MANAGEMENT OF BEETLE PESTS IN STORED RICE USING BOTANICALS

by

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(2016-11-014)

THESIS

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN AGRICULTURE

Faculty of Agriculture

Kerala Agricultural University

DEPARTMENT OF AGRICULTURAL ENTOMOLOGY

COLLEGE OF AGRICULTURE

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KERALA, INDIA

2018

DECLARATION

I, hereby declare that this thesis entitled **"MANAGEMENT OF BEETLE PESTS IN STORED RICE USING BOTANICALS"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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Certified that this thesis entitled **"MANAGEMENT OF BEETLE PESTS IN STORED RICE USING BOTANICALS"** is a record of research work done independently by Ms. Binseena S R under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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ACKNOWLEDGEMENT

*I am greatful to **God Almighty** for all the blessings showered upon me throughout my life and for the perseverance bestowed upon me especially during the course of my research work.*

*The foremost person to be thanked is **Dr. N. Anitha** Professor and Head, Department of Agricultural Entomology, College of Agriculture, Vellayani and Chairman of my advisory committee for her sustained and valuable guidance, constructive suggestions, unfailing patience, friendly approach, constant support and encouragement during the conduct of this research work and preparation of the thesis. I gratefully remember her knowledge and wisdom, which nurtured this research project in the right direction without which fulfillment of this endeavour would not have been possible.*

*I also owe my deep sense of gratitude and sincere thanks to **Dr. Ambily Paul**, Assistant professor, Department of Agricultural Entomology and member of my advisory committee for her support, untiring interest, suggestions and invaluable guidance throughout the study.*

*Words fail to express my indebtedness to **Dr. Anith K N**, Professor, Department of Agricultural Microbiology, College of Agriculture, Vellayani College of Agriculture, Vellayani for the valuable guidance, close scrutiny, precious suggestions and everwilling help rendered throughout my study.*

*I take this opportunity to express my heartful gratitude to **Dr. V.S. Amritha**, Assistant professor, Department of Agricultural Entomology, College of Agriculture, Vellayani and member of my advisory committee for her suggestions, valuable guidance, and accommodating with all facilities for the successful completion of my research work.*

*I express my sincere gratitude to **Dr. Shanas, Dr. Jiji, Dr. Reji Rani** and **Dr. Pradhapan** for their expert suggestions and critical evaluation of the thesis.*

*I also express my gratitude to **Santhu chettan, Aswathy chechi and Meri chichi** (non-teaching staff members of Department of Agricultural Entomology) for their whole-hearted cooperation and timely assistance.*

*I accord my sincere thanks to **Radhika mam**, Department of plant pathology and **Dr. Thomas George** for providing me lab facilities needed during the course of my work. I sincerely thank the facilities rendered by the **library, College of Agriculture**, Vellayani.*

I do not have words to express my love, affection and gratitude to my seniors, ***Ishrath itha, Anju chechi, Amritha chechi, Sankamesh chetta, Viswajyothi chechi, Hari chetta, Mithra chechi*** *and* ***Gayathry chechi,.*** *Without their help, suggestions and support this thesis would not have been realized. I wish to express my thanks to my batchmates* ***Kishor, Hampi, Fazeeh, Jyothis, Remya, Priyatha*** *and* ***Raeeza****, who always provided me good encouragement during difficulties. A special thanks goes to my juniors* ***Manu and Melvin*** *for their help and co-operation during the course of my work. I owe a big thanks to all my seniors* ***Ishrath itha*** *and* ***Anju chechi*** *for their valuable help and loving wishes for completing the study.*

The encouragement rendered by my friends at various stages of this investigation was invaluable and I thank ***Reshu, Sree, Karishma and Akhil*** *for their love, support and company.*

The award of KAU junior fellowship is greatly acknowledged.

This thesis would be incomplete if I do not reckon the sacrifices, love, affection and support of my family members, father ***Salim S****, mother* ***Ramla beevi,*** *husband* ***Nijam A,*** *siblings* ***Ramsi kutti*** *and* ***Bismi kutti*** *and all other relatives for their constant prayers, affection, moral support, personal sacrifice and sincere encouragement throughout the period of my studies.*

Binseena S R

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LIST OF ABBREVIATIONS

%	Per cent
µl	Micro litre
C.D.	Critical Difference
cm	Centimeter
DAT	Days After Treatment
et al	And others
F_1	First filial generation
FAO	Food and Agriculture Organisation
g	Gram
h	hour
HAT	Hours after Treatment
KAU	Kerala Agricultural University
kg	Kilogram
L	Litre
mg	Milli gram
mL	Milli litre
SE	Standard Error
sp	Species
viz.,	Namely

Introduction

1. INTRODUCTION

Stored product insects cause 5 to 10 per cent postharvest loss in developed countries and 35 per cent in developing countries around the world (Boxall, 2001). In India, total postharvest loss of stored grains accounts more than 50 billion Rupees per year and insect alone causes losses around 17 billion Rupees (Nagpal and Kumar, 2012). Pest infestation contributes to contamination in food products through the presence of dead and live insects, excretions and body fragments.

Information about major insect pests of stored product have been reported by many authors around the world. It includes both primary feeders and secondary feeders depending up on nature of food stuff and climatic conditions (Hill, 1990). Storage is a unique agro ecosystem, with less fluctuating environmental conditions which favour the development of insect pests rapidly (Phillips and Throne, 2010).

Important beetle pests reported from stored grains are rice weevil *Sitophilus oryzae* L., granary weevil *Sitophilus. granarius* L. and maize weevil *Sitophilus. zeamais* Motschulsky (Giolebiowska, 1969), lesser grain borer *Rhizopertha dominica* F. (Shaaya *et al.*, 1991), rust red flour beetle *Tribolium castaneum* Herbst (Haung *et al.*, 1997), saw toothed grain beetle *Oryzaephilus surinamensis* L. (Weston and Rattlingourd, 2000), pulse beetles *Callosobruchus chinensis* L., *C. analis* F. and *C. maculatus* F. (Ghosh and Durbey, 2003).

Effective and easy way to prevent insect damage in grain storage are by the use of chemicals. Control of storage pest depends on application of insecticides and fumigant such as organophosphates, pyrethroids, phosphine (PH_3), ethylene dichloride - carbon tetrachloride (EDCT) mixture (Leelaja *et al.*, 2007; Rajendran, 2016). Besides physical control methods such as drying, addition of inert dust, controlled atmosphere, traps and irradiation are also used. Control of pests by biorational methods like use of insect growth regulators, natural enemies and semiochemicals is also practised to some extent.

The increased awareness on the deleterious effect of chemical insecticides and the demand for insecticide free food has prompted the development of safer alternative management option. The use of botanicals offers an alternative management strategy against stored grain insect pests. It includes plant products such as dried plant parts, extracts from leaves, roots, flowers, fruits or seeds which were used for the control of stored food grains. These botanicals possess insecticidal properties like contact toxicity, repellency, feeding disruption, fumigant toxicity, and ovicidal actions (Isman, 2006). Besides these properties, non-systemic, biodegrability and low mammalian toxicity increases the preference of botanicals in stored pest management (Yildirim *et al.,* 2013). Management of stored grain insects using botanicals largely depends on availability of plants and prevailing environmental conditions. So there is a need to evaluate the efficacy of botanicals towards insect pests in each locality within a country.

Botanicals such as neem (Imti and Zudir, 1993), bird chilli fruits (*Capsicum frutescens* L.) (El-Lakwah *et al.,* 1997), tulsi leaves (*Ocimum tenuiflorum* L.) have been reported to have great potential for the control of insect pests of stored grains. Currently botanical products from pyrethrum, rotenone, neem (*Azadirachta indica* A.Juss.), garlic (*Allium sativum* L.), ryania, nicotine, sabadilla and capsicum oleoresin are used for insect control (Isman, 2006). Insecticidal property of garlic, mint (*Mentha arvensis* L.) and curry leaves (*Murraya koenigii* L.) were also reported (Nirjara and Sujatha, 2011). Insecticidal potential and inhibition of oviposition against rice weevil were reported for pepper (*Piper nigrum* L.), clove buds (*Syzygium aromaticum* L.) and nutmeg mace (*Myristica fragrans* Houtt.) (Devi and Devi, 2013).

Essential oils from plant parts exhibit contact, fumigant, repellent and antifeedant actions to several coleopteran insect pests during storage. In recent years these essential oils as insecticides acquired more attention in pesticide market. Biosynthetically different compounds in the essential oils singly or in combination shows insecticidal action. These oils are normally liquid at room temperature and easily transform to gaseous state without any decomposition. Fumigant action of volatile oils are due to the presence of monoterpenes (Koul *et al.,* 2008). In this context, four volatile essential oils such as clove oil (*S. aromaticum*), lemon grass oil (*Cymbopogon flexuosus* (Nees *ex* steud)), cinnamon oil (*Cinnamomum zeylanicum* Blume) and pepper oil (*P. nigrum*), dried plant parts and extracts of above mentioned plants were selected to assess their potential for managing beetle pests in stored rice.

The present study entitled 'Management of beetle pests in stored rice using botanicals' has been carried out to document major beetle pests of stored rice and to develop effective management measures using botanicals.

Review of literature

2. REVIEW OF LITERATURE

More than half of the population depends on rice as staple food around the world. However damage caused by insect pest during storage leads to huge loss in the availability of grains during off seasons. Harvest of cereals occur at specific time in a year and they must be stored for a long period of time for continues supply of food. Temperature and humidity in atmosphere as well as in the grains have great role in the development and establishment of insect pests.

Both whole and milled rice are severely attacked by insect pests belonging to Coleoptera and Lepidoptera. Storage of rice grains by conventional as well as modern structures are prone to attack of these insect pests and cause huge economic loss. This loss sometimes reached to 10 per cent of total production which accounts to 10 lakh tons of grain (Compton and Sherington, 1999). The presence of insects also cause menace during export over countries. While considering these factors a well-integrated pest management is required for stored grain insect pest control to reduce losses. According to Food and Agriculture Organization (FAO), world population will reache up to 9.8 billion in the year 2050. So there should be a two to five fold increase of food commodities to meet the consumption requirement of human population (Gunarathna and Karunaratna, 2009). Available literature on stored grain insect pests is depicted below.

2.1 STORED GRAIN INSECT PESTS

A stored product pest can be defined as 'any organism injurious to stored foodstuffs of all types of (especially grains and pulses, vegetables, fruits, etc.), seeds, and diverse types of plant and animal materials stored for human purpose' (Hill, 1990).

Insect pests in stored grains are grouped into two, primary and secondary pests based on their mode of attack. Those insects which can develop and feed internally within the food commodity is referred as primary pests, while secondary pests can infest only from externally and their development is carried outside the whole grains (Johnson, *et al.*, 2004). Infestation of internal feeders and processing of food grains are commonly followed by attack of secondary pests. The milled and broken grains are more susceptible to external feeders those which are unable to reach whole grains. Insect pests of stored grains also include detritus and mould feeders, animal protein feeders and predators.

Storage insect pest can cause annual damage of 10 to 40 per cent in stored food commodity all over the world (Upadhyay and Ahmad, 2011). There were 1,663 insect species are reported as pest of stored food commodities, among which few insects were known for its greater damage ability and well distribution all over the world. Their presence were reported from grain elevators, mills and retailers (Hagstrum and Phillips, 2017).

Lefroy (1909) published cautious list of storage insect pest of India in his famous book 'Indian Insect Life'. Currently more than 70 insect species are identified from warehouse conditions of India. Major insect pests of stored grains include both beetles and moths. Beetles are highly diversified and cause huge destruction of stored grain when compared with that by moth (Upadhyay and Ahmad, 2011).

Beetle pests of stored products are rice weevil *S. oryzae*, granary weevil *S. granarius* and maize weevil *S. zeamais* (Giolebiowska, 1969), lesser grain borer *R. dominica* (Shaaya *et al.*, 1991), saw toothed grain beetle *O. surinamensis* and merchant grain beetle *O. Mercator* (Arbogast, 1991), rust red flour beetle *T. castaneum* and *T. confusum* (Huang *et al.*, 1997), pulse beetles *C. chinensis*, *C. analis*, *C. maculatus*, *Acanthescolides obtectus* Say, *Bruchus pisorum* L. (Ghosh and Durbey, 2003), flat grain beetle, *Laemophiloeus pusillus Schönherr*, *Cryptolestes ferrugineus* Stephens (Riudavets *et al.*, 2009), Khapra beetle *Trogoderma glabrum* Herbst (Upadhyay and Ahmad, 2011), *Prostephanus truncates* Horn (Tefera *et al.*, 2011) and *T. granarium* Evert, cadelle beetle *Tenebroides mauritanicus* L. (Johnson, 2013) which can infest on wide range of stored products.

Storage pests also include lepidopteran pests such as indian meal moth *Plodia interpunctella* Hubner (Hamlin *et al.*, 1931), angumois grain moth *Sitotroga cerealella* Oliver, rice moth *Corcyra cephalonica* Stainton (Mbata,1989), warehouse moth *Ephestia cautella* Walker (Cox and Bell, 1991), potato tuber moth *Phthorimaea operculelella* Zeller (Ghosh and Durbey, 2003) and codling moth *Cydia pomonella* L. (Johnson, 2013).

2.2 BEETLE PESTS OF STORED GRAIN

S. oryzae, *S. zeamais*, *R. dominica* and *P. truncates* are considered as primary beetle pest species that cause huge economic loss of grains worldwide (Hansen *et al.,* 2004).

2.2.1 Rice Weevil *S. oryzae*

Rice weevil *S. oryzae* is one of the most important internal feeders of grains under storage due to its destructive and cosmopolitan nature (Shaaya *et al.*, 1991). Infestation of rice weevil cause loss of stored grains both qualitatively and quantitatively. They can infest wide range of food grains even from field itself. Attack of rice weevil was reported from rice, wheat, maize, sorghum, barley, rey, lentil, cassava, biscuits, dried potatoes, corn flour, bean, pumpkin seeds, tamarind seeds and variety of millets (Devi *et al.*, 2014).

In a report given by Giolebiowska (1969) both adult and larvae can feed on grains at a rate of 0.4 gm day^{-1} and 14 mg day^{-1} respectively. Dal-Bello *et al.* (2001) reported that infestation of rice weevil on grains lead to the loss of endosperm, carbohydrate content, protein and vitamins. Study on special distribution of weevils on wheat showed that 80 per cent of them preferred top layer of wheat (Jianab *et al.*, 2012).

Life cycle study of *S. oryzae* on rice cultivar Pusa 2-21showed that a period of 35- to 49 days required for emergence of adult weevil from egg stage (Singh, 2017). Evaluation on each life stage gave information about length of egg (0.71mm), survival period of male and female (81 to 105 and 57 to 63 days respectively), mating and incubation period. Development of larvae and pupae takes place in the grain kernel without any visible symptoms outside.

According to Choudhury and Chakraborty (2014) adult male and female can live for 85 to 109 days and 59 to 64 days in the presence of food. Study on biology of weevil by them also showed an incubation period of 6 to 7 days, larval period of 22 to 29 days and pupal period of 7 to 8 days. Weevil commenced mating 4 to 6 days after emergence.

Studies on biology of rice weevil showed greater variation in each stage of development according to environmental conditions, type of crops, variety, grain moisture and storage conditions. During favourable conditions, infestation of weevil lead to development of hot spots due to increased respiration. Heavy infestation cause caking of grains and facilitate secondary growth of several fungus (Ghosh and Durbey, 2003).

2.2.2 Saw Toothed Grain Beetle *O. surinamensis*

The insect was first named as *Dermestes surinamensis* in family Silavanidae under oder Coleoptera and later renamed as *O. surinamensis* by Blaschke. The saw toothed grain beetle is external feeder and can attack on wide range of food commodities which include cereals, cereal products, maida, suji, cotton, groundnut, beans, copra, nuts, spices and dried fruits (Hill,1990; Subramanyam, 1992). It cause menace in stored grain by their presence rather than the feeding. The beetle and larvae feed only a small fraction of food which they attack. They are widely distributed around the world. In India, they were reported from Uttar Pradesh, Bihar, Madhya Pradesh, Punjab, Haryana and Rajasthan (Ghosh and Durbey, 2003).

Study conducted by Jacob (1981) revealed that eggs of saw toothed grain beetle failed to hatch at 15°C in oatmeal. Based on temperature variation, incubation period of egg ranged from 3 to 16 days. Occurrence of beetle on top layer of wheat was only less than 30 per cent. Whereas adult chose central location of wheat mass (Jianab *et al.*, 2012). Biological parameters such as duration of egg, larval, pupal and total life cycle varied according to environmental conditions and substrate on which they feed.

2.2.3 Merchant Grain Beetle *O. mercator*

These beetles are identical to *O. surinamensis* and only difference in respect to the size of eyes. Adult beetle can live up to 18 weeks. Female can lay around 260 eggs for a period of 360 days. Growth of this beetle was hindered at relative humidity more than 96 per cent (Arbogast, 1991) and they can't penetrate the packing materials (Johnson, 2013).

2.2.4 Red Flour Beetle *T. castaneum*

Red flour beetles are serious pest of stored food products, cosmopolitan and originated in India (Hinton, 1948). They are similar in appearance with confused flour beetle *T. confusum*. Economic damage was caused by both adult and larvae through feeding, cast skins, feces and presence of dead insect.

Adult beetle measured 3 mm in length, very active and able to fly. They survived for 2 to 5 years and female can produce 300 to 600 eggs with laying capacity of 2 to 13 eggs per day up to 300 days (Good, 1936). Total life cycle was more than 40 days in peanut at 35^0C and 70 per cent relative humidity (Arbogast, 1991). Occurrence of high population of beetle produce odour due to the secretion of defensive quinones (Villaverde *et al.*, 2007). They are secondary feeders and can infest on wide range of products such as peanuts, walnuts, dried fruits, legumes, spices, processed foods and flours. They can feed on other insects and their own eggs also (Johnson, 2013).

2.2.5 Lesser grain borer *R. dominica*

A primary pest of stored grain and cosmopolitan in nature. Mostly attack on wheat, rice, maize, jower, barley and dried fruits. Occasionally recorded from field also (Ridgway and Chambers, 1996). The economic damage is caused by both adult and grub. Adult shows a preference to germinal region whereas grub eat out starchy portion of grains.

According to Hill (1990) matured female can lay 200 to 500 eggs loosely into the grain or in cracks on grains. Emerged larvae feed initially on grain debris and later bore into the grain. Larvae can even grow on low moisture content as low as 9 per cent. The larvae undergo 3 to 5 moults and take 17 days on wheat. Pupal period extends for 3 days and pupation takes place within the grains. Adult beetle is a good flier.

The hatching period of egg varied from 5 to 6 days in summer and 15 to 21 days in winter. The larvae have curved abdomen with light brown head. Total life cycle of beetle varied from 56 to 84 days with 5 to 7 generations. Both adult and grub can hibernate during December to February (Ghosh and Durbey, 2003).

2.2.6 Khapra Beetle *T. granarium*

Khapra beetles are important stored grain insect pest which is distributed in tropical and subtropical areas. They are secondary feeders and can attack on grains, cereals and other stored products. Economic damage is caused by larvae due to reduced carbohydrate, fat and protein content. Also presence of beetles, caste skin and spiny hairs of larvae reduce quality of commodity and these are harmful to human health (Ahmedani *et al.*, 2009).

Study on biology of khapra beetle on barley, rice, rye, wheat and walnut showed that highest number of ten instars was observed in walnut and least on wheat with six instars. Larval period also varied according to substrate which ranged from 48 to 85 days. Pupal period was 5 to 6 days. Highest fecundity of beetle was observed in wheat whereas highest survival was recorded in rye (Borzoui *et al.*, 2015).

2.3 MANAGEMENT

2.3.1 Conventional Methods

2.3.1.1 Sanitation and Exclusion

To avoid pest infestation in large scale storage, disinfection of harvesting equipment, containers, loading areas are necessary before harvesting the produce.

Treatment of inside walls, floors, ceiling of structures, machineries are to be done with insecticides to exclude primary source of insect pests. Exclusion of insect pests during storage can be achieved by providing insect proof screen on windows, doors, roof ventilation and sub floor intake aeration vents (Arthur *et al.*, 2009).

Sweeping or vacuum cleaning and destruction of produce residues also needed to avoid multiplication of insect pests in store houses. Cautious inspection in corners and crevices are more important to avoid insect lurk in these places. Sacks, bags, and containers must be thoroughly cleaned to eliminate hidden insects, eggs and pupae (Hill, 1990). Effective hygiene and proper ventilation can reduce 85 per cent storage pest problems (El-Aziz, 2011).

2.3.2 Physical Methods

Control of stored grain insect pests through physical method includes manipulation of environmental factors or applying physical treatments.

2.3.2.1 Inert Dusts

Inert dusts are nontoxic unreactive dusts with insecticidal capacity. Death of insects due to addition of inert dusts are mainly by means of dehydration. There are five types of inert dusts, such as sands and other soil components, diatomaceous earth, silica aerosols, non-silica dusts and particle films (Fields and Muir, 1996). The dust either cause aberration on cuticle (diatomaceous earth) or directly absorbed to waxy coating of insect cuticle and lead to dehydration. They also cause clogging of spiracles and lead to asphyxiation and death of insects (El-Aziz, 2011).

2.3.2.2 Drying

Moisture is an important factor which facilitates growth of insects and fungal spores during storage of products. Reducing moisture content in grain is an option for storage pest control. Preferred moisture content of grains for safer storage of food grains is less than 13 per cent. Moisture level at 9.5 per cent stop feeding of *S. oryzae* (Hill, 1990). Grains stored at 10 per cent moisture level can avoid infestation of insect pests except khapra beetle (Ghosh and Durbey, 2003).

2.3.2.3 Temperature

For the development of each species of stored pests, certain optimum temperature and moisture level is required. Under extreme climatic conditions, their normal development get delayed or completely arrested (Ghosh and Durbey, 2003). Temperature manipulation in stored environment controls insect population at some extent. Most of the insects were died at 50 to 60^0C within 10 to 20 minutes of exposure. Cent per cent mortality of *E. cautella*, *E. elutella*, *P. interpunctella*, *T. castaneum*, *T. confusum*, *O. surinamensis* and *S. granarius* occurred at temperature ranging from 43 to 50^0C (Ghosh and Durbey, 2003). Optimum temperature for growth and reproduction of insect pest varied from 25 to 33^0C (Phillips and Throne, 2010).

Death of insects occurs at freezing point which ranged from -10 to -20^0C. Aeration of bulk grains with cool air helps to attain lower temperature. Most of the stored grain insects stopped development at 20^0C with an exception in *S. granarius* which can grow even at 15^0C (Banks and Fields, 1995). Besides heating of grains, stored structures also heated to around 50^0C for one day to check the development of insect pests which is known as 'bake-out' (Neeson and Banks, 2000).

2.3.2.4 Controlled Atmosphere

Management of stored products using controlled atmosphere is used for protection of harvested products from deleterious factors such as pests, disease and atmospheric conditions. Modification of atmosphere is based on reduced oxygen, high carbon dioxide or nitrogen (Adler *et al.*, 2000; Navarro, 2006).

Conyers and Bell (2007) reported mortality of *S. granarius* and *S. oryzae* with O_2 level of 4 per cent and 5 per cent at 25^0C. Whereas O_2 at 3 per cent caused mortality of *O. surinamensis* and *T. castaneum*. When considering the level of N_2, there were no mortality above 10 per cent at 20^0C. Complete population inhibition of *C. ferrugineus* was observed with 3 per cent O_2 at 20 and 25^0C.

Riudavets, *et al.* (2009) concluded that most of the stored grain pests couldn't survived at 50 per cent CO_2 after 4 days of exposure except *R. dominica*. Eggs of *E. kuehniella*, *P. interpunctella*, *O. surinamensis* and *C. ferrugineus* were highly susceptible at 4 days after treatment whereas more tolerance was observed in eggs of *Lasioderma serricorne* F., *T. confusum* and *S. oryzae*.

Carbon dioxide at high pressure in modified atmosphere resulted complete mortality of nine stored insect pests within hours. High level control of pests was recorded with Carbon dioxide at a pressure of 20 bar for 60 minutes (Ruidavets *et al.*, 2010).

2.3.2.5 Irradiation

Irradiation of food commodities to reduce pest attack is legal in most countries. This technique was initially applied for the management of *L. serricorne* (Diehl, 1995). Irradiation includes use of ionizing radiations such as gamma rays and nonionizing radiations such as radio frequencies, microwaves or infrared rays (Phillips and Throne, 2010). Irradiation at high dose ranged from 5 to 10 KGy cause complete mortality of insects in treated commodity whereas reduced development and reproduction of stored insect was reported at 0.05 to 0.45 KGy (Hallman, 2013).

2.3.2.6 Traps

Currently, a number of detection devices for stored grain insects are available. These devises can be used for both monitoring and mass trapping. Tamil Nadu Agricultural University developed such traps for stored grain insect pests. It includes insect probe trap, pitfall trap, two-in-one trap for pulse beetle, indicator device, automatic insect removal bin, UV – light trap and TNAU stored grain insect pest management kit. Main principle of this traps are wandering behaviour of the insects. TNAU Insect traps are effective in the detection of

R. dominica, S. oryzae and *T. castaneum.* These traps placed at top 6 inches of the grain can remove more than 80 per cent of the insects within 10 to 20 days (White *et al.,* 1990: Mohan, 2018).

2.3.3 Chemical Method

2.3.3.1 Fumigation

During fumigation pests are exposed to a poisonous gaseous environment. This includes fumigant such as aluminium phosphide, methyl bromide, carbon dioxide, carbon tetrachloride, ethylene dichloride, ethylene oxide, hydrogen cyanide and mixture of ethylene dichloride+ carbon tetrachloride (3:1) and carbon bisulphide + carbon tetrachloride (Gain-O-cide) (Upadhyay and Ahmad, 2011). Among which most effective and safer fumigant is aluminium phosphide.

In the last few years, methyl bromide and phosphine have been widely used as chemical fumigant for the stored pest management due to their ease and availability. Indiscriminate use of synthetic chemical insecticides has caused insect resistance, resurgence, negative effect on non-target organisms like parasites and predators and toxic residues in storage conditions of food commodities (Duke, *et al.*, 2005). While considering the environmental issues of ozone depletion, methyl bromide was included under restricted use (Arabi *et al.,* 2008).

Now a days stored insect pests showed both multiple resistance and cross resistance to conventional insecticides. It is clear in *T. castaneum* with two type of malathion resistance and different pattern of cross resistance to other insecticides (Dyte, 1970). *T. castaneum* was the first to report resistance towards analogue of juvenile hormone before it was known as insecticide in field condition (Dyte, 1972). This developed resistance in insects is attributed mainly to reduced uptake of fumigant (Benhalima *et al.*, 2004).

High level resistance to PH_3 was reported in *T. castaneum* and *R. dominica* in Australia (Collins *et al.,* 2009), *O. surinamensis* in Brazil (Pimental *et al.,*

2010) and rusty grain beetle, *C. ferrugineus* (Nayak *et al.*, 2012). Phosphine resistance in rice weevil was also reported in grain samples collected from Tamil Nadu during a study conducted by Rajan *et al.* (2017). Results showed that in all tested population, level of resistance varied from 21.21 to 93.38 per cent at a dose of 0.04 mg L^{-1} for 20 h exposure.

2.3.4 Biorational methods

Biorational method is achieved by directly using biologically based materials, such as biologically derived insecticides or biological control organisms, to control, eliminate or manage pest populations through manipulation of the physical and biological environments of the target species (Phillips and Throne, 2010).

2.3.4.1. Pheromones

There are two types of pheromone systems used in storage conditions such as (a) female produced sex pheromones for short lived species and (b) male produced aggregation pheromones for long lived species. The female sex pheromone system is illustrated in many species of stored-product moths especially in the Pyralidae and beetles in the families Anobiidae, Bruchidae, and Dermestidae (Phillips and Throne, 2010).

Pheromones were mainly used for surveillance and detection of an infestation and for mating disruption and mass trapping of insects by lures. Most commonly used pheromones are those for, *T. granarium, T. variabile, P. interpunctella, L. serricorne, T. castaneum, T. confusum, Sitophilus spp, S. paniceum* and *L. serricorne* (Phillips and Throne, 2010; Upadhyay and Ahmad, 2011)

2.3.4.2. Natural enemies

Control of stored grain insect pest by natural enemies include use of parasitoids and predators. Important parasitoid families which are effective against stored pests includes Braconidae, Ichneumonidae, Pteromalidae and

Bethylidae. Predators reported from stored grain include pirate bug, assassin bug, hister beetles and predatory mites (El-Aziz, 2011).

The nymphs and adult of warehouse pirate bug *Xylocoris flavipes* Reuter can prey on indian meal moths, almond moths, flour moths, red flour beetle, saw toothed grain beetle and warehouse beetles. They can't attack on internal grain feeders (Phillips and Throne, 2010; Upadhyay and Ahmad, 2011; El-Aziz, 2011).

2.3.4.3. Microbials

Number of laboratory evaluations were conducted with fungi *Beauveria bassiana* Vuill., *Metarhizium anisopliae* Sorokin and *Muscodor albus,* the bacterium *Bacillus thuringiensis* Berliner (Bt) and granulovirus (Gv) against stored grain insect pests to check their effectiveness.

The fungus *M. albus* produced a mixture of antimicrobial volatile organic chemicals which was tested for its insecticidal activity against potato tuber moth by Lacey and Naven (2006). The results showed that at 30 g of fungal formulation, 90.60 per cent death of adult and larvae occurred.

B. thuringiensis preparations are mainly used for the control of *C. cautella, P. interpunctella, S. cerealella, E. elutella, S. zeamais, R. dominica* and *L. serricorne* (Rahman *et al.*, 2004). Mustard oil with *Pseudomonas fumosoroseus* Wize on gunny bags showed oviposition deterrency, toxicity and protection from beetle infestation for 120 days (Sabbour and Aziz, 2010).

2.3.4.4 Insect growth regulators

These are chemicals which mimic moulting hormones in insects. This concept was initially used for the control of *T. castaneum* by Thomas and Bhatnagar-Thomas (1968). Insect growth regulators include the juvenile hormone analogues such as methoprene, hydroprene, pyriproxyfen, diflubenzurone, chlorfluazurone, hexaflumurone etc,. Application of these chemicals affect the biological processes in insects such as moulting, chitin synthesis, reproduction, abnormal morphogenesis, embryonic and post embryonic development (El-Aziz, 2011).

Effect of juvenile hormone on stored pests *viz., E. cautella, O. surinamensis, P. interpunctella, R. domonica* and *S. granarius* were studied by Oberalander *et al.*, (1997) under laboratory conditions. Treatment with hydroprene caused interrupted moulting in *T. castaneum* and *T. confusum* (Arthur, 2001).

2.3.5 Botanicals

India is a country with rich traditional knowledge in insect pest management over years. Some of such knowledge make a perfect way to scientist for finding better management practices to tackle pest menace. Such type of control measures are prevalent for management of stored grain insect pest *viz.*, mixing of dried leaves of neem and fruits of chillies with grains, painting of bamboo bins and mud pots with neem cake paste and mixture of cow dung + neem oil and mixing turmeric powder and sweet flag rhizome.

Botanicals have unique mode of action in insects and more safe to use in food commodities when health issues and environmental safety are concerned. Botanicals shows different toxicity effects in test insect due to many factors. One of such factor is mode of entry *viz.,* inhaled, ingested or absorbed and phagoinhibitory, fumigation and contact effect (Regnault-Roger, 1997). Active components of essential oils were highly lipophilic in nature and cause uneven basic biochemical processes, physiological disorders and behavioural changes in insects (Santos and Rao, 2000). Mode of action and the target pest determine the toxic effect of each essential oils apart from the species of plant material and its freshness under test (Liu *et al.*, 2006).

Large number of biopesticides are available from different plant families with insecticidal, ovicidal, larvicidal and repellent nature (Cetin *et al.*, 2005). Botanicals can be used as fresh, dried, grinded, water or solvent extracted and as oil through steam distillation in direct or indirect manner. Even though botanicals have greater benefits over conventional chemical pesticides, low bioavailability, high volatility and photo instability reduce their usage in different occasions (Rani *et al.*, 2013).

2.3.5.1 Pepper

Ukeh *et al.* (2009) reported that maize weevils showed repellence towards extract of alligator pepper and ginger. Khani *et al.* (2012) conducted an experiment to evaluate effect of essential oil of pepper against rice weevil. The results showed that at a concentration of 287.7 µl L^{-1} air caused death of half population after 72 h exposure whereas 97.00 per cent mortality of weevil was recorded at 370 µl L^{-1} volume after 72 h of exposure. They identified major compounds present in the pepper oil as limonene, α and β pinene and caryophyllene. Devi and Devi (2013) assessed insecticidal and oviposition deterrent properties of eighteen spices against rice weevil and showed that pepper powder at 1 % caused complete mortality of weevil at 7 days after treatment.

Moderate repellent activity of black pepper extract were reported between 20 to 50 mg ml^{-1} of water in an experiment with modified filter paper impregnation method by Ishii *et al.* (2010). The report given by Devi and Devi (2013) on hexane extract of some common spices showed that pepper oil have potential lethal effect on rice weevil. Filter paper discs with 0.59 µl cm^{-2} resulted total mortality of weevil at 72 h after treatment.

Monoterpene derivatives, sesquiterpenes and oxygenated sesquiterpenes such as alpha pinene, beta pinene, beta myrcene, limonene and caryophyllene in the extract of fresh fruits of *P. nigrum* are the major components responsible for insect mortality (Khani *et al.*, 2012).

2.3.5.2 Neem

Neem is well known for its insecticidal property and is being used extensively for pest management in field as well as in grain storage conditions. In India, reports have indicated that a handfull of dried neem leaves along with grains, crushed neem fruits, paste of leaves mixed with mud to prepare earthen containers and treated gunny bags gave a minimum level of control over pests in storage (Ahmed *et al*, 1988; Saxena *et al.*, 1989).

Schmutterrer (1990) reported that azadiractin is the major insecticidal constituent in neem, which have properties like repellence, ovicidal action, growth regulation, reproduction inhibitor and antifeedent. There are seven closely related isomers of azadiractin *viz.*, AZA to AZG. In which AZA is mostly present in neem seed kernel extract with effect on insect growth regulation. Since they have ability to inhibit production of prothoracicotropic hormone (PTTH) from brain neurons. Component such as salannin and meliantriol also present in neem which were reported with feeding deterrent property.

El-Lakwah and El-Kashlan (1999) screened the response of commercially available formulation of neem – neemazal (powder) containing 10 % azadiractin against some stored product insects. The results showed that mortality of rice weevil reached 100 per cent in all treatment varying from 20 to 1000 ppm for 14 days observation. Storage bag treatment with prophylactic spray of commercial neem formulation (Repellin) was more effective to control major stored insects like rice weevil, flour beetle and rice moth. Monitoring of treated bag with different plant extract for six months resulted less damage on grains under treatment of nimbicidin followed by curry leaf extract (Chander *et al.*, 2000).

Paranagama *et al.* (2004) carried out laboratory experiment on bioactivity of volatiles of neem against rice weevil. This study showed that concentration of 100 mg of neem had highest percentage of repellency. Fumigant toxicity of neem towards rice weevil was reported by Koul (2004) who showed that this property was due to the presence of di-n-propyl disulphide. Survey conducted in Assam by Deka *et al.* (2006) about traditional pest management concluded that use of neem leaf repelled stored grain pests due to their odour.

Studies of Sathyaseelan *et al.* (2008) on repellent nature of botanicals against rice weevil indicated that at a concentration of 5 g per 100 g grain resulted maximum level of repellency for neem seed powder followed by persian lilac and pongam. Santeshwari *et al.* (2010) investigated the efficacy of methanolic extracts of Neem against a secondary black fungus beetle pest *Alphitobius laevigatus* F. revealed that 5 ml of extract caused mortality of 85.50 per cent.

In a study conducted by Devi *et al.* (2014) to evaluate the effect of six botanical plant powder extract against rice weevil revealed that treatment with *Melia azadiracta* L. was the best one, with 50 per cent mortality at 14 days after treatment which reached to 80.54 per cent on 35 days after treatment. Whereas *A. indica* caused 70.74 per cent mortality at 35 day of exposure. The lowest grain damage and adult emergence were attained from the treatment with *A. indica* when compared with other treatments.

Kuldipake *et al.* (2016) evaluated mortality and repellency of rice weevil against eight locally available plant materials. Treatment with neem showed mortality of 12.26 per cent and 70.00 per cent repellency which were on par with sugar apple *Annona squamosa* L. leaf powder.

2.3.5.3 Garlic

Bhatnagar -Thomas and Pal (1974) examined insecticidal activity of garlic oil against *T. granarium*. Results showed that essential oil with diallyl disulphide and diallyl trisulphide cause AChE inhibition and mortality of test insects. Ho *et al.* (1996) screened and evaluated insecticidal activity of essential oil from garlic bulb against two stored beetle pests *viz., T. castaneum* and *S. zeamais*. Filter paper impregnation bioassay showed susceptibility of egg and adult stages of flour beetle.

Garlic bulb containg methyl allyl disulphide caused reduced growth rate, food consumption, and food utilization in adult *S. zeamais* (Huang *et al.*, 2000). A study conducted to evaluate essential oil of garlic against two major stored beetle pests by Stefanazzi *et al.* (2011) showed that garlic oil containing methyl allyl disulfide and diallyl trisulfide showed contact and fumigant toxicity against *S. zeamais*. These chemicals also affect egg hatching, larval development and adult emergence of *T. castaneum*.

Insecticidal property of garlic essential oils against rice weevil was proven by Hamed *et al.* (2012). Investigation on adult mortality and weight loss of grains by the application of fresh garlic juice resulted 90.00 per cent mortality of *S. zeamais* under laboratory condition (Nwachukwu and Asawalam, 2014). Allicin (diallylthiosulfinate), an antimicrobial substance present in the level of 1.88 to 3.50 mg ml^{-1} in garlic has insecticidal potency both in field condition as well as in storage condition.

2.3.5.4 Bird chilli

Toxicity of *C. frutescens* fruits on rice weevil population has been noted by El-Lakwah *et al.* (1997) under laboratory. Both acetone and petroleum ether extracts of *C. frutescens* showed 100 per cent mortality and reduced population emergence in all treatments.

2.3.5.5 Mint

Shaaya *et al.* (1991) reported insecticidal effect of few plant species like sage, bay laurel, rosemary, lavender, basil, marjoram, thyme, anise and peppermint against stored beetle pests such as *R. dominica*, *O. surinamensis* and *T. castaneum*. Repellent property against rice weevil by plants belongs to mint family (Lamiaceae) such as areal part of lavender (*Lavandula angustifolia* Mill.) and corn mint (*Mentha arvensis* L.), leaf powder of horse mint (*M. longifolia* L.), peppermint (*M. piperita* L.), marjoram (*Origanum vulgare* L.) and sage (*Salvia officinalis* L.) were studied in experiment conducted by Ignatowicz (1998).

According to Saljoqi *et al.* (2006) ethanol extracts of mint recorded a mean mortality of 47.40 per cent at 10 days after treatment in rice weevil. Hydrodistillated peppermint yielded essential oil with high percentage of monoterpenes and oxygenated monoterpene compounds such as menthol, menthone, cineol, cyclohexanone, isomenthol acetate and limonene which showed high percentage mortality in rice weevil. Mortality of 97.00 per cent was attained in rice weevil at a concentration of 370 μl L^{-1} air for a period of 72 h (Khani, *et al.*, 2012).

Saad *et al.* (2017) screened the response of ten botanical oils as eco-friendly alternatives for controlling the rice weevil under laboratory condition in Egypt. Results revealed that essential oils from leaves of spearmint (*Mentha spicata* L.) possess biologically active compounds like menthol, isomenthone, limonene and 1,8-cineole which have greater toxicity and lower LC_{50} value of 7.79 µl 370 ml^{-1} air. Mortality response of rice weevil to essential oil in bioassay without food conditions showed that treatment with peppermint at 400µl L^{-1} air caused percentage mortality of 34.00 (Vendan *et al.*, 2017).

2.3.5.6 Tulsi

Studies on leaves of *Ocimum kilimandscharicum* Gurke by Jembere *et al.* (1995) indicated that both dried and essential oil extract of leaves could act as a good grain protectant due to the insecticidal, repellent and inhibition on F_1 population against beetle pests. Obeng-Ofori *et al.* (1997) concluded that fumigant oil of *Ocimum kenyense* Ayob. with biologically active component 1,8-cineol was highly effective to control *S. granarius* and *S. zeamais*. Another study by Ogendo *et al*, (2008) showed fumigant toxicity of *Ocimum grattissimum* L. and its components β-(Z)-ocimene and eugenol against rice weevil at 1, 5 and10 µl L^{-1} air concentrations.

Asawalam *et al.* (2008) confirmed that higher dose of essential oil from *O. grattissimum* have the ability to control *S. zeamais*. The study revealed that at the concentration of 750 mg 250 g^{-1} of maize showed mortality of 82.00 per cent, repellancy of 77.50 per cent, no progeny emergence and no significant weight loss of grains under treatment. GC-MS analysis of essential oils resulted with higher concentration of thymol, paracymene and alpha terpinene. He also concluded that essential oil of *O. grattissimum* have the potential to explore in post-harvest management of maize weevil, which showed moderate repellency towards test insect.

The studies of Kerdchoechuen *et al.* (2010) on essential oil derived from three species of *Ocimum* against maize weevil *S. zeamais* indicated that sweet basil (*O. basilicum* L.) caused percentage mortality of 96.00 to 100 at first day of experiment. Toxicity assay on filter paper and rice grains at concentrations of 30 to 120µl showed lower LD_{50} value (0.20µL cm^{-2} and 0.43mL kg^{-1} respectively) for sweet basil. Also they reported important chemical compounds in the extracted oil as methyl chavicol, methyl eugenol and α-cubebene in sweet basil, holy basil (*O. americanum* L.) and hairy basil (*O. tenuiflorum* L.) respectively.

Study conducted by Santeshwari *et al.* (2010) on the efficacy of methanolic extracts of tulsi (*Ocimum sanctum* L.) against a secondary beetle pest, *Alphitobius laevigatus* revealed that at a concentration of 5 ml caused mortality of 67.50 per cent. Study on major constituents and chemical composition of *O. grattissimum* and *O. sanctum* by Joshi (2013) reported that methyl eugenol was the major volatile constituent. Compounds which have antimicrobial and antioxidant property in these species were *α*-pinene, *E*-*β*-ocimene, terpinolene, *α*-terpineol, eugenol, *β*-cubenene, *β*-caryophyllene, *γ*- muurolene, epi-cubebol, and -cubebol, and *δ*-cadinene.

Results on effect of five leaf powders *viz.*, adarthodai (*Justicia adhatoda* L.), neem, Papaya (*Carica papaya* L.), tulsi and annona on rice weevil indicated that tulsi powder at 5 g 100 g^{-1} of rice have potential mortality (91.7 %) effect at 12 week after treatment (Karunakaran *et al.*, 2016).

Kuldipake *et al.* (2016) evaluated mortality and repellency of rice weevil on treatment with eight locally available plant materials. Treatment with tulsi showed percentage mortality and repellecy of 3.67 and 36.67 respectively at 21 days after treatment. Saad *et al.* (2017) screened the response of ten botanical oils as eco-friendly alternatives for controlling the rice weevil under laboratory condition in Egypt. Results revealed that essential oils from leaves of *O. basilicum* reported less fumigant toxicity towards rice weevil when compared with the other plant materials.

2.3.5.7 Clove

In the residual film bioassay experiment with five essential oils resulted insecticidal potential towards *C. maculatus* was in the order of neem < cardamom < cinnamon < clove < eucalyptus (Mahfuz and Khalequzzaman, 2007). While studying toxicity of essential oil from clove flower buds by Kerdchoechuen *et al.* (2010) revealed that oil was highly toxic at lowest concentration of 30 µl towards maize weevil. Whereas the highest repellency of 85.00 per cent was recorded at a concentration of 8 µl.

Devi and Devi (2013) assessed insecticidal and oviposition deterrent properties of eighteen spices against rice weevil by observing mortality, contact toxicity, persistence and effect on next generation progeny. The results showed that clove at a concentration of 5 % recorded complete mortality of weevil under laboratory condition.

In a study conducted by Saad *et al.* (2017) screened the response of ten botanical oils as eco-friendly alternatives for controlling the rice weevil under laboratory condition in Egypt. Results revealed that essential oils from clove bud containing eugenol (71.56 %) and eugenol acetate (8.99 %) gave higher toxicity after 72 h of exposure with LC_{50} value of 9.23 µl 370 ml^{-1} air.

2.3.5.8 Nutmeg

Toxic and antifeedant action of nutmeg oil against maize weevil and red flour beetle revealed ten times more susceptibility of maize weevil with LC_{50} value of 1.7 mg cm^{-2}. At higher concentrations, both pests were laid fewer eggs (Huang *et al.*, 1997).

Antifeedent property of nutmeg is well known in traditional knowledge. Adedire (2002) studied about the effect of seed powder and oil of nutmeg, *M. fragrans* against cowpea weevil. The results showed that complete mortality of weevil was obtained at a concentration of 2 % at 7 days of exposure. All the treatment with seed powder and essential oils cause some range of mortality and ovicidal action towards weevil. A study conducted by Devi and Devi (2013) showed that treatment with nutmeg at a concentration of 5 % recorded a percentage mortality of 90.00.

2.3.5.9 Curry leaf

Monitoring of treated bag with different plant extract for six months showed less damage on grains under treatment of curry leaf extract (Chander, *et al.*, 2000). Studies conducted by Paranagama *et al.* (2004) showed the highest repellency of curry leaves towards rice weevil at a concentration of 300 mg whereas at a concentration of 25 mg, curry leaf could act as insect attractant. Survey conducted in Assam by Deka *et al.* (2006) about traditional pest management concluded that use of curry leaves and ber (*Ziziphus jujube* Mill.) repelled stored grain pests due to their odour.

Adhikari and paranagama (2001) studied about the effect of volatile constituents of curry leaf *M. koenigii* against cowpea bruchid and showed that oil can cause cent per cent mortality at 2.48 g m^{-2} and 1.50 g L^{-1} concentration on contact and fumigation toxicity bioassays respectively.

Nirjara and Sujatha (2011) screened and evaluated mortality of *R. dominica* using pomegranate (*Punica granatum* L.) and curry leaves (*M. koenigii*). It was showen that pulverised leaves of both botanicals caused significantly high rate of mortality and less population development in different doses ranging from 0.05 to 1g per 10 g of beaten rice.

A laboratory study was undertaken by Kumar and Tiwari (2017) to determine insecticidal potent of few essential oils and their combinations against three major stored grain insect pests. Observation taken at bimonthly interval for a period of 10 months noticed 100 per cent inhibition of F_1 progeny in treatment with oils of *M. koenigii* and combinations of *M. koenigii, Citrus reticulate* Blanco and *Curcuma longa* L.

Khan *et al.* (2013) examined certain plant species against rice weevil and showed that powder and fresh or dried leaves of *M. koenigii* exhibit repellency and less grain damage at a concentration of 1 % (w/w).

2.3.5.10 Lemon grass

According to Saljoqi *et al.* (2006) ethanol extracts of lemon grass have fatal effect towards rice weevil at 0.4 ml 20 g^{-1} of grains. Observations on treatments showed that treatment with lemon grass extracts for 10 days at an interval of 24 h resulted 35.20 percentage mortality.

Jayaratne and Paranagama (2001) noticed that essential oil of lemongrass (*Cymbopogon citratus* Stapf.) have significantly higher repellent activity at 3 mg ml^{-1} of air and 89 per cent mortality at 2.5 g L^{-1} of air towards rice weevil. The ethanolic extracts of lemon grass showed maximum repellency of 39.75 per cent against saw toothed grain beetle (Manzoor *et al.*, 2011). Fumigation and contact toxicities were also evaluated. Powder and extract of lemon grass have potential to eliminate the menace caused by bruchids on cowpea storage and they can act as a good seed protectant also (Nelson and Bernard, 2016).

2.3.5.11 Cinnamon

Huang and Ho (1998) analysed effect of methylene chloride extract of cinnamon against *S. zeamais* under laboratory conditions. Adults showed contact toxicity towards extract with LC_{50} value of 0.7 mg cm^{-2} and LC_{95} value of 0.9 mg cm^{-2}. Fumigant toxicity studies resulted reduced food consumption with LC_{50} of 0.54 mg cm^{-2} and LC_{95} of 1.78 mg cm^{-2}. Concentration varying from 6.8 to 13.6 mg g^{-1} showed high level of antifeedent activity. Residual and vapour-phase toxicity bioassay studies of cinnamon oils showed that components such as benzaldehyde, cinnamonitrile, hydrocinnamyl acetate and α-terpineol have insecticidal activity towards *S. oryzae* (Lee *et al.*, 2008).

Study on repellent activity of five essential oils and eight extracts of spices confirmed that extract of cinnamon at 20 mg ml^{-1} were highly repellent to rice weevil (Ishii *et al.*, 2010). More than 90.00 per cent mortality of both cowpea bruchid and rice weevil could be achieved from treatment with essential oil of cinnamon at 8.0 and 16.0 μl 50 ml^{-1} air respectively (Ahmed and El-Salam, 2010).

Stefanazzi *et al.* (2011) reported that essential oil of cinnamon have properties like repellency on larvae and adults, post ingestive toxicity, variation in nutritional index and reduced relative growth rate towards rice weevil and flour beetles. A laboratory study was under taken by Kanda *et al.* (2017) to determine the effect of cinnamon powder against rice weevil in stored milled rice for one month. Results showed that complete mortality of weevil was achieved at a concentration of 10 g after 28 days of exposure. Treatment with 6.00 and 8.00 g also showed more than 90.00 percentage mortality. Observation on insecticidal component in cinnamon powder by GC pattern showed higher concentration of cinnamaldehyde.

A laboratory study was undertaken by Kim *et al.* (2003) to determine insecticidal activity of thirty aromatic medicinal plant species and five essential oils against rice weevil. Results of the study showed that *Cinnamomum cassia* oil recorded cent per cent mortality on the first day of experiment at two different concentrations, 3.5 and 0.7 mg cm^{-2}.

2.3.5.12 Other Botanicals

Aegelin and marmeline present in Bel (*Aegle marmelos* L.) cause reduced grain damage by rice weevil and lesser grain borer (Prakash *et al.*, 1983).

Sweet flag (*Acorus calamus* L.) is reported as toxic to adults and F_1 progeny of *S. oryzae*, *T. castaneum* (Chander *et al.*, 2000) and *S. granarius* (Schmidt *et al.*, 1991). Insecticidal property of sweet flag is due to the presence of β asarone-similar to precocene II (anti-juvenile hormone), eugenol, methyl eugenol, acorin, calamenol, calamene and calameone (Schmidt and Streloke, 1994).

Use of swallow root (*Decalepis hamiltonii* Wight and Arn.) as grain protectant against rice weevil was reported by George *et al.* (1999). Dried root powder at 5 and 10 % dose accounts mortality of 96 and 100 per cent against rice weevil respectively. A comparative study on repellent activity of plants against rice weevil reported that extract of *Gardenia fosbergii* Tirveng was more potent than neem (Kestenholz and Stevenson, 1998).

Antenna (2001) tested repellent effect of baner (*Cassia sophera* L.) towards rice weevil and showed that extract could act as a good grain protectant. Powder and essential oil from leaves of Mexican-tea (*Chenopodium ambrosioides* L.) showed complete mortality of *S. granarius* and *S. zeamais* under laboratory study carried by Tapondjou *et al.*, (2005).

Evaluation of essential oil of turmeric (*C. longa*) showed total progeny suppression and antifeedent action in rice weevil, lesser grain borer and red flour beetle (Tripathi *et al.*, 2002). Kiran and Prakash (2015) conducted an experiment to evaluate efficacy of essential oil of rosemary (*Rosmarinus officinalis* L.) against rice weevil and saw toothed grain beetle. Complete mortality and significant level of antifeedent activity against test insects were recorded at a concentration of 0.15µl ml^{-1}.

A study conducted by Yankanchi and Gadache (2010) explores the efficacy of glory bower (*Clerodendrum inerme* L.) and ashwagandha (*Withania somnifera* L.) against *S. oryzae*. Treatment with ethanol extract from these plant showed higher mortality and next generation inhibition. According to Chayengia *et al.* (2010) volatile oil of mandarin orange (*C. reticulate*), *C. longa*, guava (*Psidium guajava* L.), powder of ginger (*Zingiber officinale* Roscoe) and ethanol extract of patchouli (*Pogostemon cablin* Blanco) could be used as protectant to reduce the infestation of rice weevil in storage condition.

Rani *et al.* (2011) reported that coconut palm (*Cocos nucifera* L.) and the Indian almond (*Terminalia catappa* L.) provide protection against major four beetle pests in storage condition. Long term protection of grains from rice weevil could be achieved by treatment with crude extract of coconut leaves. Highest repellency was observed in treatment with almond extract.

Investigation on essential oil of ginger family towards *S. zeamais* showed higher contact toxicity and repellency. Evaluation of oil showed the presence of compounds like camphene, camphor, 1,8-cineole, alpha-humulene, isoborneol, alpha-pinene, beta-pinene and terpinen-4-ol (Suthisut *et al.*, 2011). Data on the use of Aruda (*Ruta graveolens* L.) as leaf powder and extract with hexane, ethyl acetate, methanol and water against adult rice weevil showed that even at a lower dose (1 g) can cause more than 50.00 per cent repellence (Perera and Karunaratne, 2015).

Management of rice weevil using fumigant oils from eucalyptus and orange by Patil *et al.* (2016) generated that oils at a concentration of 2 $\mu L\ cm^{-2}$ caused 82.97 and 65.53 per cent mortality after 120 h of treatment.

Karunakaran *et al.* (2016) observed that annona at a concentration of 5 g 100 g^{-1} of rice have insecticidal effect on rice weevil at 10 week after treatment. Kuldipake *et al.* (2016) evaluated mortality and repellency of rice weevil against eight locally available plant materials. They found that highest per cent mortality (13.33 %) and repellency (76.67 %) on *S. oryzae* was recorded with leaf powder of karanj (*Pongamia pinnata* L.) at 21 days after treatment.

Study of Kim *et al.* (2003) showed mustard (*Brassica juncea* L.) oil cause cent per cent mortality of rice weevil on the first day of treatment at two different concentrations, 3.5 and 0.7 mg cm^{-2}. Whereas complete mortality on treatment with *A. calamus,* dwarf sedge (*A. gramineus* Sol.) and Korean mint (*Agastache rugosa* Kuntze) oil was obtained only at three days after treatment with 3.5 mg cm^{-2} concentration.

2.3.5.13 Mechanism of Plant Derived Compounds

Most of the active components in essential oils are secondary metabolites present in the plant parts, they provide chemical defence mechanism against pests. They are grouped into terpenes (myrecene, pinene, terpinene, limonene, pcymene, α- and β- phellandrene) and terpenoids such as acyclic monoterpene alcohols (geraniol, linalool), monocyclic alcohols (menthol, 4-carvomenthenol, terpineol, carveol, borneol,), aliphatic aldehydes (citral, citronellal, perillaldehyde), aromatic phenols (carvacrol, thymol, safrol, eugenol), bicyclic alcohol (verbenol), monocyclic ketones (menthone, pulegone, carvone), bicyclic monoterpenic ketones (thujone, verbenone, fenchone), acids (citronellic acid, cinnamic acid) and esters (linalyl acetate). Also include oxides (1,8-cineole) and sesquiterpenes (Zingiberene, curcumene, farnesol, sesquiphellandrene, termerone, nerolidol) (Koul *et al.*, 2008).

Knockdown effect of essential oils containing caffeic and ferulic acid, vanillin and luteolin 7-glucoside was reported by Regnault-Roger *et al.* (2012). Several reports indicated that insecticidal and repellent property of different essential oils are due to the presence of monoterpenoids - 1,8-cineole, α pinene, carvone, linalool, phenolic acids, quercetin, caffeic acid, protocatechuic acid (Lee *et al.*, 2004, Tapondjou *et al.*, 2005: Patil *et al.*, 2016).

Toxicity and feeding deterrent study on essential oils containing monoterpenoids and phenyl propanoids against *S. oryzae, T. castaneum* and *R. dominica* revealed that thymol, carvacrol, eugenol and trans-anethole have acute contact toxicity and linalool as a general feeding deterrent to three test species. Eugenol and carvacrol showed LC_{50} value of 16.08 and 17.15 μg cm^{-2} against rice weevil. Linalool and eugenol were good feeding deterrent to rice weevil with feeding inhibition (FI_{50}) value of 0.025 and 0.041 mg g^{-1} respectively. Treatment with anethole and carvacrol also resulted increased antifeeding property. Combination study showed increase in mortality with combination of anethole and thymol. They concluded that effect of compounds were species specific and not in a generalised manner (Kanda *et al.*, 2017).

Essential oils with rapid action cause neurotoxic mode of action, interruption on neuromodulator octopamine (Kostyukovsky *et al.*, 2002) and GABA-gated chloride channels (Priestley *et al.*, 2003). Monoterpenoids, one of the major constituent of volatile essential oils from various plants showed inhibiting potential on acetylcholine esterase enzyme (AChE) in storage insect pests (Mukherjee *et al.*, 2007: Chaubey, 2011).

Contact and feeding deterrent toxicity of l-carvone, d-carvone, and dihydrocarvone against red flour beetle was reported in an experiment conducted by Tripathi *et al*. (2000). Effect of 11 monoterpene compounds derived from essential oils were evaluated against *S. oryzae* by Abdelgaleil *et al*, (2009). Results showed that the highest mortality of weevil was achieved by carvone, geraniol, and cumin aldehyde compounds. Whereas 1-8-Cineole showed highest fumigation toxicity. More inhibitory effect of on acetylcholine esterase (AChE) enzyme showed by compounds like cuminaldehyde, 1-8-cineole, limonene, and (L)-fenchone.

Materials and Methods

3. MATERIALS AND METHODS

A study on "Management of beetle pests in stored rice using botanicals" was conducted in the Department of Agricultural Entomology, College of Agriculture, Vellayani, Thiruvananthapuram during 2016 to 2018. The materials used and methods adopted were given below.

3.1 SURVEY

The occurrence of beetle pests of stored rice in public distribution retail shop (ration shops) and retail provision stores in Thiruvananthapuram district of Kerala was examined through a preliminary survey. Survey was conducted during 2017.

Rice samples were collected randomly from twenty five places in Thiruvananthapuram districts which include both open sack and closed unsold sacks. Samples were collected from different portions of the stack from bottom, middle and top layers by using sampling spear. The samples collected from different parts of the sacks were mixed thoroughly and brought to 100 g by quadrate method. Collected samples were taken in polythene bag and brought to the laboratory for further examination.

3.1.1 Observations

Collected rice samples were examined for the presence of adult and immature stages of beetle pests. Different species were collected and identified.

3.2 MASS REARING AND MAINTENANCE OF RICE WEEVIL *S. oryzae*

Initial culture of rice weevil was obtained from surveyed samples. Paddy were procured from IFSRS (Integrated Farming System Research Station), Karamana, Thiruvananthapuram for the conduct of the experiment. Moisture content was tested after milling, polishing and cleaning of rice grains. Adequate grain moisture content of 13.5 per cent was maintained by the addition of required quantity of water carefully. These grains were used for rearing *S. oryzae*. Twenty pairs of rice weevil adults were released into plastic jars of one litre capacity (11.5 cm diameter and 13 cm height) (Plate 1) containing 250 g grains.

Plate 1. Mass rearing of rice weevil *S. oryzae*

The jars were covered with korah cloth to avoid moisture build up and fungal growth. The mated females were allowed to oviposit on the grains for a period of two weeks and thereafter the adults were removed from the grains. Such jars were maintained to get sufficient number of beetles for the conduct of the experiments. Damaged grains were replaced at regular intervals. The culture was upholds in the laboratory conditions of temperature 24 to 32^0 C and relative humidity 73 to 92 per cent.

3.3 BIOLOGY OF MAJOR BEETLE PESTS

3.3.1 Rice Weevil *S. oryzae*

Ten mated females were released initially in jars containing 100 g rice grains. Grains containing eggs were separated and observed under microscope. Ten grains were dissected regularly to observe different life stages of weevil. Larval instars were identified by the presence of moulted head capsule and larval size. Dissection of grains were carried till the pupal stage. Newly emerged male and female adults were separated and observed for mating and oviposition.

3.3.2 Saw Toothed Grain Beetle, *O. surinamensis*

Study was conducted to document biology and nature of injury by saw toothed grain beetles in rice grains. Initially fifteen beetles were released in each jar containing 100 g of coarsely ground rice and observation on various stages of beetles were taken for a period of two months. Grains were strained carefully to obtain eggs. Observations were taken until adult beetles emerged.

3.4 MANAGEMENT OF *S. oryzae* USING EXTRACT OF PLANT PARTS

An experiment was conducted to evaluate the effectiveness of aqueous extract of different plant parts against *S. oryzae* in rice under laboratory conditions.

Design : CRD

Replication : 3

Treatments : 13

T1: Pepper seeds (*Piper nigrum* L.) 5 % (w/v)

T2: Pepper seeds 10 % (w/v)

T3: Tulsi leaves (*Ocimum tenuiflorum* L.) 5 % (w/v)

T4: Tulsi leaves 10 % (w/v)

T5: Bird chilli fruits (*Capsicum frutescens* L.) 5 % (w/v)

T6: Bird chilli fruits 10 % (w/v)

T7: Neem leaves (*Azadirachta indica* A.Juss.) 5 % (w/v)

T8: Neem leaves 10 % (w/v)

T9: Mint leaves (*Mentha arvensis* L.) 5 % (w/v)

T10: Mint leaves 10 % (w/v)

T11: Garlic bulblets (*Allium sativum* L.) 5 % (w/v)

T12: Garlic bulblets 10 % (w/v)

T13: Control (Water)

3.4.1 Preparation of Plant Extracts

Fresh leaves of tulsi and neem were collected from the premises of College of Agriculture, Vellayani. Garlic bulblets, bird chilli fruits, mint leaves and pepper seeds were procured from the local market, Chalai, Thiruvananthapuram. Afore mentioned botanicals were thoroughly washed under running tap water to dislodge the dust particles.

Water extracts (5 and 10 %) of each treatments were prepared. For which, 15 g and 30 g of each plant parts were weighed and blended in a normal mixer. Blended substance were transferred to muslin cloth which is then tied and immersed in a beaker containing 300 ml of distilled water for 12 h. Muslin cloth containing blended plant parts were squeezed to obtain fine extract. Muslin cloth pouches (17 cm length and 13 cm width) were immersed in the extract for a period of 24 h and shade dried for one day. This treated pouches were used for storing grains.

Containers were arranged in such a way that a 500 ml capacity transparent plastic container (7.5 cm diameter and 11 cm height) was placed in another plastic container of 1000 ml capacity (11.5 cm diameter and 13 cm height). Treated muslin pouches were lined inside the small container and fixed at the mouth region with a rubber band and filled with 100 g of grains (Plate 2). Ten pairs of rice weevil were released and container was closed for one day for their settlement. On the next day a piece of korah cloth was used to cover the mouth of the small container. These small container was placed inside the large container. Finally large container was closed with a lid having 10 to 15 pin holes. Muslin cloth pouches treated with distilled water was maintained as control.

3.4.2 Observations

3.4.2.1 Insecticidal Effect of Plant Extracts

Mortality of beetles in all the treatments were recorded at 7^{th}, 14^{th}, 21^{st}, 28^{th}, 30^{th} and 35^{th} day after treatment.

Percentage mortality in all treatments were corrected for control mortality by Abbott's formula (Abbott, 1925).

$$\text{Corrected per cent mortality} = \frac{(Tm - Cm) \times 100}{(100 - Cm)}$$

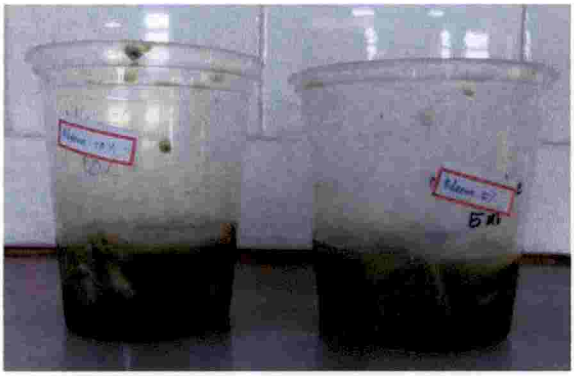
Tm – Per cent mortality in treatment

Cm – Per cent mortality in control

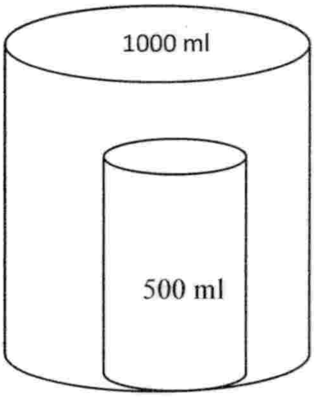
3.4.2.2 Repellent Effect of Plant Extracts

Weevils coming out of small container as well as live and dead weevils in the large container were counted as repelled insects. These weevils were removed after taking observation.

Muslin cloth pouch



Pouches immersed in plant extract



Arrangement of containers

Plate 2. Experimental setup for the management of rice weevil using plant extracts

$$\text{Repellent effect (per cent)} = \frac{\text{Number of repelled insects x 100}}{\text{Total number of insects}}$$

3.4.2.3 Progeny Emergence

After taking observation on mortality and repellency at 35th day of treatment, weevils were removed from bottles. Emerged adults were counted after 55th day of treatment and recorded. Progeny emergence inhibition was calculated using the formula,

$$\text{Progeny emergence inhibition (\%)} = \frac{(Cp - Tp) \times 100}{Cp}$$

Cp – Number of progenies emerged in control

Tp – Number of progenies emerged in treatment

3.4.2.4 Grain Damage

After recording the progeny emergence on 55th day of treatment, damaged grains were counted. The intensity of infestation was calculated using the formula,

$$\text{Infestation reduction (\%)} = \frac{(Ci - Ti) \times 100}{Ci}$$

Ci – Number of grains infested in control

Ti – Number of grains infested in treatment

3.4.2.5 Fungal Growth

Fungal growth on treated grains were examined on 35th and 55th days after treatment.

3.5 MANAGEMENT OF *S. oryzae* USING DRIED PLANT PARTS

An experiment was conducted to evaluate the effectiveness of different dried plant parts against *S. oryzae* in rice under laboratory conditions.

Design : CRD

Replication : 3

Treatments : 13

T1: Nutmeg mace (*Myristica fragrans* Houtt.) 2% (w/w)

T2: Nutmeg mace 4 % (w/w)

T3: Clove flower buds (*Syzygium aromaticum* (L.)) 2 % (w/w)

T4: Clove flower buds 4 % (w/w)

T5: Tulsi leaves (*O. tenuiflorum*) 2 % (w/w)

T6: Tulsi leaves 4 % (w/w)

T7: Mint leaves (*M. arvensis*) 2 % (w/w)

T8: Mint leaves 4 % (w/w)

T9: Neem leaves (*A. indica*) 2 % (w/w)

T10: Neem leaves 4 % (w/w)

T11: Curry leaves (*Murraya koenigii* (L.)) 2 % (w/w)

T12: Curry leaves 4 % (w/w)

T13: Control (untreated)

3.5.1 Preparation of Dried Plants

Fresh leaves of tulsi, neem and curry leaves were collected from the premises of College of Agriculture, Vellayani. Clove flower bud, nutmeg mace and mint leaves were procured from the local market, Chalai, Thiruvananthapuram (Plate 3). Leaves of tulsi, neem, curry leaves and mint were washed under running tap water to remove dirt particles. Subsequently they were kept in shade for air drying in normal room temperature. Proper drying was ensured to avoid development of mould growth while placing inside the container. After drying, plant parts were stored in air tight jars. Experiment was conducted as described in 3.4.1.

Nutmeg mace

Clove flower buds

Tulsi leaves

Mint leaves

Neem leaves

Curry leaves

Plate 3. Dried plant parts for management of rice weevil

Dried plant parts were placed within the small korah cloth pouches (11 cm length and 8 cm width) and pouches were placed horizontally inside the small bottle and filled with 100 g of grains (Plate 4). Ten pairs of weevil were released and kept for their settlement. On the next day a small piece of korah cloth was fixed at mouth region with a rubber band. Finally large container was closed with 10 to 15 pin holed lid. Small container without any dried plant parts was maintained as control.

Observations were taken as described in 3.4

3.6 MANAGEMENT OF *S. oryzae* USING VOLATILE ESSENTIAL OILS

Toxicity of volatile essential oils on *S. oryzea* was studied by dosage mortality bioassays. A plastic jar of 500 ml capacity (11 cm height and 7.5 cm diameter) was used for the experiment (Plate 5). A preliminary test was conducted to find any lethal effect of new plastics on insect mortality.

3.6.1 Bioassay - Without Food Materials

A bioassay experiment was conducted to find mortality of *S. oryzae* by essential oils without food under laboratory conditions.

Design : CRD

Replication : 4

Treatment : 23

1. Clove oil (*S. aromaticum*) (5, 10, 15, 20 and 25 μl)

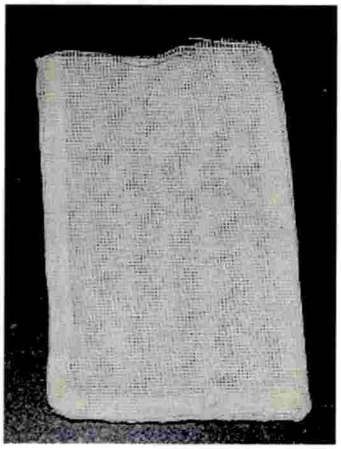
2. Cinnamon oil (*Cinnamomum zeylanicum* Blume) (5, 10, 15, 20 and 25 μl)

3. Lemon grass oil (*Cymbopogon flexuosus* (Nees *ex* steud)) (5, 10, 15, 100, 150 and 200 μl)

4. Pepper oil (*P. nigrum*) (5, 10, 15, 100, 150 and 200 μl)

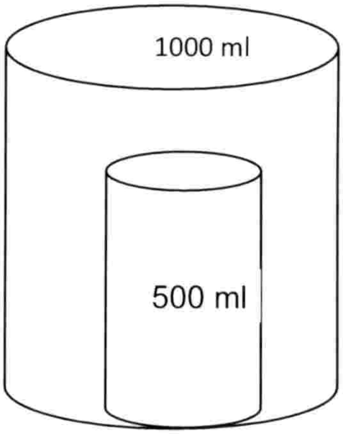
5. Untreated control

Ten weevils were released in each bottle. Filter paper (Whatman No.1) discs of 7 cm diameter attached to lids of plastic jars were impregnated with respective



Korah cloth pouches

Pouches filled with dried plant parts



Arrangement of containers

Plate 4. Experimental setup for the management of rice weevil using dried plant parts

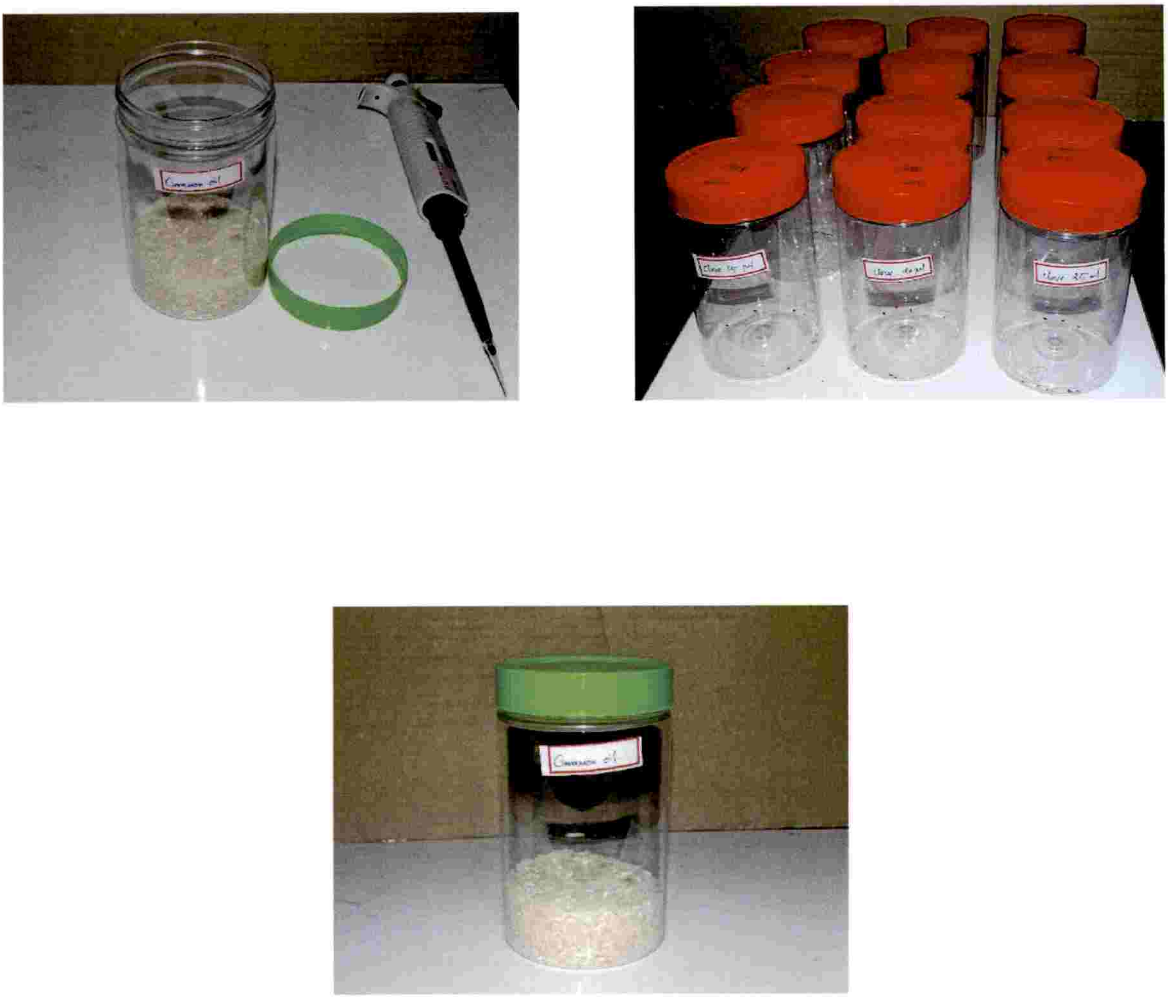


Plate 5. Experimental setup for the management of rice weevil using volatile oils.

concentrations of each oils using a micro pipette and then closed tightly. An untreated control without oil was also maintained.

3.6.1.1 Observations

The dead adults were counted in all the treatment and recorded at 12, 24 and 48 h of exposure time. Results were used for fixing the concentration of succeeding experiment.

3.6.2 Bioassay - With Food Materials

Experiment was conducted to find the effect of essential oils on *S. oryzae* under laboratory conditions.

Design : CRD

Replication: 3

Treatment : 21

1. Clove oil (4, 6, 8, 10 and 15 µl)

2. Cinnamon oil (4, 6, 8, 10 and 15 µl)

3. Lemon grass oil (50, 60, 70, 80 and 100 µl)

4. Pepper oil (50, 60, 70, 80 and 100 µl)

5. Untreated control

Thirty weevils were released in each bottle contained 100 g of grains. Filter paper (Whatman No.1) discs of 7 cm diameter attached to lids were impregnated with respective concentrations of each oils using a micro pipette. The bottles were closed tightly. An untreated control without oil was also maintained.

3.6.2.1 Observations

Observation on mortality were recorded at 2nd, 4th, 6th and 8th days after treatment. Number of dead insects were counted and recorded. Results obtained after analysis on LC_{50} were used for fixing concentration of succeeding experiment. Observation on fungal growth was also recorded during experiment.

3.6.3 Management Using Volatile Essential Oils

Experiment was conducted to find the effect of essential oils on *S. oryzae* under laboratory conditions.

Design : CRD

Replication: 3

Treatment : 13

1. Clove oil (20, 25 and 30 µl)

2. Cinnamon oil (20, 25 and 30 µl)

3. Lemon grass oil (125, 150 and 200 µl)

4. Pepper oil (125, 150 and 200 µl)

3.6.3.1 Observations

Observation on mortality were recorded at 2nd, 4th, 6th, 8th and 10th day after treatment. Number of dead insects were counted and recorded.

Observation on progeny emergence was recorded at 35 days after treatment. Observation on fungal growth was also recorded during experiment.

3.7 STATISTICAL ANALYSIS

Collected data were analysed statistically after proper transformation using the WASP (Web based Agricultural Statistics software Package) and SPSS (Statistical Package for Social Sciences) software.

Results

4. RESULT

A study was conducted at College of Agriculture, Vellayani during 2016 to 2018 to document major beetle pests of stored rice and to develop effective management measures using botanicals. The data were collected and analysed statistically after proper transformation and the important findings obtained from the present study are described below.

4.1 SURVEY

The data on survey conducted to study the occurrence of beetle pests of stored rice in Thiruvananthapuram district are presented in Table 1.

The insects recorded from ration shops and retail shops during the survey were rice weevil *S. oryzae*, saw toothed grain beetle *O. surinamensis*, red flour beetle *T. castaneum* and lesser grain borer *R. dominica* (Plate 6). In Thiruvananthapuram district, out of 25 rice samples 23 were contaminated with rice weevil, followed by saw toothed grain beetle (13), red flour beetle (9) and lesser grain borer (7) (Fig.1).

Among the insect pests observed in stored rice samples, the most abundant one was *S. oryzae* with a mean number of 14.68 (Fig. 2). Rice weevil was found to be the only internal feeder and rest of them were secondary in nature. A mean number of 4.20 saw toothed grain beetle *O. surinamensis* was recorded as the second most abundant pest. Other pests such as *T. castaneum* (2.32) and *R. dominica* (0.84) were also found in whole grains even though they are reported as secondary feeders.

The rice weevil, *S. oryzae* has been found to be the most important stored beetle pest in Thiruvananthapuram district. In the light of the above facts, the study was undertaken to manage rice weevil using botanicals.

4.1.1 Rice Weevil – *S. oryzae* (Coleoptera : Curculionidae)

The adult is a dark brown tiny beetle with cylindrical body, 2.3 to 4.5 mm long, with four reddish brown spot on the elytra (Plate 7). Antenna inserted near

Table 1. Occurrence of beetle pests of stored rice in Thiruvananthapuram district

Locations	Number of insects in 100 g rice							
	S. oryzae		*T. castaneum*		*O. surinamensis*		*R. dominica*	
	Adult	**Immature stage**	**Adult**	**Immature stage**	**Adult**	**Immature stage**	**Adult**	**Immature stage**
Sreekaryam	20	6	5	3	-	-	1	-
Chembazhanthi	8	-	-	-	9	4	-	-
Chavadimukk	18	3	-	-	3	-	-	-
Palamkonam	8	2	-	-	-	-	2	-
Alamcodu	-	-	-	-	9	2	-	-
Venjaramoodu	9	4	6	-	8	-	-	-
Karete	7	2	-	-	-	-	-	-
Kallara	13	-	-	-	11	-	4	-
Kilimanoor	16	4	-	-	4	-	2	-
Pangodu	17	6	-	-	-	-	-	-
Pothancodu	15	2	5	2	8	3	-	-
Nedumangadu	8	-	-	-	-	-	-	-
Balaramapuram	12	3	8	2	-	-	4	-
Kalliyoor	-	-	4	-	7	4	-	-
Poojappura	14	3	9	3	1	-	4	-
Chalai market	18	8	-	-	8	1	-	-
Karamana	6	-	2	-	10	-	-	-
Poonkulam	11	2	-	-	-	-	-	-
Kazhakoottam	16	5	4	-	-	-	-	-
Mangalapuram	21	9	-	-	-	-	-	-
Nalanchira	12	4	-	-	-	-	4	-
Neyyattinkara	14	2	5	-	-	-	-	-
Chirayinkeezhu	13	6	-	-	-	-	-	-
Attingal	9	-	-	-	5	2	-	-
Varkala	17	4	-	-	6	-	-	-
Total	**302**	**75**	**48**	**10**	**89**	**16**	**21**	**-**

Rice weevil S. *oryzae*

Saw toothed grain beetle *O. surinamensis*

Red flour beetle *T. castaneum*

Lesser grain borer *R. dominica*

Plate 6. Major beetle pests of stored rice

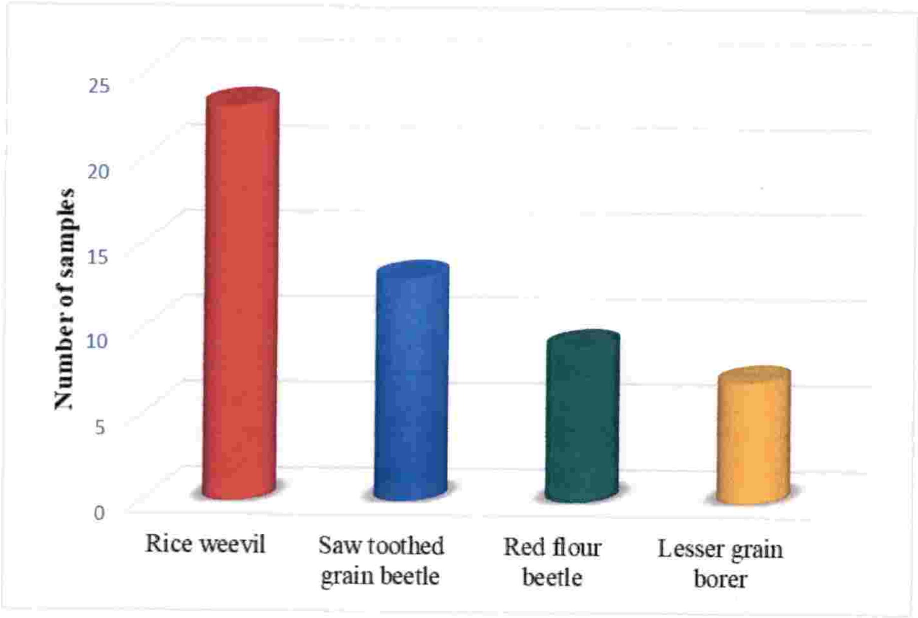


Figure 1. Comparative abundance of storage beetle pests of rice grains in Thiruvananthapuram District

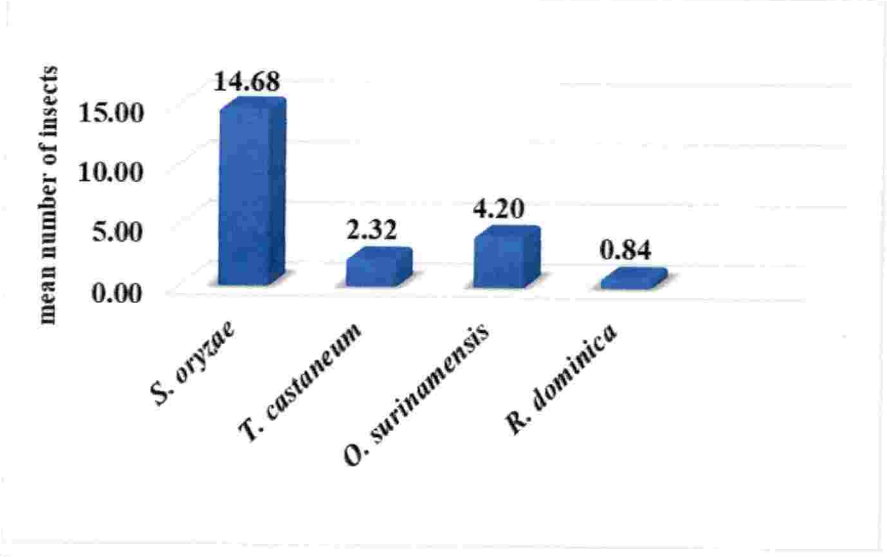


Figure 2. Mean number of beetle pests observed in 100 g of stored rice in Thiruvananthapuram

Position of antennae

Pygidium

Reddish brown spots on elytra

Plate 7. Morphological characters of rice weevil *S. oryzae*

base of cylindrical snout, just in front of eyes. Pygidium largely exposed. On disturbing they remain immobile for a while and then move fastly on side of container. They have ability to fly also. Larvae were creamy white colour, sluggish and apodous. Damage to the grains was due to the feeding and development of grubs and also feeding by the adults. Pupation also takes place inside the grains. Circular adult emergence holes were seen on the grains. Severely infested grains become powdery mass and serve as substrate for secondary feeders.

4.1.2 Saw Toothed Grain Beetle – *O. surinamensis* (Coleoptera : Silvaniidae)

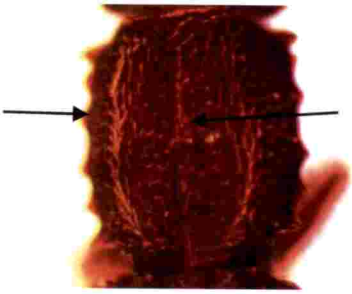
This is a slender, dark brown, flattened beetle with a row of sharp teeth like projections on either side of the prothorax. Dorsal surface of pronotum have three longitudinal ridges (Plate 8). The adults and larvae of this beetle were observed in the rice sample collected. Larvae are worm like with dull white, elongate and full of hairs on body. They were seen feeding on the powdered portions of the grain.

4.1.3 Red Flour Beetle – *T. castaneum* (Coleoptera : Tenebrioniidae)

This is a reddish brown, flat, elongate beetle. The head, thorax and abdomen are distinct. The antennae are well developed and the last three segments are enlarged at terminal end. The larva is small and slender with body segments having number of fine hairs. Pupation takes place on the surface of food. Initially pupa is white colour which later turns to yellow (Plate 8). Adults and larvae show preference to broken grains. Adults of this beetle were found in small numbers in the samples collected.

4.1.4 Lesser Grain Borer – *R. dominica* (Coleoptera : Bostrychidae)

The adult is a small dark brown cylindrical beetle. Head of the beetle being bent under the thorax and the posterior abdominal end blunt. Antennae are ten segmented with a large three segmented club. The elytra have rows of punctures with short setae.



Teeth like projections and pronotal ridges of saw toothed grain beetle *O. surinamensis*

Antennae of *T. castanium*

Larva of *T. castanium*

Pupa of *T. castanium*

Plate 8. Morphological characters of *O. surinamensis* and *T. castanium*

4.2 BIOLOGY OF MAJOR BEETLE PESTS

4.2.1 Rice Weevil *S. oryzae*

Biological parameters of rice weevil *S. oryzae* are depicted in Table 2.

Observation on dissected grains gave duration of each stages of weevil. The adult female laid egg in a tiny hole in the intact grain surface at the end portion of grains and sealed with a waxy secretion (Plate 9 and 10). Incubation period was 5 to 7 days. Emerged larvae was creamy white and apodous. They feed inside the grain continuously and undergo series of three moulting. Each instar was identified by size of the larvae and head capsule. Larval period varied from 24 to 29 days. Pupal stage lasted for 7 to 8 days. Total length of life cycle ranged from 37 to 42 days. There were characteristic circular hole on grain during emergence (Plate 11). Newly emerged adults were light brown in colour with prominent dark patches on elytra. Mating occurred after a period of 4 to 6 days. During mating, female carry the male on top of the body.

S. oryzae was found infesting on pulses also. Observation on feeding nature of weevils on pulses gave idea about host range (Table 3). They can infest on red gram (Thuvaran parippu), bengal gram (Chana) and dolichos bean. Infestation of cowpea weevil in kabuli chana facilitated rice weevil attack and completed life cycle in split chana. Adult weevil can infest and complete their life cycle within whole red gram. Whereas a soft portion of dolichos bean was found infested by rice weevil (Plate 12).

4.2.2 Saw Toothed Grain Beetle *O. surinamensis*

Biological parameters of saw toothed grain beetle are presented in Table 4.

These small beetles were easily identified by the presence of six tooth like projections on lateral side of pronotum. The adult female laid eggs singly on ground rice at the bottom of the container along with faecal matter. Eggs were shiny and translucent in nature with incubation period of 5 to 10 days. The emerged larvae were worm like, white coloured and mobile (Plate 13). Larvae feed on broken grains

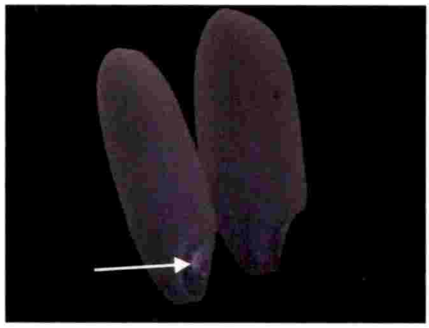
Table 2. Biological parameters of rice weevil *S. oryzae*

Parameters	Days	Mean ± SE
Egg period	5 - 7	6.00±0.26
Larval period	24 -29	26.40±0.54
Pupal period	7 - 9	7.60±0.22
Total life cycle	37 - 42	36.20±3.60

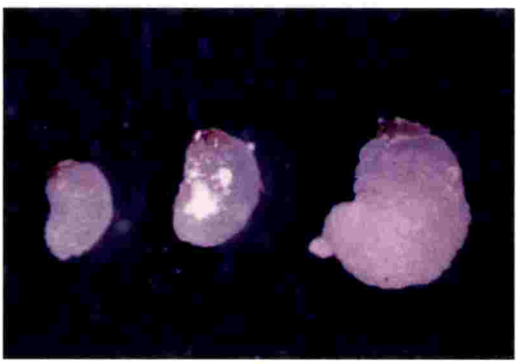
SE – standard error

Table 3. Infestation of rice weevil *S. oryzae* in pulses

Pulses	Damage
Cowpea (*Vigna unguiculata*)	Absent
Bengal gram (*Cicer arietinum*)	Infestation of cowpea bruchid facilitate attack of rice weevil and can complete life cycle in split kabuli chana. Infestation is absent in desi channa.
Green gram (*V. radiata*)	Absent
Red gram (*Cajanus cajan*)	Adult beetle can infest and complete life cycle within whole gram.
Black gram (*V. mungo*)	Absent
Rajma (*Phaseolus vulgaris*)	Absent
Soybean (*Glycine max*)	Absent
Dolichos bean (*Lablab purpureus*)	Weevil can feed on white portion of seed. Cannot develop within.



(A) Position of egg on grain

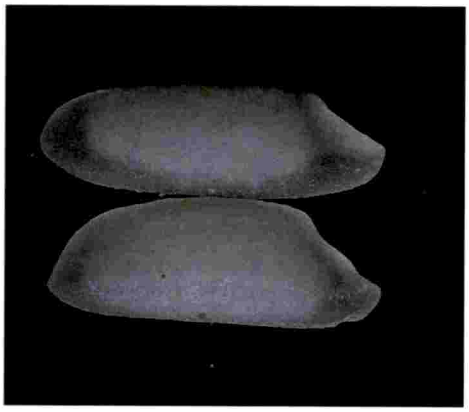


(B) Larval instars

(C) Dorsal, ventral and lateral view of pupae

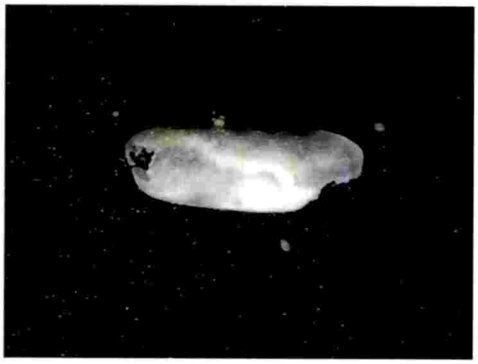
(D) Dorsal and ventral view of adult

Plate 9. Life stages of rice weevil *S. oryzae*



Larval growth within grain

Matured larvae within grain

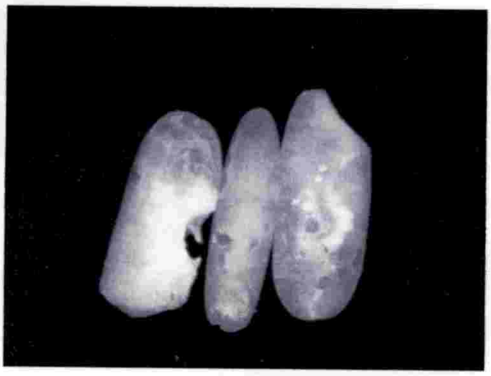


Grain with emerging hole

Adult emergence

Newly emerged adult

Plate 10. Growth stages of larvae of rice weevil inside the grain



Damage by feeding of adults

Damage due to development of larva and pupa

Plate 11. Symptoms of damage on grains by rice weevil *S. oryzae*

Kabuli chana

Split kabuli chana

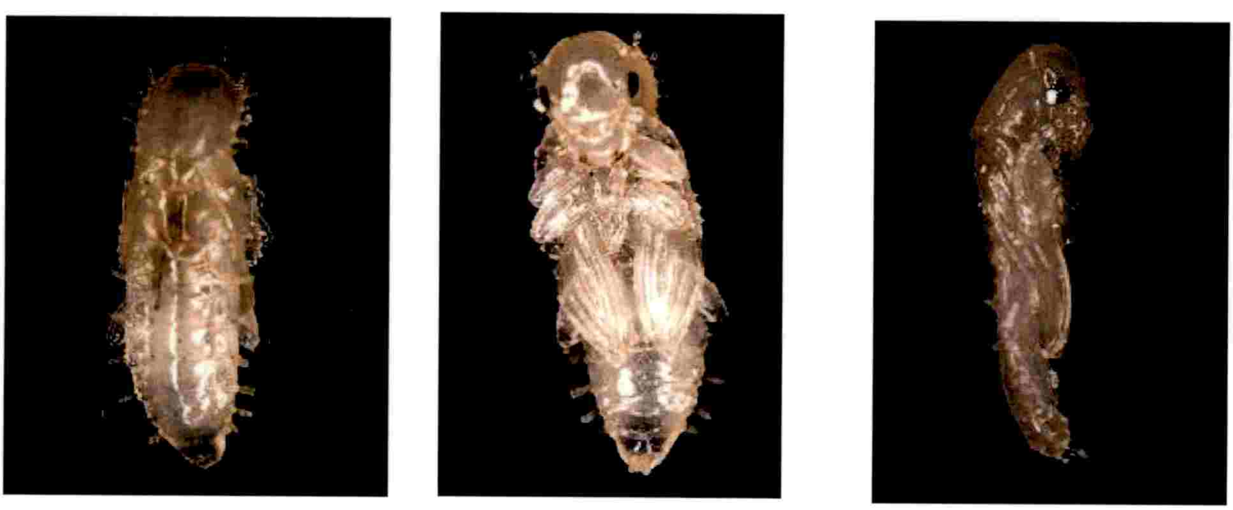
Red gram

Damage on red gram

Damage on dolichos bean

Plate 12. Symptoms of damage on pulses by rice weevil *S. oryzae*

(A) Dorsal, lateral and ventral view of larva



(B) Dorsal, lateral and ventral view of pupa

Plate 13. Life stages of saw toothed grain beetle *O. surinamensis*

Table 4. Biological parameters of saw toothed grain beetle *O. surinamensis*

Parameters	**Days**	**Mean ± SE**
Egg period	5 - 10	7.10±0.53
Larval period	18 - 27	23.30±1.16
Pupal period	5 - 8	6.70±0.37
Total life cycle	31 - 40	36.10±1.02

SE – standard error

or germ portion of grains. Larval period ranged from 18 to 27 days with four moults. Pupation takes place on powdery grain mass and lasted for 5 to 8 days. The life cycle completed in 30 to 40 days. Adults were fast movers compared to rice weevil.

Observation on attack of saw toothed beetle on whole grains gave information about their feeding nature. Adult beetles and larvae were found feeding on the germ portion of grain. Emerged larvae initially feed on germ portion. Later larvae make webbing with grains over body for protection (Plate 14). They feed and pupate within the webbings. This observation showed that even though they were grouped under secondary feeder they can cause damage to whole grains also.

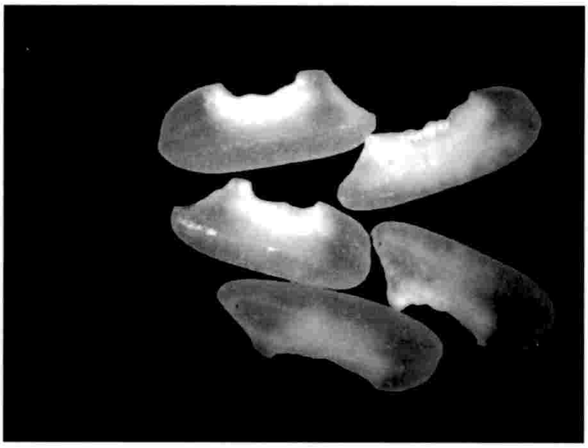
4.3 MANAGEMENT OF *S. oryzae* USING EXTRACT OF PLANT PARTS

4.3.1 Effect of Plant Extracts on Mortality of Rice Weevil *S. oryzae*

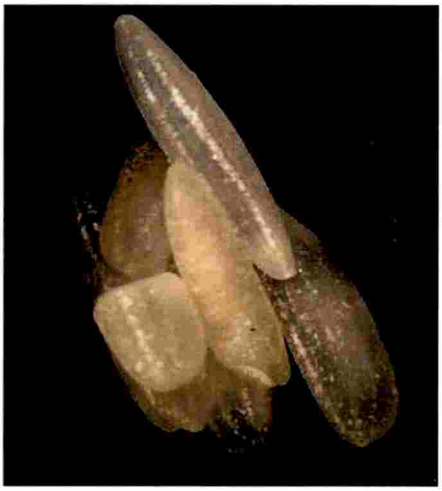
The data on effect of different plant extracts on the mortality of rice weevil *S. oryzae* in stored rice at 7, 14, 21, 28 and 35 days after treatment are depicted in Table 5.

The percentage mortality of weevils ranged from 0.00 to 16.67 at seven days after treatment. On examining the percentage mortality, garlic bulb 10 % recorded the highest mortality of 16.67 followed by bird chilli fruit 10 % (15.00), tulsi leaves at 5 % and 10 % (8.33) which were statistically on par. No mortality was observed in rice treated with extract of pepper seed (5 and 10 %), neem leaves (5 and 10 %) and mint leaves (5 %) and control. These treatments were on par with mint leaves 10 % and bird chilli fruit 5 % with a mortality of 3.33 per cent and 6.67 per cent respectively.

At 14 days after treatment, the percentage mortality of weevils ranged from 0.00 to 30.00. Rice treated with garlic bulb 5 and 10 % showed the highest mortality over all other treatments with percentage mortality of 30.00. It was followed by treatments with bird chilli fruit 10 % (20.00) and tulsi leaves 10 % (15.00) and were statistically on par. Extract from bird chilli fruit 10 % recorded mortality of 11.67 per cent followed by tulsi leaves 5 % (10.00), neem leaves 10 % (8.33), and mint



Feeding damage in whole grain



Webbing of grains by larvae

Larva and pupa within webbing

Plate 14. Damage symptoms on whole grain by *O. surinamensis*

Table 5. Effect of plant extracts on the mortality of rice weevil *S. oryzae*

Treatments	Percentage mortality* at DAT				
	7	**14**	**21**	**28**	**35**
Pepper seed 5%	0.00 (0.64)[d]	0.00 (0.64)[d]	6.67 (12.11)[de]	8.33 (16.59)[d]	15.00 (11.02)[de]
Pepper seed 10%	0.00 (0.64)[d]	3.33 (6.57)[cd]	8.33 (16.59)[cde]	13.33 (17.80)[cd]	20.00 (19.33)[bcd]
Tulsi leaves 5%	8.33 (13.37)[abc]	10.00 (14.52)[bcd]	10.00 (14.52)[cde]	13.33 (19.68)[cd]	15.00 (13.03)[de]
Tulsi leaves 10%	8.33 (13.37)[abc]	15.00 (18.45)[abc]	20.00 (22.15)[bcd]	23.33 (27.38)[abcd]	38.33 (32.06)[ab]
Bird chilli fruits 5%	6.67 (9.28)[bcd]	11.67 (16.35)[bc]	11.67 (16.35)[cde]	13.33 (17.80)[cd]	18.33 (13.53)[cde]
Bird chilli fruits 10%	15.00 (22.59)[a]	20.00 (26.62)[ab]	26.67 (30.78)[abc]	30.00 (33.07)[abc]	36.67 (31.05)[abc]
Neem leaves 5%	0.00 (0.64)[d]	0.00 (0.64)[d]	13.33 (20.75)[bcd]	13.33 (20.75)[bcd]	21.67 (20.24)[bcd]
Neem leaves 10%	0.00 (0.64)[d]	8.33 (16.59)[bc]	13.33 (21.34)[bcd]	20.00 (26.45)[bcd]	23.33 (21.89)[bcd]
Mint leaves 5%	0.00 (0.64)[d]	0.00 (0.64)[d]	6.67 (12.11)[de]	8.33 (13.95)[de]	11.67 (12.13)[de]
Mint leaves 10%	3.33 (8.82)[cd]	6.67 (12.50)[bcd]	10.00 (18.04)[cd]	11.67 (19.49)[cd]	16.67 (15.53)[bcde]
Garlic bulbs 5%	13.33 (21.15)[ab]	30.00 (32.89)[a]	35.00 (36.07)[ab]	35.00 (36.07)[ab]	38.33 (32.19)[ab]
Garlic bulbs 10%	16.67 (24.04)[a]	30.00 (33.17)[a]	41.67 (40.13)[a]	46.67 (43.06)[a]	53.33 (41.79)[a]
Control	0.00 (0.64)[d]	0.00 (0.64)[d]	0.00 (0.64)[e]	0.00 (0.64)[e]	3.33 (8.82)[e]
CD (0.05)	**(11.906)**	**(15.352)**	**(16.911)**	**(15.926)**	**(16.235)**

DAT-Days after treatment *Mean of three replications
Figures in parenthesis are angular transformed values
**Figures in a column followed by same letter do not differ significantly

leaves 10 % (6.67). no mortality was observed in treatment with pepper seed, neem leaves and mint leaves at 5 % and control.

Efficacy of various plant extracts at twenty one days after treatment exhibited significant difference on comparison with the untreated control (0.00). Significantly highest mortality was observed in rice treated with garlic bulb 10 % (41.67 per cent) which was statistically on par with garlic bulb 5 % (35.00) and bird chilly fruit 10 % (26.67). Lowest percentage mortality was recorded in treatment with extract of neem leaves 5 % and 10 % (13.33) which was on par with bird chilli fruit 5 % (11.67), tulsi leaves 5 % (10.00), mint leaves 10 % (10.00), pepper seed 10 % (8.33), pepper seed 5 % (6.67) and mint leaves 5 % (6.67). Among the various plant extracts at 10 % concentration, rice treated with garlic bulb was the most effective treatment which was statistically on par with 5 % concentration.

Significant difference was observed in percentage mortality of weevils at 28 days after treatment with no mortality recorded from untreated control. The mortality ranged from 8.33 to 46.67 per cent. The highest percentage mortality was observed from treatment with garlic bulb 10 % (46.67) which was on par with garlic bulb 5 % (35.00), bird chilli fruit 10 % (30.00) and tulsi leaves 10 % (23.33). Rice treated with pepper seed 5 % and mint leaves 5 % showed less mortality of 8.33 per cent among the treatment, which was on par with mint leaves 10 % (11.67), pepper seed 10 % (13.33), tulsi leaves 5% (13.33), bird chilli fruit 5 % (13.33), neem leaves 5 % (13.33) and control.

Similar trend was also observed at 35 days after treatment. The highest percentage mortality was observed in rice treated with garlic bulb 10 % (53.33). It was followed by garlic bulb 5 % and tulsi leaves 10 % with same percentage mortality (38.33) and on par with bird chilli fruit 10 % (36.67). Rice treated with neem leaves 10 % recorded mortality of 23.33 per cent which was statistically on par with neem leaves 5 % (21.67), pepper seed 10 % (20.00) mint leaves 5 % (11.67) and control (3.33).

4.3.2 Repellent Effect of Plant Extracts on Rice Weevil *S. oryzae*

The data on repellent effect of plant extracts on rice weevil *S. oryzae* in stored rice at 5, 10, 15, 20, 25 and 30 days after treatment are furnished in Table 6.

The repellent effect (percentage) ranged from 0.00 to 23.33 at five days after treatment. The highest repellent percentage was observed in tulsi leaves 10 % (23.33) followed by bird chilli fruit 10 % (11.67) which were statistically on par. Treatment with pepper seed 5 % recorded repellent percentage of 10.00 which was on par with bird chilli fruit 5 % (8.33) and pepper seed 10 % (6.67). Rice treated with garlic bulb 5 and 10 % recorded a lowest repellent effect of 1.67 per cent which was on par with neem leaves 10 % (3.33) and tulsi leaves 5 % (3.33). There were no repellent effect in treatment with neem leaves 10 % and mint leaves 5 % and 10 % as in control.

On examining the repellent effect at ten days after treatment, tulsi leaves 10 % recorded the highest percentage of 28.33 followed by bird chilli fruit 10 % (15.00). It was followed by pepper seed 10 % (11.67), pepper seed 5 % (10.00), tulsi leaves 5 % (10.00) and bird chilli fruit 5 % (8.33) and were statistically on par. Lowest repellent percentage was recorded in treatment with extract of garlic bulb 5 % and 10 % (1.67) which was on par with neem leaves 10 % (3.33).

At fifteen days after treatment, the percentage of weevils repelled ranged from 0.00 to 36.67. Rice treated with extract of tulsi leaves 10 % was significantly superior to all other treatments with 36.67 per cent repellent effect. Extract from pepper seed 10 % recorded repellent percentage of 16.67 followed by bird chilli fruit 10 % (15.00), tulsi leaves 5 % (13.33), pepper seed 5 % (10.00) and bird chilli fruit 5 % (10.00) and were statistically on par. The lowest percentage of 3.33 was observed in mint leaves extract 5 % and garlic bulb 5 and 10%.

Observation at twenty days after treatment showed that all treatments were significantly superior to untreated control. The percentage repellency varied from 0.00 to 36.67. Tulsi leaves 10 % recorded the highest repellent effect (36.67 per cent) followed by pepper seed 10 % (18.33) and bird chilli fruit 10 % (15.00) and

Table 6. Repellent effect of plant extracts on rice weevil *S. oryzae*

Treatments	Percentage repelled weevil*at DAT					
	5	10	15	20	25	30
Pepper seed 5%	10.00 (18.04)[b]	10.00 (18.04)[bc]	10.00 (18.04)[bcd]	11.67 (19.31)[bcd]	16.67 (24.04)[abc]	18.33 (25.30)[bcd]
Pepper seed 10%	6.67 (14.76)[bcd]	11.67 (19.88)[b]	16.67 (24.04)[b]	18.33 (25.19)[ab]	26.67 (31.07)[ab]	38.33 (38.17)[a]
Tulsi leaves 5%	3.33 (6.57)[de]	10.00 (15.21)[bcd]	13.33 (17.92)[bcd]	13.33 (17.92)[bcd]	13.33 (17.92)[bcd]	15.00 (22.01)[bcd]
Tulsi leaves 10%	23.33 (28.23)[a]	28.33 (31.26)[a]	36.67 (36.93)[a]	36.67 (36.93)[a]	38.33 (37.89)[a]	40.00 (39.04)[a]
Bird chilli fruit 5%	8.33 (16.59)[bc]	8.33 (16.59)[bc]	10.00 (18.44)[bcd]	10.00 (18.44)[bcd]	11.67 (19.88)[bcd]	13.33 (21.34)[bcd]
Bird chilli fruit 10%	11.67 (19.88)[ab]	15.00 (22.59)[ab]	15.00 (22.59)[bc]	15.00 (22.59)[abc]	18.33 (25.00)[abc]	23.33 (28.78)[abc]
Neem leaves 5%	0.00 (0.64)[e]	0.00 (0.64)[e]	0.00 (0.64)[e]	5.00 (8.02)[de]	6.67 (9.28)[de]	10.00 (14.53)[d]
Neem leaves 10%	3.33 (8.82)[de]	3.33 (8.82)[cde]	5.00 (10.66)[cde]	5.33 (10.66)[cde]	8.33 (16.59)[cd]	13.33 (21.15)[bcd]
Mint leaves 5%	0.00 (0.64)[e]	0.00 (0.64)[e]	3.33 (8.82)[de]	3.33 (8.82)[cde]	5.00 (12.93)[cde]	10.00 (18.04)[cd]
Mint leaves 10%	0.00 (0.64)[e]	0.00 (0.64)[e]	5.00 (10.66)[cde]	5.00 (10.66)[cde]	10.00 (15.40)[cd]	26.67 (30.78)[ab]
Garlic bulbs 5%	1.67 (4.73)[e]	1.67 (4.73)[de]	3.33 (6.57)[de]	6.67 (12.50)[bcde]	10.00 (15.40)[cd]	10.00 (15.40)[d]
Garlic bulbs 10%	1.67 (4.73)[e]	1.67 (4.73)[de]	3.33 (8.82)[de]	5.00 (10.66)[cde]	13.33 (21.34)[bcd]	13.33 (21.34)[bcd]
Control	0.00 (0.64)[e]	0.00 (0.64)[e]	0.00 (0.64)[e]	0.00 (0.64)[e]	0.00 (0.64)[e]	0.00 (0.64)[e]
CD (0.05)	**(9.188)**	**(10.692)**	**(12.580)**	**(14.442)**	**(14.270)**	**(12.108)**

DAT-Days after treatment * Mean of three replications
Figures in parenthesis are angular transformed values
**Figures in a column followed by same letter do not differ significantly

were statistically on par. It was followed by tulsi leaves 5 % (13.33), pepper seed 5 % (11.67), bird chilli fruit 5 % (10.00) and on par with garlic bulb 5 % (6.67). Least effective treatment was mint leaves 5 % with repellent effect of 3.33 per cent.

Efficacy of various plant extracts at twenty five days after treatment exhibited significant difference in comparison with the untreated control (0.00). Significantly highest percentage repellency was observed in rice treated with tulsi leaves 10 % (38.33) which was on par with pepper seed 10 % (26.67), bird chilli fruit 10 % (18.33) and pepper seed 5 % (16.67). Extracts of tulsi leaves 5 % and garlic bulb 10 % recorded same repellent effect of 13.33 per cent which were on par with bird chilli fruit 5 % (11.67), mint leaves 10 % (10.00), garlic bulb 5 % (10.00) and neem leaves 10 % (8.33).

Similar trend was observed at thirty days after treatment. All the treatments were significantly superior to untreated control. The repellency percentage varied from 0.00 to 40.00 per cent. The treatment with tulsi leaves 10 % showed maximum repellency of 40.00 per cent which was on par with pepper seed 10 % (38.33), mint leaves 10 % (26.67) and bird chilli fruit 10 % (23.33). It was followed by pepper seed 5 % (18.33), tulsi leaves 5 % (15.00), bird chilli fruit 5 % (13.33), neem leaves 10 % (13.33) and garlic bulb 10 % (13.33). Lowest percentage repellency of 10.00 was observed in treatment with neem leaves 5 %, mint leaves 5 % and garlic bulb 5 % and were statistically on par. Among the various plant extracts, tulsi leaves 10 % was the most effective treatment.

4.3.3 Effect of Plant Extracts on the Progeny Emergence of Rice Weevil *S. oryzae*

The data on effect of plant extracts on the progeny emergence of rice weevil *S. oryzae* at 55 days after treatment is presented in Table 7.

All plant extracts differed significantly in their effect on the emergence of second generation. Number of weevils emerged ranged from 4.00 to 43.66 progeny with 70.33 in untreated control. Tulsi leaves 10 % recorded as best treatment with lowest number of progeny emergence (4.00) followed by pepper seed 10 % (7.00),

Table 7. Effect of plant extracts on the progeny emergence of rice weevil *S. oryzae*

Treatments	**Number of progeny emerged (55 DAT)**	**Percentage inhibition of progeny emergence over control**
Pepper seed 5%	19.33 (4.35)[d]	72.43
Pepper seed 10%	7.00 (2.64)[ab]	90.08
Tulsi leaves 5%	7.66 (2.64)[ab]	89.30
Tulsi leaves 10%	4.00 (1.81)[a]	93.89
Bird chilli fruits 5%	20.00 (4.41)[d]	70.55
Bird chilli fruits 10%	11.00 (3.11)[bc]	83.44
Neem leaves 5%	14.00 (3.71)[bcd]	79.79
Neem leaves 10%	13.66 (3.67)[bcd]	80.69
Mint leaves 5%	43.66 (6.60)[e]	37.13
Mint leaves 10%	11.33 (3.35)[bcd]	84.02
Garlic bulbs 5%	18.00 (4.22)[cd]	74.63
Garlic bulbs 10%	8.67 (2.93)[ab]	87.47
Control	70.33 (8.38)[f]	-
CD (0.05)	**(1.237)**	

DAT-Days after treatment Mean of three replications

Figures in parenthesis are square root transformed values

**Figures in a column followed by same letter do not differ significantly

tulsi leaves 5 % (7.66) and garlic bulb 10 % (8.67). It was followed by bird chilli fruit 10 % (11.00), mint leaves 10 % (11.33), neem leaves 5 % (14.00) and neem leaves 10 % (13.66). Twenty weevils were emerged from treatment with bird chilli fruit 5 % followed by pepper seed 5 % (19.33) and garlic bulb 5 % (18.00). The highest number of weevil emergence was recorded from mint leaves 5 % (43.66) which was not effective in controlling next generation of rice weevil.

Tulsi leaves 10 % caused 93.89 per cent inhibition of progeny emergence over control followed by pepper seed 10 % (90.08), tulsi leaves 5 % (89.30), garlic bulb 10 % (87.47), bird chilli fruit 10 % (83.44) and mint leaves 10 % (84.02). Treatment with neem leaves 10 % showed 80.69 per cent inhibition of progeny emergence followed by neem leaves 5 % (79.97), garlic bulb 5 % (74.63) and pepper seed 5 % (72.43). Mint leaves 5 % inhibited only 37.13 per cent progeny emergence which was noted as least effective treatment in the control of *S. oryzae*.

4.3.4 Effect of Plant Extracts on Grain Damage by *S. oryzae*

The data on effect of plant extracts on grain damage by rice weevil *S. oryzae* after 55 days of storage is depicted in Table 8.

Least number of grains was found to be infested in treatment with tulsi leaves 10 % (12.00) which was on par with garlic bulb 10 % (14.33). Number of grains infested in treatment with pepper seed and bird chilli fruit at 10 % were 22.67 and 26 respectively. Treatment with mint leaves 5 % recorded the highest number of damaged grains (118) followed by bird chilli fruit 5 % (99.33) and neem leaves 10 % (96.67) and were statistically on par. Rice treated with neem leaves 5 % showed 55.67 infested grains followed by pepper seed 5 % (50.00) and mint leaves 10 % (45.67).

Tulsi leaves 10% caused 93.45 per cent reduction of grain infestation over control followed by garlic bulb 10 % (91.98), pepper seed 10 % (87.59) and bird chilli fruit 10 % (85.70). Garlic bulb 5 % recorded 80.30 per cent reduction of grain infestation over control. Percentage reduction of 72.44 was observed in pepper seed 5 % which was followed by mint leaves 10 % (72.21). Less than 50 per cent

Table 8. Effect of plant extracts on grain damage by *S. oryzae*

Treatments	Number of grains infested	Percentage reduction of infestation over control
Pepper seed 5%	50.00 (7.07)[ef]	72.44
Pepper seed 10%	22.67 (4.74)[bc]	87.59
Tulsi leaves 5%	87.33 (9.34)[g]	51.79
Tulsi leaves 10%	12.00 (3.45)[a]	93.45
Bird chilli fruits 5%	99.33 (9.96)[gh]	45.08
Bird chilli fruits 10%	26.00 (5.08)[cd]	85.70
Neem leaves 5%	55.67 (7.37)[f]	68.85
Neem leaves 10%	96.67 (9.82)[gh]	46.35
Mint leaves 5%	118.00 (10.89)[h]	34.84
Mint leaves 10%	45.67 (6.66)[ef]	72.21
Garlic bulbs 5%	35.67 (5.97)[de]	80.30
Garlic bulbs 10%	14.33 (3.78)[ab]	91.98
Control	182.33 (13.49)[i]	
CD (0.05)	**(1.156)**	

*Mean of three replications

Figures in parenthesis are square root transformed values

**Figures in a column followed by same letter do not differ significantly

reduction of grain infestation was observed in neem leaves 10 % (46.35), bird chilli fruit 5 % (45.08) and mint leaves 5 % (34.84).

4.3.4 Fungal Growth

No fungal growth was observed in the treated grains during the experiment.

4.4 MANAGEMENT OF *S. oryzae* USING DRIED PLANT PARTS

4.4.1 Effect of Dried Plant Parts on Mortality of Rice Weevil *S. oryzae*

The data on effect of different dried plant parts on the mortality of rice weevil *S. oryzae* in stored rice at 7, 14, 21, 28 and 35 days after treatment are depicted in Table 9.

Efficacy of various plant extracts at seven days after treatment exhibited significant difference on comparison with the untreated control. The mortality of weevils ranged from 0.00 to 8.33 per cent. Rice treated with mint leaves 4 % recorded the highest mortality of 8.33 per cent which was statistically on par with mint leaves 2 % (6.67), nutmeg mace 4 % (5.00), tulsi leaves 2 % (5.00), neem leaves 4 % (5.00) and neem leaves 2 % (3.33). The lowest mortality (1.67) was observed in rice treated with nutmeg mace and clove flower buds at 2 % concentration and tulsi leaves 4 %.

The percentage mortality of weevils ranged from 0.00 to 18.33 at fourteen days after treatment. The highest mortality was observed in treatment with nutmeg mace 4 % (18.33 per cent) which was on par with mint leaves 4 % (15.00) and neem leaves 4 % (11.67). Mortality of 6.67 per cent was recorded in nutmeg mace 2 %, tulsi leaves 2 %, mint leaves 2 % and curry leaves 4 %. These treatments were on par with clove flower bud 4 %, tulsi leaves 4 % and neem leaves 2 % with mortality of 5.00 per cent. Treatment with curry leaves 2 % showed no mortality as in control which was on par with clove flower buds 2 % (3.33).

On examining the percentage mortality caused by various dried plants at 21 days after treatment, nutmeg mace 4 % and mint leaves 4 % recorded the highest mortality of 20.00 followed by nutmeg mace 2 % (13.33), neem leaves 4 % (13.33),

Table 9. Effect of dried plant parts on mortality of rice weevil *S. oryzae*

Treatments	**Percentage mortality* at DAT**				
	7	**14**	**21**	**28**	**35**
Nutmeg mace 2%	1.67 (4.73)[bc]	6.67 (12.50)[cd]	13.33 (17.43)[ab]	16.67 (20.14)[bc]	25.00 (25.32)[bcd]
Nutmeg mace 4%	5.00 (8.02)[abc]	18.33 (24.82)[a]	20.00 (25.84)[a]	26.67 (30.18)[ab]	35.00 (36.18)[ab]
Clove flower buds 2%	1.67 (4.73)[bc]	3.33 (8.82)[de]	8.33 (16.20)[ab]	10.00 (18.04)[bc]	13.33 (20.46)[cde]
Clove flower buds 4%	0.00 (0.64)[c]	5.00 (12.93)[cd]	5.00 (12.93)[b]	20.00 (26.45)[abc]	23.33 (28.85)[bc]
Tulsi leaves 2%	5.00 (12.93)[ab]	6.67 (14.76)[bcd]	6.67 (14.76)[ab]	6.67 (14.76)[cd]	15.00 (22.01)[bcde]
Tulsi leaves 4%	1.67 (4.73)[bc]	5.00 (12.93)[cd]	5.00 (12.93)[b]	13.33 (21.34)[bc]	21.67 (27.21)[bc]
Mint leaves 2%	6.67 (14.76)[ab]	6.67 (14.76)[bcd]	8.33 (16.59)[ab]	10.00 (18.04)[bc]	26.67 (30.94)[bc]
Mint leaves 4%	8.33 (16.59)[a]	15.00 (22.29)[ab]	20.00 (26.07)[a]	33.33 (35.00)[a]	56.67 (48.84)[a]
Neem leaves 2%	3.33 (8.82)[abc]	5.00 (10.66)[d]	8.33 (13.95)[b]	8.33 (13.95)[cd]	15.00 (22.59)[bcde]
Neem leaves 4%	5.00 (12.93)[ab]	11.67 (19.88)[abc]	13.33 (21.15)[ab]	16.67 (24.04)[abc]	21.67 (27.53)[bc]
Curry leaves 2%	0.00 (0.64)[c]	0.00 (0.64)[e]	0.00 (0.64)[c]	1.67 (4.73)[de]	6.67 (12.11)[de]
Curry leaves 4%	0.00 (0.64)[c]	6.67 (14.76)[bcd]	6.67 (14.76)[ab]	8.33 (16.56)[cd]	10.00 (18.44)[cde]
Control	0.00 (0.64)[c]	0.00 (0.64)[e]	0.00 (0.64)[c]	0.00 (0.64)[e]	3.33 (8.82)[e]
CD (0.05)	**(9.135)**	**(9.041)**	**(11.680)**	**(12.930)**	**(14.353)**

DAT-Days after treatment *Mean of three replications
Figures in parenthesis are angular transformed values
**Figures in a column followed by same letter do not differ significantly

clove flower buds 2 % (8.33), mint leaves 2 % (8.33), tulsi leaves 2 % and curry leaves 4 % (6.67). Treatment with clove flower buds and tulsi leaves at 4 % concentration recorded a mortality of 5.00 per cent which were on par with neem leaves 4 % (8.33). Treatment with curry leaves 4 % and control recorded no mortality.

Significant difference was observed in percentage mortality of weevils at 28 days after treatment. The mortality ranged from 1.67 to 33.33 per cent. The highest percentage mortality was observed in treatment with mint leaves 4 % (33.33) which was on par with nutmeg mace 4 % (26.67), clove flower 4 % (20.00) and neem leaves 4 % (16.67). It was followed by nutmeg mace 2 % (16.67), tulsi leaves 4 % (13.33), clove flower buds 2 % (10.00) and mint leaves 2 % (10.00). Treatment with neem leaves 2 % and curry leaves at 4 % concentration recorded a mortality of 8.33 per cent which were on par with tulsi leaves 2 % (6.67). Lowest percentage mortality was recorded in treatment with dried curry leaves at 2 % (1.67).

Among the various dried plant parts, rice treated with mint leaves 4 % was the most effective treatment at 35 days after treatment with 56.67 per cent mortality which was statistically on par with nutmeg mace 4 % (35.00). Rice treated with mint leaves 2 % recorded mortality of 26.67 per cent which was on par with tulsi leaves 4 % (21.67), neem leaves 4 % (21.67), nutmeg mace 2 % (25.00) and clove flower buds 4 % (23.33). The lowest mortality (6.67) was observed in curry leaves 2 % which was on par with tulsi leaves 2 % (15.00), neem leaves 2 % (15.00), clove flower buds 2 % (13.33), curry leaves 4 % (10.00) and control (3.33).

4.4.2 Repellent Effect of Dried Plant Parts on Rice Weevil *S. oryzae*

The data on repellent effect of dried plant parts on rice weevil *S. oryzae* in stored rice at 5, 10, 15, 20, 25 and 30 days after treatment are furnished in Table 10.

The percentage repellency of weevils ranged from 0.00 to 20.00 at five days after treatment. The highest percentage of 20.00 was recorded in nutmeg mace 4 % followed by nutmeg mace 2 % (10.00), clove flower buds 4 % (8.33), mint leaves

Table 10. Repellent effect of dried plant parts on rice weevil *S. oryzae*

Treatments	**Percentage repelled weevils* at DAT**					
	5	**10**	**15**	**20**	**25**	**30**
Nutmeg mace 2%	10.00 (18.04)^{ab}	10.00 (18.04)^{ab}	15.00 (21.52)^{ab}	15.00 (21.52)^{abc}	15.00 (21.52)^{abc}	15.00 (21.52)^{abc}
Nutmeg mace 4%	20.00 (25.25)^{a}	20.00 (25.25)^{a}	23.33 (28.07)^{a}	26.67 (30.00)^{a}	28.33 (31.15)^{a}	31.67 (33.18)^{a}
Clove flower buds 2%	5.00 (10.67)^{bcde}	11.67 (18.62)^{ab}	11.67 (18.62)^{ab}	11.67 (18.62)^{abcd}	11.67 (18.62)^{abcd}	11.67 (18.62)^{bc}
Clove flower buds 4%	8.33 (16.20)^{abc}	11.67 (19.88)^{ab}	16.67 (23.74)^{a}	16.67 (23.74)^{ab}	16.67 (23.74)^{ab}	18.33 (24.82)^{ab}
Tulsi leaves 2%	1.67 (4.73)^{de}	1.67 (4.73)^{cd}	3.33 (6.57)^{cd}	3.33 (6.57)^{de}	3.33 (6.57)^{de}	5.00 (10.66)^{cd}
Tulsi leaves 4%	5.00 (12.93)^{bcd}	11.67 (19.31)^{ab}	13.33 (21.15)^{ab}	13.33 (21.15)^{abc}	13.33 (21.15)^{abc}	18.33 (25.00)^{ab}
Mint leaves 2%	3.33 (8.82)^{bcde}	5.00 (10.66)^{bcd}	8.33 (16.59)^{abc}	10.00 (18.04)^{abcd}	10.00 (18.04)^{bcd}	10.00 (18.04)^{bc}
Mint leaves 4%	8.33 (16.20)^{abc}	10.00 (18.04)^{ab}	10.00 (18.04)^{abc}	10.00 (18.04)^{abcd}	10.00 (18.04)^{bcd}	13.33 (20.75)^{abc}
Neem leaves 2%	3.33 (6.57)^{cde}	5.00 (10.66)^{bcd}	5.00 (10.66)^{bcd}	5.00 (10.66)^{cde}	5.00 (10.66)^{cde}	6.67 (14.76)^{bc}
Neem leaves 4%	5.00 (12.93)^{bcd}	6.67 (14.76)^{abc}	8.33 (16.20)^{abc}	8.33 (16.20)^{bcd}	8.33 (16.20)^{bcd}	8.33 (16.20)^{bc}
Curry leaves 2%	0.00 (0.64)^{e}	0.00 (0.64)^{d}	0.00 (0.64)^{d}	0.00 (0.64)^{e}	0.00 (0.64)^{e}	0.00 (0.64)^{d}
Curry leaves 4%	6.67 (14.76)^{abcd}	8.33 (16.20)^{ab}	8.33 (16.20)^{abc}	8.33 (16.20)^{bcd}	8.33 (16.20)^{bcd}	8.33 (16.20)^{bc}
Control	0.00 (0.64)^{e}	0.00 (0.64)^{d}	0.00 (0.64)^{d}	0.00 (0.64)^{e}	0.00 (0.64)^{e}	0.00 (0.64)^{d}
CD (0.05)	**(10.674)**	**(11.369)**	**(11.978)**	**(12.754)**	**(12.694)**	**(12.744)**

DAT-Days after treatment *Mean of three replications

Figures in parenthesis are angular transformed values

**Figures in a column followed by same letter do not differ significantly

4 % (8.33) and curry leaves 4 % (6.67) and were statistically on par. Treatment with clove flower buds 2 %, tulsi leaves and neem leaves at 4 % concentration were recorded a repellent percentage of 5.00 which were on par with mint leaves and neem leaves at 2 % (3.33). Lowest percentage repellency was recorded in treatment with dried tulsi leaves at 4 % (1.67) which was statistically on par with curry leaves 4 % and control (0.00).

Observation at ten days after treatment showed that except curry leaves 2 %, all the treatments were significantly superior to untreated control (0.00). Nutmeg mace 4 % recorded the highest repellency of 20.00 per cent which was statistically on par with clove flower buds (2 % and 4 %), tulsi leaves (4 %), nutmeg mace (2 %), mint leaves (4 %), curry leaves (4 %) and neem leaves (4 %). Treatment with mint leaves 2 % and neem leaves 2 % recorded percentage repellency of 5.00 which were on par with tulsi leaves 2 % (1.67).

Among the dried plant parts at two concentrations, nutmeg mace 4 % was the best treatment at fifteen days after treatment with repellent percentage of 23.33 followed by clove flower buds 4 % (16.67), nutmeg mace 4 % (15.00), tulsi leaves 4 % (13.33), clove flower buds 2 % (11.67) and mint leaves 4 % (10.00) and were statistically on par. These treatments were statistically on par with mint leaves 2 %, neem leaves 4 % and curry leaves 4 % with repellency of 8.33 per cent. Lowest repellent effect of 3.33 per cent was observed in tulsi leaves 2 % which was on par with curry leaves 2 % and control (0.00).

On comparison, nutmeg mace 4 % exhibited the highest percentage repellency of 26.67 at twenty days after treatment which was statistically on par with six treatments *viz.* clove flower buds 4 % (16.67), nutmeg mace 2 % (15.00), tulsi leaves 4 % (13.33), clove flower buds 2 % (11.67), mint leaves 2 % and 4 % (10.00). Treatment with neem leaves and curry leaves at 4 % recorded percentage repellency of 8.33 and were on par with neem leaves 2 % (5.00) and tulsi leaves 2 % (3.33).

At 25 days after treatment, rice treated with nutmeg mace 4 % showed repellency of 28.33 which was significantly superior to all other treatments. This was followed by clove flower buds 4 % (16.67), nutmeg mace 2 % (15.00), tulsi leaves 4 % (13.33) and clove flower buds 2 % (11.67) and were statistically on par. Dried mint leaves (2 and 4 %), neem leaves and curry leaves (4 %) were on par with each other, recorded a repellency of 10.00 per cent and 8.33 per cent respectively. It was followed by treatment with neem leaves 2 % (5.00) and tulsi leaves 2 % (3.33), which were on par.

Similar trend was observed at thirty days after treatment. The highest percentage repellency (31.67) of weevils were recorded in rice treated with nutmeg mace 4 %. This treatment was statistically on par with 4 % concentration of clove flower buds and tulsi leaves (18.33), nutmeg mace 2 % (15.00) and mint leaves 4 % (13.33). It was followed by clove flower buds 2 % (11.67), mint leaves 2 % (10.00), neem and curry leaves at 4 % (8.33) and on par with neem leaves 2 % (6.67). Least effective treatment was curry leaves 2 % with no mortality which was statistically on par with tulsi leaves 2 % (5.00) and control (0.00).

The treatment with curry leaves 2 % recorded no repellent effect in the present study. Among the various dried plant parts at 4 % concentration, rice treated with nutmeg mace was the most effective treatment which also statistically on par with 2 % concentration.

4.4.3 Effect of Dried Plant Parts on Progeny Emergence of Rice Weevil *S. oryzae*

The data on the effect of dried plant parts on the progeny emergence of rice weevil *S. oryzae* at 55 days after treatment were represented in Table 11.

At fifty five days after treatment, the number of progeny emerged from the treated rice varied from 7.00 to 43.33 with the highest number of 70.33 in control. The treatment with nutmeg mace 4 % recorded lowest number of progeny emergence (7.00) followed by mint leaves 4 % (8.33) and tulsi leaves 4 % (13.67) which were statistically on par. Clove flower buds 4 % recorded progeny emergence of 15.00 which was on par with mint leaves 2 % (16.00). Rice treated with nutmeg

Table 11. Effect of dried plant parts on progeny emergence of rice weevil *S. oryzae*

Treatment	Mean number of progeny emerged (55 DAT)	Percentage inhibition of progeny emergence over control
Nutmeg mace 2%	18.00 (4.21)[cd]	74.21
Nutmeg mace 4%	7.00 (2.57)[a]	89.81
Clove flower buds 2%	24.00 (4.89)[de]	65.71
Clove flower buds 4%	15.00 (3.85)[bcd]	78.85
Tulsi leaves 2%	30.00 (5.38)[e]	57.80
Tulsi leaves 4%	13.67 (3.62)[abc]	80.04
Mint leaves 2%	16.00 (3.89)[bcd]	76.25
Mint leaves 4%	8.33 (2.85)[ab]	88.29
Neem leaves 2%	31.33 (5.59)[ef]	55.12
Neem leaves 4%	23.00 (4.76)[de]	67.53
Curry leaves 2%	43.33 (6.58)[f]	38.02
Curry leaves 4%	31.00 (5.58)[ef]	55.27
Control	70.33 (8.38)[g]	-
CD (0.05)	**(1.144)**	

DAT-Days after treatment *Mean of three replications

Figures in parenthesis are square root transformed values

**Figures in a column followed by same letter do not differ significantly

mace 2 % recorded progeny emergence of 18.00 whereas in treatment with neem leaves 4 % and clove flower buds 2 % recorded 23.00 and 24.00 respectively. Progeny emergence in treatment with tulsi leaves 2 % was 30.00 followed by curry leaves 4 % (31.00) and neem leaves 2 % (31.33) which were on par. The highest progeny emergence was observed in treatment with curry leaves 2 % (43.33).

Nutmeg mace 4 % caused 89.81 per cent inhibition of progeny emergence over control followed by mint leaves 4 % (88.29), tulsi leaves 4 % (80.04) and clove flower buds 4 % (78.85). Mint leaves 2 % recorded 76.25 per cent inhibition of progeny emergence over control. Percentage inhibition of 74.21 was observed in nutmeg mace 2 % followed by neem leaves 4 % (67.53) and clove flower buds 2 % (65.71). More than 50 per cent inhibition over control was observed in neem leaves 2 % (55.21), curry leaves 4 % (55.27) and tulsi leaves 2 % (57.80). Treatment with curry leaves 2 % inhibited only 38.02 per cent progeny emergence which was the least effective treatment.

4.4.4 Effect of Dried Plant Parts on Grain Damage by *S. oryzae*

Results on the effect of dried plant parts on grain damage incurred by rice weevil after 55 days of storage are given in Table 12.

Damage caused by weevils on rice was assessed based on the number of damaged grains. Least infestation was recorded in treatment with nutmeg mace 4 % (23.67) which was observed as best treatment over others. Treatment with mint leaves 4 % showed 36.66 damaged grains which was the second best treatment. Tulsi leaves 4 % recorded 45.67 infested grains followed by clove flower bud 4 % (49.67), nutmeg mace 2 % (55.33) and tulsi leaves 2 % (55.67) which were statistically on par. Rice treated with clove flower buds showed 66.00 infested grains at 55 days after treatment. Whereas mint leaves 2 % recorded 85.00 infested garins followed by neem leaves 4 % (87.00). Curry leaves 4 % recorded 93.00 damaged grains followed by neem leaves 2 % (95.33). The highest number of grain infestation was observed in treatment with curry leaves 2 % (126.33).

Table 12. Effect of dried plant parts on grain damage by *S. oryzae*

Treatment	Number of grains infested	Percentage reduction of infestation over control
Nutmeg mace 2%	55.33 (7.38)[bc]	69.75
Nutmeg mace 4%	23.67 (4.83)[a]	86.74
Clove flower buds 2%	66.00 (8.06)[cd]	62.84
Clove flower buds 4%	49.67 (7.04)[bc]	72.61
Tulsi leaves 2%	55.67 (7.37)[bc]	68.99
Tulsi leaves 4%	45.67 (6.66)[bc]	74.21
Mint leaves 2%	85.00 (9.19)[de]	52.99
Mint leaves 4%	36.33 (6.03)[ab]	62.84
Neem leaves 2%	95.33 (9.74)[ef]	46.98
Neem leaves 4%	87.00 (9.30)[de]	52.55
Curry leaves 2%	126.33 (11.23)[f]	30.67
Curry leaves 4%	93.00 (9.64)[e]	48.88
Control	182.33 (13.49)[g]	-
CD (0.05)	**(1.496)**	

*Mean of three replications

Figures in parenthesis are square root transformed values

**Figures in a column followed by same letter do not differ significantly

Treatment with nutmeg mace 4 % showed 86.74 per cent infestation reduction followed by mint leaves 4 % (79.97), tulsi leaves 4 % (74.21) and clove flower buds 4 % (72.61) over control. Clove flower buds, nutmeg mace and tulsi leaves at 2 % concentrations showed infestation reduction of 62.84, 69.75 and 68.99 per cent respectively. Rice treated with mint leaves 2 % recorded infestation reduction of 52.99 per cent followed by neem leaves 4 % (52.55) and curry leaves 4 % (48.88). Least effective treatment was curry leaves 2 % with infestation reduction of 30.67 per cent over control.

4.4.5 Fungal Growth

No fungal growth was observed in the treated grains during the experiment.

4.5 MANAGEMENT OF *S. oryzae* USING VOLATILE ESSENTIAL OILS

The mortality response of four volatile essential oils *viz.,* cinnamon oil, clove oil, lemon grass oil and pepper oil on rice weevil *S. oryzae* in storage was studied and results are described below.

4.5.1 Mortality Response of Cinnamon Oil on *S. oryzae*

Toxic response of different concentration of cinnamon oil was tested by two methods of bioassays (without food and with food).

4.5.1.1 Effect of Cinnamon Oil on Mortality of Rice Weevil S. oryzae *in Bioassay Without Food*

Cinnamon oil caused mortality of 25.00 to 100.00 per cent at concentrations ranging from 5 to 25 µl 500 cm^{-3} volume over a period of 48 h after treatment (Table 13). Percentage mortality of weevils increased with increase in concentration and period of exposure. At concentration of 25 µl 500 cm^{-3} volume recorded higher mortality of 97.50 per cent at 12 h after treatment which was on par with concentrations 15 (82.50) and 20 (85.00) µl 500 cm^{-3}. The lower concentrations (5 and 10 µl 500 cm^{-3}) caused mortality of 25.00 per cent and 50.00 per cent, which were statistically on par. Complete mortality of weevils were recorded 24 h after treatment with 25 µl 500 cm^{-3} followed by 15 µl 500 cm^{-3} volume (95.00 %) which

Table 13. Effect of cinnamon oil on the mortality of rice weevil *S. oryzae* (without food)

Concentrations ($\mu l\ 500\ cm^{-3}$)	Percentage mortality* at HAT		
	12	24	48
5	25.00 $(29.88)^{b}$	65.00 $(53.78)^{d}$	67.50 $(55.29)^{c}$
10	50.00 $(45.00)^{b}$	82.50 $(65.46)^{c}$	85.00 $(67.50)^{b}$
15	82.50 $(69.30)^{a}$	95.00 $(82.67)^{ab}$	100.00 $(89.09)^{a}$
20	85.00 $(70.23)^{a}$	92.50 $(75.94)^{bc}$	100.00 $(89.09)^{a}$
25	97.50 $(84.72)^{a}$	100.00 $(89.09)^{a}$	100.00 $(89.09)^{a}$
Control	0.00 $(0.91)^{d}$	0.00 $(0.91)^{e}$	0.00 $(0.91)^{d}$
CD (0.05)	**(15.332)**	**(9.963)**	**(3.380)**

HAT- Hours after treatment *Mean of four replications

Table 14. Effect of cinnamon oil on the mortality of rice weevil *S. oryzae* (with food)

Concentrations ($\mu l\ 500\ cm^{-3}$)	Percentage mortality* at DAT			
	2	4	6	8
4	12.22 $(20.32)^{a}$	25.56 $(30.35)^{a}$	36.67 $(37.17)^{a}$	37.78 $(37.81)^{a}$
6	14.44 (22.30)a	28.89 $(32.51)^{a}$	37.78 $(37.92)^{a}$	37.78 $(37.92)^{a}$
8	14.44 $(22.30)^{a}$	30.00 $(33.22)^{a}$	37.78 $(37.86)^{a}$	38.89 $(38.49)^{a}$
10	14.44 $(22.30)^{a}$	30.00 $(33.19)^{a}$	40.00 $(39.23)^{a}$	43.33 $(41.16)^{a}$
15	24.45 $(27.42)^{a}$	31.11 $(32.99)^{a}$	51.11 $(45.75)^{a}$	52.22 $(46.49)^{a}$
Control	0.00 $(0.52)^{b}$	0.00 $(0.52)^{b}$	0.00 $(0.52)^{b}$	0.00 $(0.52)^{b}$
CD (0.05)	**(13.875)**	**(11.353)**	**(10.267)**	**(11.497)**

DAT-Days after treatment *Mean of three replications

Figures in parenthesis are angular transformed values

**Figures in a column followed by same letter do not differ significantly

were on par. Percentage mortality increased from 67.50 to 100.00 per cent at 48 h after treatment. Cinnamon oil at three higher concentrations (15, 20 and 25 μl 500 cm^{-3}) caused cent per cent mortality. No mortality was observed in control throughout the experimental period.

4.5.1.2. Effect of Cinnamon Oil on Mortality of Rice Weevil S. oryzae in Bioassay with Food

In bioassay with food, cinnamon oil at 4, 6, 8, 10 and 15 μl 500 cm^{-3} caused percentage mortality of 12.22 to 52.22 over a period of 8 days after treatment (Table 14).

The increasing dose of cinnamon oil from 4 to 15 μl 500 cm^{-3} at two days after treatment recorded mortality of 12.22 to 24.45 per cent which were statistically on par. Similar trend was also observed in four days after treatments. Up to six days after treatment, all concentrations showed no significant difference on the percentage mortality of weevils. The toxicity effect of cinnamon oil on rice weevils increased with increased exposure period. Eight days of exposure with cinnamon oil caused percentage mortality of 37.78 (4 μl 500 cm^{-3}) to 52.22 (15 μl 500 cm^{-3}). More than 50.00 per cent mortality of weevils observed only at six and eight days after treatment with concentration of 15 μl 500 cm^{-3}.

The same trend of increasing mortality with increase in dose and period of exposure was observed in both methods of bioassay. Concentration of 15 μl 500 cm^{-3} caused cent per cent mortality of weevils in bioassay without food at 48 h after treatment while the same concentration cause a mortality of 52.22 per cent under bioassay with food after eight days of exposure.

4.5.1.3. Median Lethal Concentrations of Cinnamon Oil

LC_{50} and LC_{90} values and probit regression parameters of cinnamon oil against rice weevil in two bioassay methods are represented in Table 15.

Five different concentrations of cinnamon oil was tested by two bioassay techniques, without food and with food against *S. oryzae*. LC_{50} value of 2.90 μl

Table 15. LC_{50} values and probit regression parameters of cinnamon oil against rice weevil *S. oryzae*

Bioassay method	**LC_{50} (CL) (µl 500 cm^{-3})**	**LC_{90} (CL) (µl 500 cm^{-3})**	**Probit regression parameters**			
			Regression equation	**Intercept (a)±SE**	**Slope (b)±SE**	**Chi square**
Without food	2.90 (-2.15-5.03)	10.09 (8.38-13.24)	Y= -0.518+0.178X	-0.518±0.372	0.178±0.044	1.789
With food	14.30 (10.61-52.27)	50.22 (30.77-322.09)	Y= -0.510+0.036	-0.510±0.149	0.036±0.016	0.437

LC – Lethal concentration CL – Confidential limit

500 cm^{-3} was recorded in without food bioassay. In bioassay with food the LC_{50} value was 50.22 µl 500 cm^{-3}. Cinnamon oil caused 90 per cent mortality of weevils at 10.09 and 50.22 µl 500 cm^{-3} in without and with food conditions respectively.

4.5.2 Mortality Response of Clove Oil on *S. oryzae*

Toxic response of different concentration of clove oil was tested by two methods of bioassays (without food and with food).

4.5.2.1 Effect of Clove Oil on Mortality of Rice Weevil S. oryzae in Bioassay Without Food

Data on the toxic effect of different concentrations of clove oil on rice weevil at 12, 24 and 48 h after treatment in bioassay without food are given in Table 16.

Percentage mortality data showed that clove oil concentration and mortality of weevils were directly proportional. At 12 h after treatment, higher concentrations (15, 20 and 25 µl 500 cm^{-3}) recorded mortality of 60.00 and 67.50 per cent and were statistically on par. Treatment with 5 µl 500 cm^{-3} showed no mortality which was same as in control. Toxicity of clove oil increased from 32.50 to 80.00 per cent after 24 h of exposure. The highest percentage mortality of 80.00 were observed at concentration of 25 µl 500 cm^{-3} followed by 15 and 20 µl 500 cm^{-3} volume (77.50) and were statistically on par. After 48 h of exposure, concentration of 25 µl 500 cm^{-3} showed the highest percentage mortality of 97.50 which is on par with 20 µl 500 cm^{-3} (87.50). All the treatments were significantly superior to control.

4.5.2.2. Effect of Clove Oil on Mortality of Rice Weevil S. oryzae in Bioassay with Food

The data on effect of different concentration of clove oil on mortality of rice weevil in stored rice at 2, 4, 6 and 8 days after treatment are depicted in Table 17.

At two days after treatment, the percentage mortality of weevil ranged from 11.11 to 15.56 at increasing concentrations from 4 to 15 µl 500 cm^{-3}. Similar trend was also observed at four, six and eight days after treatment. The mortality was

Table 16. Effect of clove oil on the mortality of rice weevil *S. oryzae* (without food)

Concentrations (µl 500 cm^{-3})	Percentage mortality* at HAT		
	12	24	48
5	0.00 (0.91)^{c}	32.50 (34.71)^{b}	32.50 (34.71)^{d}
10	25.00 (29.89)^{b}	52.50 (46.44)^{b}	60.00 (50.83)^{c}
15	60.00 (50.83)^{a}	77.50 (62.68)^{a}	77.50 (62.68)^{bc}
20	60.00 (50.83)^{a}	77.50 (62.68)^{a}	87.50 (74.60)^{ab}
25	67.50 (55.44)^{a}	80.00 (63.44)^{a}	97.50 (84.72)^{a}
Control	0.00 (0.91)^{c}	0.00 (0.91)^{c}	0.00 (0.91)^{e}
CD (0.05)	**(5.984)**	**(12.323)**	**(13.664)**

HAT- Hours after treatment * Mean of four replications

Table 17. Effect of clove oil on the mortality of rice weevil *S. oryzae* (with food)

Concentrations (µl 500 cm^{-3})	Percentage mortality* at DAT			
	2	4	6	8
4	11.11 (19.16)^{a}	24.44 (29.46)^{a}	28.89 (32.42)^{a}	30.00 (33.07)^{a}
6	11.11 (19.43)^{a}	27.78 (31.76)^{a}	35.56 (36.52)^{a}	36.67 (37.17)^{a}
8	13.33 (21.31)^{a}	29.99 (33.14)^{a}	37.78 (37.80)^{a}	37.78 (37.80)^{a}
10	14.44 (22.30)^{a}	31.11 (33.71)^{a}	37.78 (37.82)^{a}	37.78 (37.82)^{a}
15	15.56 (23.21)^{a}	31.11 (33.86)^{a}	38.89 (38.50)^{a}	41.11 (39.81)^{a}
Control	0.00 (0.52)^{b}	0.00 (0.52)^{b}	0.00 (0.52)^{b}	0.00 (0.52)^{b}
CD (0.05)	**(4.415)**	**(7.184)**	**(8.886)**	**(9.583)**

DAT-Days after treatment *Mean of three replications

Figures in parenthesis are angular transformed values

**Figures in a column followed by same letter do not differ significantly

ranged from 24.44 to 31.11 per cent at 4 days after treatment. The toxicity effect of clove oil on rice weevils increased with increased exposure period. Six days of exposure with clove oil caused percentage mortality of 28.89 (4 µl 500 cm^{-3}) to 38.89 (15 µl 500 cm^{-3}) on weevils. The highest percentage mortality was observed in 15 µl 500 cm^{-3} (41.11) at eight days after treatment.

4.5.2.3. Median Lethal Concentrations of Clove Oil

LC_{50} and LC_{90} values and probit regression parameters of clove oil against rice weevil in two bioassay methods are represented in Table 18.

Five different concentrations of clove oil was tested by two bioassay techniques, without food and with food against *S. oryzae*. LC_{50} value of 8.51 µl 500 cm^{-3} was obtained in without food bioassay. In bioassay with food the LC_{50} was 23.91 µl 500 cm^{-3}. Clove oil caused 90 per cent mortality of weevils at 19.95 and 81.29 µl 500 cm^{-3} in without and with food conditions respectively.

While comparing cinnamon and clove oil with same concentrations, the essential oil of cinnamon was found to have highest toxicity as well as lower LC_{50} and LC_{90} values at same period of exposure.

4.5.3 Mortality Response of Lemon Grass Oil on *S. oryzae*

Toxic response of different concentrations of lemon grass oil was tested by two methods of bioassays (without food and with food).

4.5.3.1 Effect of Lemon Grass Oil on Mortality of Rice Weevil S. oryzae *in Bioassay Without Food*

The data on mortality of lemon grass oil on rice weevil *S. oryzae* in bioassay without food at 12, 24 and 48 h after treatment are furnished in Table 19.

Efficacy of six concentrations (5, 10, 15, 100, 150 and 200 µl 500 cm^{-3}) of lemon grass oil at 12 h after treatment exhibited increased percentage mortality with increased concentrations. The highest mortality of 40.00 per cent was obtained with 200 µl 500 cm^{-3} at 12 h of exposure followed by 150 µl 500 cm^{-3} (37.50) which

Table 18. LC_{50} values and probit regression parameters of clove oil against rice weevil *S. oryzae*

Bioassay method	**LC_{50} (CL) (µl 500 cm^{-3})**	**LC_{90} (CL) (µl 500 cm^{-3})**	**Probit regression parameters**			
			Regression equation	**Intercept (a)±SE**	**Slope (b)±SE**	**Chi square**
Without food	8.51 (5.81-10.45)	19.95 (17.57-23.79)	Y=-0.954+0.112X	-0.954±0.237	0.112±0.017	0.659
With food	23.91 (21.45-27.12)	81.29 (61.13-119.98)	Y=-0.534+0.022X	-0.534±0.151	0.022±0.016	0.666

LC – Lethal concentration   CL – Confidential limit

Table 19. Effect of lemon grass oil on the mortality of rice weevil *S. oryzae* (without food)

Concentrations (µl 500 cm^{-3})	Percentage mortality* at HAT		
	12	24	48
5	0.00 (0.91)^{c}	0.00 (0.91)^{c}	0.00 (0.91)^{c}
10	0.00 (0.91)^{c}	0.00 (0.91)^{c}	0.00 (0.91)^{c}
15	0.00 (0.91)^{c}	12.50 (20.40)^{b}	15.00 (22.50)^{b}
100	25.00 (26.42)^{b}	25.00 (26.42)^{b}	100.00 (89.09)^{a}
150	37.50 (37.66)^{a}	37.50 (37.66)^{a}	100.00 (89.09)^{a}
200	40.00 (39.23)^{a}	50.00 (45.00)^{a}	100.00 (89.09)^{a}
Control	0.00 (0.91)^{c}	0.00 (0.91)^{c}	0.00 (0.91)^{c}
CD (0.05)	**(10.822)**	**(11.064)**	**(2.603)**

HAT- Hours after treatment *Mean of four replications

Table 20. Effect of lemon grass oil on the mortality of rice weevil *S. oryza* (with food)

Concentrations (µl 500 cm^{-3})	Percentage mortality* at DAT			
	2	4	6	8
50	3.33 (8.66)^{ab}	10.00 (17.68)^{c}	11.11 (18.51)^{c}	11.11 (18.51)^{c}
60	4.45 (10.15)^{a}	14.47 (21.87)^{bc}	20.00 (26.14)^{bc}	21.11 (26.88)^{bc}
70	6.67 (14.64)^{a}	18.89 (25.69)^{ab}	24.45 (29.46)^{b}	25.56 (30.17)^{b}
80	7.78 (16.12)^{a}	22.22 (28.07)^{ab}	26.67 (31.06)^{b}	26.67 (31.06)^{b}
100	8.89 (16.79)^{a}	28.89 (32.51)^{a}	43.33 (41.15)^{a}	52.22 (46.28)^{a}
Control	0.00 (0.52)^{b}	0.00 (0.52)^{d}	0.00 (0.52)^{d}	0.00 (0.52)^{d}
CD (0.05)	**(9.624)**	**(7.254)**	**(8.854)**	**(9.368)**

DAT-Days after treatment *Mean of three replications

Figures in parenthesis are angular transformed values

**Figures in a column followed by same letter do not differ significantly

were statistically on par. The lowest mortality (0.00) was observed in 5, 10 and 15 µl 500 cm^{-3} which was same as in control. Treatment with 200 µl 500 cm^{-3}volume at 24 h after exposure recorded maximum mortality of 50.00 per cent which was on par with 150 µl 500 cm^{-3} (37.50). Concentrations of 5 and 10 µl 500 cm^{-3} showed no mortality similar to control. Complete mortality of weevil were observed at 48 h after treatment with concentrations of 100, 150 and 200 µl 500 cm^{-3}. Lower concentration of 15 µl 500 cm^{-3} recorded mortality of 15.00 per cent only.

4.5.3.2. Effect of Lemon Grass Oil on Mortality of Rice Weevil S. oryzae in Bioassay with Food

The data on mortality of lemon grass oil on rice weevil *S. oryzae* in bioassay with food at 2, 4, 6 and 8 days after treatment are presented in Table 20.

Five concentrations (50, 60, 70, 80 and 100 µl 500 cm^{-3}) of lemon grass oil were evaluated against rice weevil in bioassay with food. The percentage mortality varied from 3.33 to 8.89 at two days after treatment and were statistically on par. At four days after treatment, concentration of 100 µl 500 cm^{-3} recorded the highest mortality of 28.89 per cent followed by 80 and 70 µl 500 cm^{-3} with 22.22 and 18.89 per cent respectively. Significantly highest mortality was observed in treatment with 100 µl 500 cm^{-3} with 43.33 per cent at six days after treatment. It was followed by 80, 70 and 60 µl 500 cm^{-3} with mortality of 26.67 per cent, 24.45 per cent and 20.00 per cent respectively. Similar trend was also observed at eight days after treatment with the highest percentage mortality of 52.22 with 100 µl 500 cm^{-3}.

4.5.3.3. Median Lethal Concentrations of Lemon grass Oil

LC_{50} and LC_{90} values and probit regression parameters of lemon grass oils against rice weevil in two bioassay methods are represented in Table 21.

Different concentrations of lemon grass oil was tested by two bioassay technique, without food and with food against *S. oryzae*. LC_{50} value of 19.58 µl 500 cm^{-3} was indicated in without food bioassay. Bioassay with food the LC_{50} value

Table 21. LC_{50} values and probit regression parameters of lemon grass oil against rice weevil *S. oryzae*

Bioassay method	**LC_{50} (CL) (µl 500 cm^{-3})**	**LC_{90} (CL) (µl 500 cm^{-3})**	**Probit regression parameters**			
			Regression equation	**Intercept (a)±SE**	**Slope (b)±SE**	**Chi square**
Without food	19.58	24.79	Y=-4.816+0.246X	-4.816±1.861	0.246±0.129	0.523
With food	99.9 (92.11-113.57)	155.26 (135.10-193.95)	Y=-2.315+0.023X	-2.315±0.292	0.023±0.004	2.331

LC – Lethal concentration   CL – Confidential limit

of 99.94 μl 500 cm^{-3}. Lemon grass oil caused 90 per cent mortality of weevils at 24.79 and 155.26 μl 500 cm^{-3} in without and with food conditions respectively.

4.5.4 Mortality Response of Pepper Oil on *S. oryzae*

Toxic response of different concentration of pepper oil was tested by two methods of bioassays (without food and with food).

4.5.4.1 Effect Pepper Oil on Mortality of Rice Weevil S. oryzae in Bioassay Without Food

The data on mortality of lemon grass oil on rice weevil *S. oryzae* in bioassay without food at 12, 24 and 48 h after treatment are furnished in Table 22.

The essential oils of pepper did not show any toxic effect up to 15 μl 500 cm^{-3} at 12 h after treatment. The highest mortality of 92.50 per cent was recorded at concentration of 200 μl 500 cm^{-3} which were on par with 150 μl 500 cm^{-3} (85.00). At 24 h after treatment, higher concentrations (100, 150 and 200 μl 500 cm^{-3}) recorded the highest percentage mortality (97.50, 100.00 and 100.00) which were statistically on par. At the same time lower concentrations *viz.*, 10 and 15 μl 500 cm^{-3} showed mortality of 12.50 and 22.50 per cent respectively. Cent per cent mortality of weevils were accounted at higher concentrations 100, 150 and 200 μl 500 cm^{-3} after 48 h of exposure.

4.5.4.2. Effect Pepper Oil on Mortality of Rice Weevil S. oryzae in Bioassay with Food

The data on mortality of rice weevil *S. oryzae* in bioassay with food at 2, 4, 6 and 8 days after treatment are presented in Table 23.

Toxicity of pepper oil at five concentrations (50, 60, 70, 80 and 100 μl 500 cm^{-3}) at two days after treatment exhibited significant difference on comparison with the untreated control (0.00). Significantly highest mortality was observed in 100 μl 500 cm^{-3} (38.89 per cent) which was superior to other treatment. Treatment at 50, 60, 70 and 80 μl 500 cm^{-3} were on par with percentage mortality ranged from 12.22 to 20.00. At four days after treatment, the highest concentrations (100 μl/500

Table 22. Effect of pepper oil on the mortality of rice weevil *S. oryzae* (without food)

Concentrations (µl 500 cm^{-3})	**Percentage mortality* at HAT**		
	12	**24**	**48**
5	0.00 (0.91)^{c}	12.50 (20.46)^{c}	12.50 (20.46)^{d}
10	0.00 (0.91)^{c}	12.50 (20.56)^{b}	12.50 (20.56)^{c}
15	0.00 (0.91)^{c}	22.50 (28.22)^{b}	27.50 (31.54)^{b}
100	72.50 (59.19)^{b}	97.50 (84.72)^{a}	100.00 (89.09)^{a}
150	85.00 (73.09)^{ab}	100.00 (89.09)^{a}	100.00 (89.09)^{a}
200	92.50 (78.29)^{a}	100.00 (89.09)^{a}	100.00 (89.09)^{a}
Control	0.00 (0.91)^{c}	0.00 (0.91)^{d}	0.00 (0.91)^{e}
CD (0.05)	**(14.283)**	**(5.675)**	**(2.917)**

HAT- Hours after treatment *Mean of four replications

Table 23. Effect of pepper oil on the mortality of rice weevil *S. oryzae* (with food)

Concentrations (µl 500 cm^{-3})	**Percentage mortality* at DAT**			
	2	**4**	**6**	**8**
50	12.22 (20.43)^{b}	26.67 (30.97)^{c}	33.33 (35.11)^{c}	33.33 (35.11)^{c}
60	14.44 (22.30)^{b}	35.33 (36.55)^{bc}	43.33 (41.14)^{bc}	43.33 (41.14)^{bc}
70	13.33 (21.31)^{b}	39.99 (39.19)^{abc}	45.56 (42.43)^{bc}	45.56 (42.43)^{bc}
80	20.00 (26.42)^{b}	47.78 (43.70)^{ab}	57.78 (49.58)^{ab}	57.78 (49.58)^{b}
100	38.89 (38.22)^{a}	58.89 (50.66)^{a}	72.22 (58.69)^{a}	76.66 (62.23)^{a}
Control	0.00 (0.52)^{c}	0.00 (0.52)^{d}	0.00 (0.52)^{g}	0.00 (0.52)^{d}
CD (0.05)	**(8.581)**	**(12.603)**	**(10.869)**	**(12.190)**

DAT-Days after treatment *Mean of three replications

Figures in parenthesis are angular transformed values

**Figures in a column followed by same letter do not differ significantly

ml air) of oil recorded 58.89 per cent mortality followed by 80 µl 500 cm^{-3} (47.78) and 70 µl 500 cm^{-3} (39.99) and were statistically on par. Similar trend was also observed at six days after treatment. The highest mortality of 76.66 per cent was recorded with concentration of 100 µl 500 cm^{-3} at eight days after treatment which was superior to all other treatments. The mortality of exposed adults were increased with the increase in concentration and time of exposure.

4.5.4.3. Median Lethal Concentrations of Pepper Oil

LC_{50} and LC_{90} values and probit regression parameters of pepper oil against rice weevil in two bioassay methods are represented in Table 24.

Different concentrations of pepper oil was tested by two bioassay technique, without food and with food against *S. oryzae*. LC_{50} value of 2.32 µl 500 cm^{-3} was indicated in without food bioassay. In bioassay with food the LC_{50} value observed was 70.20 µl 500 cm^{-3}. Pepper oil caused 90.00 per cent mortality of weevils at 54.18 and 126.89 µl 500 cm^{-3} in without and with food conditions respectively.

While comparing lemon grass and pepper oil with same concentrations, the essential oil of pepper was found to have highest toxicity as well as lower LC_{50} values after same period of exposure.

4.5.2 Effect of Volatile Essential Oils on Mortality of Rice Weevil *S. oryzae*

Toxic response of four volatile essential oils *viz.*, cinnamon, clove, lemon grass and pepper at different concentrations on mortality of rice weevil after 2, 4, 6, 8 and 10 days of exposure are depicted in Table 25.

Percentage mortality of rice weevil after two days of treatment recorded the highest mortality of 87.78 per cent in pepper oil at 200 µl 500 cm^{-3} which was on par with cinnamon oil 30 µl 500 cm^{-3} (83.33). Essential oil of cinnamon at 25 µl 500 cm^{-3} recorded mortality of 56.67 per cent followed by cinnamon oil 20 µl 500 cm^{-3} (48.89), pepper oil 150 µl 500 cm^{-3} (47.78) and pepper oil 125 µl 500 cm^{-3} (43.33). The lowest mortality was (17.78) was observed with lemon grass oil 125 µl 500 cm^{-3} which was followed by clove oil 20 µl 500 cm^{-3} (24.45), lemon

Table 24. LC_{50} values and probit regression parameters of pepper oil against rice weevil *S. oryzae*

Bioassay method	LC_{50} (CL) (µl 500 cm^{-3})	LC_{90} (CL) (µl 500 cm^{-3})	Probit regression parameters			
			Regression equation	Intercept (a)±SE	Slope (b)±SE	Chi square
Without food	27.32 (18.46-190.74)	54.18 (33.13-479.32)	Y=-1.303+0.048X	-1.303±0.269	0.048±0.022	0.031
With food	70.20 (64.51-75.64)	126.89 (112.79-153.31)	Y=-1.587+0.023X	-1.587±0.267	0.023±0.004	1.088

LC – Lethal concentration CL – Confidential limit

Table 25. Effect of volatile essential oils on mortality of rice weevil *S. oryzae*

Treatments (μl 500 cm^{-3})	Percentage mortality* at DAT				
	2	4	6	8	10
Cinnamon oil 20	48.89 (44.36)^{bc}	56.67 (48.84)^{de}	64.45 (53.41)^{ef}	70.00 (56.93)^{cd}	70.00 (56.93)^{bcd}
Cinnamon oil 25	56.67 (48.84)^{b}	63.33 (52.78)^{d}	69.99 (56.84)^{de}	72.22 (58.25)^{cd}	73.33 (59.02)^{bcd}
Cinnamon oil 30	83.33 (66.81)^{a}	91.11 (73.48)^{b}	92.22 (74.36)^{bc}	95.55 (79.85)^{ab}	95.55 (79.85)^{a}
Clove oil 20	24.45 (29.46)^{de}	32.22 (34.42)^{g}	38.89 (38.52)^{h}	43.33 (41.14)^{e}	44.44 (41.79)^{e}
Clove oil 25	32.22 (34.46)^{cde}	40.00 (39.16)^{fg}	50.00 (44.98)^{fgh}	56.67 (48.93)^{de}	57.78 (49.58)^{de}
Clove oil 30	34.45 (35.73)^{cde}	54.44 (47.65)^{def}	65.56 (54.79)^{e}	72.22 (59.03)^{cd}	76.67 (62.18)^{bc}
Lemon grass oil 125	17.78 (24.64)^{e}	35.55 (36.55)^{g}	45.55 (42.45)^{gh}	61.11 (51.45)^{de}	61.11 (51.45)^{de}
Lemon grass oil 150	25.56 (29.08)^{de}	38.89 (38.43)^{fg}	50.00 (45.00)^{fgh}	61.11 (51.49)^{de}	63.33 (52.78)^{cd}
Lemon grass oil 200	31.11 (33.59)^{cde}	44.44 (41.72)^{efg}	57.78 (49.53)^{efg}	68.89 (56.29)^{cd}	68.89 (56.29)^{cd}
Pepper oil 125	43.33 (41.14)^{bcd}	78.89 (62.22)^{c}	82.22 (65.08)^{cd}	82.22 (65.08)^{c}	84.44 (66.79)^{b}
Pepper oil 150	47.78 (43.72)^{bc}	83.33 (66.19)^{bc}	93.33 (77.54)^{b}	94.44 (78.69)^{b}	96.67 (81.34)^{a}
Pepper oil 200	87.78 (73.06)^{a}	100.00 (89.48)^{a}	100.00 (89.48)^{a}	100.00 (89.48)^{a}	100.00 (89.48)^{a}
Control	0.00 (0.52)^{f}	0.00 (0.52)^{h}	0.00 (0.52)^{i}	0.00 (0.52)^{f}	0.00 (0.52)^{f}
CD (0.05)	**(12.617)**	**(9.690)**	**(9.724)**	**(10.437)**	**(9.991)**

DAT-Days after treatment *Mean of three replications

Figures in parenthesis are angular transformed values

**Figures in a column followed by same letter do not differ significantly

grass oil 150 µl 500 cm^{-3} (25.56), lemon grass oil 200 µl 500 cm^{-3} (31.11), clove oil 25 µl 500 cm^{-3} (32.22) and clove oil 30 µl 500 cm^{-3} (34.45).

On comparing the different concentrations of essential oils at four days after treatment, weevil mortality correspondingly increased with concentration. All the treatments were significantly superior to control. Complete mortality of weevils were recorded in pepper oil 200 µl 500 cm^{-3} which was superior to all other treatment. Treatment with cinnamon oil 30 µl 500 cm^{-3} (91.11) was on par with pepper oil 150 µl 500 cm^{-3} (83.33). Percentage mortality of 78.89 was recorded in treatment with pepper oil 125 µl 500 cm^{-3}. Cinnamon oil at 25 µl 500 cm^{-3} recorded a mortality of 63.33 per cent which was statistically on par with concentration of 20 µl 500 cm^{-3} (56.67) and clove oil 30 µl 500 cm^{-3} (54.44). Least effective treatment was clove oil 20 µl 500 cm^{-3} with mortality of 32.22 per cent.

There was a significant difference observed in percentage mortality of weevils at six days after treatment which ranged from 50.00 to 100.00. Pepper oil 200 µl 500 cm^{-3} showed cent per cent mortality and significantly superior to all other treatments. It was followed by pepper oil 150 µl 500 cm^{-3} with percentage mortality 93.33 and on par with cinnamon oil 30 µl 500 cm^{-3} (92.22). Treatment with clove oil 30 µl 500 cm^{-3} recorded a mortality of 65.56 per cent followed by lemon grass oil 200 µl 500 cm^{-3} (57.78), cinnamon oil 20 µl 500 cm^{-3} (64.45) and 25 µl 500 cm^{-3} (69.99) and were statistically on par. Mortality recorded in both clove oil 25 µl 500 cm^{-3} and lemon grass oil 150 µl 500 cm^{-3} was 50.00 per cent which was on par with treatment with clove oil 20 µl 500 cm^{-3} (38.89) and lemon grass oil 125 µl 500 cm-3 (45.55).

On eight days after treatment the percentage mortality obtained from various concentration of four different essential oils, pepper oil 200 µl 500 cm^{-3} recorded complete mortality of weevils followed by cinnamon oil 30 µl 500 cm^{-3} (95.55) which were statistically on par. The lower concentration of pepper oil (125 µl 500 cm^{-3}) showed a mortality of 82.22 per cent which was on par with lemon grass oil 200 µl 500 cm^{-3} (68.89), cinnamon oil 20 µl 500 cm^{-3} (70.00), clove oil 30 µl 500 cm^{-3} (72.22) and cinnamon oil 25 µl 500 cm^{-3} (72.22). Least effective treatment was clove oil 20 µl 500 cm^{-3} with percentage mortality 43.33 followed by clove oil 25 µl 500 cm^{-3} (56.67) and two lower concentrations of lemon grass oil (125 and 150 µl 500 cm^{-3}) with same mortality (61.11) and were statistically on par.

Similar trend was also observed at ten days after treatment. All the treatment were significantly differed from the untreated control (0.00). The highest percentage mortality was observed in pepper oil 200 µl 500 cm^{-3} (100.00) which was on par with pepper oil 150 µl 500 cm^{-3} (96.67) and higher concentration (30 µl 500 cm^{-3}) of cinnamon oil (95.55). Pepper oil 125 µl 500 cm^{-3} recorded a mortality of 84.44 per cent which was on par with clove oil 30 µl 500 cm^{-3} (76.67) and two lower concentrations of cinnamon oil (20 and 25 µl 500 cm^{-3}) with mortality of 70.00 per cent and 73.33 per cent respectively. Concentration of lemon grass oil *viz.,* 150 and 200 µl 500 cm^{-3} were statistically on par with mortality of 63.33 per cent and 68.89 per cent respectively. The treatment with clove oil 20 µl 500 cm^{-3} recorded lower percentage mortality (44.44).

Percentage mortality of weevils by volatile essential oils increased with increase in concentration and period of exposure. On comparing percentage mortality of weevils, the highest concentration (30 µl 500 cm^{-3}) of cinnamon oil caused more than 90.00 percentage mortality than clove oil at same concentration. Higher concentration of pepper oil (200 µl 500 cm^{-3}) caused cent per cent mortality which was superior over same concentration of lemon grass oil.

4.5.3 Effect of essential volatile oils on the progeny emergence of rice weevil *S. oryzae*

The data on effect of essential volatile oils on the progeny emergence of rice weevil *S. oryzae* at 55 days after treatment is represented in Table 26.

All concentrations of essential volatile oils were differed significantly in number of progeny emerged under experimental condition. It ranged from 0.00 to 15.00 progeny with 56.33 in untreated control. Treatment with pepper oil at 200 µl 500 cm^{-3} recorded no progeny emergence. It was followed by two lower

Table 26. Effect of essential volatile oils on the progeny emergence of rice weevil *S. oryzae*

Treatments (µl 500 cm^{-3})	**Number of progeny emerged (55 DAT)**	**Percentage inhibition of progeny emergence over control**
Cinnamon oil 20	2.33 (1.56)^{bcd}	96.86
Cinnamon oil 25	1.33 (1.29)^{abc}	97.64
Cinnamon oil 30	0.67 (0.99)^{ab}	98.81
Clove oil 20	15.00 (3.91)^{h}	73.37
Clove oil 25	11.00 (3.38)^{gh}	80.47
Clove oil 30	6.00 (2.53)^{ef}	89.35
Lemon grass oil 125	8.00 (2.91)^{fg}	85.80
Lemon grass oil 150	5.00 (2.31)^{def}	91.12
Lemon grass oil 200	3.00 (1.78)^{cde}	94.67
Pepper oil 125	1.33 (1.34)^{abc}	97.64
Pepper oil 150	0.66 (0.99)^{ab}	98.83
Pepper oil 200	0.00 (0.70)^{a}	100.00
Control	56.33 (7.53)^{i}	
CD (0.05)	**(0.764)**	

DAT-Days after treatment *Mean of three replications

Figures in parenthesis are square root transformed values

**Figures in a column followed by same letter do not differ significantly

concentration of pepper oil (125 and 150 μl 500 cm^{-3}) (1.33 and 0.66 number 100 g^{-1} grains) and two higher concentrations of cinnamon oil (25 and 30 μl 500 cm^{-3}) (1.33 and 0.67 number 100 g^{-1} grains). The treatment with cinnamon oil 20 μl 500 cm^{-3} showed progeny emergence of 2.33 followed by lemon grass oil 200 μl 500 cm^{-3} (1.78). Five weevils were emerged from treatment with lemon grass oil 150 μl 500 cm^{-3} which was on par with clove oil 30 μl 500 cm^{-3} (6.00). The highest number of progeny emergence was observed from clove oil 20 μl 500 cm^{-3} (15.00).

Pepper oil 200 μl 500 cm^{-3} caused complete inhibition of progeny emergence over control. It was followed by pepper oil 150 μl 500 cm^{-3} (98.83), cinnamon oil 30 μl 500 cm^{-3} (98.81), pepper oil 125 μl 500 cm^{-3} (97.64) and cinnamon oil 25 μl 500 cm^{-3} (97.64). Treatment with cinnamon oil 20 μl 500 cm^{-3} inhibited 95.86 per cent progeny emergence followed by lemon grass oil 200 μl 500 cm^{-3} (94.67) and 150 μl 500 cm^{-3} (91.12). Clove oil 20 μl 500 cm^{-3} inhibited only 73.37 per cent progeny emergence which was noted as least effective in the control of rice weevil.

4.5.4 Fungal Growth

No fungal growth was observed in the treated grains during the experiment.

Discussion

5. DISCUSSION

Rice is one of the staple food crops of India which is under both qualitative and quantitative loss due to infestation by different insects in field and storage. Among the various storage pests of rice, the rice weevil have major concern as they infest the grain internally and externally and is considered as primary pest of stored rice. These weevils have the ability to establish within undamaged rice grains and cause complete destruction of grains.

Increased awareness on the deleterious effect of chemical insecticides and the demand for insecticide free food has prompted the development of safer management options. The use of botanicals offers an alternative management strategy against stored grain pests. Plant products such as dried plant parts, extracts from leaves, roots, flowers, fruits or seeds have been used for the management of stored food grains.

The present study aims to document major beetle pests of stored rice in Thiruvananthapuram district and to develop effective management measures using botanicals.

5.1 BEETLE PESTS OF STORED RICE

The survey conducted in ration shops and retail provision stores in Thiruvananthapuram district revealed that stored rice was mostly infested by the primary feeder, rice weevil *S. oryzae*. Low population of secondary feeders like saw toothed grain beetle *O. surinamensis*, red flour beetle *T. castaneum* and lesser grain borer *R. dominica* were also observed in rice samples collected from ration shops and retail shops. Baloch (1992) also reported that stored rice was severely damaged by *S. oryzae*. Rice samples drawn from six districts of Himachal Pradesh were found infested with *R. dominica* to the extent of 76.38 per cent and *S. oryzae* to the extent of 69.00 per cent (Thakur and Sharma, 1996). Similarly, beetle pest complex of stored rice was recorded from different places (Hagstrum and Philips, 2017). Infestation by secondary pests in rice was mainly due to the presence of broken grains during milling and polishing. Sometimes these secondary pests occur after the infestation by primary feeders.

Sinha, *et al.* (1984) reported a shorter incubation period of 3 to 5 days for rice weevil in wheat. The study on the biology of rice weevil supports results of the work done by previous workers. An incubation period of 5 to 7 days was observed in the present study and this finding was in line with the observations of Barbuiya (2002). Variation in biological parameters like larval period, pupal period and total life cycle of rice weevil were reported from rice (Choudhary and Chakraborty, 2014) and sorghum (Bhanderi *et al.*, 2015). This deviation may be due to the change in growing substrate and weather conditions *viz.*, temperature and moisture in atmosphere and substrate.

Rice weevil can infest on a wide variety of food commodities. Host range of *S. oryzae* includes wheat, maize, sorghum, small grains, flour, pasta and other cereal products (Hill, 1990). Present study showed the infestation of rice weevil on pulses like red gram, bengal gram and dolichos bean. Slow multiplication rate was observed on these substrates. Infestation of cowpea weevil on channa facilitates the entry of rice weevil.

Study on biology of saw toothed grain beetle showed a larval period of 18 to 27 and pupal period of 5 to 8 days with a total period of 30 to 40 days. Saw toothed grain beetle *O. surinamensis* is a secondary feeder on cereals and cereal products. In Kerala, infestation of saw toothed grain beetle was reported from stored copra (Kumari, 1989) and spices like ginger and turmeric (Joseph, 1992). This beetle can infest on a wide range of food commodities like date palm, cashew nuts and dried fruits (Hill, 1990: Sahito *et al.*, 2017).

During the present study, secondary feeders such as saw toothed grain beetle was observed on whole rice grains. Both adult and larvae attacked on germ portion of whole grains, may be due to its fragile nature. The last instar larvae make webbing with the grains over their body and pupate within. This might be for avoiding desiccation and injury on immobile pupae.

5.2 EFFECT OF PLANT EXTRACTS ON RICE WEEVIL *S. oryzae*

Effect of plant extracts on rice weevil revealed that the highest percentage mortality was observed with garlic bulb 10 %, though it showed only least repellency among the six plant extracts. The response of rice weevil to aqueous extract of garlic bulb showed that, even though the plant extract has insecticidal property, the repellent action was very low. Presence of chemicals like diallyl disulphide and diallyl trisulphide were reported from garlic bulbs, which cause AChE inhibition, disruption in respiratory events and mortality of test insects (Bhatnagar-Thomas and Pal, 1974; Adedire and Ajayi, 1996). The studies conducted by Hamed *et al.* (2012) showed that insecticidal property of garlic against rice weevil may be due to the presence of allicin (diallyl thiosulfinate). These results were in agreement with the study conducted by Nwachukwu and Asawalam (2014) against *S. zeamais*.

Tulsi leaves 10 % and garlic bulb 5 % showed similar percentage mortality of 38.33 each which were the next best treatment. The results obtained at 30 days after treatment on percentage repellency of rice weevil showed that tulsi leaves 10 % was the best among twelve treatments. Jembere *et al.* (1995) reported that leaves of *Ocimum kilimandscharicum* was a good grain protectant with insecticidal, repellent and inhibition over F_1 progeny. These properties of *Ocimum* might be due to the presence of β-(Z)-ocimene, eugenol (Obeng-Ofori and Reichmuth, 1997: Ogendo *et al.*, 2008), thymol, paracymene, alpha terpinene (Asawalam *et al.*, 2008), methyl chavicol, methyl eugenol and α-cubebene (Kerdchoechuen *et al.*, 2010). The results of present study were in conformity with earlier results obtained by Kuldipake *et al.* (2016) whose results showed that treatment with tulsi caused 3.67 per cent mortality and 36.67 per cent repellency of rice weevil.

In the present study treatment with pepper seed 10 % showed percentage repellency of 38.33. These findings are in line with Ishii *et al.* (2010) who observed moderate repellent activity of black pepper extract against rice weevil. This repellent activity of pepper may be due to the presence of monoterpene compounds and sesquiterpenes (Khani *et al.*, 2012).

The study also established the insecticidal as well as repellent action of bird chilli fruits against rice weevil. Toxicity of *C. frutescens* fruits on rice weevil population has been noted by El-Lakwah *et al.* (1997) under laboratory. These property of bird chilli fruit may be due to its pungency which cause interruption in respiration of insects.

Among the six tested plant extracts each at two concentrations (5 and 10 %), neem leaves recorded comparatively less mortality of rice weevil. Insecticidal property of neem leaves could mainly be attenuated to the presence of tetra nor triterpenoid – azadiractin, salannin and meliantriol which have repellence, ovicidal, growth regulation, reproduction inhibition and antifeeding property. They also have ability to inhibit production of prothoracicotropic hormone (PTTH) from brain neurons (Schmutterrer, 1990). Presence of these insecticidal chemicals on neem may vary with climate and soil conditions. Results of present experiment were in agreement with study conducted by Kuldipake *et al.* (2016) who reported only 12.26 percentage mortality of *S. oryzae* when treated with neem.

While comparing both mortality and repellent effect of plant extract towards rice weevils, treatment with tulsi leaves 10 % showed the highest control (78.33 %) followed by garlic bulb 10 % (66.67 %) (Fig. 3). The results of present study showed increased reduction of weevil on increasing concentration of extracts. All the treatments were effective in managing rice weevil in stored rice compared to untreated control.

The present study showed the effect of plant extracts on the growth and multiplication of weevil is related to progeny emergence and grain damage. On counting the number of weevils left after 35 days of exposure, treatment with tulsi leaves 10 % was the best among all treatments. This result also supported by observation on progeny emergence (4.00 number 100 g^{-1} rice) and grain damage (12.00 grains 100 g^{-1} rice) on rice treated with tulsi leaves 10 %.

Results which are inconsistent with findings of others may be due to the variation of insecticidal and repellent component of tested plant parts. This

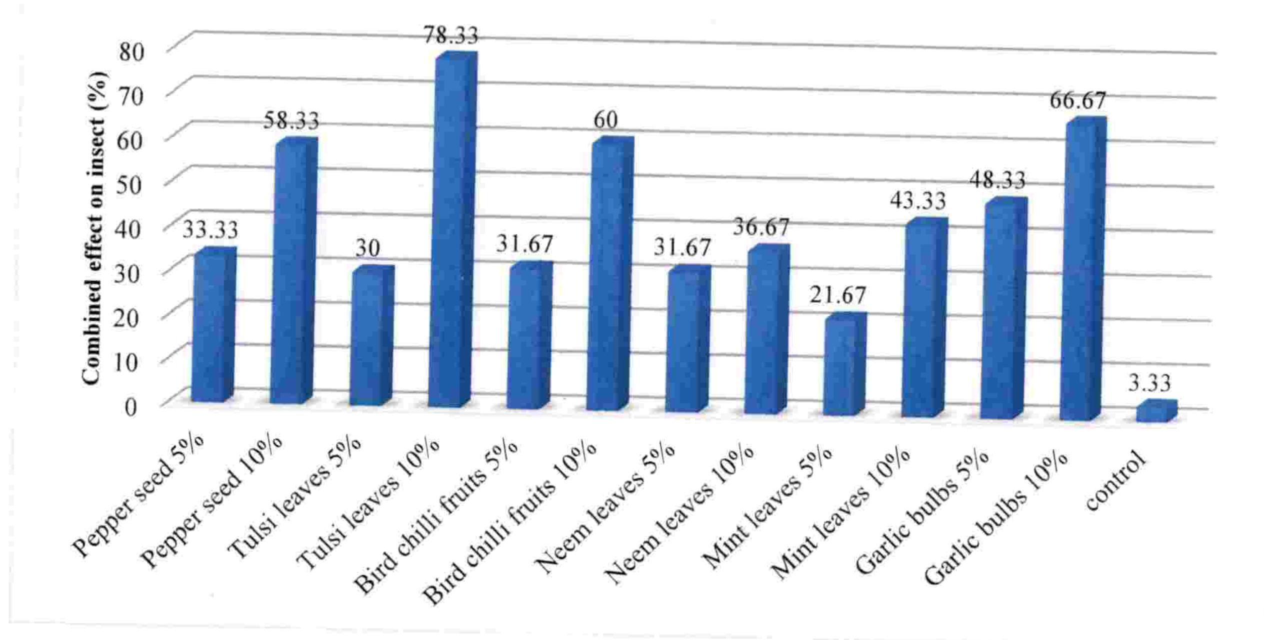


Figure 3. Combined effect (mortality + repellency) of plant extracts on rice weevil *S. oryzae*

variation could be attributed by difference in climate, soil, age, vegetative conditions of plant and experimental methodology.

5.3 EFFECT OF DRIED PLANT PARTS ON RICE WEEVIL *S. oryzae*

Effect of dried plant parts on rice weevil showed that, treatment with mint leaves 4 % showed higher percentage mortality. Study on repellency revealed that treatment with nutmeg mace 4 % recorded highest repellency. The response of rice weevil to dried mint leaves showed that even though the dried plant part has insecticidal property, the repellent action was very low. The present results were in conformity with earlier results obtained by Saljoqi *et al.* (2006) whose results showed that treatment with mint caused mean mortality of 47.40 % at 10 days after treatment. Insecticidal property of dried mint leaves may be due to the presence of monoterpenes such as menthol, menthone, cineol, cyclohexanone, isomenthol acetate and limonene (Khani *et al.*, 2012). It was also supported by findings of Saad *et al.* (2017) who screened the response of spearmint (*Mentha spicata* L.) in rice weevil under laboratory condition in Egypt.

Treatment with mint leaves 2 % recorded a percentage mortality of 26.67 which were statistically on par with clove flower bud 4 %, tulsi leaves 4 % and neem leaves 4 %. These findings are in line with results of Devi and Devi (2013) who reported complete mortality of weevils at higher concentration of clove. It has been suggested that insecticidal property of clove is due the presence of eugenol and eugenol acetate at a concentration of 71.56 % and 8.99 % respectively (Saad *et al.*, 2017).

Insecticidal and repellent property of neem against rice weevils has already been established by many researchers (El-Lakwah and El-Kashlan, 1999; Chander *et al*, 2000). Survey conducted by Deka *et al.* (2006) in Assam revealed that neem leaves can repel stored grain pests due to their odour.

Among the six tested dried plant parts at two concentrations (2 and 4 %), curry leaves *Murraya koenigii* recorded comparatively less mortality and repellency of rice weevil. Chemical analysis on curry leaves showed presence of linalool, α-pinene and α-terpeneol which cause behavioural modification in test insect (Bedoukian, 1992). These results were in agreement with the findings of Paranagama *et al*. (2004) who showed less effect of curry leaves when compared to neem leaves against rice weevil. Pulverised leaves of curry leaves caused high rate of mortality and less population development in different doses against lesser grain borer (Nirjara and Sujatha, 2011).

While examining both mortality and repellent effect of dried plant parts, mint leaves 4% recorded the highest control followed by nutmeg mace 4 % (Fig. 4). Conversely the lowest number of progeny emergence and grain damage were observed in treatment with nutmeg mace 4 %. This may be due to ovicidal property of nutmeg mace. Antifeedant property of nutmeg is well known in traditional knowledge. Mortality and ovicidal property of nutmeg *M. fragrans* has been noted by Adedire (2002) and Devi and Devi (2013).

5.4 EFFECT OF VOLATILE ESSENTIAL OILS ON RICE WEEVIL *S. oryzae*

Results on mortality effects of four volatile oils *viz.,* cinnamon, clove, lemon grass and pepper showed the highest percentage mortality of weevils within a short period of time when compared to plant extracts and dried plant parts. Insect mortality data revealed that, percentage mortality of weevils increased with increase in concentration and period of exposure.

Based on the LC_{50} value of the four oils, higher concentrations of each oils were selected for the toxicity study of essential oils. Pepper oil regarded as highly toxic followed by cinnamon oil; while clove and lemon grass oils were reported to be moderately toxic. This finding was supported by the mortality data obtained in both bioassays, without food and with food. Khani *et al.* (2012) reported that essential oil from black pepper (*P. nigrum*) caused mortality in rice weevil with LC_{50} value of 287.70 μl L^{-1}. Whereas in the present study LC_{50} value of 27.32 and 70.20 μl 500 cm^{-3} were recorded in without and with food conditions respectively. The highest mortality of weevils in without food condition may be due to the direct exposure of insect with oil which may interfere with respiratory system. While

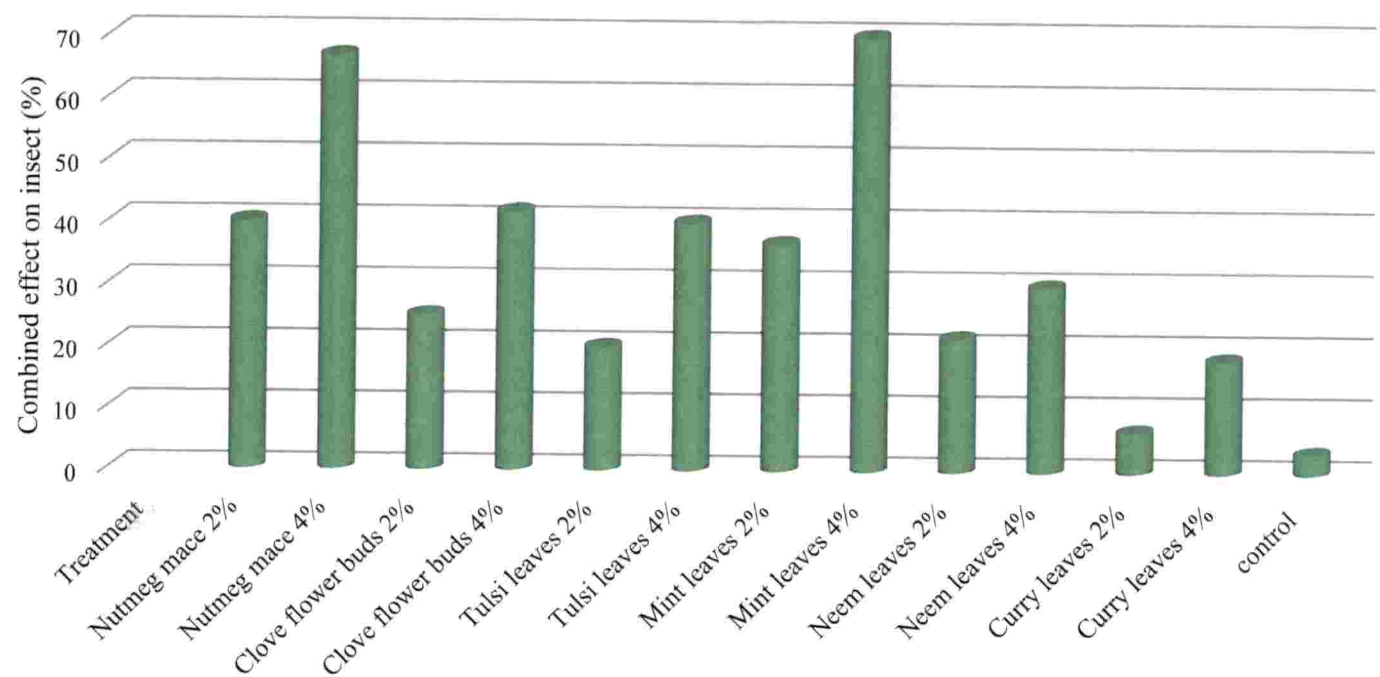


Figure 4. Combined effect (mortality + repellency) of dried plant parts on rice weevil *S. oryzae*

comparing mortality of weevils in two bioassays, without and with food condition showed that lower mortality were recorded in bioassay with food material. Hence, it was depicted that toxicities of essential volatile oils reduced in with food condition may be due to the escaping of weevils from direct contact by hiding between the grains or proportionate absorption of tested oils on to the rice grains because of its hygroscopic nature. This findings were supported by the study conducted by Vendan *et al.* (2017) where it showed that treatment with pepper oil caused reduced mortality of weevils in with food condition.

In the present study, complete mortality of weevils with no progeny emergence were recorded in treatment with pepper oil at 200 μl 500 cm^{-3} within four days of exposure which were on par with pepper oil at 150 μl 500 cm^{-3} and cinnamon oil at 30 μl 500 cm^{-3} at 10 days after treatment. Results revealed that earlier death of beetles in pepper oil treatment may be due to the pungency. Khani *et al.* (2012) suggested that major component of pepper, piperine, oleic acid, linoleic acid, caryophyllene and limonene may be the reason for mortality of test insects.

Treatment with cinnamon oil at concentration of 30 μl 500 cm^{-3} recorded a percentage mortality of 95.55 and less progeny emergence. This could be attributed to the possible insecticidal and ovicidal effect of cinnamon oil. These findings are in line with Lee *et al.* (2008) who reported insecticidal activity of cinnamon oils due to the presence of benzaldehyde, cinnamonitrile, hydrocinnamyl acetate and α-terpineol. Properties like repellency, post ingestive toxicity, alteration in nutritional index and reduced relative growth rate were observed in cinnamon oil towards rice weevil (Stefanazzi *et al.*, 2011).

Moderate mortality of lemon grass oil and clove oil were observed in the current study. Insecticidal activity of clove oil was reported in a study conducted by Devi and Devi (2013). This concurs with Saad *et al.* (2017) where they reported that clove bud oil containing eugenol (71.56 %) and eugenol acetate (8.99 %) gave higher toxicity after 72 h of exposure with LC_{50} value of 9.23 μl 370 ml^{-1}. Where as in the present study LC_{50} value of 8.51 and 23.91 μl 500 cm^{-3} were recorded in without and with food conditions for cinnamon oil.

Among the four tested volatile oils, lemon grass showed lower initial mortality which were increased on increasing exposure period. It may be due to its slow toxicity release and activation of insecticidal property. These results agree well with findings of Jayaratne *et al.* (2001) and Saljoqi, *et al.* (2006) who reported repellent and insecticidal activity in lemon grass oil.

Management of rice weevil using plant extracts, treatment with tulsi leaves 10 % showed the highest reduction of weevils with decreased progeny emergence and grain damage. Treatment with dried plant parts revealed that mint leaves (4 %) showed the highest reduction of weevils whereas the lowest progeny emergence and grain damage were observed in treatment with dried nutmeg mace 4 %. Among the essential volatile oils pepper oil 200 μl 500 cm^{-3} caused cent per cent mortality of rice weevil at four days after treatment without any progeny emergence.

Summary

6. SUMMARY

Stored-product insects can be found at many places such as warehouses, flour mills, processing plants and stores. These insects cause damage on grains and processed products by means of weight loss, nutrient loss, reduced seed viability, contamination with live or dead insects, exuviae or faeces, webbing and pathogenic microbial infections. All these leads to reduced market value of food commodities. Popular control measures for stored product insects include the use of contact insecticides and fumigants. Presence of chemical residues in food, resistance development by pest species and toxicity to non-target organisms, there is an urgent need to alternative and safer methods for storage insect pest management.

With this view, a study was conducted at College of Agriculture, Vellayani to document major beetle pests of stored rice in Thiruvananthapuram district and to develop effective management measures using botanicals.

- The important beetle pests recorded in the survey from ration shops and retail shops were rice weevil *S. oryzae*, saw toothed grain beetle *O. surinamensis*, red flour beetle *T. castaneum* and lesser grain borer *R. dominica*
- Among the insect pests observed in stored rice samples, out of 25 collected samples 23 rice samples were contaminated with rice weevil *S. oryzae* with a mean number of 14.68.
- Management of rice weevil with extract of plant parts at two concentrations (5% and 10%) (w/v) recorded the highest percentage mortality with garlic bulb 10 % (53.33) which was on par with garlic bulb 5 % (38.33), tulsi leaves 10 % (38.33) and bird chilli fruit 10% (36.67). The treatment with tulsi leaves 10 % recorded maximum repellent effect of 40.00 per cent which was on par with pepper seed 10 % (38.33), mint leaves 10 % (26.67) and bird chilli fruit 10 % (23.33).
- While examining both mortality and repellent effect of plant extract, treatment with tulsi leaves 10 % showed highest reduction (78.33)

of weevils with decreased progeny emergence (4.00 number 100 g^{-1} grains) and grain damage (12 grains 100 g^{-1} grains). Similarly tulsi leaves 10 % caused 93.89 per cent inhibition of progeny emergence over control followed by pepper seed 10 % (90.08), tulsi leaves 5 % (89.30) and garlic bulb 10 % (87.47).

- Management of beetle pest using dried plant parts showed that mint leaves 4 % was the most effective treatment with 56.67 per cent mortality which was on par with nutmeg mace 4 % (35.00) whereas the highest percentage repellency of weevils was recorded in rice treated with nutmeg mace 4 %, (31.67). This treatment was statistically on par with 4 % concentration of clove flower buds and tulsi leaves (18.33), nutmeg mace 2 % (15.00) and mint leaves 4 % (13.33).
- Considering both mortality and repellent effect of dried plants parts, treatment with mint leaves 4 % showed the highest reduction of weevils. The lowest progeny emergence (4.00 number 100 g^{-1} grains) and grain damage (23.67 grains 100 g^{-1} grains) were observed in treatment with nutmeg mace 4 %.
- Percentage mortality of weevils by volatile essential oils increased with increase in concentration and period of exposure. This same trend was also observed in two bioassays *viz.,* without and with food condition for fixing concentration levels of essential oils under study.
- Study on the mortality response of four volatile essential oils *viz.,* cinnamon oil, clove oil, lemon grass oil and pepper oil on rice weevil *S. oryzae* in storage showed cent per cent mortality with pepper oil 200 μl 500 cm^{-3}, which was on par with pepper oil 150 μl 500 cm^{-3} (96.67) and cinnamon oil 30 μl 500 cm^{-3} (95.55).
- All concentrations of essential volatile oils were differed significantly in number of progeny emerged under experimental condition. Treatment with pepper oil at 200 μl 500 cm^{-3} recorded no

progeny emergence. It was followed by two lower concentration of pepper oil (125 and 150 µl 500 cm^{-3}) and two higher concentrations of cinnamon oil (25 and 30 µl 500 cm^{-3}).

- Pepper oil 200 µl 500 cm^{-3} also caused complete inhibition of progeny emergence over control which was on par with two lower concentration of pepper oil (125 and 150 µl 500 cm^{-3}) and two higher concentrations of cinnamon oil (25 and 30 µl 500 cm^{-3}).

The results obtained from the present study highlightened the effectiveness of tulsi leaves extract, dried mint leaves and pepper oil for the management of rice weevil *S. oryzae* under storage condition.

References

REFERENCES

Abbott, W. S. 1925. A method of computing the effectiveness of an insecticide. *J. Econ. Entomol.* 18: 266-267.

Abdelgaleil, S. A. M., Mohamed, M. I. E., Badawy, M. E. I., and El-arami, S. A. A. 2009. Fumigant and contact toxicities of mono terpenes to *Sitophilus oryzae* (L.) and *Tribolium castaneum* (Herbst.) and their inhibitory effects on acetylcholin esterase activity. *J. Chem. Ecol.* 35: 518-525.

Adedire, C. O. 2002. Use of nutmeg *Myristica fragrans* (Houtt.) powder and oil for the control of cowpea storage bruchid *Callosobruchus maculatus* Fab. *J. Plant Dis. Prot.* 109: 193-199.

Adedire, C. O. and Ajayi, T. S. 1996. Assessment of the insecticidal properties of some plant extract and grain protectant against the maize weevils *Sitophilus zeamais* Motschulky. *Nigerian J. Entomol.* 13: 93-101.

Adhikari, A. A. and Paranagama, P. A. 2001. Effect of constituents of curry leaf, *Murraya koenigii* on cowpea seed bruchid, *Callosobruchus maculatus* (F.) in stored cowpea. *J. Stored Prod. Res.* 45: 19-28.

Adler, C., Corinth, H. G., and Reichmuth, C. 2000. Modified Atmospheres. In: Subramanyam, B. and Hagstrum, D. W. (ed), *Alternatives to pesticides in stored product IPM.* Kluwer Academic Publishers, MA, USA. pp 105-146.

Ahmed, K., Khalique, F., Afzal, M., Malik, B. A., and Malik, M. R. 1988. Efficacy of vegetable oils for protection of green gram from attack of bruchid beetle. *Pakist. J. Agric. Res.* 9: 413-416.

Ahmed, M. E. and El-Salam, A. 2010. Fumigant toxicity of seven essential oils against the cowpea weevil, *Callosobruchus maculatus* (F.) and the rice weevil, *Sitophilus oryzae* (L.). *Egypt. Acad. J. biol. Sci.* 2: 1- 6.

Ahmedani, M. S., Haque, M. I., Afzal, S. N., Aslam, M., and Naz, S. 2009. Varietal changes in nutritional composition of wheat kernel (*Triticum aestivum* L.) caused by Khapra beetle infestation. *Pak. J. Bot.* 41: 1511-1519.

Antenna, K. C. 2001. Repellent properties of *Cassia sophera* L. (Cesalpiniaceae) against the rice weevil *Sitophilus oryzae* L. (Coleoptera; Curculionidae) and the bruchid beetle *Callosobruchus maculatus* F. (Coleoptera; Bruchidae). *J. Stored Prod. Res*. 25: 53-56.

Arabi, F., Moharramipour, S., and Sefidkon, F. 2008. Chemical composition and insecticidal activity of essential oil from *Perovskia abrotanoides* (Lamiaceae) against *Sitophilus oryzae* (Coleoptera: Curculionidae) and *Tribolium castaneum* (Coleoptera: Tenebrionidae). *Int. J. Trop. Insect.* 28: 144-50.

Arbogast, R. T. 1991. Beetles: Coleoptera. In: Gorham, J. R. (ed). Ecology and management of food industry pests. Food and drug Administrative. Technical Bulletin. 4: 131-176.

Arthur, F. H. 2001. Susceptibility of last instar red flour beetles and confused flour beetles (Coleoptera: Tenebrionidae) to hydroprene. *J. Econ. Entomol*. 94: 772-779.

Arthur, F. H., Liu, S., Zhou, B., and Phillips, T. W. 2009. Residual efficacy of pyriproxyfen and hydroprene applied to wood, metal and concrete for controlling stored-product insects. *Pest Manage. Sci.* 65: 791–97.

Asawalam, E. F., Emosairue, S. O., and Hassanali, A. 2008. Essential oil of *Ocimum gratissimum* (Labiatae) as *Sitophilus zeamais* (Coleoptera: Curculionidae) protectant. *Afr. J. Biotechnol.* 7: 3771-3776.

Baloch, U. K. 1992. *Integrated Pest Management in Food Grains*. Food and Agriculture Organization of the United Nations and Pakistan Agricultural Research Council, Islamabad, Pakistan. 117p.

Banks, J. and Fields, P. 1995. *Physiological Methods for Insect Control in Stored Grain Ecosystem.* Agriculture and Agri-food Canada, Winnipeg, Manitoba. p 353.

Barbhuiya, M. H. 2002. Biology of rice weevil, *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae) in stored wheat *Triticum vulgare* and its control. *Environ. Ecol.* 20: 1700-1702.

Bedoukian, R. H. 1992. Regulation of some classes of phytochemicals: Flavour and fragrance ingredients related to insect behaviour-modifying chemicals. In: insect pheromones and other behaviour modifying chemicals: Application and regulation. British crop protection council, Farnham, surrey, UK. 79-92.

Benhalima, H., Chaudhry, M. Q., Mills, K. A., and Price, N. R. 2004. Phosphine resistance in stored-product insects collected from various grain storage facilities in Morocco. *J. Stored Prod. Res*. 40: 241-249.

Bhanderi, G. R., Radadia, G. G., and Patel, D. R. 2015. Biology of rice weevil, *Sitophilus Oryzae* (Linnaeus) on stored sorghum. *Indian J. Entomol.* 77(3): 307- 310.

Bhatnagar-Thomas, P. L. and Pal, A. K. 1974. Studies on the insecticidal activity of garlic oil. II. Mode of action of the oil as a pesticide in *Musca domestica* nebulo Fabr and *Trogoderma granarium* Everts. *J. Food Sci. Technol.* 11: 153-158.

Borzoui, E., Naseri, B., and Namin, F. R. 2015. Different diets affecting biology and digestive physiology of the Khapra beetle, *Trogoderma granarium* Everts (Coleoptera: Dermestidae). *J. Stored Prod. Res.* 62: 1-7.

Boxall, R. A. 2001. Post-harvest losses to insects - a world overview. *Int. Biodeterioration Biodegradation* 48: 137-152.

Cetin, H., Yanikoglu, A., and Cilek, J. E. 2005. Evaluation of the naturally-derived insecticide spinosad against *Culex pipiens* L. (Diptera: Culicidae) larvae in septic tank water in Antalya, Turkey. *J. Vector Ecol.* 30: 151-154.

Chander, H., Ahuja, D. K., Nagender, A., and Berry, S. K. 2000. Repellency of different plant extracts and commercial formulations used as prophylactic sprays to protect bagged grain against *Tribolium castaneum* - a field study. *J. Food Sci. Technol.* 37: 582-585.

Chaubey, M. K. 2011. Fumigant toxicity of essential oils against rice weevil *Sitophilus oryzae* L. (Coleoptera: Curculionidae). *J. Biol. Sci.*11: 411-416.

Chayengia, B., Patgiri, P., Rahman, Z. and Sarma, S. 2010. Efficacy of different plant products against *Sitophilus oryzae* (Linn.) (Coleoptera: Curculionidae) infestation on stored rice. *J. Biopesticides*. 3: 604-609.

Choudhury, S. D. and Chakraborty, K. 2014. Study on both the life cycle and morphometrics of *Sitophilus oryzae* on rice cultivar Sampa mashuri in laboratory condition. *J. Appl. Sci. Res.* 6: 22-28.

Collins, P. J., Daglish, G. J., Bengston, M., Lambkin, T. M. and Pavic, H. 2009. Genetics of resistance to phosphine in *Rhyzopertha dominica* (Coleoptera: Bostrichidae). *J. Econ. Entomol.* 95: 862-869.

Compton, J. A. F. and Sherington, J. 1999. Rapid assessment methods for stored maize cobs: weight losses due to insect pests. *J. Stored Products Res.* 35: 77-87.

Conyers, S. T. and Bell, C. H. 2007. A novel use of modified atmospheres: Storage insect population control. *J. Stored Prod. Res.* 43: 367-374.

Cox, P. D. and Bell, C. H. 1991. Biology and ecology of moth pests of stored foods. In: Gorham, J. R. (ed.), *Ecology and Management of Food-Industry Pests*. Arlington, VA: Association of Official Analytical Chemists.181-193.

Dal-Bello, G., Padin, S., Lopez-Lastra, C., and Fabrizio, M. 2001. Laboratory evaluation of chemical-biological control of the rice weevil (*Sitophilus oryzae* L.) in stored grains. *J. Stored Prod. Res.* 37: 77–81.

Deka, M. K., Bhuyan, M., and Hazarika, L. K. 2006. Traditional pest management practices of Assam. *J. Tradit. Knowl.* 5: 75-78.

Devi, K. C. and Devi, S. S. 2013. Insecticidal and oviposition deterrent properties of some spices against coleopteran beetle, *Sitophilus oryzae*. *J. Food Sci. Technol.* 50: 600–604.

Devi, M. B., Devi, N. V., and Singh, S. N. 2014. Effects of six botanical plant powder extracts on the control of rice weevil, *Sitophilus oryzae* L. in stored rice grains. *Int. J. Agric. Innovations Res.* 2: 683-686.

Diehl, J. F. 1995. *Safety of Irradiated Foods*. Marcel Dekker, New York. 226p.

Duke, S. O., Belz, R. G., Baerson, S. R., Pan, Z., and Cook, D. D. 2005. The potential for advances in crop allelopathy. *Outl. Pest Manag.* 16: 64-68.

Dyte, C. E. 1970. Insecticide resistance in stored-product insects with special reference to *Tribolium castaneum*. *Trop. Stored Prod. Inf.* 20: 13-18.

Dyte, C. E. 1972. Resistance to synthetic juvenile hormone in a strain of the flour beetle, *Tribolium castaneum*. *Nat.* 238: 48-49.

El-Aziz, S. H. 2011. Control strategies of stored products pests. *J. Entomol.* 8: 101-122.

El-Lakwah, F. A. and El-Kashlan, I. H. 1999. Efficiency of Neemazal (powder 10%) against some stored product insects. *Alexandria J. Agric. Res.* 44: 271-283.

El-Lakwah, F. A., Khaled, O. M., Khattab, M. M. and Abdel-Rahman, T. A. 1997. Toxic effects of extracts and powders of certain plants against the rice weevil (*Sitophilus oryzae* (L.)). *An. Agric. Sci.* 35: 553-566.

Fields, P. G. and Muir, W. E. 1996. Physical control. In: Subramanyam, B. and Hagstrum D. W. (ed), *Integrated Management of Insects in Stored Products*, Marcel Dekker Inc., New York, 195-221.

George, J., Ravishankar, G. A., Pereira, J., and Divakar, S. 1999. Bioinsecticide from swallowroot (*Decalepis hamiltonii*) Wight and Arn protects food grains against insect infestation. *Curr. Sci.* 77: 501-502.

Ghosh, S. K. and Durbey, S. L. 2003. *Integrated Management of Stored Grain Pests*. International book distributing co. Charbagh, Lucknow. 209.

Giolebiowska, Z. 1969. The feeding and fecundity of *Sitophilus granaries* (L.), *Sitophilusoryzae* (L.) and *Rizhopertha dominica* (F.) in wheat grain. *J. Stored Products Res.* 5: 143-155.

Good, N. E. 1936. The flour beetles of the genus *Tribolium*. United States Department of Agriculture. Economic Research Service. Technical Bulletin. 164672.

Gunarathna, T. V. N. M. and Karunaratne, M. M. S. C. 2009. Laboratory evaluation of some Sri Lankan plants as post-harvest grain protectants for the control of rice weevil, *Sitophilus oryzae*. *Vidyodaya J. Sci.*14: 69-83.

Hagstrum, D. W. and Phillips, T. W. 2017. Evolution of stored-product entomology: Protecting the world food supply. *Annu. Rev. Entomol.* 62: 379–97.

Hallman, G. J. 2013. Control of stored product pests by ionizing radiation. *J. Stored Prod. Res.* 52: 36-41.

Hamed, R. K. A., Ahmed, S. M. S., Abotaleb, A. O. B., and El-Sawaf, B. M. 2012. Efficacy of certain plant oils as grain protectants against the rice weevil, *Sitophilus oryzae* (Coleoptera: Curculionidae) on wheat. *Egypt. Acad. J. Biol. Sci.* 5: 49-53.

Hamlin, J. C., Reed, W. D., and Phillips, M. E. 1931. Biology of the Indian- meal moth on dried fruits in California. USDA. *Tech. Bull.* 242: 1-27.

Hansen, L. S., Skovgård, H., and Hell, K. 2004. Life table study of *Sitotroga cerealella* (Lepidoptera: Gelichiidae), a strain from West Africa. *J. Econ. Entomol.* 97: 1484- 1490.

Hill, D. S. 1990. *Pests of Stored Products and Their Control.* CBS publishers and distributors. Delhi. 264.

Hinton, H. E. 1948. A Synopsis of the Genus *Tribolium* Macleay, with some remarks on the evolution of its species-groups (Coleoptera, Tenebrionidae). *Bull. Entomol. Res.* 39: 13-55.

Ho, S. H., Koh, L., Maa, Y., Huang, Y., and Simb, K. Y. 1996. The oil of garlic, *Allium sativum* L. (Amaryllidaceae), as a potential grain protectant against *Tribolium castaneum* (Herbst) and *Sitophilus zeamais* Motsch. *Postharvest Biol. Technol.* 9: 41-48.

Huang, Y. and Ho, S. H. 1998. Toxicity and antifeedant activities of cinnamaldehyde against the grain storage insects, *Tribolium castaneum* (Herbst) and *Sitophilus zeamais* Motsch. *J. Stored Prod. Res*. 34: 11-17.

Huang, Y., Tan, J. M. W. L., Kini, R. M and Ho, S. H. 1997. Toxic and antifeedant action of nutmeg oil against *Tribolium castaneum* (Herbst) and *Sitophilus zeamais* Motsch. *J. Stored Products Res.* 4: 289-298.

Huang, Y., Xing-Chen, S., and Ho, S. H. 2000. Bioactivities of methyl allyl disulfide and diallyl trisulfide from essential oil of garlic to two species of stored-product pests, *Sitophilus zeamais* (Coleoptera: Curculionidae) and *Tribolium castaneum* (Coleoptera: Tenebrionidae). *J. Econ. Entomol.* 93: 537-543.

Ignatowicz, S. 1998. Powdered herbs of the daisy family (Compositae) as repellents or attractants for the grain weevil, *Sitophilus granarius* (L.), and the rice weevil, *S. oryzae* (L.). *Ann. Warsaw Agric. Univ.* 19: 15-28.

Imti, B. and Zudir, T. 1993. Effect of neem; *Melia azadirachta* (L.) and *Azadirachta indica* (A. Juss) on the incidence of *Sitophilus oryzae* (L.) (Coleoptera; Curculionidae) on stored paddy. *Plant Prot. Bulletin.* 49: 44-47.

Ishii, T., Matsuzawa, H., and Vairappan, C. S. 2010. Repellent activity of common spices against the rice weevil, *Sitophilus zeamais* Motsch (Coleoptera, Curculionidae). *J. Trop. Biol. Conserv*. 7: 75-80.

Isman, M. B. 2006. Botanical insecticides, deterrents, and repellents in modern agriculture and an increasingly regulated world. *Annu. Rev. Entomol.* 51: 45–66.

Jacob, T. A. 1981. Observations on the biology of *Oryzaephilus acuminatus* Halstead with comparative notes on the common species of *Oryzaephilus* (Coleoptera; Silvanidae). *J. Stored Prod. Res.*17: 17-23.

Jayaratne, K. H. T. and Paranagama, P. A. 2001. Bioactivity of the essential oil of lemongrass, (*Cymbopogon citratus*) against rice weevil- *Sitophilus oryzae* (L.) and grain moth – *Sitotroga cerealella* (Oliver). *Annu. Rev. Entomol.* 46: 17-24.

Jembere, B., Obeng-Ofori, D., Hassanali, A., and Nyamasyo, G. N. N. 1995. Products derived from the leaves of *Ocimum kilimandscharicum* (Labiatae) as post-harvest grain protectants against the infestation of three major stored product insect pests. *Bull. Entomol. Res.* 85: 361-367.

Jianab, F., Larsonb, R., Jayasa, D. S., and Whitec, N. D. J. 2012. Three dimensional temporal and spatial distribution of adult *Oryzaephilus surinamensis* and *Sitophilus oryzae* in stored wheat under different temperatures, moisture contents, and adult densities. *J. Stored Prod. Res.* 49: 155-165.

Johnson, J. 2013. Improving the Safety and Quality of Nuts - Pest control in postharvest nuts. *Food Sci. Technol. Nutr.* 4: 56–87.

Johnson, J. A., Valero, K. A., Wang, S., and Tang, J. 2004. Thermal death kinetics of red flour beetle (Coleoptera: Tenebrionidae). *J. Econ. Entomol.* 6: 1868- 1873.

Joseph Jiji. 1992. Nature and extent of damage caused by insect pests on stored pepper, cardamom, ginger and turmeric. M.Sc.(Ag) thesis, Kerala Agricultural University, Thrissur, p. 85.

Joshi, R. K. 2013. Chemical composition, in vitro antimicrobial and antioxidant activities of the essential oils of *Ocimum gratissimum*, *O. sanctum* and their major constituents. *Indian J. Pharmacol. Sci.* 75: 457-462.

Kanda, D., Kaur, S., and Koul, O. 2017. A comparative study of monoterpenoids and phenylpropanoids from essential oils against stored grain insects: acute toxins or feeding deterrents. *J. Pest Sci.* 90: 531-545.

Karunakaran, S., Prasannath, K., and Shanika, W. 2016. Insecticidal activity of plant powders against rice weevil, *Sitophilus oryzae* L. (Coleoptera: Curculionidae). *Int. J. Res.* 3: 427-429.

Kerdchoechuen, O., Laohakunjit, N., Singkornard, S., and Matta, F. B. 2010. Essential oils from six herbal plants for biocontrol of the maize weevil. *Hort. Sci.* 45: 592-598.

Kestenholz, C. and Stevenson, P. C. 1998. *Gardenia spp.* as a source of botanical pesticide against the rice weevil, *Sitophilus oryzae* L. (Coleoptera, Curculionidae), in Sri Lanka. *Pest Manag. Sci.* 49: 543-548.

Khan, F. Z. A., Sagheer, M., Mansoor-ul-Hasan, Saeed, S., Majid, A., Gul, H. T., Bukhari, M., Latif, A., Khaliq, A., and Hussain, A. 2013. Biocidal effects of acetone based plant extracts of *Murraya exotica*, *Murraya koenigii* and *Nicotiana tabacum* on stored grain insect pest, *Tribolium castaneum*. *Int. J. Biosci.* 3: 44-49.

Khani, M., Awang, M., and Omar, D. 2012. Insecticidal effects of peppermint and black pepper essential oils against rice weevil, *Sitophilus oryzae* L. and Rice Moth, *Corcyra cephalonica* (St.). *J. Med. Plants.* 11(43): 97-110.

Kim, S., Roh, J., Kim, A., Lee, H., and Ahn, Y. 2003. Insecticidal activities of aromatic plant extracts and essential oils against *Sitophilus oryzae* and *Callosobruchus chinensis*. *J. Stored Prod. Res.* 39: 293-303.

Kiran, S. and Prakash, B. 2015. Toxicity and biochemical efficacy of chemically characterized *Rosmarinus officinalis* essential oil against *Sitophilus oryzae* and *Oryzaephilus surinamensis*. *Ind. Crops Products.* 74: 817-823.

Kostyukovsky, M., Rafaeli, A., Gileadi, C., Demchenko, N., and Shaaya, E. 2002. Activation of Octopaminergic receptors by essential oil constituents isolated from aromatic plants: possible mode of action against insect pests. *Pest Manag. Sci.* 58: 1101-1106.

Koul, O. 2004. Bioactivity of volatile di-n-propyl disulfide from seeds of neem, *Azadirachta indica* (Meliaceae) to two species of stored grain pests, *Sitophilus oryzae* (L.) and *Tribolium castaneum* (Herbst). *J. Econ. Entomol.* 97: 1142–1147.

Koul, O., Walia, S., and Dhaliwal, G. S. 2008. Essential oils as green pesticides: potential and constraints. *Biopesticide Int.* 4: 63–84.

Kuldipake, S. A., Mhaske, B. M., and Patil, N. M. 2016. Study of mortality and repellency of rice weevil *Sitophilus oryzae* L. on wheat seeds during storage. *Int. J. Plant Prot.* 9: 479-482.

Kumar, R. and Tiwari, S. N. 2017. Essential oils against stored product beetles on wheat. *Indian J. Entomol.* 79(3): 300-306.

Kumari Nalina T. 1989. Studies on the extent of damage caused by pests of stored copra and control of the important pests. Ph.D.(Ag) thesis, Kerala Agricultural University, Thrissur, p. 163.

Lacey, L. A. and Neven, L. G. 2006. The potential of the fungus, *Muscodor albus*, as a microbial control agent of potato tuber moth in stored potatoes. *J. Invertebrate Pathol.* 91: 95-198.

Lee, B., Annis, P. C., Tumaalii, F., and Lee, S. 2004. Fumigant toxicity of *Eucalyptus blakelyi* and *Melaleuca fulgens* essential oils and 1, 8-cineole against different development stages of the rice weevil *Sitophilus oryzae*. *Phytoparasitica*. 32: 498-506.

Lee, E., Kim, J., Choi, D., and Ahn, Y. 2008. Toxicity of cassia and cinnamon oil compounds and cinnamaldehyde-related compounds to *Sitophilus oryzae* (Coleoptera: Curculionidae). *J. Econ. Entomol*. 101: 1960- 1966.

Leelaja, B. C., Rajashekhar, Y., Reddy, V. P., Begum, K., and Rajendran, S. 2007. Enhanced fumigant toxicity of allyl acetate to stored-product beetle pests in the presence of carbon dioxide. *J. Stored Products Res.* 43: 45-48.

Lefroy, H. M. 1909. *Indian Insect Life. A Manual of the Insects of the Plains (Tropical India).* Government of India, Agricultural Research Institute.

Liu, C. H., Mishra, A. K., Tan, R. X., Tang, C., Yang, H., and Shen, Y. F. 2006. Repellent and insecticidal activities of essential oils from *Artemisia princeps* and *Cinnamomum camphora* and their effect on seed germination of wheat and broad bean. *Bioresource Technol*. 97: 1969-1973.

Mahfuz, I. and Khalequzzaman, M. 2007. Contact and fumigant toxicity of essential oils against *Callosobruchus maculatusUniv. J. Zool. Rajshahi Univ.* 26: 63-66.

Manzoor, F., Nasim, G., Saif, S., Malik, S. A. 2011. Effect of ethanolic plant extracts on three storage grain pests of economic importance. *Pak. J. Bot*. 43(6): 2941-2946.

Mbata, G. N. 1989. Studies on some aspects of the biology of *Corcyra cephalonica* (Stainton) (Lepidoptera: Galleriidae). *J. Stored Products Res.* 25: 181-186.

Mohan, S. 2018. Eco-friendly post-harvest technologies for management of stored grain insects at farm, home and rehouse - a step towards clean grain (insect free) revolution. http://agritech.tnau.ac.in/crop_protection/crop_prot_crop_insect_sto_trap.html.

Mukherjee, P. K., Kumar, V., and Houghton, P. J. 2007. Screening of Indian medicinal plants for acetylcholinesterase inhibitory activity. *Phytotherapy Res.* 21(12): 1142-1145.

Nagpal, M. and Kumar, A. 2012. Grain losses in India and government policies. *Qual. Assurance Saf. Crops Foods* 4: 143-147.

Navarro, S. 2006. Modified atmospheres for the control of stored product insects and mites. In: Heaps, J. W. (ed.), *Insect Management for Food Storage and Processing.* AACC International, St. Paul, Minnesota, USA, 105-145.

Nayak, M. K., Holloway, J. C., Emery, R. N., Pavic, H., Bartlet, J., and Collins, P. J. 2012. Strong resistance to phosphine in the rusty grain beetle, *Cryptolestes ferrugineus* (Stephens) (Coleoptera: Laemophloeidae): its characterisation, a rapid assay for diagnosis and its distribution in Australia. *Pest Manag. Sci.* 69: 48-53.

Neeson, R. and Banks, H. J. 2000. On-farm storage of organic grain. AGFACTS - NSW *Agric.Bull.* 8.

Nelson, U. M. and Bernard, O. C. 2016. Insecticidal potentials of lemon grass (*Cymbopogon citratus*) products against stored cowpea weevil (*Callosobruchus maculatus*) (F) (Coleoptera: Bruchidae). *Int. J. Sci. Res. Knowl.* 4: 85-90.

Nirjara, G. and sujatha, P. 2011. Control of *Rhyzopertha dominica* (Coleoptera: Bostrichidae) by pulverized leaves of *Punica granatum* (Lythraceae) and *Murraya koenigii* (Rutaceae). *Int. J. Agric. Biol.* 13: 535-540.

Nwachukwu, I. D. and Asawalam, E. F. 2014. Evaluation of freshly prepared juice from garlic (*Allium sativum* L.) as a biopesticide against the maize weevil, *Sitophilus zeamais* (Motsch.) (Coleoptera: Curculionidae). *J. Plant Prot. Res.* 54: 132-139.

Obeng-Ofori, D., Reichmuth, C. H., Bekele, J., and Hassanali, A. 1997. Biological activity of 1,8-cineol, a major component of essential oil of *Ocimum kenyense* (Ayobangira) against stored product beetles. *J. Appl. Entomol.* 121: 237-243.

Oberlander, H., Silhacek, D. L., Shaaya, E., and Ishaaya, I. 1997. Current status and future perspectives of the use of insect growth regulators for the control of stored product insects. *J. Stored Prod. Res.* 33: 1-6.

Ogendo, J. O., Kostyukovsky, M., Ravid, U., Matasyoh, J. C., Deng, A. L., Omolo, E. O., Kariuki, S. T., and Shaaya, E. 2008. Bioactivity of *Ocimum gratissimum* L. oil and two of its constituents against five insect pests attacking stored food products. *J. Stored Prod. Res.* 44: 328-334.

Paranagama, P. A., Abeysekera, K. H. T., Nugaliyadde, L., and Abeywickrama, K. P. 2004. Repellency and toxicity of four essential oils to *Sitophilus oryzae* L. (Coleaptera: Curculionidae). *J. Natl. Sci. Foundation.* 32: 127-138.

Patil, N. B., Adak, T., Pandi, G. G. P., Gowda, G. B., and Jena, M. 2016. Ecofriendly approach for rice weevil, (*Sitophilus oryzae*) (Coleoptera: Curculionidae) management using fumigant oils. In: Navarro, S., Jayas, D. S., Alagusundaram, K. (eds), *Proceedings of the 10th International Conference on Controlled Atmosphere and Fumigation in Stored Products* (CAF2016), CAF Permanent Committee Secretariat, Winnipeg, Canada.

Perera, A. G. W. U. and Karunaratne, M. M. S. C. 2015. Eco-friendly alternatives for storage pest management: leaves of *Ruta graveolens* (Aruda) as a repellent against the rice weevil, *Sitophilus oryzae* L. *Int. J. Multidisciplinary Studies*. 2: 18-26.

Phillips, T. W. and Throne, J. E. 2010. Biorational approaches to managing stored product insects. *Annu. Rev. Entomol*. 55: 375-97.

Pimentel, M. A. G., Faroni, L. R. D., da Silva, F. H., Batista, M. D., and Guedes, R. N. C. 2010. Spread of phosphine resistance among Brazilian populations of three species of stored product insects. *Neotrop. Entomol.* 39: 101-7.

Prakash, A., Pasalu, I. C., and Mathur, K. C. 1983. Use of Bael (*Aegle marmelos*) leaf powder as a protectant against storage pests of paddy. *Agric. Res. J. Kerala*. 14: 112-116.

Priestley, C. M., Williamson, E. M., Wafford, K. A., and Sattelle, D. B. 2003. Thymol, a constituent of thyme essential oil, is a positive allosteric modulator of human GABA receptors and a homo-oligomeric GABA receptor from Drosophila melanogaster. *Br. J. Pharmacol*. 140: 1363-1372.

Rahman, M. M., Roberts, H. L. S., Sarjan, M., Asgari, S., and Schmidt, O. 2004. Induction and transmission of *Bacillus thuringiensis* tolerance in the flour moth *Ephestia kuehniella*. *J. Stored Products Res.* 101: 2696-2699.

Rajan, T. S., Mohankumar, S. and Chandrasekaran, S. 2017. Studies on spatial distribution of phosphine resistance in rice weevil, *Sitophilus oryzae* (L.) (Curculionidae: Coleoptera) collected from Tamil Nadu. *Indian J. Entomol.* 79(3): 307-311.

Rajendran, S. 2016. Status of fumigation in stored grains in India. *J. Grain Storage Res.* 10: 974-998.

Rani, M. J., Usha, P. I., and Rao, K. R. S. S. 2013. Organic-inorganic hybrids of nano silica and certain botanical compounds for their improved bioactivity against agricultural pests. *Curr. Trends Biotechnol. Pharmacol*. 7 (2): 615-624.

Rani, P. U., Venkateshwaramma, T., and Devanand, P. 2011. Bioactivities of *Cocos nucifera* L. (Arecales: Arecaceae) and *Terminalia catappa* L. (Myrtales: Combretaceae) leaf extracts as post-harvest grain protectants against four major stored product pests. *J. Pest Sci.* 84: 235–247.

Regnault-Roger, C. 1997. The potential of botanical essential oils for insect pest control. *Int. Pest Manag. Rev.* 2: 25-34.

Regnault-Roger, C., Vincent, C., and Arnason, J. T. 2012. Essential oils in insect control: low-risk products in a high-stakes world. *Annu. Rev. Entomol.* 57: 405-24.

Ridgway, C. and Chambers, J. 1996. Detection of external and internal insect infestation in wheat by near-infrared reflectance spectroscopy. *J. Sci. Food Agric.* 71: 251-264.

Riudavets, J., Cristina, C., Alomar, O., Pons, M. J., and Gabarra, R. 2009. Modified atmosphere packaging (MAP) as an alternative measure for controlling ten pests that attack processed food products. *J. Stored Prod. Res*. 45: 91-96.

Riudavets, J., Cristina, C., Alomar, O., Pons, M. J., and Gabarra, R. 2010. The use of carbon dioxide at high pressure to control nine stored-product pests. *J. Stored Prod. Res*. 46: 228-233.

Saad, A. S., Elsayed, A., Tayeb, H. M., and Metraw, H. L. 2017. Botanical oils as eco-friendly alternatives for controlling the rice weevil *Sitophilus oryzae*. *Alexandria Sci. Exchange J.* 38: 921-932.

Sabbour, M. M. and El-Aziz, S. E. A. 2010. Efficacy of some bioinsecticides against *Bruchidius incarnates* (Boh.) (Coleoptera: Bruchidae) infestation during storage. *J. Plant Prot. Res.* 50: 25-31.

Sahito, H. L., Mallah, N. A., Kousar, T., Kubar, W. A., Shah, Z. H., Jatoi, F. A., and Mangrio, W. M. 2017. Life table parameters of saw toothed grain beetle, *Oryzaephilus surinamensis* (L., 1758) on different varieties of stored date palm fruits infested under laboratory conditions. *J. Entomol. Zool. Stud.* 5(1): 95-99.

Saljoqi, A. U. R., Afridi, M. K., Khan, S. A. and Rehman, S. 2006. Effects of six plant extracts on rice weevil *Sitophilus oryzae* L. in the stored wheat grains. *J. Agric. Biol. Sci.* 1: 1-5.

Santeshwari, T., Govind, H., and Gundevia, H. S. 2010. Efficacy of herbal extracts of neem (*Azadirachta indica*) and tulsi (*Ocimum sanctum*) against a beetle pest, *Alphitobius laevigatus* Fabr. in stored cereals. *J. Appl. Zool. Res.* 21: 143-146.

Santos, F. A. and Rao, V. S. N. 2000. Anti-inflammatory and anti-nociceptive effects of 1,8-cineole a terpenoid oxide present in many plant essential oils. *Phytotherapy Res.* 14: 240-244.

Sathyaseelan, V., Baskaran, V., and Mohan, S. 2008. Efficacy of some indigenous pesticidal plants against pulse beetle, *Callosobruchus chinensis* (L.) on green gram. *J. Entomol.* 5: 128-132.

Saxena, R. C., Jilani, G., and Kareem, A. A. 1989. Effects of neem on stored grain insects. 97-112. In: Jacobson, M. (ed.). *Focus on Phytochemical Pesticides. Volume 1. The Neem Tree*. Boca Ratan, US, CRC Press, Inc.

Schmidt, G. H. and Streloke, M. 1994. Effect of *Acorus calamus* (L.) (Araceae) oil and its main compound β-asarone on *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae). *J. Stored Products Res.* 30(3): 227-235.

Schmidt, G. H., Risha, E. M., and El-Nahal, A. K. M. 1991. Reduction of progeny of some stored-product Coleoptera by vapours of *Acorus calamus* oil. *J. Stored Products Res.* 27(2): 121-127.

Schmutterer, H. 1990. Properties and potential of natural pesticides from the neem tree, *Azadirachta indica*. *Ann. Rev. Entomol.* 35: 271-297.

Shaaya, E., Ravid, U., Paster, N., Juven, B., Zisman, U., and Pissarev, V. 1991. Fumigant toxicity of essential oils against four stored-product insects. *J. Chem. Ecol.* 17: 499-504.

Singh, B. K. P. 2017. Study on the life cycle of *Sitophilus oryzae* on rice cultivar Pusa 2-21 in laboratory condition. *Int. J. Educ. Appl. Sci. Res.* 4: 37-42.

Sinha, S. P., Prasad, M., Ahsan, J., and Yadava, S. C. 1984. Population growth of *Sitophilus oryzae* (Linn.) in three varieties of maize with relation to different types of container. *J. Stored Products Res.* 11(3): 325-329.

Stefanazzi, N., Stadler, T., and Ferrero, A. 2011. Composition and toxic, repellent and feeding deterrent activity of essential oils against the stored-grain pests *Tribolium castaneum* (Coleoptera: Tenebrionidae) and *Sitophilus oryzae* (Coleoptera: Curculionidae). *Pests Manag. Sci.* 67: 639-646.

Subramanyam, B. H. 1992. Relative retention of adult saw toothed grain beetles in potential food baits. *Postharvest Biol. Tech.* 2: 73-82.

Suthisut, D., Fields, P. G., and Chandrapatya, A. 2011. Fumigant toxicity of essential oils from three Thai plants (Zingiberaceae) and their major compounds against *Sitophilus zeamais, Tribolium castaneum* and two parasitoids. *J. Stored Products Res.* 47(3): 222-223.

Tapondjou, A. L., Adler, C., Fontem, D. A., Bouda, H., and Reichmuth, C. 2005. Bioactivities of cymol and essential oils of *Cupressus sempervirens* and *Eucalyptus saligna* against *Sitophilus zeamais* Motschulsky and *Tribolium confusum* du Val. *J. Stored Prod. Res.* 41: 91-102.

Tefera, T., Mugo, S., Likhayo, P., and Beyene, Y. 2011. Resistance of three-way cross experimental maize hybrids to post-harvest insect pests, the larger grain borer (*Prostephanustruncatus*) and maize weevil (*Sitophilus zeamais*). *Int. J. Trop. Insect sci*. 31: 3-12.

Thakur, A. K. and Sharma, J. K. 1996. Assessment of storage losses in rice in Himachal Pradesh. *Pest Manag. Econ. Zool*. 4(2): 97-100.

Thomas, P. J. and Bhatnagar-Thomas, P. L. 1968. Use of a juvenile hormone analogue as insecticide for pests of stored grain. *Nat.* 219: 94-99.

Tripathi, A. K., Prajapati, V., Aggarwal, K. K., Kumar, S., Prajapti, V., Kumar, S., Kukreja, A. K., Dwivedi, S. and Singh, A. K. 2000. Effects of volatile oil constituents of *Mentha* species against stored grain pests, *Callosobrunchus maculatus* and *Tribolium castanum*. *J. Med. Aromat. Plant Sci.* 22: 549-556.

Tripathi, A. K., Prajapati, V., Verma, N., Bahl, J. R., Bansal, P., Khanuja, S., and Kumar, S. 2002. Bioactivities of the leaf essential oil of *Curcuma Longa* (Var. Ch-66) on three species of stored product beetles (Coleoptera). *J. Econ. Entomol.* 95(1): 183- 189.

Ukeh, D. A., Birkett, M. A., Pickett, J. A., Bowman, A. S., and Luntz, A. J. M. 2009. Repellent activity of alligator pepper, *Aframomum melegueta*, and ginger, *Zingiber officinale*, against maize weevil, *Sitophilus zeamais*. *Phytochemistry.* 70:751–758.

Upadhyay, R. K. and Ahmad, S. 2011. Management strategies for control of stored grain insect pests in farmer stores and public ware houses. *World J. Agric. Sci.* 7: 527-549.

Vendan, S. E, Manivannan, S., Sunny, A. M., and Murugesan, R. 2017. Phytochemical residue profiles in rice grains fumigated with essential oils for the control of rice weevil. *Plos One.* 12: 1-17.

Villaverde, M. L., Juárez, M. P., and Mijailovsky, S. 2007. Detection of *Tribolium castaneum* (Herbst) volatile defensive secretions by solid phase micro extraction–capillary gas chromatography (SPME-CGC). *J. Stored Prod. Res.* 43: 540-545.

Weston, P. A. and Rattlingourd, P. L. 2000. Progeny production by *Tribolium castaneum* (Coleoptera: Tenebrionidae) and *Oryzaephilus surinamensis* (Coleoptera: Silvanidae) on maize previously infested by *Sitotroga cerealella* (Lepidoptera: Gelechiidae). *J. Econ. Entomol.* 2: 533-536.

White, N. D. G., Arbogast, R. T., Fields, P. G., Hillmann, R. C., Loschiavo, S. R., Subramanyam, B., Throne, J. E., and Wright, V. F. 1990. The development and use of pitfall and probe traps for capturing insects in stored grain. J. *Kansas Entomol. Soc.* 63: 506-525.

Yankanchi, S. R. and Gadache, A. H. 2010. Grain protectant efficacy of certain plant extracts against rice weevil, *Sitophilus oryzae* L. (Coleoptera: Curculionidae). *J. Biopesticides*. 3: 511-513.

Yildirim, E., Emsen, B., and Kordali, S. 2013. Insecticidal effects of monoterpenes on *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae). *J. Appl. Bot. Food. Qual.* 86: 198–204.

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Abstract

MANAGEMENT OF BEETLE PESTS IN STORED RICE USING BOTANICALS

by

BINSEENA S R

(2016 - 11- 014)

Abstract of the thesis

Submitted in partial fulfilment of the

requirements for the degree of

MASTER OF SCIENCE IN AGRICULTURE

Faculty of Agriculture

Kerala Agricultural University

DEPARTMENT OF AGRICUTURAL ENTOMOLOGY

COLLEGE OF AGRICULTURE

VELLAYANI, THIRUVANANTHAPURAM – 695 522

2018

ABSTRACT

The study entitled "Management of beetle pests in stored rice using botanicals" was carried out at the Department of Agricultural Entomology, College of Agriculture, Vellayani, during 2016-2018. The objectives of the study was to document major beetle pests of stored rice in Thiruvananthapuram district and to develop effective management measures using botanicals.

The occurrence of beetle pests of stored rice in ration shops and retail provision stores in Thiruvananthapuram district of Kerala was examined through a preliminary survey. Effective management measures using botanicals were tested against one major beetle pest identified from survey. Three experiments were conducted using plant extract, dried plant parts and essential volatile oils for the management of the major beetle pest.

As per the results of survey, out of 25 rice samples 23 were contaminated with rice weevil *Sitophilus oryzae* L. with a mean number of 14.68 in 100 g rice followed by saw toothed grain beetle. In the light of above, further studies were undertaken to manage rice weevil using botanicals. Experiment with extract of plant parts *viz.*, tulsi leaves (*Ocimum tenuiflorum* L.), neem leaves (*Azadirachta indica* A.Juss.), garlic bulblets (*Allium sativum* L.), bird chilli fruits (*Capsicum frutescens* L.), mint leaves (*Mentha arvensis* L.) and pepper seeds (*Piper nigrum* L.) at two concentrations (5 and 10%) (w/v) were conducted. The highest percentage mortality was recorded in treatment with garlic bulb 10 % (53.33) which was on par with garlic bulb 5 % (38.33), tulsi leaves 10 % (38.33) and bird chilli fruit 10% (36.67). The treatment with tulsi leaves 10 % recorded maximum repellent effect of 40.00 per cent which was on par with pepper seed 10 % (38.33), mint leaves 10 % (26.67) and bird chilli fruit 10 % (23.33). While examining both mortality and repellent effect of plant extract, treatment with tulsi leaves 10 % showed the highest reduction (78.33) of weevils with decreased progeny emergence and grain damage.

Management of beetle pest using dried plant parts *viz.* tulsi leaves (*O. tenuiflorum*), neem leaves (*A. indica*), clove flower buds (*Syzygium aromaticum* (L.)), nutmeg mace (*Myristica fragrans* Houtt.), mint leaves (*M. arvensis*) and curry leaves (*Murraya koenigii* (L.)) at two concentrations (2 and 4%) (w/w) showed that mint leaves 4 % was the most effective treatment with 56.67 per cent mortality which was on par with nutmeg mace 4 % (35.00). The highest percentage repellency of weevils was recorded in rice treated with nutmeg mace 4 %, (31.67) and the lowest progeny emergence and grain damage also. However considering both mortality and repellent effect of dried plants parts, treatment with mint leaves 4 % showed the highest reduction of weevils.

Effect of essential volatile oils on mortality of beetles were carried with four oils *viz.*, clove (*S. aromaticum*), cinnamon (*Cinnamomum zeylanicum* Blume), lemon grass (*Cymbopogon flexuosus* (Nees *ex* steud)) and pepper (*P. nigrum*). Preliminary toxicity bioassays (without food and with food) were carried for fixing the concentrations of these oils. Percentage mortality of weevils by volatile essential oils increased with increase in concentration and period of exposure. Pepper oil 200 μl 500 cm^{-3} caused cent per cent mortality without any progeny emergence whereas cinnamon oil 30 μl 500 cm^{-3} caused 95.55 per cent mortality of weevils.

The rice weevil *S. oryzae* was found to be the major beetle pest associated with stored rice. Among the plant extracts, treatment with tulsi leaves 10 % showed the highest reduction of weevils with decreased progeny emergence and grain damage. Treatment with dried plant parts revealed that mint leaves (4 %) showed the highest reduction of weevils whereas the lowest progeny emergence and grain damage were observed in treatment with dried nutmeg mace 4 %. Among the essential volatile oils pepper oil 200 μl 500 cm^{-3} caused cent per cent mortality of rice weevil at four days after treatment without any progeny emergence.