CASHEW NUT SHELL LIQUID (CNSL) FORMULATION FOR THE MANAGEMENT OF BANANA PSEUDOSTEM WEEVIL, *Odoiporus longicollis* (Olivier)

ARCHA S NAIR

(2018-11-030)

DEPARTMENT OF AGRICULTURAL ENTOMOLOGY

COLLEGE OF AGRICULTURE

VELLAYANI, THIRUVANANTHAPURAM

KERALA, INDIA

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by

ARCHA S NAIR

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VELLAYANI, THIRUVANANTHAPURAM – 695 522

KERALA, INDIA

2020

DECLARATION

I, hereby declare that this thesis entitled **"CASHEW NUT SHELL LIQUID (CNSL) FORMULATION FOR THE MANAGEMENT OF BANANA PSEUDOSTEM WEEVIL, *Odoiporus longicollis* (Olivier)"** 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.

Vellayani **ARCHA S NAIR**

Date: (2018-11-030)

CERTIFICATE

Certified that this thesis entitled **"CASHEW NUT SHELL LIQUID (CNSL) FORMULATION FOR THE MANAGEMENT OF BANANA PSEUDOSTEM WEEVIL, *Odoiporus longicollis* (Olivier)"** is a record of research work done independently by **Ms. Archa S Nair (2018-11-030)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

Vellayani

Date: 03.09.2020

Dr. M. H. Faizal
(Major Advisor, Advisory committee)
Professor
Department of Agricultural Entomology
College of Agriculture, Vellayani

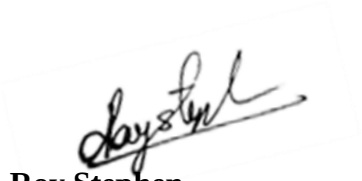
CERTIFICATE

We, the undersigned members of the advisory committee of **Ms. Archa S Nair (2018-11-030)**, a candidate for the degree of **Master of Science in Agriculture** with major in **Agricultural Entomology**, agree that the thesis entitled **"CASHEW NUT SHELL LIQUID (CNSL) FORMULATION FOR THE MANAGEMENT OF BANANA PSEUDOSTEM WEEVIL, *Odoiporus longicollis* (Olivier)"** may be submitted by **Ms. Archa S Nair** (2018-11-030), in partial fulfilment of the requirements for the degree.

Dr. M. H. Faizal
(Major Advisor, Advisory Committee)
Professor
Department of Agricultural Entomology
College of Agriculture,
Vellayani

Dr. N. Anitha
(Member, Advisory Committee)
Professor and Head
Department of Agricultural Entomology
College of Agriculture,
Vellayani

Dr. Ambily Paul
(Member, Advisory Committee)
Assistant Professor
AINP on Pest Residues
Department of Agricultural Entomology
College of Agriculture,
Vellayani



Dr. Roy Stephen
(Member, Advisory Committee)
Professor
Department of Plant Physiology
College of Agriculture,
Vellayani

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Archa S Nair

Dedicated to,

Lord Shiva

&

Achan, Amma, Ananthu and Ettan

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LIST OF ABBREVATIONS

@	-	at the rate of
˚C	-	degree Celsius
ANOVA	-	Analysis Of Variance
BC ratio/ BC	-	Benefit Cost
BPW	-	Banana Pseudostem Weevil
cm	-	centimetre
CNSL	-	Cashew Nut Shell Liquid
DPPQS	-	Directorate of Plant Protection, Quarantine and Storage
EC	-	Emulsifiable Concentrate
EPF	-	Entomopathogenic Fungi
EPN	-	Entomopathogenic Nematode
et al.	-	et alii (Latin) and others
FAO	-	Food and Agriculture Organization
FIB	-	Farm Information Bureau
g	-	gram
ha	-	hectare
h	-	hours
KAU	-	Kerala Agricultural University
KVK	-	Krishi Vigyan Kendra
L	-	Litre
LAF	-	Leaf Axil Filling

LC_{50}	-	Lethal Concentration
mL	-	millilitre
mm	-	millimetre
O. longicollis	-	*Odoiporus longicollis*
ppm	-	parts per million
SI	-	Stem Injection
spp.	-	species
viz.	-	videlicet (Latin) and namely
WG	-	Water Dispersible Granule
WP	-	Wettable Powder

1. INTRODUCTION

Banana, the world's favourite fruit is the fourth most important food crop after wheat, rice and maize in terms of production and consumption (Aurore *et al*., 2009). Banana, *Musa spp*. is cultivated in 5.6 million hectares globally in various production systems ranging from very small kitchen gardens to extensive commercial plantations. India is the largest producer of banana in the world with an annual production of 308.08 lakh tonnes from an area of 8.84 lakh hectares (FAO, 2017). In Kerala, 34.65 per cent of area under fresh fruits is occupied by banana which covers an area of 57,158 ha (FIB, 2019). The high productivity coupled with almost steady demand and fair market price make banana the most cultivated fruit crop of the state.

One of the major constraints limiting banana production and productivity is the simultaneous attack by various insect pests, of which banana pseudostem weevil (BPW) or pseudostem borer, *Odoiporus longicollis* Olivier is the major one (Dutt and Maiti, 1972). This pest, reported from Kerala in 1989 (Visalakshi *et al.*, 1989), have since then actively spread to all parts of the state causing severe yield loss extending up to 90 per cent depending upon the growth stage of the crop and severity of infestation (Padmanaban and Sathiamoorthy, 2001).

O. longicollis is a monophagous pest of banana, the grubs of which cause severe damage to the crop. Adult weevils make holes with rostrum and lay eggs in the air chamber of outer leaf sheaths of banana pseudostem. The early instars, on hatching, feed within the air chambers causing small pin sized holes on the pseudostem with gummy exudation. These symptoms often go unnoticed, making the early detection of infestation difficult. The late instars, being more active, extensively tunnel the pseudostem and feed voraciously resulting in ultimately toppling down of plants bearing immature bunches leading to complete crop loss. Pupation also takes place inside the pseudostem within cocoon woven out of banana fibre threads.

Control of the weevils is an elusive and complex problem as the life cycle of the pest is completed within the plant. An integrated management strategy

incorporating prophylactic and curative methods is practiced to tackle this pest living in a secluded habitat. Though prophylactic, mechanical and cultural measures are recommended, application of chemical pesticides becomes inevitable once the infestation progresses. The current strategy of tackling this pest with chemical pesticides cause threat to non target organisms including human beings, besides contaminating the environment, necessitating development of alternatives. Moreover, since many insecticides have been banned addressing the toxicology effects, diversion to eco-friendly and sustainable options like use of botanicals needs to be explored.

Plants produce, store and exude a variety of phyto chemicals to defend herbivores, of which many were identified and developed as botanical pesticides. Leaf extract of *Vitex negundo* L., seed extract of *Terminalia chebula* Retz. and rhizome extract of *Acoras calamus* L. were found to cause mortality of *O. longicollis* and were employed for weevil control (Padmanaban and Sathiamoorthy, 2004). Azadiractin formulation, Neem Azal (1% EC) @ 0.5% when used against BPW recorded lowest per cent of attack by weevil with highest bunch weight and good BC ratio (KAU, 2011a). A 5% solution of cassava leaf distillate, 'Nanma' and the cyanogen containing product, 'Menma' developed from cassava leaves were reported to be effective against BPW with a positive correlation between concentration of cyanogen content and mortality of larvae (Krishnan *et al.,* 2015). Exploiting more of such plant based biopesticides is still in its nascent stage.

Cashew Nut Shell Liquid (CNSL), containing plant derived phenolic constituents, is an important by-product of cashew processing industry, available in plenty at cheap rate. Its pesticidal potential has been proved against coconut root grub, *Leucopholis coneophora* Blanchard (John *et al.,* 2008), *Helicoverpa armigera* (Hubner) (Mahapatro, 2011) and *Aphis gossypii* Glov. (Sundaran and Faizal, 2018). An emulsifiable concentrate formulation of CNSL (20%) has been developed in the Department of Agricultural Entomology, College of Agriculture, Vellayani and found effective in managing pests of cowpea (Lekha, 2020). The present project, "Cashew Nut Shell Liquid (CNSL) formulation for the management of banana pseudostem weevil, *O. longicollis* (Olivier)", is undertaken to investigate the utility of this formulation for the management of BPW with the following objectives:

- To find out dose of CNSL effective against BPW through laboratory bio assay.
- To evaluate the repellent effect of CNSL, if any on adult weevils.
- To utilize the CNSL 20% EC at effective doses for the curative management of BPW.

2. REVIEW OF LITERATURE

Banana, known as ‘apple of paradise’, is one of the most important fruit crops of the world. It is the fifth largest commodity in the world after cereals, sugar, coffee and cocoa. Availability round the year and hunger satisfying attribute creates a universal demand for the fruit (Sakamma *et al*., 2018).

India is the largest producer of banana in the world contributing 23 per cent of the world pool production from about 11 per cent of total global area under the crop (FAO, 2017).

Even though the diversification in cultivation practices have tremendously increased the production and demand of the fruit, a number of vagaries including high incidence of pests and diseases curtail both production and productivity of banana. Infestation by banana stem weevil, *O. longicollis* perpetrates hefty crop loss to a tune of 10 to 90 per cent, depending on the intensity of ravage and management efficiency (Prasuna *et al*., 2008). Owing to the restricted feeding habit and monophagy, they prove to be a great menace evading control. The bionomics and management practises are reviewed here in. The pesticidal potential of Cashew Nut Shell Liquid (CNSL) is also reviewed.

2.1 BANANA PSEUDOSTEM WEEVIL

2.1.1 Taxonomy and Distribution

In the textbook of Indian Insect Life, Lefroy mentioned *O. longicollis* as a pest of plantain (Lefroy, 1909). This was perhaps the ancient history marking the occurrence of the weevil in India. Taxonomically the weevil belongs to Class Insecta of Phylum Arthropoda, Order Coleoptera and Family Dryophthoridae (Arun, 2016). The banana stem weevil, *O. longicollis* (Coleoptera: Curculionidae) is one of the most destructive pests that is widely distributed all over the world, particularly in tropical and subtropical countries (Alagesan *et al.,* 2019).

Visalakshi *et al.* (1989) elucidated its occurrence in Kerala for the first time at Vengola, Ernakulam. The destructive pest is found to be causing wide spread damage in the banana growing tracts of Ernakulam and Thrissur districts of Kerala (Jayasree, 1992). This key pest to banana and plantains, posing serious threats to banana production, is found in India, China, Malaysia, Indonesia and Thailand (Valmayor *et al.*, 1994). The pest was found to have spread all over India and was reported infesting banana in Delhi, Bihar, Gujarat, Uttar Pradesh, West Bengal, Manipur, Karnataka and Tamil Nadu (Padmanaban and Sundararaju 1999; Awasthi *et al.*, 2016).

Survey conducted by Anitha (2000) remarked notable infestation by the pest in South India. Sivakumar *et al.* (2014) reported the infestation on the leaf petiole at Konny, Pathanamthitta. Occurrence of banana pseudostem borer colourmorph on banana cultivar Nendran and Palayankodan from Kollam, Anchal, Konny, Kottarakkara and Vellayani were reported by Sivakumar and Jiji (2016). Arun (2016) could also collect weevil from the five agroclimatic regions namely Northern Zone, High range, Central Zone, Problem zone and Southern Zone as well as the forest ecosystems of Kerala. He could observe wide variations in the three groups of *O. longicollis* which require detailed studies. Singh *et al.* (2018) were able to collect the weevil from seven different agroecological regions of Kerala.

2.1.2 Bioecology

The life cycle is holometabolus having four life stages, *viz.* egg, larva, pupa and adult. The newly emerged ones appear brown in colour and later turn black (Anitha, 2000). The fully grown adults are robust and predominantly black in colour even though reddish brown colourmorphs are also present. The robust body with black to reddish brown measures 15-20 mm in length excluding the snout. The antenna is of elbow type. At the tip of snout, chewing and biting mouthpart is present. The thorax do not extend upto the posterior end of the abdomen and is a hard elytra with longitudinal grooves (Justin *et al*., 2008).

Dutt and Maiti (1979) identified a ratio range of 1:0.70 to 1:0.90 between ovipositor length and outer-wall thickness to be the most preferred site for oviposition. Accordingly, the most preferred sites for oviposition was where the circumference of

pseudostem ranged between 25 to 50 cm, height from the base upto 125 cm in case of tall varieties and upto100 cm in case of dwarf varieties. Eggs are laid in the air chambers of pseudostem by inserting the ovipositor through ovipositional slits. The mean diameter of ovipositional slit was found to be 0.67 ± 0.015 mm. Fecundity of female that was exposed to male for 24 h was estimated to be 62.0 ± 1.2. A female lays an average of 9 eggs at the rate of 1 per day after single mating (Justin *et al*., 2008). Gravid females lay yellowish white, more or less spherical eggs in the air chamber of the pseudostem. An incubation period of 4.50 ± 0.71 days was observed. Single egg is laid in an air chamber while at laboratory conditions, a cluster of 4-5 eggs are laid (Krishnan and Jayaprakas, 2016).

Visalakshi *et al.* (1989) recorded the longevity to be 90 to 20 days. Priyadarshini *et al.* (2014) found that the life span ranged from 53.0 to 65.0 (Mean 58.4 ± 4.39) days.

Five larval instars are present in the grub life cycle. The grub is apodous, sluggish, sub cylindrical with reddish-brown head and strong mandibles (Prasad and Singh, 1988). The larvae are voracious feeders that they could tunnel into the pseudostem up to the depth of 8 to 10 cm. The prepupa instar moves downwards in the first or second outer sheath for pupation (Krishnan and Jayaprakas, 2016). The total larval life span lasts about 35.00 ± 1.83 days.

The exarate pupa is found inside the cocoon and is pale yellow in colour with prominent setae. One end of the cocoon is kept open by the grub. Prior to pupation, pieces of fibres are cut from the epidermal layer within the reach of the head. This could produce a rectangular hole on the outer sheath of pseudostem that can be used for diagnosis for the presence of pupa (Anitha, 2000).

2.1.3 Symptoms and damage

Ovipositional punctures are made by the adult females on the outer leaf sheath of the pseudostem. Continuous feeding on the soft tissue of the pseudostem produces extensive tunnels. Early symptoms of the infestation are the presence of small pinhead-sized holes on the stem, fibrous extrusions from bases of leaf petioles and exudation of a gummy substance and blackened mass from the holes on the

pseudostem. During the advanced stages of infestation, extensive tunnelling is observed in both the leaf sheath and true stem. Immature ripened fruits are produced in plants having yellowed and withered leaves and decayed peduncles (Azam *et al.*, 2010). Depending upon the infestation stage and management efficiency, the weevil causes 10 to 90 per cent yield loss. In severely infested plantations, more than 20 per cent plants do not flower due to this reason (Priyadarshini *et al.*, 2014).

When wind speed is greater, the plant will fall easily because of the weak stem and results in heavy damage (Padmanaban and Sundararaju, 1999). The severity of the loss is greater when infestation occurs at the early vegetative stage (5 months old) (Padmanaban and Sathiamoorthy, 2001). Cross section of the weevil infested plant in the field revealed that the early instar tunnels only the outermost sheath of the pseudostem and its tunnelling is only in vertical direction. Fourth and fifth larval instars are highly voracious that they could produce larger tunnels and consume much of the pseudostem (Krishnan and Jayaprakas, 2016).

2.2 MANAGEMENT

Control of the weevil is an elusive and complex problem due to the secluded habitat of the insect. An integrated pest management incorporating all the control methods available will always be feasible to fetch fruitful results. This is achieved by integrated use of mechanical, cultural, biorational and chemical measures, of which chemical and botanical measures are adapted as both prophylactic and curative control (Thippaiah *et al*., 2010).

2.2.1 Monitoring

Closely monitoring for ovipositional punctures and regular check on the infested plants can help in the early detection of infestation. One of the most economical and environment friendly method, perhaps the only monitoring device available, is the use of split pseudostem traps (bait traps) and pheromone traps. Split traps @ 26 per acre and disc traps @ 25 per acre are recommended (DPPQS, 2002).

2.2.2 Cultural control

Tiwari (1971) suggested periodical pruning of the suckers and timely removal and safe disposal of infested pseudostems to prevent their spread. Regunath *et al.* (1992) found that 80 per cent of the heavily infested plants collapsed before harvest even after insecticidal application in Kerala. Hence, he suggested that it would be desirable to recommend complete destruction of such plants. Abraham and Thomas (1995) suggested mud slurry as a base and carrier for the swabbing of insecticides against the pests. Regular removal of the outer and older leaves and leaf sheath from the plant is also important as it would expose the adults in the outer sheath (Anitha, 2000). Once the harvest is over, the harvested pseudostem must be immediately removed, cut into small pieces and buried deep in the soil. The left out pseudostems after harvesting can be cut into 80 cm length pieces and could be used as a trap instead of keeping them as heaps (Shukla and Abhishek, 2010).

Host plant resistance is a prominent factor in the management of pests. The intrinsic plant characteristics such as hardiness or toughness of tissues, hairiness of leaves and stems, lack of nutrition and non-succulent stems having hard rind, low moisture level, content of ash, silica, alcohol, oils, toxins, glycosides and alkaloids imparted resistance against BPW as implicated by Tiwari (1971). Accordingly, he outlined Kathali, Poovan, Rasthali, Basrai, Poona, Harichalchini, Kabuli Chini, Pachanadan, Kothia, Batheesha, Mauritius, Pedapachaarthi and Bansi varieties to be resistant to BPW. When the field susceptibility of 212 varieties were screened by Charles *et al.* (1996) in Kerala found Zanzibar, Sugandhi, Perumpadali, Poovan, Palayankodan and Chenkadali to be slightly infested. When the life stages were studied under laboratory conditions by Anitha (2000), it was reported that Njalipoovan and Robusta were least suitable clones for completing the life cycle. A survey was conducted by Sivakumar (2017) who found that maximum infestation was seen in Nendran followed by Palayamkodan. While Red banana and Njalipoovan showed medium infestation, Robusta did not show any infestation at all.

Host finding and infestation depends on the chemical ecological aspects involving both plants and insects. Some progress has been made in devising traps and

baits utilising chemical cues used for host finding and reproduction of banana weevils. Identification of plant secondary metabolites offering repellency /resistance is still in nascent stage, the progress on which is expected to yield rich dividents for the management of weevil (Prasuna *et al*., 2008).

Alagesan *et al.* (2018) reported fatty acid derivatives of tetradecanoic acid and hexadecenoic acid, eliciting responses. 9-Octadecenal is a female-specific volatile and attracts male weevils for the performance of reproduction where as nonanal acted as an aggregation pheromone to form a cluster.

Gunawardena *et al.* (1999) found that male weevil produced an aggregation pheromone, 2-methyl-4-heptanol which attracted both male and female banana weevils. Ravi and Palaniswami (2002) could establish the presence of a female produced sex pheromone in pseudostem weevil. Male gets attracted to healthy pseudostem and female get attracted to weevil damaged pseudostem reveals the evidence of a male produced aggregation pheromone in banana pseudostem weevil (Rani *et al*., 2016).

Fu *et al*. (2019) evaluated different pseudostem trapping systems for the banana weevils, *Cosmopolites sordidus* (Germer) and *O. longicollis.* Traps with cut sections at 100 cm height captured significantly more individuals than those with cut section at 20 and 60 cm height. Sivakumar (2017) tested the efficacy of semiochemical based trap of pseudostem weevil in both laboratory and field conditions. It was brought from M/s. Chem Tica International, Costa Rica. But the trap was found less effective as compared to the pseudostem traps.

2.2.3 Biocontrol

Biocontrol or biological control advocates the utilisation of parasitoids, predators and pathogens for the regulation of pest densities. Even though predators *viz*. ants *Tetramorium* sp. and *Pheidole megacephala* (Fabricius) (Casterinas and Ponce, 1991) and parasites *Uropodia* sp. (Padmanaban and Sathiamoorthy, 2001)

have been reported, none of them are progressively utilised. One of the most commercially exploited category of biocontrol is pathogens mainly entomopathogenic fungi (EPF) and entomopathogenic nematode (EPN). Efficacy of *Beauveria bassiana* (Bals.) 17-6 isolate was evaluated by Padmanaban *et al.* (2009) and found that spraying the conidia spore suspension of *B. bassiana* 17-6 and immersion of the weevils in spore suspension recorded 100% adult mortality of both pseudostem and rhizome weevils in 6 days. Anis (2014) tested the efficacy of entomopathogenic fungi for the management of coleopteran pests. The isolates of *B. bassiana* and *Metarhizium anisopliae* (Metchinkoff) Sorokin, PDBC Bb 5 and PDBC Ma 4 respectively, were evaluated against nine coleopteran pests for the pathogenicity. Even though both the fungi were pathogenic to the grubs as well as adults of all the nine insects tested, Ma 4 was found inferior to Bb 5 in its ability to infect the adults. In field application against banana rhizome weevil, it was found that talc based application of *B. bassiana* @ 30 gL^{-1} was superior to the insecticide check, chlorpyriphos 0.03 %. The least number of galleries, the least number of grubs in the rhizomes and the lowest number of adult *C. sordidus* in soil samples were observed in talc based application of *B. bassiana* with highest B:C ratio. Awasthi *et al.* (2017) conducted an *invitro* evaluation of native isolate of the green muscardine fungus, *M. anisopliae*, where in LC_{50} of 1.0 x 10^7 spores mL^{-1} was obtained. Remya (2018) evaluated the effect of prophylactic and curative application of *B. bassiana* talc-based capsules and showed that chitosan based was effective. Alagesan *et al.* (2019) reported. *B. bassiana* isolate KH3 (1×10^8 conidia mL^1) to be more efficient which could cause more than 90 per cent mortality in 12 -18 days.

Third instar grubs of pseudostem weevil when treated with 10 to 70 and 80 to 100 Infective Juveniles (IJs) of entomopathogenic nematode *Heterorhabditis indica* Poinar, Karunakar & David (PDBC EN 13.3) produced 33.3 and 66.6 per cent mortality after 72 hours of inoculation (Padmanaban *et al.*, 2002). Application of entomopathogenic nematode *H. bacteriophora* @ 4 cadavar $plant^{-1}$ in leaf axils at 5, 6, 7 and if required at 8 months after planting was advised by KAU (2016).

2.2.4 Chemical control

Once the infestation has already occurred, curative control measures are the last hand resort for pest management. For the management of BPW, leaf axil filing, swabbing or stem injection of chemicals and botanicals are practiced (Azam *et al.,* 2010).

Dutt and Maiti (1972) observed celphos tablets @ 0.5 g x 3 tablets plant^{-1} controlled the stages of pest population within the plant. Spraying of 0.1 % of Carbaryl 50 WP was also found to be effective (Isahaque, 1978). Mathew *et al.* (1997) observed stem injection of chemicals to be much efficient and precise than swabbing of insecticides along with surfactants, mud as well as mud slurry containing insecticides and spraying and fumigation of the spaces between leaf sheaths in the pseudostem. Justin *et al*. (2008) reported that 2 mL each of stem injection of either monocrotophos or dimethoate (1:5 ratio water), at 60 and 150 cm of the pseudostem from ground level at opposite sides yielded a bunch recovery of 84.2 and 81.3 per cent respectively. Shukla and Abhishek (2010) suggested the application of chlorpyriphos (2.5 mL^{-1}) along with 1 mL sticking agent.

Sivakumar (2017) evaluated the efficacy of safe chemicals and bio-rational methods and found that thiamethoxam 0.01 %, cartap hydrochloride 0.05 % and emamectin benzoate 0.002 % were effective. He could observe that injection and leaf axil filling for thiamethoxam, swabbing and leaf axil filling for *Metarhizium majus* and spraying and leaf axil filling for neem soap were effective. Prophylactic injection of thiamethoxam 0.03 % at fifth and sixth months after planting gave fruitful results.

2.2.5 Botanicals

Discovery of novel toxins and antifeedant from plant extracts has been recently emphasized as a potential method for the development of ecologically safer pesticides (Isman, 2006; Koul *et al*., 2008).

Bhagawati *et al.* (2009) reported that neem oil (0.5 %) and pongam oil (0.5 %) has the highest repellent property among the various botanicals tested. Sivasubramanian *et al.* (2009) evaluated the efficacy of Neem Azal 1.2 EC in the weevil control. Stem injection of Neem Azal (4:4 ratio) recorded higher mortality than swabbing. Irulandi *et al*. (2012) stated that the reduction in infestation produced by stem injection of azadirachtin 2 mL plant^{-1} was on par with chemical treatment, monocrotophos. Application of crushed neem seed @ 50g plant^{-1} as leaf axil filling at 4th and 6th month after planting was found to be notably effective (KAU, 2016).

A 10 mL injection of 5 % formulation of Menma at three points in the infested plant could produce mortality of the treated insects in 12 h. Mortality of weevils were reported on treatment with Menma at concentration of hydrogen cyanide at 8 ppm or 3 mL dose of 300 ppm or by giving a sub-lethal exposure in 1 mL of Menma with 300 ppm for 10 h (Krishnan *et al.,* 2015). Extractions from the cassava leaves, the insecticidal constituent, cyano-glucosides was found to be a strong substitute for the currently available toxic pesticides that cent per cent mortality was obtained at 35 ppm of HCN (Jithu *et al.*, 2017).

Awasthi and Sridharan (2015) found that extracts of *Ocimum sanctum* Linn. and *Lantana camara* L. showed highest repellency under choice bioassays tests where as the least was in cymbopogan and pongam oil. They inferred that 10 % leaf extract of *L. camara* could be useful as a possible botanical with high repellency under field conditions but lesser antifeedant and toxicant property. Hexadecanoic acid, active compounds present in essentials oils of *Tephrosia purpurea* (L.) and *Ipomoea carnea* Jacq. were found to be a strong repellent for the males rather than females of the weevil (Sahyaraj *et al.*, 2015). Sivakumar (2017) reported that Nanma and neem soap could cause 36.67 per cent mortality.

Anitha (2000) recommended the swabbing of a mixture of slurry and neem oil 5% on the pseudostem at five months after planting in heavily infested areas to deter oviposition by gravid females. Sivasubramanian *et al.* (2009) suggested swabbing of pseudostem with 4% Neem Azal 1.2 EC. It could produce a reduction of 42.84 per cent in damage as compared to untreated plants. They could also elucidate the role of Neem Azal 1.2 EC as an oviposition deterrent.

2.3 CASHEW NUT SHELL LIQUID (CNSL)

Plant phenolics have established their diversified roles in pigmentation, growth, reproduction and many other functions such as lignification, fruit ripening as well as pesticidal properties (Harborne, 1980). Cashew Nut Shell Liquid (CNSL) is a by-product of cashew nut processing containing plant phenolics utilized in the chemical and trading industry. However, it gained much attention due to its insecticidal activities that could act as an alternative for the existing harmful pesticides.

A blend of naturally occurring phenol-based monomers, CNSL is extracted from the honeycomb, spongy structure of cashew nut (*Anacardium occidentale* L.) (Bisanda and Ansell, 1992). Varying in quantity, it is most concentrated in nuts and least in wood (Kamble *et al*., 2016).

CNSL is obtained during the process of removing the cashew kernel from the nut. Thermal, mechanical and solvent extraction are the methods for the extraction of CNSL. Solvent extraction can be carried out either by hot or cold extraction using soxhlet extractor, ultrasonication and super critical carbon dioxide extraction. Vacuum pyrolysis extraction is also followed. Better the extraction methods and isolation of the components, better is the value addition (Garkal and Bhande, 2014).

Thermal extraction includes roasting, hot oil bath or by using solar cooker. Roasting in baths save 85-90 per cent of the liquid. Hot oil bath method is the most commercial method for the production of CNSL. Specific solar cookers are used to concentrate heat on the cooker to extract the liquid by using reflectors (Subbarao *et al.,* 2011). Screw press method (Mechanical method) of CNSL extraction is the quickest and straightforward method in which raw shell nuts are put in hydraulic press and put under high pressure to yield 10-15 % CNSL (Francisco *et al.,* 2011).

Solvent extraction of CNSL leaves less than 1 % CNSL in residue. Common solvents used are either of diethyl ether groups which are less dense than water or chlorinated solvents that are denser than water. The quality and properties of CNSL

varies depending upon the type of solvent used for extraction (Subbarao *et al.,* 2011). The CNSL obtained consisted of 10% cardol, 50% cardanol and 30% anacardic acid.

The composition of CNSL varies depending upon the mode of extraction. Anacardic acid is the primary constituent in CNSL. It is a labile molecule which forms three new substances during the decarboxylation process: cardol, cardanol and polymeric material, all of which are made up of phenolic compounds with demonstrated potential for biological application (Maia *et al*., 2015).

The anacardic acid content in technical CNSL, also called as decarboxylated CNSL, was as low as 3-9 % and high in case of natural CNSL (Krishnamurthy, 1951). In technical (heat extracted) CNSL, the heating process leads to decarboxylation of the anacardic acid to produce more cardanol (Tyman *et al.*, 1978).

2.3.1 Pesticidal properties of CNSL

CNSL is primarly exploited in the varnishing and painting industries. Even though the pesticidal property as wood protectant against insects was reported by Wolcott (1944), further advancement in the area was not followed up. CNSL is a mixture of two highly reactive phenolic compounds *viz.* anacardic acid (90%) and cardol (10%) among which cardol has pronounced insecticidal and fungicidal properties as well as provide excellent preservative effect on timbers, books and stationery especially to prevent the attack of insects (Mandal, 1997). Gowri and Saxena (1997) suggested the wide applications of CNSL as insecticide, fungicide, termiticide and medicine. Venmalar and Nagarveni (2005) suggested that anacardic acid could be a potent target molecule having bactericide, fungicide, insecticide, anti-termite and molluscicide properties.

Echendu (1991) suggested the use of cashew nut as a surface protectant against the cowpea beetle, *Callsobruchus maculatus* Fab. This was validated by Ofuya and Fayape (1999) when they could control the pest with CNSL and powder.

William and Mansingh (1993) opinioned that the mode of action of CNSL could be similar to that of nicotine and pyrethrum extracts, blocking the transmission of impulses through the motor neurons of insects. The essential oil constituents of cashew have a strong contact action on insect pests as suggested by Oparaeke and Amodu (2000). Finkelstein *et al.* (2002) suggested that CNSL components may inhibit the enzyme acetyl cholinesterase and act as insecticide. Dourado *et al.* (2015) conducted a study in *Aedes aegypti* (Linnaeus) and reported that the mode of action of CNSL is same as most of the phenolic acids. The hydrophobic nature of the aliphatic chain facilitates the permeability through the cell membrane and acts on the protein-amino acid mechanism disabling them.

The wood protecting nature of CNSL against termites has been remarkedly studied. One of earliest studies was done by Lepage and Delelis (1980). They reported that CNSL has water repellency and could afford protection of wood against termites. Mwalongo *et al*. (1999) evaluated the ability of CNSL preservatives against wood blocks. They found that a combination of 40 % CNSL and 1 % copper chloride or 40 % CNSL and 2 % copper chloride caused least damage in terms of damage response and weight loss even after 108 days of treatment. Asogwa *et al.* (2007) tested the efficacy of various concentrations against the worker and solider castes of termites. CNSL at 6 %, 8 % and 10 % gave 100 per cent mortality of insects after 90 minutes for soldiers and 60 minutes for worker castes. They were found to be as efficient as the standard termiticides available then.

Lomonaco *et al.* (2009) proved that cardol was the main constituent responsible for the activity of technical CNSL. They also found that cardol completely lost its larvicidal activity, while cardanol's activity was lowered after complete hydrogenation of CNSL. The possible reason for this, as cited by them, was that a large number of hydroxyl groups prevents the substance penetrating the insect cuticle and reaching their targets. Due to hydrogenation of the side chain, unsaturation diminished the lipophilic character of the molecules, restricting their passage through the larvae membrane.

Schultz *et al.* (2006) found that the larvae of colarado potato beetle avoided food containing anacardic acid. A low feeding rate on leaves containing the same was

also noticed. Raja (2008) also reported the ovipositional deterrence by CNSL against bruchids. The surface area of the seeds decides the slight differences in dose and its effect on seed quality. He found that CNSL also has other benefits when applied. CNSL, as coating material, prevent the entry of moisture into seed. This may also reduce the ageing process of the seed.

When CNSL was used for bioassay studies of larvicidal activities against *A. aegypti*, Lomonaco *et al.* (2009) found that the LC_{50} values of technical CNSL, cardol and cardanol were 51.04 ± 0.62 mg mL^{1}, 14.20 ± 0.62 mg mL^{1} and 32.90 ± 0.25 mg mL^{1} respectively. Sodium anacardate, an anionic surface active derivative of anacardic acid was tested for its efficacy against egg, third instar and pupa of *A. aegypti* by Farias *et al*. (2009) and found that the larvicidal activity was three to seven-fold higher than ovicidal and pupicidal activities. The significant insecticidal activity was notable due to the contact activity causing damage to the external coating. Larvicidal activity may be prominent due to stomach action during larval feeding in water. Mukhopadhyay *et al.* (2010) checked the efficacy of CNSL on immature stages of two species of mosquitoes, *A. aegypti* and *Anopheles subpictus* Grassi. The larvae and pupae of *A. aegypti* and *A. subpictus* were found to be highly susceptible at 12 and 38 ppm respectively. Dourado *et al.* (2015) found that the minimum concentration that could bring mortality to third instar larvae of *A. aegypti* was 0.01 mg mL^{1} for LC_{10}, 0.07 mg mL^{-1} for LC_{50} and 0.139 mg mL^{1} for LC_{90}. They could observe degeneration of lining, hypersecretion of epithealial cells, increased vacuoles, separation of epithelial cells from basal membrane and disintegration of brush border and damage to peritrophic membrane in midgut in the treated larvae. At higher concentrations, irreversible disruption was noticed.

CNSL and cypermethrin was evaluated against insect pests of cowpea and found that at 1 % concentration, reduction in pod damage and insect count with CNSL was on par with cypermethrin 10 EC @ 100 g L^{-1} with a higher protective capability and lesser toxicity to leaves (Olotuah and Ofuya, 2010). Mahapatro (2011) tested the efficacy of CNSL against the lepidopteran pests, *Helicoverpa armigera* (Hubner) and *Spilarctia oblique* (Walker). He found that artificial diet surface incorporation on 1 % concentration resulted in delayed larval and pupal periods and deformed larvae.

Hydrogenated CNSL could produce 75 per cent mortality till pupation in *H. armigera*. In *S. oblique*, an inconsistent data was obtained which might have resulted due to the hairy nature of the larvae.

Buxton *et al.* (2017) extracted and identified three derivatives of cardanol, decarboxylated derivatives of naturally occurring anacardic acid and tested against rice weevil, *Sitophilus oryzae* (L.). They inferred a positive correlation between insecticidal activity to linear side chain and its degree of unsaturation. Accordingly compound 3 showed higher insecticidal activity. Andayanie *et al.* (2019) cited the presence of flavonoids and tannins in CNSL. Even the smallest concentration of CNSL (0.75 %) can act as antifeedant against *Bemisia tabaci* (Gennadius). Buxton *et al.* (2019) isolated cardanol from CNSL which was responsible for the insecticidal and progeny growth and development inhibition activities against rust red flour beetle, *Tribolium castaneum* (Herbst).

Laboratory evaluation of 0.2% CNSL was found to be as effective as the chemical control, 0.03% thiamethoxam against chilli aphid, *Aphis gossypii* G. at 24, 48 and 72 hours after treatment (Sundaran and Faizal, 2018). Andayanie *et al.* (2019) the effect of Cashew Nut Shell extract against the nymphs of silverleaf whitefly (Bemisia tabaci Genn). They observed more than 90 per cent mortality of first and second stage nymphs at 2 % and 6 % concentration respectively. Third instar reported lesser mortality as compared to the first two instars. The extract could penetrate into leaf and cause toxic and antifeedant effect to the early instar. Lekha (2020) evaluated CNSL based botanical insecticides for pest management in yard long bean. She found that an emulsifiable concentrate of 0.3% CNSL produced significant mortality of *Spodopetera litura* Fabricius after three days of treatment. It could also produce 90 per cent population reduction in case of mites and thrips. Steam boiled CNSL produced a higher dose mortality than drum roasted CNSL. It could produce no phytotoxicity symptoms even when the above recommended doses were applied.

2.3.2 Phytotoxicity

Even though CNSL was found to be an effective insecticide, one of the major constrains that limit its application is phytotoxicity. The component chemicals of CNSL was found to be highly corrosive that it acts as a check for plant development and seed germination.

The extracts from the leaves and stem barks of cashew was tested for their phytotoxicity on the seed germination of *Zea mays* L. by Nwokeocha and Ezhumah (2015). With the increase in concentrations of 25 %, 50 %, and 75 %, the rate of inhibition of seeds increased. Matias *et al*. (2017) evaluated the toxicity of CNSL during the germination of lettuce, tomato seeds and coffee senna and seedling formation. They found that there is a negative effect on germination and vigour of lettuce and tomato and the vigour of coffee senna. While CNSL adversely affected the root and aerial parts of lettuce and tomato, only the roots of coffee senna was affected.

Sundaran (2018) reported growth retarding effect as evidenced by inferior growth attributes in chilli plants treated with higher concentrations of 0.2 % CNSL. Those treated with higher concentrations showed significantly low plant height, number of leaves, shoot fresh weight and dry weight as compared to lower concentrations of CNSL as well as the chemical check. Lekha *et al*. (2019) reported no negative correlation in morphological characters of cowpea plant treated with CNSL concentrations ranging from 0.05 to 1.0 %. They also reported a small hike in production of total phenol content and slight reduction in yield in treatments with lower concentrations of CNSL at 0.05 and 0.08%. None of the CNSL concentrations affected the population of natural enemy, especially coccinellids in the field. Andayanie and Ermawati (2019) could observe brown spot on soybean leaves, withering followed by the death of plant tissues at a concentration of 6% CNSL. Hence a check on phytotoxicity is important at higher concentrations.

3. MATERIALS AND METHODS

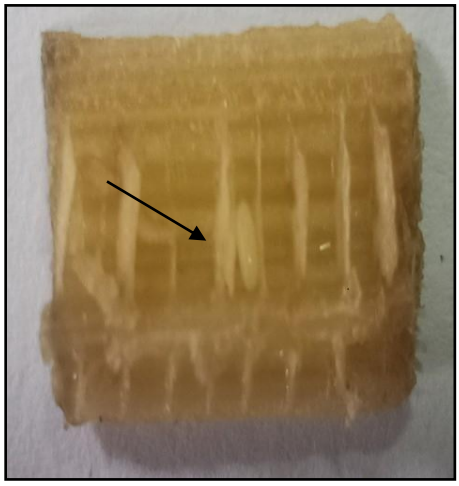
The present study entitled “Cashew Nut Shell Liquid (CNSL) formulation for the management of banana pseudostem weevil, *O. longicollis* (Olivier)” was done in the Department of Agricultural Entomology, College of Agriculture, Vellayani during 2018-2020. The efficacy of the emulsifiable concentrate formulation of Cashew Nut Shell Liquid (CNSL 20% EC) developed in the Department of Agricultural Entomology was tested against the grubs of banana pseudostem weevil under laboratory conditions. Different concentrations of the same were tested to fix effective dose along with the commonly used botanicals and chemical pesticide. The effective dose thus obtained was used to test the repellent effect on adult weevils as well as the curative management of the pest. The materials used and methods followed in the study are detailed herewith.

3.1 LABORATORY MAINTENENCE OF *O. longicollis*

3.1.1 Maintenance of laboratory culture

Pseudostem pieces of Nendran variety was used for laboratory maintenance of the weevil. The laboratory bioassay of CNSL formulation was performed on third instar grubs. The adults were collected from the instructional farm (Plate 1 A), sexed and maintained under laboratory conditions for mating and oviposition. Ten pairs were kept in each rearing jar (1 L volume) with pseudostem piece of 15×10 cm (variety Nendran) and maintained under dark conditions. The inner sheaths of pseudostem were used for rearing. The pseudostem pieces were daily checked for the eggs. Eggs were collected by using a camel hair brush from the air chambers and maintained separately in fresh pseudostem pieces of 5×5 cm (Plate 1 B). The emerging grubs were maintained individually in separate pseudostem pieces to avoid cannibalism and supplied with fresh pseudostem pieces every 24 hours (Plate 1 C). The early instars were given inner pseudostem pieces of 10×10 cm that were soft and easily palatable. Holes were made on the pseudostem pieces and the grubs were

A. Field collected adults



B. Eggs deposited in the air cavity of pseudostem

C. Rearing of grubs in pseudostem pieces

Plate 1. Laboratory maintenance of *O. longicollis*

introduced through this hole. Third instar grubs obtained from this stock culture were used for the experiments.

3.1.2 Preparation of botanical pesticides

3.1.2.1 CNSL 20% EC formulation

The emulsifiable concentrate formulation of CNSL (CNSL 20% EC) is a mixture of 20% active ingredient, 12% emulsifier, 53% solvent, 5% cosolvent and 10% water. The active ingredient is CNSL, the byproduct of drum roasting method of cashew, purchased from the Mahatma Cashew Exports, Kollam, Kerala. The emulsifier is a blend of sodium oleate and span 20 in 91:9 ratio. The solvent is isopropyl alcohol and cosolvent is cyclohexanol.

The formulation was prepared in three steps. To obtain 1 L of the formulation 109.2 g of sodium oleate was dissolved in 100 mL of sterile distilled water by placing it in a water bath at 50 °C. After dissolution, it was mixed with 10.8 mL of span 20 and well shaken with the help of mechanical shaker for thirty minutes (Plate 2 A). 200 mL of CNSL was mixed with 530 mL isopropyl alcohol and 50 mL cyclohexanol and shaken in mechanical shaker for 30 minutes separately (Plate 2 B). The above two mixtures were slowly blended together (Plate 2 C) and well mixed in a mechanical shaker for about 45 minutes to obtain the final formulation (Plate 3 A). The stock solution (CNSL 20 % EC) so obtained was maintained in air tight container until further use (Lekha, 2020).

3.1.2.2 Neem oil emulsion (3%)

For the preparation of 1 L of neem oil emulsion, 6 g of vegetable soap was sliced into very small pieces and dissolved in 100 mL of lukewarm water. The emulsifier was slowly mixed with 30 mL neem oil under constant agitation and the final volume was made up to one litre by mixing with water to make 3 % neem oil emulsion.

A. Blending of emulsifier

B. Blending of solvent and cosolvent

C. Blending mixture of emulsifier with solvent and cosolvent

Plate 2. Preparation of CNSL 20% EC formulation

3.1.2.3 Pongam oil emulsion (1%)

For the preparation of of pongam oil emulsion**,** 6 g of vegetable soap was sliced into very small pieces and dissolved in 100 mL of lukewarm water. The emulsifier was slowly mixed with 10 mL pongam oil under constant agitation and the final volume was made up to one litre by mixing with water to make 1 % pongam oil emulsion.

3.1.2.4 Nanma 5% solution

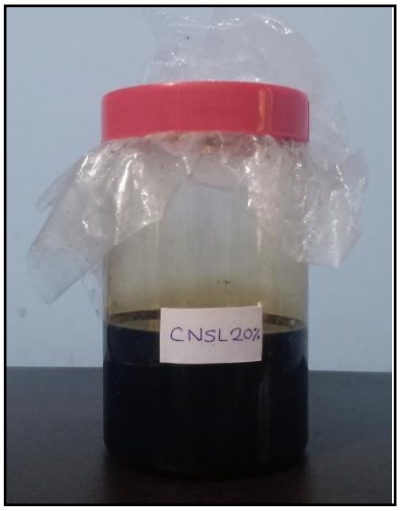
Nanma, a readymade biorational is a combination of the cassava leaf distillate and neem oil. The product has been developed by Central Tuber Crops Research Institute, Sreekaryam, Thiruvananthapuram. It was purchased from Mithraniketan KVK, Vellanad. A 5% solution of Nanma was prepared by mixing 50 mL of the same with one litre of water (Plate 3 B).

3.1.2.5 Menma

Menma, a readymade product developed by Central Tuber Crops Research Institute, Sreekaryam, Thiruvananthapuram, was purchased from Mithraniketan KVK, Vellanad (Plate 3 C). The botanical was injected at three points, @ 5 mL each injection, on the stem through the bore holes made by the weevil. The special needle with three holes were used for the same.

3.2 LABORATORY EVALUATION OF CNSL AGAINST *O. longicollis*

The different concentrations of CNSL formulation were applied on the pseudostem pieces and given to the third instar grubs for feeding. Based on the mortality per cent, the effective dose was fixed. The different concentrations of CNSL *viz.* 0.5, 0.75, 1, 2, 3, 4 and 5% were prepared by mixing 6.25, 9.375, 12.5, 25, 37.5,



A. CNSL 20% EC

B. Nanma

C. Menma

D. Grubs released to the central hole of treated pseudostem

Plate 3. Evaluation of botanicals against *O. longicollis*

50 and 62.5 mL of CNSL 20% EC with 250 mL of water. Neem oil emulsion 3 % and Pongam oil emulsion 1 % were used as botanical check and thiamethoxam, Actara 25% WG @ 0.01% served as chemical check. The bioefficacy evaluation was conducted using third instar grubs derived from the stock culture (5 numbers per replication) in completely randomized block design with 11 treatments and 3 replications as detailed below:

T_1: CNSL 0.5 %
T_2: CNSL 0.75 %
T_3: CNSL 1.0 %
T_4: CNSL 2.0 %
T_5: CNSL 3.0 %
T_6: CNSL 4.0 %
T_7: CNSL 5.0 %
T_8: Neem oil emulsion 3.0 %
T_9: Pongam oil emulsion 1.0 %
T_{10}: Thiamethoxam 25% WG 0.01%
T_{11}: Untreated

Pseudostem pieces from inner sheath (third or fourth sheath from outside) was cut into square pieces (10 ×10 cm). A hole was made in the centre of the pieces for the easy entry of the grubs as well as to sustain the formulations within the pseudostem (Plate 3 D). They were immersed in respective treatments for about 30 minutes. After draining the excess liquid, the grubs that were uniformly sprayed with respective treatments using potter's precision spray tower @ 1 mL were introduced through the holes. Pseudostem pieces treated with water served as untreated. The larvae were allowed to remain on the treated pseudostem for a day and subsequently transferred to fresh pseudostem pieces. Observations were made on 1, 2, 3, 5, 7 and 14 days after treatment. The data obtained was subjected to probit analysis (using SPSS 16.0 version) to determine the effective dose.

3.3 REPELLENCY EFFECT OF CNSL FORMULATION ON ADULTS OF *O. longicollis*

Pseudostem pieces from inner sheath (third or fourth sheath from outside) was cut into square pieces (10×10 cm) of equal lengths. Both multiple choice and no choice tests were conducted to analyse the individual as well as cumulative effects. The number of adults attracted and repelled were observed and computed for ANOVA.

The preference of pseudostem pieces receiving different concentrations of CNSL as detailed below were determined.

T_1: The effective concentration of CNSL
T_2: Half the effective concentration of CNSL
T_3: Double the effective concentration of CNSL
T_4: LC_{50} value
T_5: Nanma 5.0%
T_6: Neem oil emulsion 3.0%
T_7: Pongam oil emulsion 1.0%
T_8: Untreated

3.3.1 Multiple choice test

Banana pseudostem pieces of uniform dimensions (10 ×10 cm) were dipped in the above treatments for 30 minutes, drained well and used for experiment. Pseudostem pieces dipped in water served as untreated check. The treated pseudostems were placed around the periphery of a circular basin equidistant to each other. Adult weevils were released @ 40 numbers per basin to the middle of the basin and secured with a nylon net. Three replications were kept. The movement and behavior of the weevils were observed at hourly intervals for 12 h and then at 24 h. Number of weevils attracted to treated pieces were observed and expressed as percentage.

3.3.2 No choice test

Banana pseudostem pieces of uniform dimensions (10 ×10 cm) were dipped in the above treatments for 30 minutes, drained well and used for experiment. Pseudostem pieces dipped in water served as untreated check. The treated pseudostems were placed individually in separate basins. Adult weevils were released @ 10 numbers per basin and secured with a nylon net. Three replications were kept. The movement and behavior of the weevils were observed at hourly intervals for 12 h and then at 24 h. Number of weevils settling on treated pieces were observed and expressed in percentage.

3.4 PHYTOTOXICITY EVALUATION OF CNSL TO BANANA

Phytotoxicity evaluation of CNSL was conducted by applying the following treatments to banana plants (variety Nendran) of uniform age and size grown at Instructional Farm, College of Agriculture, Vellayani following the package of practices of Kerala Agricultural University. Three replications (three numbers per replication) of each treatment were carried out in completely randomized block design.

T_1: CNSL 0.5 % as leaf axil filling
T_2: CNSL 0.5 % as stem injection
T_3: CNSL 1.0 % as leaf axil filling
T_4: CNSL 1.0 % as stem injection
T_5: CNSL 3.7 % as leaf axil filling
T_6: CNSL 3.7 % as stem injection
T_7: Untreated check

3.4.1 Methods of application

3.4.1.1 Leaf Axil Filling

For leaf axil filling, the treatments were applied through the leaf axils of the plants by pouring the solution to each leaf axil until it gets fully filled**.** 250 mL was applied on each plant (Plate 4 A).

3.4.1.2 Stem Injection

To ensure delivery of treatments to the inner sheaths, a special injection needle having 1 hole on the tip and 3 holes on the surface was used. A 20 mL syringe was used (Plate 4 B). The syringe was filled with 20 mL of each treatment and the needle was inserted through the bore hole made by the pest until it reached the innermost damaged sheath and injected until they get fully filled (Plate 4 C).

3.4.2 Phytotoxicity test

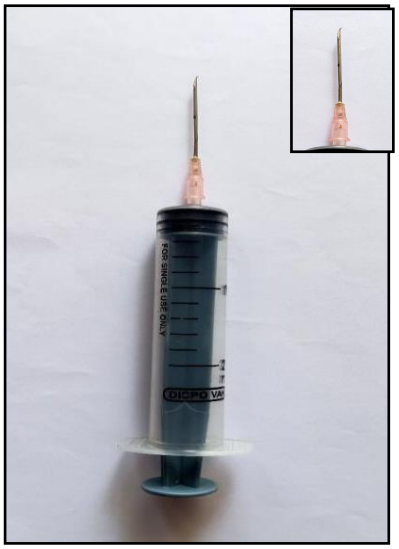
The plants were observed for two weeks and the symptoms, if any were noted. All the existing leaves and those emerged after the application of treatments were carefully observed for symptoms of yellowing, necrosis and scorching. The length and breadth of all the leaves including those emerged after the application of treatments were recorded. 14 days after treatment, the plants were cut and individual leaf sheath were observed for damage if any due to the treatment application.

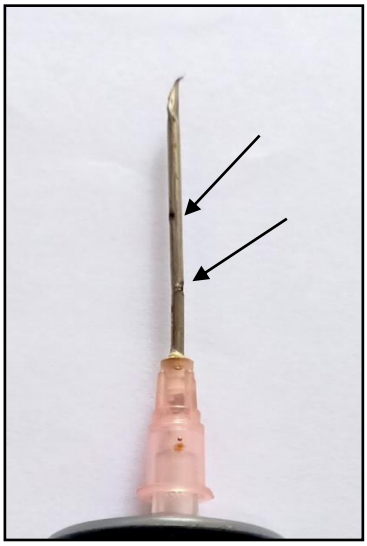
At two weeks after treatment, when the plants were cut down, the extent of damage by BPW *viz.* number of bore holes plant^{-1} (including probing marks), number of leaf sheaths damaged, the vertical and horizontal damage (in cm) on the individual leaf sheaths were also recorded.

3.5 MANAGEMENT OF BPW

CNSL formulation was tested for its curative effect by applying the following treatments in banana uniformly infested with BPW. The effective concentration, obtained on the basis of laboratory evaluation of grubs against CNSL, is applied as leaf axil filling and stem injection as explained in 3.3.1.1 and 3.3.1.2. Menma was

A. Treatment of plants through leaf axil filling





B. 20 mL syringe with multiple holes on the needle employed for stem injection

C. Treatment of plants through stem injection

Plate 4. Treatment of *O. longicollis* infested banana plants

used as the botanical check. Thiamethoxam 0.03% as stem injection was used as chemical check. Water was used in the un treated control.

Evaluation of CNSL for the management of pseudostem weevil was conducted by applying the treatments on to banana plants (Variety Nendran) of uniform age and size grown in farmer's field selected at Varkala, Thiruvananthapuram. The plants uniformly infested with pseudostem weevil were purposefully selected by looking at the number of bored holes present on the pseudostem. Plants exhibiting 40-45 probes of the adult weevil possessing at least 10 active bored holes with gummy exudation were selected for the experiment. The following treatments were applied in three replications.

T_1: CNSL 0.5 % as leaf axil filling
T_2: CNSL 0.5 % as stem injection
T_3: CNSL 1.0 % as leaf axil filling
T_4: CNSL 1.0 % as stem injection
T_5: CNSL 3.7 % as leaf axil filling
T_6: CNSL 3.7 % as stem injection
T_7: Menma – 15 mL/plant injection
T_8: Thiamethoxam 0.03% as injection
T_9: Untreated

At the fifth day of treatment, the plants were cut down and the leaf sheaths were individually removed and observed for number of bore holes plant^{-1} (including probing marks) and number of live grubs, pupae and adults. The vertical and horizontal damage on the individual leaf sheaths and the central spindle were recorded using a scale and expressed as average.

4. RESULTS

The current study dealt with the evaluation of different concentrations of the CNSL formulation (CNSL 20% EC) against banana pseudostem weevil. The effective concentrations of CNSL worked out based on laboratory bioassay against *O. longicollis* grubs were tested for the repellent effect against the adults and for the curative management of the pest under field conditions.

4.1 LABORATORY EVALUATION OF CNSL AGAINST *O. longicollis*

4.1.1 Characteristics of *O. longicollis*

While maintaining the culture of *O. longicollis* in the laboratory, characterictics observed are presented below. Different stages of *O. longicollis* was maintained in pseudostem pieces in the laboratory. Fecundity of field collected females and egg hatching was observed and are presented in Table 1. From 10 pairs, 60 to 70 eggs were collected. On an average of 6.5 eggs per female were obtained. From 100 pairs, the number of eggs collected varied from as low as 17 to as high as 177 eggs per day.

Most of the weevils laid only one egg in an air chamber. However, a cluster of 2-3 eggs was also observed. The eggs period was noted to be 2-3 days. Some remained unhatched and disintegrated later. The rate of egg hatching varied from 27.78 per cent to 92.16 per cent in the batches of eggs collected at different days with the average being 65.58 per cent. The rate of hatching was low being less than 70 per cent in most of the cases.

The emerging grubs were maintained up to third instars for the experiments in cut pseudostem pieces that were changed every alternate day. The number of first instars reaching second instars and that of second reaching third instars were observed to have an idea of the rate of grub survival under laboratory conditions (Table 2).

Table 1. Rate of oviposition and egg hatching of field collected *O. longicollis* adults under laboratory conditions

Date	Total number of eggs collected*	Number of eggs hatched in 2-3 days after collection	Egg hatch (%)
6-9 -2019	17	12	70.58
5-10 -2019	40	12	30
6-10-2019	17	12	70.58
7-10 -2019	20	13	65
15- 10 -2019	39	27	69.23
17- 10 -2019	53	37	69.81
18- 10 -2019	49	33	67.35
22- 10 -2019	67	49	73.13
24- 10 -2019	51	47	92.16
26- 10-2019	57	49	85.60
29- 10-2019	52	39	75.00
6- 11 -2019	68	56	82.35
10- 11-2019	77	59	76.62
20- 11-2019	90	25	27.78
8- 12 -2019	107	89	83.18
12- 12 -2019	95	69	72.63
13- 12 -2019	177	117	66.11
15- 12 -2019	97	57	58.76
19- 12 -2019	57	33	57.89
24- 12 -2019	49	28	57.14
30- 12 -2019	57	21	36.84
31- 12 -2019	36	19	52.77
4- 01 -2020	57	28	49.12
9 - 01 -2020	59	34	57.63
15- 01 -2020	70	51	72.86
16- 01 -2020	51	39	76.47
Average	**61.88**	**40.58**	**65.58**

*From 100 females kept paired with as many males

Table 2. Survival rate of *O. longicollis* grubs under laboratory conditions

SI. No	Number of first instar grubs obtained per day	Number that reached second instar stage	Per cent survival from first to second instar	Number that reached third instar stage	Per cent survival from second to third instar	Per cent survival from first to third
1	12	9	75.00	8	88.89	66.67
2	12	7	58.33	7	100.00	58.33
3	12	8	66.67	6	75.00	50.00
4	13	9	69.23	6	66.67	46.15
5	27	20	74.07	18	90.00	66.67
6	37	28	75.68	24	85.71	64.86
7	33	23	69.69	19	82.61	57.58
8	49	41	83.67	37	90.24	75.51
9	47	38	80.85	33	86.84	70.21
10	49	41	83.67	37	90.24	75.51
11	39	20	51.28	17	85.00	69.23
12	56	47	83.93	41	87.23	73.21
13	59	51	86.44	47	92.16	79.67
14	25	16	64.00	14	87.50	56.00
15	89	61	68.54	51	83.61	57.03
16	69	58	84.06	50	86.21	72.46
17	117	69	58.97	58	84.06	49.57
18	57	43	75.44	32	74.42	56.14
19	33	21	63.64	18	85.71	54.54
20	28	19	67.86	14	73.68	50.00
21	21	15	71.43	10	66.67	47.61
22	19	15	78.95	13	86.67	68.42
23	28	21	75.00	18	85.71	64.28
24	34	23	67.65	19	82.61	55.88
25	51	28	54.90	21	75.00	41.18
26	39	26	66.67	21	80.77	53.85
Average	1055	757	71.75	639	84.41	84.36

Each instar lasted for two to three days. Hence it took nearly four to six days for the first instars to become third instars. The instars were differentiated with the help of Dyar's law. The mean larval length of third instar ranged from 11.5 to 12.5 mm with a width range from 2.5 to 3 mm. The mean width of head capsule ranged between 2 to 2.5 mm.

The per cent survival from first instar to second instar varied from 51.28 to 86.44 with the average being 71.75. This was found to be less than that of the per cent survival from second instar to third instar which varied from 66.67 to 100.00 with the average being 84.41. The per cent survival from first instar to third instar varied from 41.18 to 79.67 with the average being 84.36.

Most of the first instars were found to be feeding across the air chamber, horizontally whereas the second and third instars were found to be feeding by boring holes through the pseudostem towards the inner sheath. The initial instars are crystalline white whereas the later instars were creamy white.

4.1.2 Laboratory bioassay of CNSL against *O. longicollis*

Bioassay of different concentrations of CNSL *viz.* 0.5, 0.75, 1, 2, 3, 4 and 5% prepared out of CNSL 20% was done against *O. longicollis* so as to fix the effective concentrations (LC_{50} and LC_{90} values).

Different concentrations of CNSL was tested against the third instar grubs of pseudostem weevil along with two botanicals, a chemical check and an untreated control. Mortality of the grubs observed at different time intervals after treatment are presented in Table 3.

Mortality ranging from 40 to 93.33 per cent was observed in various CNSL treatments at 1 DAT, with a concentration dependent increase in mortality. Grubs exposed to lower concentrations were found to be dead away from the pseudostem pieces given for feeding pieces given for feeding (Plate 5 A). There was no discolouration outside or within the body (Plate 5 B). At higher concentrations they were found dead and shrunken within the pseudostem itself with dark brown to black coloration of the abdominal region (Plate 5 C, D). The grubs treated with the highest

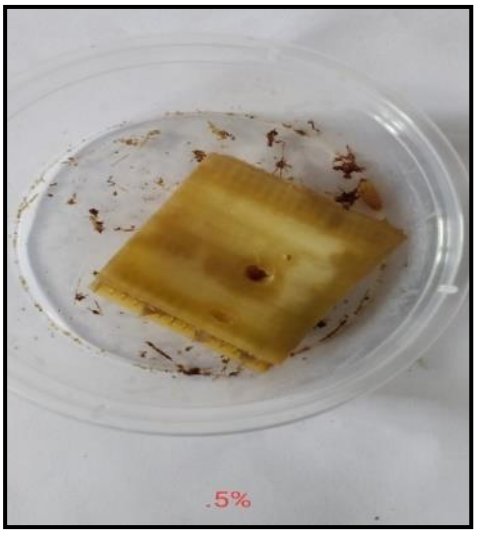
Table 3. Per cent mortality of third instar grubs of *O. longicollis* treated with different concentrations of CNSL

Treatments	Per cent mortality*					
	1DAT	2DAT	3DAT	5DAT	7DAT	14DAT
CNSL 0.5 %	40.00(39.23)^{cd}	40.00(39.23)^{ef}	53.33(46.92)^{ef}	60.00 (50.77)^{d}	60.00(50.77)^{d}	60.00(50.77)^{d}
CNSL 0.75 %	40.00(39.23)^{cd}	53.33(46.92)^{def}	60.00 (50.77)^{de}	60.00(50.77)^{d}	60.00(50.77)^{d}	60.00(50.77)^{d}
CNSL 1 %	60.00(50.77)^{c}	60.00 (50.77)^{de}	60.00(50.77)^{de}	66.67(54.99)^{d}	73.33(54.99)^{cd}	73.33(54.99)^{cd}
CNSL 2 %	66.67(54.99)^{c}	73.33(59.21)^{cd}	80.00(63.43)^{cd}	80.00(63.44)^{cd}	80.00(63.44)^{cd}	80.00 (63.44)^{cd}
CNSL 3 %	86.67(72.19)^{b}	86.67(72.19)^{bc}	86.67(72.19)^{bc}	86.67(72.19)^{bc}	86.67(72.19)^{bc}	86.67(72.19)^{bc}
CNSL 4 %	93.33(80.95)^{ab}	93.33(80.95)^{ab}	93.33(80.95)^{ab}	93.33(80.95)^{ab}	93.33(80.95)^{ab}	93.33(80.95)^{ab}
CNSL 5 %	93.33(80.95)^{ab}	93.33(80.95)^{ab}	93.33(80.95)^{ab}	93.33(80.95)^{ab}	93.33(80.95)^{ab}	93.33(80.95)^{ab}
Neem oil emulsion 3.0 %	93.33(80.95)^{ab}	93.33(80.95)^{ab}	93.33(80.95)^{ab}	93.33(80.95)^{ab}	93.33(80.95)^{ab}	93.33(80.95)^{ab}
Pongam oil emulsion 1.0 %	26.67(30.79)^{d}	26.67(30.79)^{f}	26.67(30.79)^{f}	26.67(30.79)^{e}	26.67(30.79)^{e}	26.67(30.79)^{e}
Thiamethoxam 0.01 %	100.00(89.71)^{a}	100.00(89.71)^{a}	100.00(89.71)^{a}	100.00(89.71)^{a}	100.00(89.71)^{a}	100.00 (89.71)^{a}
Untreated	0.00 (0.29)^{e}	0.00 (0.29)^{g}	0.00 (0.29)^{g}	0.00 (0.29)^{f}	0.00 (0.29)^{f}	0.00 (0.29)^{f}
CD (0.05)	(16.368)	(16.718)	(16.296)	(16.368)	(16.368)	(16.368)

* Mean of three replications comprising of five grubs each

Values in parentheses are angular transformed values

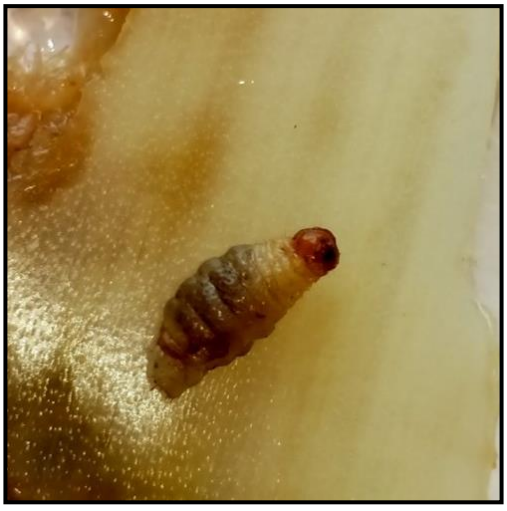
DAT – Days After Treatment



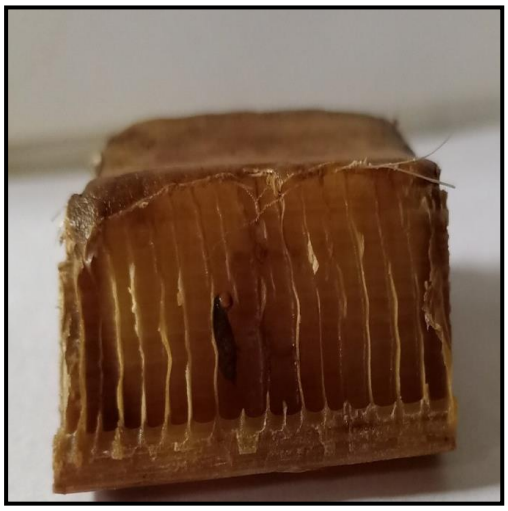
A. Dead grubs away from the pseudostem treated with 0.5 % CNSL

B. Dead grubs without discolouration upon treatment with 0.5% CNSL

C. Dead grubs away from the pseudostem treated with 2% CNSL



D. Dead grubs with black discolouration upon treatment with 2% CNSL



E. Dead grubs away from the pseudostem treated with 5% CNSL

F. Dead grubs found shrunken and constricted when treated with 5% CNSL

Plate 5. Symptoms exhibited by *O. longicollis* grubs exposed to CNSL treatments

concentrations of 4% and 5 % were found to have shrunken and constricted body (Plate 5 E, F).

The highest mortality (100 per cent) was produced by thiamethoxam 0.01 % within 1 day after treatment. This was on par with CNSL 4%, CNSL 5% and 3% neem oil emulsion that produced 93.33 per cent mortality. CNSL 3% produced 86.67 per cent mortality within the same time, an effect at par with the higher concentrations of CNSL. There was no subsequent increase in mortality in these treatments with increase in time and the trend remained the same at 14 DAT. Mortality produced by the lower concentrations (0.5-2 %) of CNSL at different intervals were inferior than the higher concentrations, though superior over untreated. The least mortality (26.67 per cent) was observed in grubs treated with 1% pongam oil emulsion.

The mortality increased with the number of days in lower concentrations of CNSL *viz.* 0.05%, 0.75%, 1% and 2%, though inferior to the chemical check and higher concentrations of CNSL. CNSL 0.5%, 0.75%, 1% and 2% could produce 40, 53.33, 60 and 73.33 per cent mortality respectively at 2 DAT which increased to 60.0, 60.0, 73.33 and 80 per cent respectively at 7 DAT and 14 DAT

The mortality data obtained was subjected to probit analysis to determine the effective dose. The statistical tool used was SPSS 16.0 version. The LC_{50} and LC_{90} values obtained at different intervals after treatment are tabulated in Table 4.

There was a decreasing trend in LC_{50} (the lethal concentration required to kill 50% of the population) values. It was 0.83 per cent at one day after treatment, decreasing uniformly reaching 0.38 per cent at fourteen days after treatment. The LC_{90} (the lethal concentration required to kill 90 per cent of the population) values also followed the the same trend. The LC_{90} value was 4.04% at 1 DAT decreased to 3.62 % by 14 DAT.

4.2 REPELLENCY EFFECT OF CNSL FORMULATION ON WEEVILS

The doses of CNSL effective against grubs *viz.* LC_{90} (3.7%), half LC_{90} (1.5%), double LC_{90} (7.4%) and LC_{50} (0.5 %) were evaluated for repellent effect on adult weevils under multiple choice and no choice tests along with other botanicals

Table 4. Dose mortality response of *O. longicollis* grubs to CNSL concentrations

Days	LC_{50}			LC_{90}			Chi square value
	Estimate	Lower bound	Upper bound	Estimate	Lower bound	Upper bound	
1	0.83	0.60	1.04	4.04	2.99	6.52	136.003
2	0.71	0.49	0.92	3.79	2.79	6.19	131.099
3	0.52	0.30	0.72	3.71	2.66	6.52	118.603
5	0.42	0.19	0.63	3.72	2.58	7.23	118.651
7	0.38	0.16	0.59	3.62	2.49	7.23	121.143
14	0.38	0.16	0.59	3.62	2.49	7.23	121.143

viz. Nanma 5.0%, neem oil emulsion 3.0%, Pongam oil emulsion 1.0% and water, under laboratory conditions.

4.2.1 Multiple choice test

The per cent of weevils present on each treatment at hourly intervals in the multiple choice test is presented in Table 5.

The maximum number of weevils (61.67 to 70 per cent) were attracted to the untreated check at various intervals which was significantly different from the rest of the treatments. No weevil was attracted to pseudostem treated with Nanma 5% and 3 % neem oil emulsion during the first five hours, an effect that significantly differed from other treatments. After that, they attracted few weevils whose numbers increased with increase in exposure time. These two treatments remained statistically superior in its non-preference till 8 HAT, as evident from the result that showed presence of only 0.83 to 2.5 per cent weevils.

An opposite trend was observed in pseudostem treated with different concentrations of CNSL. A considerable proportion of weevils (5 to 12.5 per cent) were attracted to the pseudostem treated with various concentrations of CNSL in the initial hours till 5 HAT. However, a decreasing trend in attraction was noticed there after that with only 5 to 1.67 per cent remaining in them from 9 to 24 HAT. Among the CNSL treatments repellent effect was less to lower concentration of 0.5 % CNSL (12.5 per cent at 5 HAT) and this treatment remained significantly inferior than the higher concentrations of CNSL till 5HAT. Significantly low proportion of weevils (2.5 to 7.5 per cent) settled on pseudostem treated with CNSL 3.7 % and 7.4 % till 5 HAT indicating quick repellent effect. However, all the botanicals tested were found to have repellent effect against the weevils with no significant difference between them at 9 to 11 HAT attracting only 2.5 to 6.67 per cent weevils. At the end of test period (24 HAT), the repellent effect was less in 7.4 % CNSL (1.67%). All lower concentrations of CNSL were found to be on par with botanical checks, attracting only 4.17 to 5 per cent of weevils and significantly superior over untreated (69.17 per cent) at 24 HAT.

Table 5. Weevils attracted to pseudostem pieces exposed to different treatments under multiple choice test

Treatments	Weevils attracted (%) *												
	1HAT	**2HAT**	**3HAT**	**4HAT**	**5HAT**	**6HAT**	**7HAT**	**8HAT**	**9HAT**	**10HAT**	**11HAT**	**12HAT**	**24HAT**
CNSL 3.7% (LC_{90})	5.00 $(12.92)^{c}$	5.00 $(12.92)^{c}$	7.50 $(15.89)^{c}$	7.50 $(15.89)^{c}$	5.83 $(13.91)^{d}$	5.83 $(13.91)^{b}$	5.83 $(13.91)^{b}$	5.83 $(13.91)^{bc}$	5.00 $(12.92)^{b}$	4.17 $(11.65)^{bc}$	4.17 $(11.65)^{bc}$	4.17 $(11.65)^{bcd}$	4.17 $(11.65)^{bc}$
CNSL 1.85% ($0.5LC_{90}$)	7.50 $(15.89)^{b}$	7.50 $(15.89)^{b}$	10.00 $(18.44)^{bc}$	10.00 $(18.44)^{bc}$	10.00 $(18.44)^{c}$	7.50 $(15.75)^{b}$	5.83 $(13.91)^{b}$	5.83 $(13.91)^{bc}$	4.17 $(11.65)^{b}$	4.17 $(11.65)^{bc}$	4.17 $(11.65)^{bc}$	4.17 $(11.65)^{bcd}$	3.33 $(10.37)^{cd}$
CNSL 7.4% ($2LC_{90}$)	5.00 $(12.92)^{c}$	5.00 $(12.92)^{c}$	2.50 $(9.1)^{d}$	2.50 $(9.1)^{d}$	3.33 $(10.37)^{e}$	5.83 $(13.91)^{b}$	5.83 $(13.91)^{b}$	4.17 $(11.65)^{cde}$	4.17 $(11.65)^{b}$	2.50 $(7.44)^{c}$	2.50 $(7.44)^{c}$	2.50 $(7.44)^{cd}$	1.67 $(6.16)^{d}$
CNSL 0.5% (LC_{50})	10.00 $(18.44)^{b}$	10.00 $(18.44)^{b}$	10.83 (19.19)b	10.83 (19.19)b	12.50 $(20.71)^{b}$	9.17 $(17.59)^{b}$	7.50 $(15.75)^{b}$	6.67 $(14.9)^{b}$	5.00 $(12.92)^{b}$	4.17 $(11.65)^{bc}$	4.17 $(11.65)^{bc}$	1.67 $(6.16)^{d}$	4.17 $(11.36)^{bc}$
Nanma 5.0%	0.00 $(0.29)^{d}$	0.00 $(0.29)^{d}$	0.00 $(0.29)^{e}$	0.00 $(0.29)^{e}$	0.00 $(0.29)^{f}$	0.83 $(3.22)^{c}$	1.67 $(6.16)^{d}$	2.50 $(9.1)^{e}$	5.00 $(12.92)^{b}$	4.17 $(11.65)^{bc}$	4.17 $(11.65)^{bc}$	5.00 $(12.92)^{bc}$	5.00 $(12.92)^{bc}$
Neem oil emulsion 3.0%	0.00 $(0.29)^{d}$	0.00 $(0.29)^{d}$	0.00 $(0.29)^{e}$	0.00 $(0.29)^{e}$	0.00 $(0.29)^{f}$	1.67 $(6.16)^{c}$	2.50 $(9.1)^{cd}$	3.33 $(10.37)^{de}$	4.17 $(11.65)^{b}$	5.00 $(12.92)^{b}$	5.00 $(12.92)^{b}$	5.00 $(12.92)^{bc}$	5.00 $(12.92)^{bc}$
Pongam oil emulsion 1.0%	4.17 $(11.36)^{c}$	4.17 $(11.36)^{c}$	4.17 $(11.36)^{d}$	4.17 $(11.36)^{d}$	6.67 $(14.9)^{d}$	6.67 $(14.9)^{b}$	5.00 $(12.92)^{bc}$	5.00 $(12.92)^{bcd}$	5.00 $(12.92)^{b}$	6.67 $(14.9)^{b}$	6.67 $(14.9)^{b}$	7.50 $(15.89)^{b}$	7.50 $(15.89)^{b}$
Untreated	68.33 $(55.77)^{a}$	68.33 $(55.77)^{a}$	65.00 $(53.74)^{a}$	65.00 $(53.74)^{a}$	61.67 $(51.75)^{a}$	62.50 $(52.25)^{a}$	65.83 $(54.25)^{a}$	66.67 $(54.75)^{a}$	67.5 $(55.25)^{a}$	69.17 $(56.32)^{a}$	69.17 $(56.32)^{a}$	70.00 $(56.83)^{a}$	69.17 $(56.32)^{a}$
CD (0.05)	(2.634)	(2.634)	(2.694)	(2.694)	(2.074)	(5.213)	(4.227)	(2.851)	(2.520)	(5.304)	(5.304)	(5.647)	(4.808)

* Per cent of the total of 40 weevils released

Values in parentheses are angular transformed values

HAT – Hours After Treatment

4.2.2 No choice test

The weevils were freely released in the rearing jars containing the treated pseudostems. Their movements and settling behavior were observed. The number of weevils settling on treated pseudostem was recorded at hourly intervals for 24 hours. The data obtained was subjected to ANOVA and presented in Table 6.

No weevils were found attracted to various treatments except untreated and pongam oil 1%, during the initial 3 h. Afterwards, attraction increased with increase in time. The maximum attraction (46.67 to 100 per cent) was observed to untreated control. Among the various botanicals tested, least preference was shown to Nanma 5% (0 to 60 per cent) followed by 3% neem oil emulsion (0 to 66.67 per cent). It showed attraction only after third hour of treatment and attraction increased gradually from 20 at 6 HAT to 66.67 per cent at 24 HAT.

CNSL treated pseudostems were also less preferred by the weevils. The repellent effect was both dose and time dependent as evidenced by a decrease in the number of weevils attracted with increase in concentration, though more weevils settled on the treated pseudostems with progress in time due to absence of choice.

The least attraction was shown to 7.4 % CNSL in which no weevils settled till 5 HAT. Only13.33 to 46.67 per cent of weevils settled on this treatment from 6 to 12 HAT exhibiting repellent effect on par with botanicals Nanma 5% (20 to 46.67 per cent) and 3% neem oil emulsion (20 to 60 per cent) and superior over other treatments.

At 24 HAT, Nanma 5 %, Neem oil emulsion 3.0% and 7.4 % CNSL exhibited significantly superior repellent effect, on which only 60 and 73.33 per cent weevils respectively settled. CNSL 0.5%, 3.7%, pongam oil 1% and water attracted 100 per cent of weevils making them ineffective.

4.3 PHYTOTOXICITY EVALUATION OF DIFFERENT CONCENTRATIONS OF CNSL TO BANANA

Table 6. Weevils attracted to pseudostem pieces exposed to different treatments under no choice test

Treatments	Weevils attracted (%)*												
	1HAT	**2HAT**	**3HAT**	**4HAT**	**5HAT**	**6HAT**	**7HAT**	**8HAT**	**9HAT**	**10HAT**	**11HAT**	**12HAT**	**24HAT**
CNSL 3.7% (LC_{90})	0.00 (0.29)^{b}	0.00 (0.29)^{c}	0.00 (0.29)^{d}	6.67 (9.05)^{de}	20.00 (26.57)^{c}	20.00 (26.57)^{cd}	20.00 (26.57)^{c}	20.00 (26.57)^{d}	33.33 (35.01)^{de}	40.00 (39.23)^{de}	60.00 (50.77)^{de}	80.00 (63.44)^{cd}	100.00 (89.71)^{a}
CNSL 1.85% ($0.5LC_{90}$)	0.00 (0.29)^{b}	0.00 (0.29)^{c}	26.67 (30.79)^{bc}	26.67 (30.79)^{bc}	26.67 (30.79)^{bc}	33.33 (34.63)^{bc}	46.67 (43.08)^{b}	46.67 (43.08)^{c}	46.67 (43.08)^{cd}	60.00 (50.77)^{cd}	73.33 (59.21)^{cd}	80.00 (63.44)^{cd}	93.33 (80.95)^{a}
CNSL 7.4% ($2LC_{90}$)	0.00 (0.29)^{b}	0.00 (0.29)^{c}	0.00 (0.29)^{d}	0.00 (0.29)^{e}	0.00 (0.29)^{d}	13.33 (17.81)^{d}	20.00 (26.57)^{c}	20.00 (26.57)^{d}	26.67 (30.79)^{e}	33.33 (35.01)^{e}	46.67 (43.08)^{e}	46.67 (43.08)^{e}	73.33 (59.21)^{b}
CNSL 0.5% (LC_{50})	0.00 (0.29)^{b}	0.00 (0.29)^{c}	20.00 (26.57)^{c}	26.67 (30.79)^{bc}	26.67 (30.79)^{bc}	40.00 (39.23)^{bc}	46.67 (43.08)^{b}	60.00 (50.77)^{b}	60.00 (50.77)^{bc}	66.67 (54.99)^{c}	80.00 (63.44)^{bc}	86.67 (72.19)^{bc}	100.00 (89.71)^{a}
Nanma 5.0%	0.00 (0.29)^{b}	0.00 (0.29)^{c}	0.00 (0.29)^{d}	0.00 (0.29)^{e}	0.00 (0.29)^{d}	20.00 (26.57)^{cd}	20.00 (26.57)^{c}	20.00 (26.57)^{d}	33.33 (35.01)^{de}	40.00 (39.23)^{de}	40.00 (39.23)^{e}	46.67 (43.08)^{e}	60.00 (50.77)^{b}
Neem oil emulsion 3.0%	0.00 (0.29)^{b}	0.00 (0.29)^{c}	0.00 (0.29)^{d}	13.33 (17.81)^{cd}	20.00 (26.57)^{c}	20.00 (26.57)^{cd}	26.67 (30.79)^{c}	26.67 (30.79)^{d}	46.67 (43.08)^{cd}	46.67 (43.08)^{cde}	46.67 (43.08)^{e}	60.00 (50.77)^{de}	66.67 (54.99)^{b}
Pongam oil emulsion 1.0%	0.00 (0.29)^{b}	20.00 (26.57)^{b}	33.33 (35.01)^{b}	40.00 (39.23)^{b}	40.00 (39.23)^{b}	53.33 (46.92)$_{b}$	60.00 (50.77)^{b}	60.00 (50.77)^{b}	73.33 (59.21)^{b}	86.67 (72.19)^{b}	86.67 (72.19)^{b}	93.33 (80.95)^{ab}	100.00 (89.71)^{a}
Untreated	46.67 (43.08)^{a}	46.67 (43.08)^{a}	66.67 (54.99)^{a}	73.33 (59.21)^{a}	93.33 (80.95)^{a}	93.33 (80.95)^{a}	93.33 (80.95)^{a}	100.00 (89.71)^{a}	100.00 (89.71)^{a}	100.00 (89.71)^{a}	100.00 (89.71)^{a}	100.00 (89.71)^{a}	100.00 (89.71)^{a}
CD (0.05)	(2.038)	(4.076)	(7.752)	(15.248)	(11.237)	(16.192)	(11.810)	(6.054)	(10.647)	(11.954)	(11.810)	(14.341)	(12.237)

***** Per cent of the total of 10 weevils released

Values in parentheses are angular transformed values

HAT – Hours After Treatment

Phytotoxicity evaluation of CNSL @ 0.5, 1 and 3.7 % was conducted by applying the treatments on banana plants (variety Nendran) both as leaf axil filling and stem injection. Date of next leaf emergence after CNSL application, length of leaves, abnormalities in plant due to treatments, if any and the extent of damage caused by BPW *viz.* number of bore holes on outer sheath, number of sheaths bored and mean horizontal and vertical damage suffered were recorded.

4.3.1 Plant attributes

4.3.1.1 Leaf emergence

There was no delay in the emergence of next leaf following application of CNSL irrespective of concentration and method of application. Even though the cigar leaf base was also treated with CNSL concentrations, they opened within five to seven days after the treatment. The newly emerged cigar leaf after CNSL application was noted to have no abnormalities, except some discoloration in case of leaf axil filling as detailed below. Even the precursory appendage was also present in the newly emerged leaves. No abnormalities were noted in plants entering the reproductive stage and they exhibited normal development of the thyrse (inflorescence).

4.3.1.2 Leaf characteristics (Leaf axil filling)

Leaf axil filling was done in all existing leaf base, irrespective of time of emergence. The older and outer leaves showed no discolouration or any other abnormalities. Only the central leaf showed some discolouration. The innermost central leaf axil was also filled with CNSL concentrations by pouring through the centre. At lower concentrations of 0.5 % and 1 % CNSL there was slight discolouration (yellowing surrounded by little brownish tinge and slight necrosis). Only the pipe leaf exposed at the time of treatment showed these symptoms (Plate 6 A). However, the leaves that emerged subsequent to treatment application did not record any abnormalities (Plate 6 B).

The higher concentration of 3.7% CNSL produced discoloration in the pipe leaf that was exposed during axil filling. Though such leaves opened within seven days after treatment, the tip portion remained unfurled with intense browning and scorching (Plate 6 C). However, the leaves that emerged subsequently were normal (Plate 6 D). The older and outer leaves showed no discolouration or any other abnormalities.

The dimensions of newly emerged leaf after treatment was compared with the rest of the leaf leaves. The length and width of the leaf emerged after treatment did not differ significantly from that of the previous leaves in any of the treatments or from the untreated (Table 7).

4.3.1.3 Pseudostem characteristics (Stem injection)

Stem injection was done through the bored holes. The bored holes were filled with the respective concentrations till it overflowed so as to ensure that the emulsion filled the
holes. Stem injection did not produce any abnormality in the pseudostem except slight brown discolouration at the site of treatment. The intensity of colouration was more in 3.7 % CNSL than the lower concentrations (Plate 7 A - C).

4.3.2 Extent of damage by BPW

The extent of damage caused by the pest was also recorded in the treated plants by destructive sampling, two weeks after treatment.

4.3.2.1 Number of bore holes

The number of bore holes (including probing marks) was found reduced in various treatments than in untreated (Fig. 1 A). It was lower in 3.7 % CNSL stem injection, followed by leaf axil filling with the same concentration, as compared to other treatments. The highest number of bore holes were found in the untreated followed by 0.5 % CNSL leaf axil filling.

A. Discolouration of exposed pipe leaf upon treatment with 0.5% CNSL

B. Fully emerged pipe leaf exposed after treatment with 0.5% CNSL

C. Discolouration of exposed pipe leaf upon treatment with 3.7% CNSL

D. Fully emerged pipe leaf exposed after treatment with 3.7% CNSL

Plate 6. Effect of CNSL leaf axil filling on banana leaves

Table 7. Leaf dimensions of banana after exposure to different concentrations of CNSL

Treatments	Leaf Length (cm)*		Leaf Width (cm)*	
	Leaf after treatment	Previous leaf	Leaf after treatment	Previous leaf
CNSL 0.5 % as leaf axil filling	138.30	145.67	38.70	40.67
CNSL 0.5 % as stem injection	272.97	280.37	44.27	46.47
CNSL 1.0 % as leaf axil filling	124.27	138.13	37.37	38.33
CNSL 1.0 % as stem injection	174.20	181.17	41.57	43.47
CNSL 3.7 % as leaf axil filling	166.20	172.77	43.67	44.97
CNSL 3.7 % as stem injection	181.43	188.77	46.93	48.97
Untreated	144.90	157.00	39.43	41.10
CD (0.05)	NS	NS	NS	NS

* Mean of three replications

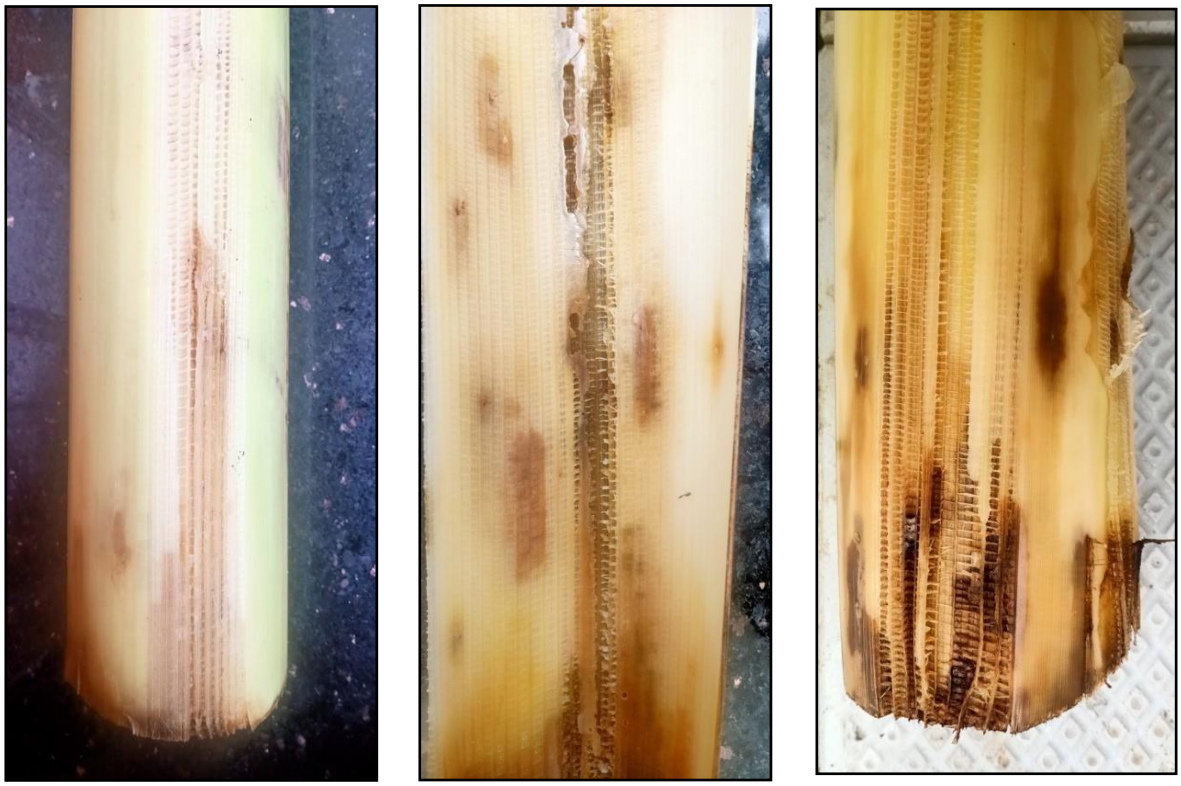


Plate 7. Discolouration of banana pseudostem exposed to CNSL stem injection

4.3.2.2 Number of sheaths bored

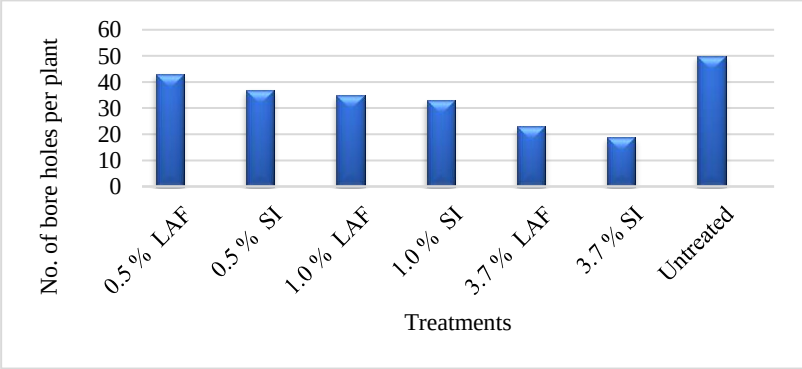
The number of sheaths bored per plant, by the grubs were also counted. Even though the bore holes were seen in the inner sheaths also, no life stages could be found in any of the treatments. Gummy exudation and bore holes were evident in all the plants treated. Only two to three outer sheaths were bored in both treatments with 3.7 % CNSL. In the rest of the treatments, the number of bored sheaths were more or less the same (between three to five). In untreated, the tunneling extended up to the 6th sheath (Fig. 1 B).

4.3.2.3 Horizontal and vertical damage

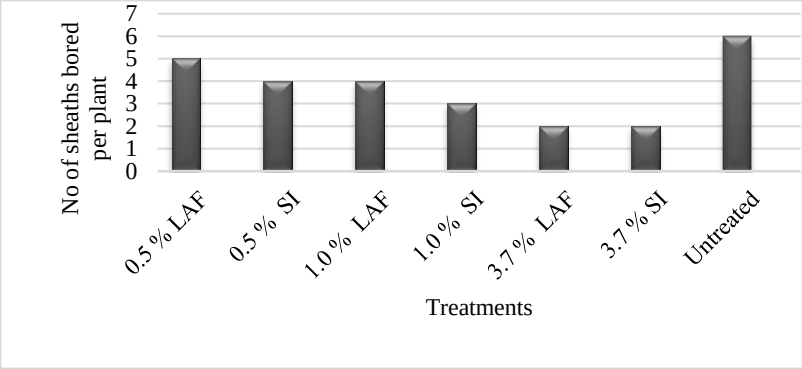
The average horizontal and vertical damage per sheath, caused by the grubs were also compared (Fig. 1 C, D) and recorded. More damage (both the horizontal and vertical) was observed in plants treated with 0.5 % CNSL leaf axil filling, though lower than in untreated. Mean vertical damage was found to be 29.3 cm and the horizontal damage 18.1 cm. This was closely followed by 0.5 % CNSL stem injection. The least damage was observed in 3.7 % CNSL stem injection wherein mean vertical damage was found to be 17.3 cm and the horizontal damage 10.75 cm. For the rest of the three treatments *viz.* 1 % CNSL leaf axil filling, 1 % CNSL stem injection and 3.7 % CNSL leaf axil filling, the extent of damage caused was more or less similar. This value ranged between 19.9 – 21.9 cm in case of vertical damage and 12.1 – 15.1 cm in case of horizontal damage.

4.4 CURATIVE MANAGEMENT OF BPW

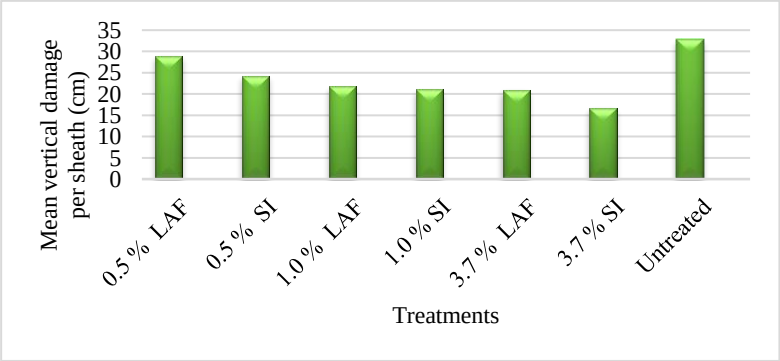
The effective concentrations of CNSL @ 0.5, 1 and 3.7% were applied onto banana plants (variety Nendran) uniformly infested with BPW, both as leaf axil filling and stem injection and the number of bore holes, population of the pest and the extent



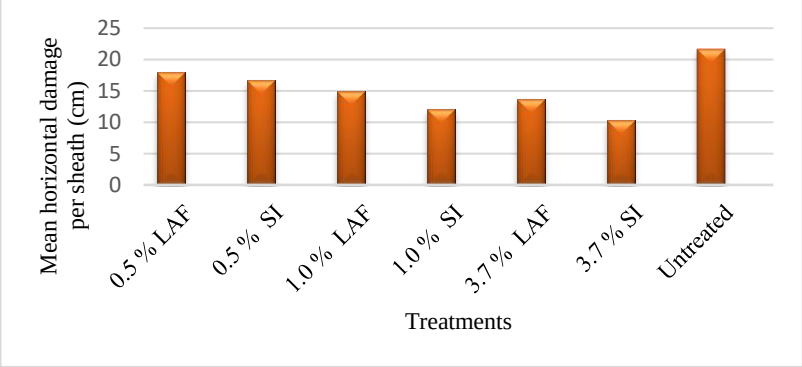
A. Number of bore holes/plant



B. Number of sheaths bored/plant



C. Mean vertical damage/sheath



D. Mean horizontal damage/sheath

LAF – Leaf Axil Filling

SI – Stem Injection

Fig. 1. Extent of damage by BPW in banana plants exposed to different CNSL treatments

of damage caused was recorded by destructive sampling at five days after treatment. It was done so carefully that none of the life stages got damaged during the destructive sampling. The plants were cut from the top just below the last leaf base and just above the ground level. The number of bore holes, grubs, pupae and adults per plant were counted. The extent of damage caused was measured in mean horizontal and vertical damage per sheath in cm.

4.4.1. Number of bore holes

Maximum number of bore holes per plant (60.67) was recorded in the untreated plants, which was significantly higher than plants that received different treatments except the lowest concentrations of 0.5 % CNSL. The untreated plants were found to be highly damaged with profuse gummy exudation and were on the verge of collapse. Significantly low number of bore holes plant^{-1} were recorded in plants that received treatments with Menma – 15 mL/plant injection (49.33) and thiamethoxam 0.03% as injection (50.33) which were on par with those treated with CNSL @ 3.7 % and 1% both as stem injection and leaf axil filling (Table 8). The least number of bored holes (47.67 plant^{-1}) was observed in the plants that received CNSL 1% as leaf axil filling.

4.4.2. Population of BPW

The mean number of live grubs, pupae and adults present in plants, that received various treatments, at five days after treatment are presented in Table 9.

4.4.2.1 Grubs

Untreated plants recorded the highest number of grubs per plant (18.67) which was significantly more than that of various treatments. Significantly low number of grubs were noted in plants that received treatments with Menma 15mL/plant injection, thiamethoxam 0.03% as injection and 3.7% CNSL stem injection recording 4, 4.33,

Table 8. Number of bore holes by BPW in plants treated with different concentrations of CNSL

Treatments	Mean number of bored holes plant^{-1} *
CNSL 0.5 % as leaf axil filling	56.00 (48.46)^{abc}
CNSL 0.5 % as stem injection	58.00 (49.64)^{ab}
CNSL 1.0 % as leaf axil filling	47.67 (43.66)^{d}
CNSL 1.0 % as stem injection	51.67 (45.96)^{bcd}
CNSL 3.7 % as leaf axil filling	54.67 (47.68)^{abcd}
CNSL 3.7 % as stem injection	49.33 (44.62)^{cd}
Menma – 15 ml plant^{-1}	49.33 (44.62)^{cd}
Thiamethoxam 0.03% as injection	50.33 (45.19)^{cd}
Untreated	60.67 (51.17)^{a}
CD (0.05)	(4.027)

* Mean of three replications recorded at 5 DAT

Values in parentheses are angular transformed values

Table 9. Number of BPW in plants treated with different concentrations of CNSL

Treatments	Mean numbers plant^{-1} *		
	Grubs	**Pupae**	**Adults**
CNSL 0.5 % as leaf axil fillng	15.00 (22.78)^{b}	5.67 (13.76)^{cde}	5.00 (12.92)^{a}
CNSL 0.5 % as stem injection	14.00 (21.92)^{bc}	7.00 (15.32)^{abc}	4.33(11.99)^{ab}
CNSL 1.0 % as leaf axil fillng	12.67 (20.81)^{bcd}	4.67 (12.46)^{e}	5.33(13.34)^{a}
CNSL 1.0 % as stem injection	10.00 (18.42)^{d}	6.00 (14.15)^{bcd}	3.67(11.02)^{bc}
CNSL 3.7 % as leaf axil fillng	11.33 (19.65)^{cd}	5.33 (13.34)^{de}	3.33(10.49)^{cd}
CNSL 3.7 % as stem injection	4.33 (12)^{e}	5.00 (12.88)^{de}	2.33(8.74)^{e}
Menma – 15 ml plant^{-1}	4.00 (11.48)^{e}	5.67 (13.76)^{cde}	2.67(9.36)^{de}
Thiamethoxam 0.03% as injection	4.33 (12)^{e}	7.33 (15.7)^{ab}	2.67(9.36)^{de}
Untreated	18.67 (25.57)^{a}	8.00 (16.41)^{a}	5.33(13.34)^{a}
CD (0.05)	(2.434)	(1.639)	(1.483)

* Mean of three replications recorded at 5 DAT

Values in parentheses are angular transformed values

and 4.33 grubs plant^{-1} respectively. This was followed by 1% CNSL stem injection (10 grubs plant^{-1}), 3.7% CNSL leaf axil filling (11.33 grubs plant^{-1}) and 1% CNSL leaf axil filling (12.67 grubs plant^{-1}) which were on par. CNSL 0.5% leaf axil filling with 15 grubs plant^{-1} which was on par with 3.7% CNSL leaf axil filling and 1% CNSL leaf axil filling with respect to the live grubs harboured. In general, stem injection at various concentrations were found to be more effective than that of their respective leaf axil filling in reducing the number of grubs.

The live grubs collected after the treatment were also observed. The grubs were found to have low intensity stains of CNSL on its surface when treated with low concentrations of the same. The intensity of stains observed increased as the concentration increased. Grubs with highly intense stains were found to show sluggish movement. Such grubs showed less feeding activity and was found to be very week. The grubs collected from pseudostems treated with leaf axil filling was found to be more active in movements and feeding as compared to those collected from that treated with stem injection. Remnants of dead grubs were observed in various treatments but an exact estimation could not be made due to disintegration of the cadaver.

4.4.2.2 Pupae

There was not much difference in the number of pupae collected from the plants that received various treatments (4.67 to 7.33 plant^{-1}). The pupae collected were found to be significantly low in plants that received treatments with CNSL 1% leaf axil filling (4.67 plant^{-1}), CNSL 3.7% stem injection (5 plant^{-1}), CNSL 3.7% leaf axil filling (5.33 plant^{-1}), Menma 15 mL/ plant injection (5.67 plant^{-1}) and CNSL 0.5% leaf axil filling (5.67 plant^{-1}). Plants treated with thiamethoxam 0.03% as injection, CNSL 0.5% leaf axil filling and untreated recorded significantly high number of live pupae.

4.4.2.3 Adults

Much difference was not observed in the number of adults (2.33 to 5.33 plant $^{-1}$) present in plants that received various treatments. Stem injections with CNSL 3.7%, Menma 15 mL/plant injection and thiamethoxam 0.03% recorded significantly low number of adults (2.33, 2.67 and 2.67 plant^{-1} respectively). Among leaf axil filling, 1 % CNSL was found to be on par with 3.7 % CNSL and hence superior to others. Hence, for the curative management of the pest, 3.7 % CNSL stem injection or 1 % leaf axil filling is found to be highly effective with no phytotoxic effects.

4.4.3 Damage caused by BPW

The horizontal and vertical damage caused by BPW to each sheath of pseudostem was measured and the mean damage sheath per sheath (cm) in the plants that received various treatments are presented in Table 10. In general, the grubs preferred to bore vertically through the sheaths than horizontally as evidenced by corresponding damage ranging from 27.07 to 68.87 cm and 15.27 to 53.83 cm respectively. All the treatments could significantly reduce the damage. The least damage was recorded in plants that received thiamethoxam 0.03% as stem injection (vertical damage of 25.07 cm and horizontal damage of 15.27 cm). This was followed by injection with Menma @ 15 mL/plant injection with 30.97 cm mean vertical damage and 16.6 cm mean horizontal damage. 3.7 % CNSL stem injection (31.63 cm of vertical damage) produced an effect on par with botanical check Menma. The untreated plants were heavily infested exhibiting highest vertical (68.87 cm) and horizontal (53.83 cm) damage.

CNSL @ 3.7% leaf axil filling and 1% both as stem injection and leaf axil filling were on par with comparatively low vertical damage (36.37, 37.17 and 37.2 cm respectively) as well as horizontal damage (24.03, 23.87 and 24.4 cm respectively). Plants treated with the lower concentration of CNSL @ 0.5 % exhibited more damage by BPW, though superior over untreated.

Table 10. Damage caused by BPW in plants treated with different concentrations of CNSL

Treatments	Mean damage sheath^{-1} (cm)	
	Vertical	Horizontal
CNSL 0.5 % as leaf axil fillng	47.60 (43.62)[b]	32.57 (34.8)[b]
CNSL 0.5 % as stem injection	44.70 (41.96)[c]	28.67 (32.37)[c]
CNSL 1.0 % as leaf axil fillng	37.20 (37.58)[d]	24.40 (29.6)[d]
CNSL 1.0 % as stem injection	37.17 (37.56)[d]	23.87 (29.24)[d]
CNSL 3.7 % as leaf axil fillng	36.37 (37.09)[d]	24.03 (29.36)[d]
CNSL 3.7 % as stem injection	31.63 (34.22)[e]	18.30 (25.33)[e]
Menma – 15 ml plant injection^{-1}	30.97 (33.81)[e]	16.60 (24.04)[f]
Thiamethoxam 0.03% as injection	25.07 (30.04)[f]	15.27 (23.00)[g]
Untreated	68.87 (56.09)[a]	53.83 (47.20)[a]
CD (0.05)	(1.294)	(0.806)

* Mean of three replications recorded at 5 DAT

Values in parentheses are angular transformed values

5. DISCUSSION

Banana is the fourth important crop in the developing world owing to the nutritional quality and income generation. India is the largest producer of banana in the world contributing 23 per cent of the world pool production from about 11 per cent of total global area under the crop (FAO, 2017). High productivity, demand and almost constant fair market makes it the most cultivated fruit crop of Kerala. Even though the diversification in cultivation practices have tremendously increased the production and demand of the fruit, a number of vagaries' including high incidence of pests and diseases curtail both production and productivity of banana.

Banana plant is affected by a slew of pests that attack the plants from root to pipe leaf and bunches, among which pseudostem borer of banana, *O. longicollis*, is the most damaging one. The grubs that emerge at the ovipositional site on the outer leaf sheath of the pseudostem feeds on the soft tissue of the pseudostem producing extensive tunnels. During the advanced stages of infestation, extensive tunneling is observed in both the leaf sheath and central core leading to toppling of the bunch bearing plants resulting in serious economic loss to the tune of 10 to 90 per cent depending upon the growth stage of the crop and management efficiency (Padmanaban and Sathiamoorthy, 2001).

Control of the weevil is an elusive and complex problem due to the secluded habitat of the insect. Though an integrated management incorporating all the control methods are available, farmers are solely dependent on chemical insecticides as leaf axil filing, swabbing or stem injection for the management of this pest (Azam *et al.,* 2010), ignoring the adverse effects on environment. Recommended management practices against *O. longicollis* included use of chlorpyrifos 0.03 %. Sivakumar (2017) evaluated the management efficacy of various chemicals and found that thiamethoxam 0.01 %, cartap hydrochloride 0.05 % and emamectin benzoate 0.002 % were effective.

Studies conducted across the world have revealed that chlorpyriphos caused DNA damage altering the genetic material particularly chromosomes in mammalian cultures (Jamil *et al.,* 2005). Indiscriminate use of chemical insecticides results in many insecticide related complications such as toxicity to non-target organisms, human health hazards, pest resurgence, secondary pest outbreak and environmental

pollution necessitating exploration of alternatives like use of botanicals (Mamun *et al.*, 2009).

Plants being stationary produce certain metabolites to ward off pests and botanicals containing such secondary metabolites are widely used for combating pest infestations. Bhagawati *et al.* (2009) reported that neem oil (0.5 %) and pongam oil (0.5 %) has the repellence effect against BPW. Neem based insecticides Neem Azal 1.2% EC (Sivasubramanian *et al.*, 2009) and Azadirachtin @ 10000ppm - 2mL plant^{-1} (Irulandi *et al*., 2012) and cyano-glucoside containing Menma, developed from cassava leaves (Krishnan *et al.*, 2015) were employed for the management of *O. longicollis.*

A completely different strategy is utilized by the plant secondary metabolite containing agro industrial by products for pest management. Cashew plant (*A. occidentale*) produce phenolic secondary metabolites and stores them in the honeycomb structure in the pericarp, which is expelled during cashew processing and is available in plenty as technical cashew nut shell liquid (CNSL) at cheap rate. CNSL is reported to have insecticidal potential against *Leucopholis coneophora* (John, 2008), *Aphis craccivora* (Olotuah and Ofuya, 2010) *Helicoverpa armigera*, *Spilarctia obliqua* (Mahapatro, 2011) and *Aphis gossypii* (Sundaran and Faizal, 2018). A formulation of CNSL in an emulsifiable concentrate form (CNSL 20 % EC) has been developed in the Department of Entomology, College of Agriculture, Vellayani and found effective to manage sucking pests of cowpea @ 0.3 %, without any adverse effect on the plant (Lekha, 2020). The present project was envisaged to explore the utility of this formulation for the management of BPW.

O. longicollis was successfully reared in the laboratory on pseudostem pieces. From the total mates of 100 pairs, the number of eggs collected varied from as low as 17 to as high as 177 eggs per day with an average of 6.5 eggs per female. The rate of egg hatching varied from 27.78 per cent to 92.16 per cent in the batches collected at different days. The number of first instar reaching second instar (71.75 per cent) was less as compared to number of second instar reaching third instar (84.41 per cent). The survival rate from first instar to third instar was 84.36 per cent. Justin *et al*. (2008) reported egg laying at the rate of nine per day with a range of 15-20 eggs in a season.

Krishnan and Jayaprakas (2016) estimated the fecundity of the females to be 60-65 eggs. Since the field collected weevils were used in the current study for getting the eggs, there was a decrease in the number of eggs obtained.

The first instar grubs remain confined to the leaf sheath area wherein the eggs were laid. The second instars riddled the pseudostem horizontally as well as in slight oblique direction whereas the third instar grubs were found to be more voracious tunneling the pseudostem in different directions. The artificial environmental conditions coupled with this unique feeding habit may be the reason for the low rate of egg hatching as well as survival of early instars in laboratory culture, wherein the cut pseudostem with reduced turgor was used for rearing. The feeding and tunneling behaviour of *O. longicollis* are regulated by the rhythmic movement of the body as well as propulsive action of the anal plate which becomes well chitinised only from the third instar (Dutt and Maiti, 1974) that enhances the better survival of late instars.

Bio assay of different concentrations of CNSL *viz.* 0.5, 0.75, 1, 2, 3, 4 and 5% prepared out of CNSL 20% EC was carried out in third instar grubs of *O. longicollis* derived from the laboratory culture. Concentration and time dependent increase in mortality of grubs was observed upon exposure to CNSL. Grubs exposed to lower concentrations were found to be dead with no discolouration, away from the pseudostem pieces, whereas those treated with higher concentrations were found dead with dark brown to black coloration of the abdominal region within the pseudostem itself. This indicated antifeedant action at lower concentrations and corrosive contact and stomach action at higher concentrations. It was reported that the toxic compounds in CNSL (anacardic acid and cardol), have corrosive action in mammalian skin and thus may be responsible for its insecticidal properties also (Oparaeke and Amodu 2000; Amatobi 2000). The strong contact action of essential oil of cashew on insect pests was reported by Oparaeke and Bunmi (2006). Dourado *et al.* (2015) reported that the mode of action of CNSL is same as most of the phenolic acids. The hydrophobic nature of the aliphatic chain facilitates the permeability through the cell membrane and acts on the protein-amino acid mechanism disabling them.

CNSL 20% EC @ 4% and 5% produced quick high mortality of 93.33 per cent within 24 h, an effect on par with chemical check, thiamethoxam @ 0.01% and

botanical check, 3% neem oil. Such high and quick mortality was reported against bruchid *Callosobruchus subinnotatus* on groundnut, wherein 100 per cent mortality within 48 h was observed when exposed to 7.5% CNSL (Oparaeke and Bunmi, 2006). Similarly, Asogwa *et al.* (2007) found that CNSL at 6 %, caused 100 per cent mortality of termite soldier in 90 minutes and worker in 60 minutes. Andayanie and Ermawati (2019) evaluated the mortality rate of Cashew Nut Shell extract against the nymphs of silverleaf whitefly (*Bemisia tabaci*) and observed more than 90 per cent mortality of first and second stage nymphs at 2% and 6% concentration respectively.

Mortality produced by the lower concentrations (0.5 to 2 %) of CNSL at different intervals were inferior to the higher concentrations. CNSL 20% EC @ 0.5 %, 0.75 %, 1 % and 2% produced 40, 53.33, 60 and 73.33 per cent mortality respectively at 2 DAT which increased to 60.0, 60.0, 73.33 and 80 per cent respectively at 7 DAT and remained constant thereafter. A lower dose of 0.2 % CNSL was found to cause high mortality in chilli aphid, *Aphis gossypii* under laboratory conditions (Sundaran and Faizal, 2018). They also reported increased mortality with increase in concentration. In the current study, a matching effect could be observed with CNSL @ 4% and 5%. Thiamethoxam 0.01 % was reported to be effective against BPW by Sivakumar (2017).

When the mortality data was subjected to probit analysis the LC_{50} and LC_{90} values were found to vary from 0.83 to 0.38 per cent and 4.04 to 3.62 per cent respectively from 1 to 14 DAT. Since the mortality was found to be more or less constant three days after treatment, the LC_{50} and LC_{90} values of 0.5 and 3.7 per cent obtained at 3 DAT was selected as effective lethal doses for further evaluation. The lethal doses obtained in the present study against *O. longicollis* were comparable with the LC50 and LC90 values (0.275 and 2.979 per cent respectively) obtained against another chewing insect *S. litura* in cowpea (Lekha, 2020), but was very high when compared with that of the sucking pests *Riptortus pedestris* (0.095 and 0.275 per cent respectively) and *Aphis craccivora* (0.079 and 0.250 per cent respectively).

The doses of CNSL effective against grubs *viz.* LC_{90} (3.7%), half LC_{90} (1.5%), double LC_{90} (7.4%) and LC_{50} (0.5 %) were evaluated for preference of adult weevils under multiple choice and no choice tests to find out repellent effect if any.

In multiple choice test the maximum number of weevils (61.67 to 70 per cent) were attracted to the untreated check at various intervals which was significantly different from the rest of the treatments indicating repellant effect of various treatments. No weevil was attracted to pseudostem treated with the botanical checks, 5 % Nanma and 3 % neem oil emulsion during the first five hours. Significantly low proportion of weevils (2.5 -7.5 per cent) settled on pseudostem treated with CNSL @ 3.7 % and 7.4 % till 5 HAT indicating quick repellent effect. From eight hours after treatment, the per cent weevils attracted to 3.7 % and 7.4 % CNSL (0.83 to 2.5 per cent weevils) were on par with Nanma and neem oil. Hence these two treatments were less preferred by the weevils. However, all the botanicals tested were found to have repellent effect against the weevils with no significant difference between them at 9 - 11 HAT attracting only 2.5 to 6.67 per cent weevils though significantly superior over untreated (67.5 - 69.17 per cent).

In no choice test, no weevils were found attracted to various treatments except pongam oil 1 %, during the initial 3 h. Afterwards, attraction increased with increase in time. Cent per cent weevils released were found to settle to untreated control from eighth hour. Among the various botanicals tested, least attraction was shown to 5 % Nanma (0 to 60 per cent) followed by 3 % neem oil emulsion (0 to 66.67 per cent). CNSL treated pseudostems were also less preferred by the weevils. The repellent effect was both dose and time dependent as evidenced by a decrease in the number of weevils attracted with increase in concentration, though more weevils settled on the treated pseudostems with progress in time due to absence of choice. The least attraction was shown to 7.4 % CNSL in which no weevils settled till 5 HAT. Only 13.33 to 46.67 per cent of weevils settled on this treatment from 6 to 12 HAT exhibiting repellent effect on par with botanicals Nanma 5% (20-46.67 per cent) and 3% neem oil emulsion (20-60 per cent) and superior over other treatments. CNSL @ 3. 7 % was also equally effective attracting only 20 to 60 per cent of weevils from 6-11 HAT.

Anitha (2000) recommended the swabbing of a mixture of slurry and neem oil five per cent on the pseudostem at five months after planting in heavily infested areas so as to deter BPW. The present study indicated the suitability of CNSL as a potential repellent of BPW, which can be utilized for the prophylactic management of the pest.

Though the higher concentrations of 7.4 and 3.7 % produced better effects, the lower concentration of 0.5% also produced comparable effect especially under multiple choice test. Boongaling *et al*. (2008) found that natural CNSL was repellent to *Coptotermes vastator* Light at a concentration as low as 0.1% which prevented the termites from exploring or tunneling. Bhagawati *et al.* (2009) tested the efficacy of different botanicals for their repellent properties against *O. longicollis* under laboratory conditions employing multiple and no choice tests and found that that 0.5 % neem oil followed by 0.5 % pongam oil showed strong repellent effect. Cassava leaf extract based cyano-glucosides containing products, Nanma and Menma, were recommended for prophylactic management of pseudostem weevil (Krishnan *et al.,* 2015). CNSL treatments exhibited excellent repellent effect comparable to neem oil and Nanma in the in the current study. Repellent effect of CNSL against *Aedes aegypti* was mentioned by Romano *et al*. (2018). CNSL was also found to repel *Rhipicephalus microplus* (ticks on cattle) at 50.0 mg mL^{-1} Castro *et al.* (2019).

Phytotoxicity has been reported upon application of CNSL in crops like coffee senna, tomato (Matias *et al*., 2017) and chilli (Sundaran, 2018). Hence, in order to check crop safety the effective doses of CNSL *viz.* 0.5% (LC_{50}), 1% (2 LC_{50}) and 3.7% (LC_{90}) were applied on banana plants following the two commonly adopted methods of application, leaf axil filling and stem injection. No abnormalities, except slight discoloration of the pipe leaf exposed to axil filling was observed in the plants treated with CNSL @ 0.5 and 1 %. The higher concentration of 3.7 % CNSL resulted in unfurling, browning and scorching of the tip of leaf which was at pipe stage at the time of treatment. Stem injection of various doses of CNSL tested were also found safe without any adverse effect except brown colourations at the site of application. No insignificant change was found in length and width of leaves that emerged after CNSL treatments and the previous leaves which proved absence of physiological ill effects. Thus, the CNSL doses tested were found safe to banana plants. Lekha *et al*. (2019) reported CNSL 20 % EC to be safe to vegetable cowpea at concentrations ranging from 0.05 to 1.0 per cent without any adverse effects whereas Andayanie and Ermawati (2019) could observe brown spot on soybean leaves, withering followed by the death of plant tissues at a higher concentration of CNSL.

Phenolic secondary metabolites of cashew plants were also reported to affect seed germination in several crops like cucumber (Noorfatiehah *et al*., 2011), *Zea mays* (Nwokeocha and Ezhumah, 2015), lettuce and tomato (Matias *et al*., 2017).

Inhibition of germination and growth occurs due to the interference of certain chemical compounds in cell division, membrane permeability and the activation of enzymes (Reigosa *et al.,* 2013) and the response of different crops towards the secondary metabolites varies due to physiological differences (Rizzi *et al*., 2016). Banana being a comparatively large and sturdy plant could withstand exposure to higher doses of CNSL. Since the reason for the biological effect of phenolic lipid constituents of CNSL are yet to be understood, more studies in this direction are required for the safe and efficient exploitation of this potential biorational pesticide.

The extent of damage caused by the pseudostem weevil, in the plants treated with CNSL for phytotoxicity evaluation, was also assessed by destructive sampling, two weeks after treatment. Reduction in damage indices *viz*. number of bore holes, number of sheaths attacked and vertical and horizontal damage of leaf sheaths were observed in CNSL treated plants over control indicating its potential pest control. This effect was dose dependent and varied with method of application. The stem injection treatments always produced lesser horizontal and vertical damage than the respective leaf axil filling.

Detailed field evaluation of the curative effect of CNSL was carried by applying effective doses of CNSL *viz.* 0.5% (LC_{50}), 1% (2 LC_{50}) and 3.7% (LC_{90}) via leaf axil filling and stem injection, in banana plants purposefully selected to have uniform infestation of BPW. Menma 15 mL/plant injection and thiamethoxam 0.03 % injection served as botanical and chemical check respectively. The number of bore holes, population of different stages of the pest and the damage (vertical and horizontal) were assessed five days after treatment by destructive sampling.

Stignificantly low number of bore holes per plant, population of BPW and damage were recorded in plants that received treatments with Menma 15 mL/plant injection and thiamethoxam 0.03% as injection. The effectiveness of these treatments against *O. longicollis* was reported earlier. Mortality of insects was noticed in 12 h due to the treatment with Menma at concentration of hydrogen cyanide @ 8 ppm or 3

mL dose of 300 ppm (Krishnan *et al.,* 2015). They recommended injection of 5% Menma formulation at three points in the infested plant against BPW. Prophylactic injection of thiamethoxam 0.03 % at fifth and sixth months after planting @ 2.5 mL injection^{-1} of same at four diagonally opposite sides of the pseudostem at 60, 90, 120 and 150 cm above the ground was found fruitful by Sivakumar (2017).

CNSL @ 3.7 % and 1% both as stem injection and leaf axil filling in the current study produced an effect on par with these treatments with respect to number of bore holes per plant. The ovipositional deterrent effect leading to reduction in oviposition and probing by BPW subsequent to treatment with botanical Neem Azal was documented by Sivasubramanian *et al.* (2009).

Similarly the number of live grubs were also low in CNSL treatments @ 3.7% stem injection (4.33 grubs plant^{-1}) followed by 1% CNSL stem injection (10 grubs plant^{-1}), 3.7% CNSL leaf axil filling (11.33 grubs plant^{-1}) and 1% CNSL leaf axil filling (12.67 grubs plant^{-1}) which were at par. There was not much difference in the number of pupae and adults which remained low in all these treatments.

The vertical and horizontal damage observed in leaf sheaths were recorded to know the extent of damage in the treated plants. *O. longicollis* tunneled more vertically (25.07 to 68.87 cm sheath^{-1}) than horizontally (16.6 to 53.83 cm sheath^{-1}) irrespective of the treatment effects. Azam *et al.* (2010) reported that the bore holes can be seen even up to six feet from the ground in heavily infested older plants and the sequence of holes, which is approximately equidistantly placed, is a characteristic feature found along a vertical line. They also found that the grub makes tunnels in the pseudostem and move upwards till pupation. This could be the reason for more vertical damage than horizontal damage.

Damage (vertical and horizontal) produced by the pest was significantly low in thiamethoxam 0.03% as stem injection (vertical damage of 25.07 cm and horizontal damage of 15.27 cm sheath^{-}1) closely followed by injection with Menma @ 15 ml/plant injection (30.97 cm mean vertical damage and 16.6 cm mean horizontal damage sheath^{-1}). Mathew *et al.* (1997) observed stem injection of chemicals to be much efficient and precise than swabbing of insecticides along with surfactants, mud as well as mud slurry containing insecticides and spraying and fumigation of the spaces between leaf sheaths in the pseudostem. In the present investigation 3.7 %

CNSL stem injection produced an effect (31.63 cm of vertical damage sheath^{-1}) on par with botanical check Menma. CNSL @ 3.7% leaf axil filling and 1% both as stem injection and leaf axil filling were on par with comparatively low vertical damage (36.37, 37.17 and 37.2 cm sheath^{-1} respectively) as well as horizontal damage (24.03, 23.87 and 24.4 cm sheath^{-1} respectively). In all the cases, plants treated with the lower concentration of CNSL @ 0.5 % exhibited more damage and population of BPW, though superior over untreated.

The per cent reduction of bore holes, mean horizontal and vertical damage per sheath and number of live grubs retained plant^{-1} that received different CNSL treatments over control are represented in the (Fig. 2.). Significant reduction of population and damage over untreated control were observed in plants that received treatments with Menma 15 mL/plant injection, thiamethoxam 0.03% injection and CNSL @ 3.7 % stem injection. Substantial reduction in the number of bore holes in plants (17.04 to 18.69 per cent), number of grubs (76.81 to 78.58 per cent), vertical damage (54.07 to 63.60 per cent) and horizontal damage (66.01 to 71.63 per cent) was noted in plants that received these treatments.

Thus, this study makes it evident that stem injection of CNSL 20 % EC @ 3.7% through the bored holes at 20 mL plant^{-1} is effective for the curative control of *O. longicollis*. Lekha (2020) developed this CNSL based botanical insecticide formulation (CNSL 20% EC), which when applied @ 0.3 % in yard long bean, could significantly reduce the population of *A. craccivora* (0.56 aphids leaf^{-1}), *Tetranychus* sp. (1.0 mite leaf$^{-1)}$, *Emposca kerri* (0.44 hopper leaf^{-1}) and *R. pedestris* (0.83 plant^{-1}) over untreated control (20.67 aphids leaf^{-1}, 19.33 mites leaf^{-1}, 10.22 hoppers leaf^{-1} and 9.17 bugs plant$^{-1)}$. However, @ 0.3% it was less effective against the chewing pest *S. litura*. A comparatively very high dose of 3.7 % CNSL was required against BPW, it being a coleopteran borer pest with unique habit and habitat. Stem injection with chemicals *viz*. monocrotophos or diamethoate in water @ 1:5 ratio or monocrotophos 4 mL plant^{-1} (Vijayalalitha and Vallalkannan, 2006; Justin *et al*., 2008; Irulandi *et al*., 2012; Shanmugham *et al*., 2013) as well as botanicals like Neem Azal in water @ 4:4 ratio (Sivasubramanian *et al.*, 2009), Azadirachtin @ 10000ppm - 2mL plant^{-1} (Irulandi *et al*., 2012) were earlier recommended for the management of BPW.

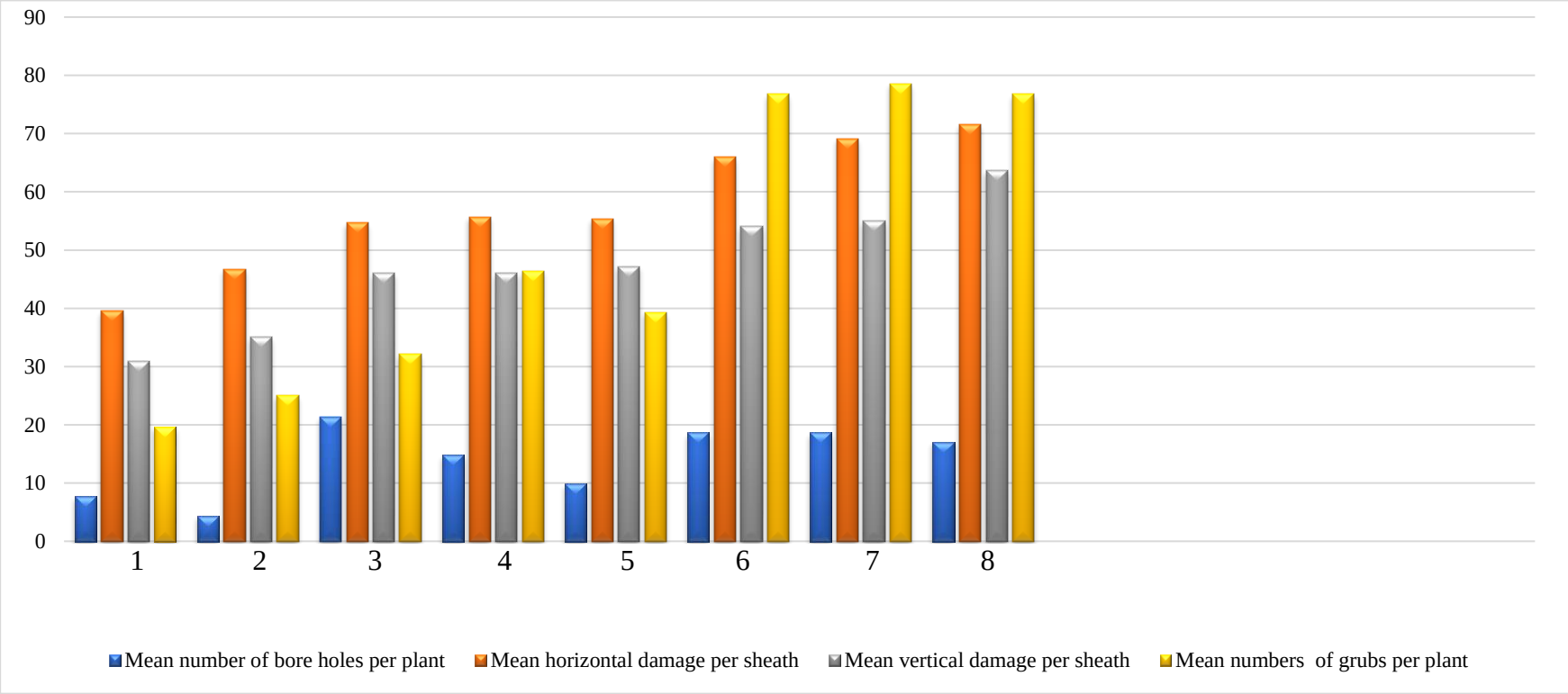


Fig 2. Per cent reduction in population and damage of *O. longicollis* in plants treated with CNSL

1. CNSL 0.5 % as leaf axil filling
2. CNSL 0.5 % as stem injection
3. CNSL 1.0 % as leaf axil filling
4. CNSL 1.0 % as stem injection
5. CNSL 3.7 % as leaf axil filling
6. CNSL 3.7 % as stem injection
7. Menma – 15 ml/plant injection
8. Thiamethoxam 0.03% as injection

Sivasubramanian *et al.* (2009) found that stem injection of Neem Azal (4:4) could produce significant mortality over swabbing of the same as well as the lower concentrations of stem injection. Stem injection of high concentration of Neem Azal (4:4) could produce highest per cent mortality (93.81) with lowest per cent damage as against swabbing of Neem Azal (4%) that could produce low mortality (43.47 per cent) after 96 hours of application.

CNSL @ 3.7 % leaf axil filling and 1% both as stem injection and leaf axil filling also could reduce the damage by BPW comparable with CNSL @ 3.7 % injection with low vertical damage (45.99 - 47.19 per cent reduction over control) as well as horizontal damage (54.67 - 55.66 per cent reduction over control). However, among these treatments, leaf axil filling with 1% CNSL gave better protection from probing and oviposition as evidenced by 21.43 per cent reduction of number of bore holes over control as against 4.4 to 18.69 per cent noted in other CNSL treatments, making it ideal for prophylactic control. At 1% concentration, CNSL was earlier found to be as effective as cypermethrin against insect pests of cowpea under field conditions, with a higher protective capability and lesser toxicity to leaves (Olotuah and Ofuya 2010).

Prophylactic application of a mixture of mud slurry and neem oil 5 % on pseudostem prevented oviposition by adults (Anitha, 2000). Leaf axil filling with entomopathogenic nematode *Heterorhabditis bacteriophora* @ 4 cadavar plant^{-1} at 5,6,7 and if required at 8 months after planting as well as application of crushed neem seed @ 50 g plant^{-1} as leaf axil filling at 4th and 6th month after planting was advised by KAU (2016). Prophylactic stem injections of thiamethoxam 0.03 % or application of *Metarhizium majus* followed by thiamethoxam 0.001 % leaf axil filling or 0.03 % stem injection at fifth and sixth months after planting gave fruitful results (Sivakumar, 2017). Remya (2018) evaluated the effect of prophylactic and curative application of *Beauveria bassiana* talc-based capsules and showed that chitosan-based ones to be effective.

The suitability of CNSL 20% EC @ 1% leaf axil filling for prophylactic control of BPW have to be further investigated in the field along with other agents and methods of application. CNSL @ 1 % leaf axil filling and injection could not however reduce the number of grubs (32.14 to 46.44 per cent over control) to the

extent of injection with 3.7% (76.81 per cent over control) which might have resulted in more internal damage, making it comparatively less effective than 3.7% stem injection, for the curative control of BPW.

Thus, based on the results of laboratory and field evaluation on effectiveness, crop safety as well as population and damage reduction, the 20% EC formulation of CNSL @ 3.7 % stem injection and 1% leaf axil filling are better choices for bio-rational eco-friendly management of pseudostem weevil of banana, with the former being better for the curative control.

6. SUMMARY

The production and productivity of banana, the most important fruit crop of the state, is seriously affected by the incidence of a number of pests of which ravages by banana pseudostem borer, *O. longicollis* causes huge economic loss to the cultivators. This pest is capable of causing upto cent per cent reduction in the quality and quantity of the produce, if proper and timely management measures are not taken. Non judicious use of chemical pesticides, including those banned for agricultural purposes are resorted by the growers resulting in environmental and health hazards. Development of an eco-friendly botanical pesticide to tackle this pest is the need of the hour, to sustain the cultivation the crop, ensuring environmental safety and economic returns to farmers. The present study is a step in this direction and was undertaken with an objective to investigate the suitability of the Cashew Nut Shell Liquid based emulsifiable formulation (CNSL 20% EC), developed at the Department of Entomology, College of Agriculture, Vellayani as a botanical pesticide against BPW. The study was carried out during 2018-20 at the College of Agriculture, Vellayani and farmer's field at Varkala, Thiruvanthapuram.

CNSL 20% EC was tested for its efficacy against third instar grubs of *O. longicollis* at different concentrations, *viz.* CNSL @ 0.5, 0.75, 1, 2, 3, 4 and 5 % under laboratory conditions. Neem oil emulsion 3% and pongam oil emulsion 1% were used as botanical checks. Thiamethoxam 0.01 % served as chemical check.

Grubs treated with lower concentrations of CNSL (0.5 % and 0.75 %) were found to be dead away from the treated pseudostem pieces with bloated body without any discolouration. The treated pseudostem pieces were not preferred indicating the antifeedant property of CNSL. At concentrations of 1%, 2% and 3%, they were found to be dead with black discolouration of the abdominal region indicating contact and stomach action. At the higher concentrations of 4 and 5 %, the grubs were found dead, shrunken and constricted indicating the corrosive nature of CNSL. The grubs were found to be highly discoloured too.

Higher concentrations of CNSL (4 % and 5%) was found to cause quick mortality of 93.33 per cent which was on par with that of chemical check, thiamethoxam 0.01 % and botanical check, neem oil emulsion 3%. CNSL @ 3 % caused mortality of 86.67 per cent and was on par with the higher concentrations of CNSL. Lower concentrations of CNSL (0.5 to 2 %) though produced superior mortality over control (40 to 80 per cent) were found to be less effective than the higher concentrations. Even though Pongam oil 1% was found to be on par with 0.5 and 1 % CNSL at the initial hours of treatment, they were found to be least effective throughout the test period.

Dose mortality response was investigated by probit analysis and the LC_{50} and LC_{90} values of CNSL against *O. longicollis* were computed as 0.52 and 3.71 per cent respectively at 3 days after treatment.

Adult weevils were exposed to pseudostem pieces treated with effective concentrations of CNSL *viz.* 1.85 % (0.5 LC_{90}), 3.7% (LC_{90}), 7.4% (2 LC_{90}) and 0.5 % (LC_{50}) along with botanicals, Nanma 5%, neem oil emulsion 3%, pongam oil emulsion 1% in multiple choice and no choice conditions to understand repellent effect.

In multiple choice test, the adults were found to be highly reluctant to treatments with Nanma 5% and neem oil 3% in the initial hours (1-5 HAT) of treatment with no weevils settling to them. Among the CNSL treatments, 3.7 and 7.4 % CNSL showed repellent effect to the weevils with only 3.33 to 5.83 per cent of the weevils moving towards them initially. 7.5 to 12.5 per cent of the weevils moved towards pseudostem pieces treated with CNSL @ 0.5 and 1.85 %. Upon longer exposure 7.5 % was the least preferred among the CNSL treatments with only 1.67 per cent of the weevils remaining on it at 24 HAT which was found superior to Nanma 5% and neem oil 3%. Other CNSL treatments were also less preferred (3.33 to 4.17 per cent weevils) as in the case of Nanma and neem oil (5 per cent weevils). Maximum weevils were found attracted towards the untreated (65 to 70 per cent) irrespective of the length of exposure. Among the CNSL treatments the per cent attraction ranged between 1.67 per cent (@ 3.7 % CNSL) to 12.5 per cent (@ 0.5 % CNSL) which were far superior from the untreated.

Under no choice test, as time progressed, all the treatments were shown to retain more number of the weevils on their surface. Initially (1 to 5 HAT), less number of weevils moved towards the CNSL treated pieces irrespective of the concentration (0 to 26.67 per cent) as compared to untreated check (46.67 to 93.33 per cent). Large number of weevils (93.33 to 100 per cent) were found to settle on pseudostem pieces treated with CNSL @ 0.5 to 3.7 % as against less numbers in Nanma 5% and neem oil 3% (60 to 66.67 per cent) at 24 HAT. 7.4 % attracted only 73.33 per cent weevils and was found to be superior comparable to treatments with Nanma and neem oil. Even at 12 HAT, CNSL 7.4 % was found to be on par with the botanical check. Untreated retained majority of the weevils from the initial hours after treatment itself and was found to be higher than other treatments throughout the test period.

Phytotoxicity evaluation of CNSL concentrations 0.5% (LC_{50}), 1% (2 LC_{50}) and 3.7% (LC_{90}) were conducted on banana adopting two methods of applications *viz.* leaf axil filling and injection into the pseudostem through the bored holes. The plants were observed for 14 days and noted for any abnormalities, if any.

No discolouration/phytotoxicity symptoms were observed in any of the existing leaves and leaf sheaths following application of treatments. They were found to be unfold within five to seven days after treatment. There was no time delay in the next leaf emergence, after treatment, as compared to the untreated. However, the central leaf at the time of application when unfolded have exhibited slight necrosis (less than 5 per cent) at the point of contact during leaf axil filling with 0.5 and 1 % of CNSL. Whereas upon treatment with 3.7 % CNSL the cigar leaf exhibited brownish discolouration in which 3 to 5 per cent of the tip portion failed to unfold. However, the next leaf emerged after treatment did not show any abnormalities. Infact, the comparison between dimensions of last leaf emerged after CNSL treatment with that of the mean of previous leaves was also found to be insignificant.

Various stem injection treatments of CNSL exhibited no abnormalities either in the leaf sheath or in the leaves of plants injected with different concentrations of CNSL except slight brownish discolouration in the leaf sheaths of the point of application.

Since there was no phytotoxicity to the crop, the same CNSL concentrations were evaluated for the management of BPW by applying on to banana plants (variety

Nendran) of uniform age and size, infested more or less uniformly with the pest at farmers field selected at Varkala, Trivandrum.

CNSL @ 0.5, 1 and 3.7 % following two methods of application: leaf axil filling (250 ml plant^{-1}) and stem injection (20 ml plant^{-1}) were applied. Menma 15 ml/plant injection served as the botanical check and stem injection with thiamethoxam 0.03 % as the chemical check. Population of the pest (number of live insects per plant) and the damage produced (number of bored holes per plant and mean vertical and horizontal feeding per leaf sheath) was studied by destructive sampling after five days of treatment.

Stem injection with 3.7 % CNSL was found to be superior in managing the pseudostem weevil with reduced number of bore holes (49.33 plant^{-1}), number of insects (4.33 larvae plant^{-1}, 5 pupae plant^{-1}and 2.33 adults plant^{-1}) and mean vertical and horizontal damage (31.63 cm sheath^{-1} and 18.3 cm sheath^{-1}). This treatment was found to be as effective as stem injection with thiamethoxam 0.03 % and Menma 15 mL plant^{-1}. Significant reduction of population and damage over untreated were observed in plants that received treatments with Menma 15 mL/plant injection, thiamethoxam 0.03 % injection and CNSL @ 3.7 % stem injection. Substantial reduction in the number of bore holes in plants (17.04 to 18.69 per cent), number of grubs (76.81 to 78.58 per cent), vertical damage (54.07 to 63.60 per cent) and horizontal damage (66.01 to 71.63 per cent) was noted in plants that received these treatments. Thus, this study indicated that stem injection of CNSL 20% EC @ 3.7% through the bore holes at 20 mL plant^{-1} is effective for the curative control of *O. longicollis.*

CNSL @ 3.7 % leaf axil filling and 1% both as stem injection and leaf axil filling also could reduce the damage by BPW comparable with CNSL @ 3.7 % injection with low vertical damage (45.99 to 47.19 per cent reduction over control) as well as horizontal damage (54.67 to 55.66 per cent reduction over control). However, among these treatments, leaf axil filling with 1% CNSL gave better protection from probing and oviposition as evidenced by 21.43 per cent reduction in number of bore holes over control as against 4.4 to18.69 per cent noted in other CNSL treatments, making it ideal for prophylactic control.

Thus, based on the results of laboratory and field evaluation on effectiveness, crop safety as well as population and damage reduction, the 20 % EC formulation of CNSL @ 3.7 % stem injection and 1% leaf axil filling are better choices for bio-rational eco-friendly management of pseudostem weevil of banana, with the former being better for the curative control.

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CASHEW NUT SHELL LIQUID (CNSL) FORMULATION FOR THE MANAGEMENT OF BANANA PSEUDOSTEM WEEVIL, *Odoiporus longicollis* (Olivier)

by

ARCHA S NAIR

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ABSTRACT OF THESIS

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ABSTRACT

The study entitled "Cashew Nut Shell Liquid (CNSL) formulation for the management of banana pseudostem weevil, *Odoiporus longicollis* (Olivier)" was undertaken in the Department of Agricultural Entomology, College of Agriculture, Vellayani during 2018-20 with an objective to evaluate Cashew Nut Shell Liquid formulation (CNSL 20% EC) for the curative management of the pest.

Cashew Nut Shell Liquid (CNSL), a potential insecticide and a cheap by-product of cashew industry, was formulated into an emulsifiable concentrate formulation (CNSL 20 % EC) in the Department of Agricultural Entomology, College of Agriculture, Vellayani was tested against *O. longicollis*. Different concentrations *viz.* CNSL @ 0.5, 0.75, 1, 2, 3, 4 and 5 % were evaluated against third instar grubs of *O. longicollis* under laboratory conditions. Grubs treated with lower concentrations of CNSL (0.5 % and 0.75 %) were found to be dead with bloated body without any discolouration. At concentrations of 1%, 2% and 3%, they were found to be dead with black discolouration of the abdominal region. At the higher concentrations (4 and 5%), the grubs were found dead, shrunken and constricted.

Higher concentrations of CNSL (4% and 5%) was found to cause mortality of 93.33 per cent which was on par with that of chemical check, thiamethoxam 0.01 % and neem oil emulsion 3%. CNSL @ 3 % caused mortality of 86.67 per cent and was on par with the higher concentrations of CNSL. The LC_{50} and LC_{90} values of CNSL against *O. longicollis* was found to be 0.52 and 3.71 per cent respectively at 3 days after treatment.

CNSL concentrations *viz*. 1.85 % (0.5 LC_{90}), 3.7% (LC_{90}), 7.4% (2 LC_{90}) and 0.5% (LC_{50}) applied on pseudostem pieces were evaluated along with botanicals, Nanma 5 %, neem oil emulsion 3% and pongam oil emulsion 1% to ascertain the repellent effect on adult weevils in multiple choice and no choice test. The adults were found to be highly reluctant to Nanma 5% and neem oil 3% in the initial hours (1 to 5 HAT) of treatment in the multiple-choice test with no weevils getting settled on them. CNSL treatments @ 3.7 and 7.4 % were found to be less attractive to the weevils with only 3.33 to 5.83 per cent of the weevils moving towards them initially.

7.5 to 12.5 per cent of the weevils moved towards pseudostem pieces treated with CNSL @ 0.5 and 1.85 %. Upon longer exposure 7.4 % was the least preferred among the CNSL treatments with only 1.67 per cent of the weevils remaining on it at 24 HAT which was found superior to Nanma 5% and neem oil 3%.

When no choice was given, initially (1 to 5 HAT), less number of weevils (0 to 26.67 per cent) moved towards to CNSL treated pieces irrespective of the concentration as compared to untreated check (46.67 to 93.33 per cent). Large number of weevils (93.33 to 100 per cent) were found to settle on pseudostem pieces treated with CNSL @ 0.5 to 3.7 % as against less numbers in Nanma 5% and neem oil 3% (60 to 66.67 per cent) at 24 HAT. CNSL @ 7.4 % attracted only 73.33 per cent weevils and was found to be superior comparable to treatments with Nanma and neem oil.

Banana plants uniformly infested with pseudostem weevil were applied with CNSL @ 0.5, 1 and 3.7 % following two methods of application *viz*. leaf axil filling (250 mL plant^{-1}) and stem injection (20 mL plant^{-1}). Menma 15 mL/plant injection served as the botanical check and stem injection with thiamethoxam 0.03 % as the chemical check. The number of bore holes, mean vertical and horizontal damage produced by the pest and the number of live insects retained were assessed by destructive sampling. No phytotoxicity was observed.

CNSL @ 3.7 % and 1% both as stem injection and leaf axil filling produced an effect on par with other treatments with respect to number of bored holes plant^{-1}. Similarly the number of live grubs were also low in CNSL treatments @ 3.7% stem injection (4.33 grubs plant^{-1}) followed by 1% CNSL stem injection (10 grubs plant^{-1}), 3.7% CNSL leaf axil filling (11.33 grubs plant^{-1}) and 1% CNSL leaf axil filling (12.67 grubs plant^{-1}) which were on par.

Stem injection with 3.7 % CNSL was found to be superior in managing the pseudostem weevil with reduced number of bore holes (49.33 plant^{-1}), number of insects (4.33 grub plant^{-1}, 5 pupae plant^{-1}and 2.33 adults plant^{-1}) and mean vertical and horizontal damage (31.63 cm sheath^{-1} and 18.3 cm sheath^{-1}). The per cent reduction over control was found to be 18.69, 54.07, 66.01 and 76.81 respectively for number of bore holes per plant, mean vertical and horizontal damage and number of live grubs retained per plant. This treatment was found to be as effective as stem injection with

thiamethoxam 0.03 % and Menma 15 mL plant^{-1} for the curative management of banana pseudostem weevil.

CNSL 20% EC @ 3.7 % leaf axil filling and 1 % both as stem injection and leaf axil filling also could reduce the damage by BPW comparable with CNSL 20% EC @ 3.7 % injection with low vertical damage (45.99 to 47.19 per cent reduction over control) as well as horizontal damage (54.67 to 55.66 per cent reduction over control). However, among these treatments leaf axil filling with 1% CNSL 20% EC gave better protection from probing and oviposition as evidenced by 21.43 per cent reduction of number of bore holes over control as against 4.4 to18.69 noted in other CNSL treatments, making it ideal for prophylactic control.

Thus, application of CNSL 20% EC 1% both through leaf axil filling and stem injection and CNSL 20% EC 3.7 % leaf axil filling are successful in significantly reducing the population and damage by *O. longicollis* over untreated check though inferior to 3.7 % stem injection. Leaf axil filling treatment with 1 % CNSL and 3.7 % CNSL 20% EC were at par in reducing the population and damage.

Thus, CNSL 20% EC 3.7 % stem injection (20 mL plant^{-1}) and 1 % CNSL leaf axil filling can be resorted to, for the eco-friendly management of pseudostem weevil with the former being more effective for curative treatment.