plants each (Values in the parentheses are square root transformed)

DAT: Days After Treatment

from 0.33 to 0.8 thrips $leaf^{-1}$ though inferior to the chemical check. The untreated plants exhibited significantly higher population of 4.43 $leaf^{-1}$.

On seventh day after treatment, thiamethoxam 0.015 % (0.17 $leaf^{-1}$) showed superiority over other treatments followed by the CNSL 0.2 %, *L. lecanii* @ 10^7 spores mL^{-1}, CNSL 0.075 %, combination of CNSL 0.2 % + *L. lecanii* (10^7 spores mL^{-1}) and neem oil 2 % with mean populations of 0.3, 0.37, 0.53, 0.57 and 0.63 thrips $leaf^{-1}$ respectively which were at par. The untreated plants recorded a population of 4.43 $leaf^{-1}$.

At 14 DAT, an increase in population of thrips was observed in all treatments. Lowest population of thrips was recorded in thiamethoxam 0.015 % treated plants (1.17 $leaf^{-1}$) which was statistically on par with those treated with combination CNSL 0.2 % + *L. lecanii* (10^7 spores mL^{-1}), *L. lecanii* @ 10^7 spores mL^{-1} and CNSL 0.2% with 1.23, 1.23 and 1.27 thrips $leaf^{-1}$ respectively. These were followed by CNSL 0.075 % (1.57 $leaf^{-1}$), neem oil 2 % (2.23 $leaf^{-1}$) and oxuron 5 mL L^{-1} (2.27 $leaf^{-1}$). Untreated plants recorded 4.5 thrips $leaf^{-1}$.

4.4.2.2 Chilli aphid A. gossypii

A constantly low population of *A. gossypii* was observed in the reproductive phase of the crop. The mean population of aphids before treatment, 1, 3 and 5 days after treatment are presented in table 8. There was no significant difference in the population of aphids between treatments. No aphid population was observed on seventh DAT onwards.

4.4.2.3 Yellow mite P. latus

Mean population of chilli mites at different intervals after treatment are expressed in Table 9.

In general, the mite population was relatively low during the reproductive phase than the vegetative phase of the crop as evidenced by the low pre treatment

Table 8 : Mean population of chilli mites at different intervals after second spraying

Treatment	Mean population (Number leaf^{-1}) *				
	1 DAT	3 DAT	5 DAT	7 DAT	14 DAT
CNSL 0.075 %	0.90 (0.93)^{de}	0.77 (0.86)^{de}	1.4 (1.18)^{bcd}	1.47 (1.21)^{bcd}	2.70 (1.92)
CNSL 0.2 %	0.60 (0.77)^{e}	0.57 (0.74)^{e}	0.90 (0.93)^{de}	1.07 (1.03)^{d}	2.53 (1.86)
Neem oil emulsion 2 %	1.93 (1.38)^{bc}	1.37 (1.16)^{c}	1.53 (1.23)^{bc}	2.00 (1.41)^{b}	4.07 (2.25)
Oxuron 5 mL L^{-1}	1.53 (1.22)^{c}	1.40 (1.18)^{c}	1.53 (1.23)^{bc}	1.43 (1.18)^{bcd}	4.40 (2.32)
L. lecanii@ 10^{7} spores mL^{-1}	2.33 (1.52)^{b}	2.37 (1.54)^{b}	1.30 (1.14)^{cd}	0.97 (0.97)^{d}	2.17 (1.73)
L. lecanii+ CNSL 0.2 %	1.47 (1.21)^{cd}	1.00 (0.99)^{cd}	1.93 (1.38)^{b}	1.83 (1.35)^{bc}	3.50 (2.12)
Thiamethoxam 0.015%	0.70 (0.81)^{e}	0.63 (0.79)^{e}	0.70 (0.83)^{e}	1.27 (1.10)^{cd}	2.80 (1.95)
Control	3.27 (1.81)^{a}	3.37 (1.83)^{a}	3.00 (1.73)^{a}	3.10 (1.76)^{a}	3.93 (2.22)
SE(m)	0.077	0.054	0.068	0.073	0.139
CD (0.05)	0.284	0.199	0.249	0.268	NS

*Mean of 3 replications comprising 2 plants each (Values in the parentheses are square root transformed)

DAT: Days After Treatment

Table 9 : Mean population of chilli aphids at different intervals after second spraying

Treatment	Mean population *		
	1 DAT	3 DAT	5 DAT
CNSL 0.075 %	1.00(1.09)	0.67(0.99)	0(0.71)
CNSL 0.2 %	0.83(1.05)	0.67(0.99)	0.67(0.88)
Neem oil emulsion 2 %	1.67(1.25)	0.50(0.94)	0.33(0.71)
Oxuron 5 mL L^{-1}	0(0.71)	0(0.71)	0(0.71)
L. lecanii@ 10^7 spores mL^{-1}	3.67(1.60)	2.33(1.38)	0.67(0.99)
L. lecanii+ CNSL 0.2 %	0(0.71)	0(0.71)	0(0.71)
Thiamethoxam 0.015%	0.67(0.99)	0(0.71)	0(0.71)
Control	0(0.71)	0(0.71)	0(0.71)
SE(m)	0.347	0.238	0.097
CD (0.05)	NS	NS	NS

*Mean of 3 replications comprising 2 plants each (Values in the parentheses are square root transformed)

DAT: Days After Treatment

population. Significant reduction in the population of mites over untreated check was observed in all treatments from one to seven days after treatment.

Significantly low population of mite was observed in CNSL 0.2 % (0.6 leaf^{-1}) and CNSL 0.075% (0.9 leaf^{-1}) sprayed plants which did not vary from the chemical check thiamethoxam 0.015 % (0.7 leaf^{-1}) treated plants. The combination of CNSL 0.2 % + *L. lecanii* 10^7 spores mL^{-1} and oxuron 5 mL L^{-1} were the next effective treatments with a mean population of 1.47 and 1.53 mites leaf^{-1}. The untreated control plants had higher mite population than all other treatments (3.27 leaf^{-1}).

At third DAT, CNSL 0.2 % (0.57 leaf^{-1}), thiamethoxam 0.015 % (0.63 leaf^{-1}) and CNSL 0.075% (0.77 leaf^{-1}) recorded lower mite population and were significantly superior to other treatments. The combination CNSL 0.2 % + *L. lecanii* @ 10^7 spores mL^{-1} with population of 1.0 mite leaf^{-1} was found as the next effective treatment which was on par with neem oil 2 % (1.37 leaf^{-1}) and oxuron 5 mL L^{-1} (1.4 leaf^{-1}) in containing the population of *P. latus*. The mite population remained high in untreated plants (3.37 leaf^{-1}).

The mite population slightly increased in the fifth day after treatment where in thiamethoxam 0.015 % (0.7 leaf^{-1}) and CNSL 0.2% (0.9 leaf^{-1}) treatments recorded significantly lower population than other treatments. *L. lecanii* @ 10^7 spores mL^{-1}, CNSL 0.075 %, neem oil 2 %, oxuron 5 mL L^{-1} and combination CNSL 0.2 % + *L. lecanii* (10^7 spores mL^{-1}) having 1.3, 1.4, 1.53, 1.53 and 1.93 mites leaf^{-1}, respectively followed the above treatments. Though plants received the treatments recorded higher number of mites at 5 DAT, it was significantly lower than untreated plants (3 leaf^{-1}).

At seven days after treatment, the mite population was significantly lower in plants treated with *L. lecani* (0.97 leaf^{-1}) followed by CNSL 0.2% (1.07 leaf^{-1}) and thiamethoxam 0.015 % (1.27 leaf^{-1}) which were on par. Mite population ranged from 1.43 to 2.0 leaf^{-1} in the other treatments except the untreated plants which had a higher population of 3.1 leaf^{-1}. Fourteen days after treatment, the treatments have no significant influence on the population of mites.

4.4.3 Damage Caused by Sucking Pests

4.4.3.1 Chilli thrips S. dorsalis

Thrips were observed on both abaxial and adaxial surfaces of leaves particularly on the upper strata of the plant. The feeding resulted in cupping and curling of the leaves with pronounced crinkling (Plate 4). The wounds caused on the tender tissues resulted in the malformation and shriveling of leaves, buds and fruits. The leaves showed rolling up symptoms with raising of interveinal area. In severe cases the buds became brittle and dropped down.

4.4.3.2 Chilli aphid A. gossypii

Aphids were mostly observed congregating on the lower side of older leaves, tender shoots and flower stalks (Plate 5). Feeding resulted in stunted plants with deformed and discolored leaves and fruits. The aphids were found to suck the cell sap and secrete honey dew on which black sooty mould developed which retarded the plant growth.

4.4.3.3 Yellow mite P. latus

Mites were observed on both sides of the middle and upper leaves of chilli plants. They were also found on the fruits. First symptoms of damage was observed on the tender shoots and leaves. The feeding by mites resulted in development of shiny spots on lower surface of leaves. On later stages the leaves showed downward curling, elongation and narrowing.The leaf size also get reduced (Plate 6). The infected leaves became leathery.

4.4.3.4 Combined Infestation of Sucking Pests

The combined infestation by sucking pests showed symptoms of leaf curling, crinkling, thickening and swelling of veins. In severe cases, the plants

Plate 4a: Cupping and curling of leaves

Plate 4b: Upward curling and crinkling of leaves

Plate 4: Symptoms of damage by *S. dorsalis*

Plate 5a: Aphid infestation on leaves

Plate 5b: Aphid infestation on shoot and flowers

Plate 5c: Aphid infestation on petiole

Plate 5d: Fruit deformed due to aphid feeding

Plate 5: Symptoms of damage by *A.gossypii*

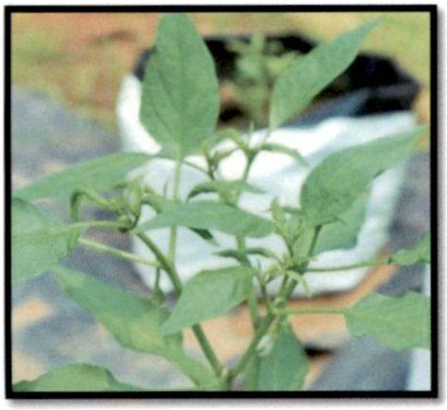


Plate 6a: Tender shoots and leaves showing initial crinkling

Plate 6b: Downward curling of leaves and elongation of petiole

Plate 6c: Reduction in leaf size observed in severe infestation

Plate 6d: Dried flowers due to mite infestation

Plate 6: Symptoms of damage by *P. latus*

exhibited stunted growth resulting in a bushy stature (Plate 7). Also the flowering in such plants were found to be very less.

Infestation by other sucking pests including whiteflies were not observed during the field evaluation.

4.4.4 Effect of Treatments on Damage by Sucking Pests (Leaf Curl Index)

The effectiveness of botanical and microbial pesticide application on the intensity of damage was assessed by working out leaf curl index (LCI) at 40 days after planting (10 days after first spraying), 70 DAP (10 days after second spraying) and 90 DAP (end of the crop). The results are presented in Table 10.

The application of various treatments did not exhibit statistically significant difference at 40 days after planting, in the damage by sucking pests assessed based on the five grades of leaf damage. No leaf curling was observed in thiamethoxam 0.015 % treated plants. CNSL 0.075 %, CNSL 0.2%, *L. lecanii* @ 10^7 spores mL^{-1} and oxuron 5 mL L^{-1} treated plants recorded low damage with leaf curl index of 0.67. The rest of the treatments had a mean leaf curl index of 1 with less than 25 % leaves exhibiting symptoms of damage.

The damage by sucking pests became more pronounced by 70 DAP. All the treatments except oxuron 5 mL L^{-1} application significantly reduced the damage over untreated check. The lowest leaf curl index was noticed in thiamethoxam 0.015 % and CNSL 0.075 % treated plants with a leaf curl index of 1.0. Plants treated with CNSL 0.2 %, neem oil 2 % and the combination CNSL 0.2 % + *L. lecanii* (10^7 spores mL^{-1}) treatments though showed increased leaf curl index (1.33) were on par with thiamethoxam 0.015 %. *L. lecanii* @ 10^7 spores mL^{-1} was also found to reduce the leaf curl index but the effect was inferior to the effective treatments. High leaf damage was observed in oxuron 5 mL L^{-1} (LCI of 2) and in untreated check (LCI of 3).

Plate 7a: Crinkling of leaves

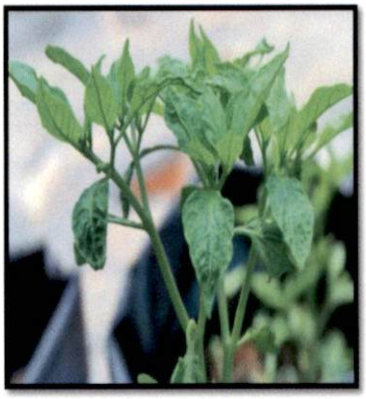


Plate 7b: Thickening and swelling of veins

Plate 7c: Plant exhibiting stunted growth

Plate 7d: Stunted plant with bushy stature

Plate 7: Symptoms of damage by sucking pest complex

Table 10 : Leaf Curl Index in chilli at different intervals after treatment

Treatments	40 DAP*	70 DAP**	90 DAP***
CNSL 0.075 %	0.67	1.00	1.50
CNSL 0.2 %	0.67	1.33	1.67
Neem oil emulsion 2 %	1.00	1.33	2.17
Oxuron 5 mL L^{-1}	0.67	2.00	2.00
L. lecanii@ 10^7 spores mL^{-1}	0.67	1.67	1.50
L. lecanii+ CNSL 0.2 %	1.00	1.33	1.83
Thiamethoxam 0.015%	0	1.00	1.00
Control	1.00	3.00	3.17
CD	NS	0.329	0.259

* 10 days after first spraying

** 10 days after second spraying

*** At the end of the crop

At the end of the crop (90 DAP), the damage by sucking pests increased in all treatments except thiamethoxam 0.015 % as evidenced by a higher value of leaf curl index. Application of thiamethoxam 0.015 % was found to significantly reduce the leaf damage (LCI 1.0) in comparison with other treatments. CNSL 0.075 % and *L. lecanii* @ 10^7 spores mL^{-1} treatments were also found to reduce leaf damage as indicated by leaf curl index of 1.5 though inferior to the chemical treatment. Leaf curl index of 1.67 to 2.17 was observed in other treatments did not vary significantly from that of the control (3.17).

4.4.5 Biometric Observations of Chilli Plants Treated with Different Pesticides

The influence of pesticide application on plant height, number of leaves per plant and fruit yield per plant at different intervals are presented in Table 11.

4.4.5.1 Plant Height

The results revealed a significant difference among the treatments. At 40 DAP i.e., 10 days after application of treatments in the vegetative phase, thiamethoxam 0.015 % treated plants recorded maximum plant height (23.1 cm) followed by the plants treated with neem oil 2 % (19.5 cm) and *L. lecanii* @ 10^7 spores mL^{-1} (19.6 cm) which were found to be on par and significantly superior than other treatments. The lowest plant height was recorded in the untreated plants (15.1 cm). Treatments with CNSL 0.2 % as well as the combination of CNSL 0.2 % + *L. lecanii* (10^7 spores mL^{-1}) with plant height of 16.3 and 17.33 cm respectively did not show significant difference from untreated check.

At 70 and 90 days after planting, thiamethoxam 0.015 % treated plants exhibited significantly superior growth over other treatments with plant height of 43.24 and 50.43 cm respectively. The lowest plant height during the period was recorded in untreated check (20.6 and 21.6 cm respectively). CNSL 0.2 % and combination of CNSL 0.2 %+ *L. lecanii* (10^7 spores mL^{-1}) treated plants also recorded low plant height (20.83 and 22.33 at 70 DAP ; 23.2 and 25.8 cm at 90

Table 11: Effect of treatments on biometric characters of chilli

Treatment	Plant height (cm)			Number of leaves plant^{-1}			Yield (g plant^{-1})
	40 DAP*	70 DAP**	90 DAP***	40 DAP*	70 DAP**	90 DAP***	
CNSL 0.075 %	17.43^{bc}	25.70^{bc}	30.53^{bc}	28.50^{abc}	52.00^{bc}	57.00^{bc}	189.22
CNSL 0.2 %	16.30^{bc}	20.83^{d}	23.20^{ef}	22.70^{d}	45.83^{cd}	45.33^{e}	177.38
Neem oil emulsion 2 %	19.50^{ab}	26.13^{bc}	28.23^{cd}	25.67^{cd}	44.83^{cd}	50.67^{cde}	193.20
Oxuron 5 mL L^{-1}	18.73^{bc}	27.47^{b}	30.13^{bc}	25.50^{cd}	54.00^{ab}	53.67^{bcd}	194.24
L. lecanii@ 10^7 spores mL^{-1}	19.60^{ab}	28.93^{b}	32.63^{b}	30.83^{ab}	57.83^{ab}	59.33^{b}	196.00
L. lecanii+ CNSL 0.2 %	17.33^{bc}	22.33^{cd}	25.80^{de}	27.50^{bc}	39.83^{de}	48.67^{de}	178.64
Thiamethoxam 0.015%	23.10^{a}	43.24^{a}	50.43^{a}	32.67^{a}	60.33^{a}	96.00^{a}	210.84
Control	15.10^{c}	20.60^{d}	21.60^{f}	24.47^{cd}	35.50^{e}	36.00^{f}	181.02
SE(m)	1.245	1.625	1.228	1.559	2.436	2.751	2.880
CD (0.05)	3.729	4.615	3.704	4.274	7.303	8.249	NS

*10 days after first spraying

**10 days after second spraying

***At the end of the crop

DAP respectively) which were found to be on par with untreated check. At 70 DAP, CNSL 0.075, neem oil 2 %, *L. lecanii* @ 10^7 spores mL^{-1}, oxuron 5 mL L^{-1} treated plants recorded height of 25.7, 26.13, 28.93 and 27.47 cm respectively making them superior over untreated check as well as CNSL 0.2 % and its combination with *L. lecanii* @ 10^7 spores mL^{-1}. The same trend was noticed at the end of the crop (90 DAP) (Plate 8).

4.4.5.2 Number of Leaves

Thiamethoxam 0.015 % treated plants had significantly more number of leaves (32.67, 60.33 and 96 at 40, 70 and 90 DAP respectively) than all other treatments. The lowest number of leaves was observed in the untreated check at 70 and 90 DAP with 35.5 and 36 leaves $plant^{-1}$ respectively. The number of leaves in CNSL 0.2 % treated plants was found to be on par with untreated check at 40 and 70 DAP.

Treatments with *L. lecanii* @ 10^7 spores mL^{-1} (30.83 leaves $plant^{-1}$), CNSL 0.075 % (28.5) and the combination of CNSL 0.2 % + *L. lecanii* (10^7 spores mL^{-1}) (27.5) exhibited more number of leaves per plant at 40 DAP though inferior to the thiamethoxam 0.015 % treated plants.

At 70 DAP, plants treated with *L. lecanii* @ 10^7 spores mL^{-1}, oxuron 5 mL L^{-1} and CNSL 0.075 % with 57.83, 54 and 52 leaves per plant respectively was found to be next best to thiamethoxam 0.015 % treatment and significantly superior than other treatments. The untreated plants recorded the lowest number of leaves (35.5 per plant).

At the end of the crop (90 DAP), plants treated with *L. lecanii* @ 10^7 spores mL^{-1}, CNSL 0.075 % and oxuron 5 mL L^{-1} with 59.33, 57 and 53.67

Plate 8a: Thiamethoxam 0.015 %

Plate 8 b: CNSL 0.2 %

Plate 8c: CNSL 0.075 %

Plate 8d: Untreated

Plate 8 : Plants applied with different treatments

leaves per plant respectively followed the chemical check. CNSL 0.2 % treated plants recorded the lowest number of leaves among the treatments though superior to the untreated check.

4.4.5.3 Yield

The yield obtained during the crop period was not influenced by the treatments. Highest yield of 210.84 g plant $^{-1}$ was obtained from the plants treated with thiamethoxam 0.015 % (Table 11).

4.4.5.4 Effect of Different Treatments on Other Growth Characteristics

Other growth parameters like internodal length, number of branches, basal girth, root length, shoot fresh and dry weight, root fresh and dry weight were recorded at the end of crop (90 DAP) by uprooting the crop (Table 12). Thiamethoxam 0.015 % treated plants was found to be significantly superior in all the parameters *viz.*, internodal length (5.03 cm), number of branches (15), basal girth (4.77 cm), root length (14.37 cm), shoot fresh weight (33.32 g plant^{-1}), shoot dry weight (3.11 g plant^{-1}), root fresh weight (5.63 g plant^{-1}) and root dry weight (0.62 g plant^{-1}). Internodal length, number of branches, basal girth, root length, shoot fresh and dry weight in plants treated with *L. lecanii* @ 10^7 spores mL^{-1} and oxuron 5 mL L^{-1} followed the chemical check.

Plants treated with the higher concentration of CNSL (0.2 %) did not differ significantly from untreated ones in the growth characters *viz.*, internodal length (2.13 cm), number of branches (6.33), basal girth (1.7 cm), shoot fresh (13.25 g plant^{-1}) and dry weight (1.05 g plant^{-1}), root fresh (1.09 g plant^{-1}) and dry weight (0.11 g plant^{-1}), which revealed the possibility of growth retarding effect. On contrast, the lower dose of CNSL (0.075 %) was found to be significantly superior to untreated check in the above parameters except basal girth. CNSL 0.075 % recorded 8.33 cm, 9.57 cm, 17.45 g plant $^{-1}$, 1.54 g plant $^{-1}$, 2.01 g plant $^{-1}$ and 0.21 g plant $^{-1}$ of number of branches, root length, shoot fresh and dry weight,

Table 12: Effect of different treatments on other growth characteristics (pot culture studies)

Treatments	Internodal length (cm)	No.of branches	Basal girth (cm)	Root length (cm)	Shoot		Root	
					Fresh weight(g plant $^{-1}$)	Dry weight(g plant $^{-1}$)	Fresh weight(g plant $^{-1}$)	Dry weight(g plant $^{-1}$)
CNSL 0.075%	2.97^{bc}	8.33^{d}	1.83^{c}	9.57^{b}	17.45^{c}	1.54^{d}	2.01^{c}	0.21^{c}
CNSL 0.2 %	2.13^{e}	6.33^{e}	1.70^{cd}	7.33^{c}	13.25^{de}	1.05^{de}	1.09^{d}	0.11^{de}
Neem oil emulsion 2 %	2.60^{cd}	10.33^{c}	1.53^{d}	9.47^{b}	17.27^{c}	1.56^{cd}	1.71^{c}	0.18^{c}
Oxuron 5 mL L^{-1}	3.07^{b}	13.00^{b}	1.90^{bc}	10.00^{b}	21.49^{b}	2.09^{bc}	1.91^{c}	0.21^{c}
L. lecanii@10^7 spores mL^{-1}	3.10^{b}	13.00^{b}	2.17^{b}	13.60^{a}	25.23^{b}	2.23^{b}	2.97^{b}	0.33^{b}
L. lecanii+ CNSL 0.2 %	2.20^{de}	12.00^{b}	1.87^{c}	8.80^{bc}	16.98^{cd}	1.52^{d}	1.09^{d}	0.12^{d}
Thiamethoxam 0.015%	5.03^{a}	15.00^{a}	4.77^{a}	14.37^{a}	33.32^{a}	3.11^{a}	5.63^{a}	0.62^{a}
Control	1.93^{e}	5.33^{e}	1.70^{cd}	6.93^{d}	11.16^{e}	0.92^{e}	0.71^{d}	0.067^{e}
SE(m)	0.144	0.514	0.093	0.704	1.135	0.177	0.157	0.018
CD	0.431	1.540	0.278	2.110	3.94	0.531	0.470	0.053

root fresh and dry weight respectively as against 5.33 cm, 6.93 cm, 11.16 g plant $^{-1}$, 0.92 g plant $^{-1}$, 0.71 g plant $^{-1}$ and 0.067 g plant $^{-1}$ in untreated check.

DISCUSSION

5. DISCUSSION

Chilli, *Capsicum annuum* L. is one of the most important spice crops cultivated in an area of 774.9 thousand ha in India contributing 36 per cent of chilli production in the world (Geetha and Selvarani, 2017). Ravages by pests particularly those with the sucking mouth parts is identified as a major yield limiting factor in chilli.

Chilli leaf curl complex, "murda" is the most destructive syndrome that devastate chilli in India (Puttarudriah, 1959). Desapping by the sucking pest complex comprising of thrips (*Scirtothrips dorsalis* Hood), aphids (*Aphis gossypii* Glover) and mites (*Polyphagotarsonemus latus* Banks) along with the infection by begomoviruses vectored by them are attributed to the development of the leaf curl syndrome (Amin, 1979; Zehra *et al.*, 2017).

In the present agricultural scenario chemical pesticides are the major arsenal employed for the management of pests. Growers often resort to five to six rounds of application of chemical pesticides to manage sucking pests in chilli (Khan and Ram, 2016).

Although effective in reducing pest population in short term, these chemicals have long term negative impact on pest population and causes adverse effects on environment and human health. Botanical and microbial pesticides, being natural products, are environment friendly and are potential alternatives to chemical pesticides for producing healthy and good quality crop (Mandi and Senapati, 2009; Nerio *et al.*, 2010).

Tropical plants are vast untapped source of potentially useful phytochemicals that contribute to defence against biotic agents (Isman, 1994; Pichersky and Lewinsohn, 2011). Plants being long-lived stationary organisms with an intention to resist attackers over their lifetime, produce, store and exude a variety of secondary metabolites, that plays an important role in their defence against herbivores including insect pests (Forim *et al.*, 2012).

Many such secondary metabolites such as pyrethrin (Casida, 1980), azadirachtin (Khater, 2012), nicotine (El-Wakeil, 2013) and ryanoids (Martina and Kristina, 2013) have been developed as commercial botanical pesticides.

A completely different strategy involves investigating industrial by-products from the agrifood and forest industries, where the starting material is already available in quantity at minimal cost. Cashew nut shell liquid (CNSL) is such a versatile by-product of the cashew industry that contain plant derived phenolic compounds. Besides its industrial use in polymer industry CNSL has the potential to be developed as a pesticide (Mahapatro, 2011).

Entomopathogenic fungi are emerging as potent biocontrol agents of sucking pests owing to their ability to penetrate through the cuticle (Rabindra and Ramanujam, 2007). *Beauveria bassiana* (Arthurs *et al.,* 2013), *Metarhizium anisopliae* (Jandricic *et al.*, 2014), and *Lecanicillium lecanii* (Lokesh, 2014) have been reported to be effective against sucking pests.

In this backdrop, the present study was taken up as a preliminary step to evolve a suitable eco-friendly management strategy against sucking pest complex of chilli comprising of aphids, thrips and mites utilizing potential botanical and microbial pesticides.

Cashew nut shell liquid was procured from Mahatma cashew exports, Kollam district, made into emulsions of 0.025, 0.05, 0.075, 0.1 and 0.2 % and evaluated for its efficacy as pesticide against *A. gossypii* as test insect along with established botanical pesticides. Though all concentrations of CNSL were found to cause early mortality at 24 hours after treatment (HAT), CNSL 0.2 % was found to be significantly superior causing 64 per cent mortality, an effect on par with chemical pesticide thiamethoxam 0.015 %. At 48 HAT, CNSL 0.075 %, CNSL 0.1 % and CNSL 0.2 % showed significantly higher mortality than other botanical treatments and was on par with the commercial botanical product oxuron @ 5 mL L^{-1} and chemical thiamethoxam 0.015 %. The toxicity of CNSL was reported in controlling cowpea pests with better yield components. The pesticidal property of CNSL is attributed due to the presence of the phenolic compounds cardanol and cardol (Venmalar and Nagaveni, 2005). The toxicity of CNSL was also documented against termites (Asogwa *et al.*, 2007), coconut root grub (John *et al.*, 2008), *Helicoverpa armigera* and *Spilarctia oblique* (Mahapatro, 2011) at concentrations ranging from 1- 25 %. In the present study, CNSL was found to have insecticidal effect against *A. gossypii* at a much lower concentrations of 0.075 to 0.2 %. Olotuah and Ofuya (2010) evaluated CNSL at concentrations ranging from 0.01 to 1 % against *A. craccivora* and identified that the 1% formulation was most effective.

Neem oil 2 % was found to be effective against *A. gossypii* causing quick mortality of 50 % at 24 HAT in the present investigation. The mortality of aphids in treatment with neem oil can be attributed to the presence of azadirachtin, the tetranortriterpenoid plant limonoid having insecticidal properties (Kumar *et al.*, 2003; Pavela, 2007). The toxicity of neem oil on the adults and nymphs of *A. gossypii* was reported earlier by Souza *et al.* (2015).

Oxuron, a commercial botanical product comprising of neem oil and karanja oil was also found effective against *A. gossypii* in the laboratory evaluation. The toxicity of neem and pungam oil was proved by several workers (Chockalingam *et al.,* 1983; Devakumar *et al.,* 1986). Arya (2015) reported oxuron to be effective against sucking pests in brinjal.

Thiamethoxam which was reported as an effective insecticide against sucking pests in cotton (Nagger and Zidan, 2013), okra (Ghosh *et al.*, 2016) and green gram (Sujatha and Bharpoda, 2017) remained highly effective against *A. gossypii* also.

CNSL 0.2 % which was found equally effective as thiamethoxam 0.015 % against *A. gossypii* in the laboratory was selected for further evaluation against sucking pest complex of chilli along with CNSL 0.075 %, the lowest effective concentration. Neem oil 2 % which had early mortality on the aphids (58 % at 24

HAT) and the commercial botanical product oxuron with 85.33 per cent mortality at 48 HAT were also included as treatments for field evaluation.

All entomopathogenic fungi *viz*., *B. bassiana, M. anisopliae*, *L. lecanii* and *L. saksenae* were found to infect *A. gossypii* with 35.5, 31, 54.5 and 55 per cent mortality by 24 HAT in the present study. *B. bassiana* was reported to cause a per cent mortality of 94 against *A. gossypii* in a study done by Herlinda (2010). An aphid mortality of 73-77 per cent by *M. anisopliae* was reported by Hundessa (2016).

L. lecanii and *L. saksenae* @ 10^7 spores mL^{-1} were found to cause significantly higher mortality of *A. gossypii* at 24 and 48 HAT an effect on par with chemical thiamethoxam 0.015 %. Hundred per cent mortality was achieved at 72 HAT. The isolates of *L. lecanii* (V24 and VI8) resulted in a per cent mortality of 90 and 82 of *A. gossypii* in a study conducted by Alavo *et al*. (2002). An isolate of *L. saksenae* obtained from Vellayani soil was earlier reported to be pathogenic to *A. craccivora*, *A. gossypii* and *B. tabaci* (Rani *et al*., 2015).

Entomopathogenic fungi infect their hosts by penetrating through the cuticle, gaining access to the hemolymph where they produce toxins, and grow by utilizing nutrients present in the haemocoel. Thus insect mortality is said to be due to the nutritional deficiency, destruction of tissues and releasing of toxins following the fungal infection (Rabindra and Ramanujam, 2007).

The effectiveness of the botanical pesticides as well as the microbial agents often falls behind chemical pesticides making them less preferred among growers (Vinodhini and Malaikozhundan, 2011; Bharani *et al*., 2015). A combination of plant derived compounds with microbials may improve the effectiveness of both provided the phytochemical does not substantially reduce the fungal growth and sporulation. Compatibility studies are essential before arriving at such combinations.

Steinhaus (1958) outlined the compatibility of pathogens and insecticides as one of the advantages of microbial pest control. The growth of fungi in presence of CNSL 0.2 % was assessed in PDA medium using disc diffusion technique with an intention of identifying a suitable combination. All fungal pathogens tested were found to grow in the presence of CNSL. Radial growth of 1.13, 1.7, 1.28 and 1.47 cm was observed with respect to *B. bassiana*, *M. anisopliae*, *L. lecanii* and *L. saksenae* respectively in the presence of CNSL as against 3.23, 4.7, 3.3 and 3.73 cm in control at 21 days after inoculation. Hassan (1989) devised a 1-4 scale scoring based on inhibition to ascertain the compatibility of entomopathogenic fungi and insecticides. The per cent growth inhibition noticed with respect to all the microbial agents tested in the present study fell in the score two. In Hassan's classification the score 2 causing growth inhibition of 50-79 per cent is categorized as slightly harmful. *L. lecanii*, the widely used myco insecticide which recorded only 61.21 per cent growth inhibition in presence of CNSL was thus concluded to be compatible with CNSL.

Though several authors studied the compatibility of insecticides and microbial agents (Amutha *et al.*, 2010; Rashid *et al.*, 2010), compatibility study of botanicals and microbial agents are scanty. However Rani (2001) has evaluated the compatibility of *Fusarium pallidoroseum* (Cooke) Sacc with commonly used botanicals and revealed that seed oil emulsions of neem highly inhibited the sporulating ability of the fungus.

The botanical, neem oil was reported to be non compatible with the microbial agent *B. bassiana* since it reduced the vegetative growth and conidiogenesis of the fungus due to the presence of azadirachtin (Depieri *et al.*, 2005).

L. lecanii was found to be inhibited by several insecticides *viz.*, dichlorvos, carbaryl, monocrotophos, malathion and endrin (Easwaramoorthy and Jayaraj, 1977), fenthion and phosphamidon (Easwaramoorthy *et al.*, 1978) at higher concentration of 0.1 % under *in-vitro* conditions. The slight inhibition in growth of microbial agents in the presence of cashew nut shell liquid may be due to the phenolic compounds present in it that may be inhibiting the growth of the fungus. The antifungal properties of CNSL against plant pathogens was reported by Garcia *et al.* (2017).

Field efficacy of selected botanical and microbial pesticides for the management of sucking pest complex in chilli was also studied. Botanical pesticides *viz*, CNSL 0.075, CNSL 0.2 %, neem oil 2 % and oxuron 5 mL L^{-1} and microbial agent *L. lecanii* @ 10^7 spores mL^{-1} and the combination of CNSL 0.2 % + *L. lecanii* @ 10^7 spores mL^{-1} found effective in laboratory evaluation were included as treatments along with thiamethoxam 0.015 % as the chemical check. The experiment was carried out in chilli variety Jwalamukhi raised in grow bags. Two rounds of treatments were applied first at vegetative phase (30 DAP) and the second at the reproductive phase (60 DAP).

After the first spraying in the vegetative phase, the population of chilli thrips (*S. dorsalis*) was found to be significantly lower in all the treatments at different intervals than the untreated check. The treatments CNSL 0.2 % + *L. lecanii* @ 10^7 spores mL^{-1}, *L. lecanii* @ 10^7 spores mL^{-1}, CNSL 0.2 %, CNSL 0.075 % were found to manage chilli thrips effectively upto five days after spraying. The thrips population was found to be low in the combination of CNSL 0.2 % + *L. lecanii* @ 10^7 spores mL^{-1} (0.001 thrips leaf $^{-1}$) which was on par with the treatments CNSL 0.075 %, CNSL 0.2 %, *L. lecanii* @ 10^7 spores mL^{-1} and the chemical check thiamethoxam 0015 % recording 0.04, 0.31, 0.34 and 0.12 thrips per leaf respectively at three DAT. Though a slight increase in population of thrips was observed from 7 DAT onwards in all treatments except chemical check, it remained significantly lower than the untreated check.

Significantly low population of chilli mites than control was also observed in all the treatments. The population of mites was the lowest in plants treated with thiamethoxam 0.015 % at all intervals. CNSL at both concentrations was found to effectively manage chilli mites upto five DAT.

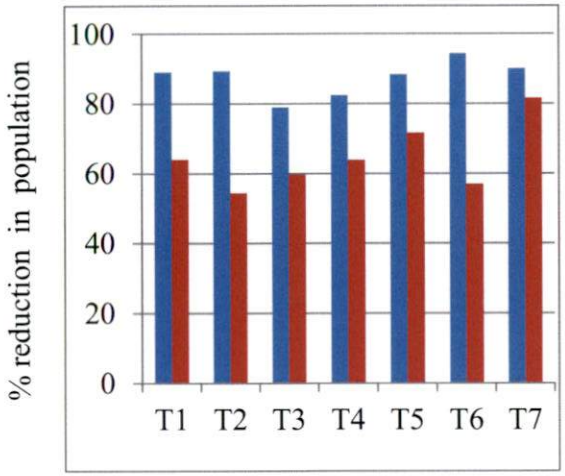
Percentage population reduction of thrips and mites in treatments over control are depicted in figure 1. 99.96, 88.87, 98.66 and 88.94 per cent reduction in thrips population over control was observed in treatments with CNSL 0.2 % + *L. lecanii* @ 10^7 spores mL^{-1}, *L. lecanii* @ 10^7 spores mL^{-1}, CNSL 0.075 % and CNSL 0.2 % respectively at three DAT. CNSL 0.075 % and CNSL 0.2 % reduced 85.61 and 72.58 per cent mite population over control at 3 DAT.

It can be concluded that combination treatment of CNSL 0.2 % + *L. lecanii* @ 10^7 spores mL^{-1} was effective in managing the population of sucking pests in the vegetative stage of the chilli crop. For the management of chilli thrips alone, CNSL 0.2 % + *L. lecanii* @ 10^7 spores mL^{-1}, *L. lecanii* @ 10^7 spores mL^{-1}, CNSL 0.2 %, CNSL 0.075 % were effective upto five days after spraying and were equally effective as chemical insecticide thiamethoxam 0.015 %. The CNSL at both concentrations was found to be effective in managing chilli mites. *L. lecanii* @ 10^7 spores mL^{-1} alone was not as effective as CNSL and its combination with *L. lecanii* @ 10^7 spores mL^{-1} against mites indicating that the mite control is mainly due to the effect of CNSL.

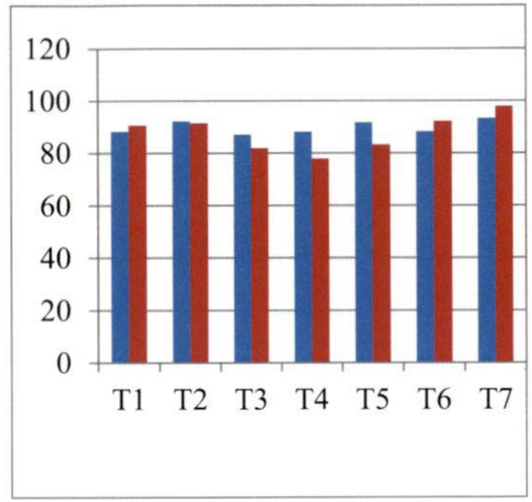
After second spraying in the reproductive phase also the chemical check thiamethoxam 0.015% was found superior to other treatments at different intervals. The treatments CNSL 0.2 % + *L. lecanii* @ 10^7 spores mL^{-1} and CNSL 0.2 % managed chilli thrips with 0.33 and 0.77 thrips $leaf^{-1}$ at 1 DAT on par with the chemical check. CNSL 0.2 % and *L. lecanii* @ 10^7 spores mL^{-1} had low thrips population of 0.27 and 0.4 thrips per leaf at 3 DAT which were also on par with the chemical check.

Thiamethoxam 0.015 % was found to effectively control chilli mites also in reproductive phase of the crop with 0.7, 0.63, 0.7 and 1.27 mite $leaf^{-1}$ at 1, 3, 5 and 7 DAT respectively. CNSL 0.075 % and CNSL 0.2 % were effective in managing chilli mites with 0.6 and 0.9 $leaf^{-1}$ respectively at first DAT and maintained their superiority at 3 DAT with 0.57 and 0.77 $leaf^{-1}$. Neem oil 2 % and

Fig. 1a: 1 DAT



1c: 5 DAT



T1 – CNSL 0.075 %

T2 – CNSL 0.2 %

T3 – Neem oil emulsion (2 %)

T4 – Oxuron (5 mL L^{-1})

T5 – *L. lecanii*@ 10^7 spores mL^{-1}

T6 – *L. lecanii*+ CNSL 0.2 %

T7 –Thiamethoxam (0.015 %)

Fig. 1b: 3 DAT

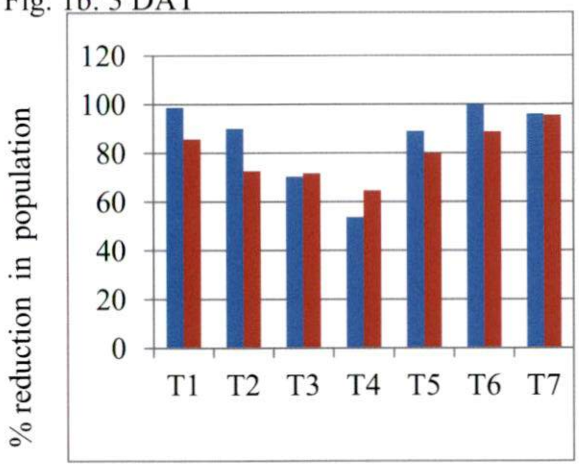


Fig. 1d: 7 DAT

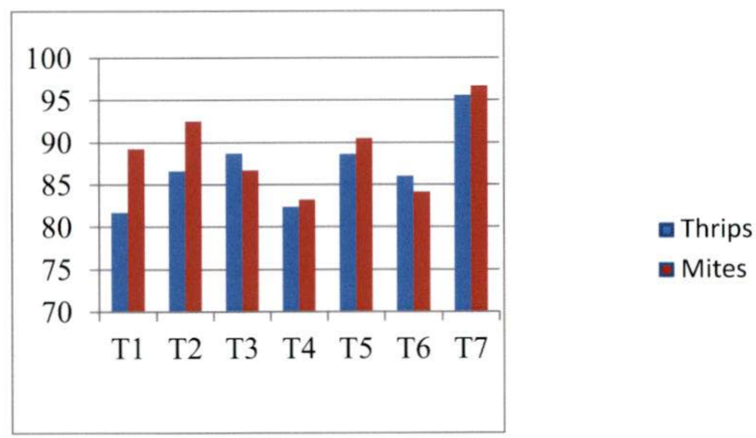


Fig. 1: Per cent reduction of population of thrips and mites over control at 30 DAP

oxuron 5 mL L^{-1} were found to be the next effective treatments against chilli mites.

More than 70 per cent reduction in population of thrips and more than 40 per cent reduction in population of mites over untreated check were observed in different treatments (Fig. 2). With respect to *S. dorsalis*, a per cent reduction of 94.04, 70.33 and 91.17 over control were observed in CNSL 0.2 % , CNSL 0.2 % + *L. lecanii* @ 10^7 spores mL^{-1} and *L. lecanii* @ 10^7 spores mL^{-1} respectively at 3 DAT. 77.15 and 83.09 per cent population reduction of mites in CNSL 0.075 % and CNSL 0.2 % respectively was also achieved at 3 DAT.

Thus it can be concluded that CNSL 0.2 % , CNSL 0.2 % + *L. lecanii* @ 10^7 spores mL^{-1} and *L. lecanii* @ 10^7 spores mL^{-1} are effective in reducing population of thrips and CNSL 0.075 % and CNSL 0.2 % are effective in managing population of mites in the reproductive phase. *L. lecanii* @ 10^7 spores mL^{-1} though found to be effectively manage both thrips and mites at 7 and 14 days, did not show promising result against chilli mites during the early period.

The feeding of sucking pests result in curling of chilli leaves. This damage in plants that received different treatments was quantified by working out the leaf curl index (LCI) as per the procedure of Niles (1980). Lowest LCI was recorded in the chemical check. Treatments with CNSL 0.075 %, *L. lecanii* @ 10^7 spores mL^{-1} were also effective in reducing the damage. Nagaraj *et al*. (2007) reported a minimum leaf curl index in plants treated with thiamethoxam 25 WG which is in confirmation with the present result obtained. Though neem oil was effectively reduced LCI at 70 DAP, it failed to retain the effect at 90 DAP indicating short lived control of pests. Chakraborty and Nath (2015) reported neem oil to be effective in reducing LCI.

The present study thus revealed the suitability of cashew nut shell liquid as a botanical pesticide for the management of sucking pest complex in chilli. CNSL 0.075 % and CNSL 0.2 % was found effective in managing both thrips and mites. CNSL was earlier reported to be effective against termites (Asogwa *et al*., 2007)

Fig. 2a: 1 DAT

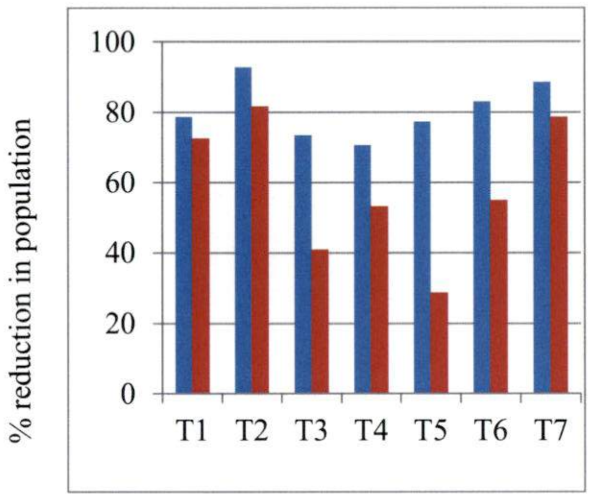
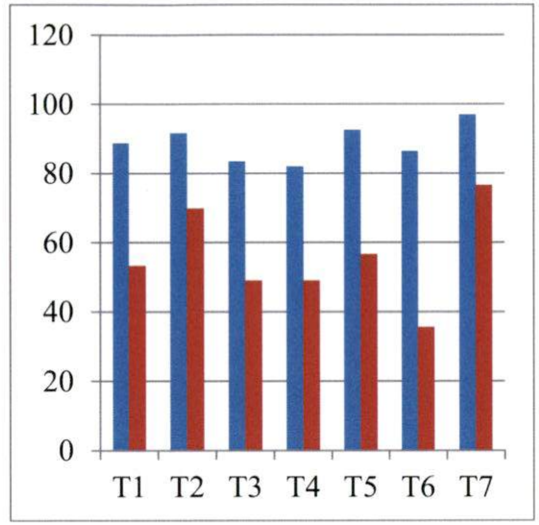


Fig. 2c: 5 DAT



T1 – CNSL 0.075 %

T2 – CNSL 0.2 %

T3 – Neem oil emulsion (2 %)

T4 – Oxuron (5 mL L^{-1})

T5 – *L. lecanii*@ 10^7 spores mL^{-1}

T6 – *L. lecanii*+ CNSL 0.2 %

T7 –Thiamethoxam (0.015 %)

Fig. 2b: 3 DAT

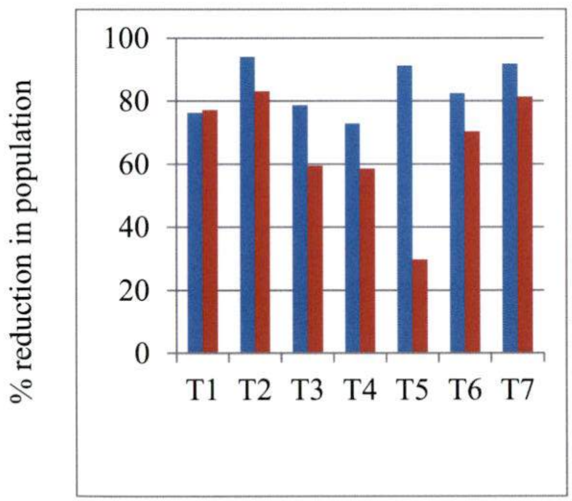
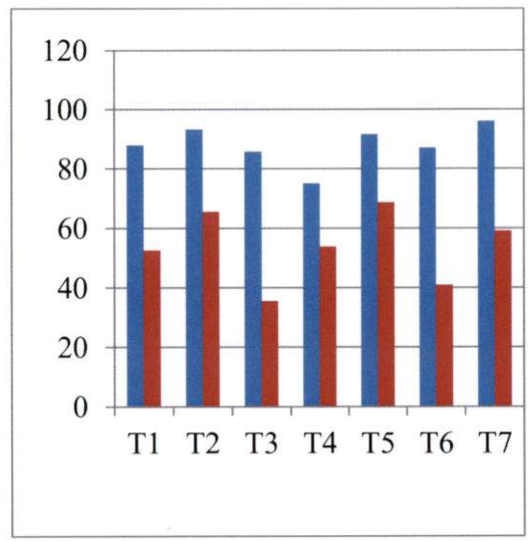


Fig. 2d: 7 DAT



Thrips
Mites

Fig. 1: Per cent reduction of population of thrips and mites over control at 60 DAP

and root grubs (John *et al.*, 2008) but the concentration required was on a higher range 5-25 %. The subterranean nature of these pests requisites application at higher concentration. Against *H. armigera*, a lower concentration of 1 % was reported to cause 75 % mortality (Mahapatro, 2011).

Against soft bodied sucking pests of chilli CNSL was found to be effective at a much lesser concentration. Though the efficacy of cashew nut shell liquid against another sucking pest cowpea aphid (*A. craccivora)* were reported earlier the concentration evaluated in field was 1 % (Olotuah and Ofuya, 2010).

The combination treatment CNSL 0.2 % + *L. lecanii* @ 10^7 spores mL^{-1}, though managed the thrips population was not that effective against mites. There are reports (Shirish, 2010) indicating effectiveness of *L. lecanii* against *S. dorsalis*. CNSL 0.075 %, CNSL 0.2 %, *L. lecanii* were found effective in controlling chilli thrips (Lokesh, 2014). No synergistic effect against sucking pests of chilli was noticed when CNSL was combined with *L. lecanii* in the present study.

This is in contrast to the previous reports indicating synergistic effect between entomopathogens and pesticides (Islam *et al.,* 2010). Fungicidal effect of CNSL has been documented against *Colletotrichum gloeosporioides* and *Lasiodiplodia theobromae* (Garcia *et al.,* 2017). In the disc diffusion assay in PDA plates also, inhibition of *L. lecanii* (61.21 %) in presence of CNSL was observed.

Among the other botanical agents tried, neem oil 2 % gave better control of sucking pests of chilli in the field though inferior to chemical treatment thiamethoxam 0.015 %. The efficacy of neem in controlling pests were reported by several authors on mites (Venzon *et al.*, 2008), aphids (Ghosh *et al*., 2009) and thrips (Meena and Tayde, 2017).

In the field evaluation *L. lecanii* @ 10^7 spores mL^{-1} was also found to reduce population as well as damage by the sucking pests. *L. lecanii* could also be selected as an eco-friendly management measure of sucking pests owing to its environmental safety as well as proven track record against sucking pests (Rabindra and Ramanujam, 2007).

In the present study, the chemical check thiamethoxam 0.015 % stood superior in controlling sucking pests of chilli than botanical and microbial agents. Thiamethoxam, a neonicotinoid with systemic action is found to have a broad spectrum of activity against many insects. Nagaraj *et al.* (2007) found thiamethoxam effective against *S. dorsalis*. The mean thrips population (2.95 thrips $leaf^{-1}$) and leaf curl index (1.66) observed in his study was less in thiamethoxam 25 WG treatment than in control (8.85 thrips $leaf^{-1}$). Neonicotinoids including thiamethoxam interact with nAChR in a structure–activity relationship, resulting in excitation and paralysis leading to quick death of insects (Ishaaya *et al.*, 2007) and hence are more effective than botanical and microbial pesticides.

In addition to pest management the control tactics should also improve growth and yield attributes of the crop. The treatment effect on yield was not significant in the present study. It may be due to the high population of the sucking pests purposefully maintained in the initial crop phase that might have hindered the plants from expressing the effect of treatments in the later phase of the crop. Plant damage level of more than 50 per cent curled shoots by sucking pest infestation leads to growth inhibition resulting in a significant yield loss (Vichitbandha and Chandrapatya, 2011).

From the fig. 3 and 4, it is clear that the chemical treated plants resulted in significantly improved plant growth parameters *viz.*, plant height, number of leaves, shoot and root fresh weight compared to other treatments which implies the efficacy of this treatment in reducing growth retardation by sucking pest infestation. The reduction in leaf damage by *S. dorsalis* by application of thiamethoxam was reported by Ghosh *et al.* (2009).

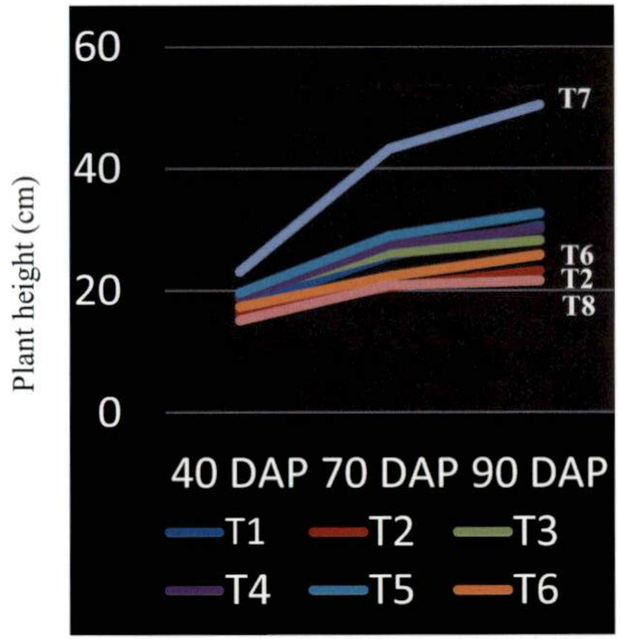


Fig. 3a: Effect of treatments on plant height

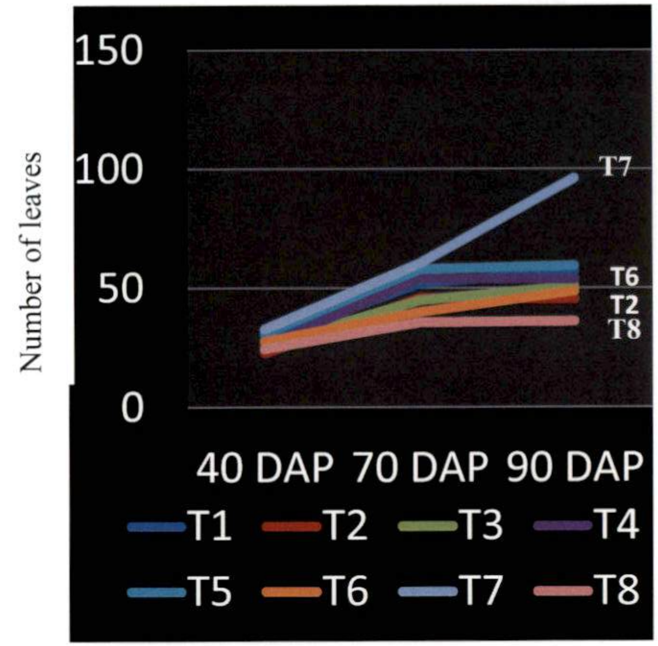
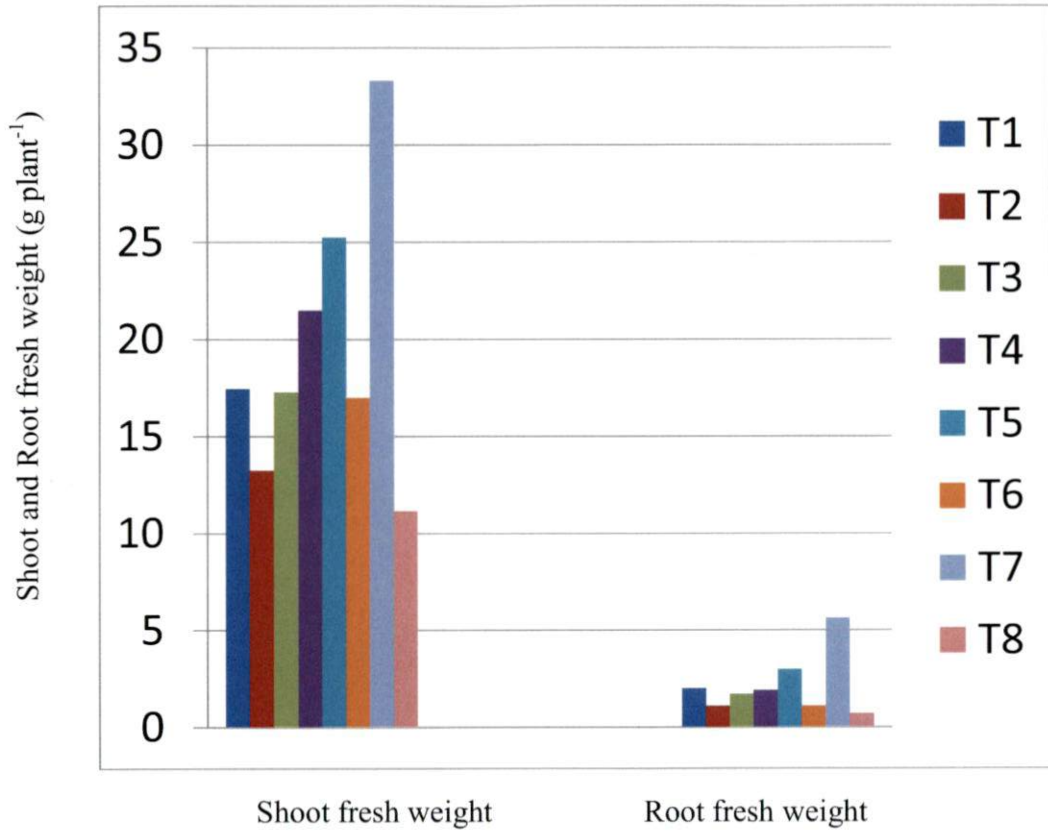


Fig. 3b: Effect of treatments on number of leaves

T1 – CNSL 0.075 %; T2 – CNSL 0.2 %; T3 – Neem oil emulsion (2 %); T4 – Oxuron (5 mL L^{-1}); T5 – *L. lecanii*@ 10^7 spores mL^{-1}; T6 – *L. lecanii*+ CNSL 0.2 %; T7 –Thiamethoxam (0.015 %)

Fig. 3: Effect of treatments on plant height and number of leaves



T1 – CNSL 0.075 %; T2 – CNSL 0.2 %; T3 – Neem oil emulsion (2 %); T4 – Oxuron (5 mL L^{-1}); T5 – *L. lecanii*@ 10^7 spores mL^{-1}; T6 – *L. lecanii*+ CNSL 0.2 %; T7 –Thiamethoxam (0.015 %)

Fig. 4: Effect of treatments on shoot fresh weight and root dry weight

Among the botanical and microbial agents that exhibited superior control of sucking pests, CNSL at higher concentration of 0.2 % as well as its combination treatment with *L. lecanii* did not significantly improve the plant growth parameters *viz*., plant height, number of leaves, internodal length, basal girth, shoot fresh and dry weight, root fresh and dry weight over untreated check. Thus despite significant pest control CNSL 0.2 % is exhibiting some growth retarding effect on chilli. Technical CNSL is rich in phenolic compounds, cardanol (52 %) and cardol (10 %) (Venmalar and Nagaveni, 2005). These phenolic compounds at higher concentration may be the factor responsible for the growth retardation effect.

Exogenously applied phenolic compounds, p-coumaric acid, P-hydroxybenzoic acid at 1.0 mM concentration were reported to inhibit growth of clover and sorghum (Fries *et al*., 1997). Allelopathic effect of root and bark extracts of *Anacardium occidentale* on growth of maize and cucumber seedlings was also reported (Noorfatiehah *et al*., 2011). Also the negative affect of cashew nut shell liquid on the germination and vigor of lettuce and tomato was reported by Matias *et al*. (2017).

CNSL 0.075 % and *L. lecanii* @ 10^7 spores mL^{-1}, the other treatments which were effective against sucking pests significantly improved growth attributes *viz*., plant height, number of leaves, internodal length, root length over untreated check. This confirms that the plant growth retarding effect of CNSL is dose dependant. Li *et al*. (2010) observed concentration dependant allelopathic properties of the isolated phenolic compounds such as chlorogenic, gallic, *p*-hydroxybenzoic, protocatechuic, caffeic, 3, 5- dinitrozenzoic acids and 3, 4- dihydroxybenzaldehyde on lettuce.

According to Kefeli and Kutacek (1977), the growth inhibitory action of phenols may be due to the depression of IAA biosynthesis, lowering growth stimulating activity of IAA, gibberellins and cytokinins or by interaction of the quinine forms of phenols with proteins and the resultant inhibition of any plant growth hormone.

Thus the results of the study indicated the suitability of CNSL 0.2 % , CNSL 0.075 % and the combination treatment of CNSL 0.2 % + *L. lecanii* @ 10^7 spores mL^{-1} in sucking pest complex management in chilli. However since CNSL 0.2 % did not improve the plant growth parameters over untreated check, CNSL 0.075 % and *L. lecanii* @ 10^7 spores mL^{-1} which reduced pest population and damage without any negative influence on growth are better choices for eco-friendly management of sucking pest complex of chilli.

SUMMARY

6. SUMMARY

Over the years, insect attack has been found as one among the major biotic constraints of vegetable production across the world. Chilli (*Capsicum annuum* L.) is one of the versatile spice and vegetable crop grown in India. Sucking pest complex comprising of thrips, aphids and mites are one of the major constraints in chilli production. Indiscriminate use of chemical pesticides resorted by the growers to tackle this menace is having serious economical and ecological consequences warranting development of alternate eco-friendly pest management tactics.

Plant derived secondary metabolites as well as naturally occurring insect pathogens play a vital role in minimizing insect damage on crop plants. Cashew nut shell liquid (CNSL), a cheap by-product of cashew industry is a potential insecticide of plant origin. Broad spectrum entomopathogens, *Beauveria bassiana, Metarhizium anisopliae, Lecanicillium lecanii* are natural population regulation factors. The present study entitled "Management of sucking pest complex in chilli using botanical and microbial pesticides" was conducted during the period 2016-2018, in the Department of Agricultural Entomology, College of Agriculture, Vellayani with an objective to evaluate these potential botanical and microbial pesticides against sucking pest complex comprising of thrips (*S. dorsalis*), aphids (*A. gossypii*) and mites (*P. latus*) chilli.

The efficacy of four botanical pesticides *viz.*, cashew nut shell liquid (CNSL) at different concentrations (0.025, 0.5, 0.075, 0.1 and 0.2 %), neem seed kernel extract (NSKE) 5 %, neem oil 2 % and the commercial botanical product oxuron 5 mL L^{-1}, and four microbial agents *viz.*, *B. bassiana*, *M. anisopliae*, *L. lecanii* and *L. saksenae* were evaluated taking chilli aphid (*A. gossypii*) as test insect under laboratory conditions. Thiamethoxam 0.015 % served as chemical check.

Among the various botanical pesticides evaluated, significantly high mortality of aphids was observed in chemical check thiamethoxam 0.015 %,

CNSL 0.2 % and neem oil 2 % with 66.67, 64 and 58 per cent respectively at 24 hours after treatment (HAT). At 48 HAT, CNSL 0.2 %, CNSL 0.075 %, thiamethoxam 0.015 %, CNSL 0.1 % and oxuron 5 mL L^{-1} showed superiority over other treatments with per cent mortality of 92.67, 88.67, 86.67, 86 and 85.33 respectively. Though the treatments did not vary significantly at 72 HAT, cent per cent mortality was observed in thiamethoxam 0.015 %, oxuron 5 mL L^{-1}, CNSL 0.2 % and CNSL 0.1 %.

All microbial agents evaluated *viz*., *B. bassiana*, *M. anisopliae*, *L. lecanii* and *L. saksenae* were found to infect *A. gossypii,* among which *L. lecanii* and *L. saksenae* @ 10^7spores mL^{-1} produced significantly high mortality on par with the chemical check. *L. lecanii* @ 10^7 spores mL^{-1} caused in 54.5, 87.5, 100 per cent and *L. saksenae* @ 10^7 spores mL^{-1} 55, 85.5 and 100 per cent mortality of aphids at 24, 48 and 72 HAT respectively.

The *in vitro* assessment of growth of microbial agents, *B. bassiana, M. anisopliae, L. lecanii* and *L. saksenae* in the presence of CNSL 0.2 % revealed growth inhibition of 65.01, 63.8, 61.21 and 60.58 per cent respectively over control after 21 days of incubation. As per Hassan's classification scheme (Hassan, 1989), inhibition percentage of 50 to 79 falls under the category slightly inhibitory (score 2) indicating compatible nature.

A pot culture experiment was carried out in chilli variety Jwalamukhi with effective botanical pesticides (CNSL 0.075 %, CNSL 0.2 %, neem oil 2 %, oxuron 5 mL L^{-1}) selected based on laboratory evaluation along with *L. lecanii* @ 10^7 spores mL^{-1} and a combination treatment (CNSL 0.2 % + *L. lecanii* @ 10^7 spores mL^{-1}) to assess the field efficiency against sucking pest complex. Thiamethoxam 0.015 % served as chemical check.

After the first round of application of treatments in the vegetative stage, per cent reduction in thrips population of 99.96, 88.87, 98.66, 88.94 over control was observed in CNSL 0.2 % + *L. lecanii* @ 10^7 spores mL^{-1}, *L. lecanii* @ 10^7 spores mL^{-1}, CNSL 0.075 % and CNSL 0.2 % respectively at 3 DAT. Upto five days after spraying these treatments were equally effective as chemical insecticide thiamethoxam 0.015 %. The mite population was found to be least in the treatments CNSL 0.2 % and CNSL 0.075 % which did not vary significantly with the combination of CNSL 0.2 % + *L. lecanii* @ 10^7 spores mL^{-1} at 3 and 5 DAT. It was observed that *L. lecanii* @ 10^7 spores mL^{-1} alone was not as effective as CNSL and its combination with *L. lecanii* against mites indicating that the mite control is mainly due to the effect of CNSL.

CNSL 0.2 %, *L. lecanii* @ 10^7 spores mL^{-1} and the combination of CNSL 0.2 % + *L. lecanii* @ 10^7 spores mL^{-1} were found to be superior in managing chilli thrips and as effective as chemical check thiamethoxam 0.015 % in the reproductive phase. CNSL 0.2 % and *L. lecanii* @ 10^7 spores mL^{-1} had low thrips population of 0.27 and 0.4 thrips $leaf^{-1}$ at 3 DAT which were on par with the chemical check. The mites were controlled effectively by both CNSL 0.2 % and CNSL 0.075 % upto 3 DAT. CNSL 0.2 % gave control upto 7 DAT with 1.07 mites $leaf^{-1}$ as against 3.1 mites $leaf^{-1}$ in control. Neem oil 2 % and oxuron 5 mL L^{-1} were found to be the next effective treatments against chilli mites. *L. lecanii* @ 10^7 spores mL^{-1} though found to be effective in managing both thrips and mites at 7 and 14 days, did not show promising result against chilli mites during the early period.

CNSL 0.075 %, CNSL 0.2%, combination of CNSL 0.2 % + *L. lecanii* @ 10^7 spores mL^{-1} and neem oil 2 % substantially reduced damage by sucking pests as evidenced by lesser value of leaf curl index at 70 days after planting. *L. lecanii* @ 10^7 spores mL^{-1} was also found to reduce the leaf curl index (1.67) though inferior to the above treatments.

The highest yield of 210.84 g $plant^{-1}$ was obtained in thiamethoxam 0.015 % treated plants but there was no significant difference between the treatments. Other biometric characters including plant height, number of leaves, internodal length, number of branches, basal girth, root length, shoot fresh weight, shoot dry weight, root fresh weight and root dry weight of the plants treated with thiamethoxam 0.015 % showed significant improvement over untreated check whereas these characters in CNSL (0.2 %) applied plants did not show significant improvement over control implicating growth retarding effect of CNSL at the higher concentration. CNSL 0.075 % as well as *L. lecanii* @ 10^7 spores mL^{-1} treated plants exhibited significant improvement in growth attributes *viz.*, plant height, number of leaves, internodal length, root length though inferior to chemical check.

CNSL 0.2 %, CNSL 0.075 % and the combination treatment of CNSL 0.2 % + *L. lecanii* @ 10^7 spores mL^{-1} were found effective in managing the population of sucking pest complex in the present study. However since CNSL 0.2 % did not substantially improve the plant growth parameters over untreated check, CNSL 0.075 % and *L. lecanii* @ 10^7 spores mL^{-1} which reduced pest population and damage without any negative influence on growth are better choices for eco-friendly management of sucking pest complex of chilli.

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MANAGEMENT OF SUCKING PEST COMPLEX IN CHILLI USING BOTANICAL AND MICROBIAL PESTICIDES

by

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Abstract of the thesis

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ABSTRACT

The study entitled "Management of sucking pest complex in chilli using botanical and microbial pesticides" was conducted during 2016-2018, in the Department of Agricultural Entomology, College of Agriculture, Vellayani with an objective to manage the sucking pest complex of thrips (*Scirtothrips dorsalis* Hood), aphids (*Aphis gossypii* Glover) and mites (*Polyphagotarsonemus latus* Banks) in chilli using botanical and microbial pesticides.

Laboratory evaluation of the botanical and microbial agents was done taking aphid (*A. gossypii*) as test insect. Cashew nut shell liquid (CNSL), a potential insecticide and a cheap by-product of cashew industry containing a mixture of phenolic compounds was evaluated as emulsions at different concentrations (0.025, 0.05, 0.075, 0.1 and 0.2 %) along with Neem Seed Kernel Extract (NSKE) emulsion 5 %, neem oil emulsion 2 % and commercial botanical pesticide oxuron 5 mL L^{-1}. Thiamethoxam 0.015 % served as chemical check.

CNSL 0.2 % and neem oil 2 % caused significantly high mortality of 64 and 58 per cent respectively at 24 hours after treatment (HAT) and was on par with chemical check thiamethoxam 0.015 %. At 48 HAT, CNSL 0.075, 0.1 and 0.2 % with per cent mortality 88.67, 86 and 92.67, respectively was found to be as effective as oxuron 5 mL L^{-1} and thiamethoxam 0.015 % and significantly superior over other treatments. At 72 HAT, thiamethoxam 0.015 %, oxuron 5 mL L^{-1}, CNSL 0.2 % and CNSL 0.1 % showed 100 per cent mortality which did not vary significantly from the other treatments *viz.,* CNSL 0.075 %, CNSL 0.05 %, CNSL 0.025 %, neem oil 2 % and NSKE 5 % with 99.33, 98.67, 98, 98 and 97.33 per cent mortality respectively. Based on the results of the laboratory evaluation, CNSL 0.2 % which was found superior at different intervals and CNSL 0.075 % the lowest effective concentration were selected for further evaluation.

All the microbial agents evaluated *viz.*, *Beauveria bassiana*, *Metarhizium anisopliae*, *Lecanicillium lecanii* and *Lecanicillium saksenae* were found to infect

A. gossypii, among which *L. lecanii* and *L. saksenae* @ 10^7 spores mL^{-1} were significantly superior. *L. lecanii* @ 10^7 spores mL^{-1} caused in 54.5, 87.5, 100 per cent and *L. saksenae* @ 10^7 spores mL^{-1} 55, 85.5 and 100 per cent mortality of aphids at 24, 48 and 72 HAT respectively.

CNSL was found to be compatible with all microbial agents tested as per Hassan's classification scheme showing 60-65 per cent growth inhibition in disc diffusion assay in Potato dextrose agar plates.

A pot culture experiment was carried out in chilli variety Jwalamukhi with effective botanical pesticides (CNSL 0.075 %, CNSL 0.2 %, neem oil 2 %, oxuron 5 mL L^{-1}) selected based on laboratory evaluation along with *L. lecanii* @ 10^7 spores mL^{-1} and a combination treatment (CNSL 0.2 % + *L. lecanii* @ 10^7 spores mL^{-1}) to assess the field efficiency against sucking pest complex. Thiamethoxam 0.015 % served as chemical check. Two rounds of application one each at vegetative (30 days after planting) and reproductive phase (60 days after planting) of the crop were administered.

In the vegetative stage, 99.96, 88.87, 98.66, 88.94 per cent reduction in thrips population over control was observed in treatments with CNSL 0.2 % + *L. lecanii* @ 10^7 spores mL^{-1}, *L. lecanii* @ 10^7 spores mL^{-1}, CNSL 0.075 % and CNSL 0.2 % respectively at 3 DAT. The mite population was found to be least in the treatments CNSL 0.2 % (0.32 mites $leaf^{-1}$ at 5 DAT) and CNSL 0.075 % (0.53 and 0.35 mites $leaf^{-1}$ on 3 and 5 DAT) which did not vary significantly with the combination of CNSL 0.2 % + *L. lecanii* @ 10^7 spores mL^{-1} with 0.42 and 0.29 mites $leaf^{-1}$ on 3 and 5 DAT respectively. The population of mites was significantly lower (0.15 $leaf^{-1}$) in chemical check than all other treatments at seven days after treatment followed by CNSL 0.2% and *L. lecanii* @ 10^7 spores mL^{-1} recording mite population of 0.34 and 0.43 $leaf^{-1}$ respectively.

CNSL 0.2 %, *L. lecanii* @ 10^7 spores mL^{-1} and the combination treatment were found to be superior in managing chilli thrips and as effective as chemical check thiamethoxam 0.015 % in the reproductive phase. These treatments recorded low population (1.27, 1.23 and 1.23 thrips leaf^{-1} respectively) at 14 DAT as against 4.5 thrips leaf^{-1} in control. The mites were controlled effectively by both CNSL 0.2 % and CNSL 0.075 % upto 3 DAT. The botanical CNSL 0.2 % gave control upto 7 DAT with 1.07 mites leaf^{-1} as against 3.1 mites leaf^{-1} in control. Neem oil 2 % and oxuron 5 mL L^{-1} were found to be the next effective treatments against chilli mites.

Reduced leaf curl, on par with chemical check was observed in treatments CNSL 0.075 %, CNSL 0.2%, combination of CNSL 0.2 % + *L. lecanii* @ 10^7 spores mL^{-1} and neem oil 2 % as evidenced by lesser value of leaf curl index, an indicator of damage by sucking pest complex (1, 1.33, 1.33 and 1.33 respectively), at 70 days after planting. The corresponding index in the control during the same period was 3.0. *L. lecanii* @ 10^7 spores mL^{-1} was also found to reduce the leaf curl index (1.67) though inferior to the above treatments.

CNSL at the higher concentration of 0.2 % though found effective in managing the population of thrips and mites, did not show improved plant growth characters indicating possible growth retarding effect as evidenced by inferior growth attributes in comparison with chemical check. Significantly low plant height (23.2 cm), number of leaves (45.33), shoot fresh weight (13.25 g plant^{-1}) and shoot dry weight (1.05 g plant^{-1}) were observed in comparison to chemical check. *L. lecanii* @ 10^7 spores mL^{-1} and CNSL 0.075 % treated plants showed better growth characters than those treated with CNSL 0.2 %.

The results of the study indicated the suitability of CNSL 0.2 %, CNSL 0.075 % and the combination treatment of CNSL 0.2 % + *L. lecanii* @ 10^7 spores mL^{-1} in sucking pest complex management. Thus considering the effectiveness in managing the sucking pests and their effect on plant growth attributes, CNSL 0.075 % and *L. lecanii* @ 10^7 spores mL^{-1} are better choices for eco-friendly management of sucking pest complex of chilli.