ACKNOWLEDGEMENTS

All the praises and gratitude are due to the omniscient, omnipresent and omnipotent **Almighty Allah**, who has kindly enabled the author to complete his research work and complete this thesis successfully for increasing knowledge and wisdom.

The author sincerely desires to express his deepest sense of gratitude, respect, profound appreciation and indebtedness to his research Supervisor, **Professor Dr. Md. Razzab Ali**, Chairman, Department of Entomology, Sher-e-Bangla Agricultural University, Dhaka for his kind and scholastic guidance, untiring effort, valuable suggestions, inspiration, co-operation and constructive criticisms throughout the entire period of the research work and the preparation of the manuscript of this thesis.

The author expresses heartfelt gratitude and indebtedness to his Co-Supervisor, **Professor Dr. Md. Abdul Latif**, Department of Entomology, Sher-e-Bangla Agricultural University, Dhaka for his co-operation, criticisms on the manuscript and helpful suggestions for the successful completion of the research work.

The author also expresses his heartfelt thanks to all the respected teachers of the Department of Entomology, Sher-e-Bangla Agricultural University,Dhaka.

The author also likes to give thanks to all of his friends for their support and inspiration throughout his study period in SAU, Dhaka. Special thanks to Tithi, Rashed, Jony and Sibly apa for their cordial support, co-operation and inspiration in preparing this thesis.

Finally, the author found no words to thank his parents, his wife and brothers for their unquantifiable love and continuous support, their sacrifice, never ending affection, immense strength and untiring efforts for bringing his dream to proper shape. They were constant source of inspiration, zeal and enthusiasm in the critical moment of his studies.

The author

TABLE OF CONTENTS

CHAPTER	TITLE		PAGE
	ACKNOWLEDGEMENTS		i
	LIST OF CONTENTS		ii
	LIST OF TABLES		v
	LIST OF PLATES		vi
	ABSTRACT		vii
I	**INTRODUCTION**		**1-4**
II	**REVIEW OF LITERATURE**		**5-32**
	2 .1.	Taxonomy of rice weevil, *Sitophilus oryzae* L.	5
	2.2.	Biology of rice weevil	6
	2.2.1.	Mating	6-8
	2.2.2.	Oviposition and incubation	8-11
	2.2.3.	Larval period	11-12
	2.2.4.	Pupal period	13
	2.2.5.	Adult emergence and its longevity	13-15
	2.2.6.	Identification of male and female	15
	2.3.	Nature and extent of damage	15
	2.4.	Origin and distribution of rice weevil	16
	2.5.	Alternative management of rice weevil on rice	16
	2.5.1.	Botanicals for the management of rice weevil	17-30
	2.5.2.	Fumigants for the management of rice weevil	30-32
III	**MATERIALS AND METHODS**		33-46
Experiment 1	**Efficacy of some botanicals for the management of rice weevil (*Sitophilus oryzae* L.) in stored rice**		
	3.1.1	Design of the experiment	33
	3.1.2.	Materials used in the study	34
	3.1.3.	Treatments	34
	3.1.4	Collection and preparation of botanicals	34-35
	3.1.4a.	Neem leaf	35
	3.1.4b.	Biskatali leaf	35
	3.1.4c.	Marigold leaf	35

	3.1.4d.	Dholkolmi leaf	36
	3.1.4e.	Mehogany leaf	36
	3.1.5.	Application of the botanicals	38
	3.1.6.	Release of rice weevil, *Sitophilus oryzae* L.	38
	3.1.7.	Data sampling	38-39
	3.1.8.	Data collection and calculation	39
	3.1.9.	Data on grain infestation by number and weight	39
Experiment 2	**Efficacy of commonly used fumigants for the management of rice weevil (*Sitophilus oryzae* L.) in stored rice**		
	3.2.1.	Design of the experiment	41
	3.2.2.	Materials used in the study	41
	3.2.3.	Treatments	41
	3.2.4.	Collection and description of the fumigants	42
	3.2.4a.	Camphor	42
	3.2.4b.	Phostoxin	42
	3.2.4c.	Naphthalene	42-43
	3.2.4d.	Untreated control	44
	3.2.5.	Application of the fumigants	44
	3.2.6.	Release of rice weevil, *Sitophilus oryzae* L.	45
	3.2.7.	Data sampling, collection and recording	45
	3.2.8.	Data analysis	45
IV	**RESULTS AND DISCUSSION**		47-66
Experiment 1	**Efficacy of some botanicals for the management of rice weevil (*Sitophilus oryzae* L.) in stored rice**		
	4.1.	Effect of botanicals on grain infestation by number	47-50
	4.2.	Effect of botanicals on grain infestation by weight	50-52
	4.3.	Effect of botanicals on the survibility of weevil larvae	52-55
	4.4.	Effect of botanicals on the survibility of weevil pupae	55-58

Experiment 2	**Efficacy of some fumigants for the management of rice weevil (*Sitophilus oryzae* L.) in stored rice**		
	4.5.	Effect of fumigants on grain infestation by number	58-60
	4.6.	Effect of fumigants on grain infestation by weight	60-63
	4.7.	Effect of fumigants on the survibility of weevil larvae	63-65
	4.8.	Effect of fumigants on the survibility of weevil pupae	65-66
V	**SUMMARY AND CONCLUSION**		66-72
VI	**REFERENCES**		73-95

LIST OF TABLES

TABLE NO.	TITLE	PAGE
1.	Effect of botanicals on grain infestation by number during the storing period from September 2011 to February 2012	49
2.	Effect of botanical on grain infestation by weight during the storing period from September 2011 to February 2012	51
3.	Effect of botanicals on the larval survibility of rice weevil during the storing period of rice from September 2011 to February 2012	54
4.	Effect of botanicals on the pupal survibility of rice weevil during the storing period of rice from September 2011 to February 2012	57
5.	Effect of fumigants on grain infestation by number during the storing period from September 2011 to February 2012	59
6.	Effect of fumigants on grain infestation by weight during the storing period from September 2011 to February 2012	62
7.	Effect of fumigants on the incidence of weevil larvae during the storing period from September 2011 to February 2012	64
8.	Effect of fumigants on the incidence of weevil pupae during the storing period from September 2011 to February 2012	66

LIST OF PLATES

PLATE NO.	TITLE	PAGE
1.	Neem leaves (left) and dried neem leaf powder treated rice (right) on a plate	36
2.	Bishkatali leaves (left) and dried bishkatali leaf powder treated rice (right) on a plate	36
3.	Marigold leaf (left) and dried marigold leaf powder treated rice (right) on a plate	37
4.	Dried dholkolmi leaves (left) and dried dholkolmi leaf powder treated rice (right) on a plate	37
5.	Dried mahogany leaves (left) and dried leaf powder treated rice (right) on a plate	37
6.	Different developmental stages of rice weevil, *Sitophilus oryzae* L.	40
6.a.	Egg mass	40
6.b.	Larvae	40
6.c.	Pupae	40
6.d.	Adult	40
7.	Camphor (left) and camphor treated rice (right) on a plate	43
8.	Naphthalene (left) and naphthalene treated rice (right) on a plate	43
9.	Phostoxin (left) and phostoxin treated rice (right) on a plate	44
10.	Botanical and fumigant treated rice preserved in plastic pots according to design	46
11.	Infested stored rice in experimental condition	46

ECO-FRIENDLY MANAGEMENT OF RICE WEEVIL, *SITOPHILUS ORYZAE* LINN. USING SOME BOTANICALS AND FUMIGANTS ON STORED RICE

BY

MOHAMMAD SHARIFUZZAMAN

ABSTRACT

Two experiments were conducted in the laboratory under the Department of Entomology, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh during the period from September 2011 to February 2012 to find out the efficacy of some promising botanicals and fumigants applied against rice weevil, *Sitophilus oryzae* Linn. on stored rice. Under experiment where five botanicals along with one untreated control were used viz. dried neem leaf powder @ 2.5 g/kg rice, dried bishkatali leaf powder @ 2.5 g/kg rice, dried marigold leaf powder @ 2.5 g/kg rice, dried dholkolmi leaf powder @ 2.5 g/kg rice, dried mahogany leaf powder @ 2.5 g/kg rice, and untreated control. In experiment three fumigants along with untreated control treatments were used viz. camphor @ 1 gm/kg rice, phostoxin tablet @ 200 mg/kg rice, naphthalene @ 500 mg/kg rice and untreated control. Both the experiments were laid out in Completely Randomized Design (CRD) with 4 replications. Among five botanicals, the dried neem leaf powder @ 2.5 gm/kg rice reduced the highest percent of grain infestation by number (65.81%) and weight (57.42%) over control during the management of rice weevil, *S. oryzae* in storage than dried leaf powder of bishkatali, marigold, dholkalmi and mahogany; whereas, the dried mahogany leaf powder reduced showed the least performance in reducing the percent grain infestation by number (32.14% and weight (26.76%) over control. Among three fumigants, camphor @ 1 gm/kg rice reduced the highest percent of grain infestation by number (73.34%) and weight (76.19%) over control than phostoxin tablet and naphthalene, where naphthalene @ 500 mg/kg rice reduced the lowest percent of grain infestation by number (55.15%) and weight (59.96%) over control. Irrespective of botanicals and fumigant based management practices, all fumigants performed superior in terms of the reduction of percent grain infestation and survibility of larvae and pupae of rice weevil than botanicals, where camphor @ 1.0 gm/kg rice grains showed the best performance in controlling rice weevil on rice in storage. Camphor is also acceptable for the consumers in terms of environmental safety point and human health hazards free measures applied against insect pests of stored products, because it is derived from *Cinnamonum camphora* plant.

CHAPTER I

INTRODUCTION

Rice is the main food crop for more than half of the worlds' population. It is the major source of carbohydrate and also plays a vital socio-economic role in the diet of the people of Bangladesh. The rice occupies about 70% of the total cultivable land of the country. Bangladesh produced a total of 3.13 million ton of rice from an area of 15.09 million acres (BBS, 2010). About 90% of the total population of Bangladesh depends on rice for their major food intake (Anon., 1981). The farmers store more than 65% of the total rice produces till the next season for their food, feed and seed purposes. Rice is stored as paddy (unhusked rice), brown and polished milled rice. In Bangladesh, rice is stored as raw parboiled in bamboo made container (called *dhole* and *gola*) or stored as parbolied milled rice in earthen pot (called *motka*) (BRRI, 1984). Prakash *et al.* (1987) reported that about 5 - 8% of rice was stored for seed.

Rice is being damaged by a number of agents, such as insects, rodents, fungi, mites, birds and moisture (Prakash and Rao, 1983). Insect infestations in stored grains and grain products can arise from several sources, depending on the specific insect species. Some species can infest grain crops either in the field or after the crop has been cut and harvested (Cogburn and Vick, 1981; Hagstrum, 1985; Dix and All, 1986). Nearly seventeen species of insects have been found to infest stored rice (Prakash *et al.* 1987) of which rice moth *(Sitotroga cerealella);* rice weevil *(Sitophilus oryzae* L.) and beetles *(Tribolium castaneum)* predominate in parboiled rice. On the other hand, moth and beetles predominate in raw rice and weevils predominate in milled rice (BRRI, 1984). Among which rice weevil, *Sitophilus oryzae* L. is one of the most destructive pest of stored rice, other grains and their products (Asmanizar *et al*. 2008; Alam, 1971) throughout the world. This insect infests rice (both husked and unhusked), wheat, maize, sorghum and some pulses (Gelosi 1982). BRRI (1985) reported that, weight loss caused by rice weevil was 0.69% to 5.93% in parboiled rice and 0.52% to 2.06% in non-parboiled rice in 2 - 6 month storage period.

Synthetic chemicals have become a common practice among the farmers and stockholders to control the storage pests. Several reports are available on the efficacy of different chemicals for controlling insect pests in stored production (Prakash and Rao, 1983; Stoyanova and Shikrenov, 1983; Yadav, 1983; Singh *et al*., 1989; Dilwari *et al.*, 1991). It is now widely known that the chemical method has several problems, which include health hazards to the users and grain consumers. It causes residual toxicity, environmental pollution and development of pesticide resistance against insects. The residues of the chemical insecticides remain in the stored grain and also in the environment (Srivastava, 1980; Prakash and Kauraw, 1982). Besides this, reports are also available on the efficacy of plant oils (Singh *et al.* 1989, Chander *et al.* 1991, Su 1991). But the oils are not always available, not good in efficacy, have pungent smell and cannot de-infest the seeds. Hence, search for the alternative method of rice weevil control utilizing some non-toxic, environment friendly and human health hazard free methods are being pursued now a day. In Bangladesh, most of the farmers are poor and marginal. They store small quantities of seed for edible rice and cannot offer expensive control measures. Therefore, they essentially need some cheap, easy to use, readily available but effective methods for safe storing of rice. Plant products are liberally available as indigenous source of insecticides and insect repellents has been using for more than one century in India. The insecticidal property is not very quick (except natural pyrethrins) as compared to that of synthetic insecticides and fumigants. The plant products certainly possess surface persistence for a long period, have least or no adverse effect on germination ability of seed, cooking quality and milling, less expensive, easily available and some of the products like natural pyrethrums have rapid killing action (Prakash and Mathur, 1981). In the world, as many as 2400 plant species have been recorded those have potential pesticidal properties and biological activity against a wide range of pests (Grainge and Ahmed, 1988). In Bangladesh, as many as 54 plant species have been evaluated for their bio-efficacy against different insect pests, pathogens and weeds (Karim, 1994). A number of botanicals and their derivatives have been tested in Bangladesh and other developing countries particularly against stored grain pests including rice weevil and have shown promising results (Yadava and Bhatnagar, 1987). Among the plant products, neem *(Azardirachta indica)* products like leaves, seed, bark from which oil cake and extracts are prepared have been reported to possess fungicidal, nematicidal, insecticidal, insect repellent and antifeedent properties (Ketkar, 1976). Mixing dried leaves of neem with grains repel the insect pests (Prakash and Rao, 1983).

Bhuiyah (2001) reported that the oils of neem, royna and castor at 6 and 8 ml/kg and leaf powder of bishkatali, marigold and castor at 5% w/w were most effective in preventing the egg laying in lentil and chickpea and leaf powder of bishkatali, marigold, castor and mango at 5% were most effective in reducing the adult emergence in lentil and chickpea, whereas the adult emergence were nil in pre and post storage release methods. Singh *et al.* (1989) observed that volatile oil of *Pinus longifolia* reduced the population of *S. oryzae* up to 37.51, 75.21 and 86.82% compared to control at 30, 60 and 90 days after application, respectively.

Now a day, Camphor ($C_{10}H_{16}O$), locally named as *Karpur* in Bangladesh is very new and unexploited approach in this context, which extracted from the leaves and wood of Camphor tree (*Cinamomum camphora*). Chauvin *et al.* (1994) reported that camphor has fumigation properties and has got a very low mammalian toxicity. Rahman *et al.,* (2001) reported the fumigation action of camphor against pulse beetle, *C. chinensis.* Abivardi (1976) reported that 100% mortality of adults and larvae of stored grain insect pests including *Sitophilus granarius* and *S. oryzae* were achieved when the grains exposed to camphor (1,7,7 trimethylbicyclo (2.2.1) heptanc 2 one) at 5 concentrations in air tight containers in the laboratory. Another fumigant, the phostoxin is available in the market at its tablet or pellet form. The chemical name phostoxin is aluminium phosphide (Onu and Aliyu, 1995), which is used as a rodenticide, insecticide, and fumigant for stored cereal grains (Mahadi and Hamoudi, 2010). Naphthalene is a household fumigant also, which build up vapors that are toxic to both the adult and larval forms of many insects that attack textiles (Bryn, 2002) and other stored products. But a very little study has so far been reported on the efficacy of phostoxin and naphthalene against pulse beetles. However, the use of quality insecticides and their proper management is a burning issue in respect of agro-socio economic, environmental aspect and health of consumers. At present situation in Bangladesh, there is a great need of research about appropriate environment friendly and human health hazards free management practices to pulse beetles in stored pulses.

Objectives

Considering above points view in mind the present studies were undertaken with the following objectives:

1. To assess the level of infestation of rice weevil, *S. oryzae* on stored rice;
2. To find out the effectiveness of some botanicals against rice weevil and
3. To find out the effectiveness of some fumigants against rice weevil.

CHAPTER II

REVIEW OF LITERATURE

Stored grains suffer seriously from the attack of a number of insect pests. Now a day, the botanical products have been recognized as potential pests controlling measures all over the world. Review of literatures cited some information about the use of chemical and botanical products at home and abroad. In this chapter, relevant research works on stored product insect pest management by botanical insecticides have been cited.

2.1. Taxonomy of rice weevil, *Sitophilus oryzae* L.

The rice weevil, (*S. oryzae* L.) is somewhat black or reddish brown and measures 3 - 4 mm in length. Body is elongate and head has well defined snout. There are two light pale spots on each elytron (Willium, 1991). Pronotum is pitted with deep, round punctures.

Taxonomic position of *Sitophilus oryzae* L.

Kingdom: Animalia

Phylum: Arthropoda

Class: Insecta

Sub-class: Pterygota

Division: Endopterygota

Order: Coleoptera

Family: Curculionidae

Genus : *Sitophilus*

Species: *Sitophilus oryzae* (L.)

Body length 2.3 - 3.5 mm, reddish-brown to black in colour with four reddish or paler spots on the corners of the elytra; prothorax is strongly pitted with round or irregularly shaped pits and the elytra have rows of pits within longitudinal grooves (Walker, 2008b; Koehler, 2008). The midline of the prothorax is usually free of pits (Mason, 2003). Rostrum slender, cylindrical, elbowed antennae, three-fourths as long as thorax, at base slightly dilated, above with four rows of rather coarse punctures and with a slight fovea between the eyes. The head with rostrum is as long as the prothorax or the elytra.

Generally have four lighter colored areas on the back, two on each wing cover which are light red to yellow in color. Adults do not fly readily. Bumping outside of bagged grain or walking on surface of bulk grain will cause adults to appear at the surface a few minutes later. This is one method that can be used to detect an infestation. Adults will feign death for a short period of time after being disturbed. Mouthparts are chewing type. Metamorphosis is complete.

2.2. Biology of rice weevil

Most of the insects are controlled by using insecticides. Several species of insect pests both in field and in storage have been reported to be controlled by the application of botanical products such as powder, extract and oil as potential source of antifeedant, repellent and growth inhibitor (Islam, 1984 and 1987, Talukder and Howse, 1994 and 1995). But very few works have been done for their control in Bangladesh.

2.2.1. Mating

According to Perez-Mendoza *et al.,* (2004) physiological and morphological changes in the ovarian system in rice weevils, *Sitophilus oryzae* (L.) reared on wheat seeds were studied as a mating status. This analysis was determine time of adult eclosion and the duration of development of pre-emergent weevils within the seeds, a process

that lasted almost 4 days at 25oC and 60% RH. There was no follicular differentiation in pre-emergent weevils. Oocyte maturation began after adults emerged from the seeds and started to feed. There was a significant increase in mean germarium length and the size of proximal follicles within the first 5 days when newly emerged weevils were mated and fed ad lib. Maximum number of follicles and mature eggs per ovariole in mated females occurred at 5–30 days of age. The number of mature eggs decreased in 60 days old weevils, at the same time that adult mortality increased. Development of the ovarian system was much slower in unmated females than in mated females. Although there was follicle development in unmated females, ovulation never occurred and no eggs were laid. Starvation of mated females resulted in a rapid reduction in numbers of follicles and mature eggs, probably as a result of oosorption. Females were categorized into two nulliparous and three parous stages according to ovarian development and the degree of accumulation of follicular relics. Parity was directly correlated with both weevil age and the number of progeny produced and was the physiological basis used to construct an age-grading model for this species. The method will be useful for determining the age structure and reproductive potential of rice weevil populations in the field.

Over 60 days, females that permanently paired with males, mated twice with different males or four times with the same males did not suffer from significant decline of offspring survival, while females mated once, twice with the same males and four times with different males had significant declines. It is suggested that mating once or twice with the same males is not enough for females to maximize their reproductive fitness. The significant decline of offspring survival in females that mated with four different males may be caused by reproductive organ damage or other factors that reduce their fertility due to excessive polyandry (Flay *et al.*, 2010).

Female resistance to mating may also be costly to (Rowe 1994, Watson *et al.*, 1998). If males constantly harass females, resisting mating can be more costly than mating itself (Rowe, 1994). Many *Sitophilus* species, including *S. oryzae* (Linnaeus), *S. granarius* (L.) and *S. zeamais* (Motschulsky), are closely related and have similar biology and mating patterns (Longstaff 1981, Rees, 2004).

The mating behavior of the maize weevil, *Sitophilus zeamais*, was examined under laboratory conditions, and an ethogram was constructed. Using transition probabilities between two successive acts, copulatory sequence was analyzed. Copulation lasted an average of 4.8 h and was characterized by abdominal flexing by the males. Within 3.8 min of dismounting, on average, the male completely extruded his aedeagus. Mating did not occur before the age of 3 d. Virgin females began copulation sooner and were more likely to mate than previously mated females. Experienced males were more successful than virgins. Copulation duration was not affected by the age or mating status of the female, nor by the period of time since the first copulation (Catherine and Wendell, 1987).

2.2.2. Oviposition and incubation period

According to Russel and Mercer (1962) the most drastic effect of sorghum varieties on production of subsequent rice weevil (*Sitophilus oryzae*) populations was due to relative grain hardness as it affected the oviposition rate: the harder the grain, the fewer were the eggs deposited and reduction of relative humidity below 83% resulted in separate and significant reductions in oviposition rates. The one exception noted involved the waxy type sorgum, Texioca-54, which though hard-grained was very attractive for oviposition. Percent mortality was not significantly affected by the varieties used, so that first-generation emergence paralleled the oviposition findings. When sorghum varieties were mixed, oviposition preference was greatest for the largest seeds, least for the smallest ones. Further, the smaller the seeds, the shorter and lighter were the weevils that emerged. When the variety Sagrain was mixed with others, the high tannin content of its seed coat may have been a further deterrant to oviposition. Reduction of relative humidity below 83% resulted in separate and significant reductions in oviposition rates, and in the size and weight of the emergent weevils.

All three species (*S. oryzae, S. granarius* and *S. zeamais*) have similar life cycles. The female drills a hole into the kernel, deposits the egg, and then secretes a mucilaginous plug to enclose the egg as the ovipositor is withdrawn. The plug rapidly hardens, leaving a small raised area above the seed surface, which provides the only external evidence that the kernel is infested. Eggs may be laid anywhere in the kernel, but few are laid in the embryo. In wheat, most eggs are deposited at the end farthest from the embryo. Sometimes, more than one egg may be laid in a single grain but it is rare for more than one larva to develop to maturity, because of cannibalism (Longstaff, 1981). Female *Sitophilus* sp do not oviposit into all excavated holes; some are abandoned and others are expanded into feeding holes (Campbell, 2002). Females lay 300 - 400 eggs during their lifetime, at an average of 4 per day. Oviposition in *S. oryzae* is adversely affected by reducing humidity below 60% RH (ie. grain moisture <12%) but not eliminated, or increasing the temperature to 35^{o}C (Shazali & Smith, 1985).

Eggs are opaque, shining white, ovoid to pear-shaped in form, widest below middle, bottom broadly rounded, and neck narrowing sharply toward top which is somewhat flat and bears a small rounded protuberance that fits into a cap or plug that cements the egg in place. Length of egg is 0.65 to 0.70 mm, width 0.28 to 0.29 mm (Cotton, 1921).

Wenholz (1927) reported that egg stage on an average occupied three days under warm moist conditions. The eggs of *S. oryzae* laid on maize hatched in five to six days after oviposition (Anonymous, 1933). The egg period of rice weevil occupied an average of 4.41 days (Anonymous, 1934). Treiman (1937) reared rice weevil in laboratory on unpolished rice at 27 to 28^{0}C and 90 to 95 % RH. According to him, the egg period occupied 6 to 7 days. Lefevre (1953) recorded on an average of 2.65 days of incubation period in laboratory. According to Lopez-Cristobal (1953) the egg period lasted for 5 to 10 days whereas Lin (1958) recorded 3 to 10 days of incubation period in Formosa and the hatchability of egg of *S. oryzae* was influenced by the female age (Anand Prakash, 1980). Bheemanna (1986) recorded incubation period of 5 to 8 days on CSH-5 sorghum cultivar. Bhuiyah *et al.,* (1990) observed 5 to 6 days of incubation period of rice weevil on maize at 23 to 30^{0}C and 79 to 87 % RH. Barbuiya *et al.,* (2002) reported incubation of 5 to 7 days on rice. Yevoor (2003) observed incubation period of 5 days on maize grains at 14 to 34^{0}C and 55 to 88 % RH.

Sattigi (1982) carried out detailed work on biology of *S. oryzae* on sorghum. According to him the freshly laid eggs were white and oval shaped and became pink and opaque prior to hatching. The incubation period ranged from five to nine days and length and breadth of egg measured on an average of 0.46 mm and 0.11 mm, respectively. Bheemanna (1986) reported that eggs were laid singly inside the scooped grains. Generally only one egg was found inside the grain. Egg measured 0.341 mm to 0.0379 mm in length and 0.151 mm to 0.189 mm in width.

Insect oviposition behavior is an important contributor to the fitness of insects because of the consequent effect on the number and quality of offspring (Smith, 1986; Honek, 1993; Stejskal and Kucerova, 1996). Oviposition behavior varies according to insect species and/or strain, population density, environmental conditions, food, age, and size of the individuals. According to Fava and Springhetti (1991) *Sitophilus* females do not mark the grain, where they have laid their eggs before; therefore, they are unable to recognize the presence of eggs. Because of the careful sealing of them with gelatinous plug helps the hide of the oviposition punctures. This behavior of egg laying is surprising because it is not clear how *Sitophilus* benefits from laying more eggs in the same grains. The eggs of S. *oryzae* are opaque white and elliptical, the size is 0.665 mm in length.

2.2.3. Larval period

There are four larval instars all of which remain within the grain. Immediately on hatching, the first instar feeds by burrowing through the tissues of the grain. At the end of the fourth instar the larva uses a mixture of frass and larval secretion to close off the end of the burrow, to form a pupal cell. Under normal developmental conditions, weevil larvae allow their frass to accumulate around them inside the grain in which they are feeding. However, if the carbon dioxide level exceeds 5%, the fourth instar larva makes a small hole in the grain and ejects much of the frass. The larva then assumes a prepupal form for a short period before transforming into the pupa (Longstaff, 1981). The development time of the rice weevil is much longer at 40% RH (about 10% grain moisture) than 70% RH (about 13% grain moisture) (Pittendrigh *et al.,* 1997). Larvae developed through four instars in moist grain but sometimes entered a fifth instar in dry grain. Supernumerary moults are associated with low humidity conditions in several other insects.

Wille (1923) reported that each grain containing single grub of *S. oryzae* and total larval period ranged from 12 to 17 days during summer whereas it varied from 21 to 24 days with four moults according to Okuni (1924). Newman (1927) recorded 20 to 30 days of larval period of rice weevil and Wenholz (1927) observed three weeks of larval stage on maize. Different instars were recognized by the width of the head capsule (Nakayama, 1931). Larval period of 30 and 23.22 days were recorded on maize (Anonymous, 1933 and 1934). Treiman (1937) recorded upto four larvae in a grain which occupied 18 to 20 days to complete larval stage in rice. According to Lopez-Cristobal (1953) the larval stage ranged from 10 to 30 days. Lin (1958) in his study on biology of *S. oryzae* on stored rice in Formosa recorded the larval period of 15 to 29 days with an average of 19.20 days. Further, he also opined that the development of larva was better on rice, wheat and barley without husk as compared to the seeds of pea, tur, sorghum and maize. According to Sattigi (1982) the larval period ranged from 23 to 33 days with an average of 28 days during February to March, 1982. There were three moults and four instars on CSH-1 genotypes. Bheemanna (1986) reported larval period of 25-34 days on CSH-5 sorghum hybrid. Urrelo and Wright (1989) observed four instars of *Sitophilus zeamais* (M.) on maize at 70 % RH and temperature of 27^0C. The larval period ranged from 16 to 20 days on maize grain at 23 to 35^0C and 79 to 87 % RH (Bhuiyah *et al.*, 1990). Rice weevil *S. oryzae* when reared on maize grains the developmental period from egg to pupation was longer than on rice as studied by Pittendrigh *et al.*, (1997). Yevoor (2003) reported larval period of 27.25 days on maize grains at temperature of 14 to 34^0C and 55 to 88 % RH. Larval development takes place inside the grain. There are four larval instars. The life cycle of the weevil is 34.8 days at 27^0C and 69% RH (Sharifi & Mills, 1971).

2.2.4. Pupal period

Wille (1923) noticed 7 to 11 days of pupal period but Okuni (1924) and Wenholz (1927) recorded 5 to 20 days and 3 to 4 days, respectively. Pupal stage lasted for 5 to 12 days with an average of 5.25 days (Anonymous, 1933 and 1934). Treiman (1937) reported 5 to 7 days of pupal period when *S. oryzae* was reared on unpolished rice. The laboratory temperature and relative humidity were 27 to 28^{0}C and 96 to 95 % RH, respectively. Lopez-Cristobal (1953) opined 6 to 16 day's pupal period of *S. oryzae*. Lin (1958) observed 1 to 2 and 3 to 13 days of pre-pupal and pupal period on stored rice, respectively. The pupa resembled adult in all respects. Pupal period occupied six to nine days with an average of eight days and pre-puapl period occupied one to two days (Sattigi, 1982). Pupal period ranged from 8 to 11 days on CSH-5 sorghum genotypes (Bheemanna, 1986), while 8 to 9 days was recorded on maize by Bhuiyah *et al.,* (1990). Yevoor (2003) reported pupal period of 8 to 9 days on maize at temperature of 14 to 34^{0}C and 55 to 88 % RH.

2.2.5. Adult emergence and its longevity

The newly-emerged adult remains inside the grain for several days for its cuticle to harden (Longstaff, 1981). Adult exit holes are smaller, rounder and neater exit hole than *S. granarius*. After emergence, adult females feed on damaged grains, mate and lay eggs immediately. Adults live 4 - 12 months (Anon., 2009). Longevity on sorghum is affected by both humidity and variety of sorghum, with weevils living between 10 and 22 weeks at 28^{o}C; lifespan is significantly increased by higher humidity and softer grain varieties (Shazali & Smith, 1985). Complete development time for the life cycle of *S. oryzae* averaged 37 days (range 33-49) at 27 ± 1^{o}C, and 69 ± 3% RH (Sharifi & Mills, 1971). Optimal conditions for development of *S. oryzae* are 30^{o}C and 75% RH (Singh *et al.,* 1974). Development stops if the temperature falls below 17^{o}C (Anon., 2009). Rice weevils feign death by drawing their legs close to the body, falling and remaining immobile when disturbed, (Koehler, 2008).

Wille (1923) observed 45 days in summer, five months in cool weather of autumn and winter for completion of one generation whereas Okuni (1924) reported eight generations of *S. oryzae* in a year and the adult lived on an average for 160 days. According to Newman (1927) the adult lived for 12 months and had seven to eight generations per year as the life cycle was completed in 30 days in summer. The life cycle was completed in about a month or may be prolonged for several months under favourable conditions (Wenholz, 1927). Nakayama (1931) recorded three to four generations in a year in Korea. The total life cycle of *S. oryzae* on sorghum grain (11.80 – 12.33% moisture) averaged almost 54 days and there were six to seven overlapping generations per year. Male survived for 12 to 122 days with an average of 70.2 days and females for 51 to 122 days with an average of 83.9 days. The emerged male and female were approximately equal in number and they survived for a maximum of 19 days when enclosed without food (Lefevre, 1953). According to Lopez-Cristobal (1953) the adult survived for 15 to 30 days with food. Lin (1958) reported eight generations per year in Formosa. The adult males survived for 12 to 130 days and 1 to 139 days, respectively. The adult male and female lived for 16 to 172 and 14 to 196 days, respectively. In the absence of food the adult female lived for 9 to 17 days and male for 7 to 13 days as per the report placed on records by Sattigi (1982). Bheemanna (1986) observed adult longevity ranging from 14 to 165 and 7 to 11 days with and without food, respectively. Bhuiyah *et al.*, (1990) reported that adult longevity in male and female was 114 to 115 and 119 to 120 days, respectively when a day old adults were released into 2 kg sacks of maize. Yevoor (2003) observed that female lived for 115.76 days; male lived for 97.42 days with food. Female lived for 9.50 days; male lived for 7.32 days without food.

2.2.6. Identification of male and female

Females: Rostrum relatively long and narrow punctures along rostrum in regular rows and not touching each other.

Males: Rostrum relatively short and wide, punctures along rostrum large & irregular, not in rows, and often touching each other (Walker, 2008b; Halstead, 1963). The snout of the male is shorter and broader than that female.

2.3. Nature and extent of damage

Rice, wheat, barley, sorghum and other raw or processed cereals such as pasta, but not uncompacted products *Sitophilus* spp. have been reported to prefer large seeds for oviposition; large seeds are more likely to be parasitized or contain multiple eggs (Anon., 2009; Campbell, 2002). *S. oryzae* is a common contaminant of processed animal foods but will breed only when whole grains are present and when grain moisture is between 10% and 16% (Longstaff, 1981). Rice weevils are pests of stored grain and seeds. They develop inside whole grain kernels as small, white, wrinkled, grub-like larvae. There is generally no external evidence that the larvae have been eating and growing inside the seed until after about one month when the adult weevil chews through the seed coat and emerges. Rice and granary weevils are harmless to people, houses, furniture, clothing and pets. They cannot bite or sting and they do not carry diseases. They will not feed on furniture, the house structure or other items. The harm they do is destruction of the seeds they infest.

2.4. Origin and distribution of rice weevil

S. oryzae originated in India and has been spread worldwide by commerce (Koehler, 2008). It is common in tropical environments, but is also established in temperate environments due to changes in transportation and storage of rice (Anon., 2009). It is only able to survive winters in colder areas if it has become established in heated situations. It is not successful in regions with very high summer temperatures and is often displaced in hot, humid areas by the closely related *S. zeamais* (Longstaff, 1981). Adults may fly and are attracted to lights (Anon., 2009; Koehler, 2008). They may also walk great distances inside warehouses and bulk grain storages. Weevils from infested grain may become entrained in a product stream prior to packaging in processing plants, and may be carried in or on packaging materials such as boxes and pallets. Kiritani (1965) reported that Japanese *S. oryzae* lacks the ability to fly. Temperature and light intensity are among the major factors inducing flying activity in *S. oryzae*. In the United States, peak flying activity has coincided with the time that maize in the field attained a moisture content of 65%, permitting oviposition. Flight activity generally occurs during the warmer part of the day (Longstaff, 1981).

2.5. Alternative management of rice weevil

Control of storage pests by using synthetic chemicals has become a common practice among the farmers and stockholders. It is now widely known that the chemical method has several problems, which include health hazards to the users and grain consumers. It causes residual toxicity, environmental pollution and development of pesticide resistance. On the other hand, the traditional method of controlling storage pests by sun-drying is safer to human health and environment. But this method is laborious, time consuming, often expensive and requires suitable drying yard, when large volume of storage grain, is involved. Moreover, it depends on favorable weather condition. Recently, the use of different plants and their derivatives has appeared as an effective alternative to the use of poisonous chemical insecticides or the cumbersome traditional methods for the control of various insect pests of crops and storage.

Literatures on some of such studies relevant to the present study collected from various sources including Bangladesh were reviewed here in brief.

2.5.1. Botanicals for the management of rice weevil

Botanical insecticides composed of essential oils may prove to be a reasonable alternative to the more persistent synthetic pesticides (Chiasson *et al.,* 2004). It has also provoked undesirable effects, including toxicity to non target organisms and fostered environmental and human health concerns (Lee *et al.*, 2001).

Salama (2008) observed the leaf extracts of three ornamental plants, *Myoporum pictum*, *Pittosporum tobira* and *Thevetia peruviana*, used as seed protectants, were tested for their efficiency in controlling two stored product insects, the rice weevil, *Sitophilus oryzae* (Coleoptera: Curculionidae), and the pulse beetle, *Callosobruchus maculatus* (Coleoptera: Bruchidae). *M. pictum* was the most efficient in controlling both insects as depicted by its LC< sub>50</ sub> and LC< sub>90</ sub> values when used either as leaf powder or organic solvent extracts. *T. peruviana* was the least efficient among the test plants, as it had no toxic effect on *S. oryzae* when used in powder form. *C. maculatus* was generally more sensitive to the *M. pictum* extracts than the *S. oryzae*. The chloroform extract of *M. pictum* more effective than the other extracts of this plant in controlling both insects. *P. tobira* petroleum either extract showed higher efficiency than that its chloroform extract. Generally, extraction by n-hexane or acetone exhibited the lowest efficiency against both insects. *M. pictum* had the longest residual effect when used in powder form and as extracts especially when chloroform was used as the solvent. *T. peruviana* showed a relatively low bio-residual activity especially when tested on *S. oryzae*.

Sunil Kumar (2003) studied that neem leaf powder at 1 percent dosage was not effective in protecting the sorghum grains after 30 days after storage against *S. oryzae*.

Valsamma and Patel (1992) tried the neem leaf powder (10%) against pulse beetle, *C. analis* on green gram and reported that at 30 and 60 days after treatment, the seed damage was 4.3 and 4.8 per cent as against 9.7 and 22.8 in untreated control. The neem leaf powder used at (5%) five percent (w/w) to protect green gram against pulse beetle *C. analis* revealed 7.5 percent adult mortality after three days of release when compared to 100 per cent mortality in the untreated control (Juneja and Patel, 1994).

Sharvale and Borikar (1998) evaluated the neem leaf powder against *C. chinensis* in chickpea and observed that the adult mortality after 48 hours of release was 1.25 percent with a weight loss of 10.78 per cent after 20 days. Rajapakse *et al.,* (1998) evaluated the neem leaf powder at 2.5, 5.0, 7.0 and 10 percent against *C. maculatus* infesting cowpea. Mean mortality after two DAT was 0.3, 0.25, 0.2, 0.3 and at four DAT mean mortality was 3.10, 3.50, 3.25 and 3.0 per cent, respectively.

Chander *et al.,* (1991) conducted laboratory studies to evaluate the efficacy of turmeric powder and mustard oil as protectants for milled rice against *S. oryzae* Linn. They observed that turmeric powder alone did not because significant mortality except at 2 or 4% concentration after 3 months storage interval. Mustard oil at 4 or 8 ml/kg dosage gave appreciable mortality of *S. oryzae* at all storage intervals. One or 2 ml/kg dosage reduced *S. oryzae* progeny by 40% even after 6 months of storage. The 4 ml/kg dosage of Mustard oil combining 1 - 2g of turmeric powder gave the best protection efficacy. Su (1991) reported that essential oil of *Chenopodium ambrosoides* was moderately toxic to *S. oryzae* (52.5% mortality at 50 mug/insects).

Singh *et al.,* (1989) observed that volatile oil of *Pinus longifolia* reduced the population of *S. oryzae* up to 37.51, 75.21 and 86.82% compared to control at 30, 60 and 90 days after application, respectively. *Mentha citrata* oil showed significant toxicity when applied to stored wheat grain but the effect lasted for only 30 days. Oils of coconut, groundnut and the African palm admixed with maize at the rate 5 and 10 ml/kg killed 67 - 100% of adults of *S. oryzae* within 24 hours. At 1ml/kg, 100% mortality of adults was observed after 7 days. The oils significantly reduced the oviposition and development of the progeny of weevils. All oils prevented infestation for more than 90 days (Ivbijaro *et al.*, 1985). Root bark powder of *Celastrus angulatus* and *Tripterygium wilfordi* admixed with rice grains at 0.5% found protecting the infestation of *oryzae* by 90% (Zhang and Zhao, 1983).

Jilani and Su (1983) indicated the repellent activity of neem leaf powder to *S. granarius* and *R. dominica* on wheat seeds. It was reported that the average number of *R. dominica* adult emergence was 3.08, 5.16 and 20.16 with neem leaf powder used at 2.0 and 1.0 per cent and untreated control, respectively. This repellent activity of neem leaf powder was supported by Banarjee and Nigam (1985).

Malik and Naqvi (1984) reported that reduced adult emergence of *C. chinensis* when they mixed the leaf and seed powder of neem, nishinda and dutura with cowpea, mungbean, blackgram, chickpea and lentil. Das (1986) studied on the pesticidal properties of the oils of neem, coconut, sesame, mustard or soybean mixed with pulses and found that all *C. chinensis* adults died after four days of release into treated foods. He also reported that neem oil was found to be superior to til oil for its protectant activity. He checked the weight loss of treated seeds of khesari, lentil and chickpea. No adverse effect on the germination of the oil treated seed was observed.

Karim (1986) reported that local botanicals like dholkolmi *(I. sepiara)* and dutura *(Datura fastuosa)* were found very effective in killing on an average about 88 % of the hispa adult at 48 hours after application. Singh (1987) evaluated six plant extracts against *R. dominica* in the laboratory, extracts of neem, *Azadirachta indica, Bassia longifolia* and *Pongamia glabra* were highly toxic. The crude extract of water hyacinth *(Eichhornia rassipes)* was evaluated for its biological activity against the *T. castanium. S. oryzae, Callosobruchus maculates* and *C. cephalonica.*

Rani and Jamil (1989) mixed crude extracts of water hyacinth, *Eichhornia crasipes* with the larval diet of *T. castanium, S. oryzae. C. maculatus* and C. *cephalonica* and found that the extracts caused mortality of the larvae of *S. castaneum* and *C cephalonica at 4th* instar. Insects exposed to surfaces treated by crude extract showed high mortality of adults of *C. maculates.* Srivastava *et al.,* (1989) reported that, *M. arvensis; Cymbopogon martini; Eucalyptus globules* and *C. winterianus* were most effective for the control of *C. chinensis* on arhar, *Cajanus cajan.*

Sharaby (1989) did an experiment of sun-dried guava and *E. globules* for evaluating their repellency and toxicity to *S. oryzae* and *S. granaries* under laboratory conditions. The experiment showed that LC_{50} of sun-dried guava and Eucalyptus leaves admixed with rice grains against *S. oryzae* were 2.251 and 4.140g leaves /100 g rice grains against respectively, while they were 2.278 and 4.857 g leaves/100 g rice grains respectively in case of *S. granaries.*

Adgesh and Rejesus (1991) reported that oils and powders form neem, lagudi *(Vetex negundo)* mixed with grains at different storage intervals for 180 days effectively controlled the emergence of adults of *Sitophilus garnarius, Sitophilus oryzae,* *Rhizopertha dominica* and *Callosobruchus chinensis* and maintained viability of the seeds. Niber *et al.,* (1992) tested plant extracts *(A. indica, Ricinus communis* and *Solanum nigrum)* for their toxicity to three species *(Acanthoscelides obtectus, Prostephanus tuncatus* and *Sitophilus oryzae)* under laboratory condition. Crude ethanol extract at concentration at 10 % (w/v) were used ad topical application.

The effects of the plant extracts were compared with those of three extracts and the crude materials were most toxic to the three pest species. Ryoo and Cho (1992) carried out an experiment and found that exposure of first instar nymphs of *Dysdercus koenigii* between 24 and 48 hours old in Eucalyptus oil odor for 2 hours resulted in greater mortality in the 3rd instar.

Sharaby (1992) studied on the effects of powdered guava and eucalyptus leaves admixed with rice grains on adults of *S. oryzae* and *S. granaries.* Guava was found rather more toxic (LD_{50} value about 2.2g /100g rice grains in each case) than the eucalyptus (LD_{50} value about 4.1- 4.6g). Sub-lethal doses above the LD_{50} value suppressed the development of progeny sat doses 15 g rice grains.

Kashyap *et al.,* (1992) determined the efficacy of powdered dry leaves of *V. negundo, Ageratum haustorianum, Mentha longifolia, Cinnamomum tamala, Cannabis sativa, Lantana camara, Murraya koenigii* and *Eucalyptus sp.* in controlling *Phthorimaea operculella* on stored potato. They found *A. haustorianum, V. negundo M. longifolia* protected potatoes for up to 120%.

Khalequzzaman and Islam (1992) stated that various extracts of leaves of *Datura metel* were tested for their effects on 2 stains of *Tribolium castaneum* when applied topically, all extracts were toxic to the pests, a methanol extracts was the most toxic. Azmi *et al.,* (1993) observed in laboratory studies that the toxicity of a compound containing 10 % cyfluthrin (Slofac) and a neem formulation containing crude extract from ripe berries of *Azadirachta indica* against *S. oryzae* was determined. The tests were carried out by releasing the curculionids on treated filter papers treated with different concentration of the compounds. A mortality rate of 90 % was obtained with a 0.5 % conc. of cyfluthrin and a 1 % conc. of the neem compound.

Porkash *et al.,* (1993) observed that twenty plant products were evaluated against *Sitophilus oryzae.* Only seven products significantly reduced adult populations and weight loss of grain. Neem seed oil was the most effective, followed by *Piper nigram* seed powder, leaves of *Vitex neganda,* leaves of *Andrographis paniculata,* dried mandarin fruit peel, rhizome powder of turmeric and seed powder of *Cassia fistula,* respectively. Dey and Sarup (1993) tested eight vegetable oils viz. mustard, soybean, coconut, neem, groundnut, cotton, sesame and castor at 5 doses against adults of the stored product pests, *Sitophilus oryzae,* in three varieties of stored maize in India and showed that weevil mortality as highest one day after treatment.

Sarac and Tunc (1995) reported that oil of *Pimpinella anisum* caused 95% mortality of *T. Confusum* and *S. oryzae* within shorter exposure. Oils of *Tuymbra spicata* and *Satureja thymbra* showed higher toxicity only to *S. oryzae.* Hiremath *et al.,* (1997) tested methanol extracts of 84 samples of 49 Indian plants species for insecticidal activities against *Nilaparvata lugens* by topical application method at a dose of 0.5µg/female. The identified significant and toxic plants species were *Adahota vasica* leaves (100% mortality), *Annanosa squamosa* seeds (100%), *Nerium indicum* stems (100%), *Clerodendrum inerme* whole plants (90%), *Azadirachta indica* seeds (89%), *Azadiracta indica* stems (85%) *Aegle marmelos* leaves (88%) and *Madhuca indica* seed oil (88%).

Sahayaraj and Paulraj (1998) carried out an experiment in the laboratory study to evaluate the effect of water extracts of different plant leaves in insect pest control.

Various concentrations of the extracts (0.5, 1, 2, 4, and 6%) were used against last instar larvae of the groundnut pest *Spodoptera lotura. Calotropis gigantean* was found to be the most toxic plant product followed by *Vitex nigrndo, azakirachta indica* and *Pongamia glabra (P. pinnata).* Rahman (1998) evaluated the extracts and dust of Urmoi, Neem and Turmeric for their repellency, feeding deterrence, direct toxicity, residual effects and their potentiality against the rice weevil (*S. oryzae)* and grain weevil (*S. granaries).* The results showed that 100. 75, 50 and 25 mg/ml extracts of all three plants had repellency, deterrency and direct toxicity effect. Ethanol and acetone extracts were more effective than water extracts. The emergence of F_1 progeny, seed damage rate, percent weight loss and inhibition rate of two weevil species reduced significantly in almost all treatments compared to control reduction was significantly dose dependent.

Perveen *et al.,* (1998) mithanol extracts of two indigenous plants, *Calotropis gigantean* Linn. (Akando) and *Ipomoea nil* Linn (Kaladanah) *[Pharbitis nil]* were examined for their toxicity against the adults of *Sitophilus oryzae* Linn, *Tribolium castanium* Herbst and *Cryptolestes ferrugineus* (Stephens) after 24 hours of treatment. The $LD5_0$ of *C. gigantean* and *P. nil* for the mortality of *S. oryzae, T. castaneum and C. ferrugineus* were 0.418, 0.420, 0.206 and 0.357, 0.422, 0.143 mg/ cm^2, respectively. *C. ferrugineus* was more susceptible to *C. gigantean* and *P. nil* than *S. oryzae* and *T. castameum.*

Imtiaz *et al.,* (2001) observed the effects of neem leaf extracts on adult rice weevil, *Sitophilus oryzae.* Glass film method was adopted to determine the L_c 50 rate. After plotting a graph between mortality and concentration, the L_c 50 was found to be 0.44µg/sq. cm.

Several indigenous plant materials have traditionally been used as stored grain protectants against insect pest in various parts of the world. Neem seed powder @ 5 per cent caused cent per cent mortality of rice at 7 days after beetle release and weight loss was nil during 90 days of storage as per the observations placed on records by Sivasrinivas (2001). Mahanti (2002) reported that neem seed powder at the rate of 2 g per kg of maize seed caused 100 per cent mortality of *S. oryzae* at 10 days after beetle release and reported that neem seed powder @ 1 per cent showed less per cent of seed damage of 5 to 10 per cent from 30 to 60 days after storage (Sunil kumar, 2003). Yevoor (2003) recorded zero per cent grain damage and weight loss 90 DAS and per cent mortality 60 DAS in this work, the application of sub-lethal dose of neem oil-based pellets.

Bowry *et al.*, (1984) reported that oils and seed cake powders of neem, linseed, castor, mahua and mustard showed repellent action on *Sitophilus oryzae.* The neem preparation was most effective in reducing oviposition and linseed extracts.

Long term studies were carried out in Poland on the stored grain pest *Sitophilus granarium* and on the behavior of the pest was tested with 54 extracts from 28 plant species for their repellent activity. The most effective repellent was found in Caraway extracts, the main component of which is carvone (Nawrot, 1985). Ahmed and Eapea (1986) screened plant extracts and found that those from Gaultheria, dill *(Anethus graveoleus),* Japanese mint *(Mentha sp.)* and Eucalyptus and cineole and turpentine were promoting and strong repellent against *Sitophilus oryzae* and *Callosobruchus chinensis.*

Saxena (1986) reported that plant such as neem is important for their insect repellent properties in addition to other plant processing insecticidal and growth regulating properties. Das and Karim (1986) reported that neem oil was used as an effective surface protectant of pulses in storage. They found that treated seeds were not infested after storage for 5 months by *Callosobruchus chinensis.* Das and Karim (1986) treated grasspea, *Lathyrus sativus*; chickpea, *Cicer arietinum* and lentil seeds with neem seeds oil at 4ml/100g seeds and found that treated pulses were remained uninfested after storage for 5 months.

Jilani (1986) conducted experiments with ethanolic extract of neem seed; hexane extract of sweetflag, Acorns calamus rhizome and thymel applied to *T castaneum, R. Dominica, S. oryzae* and *S. cereallela* in wheat grain and observed significant control of the insect infestation.

Mixing of kernel powder at one to two parts of seed protected wheat seeds from *S. oryzae* for at least 269 days (Jotwani and Sircar, 1965). Deshpande (1967) investigated that neem seed powder at two per cent was effective in protecting jowar grains against *S. oryzae*. Seed powder at 1.00 per cent and 2.00 per cent reduced oviposition of adult rice weevil (Girish and Jain, 1974). Ketkar (1976) reported that seed powder at 0.5 per cent of grain reduced *S. oryzae* population. Chander and Ahmed (1983) reported that neem leaf powder at 5 per cent (w/w) protected the wheat seeds against *S. oryzae* infestation for three months.

Mishra *et al.,* (1992) reported that seed powder at 0.5 per cent (w/w) retained its effect for longer duration causing 100, 96.70, 83.30 per cent adult weevil mortality at 30, 60 and 75 days after treatment. Neem seed powder at 0.5, 1.00 and 2.5 g per kg of maize seeds recorded cent per cent mortality within five days after treatment and protected seeds for six months without affecting the seed viability. Neem seed kernel powder at 2 per cent (w/w) was found effective in protecting maize seeds against *S. oryzae* for two weeks (Sharma, 1995).

Kalasagond (1998) noticed the mortality of *S. oryzae* at 60, 120, 180 and 240 days after treatment with 0.8, 1.0, 1.2 and 1.4 per cent neem seed powder in wheat grains were 25.00, 8.33, 8.33 and 6.66 per cent, 43.33, 26.66, 25.00 and 8.33 per cent, 51.66, 41.66, 35.00 and 10.00 per cent, 61.66, 53.33, 43.33 and 26.66 per cent, respectively as against 0.00, 0.00. 6.66 and 5.00 in untreated control.

Rama Rao and Sarangi (1998) reported neem seed powder (5%) as a effective grain protectant against *S. oryzae* with 87.70 per cent mortality which reduced to 82.50 per cent from 30.00 to 90.00 days after treatment. Neem seed kernel powder @ 4 per cent when mixed with maize grains effectively protected the grains for 5 months against *S. oryzae* attack (Sharma, 1999).

Sanguanpong (1996) formulated various essential oils and volatile substances were explored based on insecticidal properties and non-direct contamination method for protecting rice grain damage caused by rice weevil. Their biological activities against *Sitophilus oryzae* such as feeding deterrence, reproductive inhibition and progeny development disrupting were determined.

Ahmed and Eapea (1986) screened some essential plant extracts and found that gaultheria, dill *(Anethum graveoleus),* Japanese mint *(Mentha),* eucalyptus, cineole and turpentine were promising as strong repellents against *S. oryzae* and *C. chinensis.*

Saim and Meloan (1986) tested fifteen volatile compounds found in leaves of *Laurus nobilis* and crushed bay leaves for their effectiveness as repellents against the adults of *T. castaneum* and reported that when the bay leaves were added to wheat flour, they act as repellent as were in 3 compounds like benzaldehyde, piperidine and geranilol.

Tanzubil (1987) applied neem fruit dust, leaf dust and seed kernel oil on stored seed and observed that neem fruit dust at 10%, protected seeds for at least 4 months. Neem seed kernel oil also gave effective control. In a study, eucalyptus powder mixed with rice was effective in reducing the number of adults of *S. cerealella* and prevented cross infestation by *R.* dominica (Dakshinamwithy, 1988). Su (1989) treated wheat with dill seed extract and found that it reduced the F_1 adult emergence of *S. oryzae.* Jilani and Saxena (1987) observed that neem, turmeric and sweetflag have repellent action on stored grain pests.

Bhuiah and Quinones (1990) treated the corn with leaf powder of biskatali and found effective on oviposition and adult emergence of *S. zeamais.* Adgesh and Rejesus (1991) observed the residual toxicity by the admixture treatment of oils and powders from neem, lagundi, *V. negundo against S. zeamais, R. dominica* and *C. chinensis* on stored grains.

Talukder and Howse (1994 and 1995) reported that the seed extracts of *Aphanamixis polystachya* had strong repellent effects on red flour beetle and rice weevil. Hussain (1995) studied that the extracts of *Ploygonum hydropiper* and *Annona squamosa* were repellent effect to adults of *T. castaneum.* Katker (1989) evaluated different oils of neem, coconut and castor against the Bruchid on green gram. He reported that neem oil was the best protectant giving complete protection at 0.75 and 1% even after 150 days of storage.

Makanjuloa (1989) investigated the activity of neem leaf and seed extracts and found that all of the extracts significantly reduced the oviposition, egg hatching and adult emergence of *C. maculatus* and only adult emergence of *S. oryzae.* Xu Hanhong and Zhao Shanhuan (1994) reported that cassia oil mixed with wheat flour completely inhibited the reproduction of *S. zeamais, R. dominica* and *T. castaneum.* Sharma

(1995) tested that neem leaf powder and cob ash to find out their efficacy on stored maize. Both the tested compounds at different dosages were effective in reducing grain damage percentage ad adult emergence of *R. dominica.*

Talukder and Howse (1994 and 1995) mixed leaf, bark and seed powders of pithraj with pulses, wheat grains and wheat flour and observed that the treated food effectively reduced the oviposition rate, egg hatching rates, emergence of F_1 adults of *C. Chinensis, S. granarius* and *T. castaneum.*

The repellency and toxicity of *Azadirachtin* and 3 neem extracts to 3 stored product insects, *Cryptolestes ferrugineous, S. oryzae* and *T. castaneum* investigated by Xie *et al.,* (1995), when *T. castaneum* was more sensitive to the repellent action of neem than the other 2 species. Igantowicz and Wesolowska (1996) confirmed and compared the repellency of several plant powders against three species of stored product pest *(C. chinensis, S. oryzae* and *S. granarius)* and reported that the powdered seed kernels of neem, *A. indica* were more effective as repellents than the powders of dry leaves and seed shells; they further reported that the repellency of neem products increased with the increase of the concentration of the product and 5% concentration by weight, was the most effective.

Igantowicz (1997) reported that powdered aerial parts of the ribbed melilot (*Melilotus officinalis*) and the white melilot (*M. albus*) were found to be strongly repellent to *Sitophilus grainarius, S. oryzae* was repelled only by high doses (25%) of these powders. Coumarin, a characteristic and volatile constituent of melilots, is thought to produce the repellent effect against weevils. Khan and Shahjahan (1998) reported that dried powdered *Eucalyptus teretocornis* leaves were extracted with n-hexane, acetone, ethanol and methanol and the extracts were tested to observe their effects on adults of *Sitophilus oryzae* and *C. chinensis.* Results showed that in *S. oryzae* was repelled and *C.*

chinensis was attracted by all the extracts. The percentages of repulsion for *S. oryzae* were 71.1, 74.7, 69.0 and 63.3 respectively.

Rahman *et al.,* (1999) reported that the extracts of urmoi *(Sapium sebiferum* L.) neem, *(Azadirachta indica, A. fuss),* and turmeric *(Curcuma longa* L.) were evaluated for their repellency against the rice weevil, *S. oryzae* L. and the granary weevil, *S.granarius* L. in the laboratory. The results showed that 100, 75, 50 and 25 mg/ml extracts of all the three plant had a repellent effect. Ethanol and acetone were found to be better solvents for extracting greater amounts of toxic component from seeds and rhizomes. Significant positive correlation was found between extract concentration and insect response. Urmoi and neem were almost similar in their effectiveness. However, the potency of turmeric decreased more rapidly than that of neem and urmoi due to higher volatilization of the active components in turmeric.

Jilani (1986) conducted experiments with ethanolic extracts of Neem, seed hexane extract of Sweet flag, rhizome and thymol applied to *T. castaneum; R. dominica; S. oryzae* and *S. cereallela* in wheat grain and observed significant control of the insect infestation. Rouf *et al.,* (1996) investigated the toxicity of the leaf powder of neem, nishinda, and biskatali and their combinations to *C. chinensis* on lentil seeds; they observed that 4g of bishkatali leaf powder/50g of lentil seeds was the most effective in reducing oviposition, adult emergence, damage of seeds by the pest and seed weight loss the combination of neem and bishkatali leaf powder ranked second followed by neem leaf powder alone. At low doses (1 - 2g) these 3 plant materials applied either alone or in combination were found to be less effective, germination of lentil seeds was not affected by bishkatali leaf powder. Application of the plant materials at intervals of 15 days up to 2 months storage did not give better protection of lentil seeds than a single application only. Singh *et al.,* (1996) studied the effects of extracts of Neem.

A. indica, Garlic *Eucallyptus hydrida, L. camara* and *V. negundo* against *R. dominica* on wheat in the laboratory. *A. indica, L. camara* and *V. negundo* were the most effective to adult and reduced grain damage (number basis and weight basis).

Sharma (1999) reported that neem seed *(Azadirachta indica)* kernel powder (nskp) used at 4% and neem leaf powder (npl) used at 5% protected maize for 5 months against *Sitophilus oryzae, Sitotroga cerealella, Rhyzopertha dominica and Trogoderma granarium,* neem oil (nimbeidine.1%) was toxic to the adults of *Sitophilus oryzae, R. dominica, Trogoderma granarium, Sitotroga cerealella* and *Tribolium castaneum.* Neem oil (nimbecidine, 2%) effectively reduced the emergence of F_1 and F_2 progeny of all the pests and completely protected maize up to 9 months. It is suggested that neem products can be mixed with stored maize to protect the grains up to 9 months from the attack of these major pests.

2.5.2. Fumigants for the management of rice weevil

Phostoxin

Stoyanova and Shikrenov (1983) reported that Phosphine preparations (Phostoxin and gastoxin) against rice weevil of stored wheat at the rate 6 and 10 tablets/ton caused 100% mortality. Yadav (1983) advised 1.75 to 3.5g/1000 kg seed dose of aluminium phosphide fumigant with an exposure of 4-5days for effective control of *S. oryzae*. Laboratory study revealed that Ethylene dichloride was the best compound and carbon tetrachloride was the least effective against rice weevil (Chandra *et al.*, 1978). Cotton (1963) reported that carbon disulphide was six times more toxic than carbon tetrachloride against *S. oryzae*. Complete mortality of larvae of rice weevil was achieved by using 1-3 aluminium phosphide tablets/ton for 15 days (Rai *et al.*, 1963).

Camphor

Latif *et al.,* (2005) conducted a study to evaluate the toxicity of camphor against different stages of rice weevil, *Sitophilus oryzae* L. (Curculionidae: Coleoptera) in parboiled polished rice grains revealed that there exists a very sharp difference among the different stages of the insect and exposure durations in respect of the toxic .action of camphor. The LD_{50} camphor against adult, egg, larva and pupa was the lowest (1.3316 mg, 1.152 mg, 6.1399 mg and 8.1093 mg respectively) at the 96 h exposure while it was the highest (4.204 mg, 3.7954 mg, 10.6040 mg and 18.9371 mg respectively) at the 24 h exposure.

Weaver *et al.,* (1995) stated that volatile components of dried leaves or *Artemisia tridentata* (Nutt.) and *Monarda fistulosa* L. were terpenoids with camphor, (9.7 mg/g) and 1,8-cineole (4.0 mg/g) but abundant in *A. tridentata* and carvacrol (26..3 mg/g) largely available in *M. fistillosa*. Both plant species were less effective against the rice weevil in wheat. The maximal control achieved against *S. oryzae* was less than 50% at 3% w/w.

According to Abivardi (1976), adults of *Bruchus lentis*, *B. rufimanus, B. pisorunt, Callosobruchus chinensis, Sitophilus granarius* and *S. oryzae*, larvae of *Plodia interpunctella* and adults and larvae of *Trogoderma granarium* and *Tribolium confusum* were exposed to camphor (1,7,7 trimethylbicyclo (2.2.1) heptanc 2 one) at 5 concentrations in air tight containers in the laboratory. The result showed that the last 5 species were not controlled; there was 100% mortality *of B. lentis*, *C. chinensis*, *B. rufimanus* and *B. pisorum* at 12, 24, 48 and 96 ppm, respectively.

Rozman *et al.,* (2006) found that camphor acted as fumigant caused 100% mortality to *Cryptolestes pusillus* at a dose of 1 µl /7.2ml vol. Latif *et al.,* (2009) stated that Wheat seeds were stored in four types of containers (Tin kouta, earthen pot, plastic container and gunny bag) with two types of chemicals (Naphthalene and camphor) and two indigenous materials (neem leaf powder and sand). Among the different containers, the lowest population of grain moth (1.40-7.93), red flour beetle (6.40-35.33) and rice weevil (0.20-9.13) was recorded from the plastic containers. At the initial stage of storage, grain moth was dominant but red flour beetle was abundant at the middle and later stage of storage. Population of rice weevil was gradually increased with storage period. Considering the storage materials, the lowest population of grain moth (3.92-28.98), red flour beetle (7.58-43.08) and rice weevil (0.75-9.08) was found in naphthalene. Camphor had the similar population level of those three insect pests during the study period.

Abivardi and Benz (1984) reported that camphor is a natural component of essential oil having very low mammalian toxicity. It was found highly effective against rice weevil as well as maize weevil (Latif and Rahman, 2000).

Naphthalene

Naphthalene also known as naphthalin, is a crystalline, aromatic, white, solid hydrocarbon with formula $C_{10}H_8$ and the structure of two fused benzene rings. It is volatile, forming a flammable vapor, and readily sublimes at room temperature, producing a characteristic odor that is detectable at concentrations as low as 0.08 ppm (Amoore and Hautala, 1983). The most familiar use of naphthalene is as a household fumigant, such as in mothballs. In a sealed container containing naphthalene pellets, naphthalene vapors build up to levels toxic to both the adult and larval forms of many moths that attack textiles (Bryn, 2002) and other stored cereals.

CHAPTER III

MATERIALS AND METHODS

The study was conducted to explore the efficiency of easily available some botanicals and fumigants for eco-friendly management of rice weevil (*Sitophilus oryzae* L.) in the laboratory of the Department of Entomology, Sher-e-Bangla Agricultural University (SAU), Dhaka during the period of September 2011 to February 2012. The study was conducted under following two separate experiments.

Experiment 1: Efficacy of some botanicals for the management of rice weevil (*Sitophilus oryzae* L.) in stored rice

Experiment 2: Efficacy of some fumigants for the management of rice weevil (*Sitophilus oryzae* L.) in stored rice

The details of the procedures for two experiments have been described considering the following sub-headings:

Experiment 1: Efficacy of some botanicals for the management of rice weevil (*Sitophilus oryzae* L.) in stored rice

This experiment was conducted to evaluate the efficiency of five botanicals viz. dried neem, bishkatali, marigold, dholkolmi and mehogoni leaves against rice weevil (*Sitophilus oryzae* L.) infesting stored rice in the laboratory condition. The detail procedure of the experiment has been described below:

3.1.1. Design of the experiment

The experiment was laid out in the ambient condition of the laboratory considering Completely Randomized Design (CRD) and the treatments were replicated four times for each.

3.1.2. Materials used in the study

Twenty four kg of stored rice (BR 28) were purchased and collected from the Agricultural Farm of Sher-e-Bangla Agricultural University, Dhaka. Collected stored rice (BR 28) were kept in 24 plastic pots maintaining one kg per pot and then these pots were kept in ambient room temperature in the laboratory under the Department of Entomology of Sher-e-Bangla Agricultural University.

3.1.3. Treatments

The five promising botanicals viz. dried leaf powders of neem, bishkatali, marigold, dholkolmi and mehogoni were evaluated in this experiment, where each botanical was treated as an individual treatment. Besides these botanicals, one untreated control was also considered. The treatments and their doses selected for the experiment have been furnished below:

Treatments	Botanicals	Dose of the botanicals
T_1	Dried neem leaf powder	2.5 gm /kg stored rice
T_2	Dried bishkatali leaf powder	2.5 gm /kg stored rice
T_3	Dried marigold leaf powder	2.5 gm /kg stored rice
T_4	Dried dholkolmi leaf powder	2.5 gm /kg stored rice
T_5	Dried mahogoni leaf powder	2.5 gm /kg stored rice
T_6	Untreated control	No botanicals were used

3.1.4. Collection and preparation of botanicals

The leaves of neem, bishakatali, marigold, dholkolmi and mehogani were collected from the campuses of Jahangirnagr University and Shere-e-Bangla Agricultural University in September 2011 to February 2012. The leaves were then directly sun dried on metal tray for 5 consecutive days until completely dried up. Each type of dried leaves was then grounded separately with the help of an electric grinder. Before grinding, the grinder was cleaned carefully for each type of plant leaves to avoid contamination. Each type of powdered leaf was then taken into a separate plastic pot and stored in cool dry place for use in the experiments.The brief description of the collected botanicals are is given below:

3.1.4a. Neem leaf

Neem (*Azadirachta indica, A. juss*) is a perennial plant belongs to the family Meliaceae. It is famous for its medicinal properties. The major active constituent is azadirachtin, which is well known for its antifeedant, toxic and growth regulating effects on insects (Saxena, 1989; Schmutterer, 1990; Mordue and Blackwell, 1993). It has been an age-old practice in rural areas of Bangladesh to mix dried neem leaves with stored stored rice to control stored-stored rice insects. A variety of preparations based on neem extracts have been tested against stored product insects. Azadirachtin-rich commercial "Margosan-O" is already produced in developing countries for controlling pests. However, neem compounds are too complex to be synthesized for practical purposes (Jacobson 1986).

3.1.4b. Biskatali leaf

The biskatali, *(Polygonum hydropiper)* is shrub type plants belongs to the family of polygonaceae. It is a medicinal plant and also used to control insect pests as repellent, antifeedant and toxic materials.

3.1.4c. Marigold leaf

The Marigold *(Tagetes erecta)* belongs to the family of Asteraceae or Compositae. It is an ornamental plant and also used to control insect pests as repellent, antifeedant and toxic materials.

3.1.4d. Dholkolmi leaf

The Dholkolmi (*Ipomoea carnea*) belongs to the family of *Convolvulaceae*. It is a weed and also used to control insect pests as repellent, antifeedant and toxic materials.

3.1.4e. Mahogany leaf

The Mahogany *(Cercocarpus ledifolius)* belongs to the family of Rosaceae. It is big tree. Seeds and leaves are also used to control insect pests as repellent, antifeedant and toxic materials.

Plate 1. Neem leaves (left) and dried neem leaf powder treated rice (right) on a plate

Plate 2. Bishkatali leaves (left) and dried bishkatali leaf powder treated rice (right) on a plate

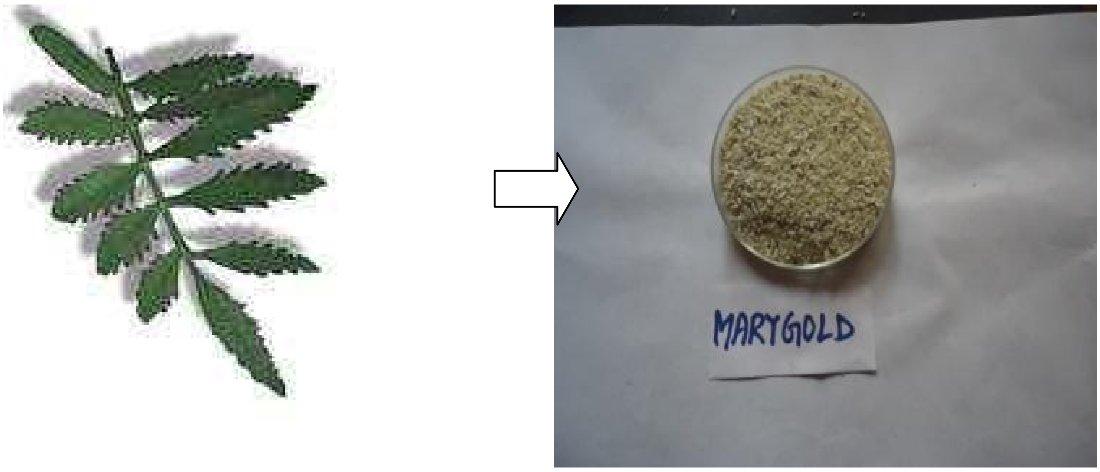

Plate 3. Marigold leaf (left) and dried marigold leaf powder treated rice (right) on a plate

Plate 4. Dried dholkolmi leaves (left) and dried dholkolmi leaf powder treated rice (right) on a plate

Plate 5. Dried mahogany leaves (left) and dried leaf powder treated rice grain (right) on a plate

3.1.5. Application of the botanicals

The 2.5 gm (0.25% w/w) of the grounded powders of the dried neem leaves were thoroughly mixed with 1 kg of the rice seeds that were already kept in a container of the plastic pot. Similarly, the rest 3 containers of the plastic pot for neem leaf based treatment were thoroughly mixed with 2.5 gm of the grounded powders of the dried neem leaves in each container containing one kg of selected rice grains. Similar procedures were also followed with same doses (2.5 gm) of grounded powders of the bishkatali, marigold, dholkolmi and mehogany leaves for each container under the experiment for used of four replications. No botanicals were mixed in rest of four containers of each category that were also kept one kg of selected rice grains as untreated control treatment of the experiment.

3.1.6. Release of the rice weevil, *S. oryzae*

The newly hatched adult of rice weevil collected from the laboratory of the Department of Entomology of Sher-e-Bangla Agricultural University, Dhaka were release in the rice grains kept in plastic containers assigned for each treatment. About 500 newly hatched adult of rice weevil were released on the stored rice kept in each container. Immediately after the release of the adult rice weevil, each container was covered with its lid. The plastic containers with rice grains for each treatment were preserved in ambient temperature of the laboratory 150 days after adult release (DAAR) for recording data.

3.1.7. Data sampling

The data on stored rice infestation by number and weight, larval survibilities of rice weevil, and pupal survibilities of rice weevil were recorded. The data were collected and recorded at 30 days intervals started from 30 DAAR and continued up to 150

DAAR considering the sampling procedure. For each sample, 100 rice grains from each replicate of each of the treatment were randomly drawn at each data recording time. The sample was taken from the middle of each container (10-15 cm below from the surface) by inserting a spoon. From each of the samples, 100 grains were used to record the data for each time and each parameter.

3.1.8. Data collection and calculation

The data on the stored rice infestation by number and weight, larval survibilities of rice weevil, and pupal survibilities of rice weevil were recorded.

3.1.9. Data on grain infestation by number and weight

The number and weight of infested grains was counted for each sample of 100 grains. The infested grains were identified by recognizing the bore grains caused by the rice moth after emerging adult from the grains. Magnifying lens and simple microscope were also used in that purpose whenever needed. The percent grain infestation and percent reduction of grain infestation over control were then calculated using the following formulae (Khosla, 1997):

$$\text{Percent stored rice infestation} = \frac{\text{Number of infested stored rice}}{\text{Number of total stored rice observed}} \times 100$$

$$\text{\% reduction of stored rice infestation over control} = \frac{X_2 - X_1}{X_2} \times 100$$

Where X_1 = Mean value of treated pot
X_2 = Mean value of untreated pot

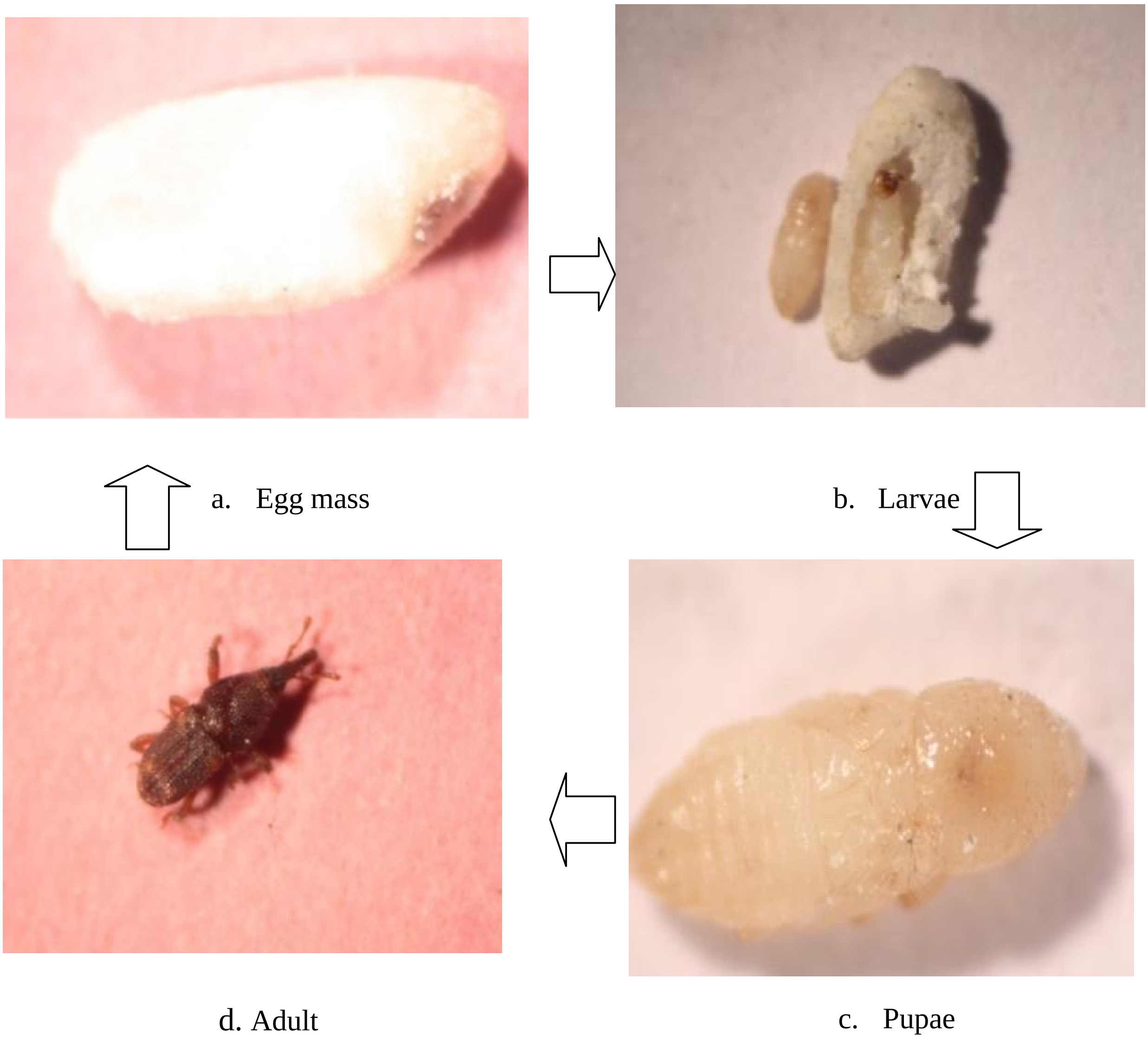

Plate 6. Different developmental stages of rice weevil, *Sitophilus oryzae* L.

Experiment 2: Efficacy of some fumigants for the management of rice weevil (*Sitophilus oryzae* L.) in stored rice

This experiment was conducted to evaluate the efficiency of three promising fumigants viz. camphor, phostoxin and naphthalene applied against rice weevil, *S. oryzae* infesting stored rice in the laboratory condition. The detail procedure of the experiment has been described below:

3.2.1. Design of the experiment

The experiment was laid out in the ambient condition of the laboratory considering Completely Randomized Design (CRD) and the treatments were replicated four times for each.

3.2.2. Materials used in the study

Sixteen (16) kg of stored rice (BR 28) were purchased and collected from the Agricultural Farm of Sher-e-Bangla Agricultural University, Dhaka. The collected rice seeds were then used in this experiment as mentioned earlier in the Experiment 1.

3.2.3. Treatments

There were three promising fumigants viz. camphor, phostoxin and naphthalene evaluated in this experiment, where each fumigant was treated as an individual treatment. Besides these fumigants, one untreated control was also considered. The treatments and their doses selected for the experiment have been furnished below:

Treatments	Fumigants	Dose of the fumigants
T_1	Camphor	1.0 gm /kg rice grains
T_2	Phostoxin tablet	200 mg /kg rice grains
T_3	Naphthalene	500 mg /kg rice grains
T_4	Untreated control	No fumigants were used

3.2.4. Collection and description of the fumigants

The camphor, phostoxin tablet and naphthalene were bought from local market of the Agargaon bazaar, and Siddik bazaar, Dhaka. The brief description of the collected fumigants is furnished below:

3.2.4a. Camphor

Camphor is a white transparent waxy crystalline solid with a strong penetrating pungent aromatic odor. It is found in wood of the camphor laurel, *Cinnamonum camphora,* which is a large evergreen tree found in Asia (particularly in Borneo and Taiwan). It is widely used for medicinal purposes, and in religious ceremonies (Mann *et al.*, 1994). In extreme cases, even topical application of camphor may lead to hepatoxicity (Bishop and Sanders, 2000). Lethal doses in adults are in the range 50–500 mg/kg (orally). Generally, 2 g causes serious toxicity and 4 g is potentially lethal (Martin *et al.*, 2004). Abiverdi (1976) reported that the insecticidal efficacy of camphor. Chauvin *et al*. (1994) reported that the camphor has fumigation properties and has got a very low mammalian toxicity.

3.2.4b. Phostoxin

Phostoxin is available in the market at its tablet or pellet form. The chemical name phostoxin is aluminium phosphide which is used as rodenticide, insecticide, and fumigant for stored cereal grains. As a pesticide, aluminium phosphide can be encountered under various brand names, e.g. Celphos, Fumitoxin, Phostoxin, and Quick Phos.

3.2.4c. Naphthalene

Naphthalene, also known as naphthalin, is a crystalline, aromatic, white, solid hydrocarbon with formula $C_{10}H_8$ and the structure of two fused benzene rings. It is volatile, forming a flammable vapor, and readily sublimes at room temperature, producing a characteristic odor that is detectable at concentrations as low as 0.08 ppm by mass (Amoore and Hautala, 1983). The most familiar use of naphthalene is as a household fumigant, such as in mothballs. In a sealed container containing naphthalene pellets, naphthalene vapors build up to levels toxic to both the adult and larval forms of many moths that attack textiles (Bryn, 2002) and other stored cereals.

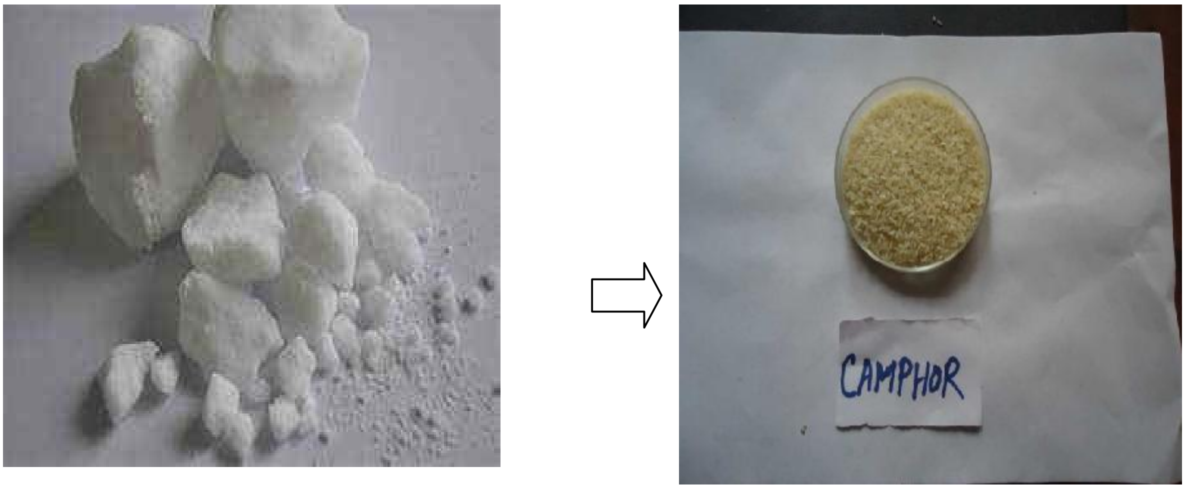

Plate 7. Camphor (left) and camphor treated rice (right) on a plate

Plate 8. Naphthalene (left) and naphthalene treated rice (right) on a plate

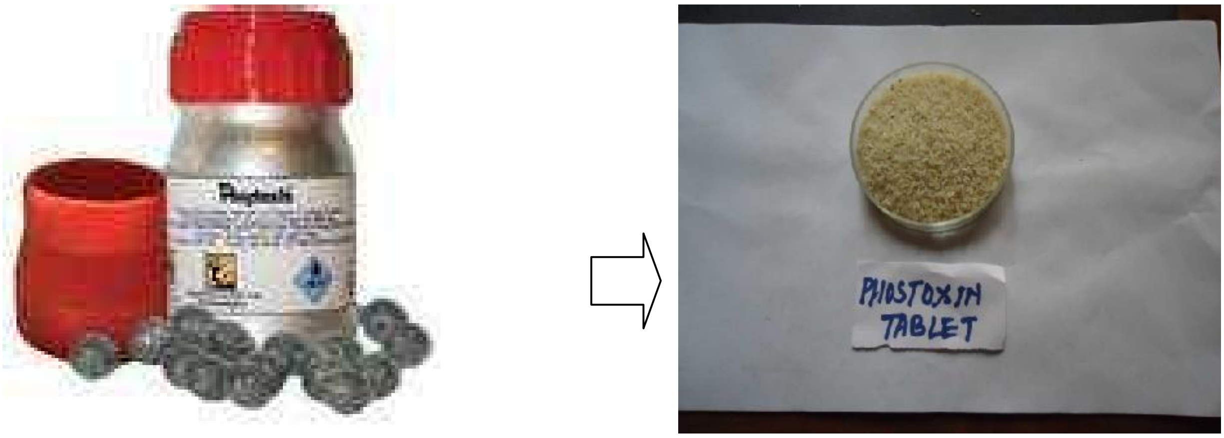

Plate 9. Phostoxin (left) and phostoxin treated rice (right) on a plate

3.2.4d. Untreated control

The stored rice used as untreated control were never treated with any of the fumigants, but only the adults of rice weevil were released on the stored rice, and stored in respective container and preserved for infestation from which necessary data were recorded.

3.2.5. Application of the fumigants

About 16 kg of the selected stored rice were taken and distributed in 16 plastic pots each having one kg of the grains. One (1.0) gm of powdered camphor was thoroughly mixed with the grains of each of the pots and the same dose of camphor was mixed with the grains of other three pots to maintain 4 replications. Similarly, 200 mg of phostoxin tablet was thoroughly mixed with grains of 4 containers assigned for phostoxin. Similarly, 500 mg of naphthalene were also mixed with the grains of each container assigned for naphthalene. The last 4 plastic pots with grains were kept as untreated control, i.e. no fumigants were mixed with the grains.

3.2.6. Release of the rice weevil, *S. oryzae*

The newly hatched adults of rice weevil were released on the stored rice for each treatment and replication considering the similar procedure as mentioned in the earlier experiment. The containers were then covered with their respective lids and preserved in ambient temperature of the laboratory up to 150 days after egg release (DAAR) for recording the data.

3.2.7. Data sampling, collection and recording

The data on stored rice infestation by number and weight, the larval survibilities of rice weevil and the pupal survibilities of rice weevil were recorded. The data were collected and recorded at 30 days intervals started from 30 DAAR and continued up to 150 DAAR considering the sampling procedure as mentioned earlier in the Experiment 1.

3.2.8. Data analysis

The data on above mentioned parameters for Experiment 1 & 2 were analyzed on one-factor CRD with help of Computer based program MSTAT-C software. The means were separated to determine the level of significance following Duncan's Multiple Range Test (DMRT) and Least Significance Difference (LSD) wherever necessary at 5% level of probability.

Plate 10. Botanical and fumigant treated rice preserved in plastic pots according to design

Plate 11. Infested stored rice in experimental condition

CHAPTER IV

RESULTS AND DISCUSSION

The study was conducted to explore the efficiency of some promising botanicals and fumigants for eco-friendly management of rice weevil, *Sitophilus oryzae* L. on stored rice in the laboratory condition is the Department of Entomology at Sher-e-Bangla Agricultural University, Dhaka during the period of September 2011 to February 2012. The findings of the study with necessary interpretations were discussed below under the following two separate experiments and sub-headings:

Experiment 1: Efficacy of some botanicals for the management of rice weevil (*Sitophilus oryzae* L.) in stored rice

The significant effects of botanicals applied in the present study were observed in respect of stored rice infestation by number and weight as well as growth and development of rice weevil during its management on stored rice and the findings were furnished below:

4. 1. Effect of botanicals on grain infestation by number

The significant variations were observed among different botanicals in terms of the infestation of stored rice by number during the management of rice weevil in different days after adult release (DAAR). In case of 30 DAAR, the highest percent (15.25%) stored rice infestation was recorded in T_6 (untreated control) where no botanicals were used followed by T_4 (9.5%) comprising dried dholkolmi leaf powder @ 2.5 gm/kg rice and T_5 (8.75%) comprising dried mahogany leaf powder @ 2.5 gm/kg rice. On the other hand, the lowest percent of grain infestation (3.25%) by number was recorded in T_1 (3.50%) comprising dried neem leaf powder @ 2.5 gm/kg stored rice (Table 1). This was statistically similar with T_2 comprised with dried bishkatali leaf powder @ 2.5 gm/kg stored rice and T_3 (4.75%) comprising dried marigold leaf powder @ 2.5 gm/kg rice. In case of 60 DAAR, the highest percent (16.42%) stored rice infestation was recorded in T_6 (untreated control), which was statistically different from all other treatments followed by T_5 (11.50%) and T_4 (11.08%). On the other hand, the lowest percent of grain infestation (3.49%) was recorded in T_1 followed by T_2 (4.16%) (Table 1) followed by T_3 (7.91%). More or less similar trends of results were also observed at 90, 120 and 150 DAAR. In case of 150 DAAR, the highest percent grain infestation (50.92%) was also recorded in T_6 (untreated control), which was statistically different from all other treatments followed by T_5 (35.08%), T_3 (30.33%) and T_4 (26.25%). On the other hand, the lowest percent of grain infestation (20.50%) was recorded in T_1 followed by T_2 (26.25%).

Considering the mean infestation, the highest percent grain infestation (29.20%) was recorded in T_6 (untreated control), which was statistically different from all other treatments followed by T_5 (19.82%), T_3 (15.53%) and T_4 (15.41%). On the other hand, the lowest percent of grain infestation (9.98%) was recorded in T_1 followed by T_2 (12.07%). Similarly, in case of percent reduction of grain infestation over control, the highest reduction (65.81%) was recorded in T_1 followed by T_2 (58.68%), T_4 (47.21%); whereas, the lowest reduction over control was recorded in T_5 (32.14%) followed by T_3 (46.81%). As a result, the order of trend of efficiency among five botanicals and untreated control in terms of percent reduction of grain infestation by number was T_1 (dried neem leaf powder) > T_2 (dried bishkatali leaf powder) > T_4 (dried dholkalmi leaf powder) > T_3 (dried marigold leaf powder) > T_5 (dried mahogany leaf powder) > T_6 (untreated control).

Table 1: Effect of botanicals on grain infestation by number during the storing period from September 2011 to February 2012

Treatment	% Grain infestation by number						% infestation reduction over control
	30 DAAR	60 DAAR	90 DAAR	120 DAAR	150 DAAR	Mean	
T_1	3.25 c	3.49d	8.08f	14.59f	20.50f	9.98 e	65.81
T_2	3.50 c	4.16d	8.83e	17.58e	26.25e	12.07 d	58.68
T_3	4.75 c	7.918c	14.33c	20.33c	30.33c	15.53 c	46.81
T_4	9.50 b	11.08b	9.83d	18.33d	28.33d	15.41 c	47.21
T_5	8.75 b	11.50b	18.75b	25.00b	35.08b	19.82 b	32.14
T_6	15.25 a	16.42a	23.83a	39.58a	50.92a	29.20 a	-
LSD(0.50)	1.68	1.40	0.54	0.67	0.79	1.02	-
CV(%)	12.88	10.22	2.58	1.97	1.67	5.86	-

DAAR = Days after adult release; In column the treatment means with same letters indicate the statistically similar at 5% level of significance

[T_1 = Dried neem leaf powder @ 2.5 g/kg rice, T_2 = Dried bishkatali leaf powder @ 2.5 g/kg rice, T_3 = Dried marigold leaf powder @ 2.5 g/kg rice, T_4 = Dried dholkolmi leaf powder @ 2.5 g/kg rice, T_5 = Dried mahogany leaf powder @ 2.5 g/kg rice, T_6 = Untreated control]

From the above findings it was revealed that among five botanicals, dried neem leaf powder applied @ 2.5 gm/kg rice performed best results in reducing the grain infestation (65.81%) by rice weevil than dried leaf powder of bishkatali, marigold, dholkalmi and mahogany; whereas, the dried mahogany leaf powder showed the least performance in reducing the percent grain infestation (32.14%) by number over control. As a result, the order of trend of efficacy among five botanicals and one untreated control in terms of percent reduction of grain infestation by number was T_1 (dried neem leaf powder) > T_2 (dried bishkatali leaf powder) > T_4 (dried dholkalmi leaf powder) > T_3 (dried marigold leaf powder) > T_5 (dried mahogany leaf powder) > T_6 (untreated control). About similar findings were also found by several researchers. Sanguanpong *et al.* (2001) stated that neem was contained 7.25% infested grain of stored rice. Amin *et al.* (2000) reported that the direct toxicity of three plant extract on the following bishkatali > neem > akand in lesser grain borer. Talukder and Howse (1993) also noted similar direct toxicity effect on red flour beetle.

4.2. Effect of botanicals on grain infestation by weight

The significant variations were observed among different botanicals in terms of the infestation of stored rice by weight during the management of rice weevil in different days after adult release (DAAR). In case of 30 DAAR, the highest percent grain infestation by weight (2.04%) was recorded in T_6 (untreated control), which was statistically different from all other treatments followed by T_4 (1.32%) and T_5 (1.18%). On the other hand, the lowest grain infestation by weight (0.44%) was recorded in T_1, which was statistically similar with T_2 (0.57%) and T_3 (0.64%) (Table 2). In case of 60 DAAR, the highest percent of grain infestation (7.08%) by weight was recorded in T_6 (untreated control), which was statistically different from all other treatments followed by T_5 (5.90%) and T_3 (4.40%). On the other hand, the lowest percent of grain infestation (2.36%) was recorded in T_1 followed by T_2 (2.75%) and T_4 (7.91%). More or less similar trends of results were also observed at 90, 120 and 150 DAAR. In case of 150 DAAR, the highest percent of grain infestation (23.02%) by weight was recorded in T_6 (untreated control), which was statistically different from all other treatments followed by T_5 (16.59%), T_3 (15.35%) and T_4 (14.34%). On the other hand, the lowest percent of grain infestation (10.57%) was recorded in T_1 followed by T_2 (12.82%).

Considering the mean infestation, the highest percent of grain infestation (12.54%) by weight was recorded in T_6 (untreated control), which was statistically different from all other treatments followed by T_5 (9.18%), T_3 (8.06%) and T_4 (7.27%). On the other hand, the lowest percent of grain infestation (5.34%) was recorded in T_1 followed by T_2 (6.21%). Similarly, in case of percent reduction of grain infestation over control, the highest reduction (57.42%) was recorded in T_1 followed by T_2 (50.50%), T_4 (42.00%); whereas, the lowest reduction over control was recorded in T_5 (26.76%) followed by T_3 (35.72%). As a result, the order of trend of efficiency of five botanicals and untreated control in terms of percent reduction of grain infestation by weight was T_1 (dried neem leaf powder) > T_2 (dried bishkatali leaf powder) > T_4 (dried dholkalmi leaf powder) > T_3 (dried marigold leaf powder) > T_5 (dried mahogany leaf powder) > T_6 (untreated control).

Table 2: Effect of botanical on grain infestation by weight during the storing period from September 2011 to February 2012

Treatment	% grain infestation by weight						% grain infestation reduction over control
	30 DAAR	60 DAAR	90 DAAR	120 DAAR	150 DAAR	Mean	
T_1	0.57 c	2.75 e	5.27 e	9.59 d	12.82 d	6.21 e	50.50
T_2	0.44 c	2.36 e	4.90 e	8.40 e	10.57 e	5.34 f	57.42
T_3	0.64 c	4.40 c	7.67 c	12.21 b	15.35 c	8.06 c	35.72
T_4	1.32 b	3.56 d	6.03 d	11.09 c	14.34 c	7.27 d	42.00
T_5	1.18 b	5.90 b	9.42 b	12.8 b	16.59 b	9.18 b	26.76
T_6	2.04 a	7.08 a	11.32 a	19.21 a	23.02 a	12.54 a	-
LSD(0.50)	0.25	0.41	0.55	0.90	1.13	0.65	-
CV(%)	14.16	5.45	4.26	4.25	4.21	6.47	-

DAAR = Days after adult release; In column the treatment means with same letters indicate the statistically similar at 5% level of significance

[T_1 = Dried neem leaf powder @ 2.5 g/kg stored rice, T_2 = Dried bishkatali leaf powder @ 2.5 g/kg stored rice, T_3 = Dried marigold leaf powder @ 2.5 g/kg stored rice, T_4 = Dried dholkolmi leaf powder @ 2.5 g/kg stored rice, T_5 = Dried mahogany leaf powder @ 2.5 g/kg stored rice, T_6 = Untreated control]

From the above findings it was revealed that among five botanicals, dried neem leaf powder applied @ 2.5 gm/kg rice performed best results in reducing the grain infestation by weight (57.42%) than dried leaf powder of bishkatali, marigold, dholkalmi and mahogany; whereas, the dried mahogany leaf powder showed the least performance in reducing the percent grain infestation (26.76%) by weight over control. As a result, the order of trend of efficiency among five botanicals and one untreated control in terms of percent reduction of grain infestation by weight was T_1 (dried neem leaf powder) > T_2 (dried bishkatali leaf powder) > T_4 (dried dholkalmi leaf powder) > T_3 (dried marigold leaf powder) > T_5 (dried mahogany leaf powder) > T_6 (untreated control). About similar findings were also found by several researchers. According to Khalequzzaman and Osman Goni (2009), no significant weight loss was obtained in tobacco leaf powder and *A. indica* seed kernel treated seeds for both bruchid species. Among the plant materials lowest percentage of weight loss was found in *P. hydropiper* leaf powder followed by *A. indica* bark, *A. squamosa* leaf and *V. negundo* leaf powder.

4. 3. Effect of botanicals on the survibility of weevil larvae

Significant variations were also observed among five botanicals in terms of larval survibility of rice weevil in stored rice during the management of rice weevil in different days after adult release (DAAR). In case of 30 DAAR, the highest incidence of weevil larvae by number (1.70 per 100 grain) was recorded in T_6 (untreated control), which was statistically different from all other treatments followed by T_4 (1.05 per 100 grains) and T_5 (0.98 per 100 grains). On the other hand, the lowest number of alive larvae (0.33 per 100 grains) was recorded in T_1 (Table 3). This result was followed by T_2 (0.50 per 100 grains) and T_3 (0.55 per 100 grains). In case of 60 DAAR, the highest incidence of weevil larvae by number (4.78 per 100 grain) was recorded in T_6 (untreated control), which was statistically different from all other treatments followed by T_5 (3.75 per 100 grains) and T_3 (2.45 per 100 grains). On the other hand, the lowest number of alive larvae (0.83 per 100 grains) was recorded in T_1 (Table 3). This result was followed by T_2 (1.15 per 100 grains) and T_4 (1.78 per 100 grains). On the other hand, more or less similar trends of results were also observed for 90, 120 and 150 DAAR, but the incidences of weevil larvae were increased with the increase of the data recording period. In case of 150 DAAR, the highest number of weevil larvae (20.73 per 100 grain) was recorded in T_6 (untreated control), which was statistically different from all other treatments followed by T_5 (14.30 per 100 grains) and T_3 (12.83 per 100 grains). On the other hand, the lowest number of alive larvae (8.35 per 100 grains) was recorded in T_1 (Table 3). This result was followed by T_2 (10.70 per 100 grains) and T_4 (11.55 per 100 grains).

Considering the mean incidence, the highest number of weevil larvae (10.46 per 100 grain) was recorded in T_6 (untreated control), which was statistically different from all other treatments followed by T_5 (7.26 per 100 grains) and T_3 (5.82 per 100 grains). On the other hand, the lowest number of alive larvae (3.70 per 100 grains) was recorded in T_1 followed by T_2 (4.57 per 100 grains) and T_4 (5.11 per 100 grains). Similarly, in case of percent reduction of larval incidence over control, the highest reduction was recorded in T_1 (64.63%), followed by T_2 (56.36%), T_4 (51.20%) and T_3 (44.40%). On the other hand, the lowest percent reduction of larval incidence over control was recorded in T_5 (30.61%). As a result, the order of trends of efficiency among five botanicals including untreated control in terms of the reduction of larval survibility was T_1 (dried neem leaf powder) > T_2 (dried bishkatali leaf powder) > T_4 (dried dholkalmi leaf powder) > T_3 (dried marigold leaf powder) > T_5 (dried mahogany leaf powder) > T_6 (untreated control).

Table 3: Effect of botanicals on the larval survibility of rice weevil during the storing period of rice from September 2011 to February 2012

Treatment	Incidence of weevil larvae (No./100 stored rice)						% reduction of larvae over control
	30 DAAR	60 DAAR	90 DAAR	120 DAAR	150 DAAR	Mean	
T_1	0.50cd	1.15e	3.40e	7.08d	10.70e	4.57 e	56.36
T_2	0.33d	0.83f	3.13f	5.88e	8.35f	3.70 f	64.63
T_3	0.55c	2.45c	5.53c	8.18c	12.38c	5.82 c	44.40
T_4	1.05b	1.78d	3.80d	7.35d	11.55d	5.11 d	51.20
T_5	0.98b	3.75b	7.25b	10.02b	14.30b	7.26 b	30.61
T_6	1.70a	4.78a	9.20a	15.90a	20.73a	10.46 a	-
LSD(0.50)	0.21	0.11	0.24	0.29	0.31	0.23	-
CV(%)	16.03	3.00	2.91	2.09	1.60	5.13	-

DAAR = Days after adult release; In column the treatment means with same letters indicate the statistically similar at 5% level of significance
[T_1 = Dried neem leaf powder @ 2.5 g/kg rice, T_2 = Dried bishkatali leaf powder @ 2.5 g/kg rice, T_3 = Dried marigold leaf powder @ 2.5 g/kg rice, T_4 = Dried dholkolmi leaf powder @ 2.5 g/kg rice, T_5 = Dried mahogany leaf powder @ 2.5 g/kg rice, T_6 = Untreated control]

From the above findings it was revealed that among five botanicals, dried neem leaf powder applied @ 2.5 gm/kg rice performed best results in reducing the larval incidence by number (64.63%) over control than dried leaf powder of bishkatali, marigold, dholkalmi and mahogany; whereas, the dried mahogany leaf powder showed the least performance in reducing the percent larval incidence (30.61%) by number over control. As a result, the order of trend of efficiency among five botanicals and one untreated control in terms of percent reduction of larval incidence by number was T_1 (dried neem leaf powder) > T_2 (dried bishkatali leaf powder) > T_4 (dried dholkalmi leaf powder) > T_3 (dried marigold leaf powder) > T_5 (dried mahogany leaf powder) > T_6 (untreated control). About similar findings were also found by several researchers, but not directly with rice weevil. Kundu *et al.* (2007) stated that toxicity, repellency and residual effects of bishkatali plant extracts in chloroform and ethyl alcohol solvents were evaluated against the *Tribolium castaneum*. Five concentrations viz. 500, 250, 125, 62.5 and 31.25mg/ml of bishkatali plant extracts of both solvents were used in the experiment. The plant extracts in both solvents were moderately toxic to *Tribolium castaneum*. The rate of repellency was increased with the increment of concentration. Both the extracts have produced remarkable residual effect in reducing the progeny of *T. castaneum*.

4. 4. Effect of botanicals on the survibility of weevil pupae

Significant variations were also observed among five botanicals in terms of pupal survibility of rice weevil in stored rice during the management of rice weevil in different days after adult release (DAAR). In case of 30 DAAR, the highest incidence of weevil pupae by number (2.20 per 100 grains) was recorded in T_6 (untreated control), which was statistically different from all other treatments followed by T_4 (1.30 per 100 grains) and T_5 (1.25 per 100 grains). On the other hand, the lowest number of alive larvae (0.45 per 100 grains) was recorded in T_1 (Table 4). This result was followed by T_2 (0.65 per 100 grains) and T_3 (0.67 per 100 grains). In case of 60 DAAR, the highest incidence of weevil pupae by number (5.57 per 100 grains) was recorded in T_6 (untreated control), which was statistically different from all other treatments followed by T_5 (4.45 per 100 grains) and T_3 (2.90 per 100 grains). On the other hand, the lowest number of alive pupae (0.97 per 100 grains) was recorded in T_1. This result was followed by T_2 (1.35 per 100 grains) and T_4 (2.07 per 100 grains) (Table 4). More or less similar trends of results were also observed at 90, 120 and 150 DAAR, but the incidences of weevil pupae were increased with the increase of the data recording period. Therefore, in case of 150 DAAR, the highest number of weevil pupae (22.23 per 100 grains) was recorded in T_6 (untreated control), which was statistically different from all other treatments followed by T_5 (15.32 per 100 grains) and T_3 (13.20 per 100 grains). On the other hand, the lowest number of alive larvae (8.95 per 100 grains) was recorded in T_1 followed by T_2 (11.43 per 100 grains) and T_4 (12.38 per 100 grains) as presented in Table 3.

Considering the mean incidence of pupae, the highest number of weevil pupae (11.40 per 100 grains) was recorded in T_6 (untreated control), which was statistically different from all other treatments followed by T_5 (7.95 per 100 grains) and T_3 (6.32 per 100 grains). On the other hand, the lowest number of alive pupae (4.00 per 100 grains) was recorded in T_1 followed by T_2 (4.92 per 100 grains) and T_4 (5.55 per 100 grains). Similarly, in case of percent reduction of pupal incidence over control, the highest reduction was recorded in T_1 (64.92%), followed by T_2 (56.84%), T_4 (51.36%) and T_3 (44.61%). On the other hand, the lowest percent reduction of pupal incidence over control was recorded in T_5 (30.28%). As a result, the order of trends of efficiency of five botanicals including untreated control in terms of the reduction of pupal survibility was T_1 (dried neem leaf powder) > T_2 (dried bishkatali leaf powder) > T_4 (dried dholkalmi leaf powder) > T_3 (dried marigold leaf powder) > T_5 (dried mahogany leaf powder) > T_6 (untreated control).

Table 4: Effect of botanicals on the pupal survibility of rice weevil during the storing period of rice from September 2011 to February 2012

Treatment	Incidence of weevil pupa (No./100 stored rice)						% reduction of pupae over control
	30 DAAR	60 DAAR	90 DAAR	120 DAAR	150 DAAR	Mean	
T_1	0.65 c	1.35 e	3.90 e	7.27 e	11.43 e	4.92 e	56.84
T_2	0.45 d	0.97 f	3.55 f	6.07 f	8.95 f	4.00 f	64.92
T_3	0.67 c	2.9 c	6.32 c	8.47 c	13.20 c	6.32 c	44.61
T_4	1.30 b	2.07 d	4.35 d	7.625 d	12.38 d	5.55 d	51.36
T_5	1.25 b	4.45 b	8.32b	10.4 b	15.32 b	7.95 b	30.28
T_6	2.2 a	5.57 a	10.55 a	16.45 a	22.23 a	11.40 a	-
LSD(0.50)	0.18	0.11	0.26	0.28	0.34	0.24	-
CV(%)	11.21	2.75	2.91	2.03	1.62	4.10	-

DAAR = Days after adult release; In column the treatment means with same letters indicate the statistically similar at 5% level of significance
[T_1 = Dried neem leaf powder @ 2.5 g/kg rice, T_2 = Dried bishkatali leaf powder @ 2.5 g/kg rice, T_3 = Dried marigold leaf powder @ 2.5 g/kg rice, T_4 = Dried dholkolmi leaf powder @ 2.5 g/kg rice, T_5 = Dried mahogany leaf powder @ 2.5 g/kg rice, T_6 = Untreated control]

From the above findings it was revealed that among five botanicals, dried neem leaf powder applied @ 2.5 gm/kg rice performed best results in reducing the pupal incidence by number (64.92%) over control than dried leaf powder of bishkatali, marigold, dholkalmi and mahogany; whereas, the dried mahogany leaf powder showed the least performance in reducing the percent pupal incidence (30.28%) by number over control. As a result, the order of trend of efficiency among five botanicals and one untreated control in terms of percent reduction of pupal incidence by number was T_1 (dried neem leaf powder) > T_2 (dried bishkatali leaf powder) > T_4 (dried dholkalmi leaf powder) > T_3 (dried marigold leaf powder) > T_5 (dried mahogany leaf powder) > T_6 (untreated control). About similar findings were also found by several researchers, but not directly with rice weevil. Among of the researchers, Mamun *et al.* (2009) found that, mahogany leaves treated rice contained 41.91 number of pupa against of *T. castaneum* which showed similar results with this findings. Facknath and Sunita (2006) reported that neem leaf extract (*Azadirachta indica* A. Juss.) reduced insect populations in stored products through its toxic and growth disrupting and other effects on the pests.

Experiment 2: Efficacy of some fumigants for the management of rice weevil (*Sitophilus oryzae* L.) in stored rice

The significant effects of fumigants applied in the present study were observed in respect of grain infestation by number and weight as well as growth and development of rice weevil during its management on stored rice and the findings were given below:

4. 5. Effect of fumigants on grain infestation by number

Significant variations were observed among three fumigants in terms of grain infestation by number during the management of rice weevil in different days after adult release (DAAR) of rice weevil. In case of 30 DAAR, the highest percent grain infestation by (15.25%) by number was recorded in T_4 (untreated control), followed by T_3 (5.75%) comprising naphthalene @ 500 mg/kg rice (Table 5). On the other hand, the lowest percent of grain infestation (1.25%) by number was in T_1 comprised of camphor @ 1 gm/kg rice (Table 5). This result was statistically similar in T_2 (2.50%) comprising phostoxin tablet @ 200 mg/kg rice. In case of 60 DAAR, the highest percent of grain infestation by number (15.17%) was recorded in T_4 (untreated control), which was statistically different from all treatments followed by T_3 (8.00%). On the other hand, the lowest percent of grain infestation (3.83%) by number was recorded in T_1 followed by T_2 (5.17%). More or less similar trends of results were also observed at 90, 120, 150 DAAR, but the level of grain infestation were increased with the increase of data recording time. Therefore, in case of 150 DAAR, the highest percent of grain infestation by number (50.29%) was recorded in T_4 (untreated control), which was statistically different from all treatments followed by T_3 (21.58%). On the other hand, the lowest percent of grain infestation (15.75%) by number was recorded in T_1 followed by T_2 (15.58%) as presented in Table 5.

Considering the mean infestation by number, the highest percent of grain infestation by number (28.95%) was recorded in T_4 (untreated control), which was statistically different from all treatments followed by T_3 (12.98%). On the other hand, the lowest percent of grain infestation (7.72%) by number was recorded in T_1 followed by T_2 (9.33%). Similarly, in case of percent reduction of grain infestation by number, the highest reduction (73.34%) over control was recorded in T_1 followed by T_2 (67.76%) and T_3 (55.15%). As a result, the order of trend of efficiency among three fumigants including one untreated control in terms of percent grain infestation by number was T_1 (camphor) > T_2 (phostoxin tablet) > T_3 (naphthalene) > T_4 (untreated control).

Table 5. Effect of fumigants on grain infestation by number during the storing period from September 2011 to February 2012

Treatment	% grain infestation by number						% reduction of grain infestation over control
	30 DAAR	60 DAAR	90 DAAR	120 DAAR	150 DAAR	Mean	
T_1	1.25c	3.83d	6.5d	11.25d	15.75d	7.72 d	73.34
T_2	2.50c	5.17c	8.49c	12.92c	17.58c	9.33 c	67.76
T_3	5.75b	8.00b	12.84b	16.75b	21.58b	12.98 b	55.15
T_4	15.25a	15.17a	23.83a	39.58a	50.92a	28.95 a	-
LSD(0.50)	1.56	0.29	0.53	0.61	0.61	0.72	-
CV(%)	15.76	2.3	2.59	1.93	1.45	4.81	-

DAAR = Days after adult release; In column the treatment means with same letters indicate the statistically similar at 5% level of significance
[T_1 = Camphor@1 gm/kg rice, T_2 = Phostoxin tablet @ 200 mg/kg rice, T_3 = Naphthalene @ 500 mg/kg rice, T_4 = Untreated control]

From the above results it was revealed that among three fumigants, Camphor showed best performance in reducing grain infestation by number (73.34%) over control than Phostoxin tablet and Naphthalene, where Naphthalene @ 500 mg/kg rice showed the least performance in reducing grain infestation by number (55.15%) over control. As a result, the order of trend of efficiency among three fumigants including one untreated control in terms of percent grain infestation by number was T_1 (camphor) > T_2 (phostoxin tablet) > T_3 (naphthalene) > T_4 (untreated control). According to the some researchers, Hamed *et al*. (2012) stated that to evaluate the toxicities of celery, camphor and garlic oils against the rice weevil, *Sitophilus oryzae* adults through laboratory tests by treating wheat stored rice with such plant oils. Mortality increased with increasing of both concentration and exposure period. The most effective oil was camphor (LC50 = 0.84 and LC95 =2.85 ml/Kg wheat), followed by the celery oil (LC50 = 0.89 and LC95 =3.84 ml / Kg wheat) and garlic oil (LC50 =1.27 and LC95 =10.81 ml / kg).

4.6. Effect of fumigants on grain infestation by weight

Significant variations were observed among three fumigants in terms of grain infestation by weight during the management of rice weevil in different days after adult release (DAAR) of rice weevil. In case of 30 DAAR, the highest percent of grain infestation by (2.09%) by weight was recorded in T_4 (untreated control), which was statistically different from all others treatments followed by T_3 (0.80%) (Table 6). On the other hand, the lowest percent of grain infestation (0.17%) by weight was in T_1. This result was statistically similar in T_2 (0.34%). In case of 60 DAAR, the highest percent of grain infestation by weight (7.24%) was recorded in T_4 (untreated control), which was statistically different from all treatments followed by T_3 (3.13%). On the other hand, the lowest percent of grain infestation (1.18%) by weight was recorded in

T_1 followed by T_2 (1.78%). More or less similar trends of results were also observed at 90, 120, 150 DAAR, but the level of grain infestation were increased with the increase of data recording time. Therefore, in case of 150 DAAR, the highest percent of grain infestation by weight (23.51%) was recorded in T_4 (untreated control), which was statistically different from all treatments followed by T_3 (8.90%). On the other hand, the lowest percent of grain infestation (6.43%) by weight was recorded in T_1 followed by T_2 (7.19%) as presented in Table 6.

Considering the mean infestation by weight, the highest percent of grain infestation (12.80%) was recorded in T_4 (untreated control), which was statistically different from all treatments followed by T_3 (5.12%). On the other hand, the lowest percent of grain infestation (3.05%) by weight was recorded in T_1 followed by T_2 (3.67%). Similarly, in case of percent reduction of grain infestation by weight, the highest reduction (76.19%) over control was recorded in T_1 followed by T_2 (71.35%), whereas the lowest grain infestation reduction by weight was recorded in T_3 (59.96%). As a result, the order of trend of efficiency of three fumigants including one untreated control in terms of percent grain infestation by weight was T_1 (camphor) > T_2 (phostoxin tablet) > T_3 (naphthalene) > T_4 (untreated control).

Table 6: Effect of fumigants on grain infestation by weight during the storing period from September 2011 to February 2012

Treatment	% grain infestation by weight						% Grain infestation reduction over control
	30 DAAR	60 DAAR	90 DAAR	120 DAAR	150 DAAR	Mean	
T_1	0.17 c	1.18 d	2.65 d	4.81 c	6.43 c	3.05 c	76.19
T_2	0.34 c	1.78 c	3.40 c	5.62 c	7.19 c	3.67 c	71.35
T_3	0.80 b	3.13 b	5.41 b	7.39 b	8.90 b	5.12 b	59.96
T_4	2.09 a	7.24 a	11.56 a	19.61 a	23.51 a	12.80 a	-
LSD(0.50)	0.23	0.38	0.55	0.90	1.09	0.63	-
CV(%)	14.24	5.97	5.03	5.11	5.01	7.07	-

DAAR = Days after adult release; In column the treatment means with same letters indicate the statistically similar at 5% level of significance
[T_1 = Camphor@1 gm/kg stored rice % w/w, T_2 = Phostoxin tablet 200 mg/kg stored rice, T_3 = Naphthalene 500 mg/kg stored rice % w/w, T_4 = Untreated control]

From the above results it was revealed that among three fumigants, Camphor showed best performance in reducing grain infestation by weight (76.19%) over control than Phostoxin tablet and Naphthalene, where Naphthalene @ 500 mg/kg rice showed the least performance in reducing grain infestation by weight (59.96%) over control. As a result, the order of trend of efficiency of three fumigants including one untreated control in terms of percent grain infestation by weight was T_1 (camphor) > T_2 (phostoxin tablet) > T_3 (naphthalene) > T_4 (untreated control). About similar works also done by several researchers. Sanguanpong *et al.* (2001) reported that among the fumigant treatments the best results was found in camphor treated rice applied against rice weevil. The present study with camphor reduced feeding damage on stored rice stored rice. This volatile substance showed satisfactory activities and the addition camphor with rice proved to be promising as control agents against *S. oryzae*. They also said that the treatment camphor could maintain the weight of stored stored rice and only 6.32 percent of weight loss was occurred after 36 weeks. Siddika (2004) reported that the camphor significantly reduced the infestation of pest in storage. On the other hand, Kabir *et al*. (2003) reported that camphor and naphthalene showed the best performance in protecting against insect pests in storage. Positive results for contact and fumigant activity of monoterpenes were obtained against *S. oryzae*.

4. 7. Effect of fumigants on the survibility of weevil larvae

Significant variations were observed among three fumigants in terms of the incidence of larval survibility during the management of rice weevil in different days after adult release (DAAR) of rice weevil in stored rice. In case of 30 DAAR, the highest number of weevil larvae (1.70 per 100 grains) was observed in T_4 (untreated control), which was statistically different from all other treatments followed by T_3 (0.70). On the other hand, the lowest number (0.13 per 100 grains) of alive larvae was recorded in T_1 (Table 7). This result was statistically similar with T_2 (0.33 per 100 grains). More or less similar trends of results were also observed at 90, 120 and 150 DAAR, but the incidences of weevil larvae were increased with the increase of the data recording time. Therefore, in case of 150 DAAR, the highest number of weevil larvae (20.73 per 100 grain) was recorded in T_4 (untreated control), which was statistically different from all other treatments followed by T_3 (7.65 per 100 grains). On the other hand, the lowest number of alive larvae (5.68 per 100 grains) was recorded in T_1 (Table 7). This result was followed by T_2 (6.28 per 100 grains).

Considering the mean incidence, the highest number of weevil larvae (10.46 per 100 grain) was recorded in T_4 (untreated control), which was statistically different from all other treatments followed by T_3 (4.20 per 100 grains). On the other hand, the lowest number of alive larvae (2.55 per 100 grains) was recorded in T_1 followed by T_2 (3.08 per 100 grains). Similarly, in case of percent reduction of larval incidence over control, the highest reduction was recorded in T_1 (75.67%), followed by T_2 (70.56%).

On the other hand, the lowest percent reduction of larval incidence over control was recorded in T_3 (59.90%). As a result, the order of trends of efficiency of three fumigants including untreated control in terms of the reduction of larval survibility by number was T_1 (camphor) > T_2 (phostoxin tablet) > T_3 (naphthalene) > T_4 (untreated control).

Table 7: Effect of fumigants on the incidence of weevil larvae during the storing period from September 2011 to February 2012

Treatment	Incidence of weevil larvae (No./100 stored rice)						% infestation reduction over control
	30 DAAR	60 DAAR	90 DAAR	120 DAAR	150 DAAR	Mean	
T_1	0.13 c	1.00 d	2.23 d	3.70 d	5.68 d	2.55 d	75.67
T_2	0.33 c	1.48 c	2.95 c	4.38 c	6.28 c	3.08 c	70.56
T_3	0.70 b	2.55 b	4.48 b	5.6 b	7.65 b	4.20 b	59.90
T_4	1.70 a	4.78 a	9.20 a	15.9 a	20.73 a	10.46 a	-
LSD(0.50)	0.21	0.22	0.18	0.29	0.16	0.22	-
CV(%)	18.86	5.61	2.42	2.45	1.02	6.07	-

DAAR = Days after adult release; In column the treatment means with same letters indicate the statistically similar at 5% level of significance
[T_1 = Camphor@1 gm/kg stored rice % w/w, T_2 = Phostoxin tablet 200 mg/kg stored rice, T_3 = Naphthalene 500 mg/kg stored rice % w/w, T_4 = Untreated control]

From the above findings it was revealed that among three fumigants, camphor @ 1 gm/kg rice performed best results in reducing the larval incidence by number (75.67%) over control than phostoxin and naphthalene; whereas, the naphthalene showed the least performance in reducing the percent larval incidence (59.90%) by number over control. As a result, the order of trend of efficiency among three fumigants and one untreated control in terms of percent reduction of larval incidence by number was T_1 (camphor) > T_2 (phostoxin tablet) > T_3 (naphthalene) > T_4 (untreated control). About similar findings were also found by several researchers. Moreno and Ramirez (1988) reported that Garlic oil is toxic to adults of *S. zeamais* and *P.*

truncatus and oils of coconut, sunflower, sesame and mustard, alone and in combination with eucalyptol, eugenol or camphor have been found to be toxic to *S. zeamais* in wheat and maize-treated stored rice.

4. 8. Effect of fumigants on the survibility of weevil pupae

Significant variations were observed among three fumigants in terms of the incidence of pupal survibility during the management of rice weevil in different days after adult release (DAAR) of rice weevil in stored rice. In case of 30 DAAR, the highest number of weevil pupae (2.20 per 100 grains) was observed in T_4 (untreated control), which was statistically different from all other treatments followed by T_3 (0.65). On the other hand, the lowest number (0.13 per 100 grains) of alive pupae was recorded in T_1 (Table 8). This result was statistically similar with T_2 (0.25 per 100 grains). More or less similar trends of results were also observed at 90, 120 and 150 DAAR, but the incidences of weevil pupae were increased with the increase of the data recording time. Therefore, in case of 150 DAAR, the highest number of weevil pupae (22.23 per 100 grain) was recorded in T_4 (untreated control), which was statistically different from all other treatments followed by T_3 (6.73 per 100 grains). On the other hand, the lowest number of alive pupae (4.93 per 100 grains) was recorded in T_1 (Table 8). This result was followed by T_2 (5.58 per 100 grains).

Considering the mean incidence of pupae, the highest number of weevil pupae (11.40 per 100 grains) was recorded in T_4 (untreated control), which was statistically different from all other treatments followed by T_3 (3.88 per 100 grains). On the other hand, the lowest number of alive pupae (2.34 per 100 grains) was recorded in T_1 followed by T_2 (2.87 per 100 grains). Similarly, in case of percent reduction of pupal incidence over control, the highest reduction was recorded in T_1 (79.52%), followed by T_2 (74.87%). On the other hand, the lowest percent reduction of pupal incidence over control was recorded in T_3 (66.01%). As a result, the order of trends of efficiency of three fumigants including untreated control in terms of the reduction of pupal survibility by number was T_1 (camphor) > T_2 (phostoxin tablet) > T_3 (naphthalene) > T_4 (untreated control).

Table 8: Effect of fumigants on the incidence of weevil pupae during of the storing period from September 2011 to February 2012

Treatment	Incidence of weevil pupae (No./100 stored rice)						% reduction pupae over control
	30 DAAR	60 DAAR	90 DAAR	120 DAAR	150 DAAR	Mean	
T_1	0.13 c	0.90 d	2.20 d	3.53 d	4.93 d	2.34 d	79.52
T_2	0.25 c	1.35 c	2.88 c	4.28 c	5.58 c	2.87 c	74.87
T_3	0.65 b	2.25 b	4.33 b	5.43 b	6.73 b	3.88 b	66.01
T_4	2.20 a	5.58 a	10.55 a	16.45 a	22.23 a	11.40 a	-
LSD(0.50)	0.20	0.17	0.21	0.25	0.19	0.21	-
CV(%)	15.78	4.09	2.69	2.11	1.21	5.18	-

DAAR = Days after adult release; In column the treatment means with same letters indicate the statistically similar at 5% level of significance
[T_1 = Camphor@1 gm/kg stored rice % w/w, T_2 = Phostoxin tablet 200 mg/kg stored rice, T_3 = Naphthalene 500 mg/kg stored rice % w/w, T_4 = Untreated control]

From the above findings it was revealed that among three fumigants, camphor @ 1 gm/kg rice performed best results in reducing the pupal incidence by number (79.52%) over control than phostoxin and naphthalene; whereas, the naphthalene showed the least performance in reducing the percent pupal incidence (66.01%) by number over control. As a result, the order of trend of efficiency among three fumigants and one untreated control in terms of percent reduction of pupal incidence by number was T_1 (camphor) > T_2 (phostoxin tablet) > T_3 (naphthalene) > T_4 (untreated control). Latif *et al*. (2004) stated that camphor provided more than 90% efficacy against the rice weevil. According to Kim *et al.* (2010), camphor developed 8.04 number of pupa which is similar to this result. Rozman *et al.* (2007) also said that camphor is the best fumigant agent for controlling *S. oryzae*.

CHAPTER V

SUMMARY AND CONCLUSION

The study was conducted to find out the efficacy of some promising botanicals and fumigants applied against rice weevil, *Sitophilus oryzae*. on stored rice in the laboratory under the Department of Entomology of Sher-e-Bangla Agricultural University, Dhaka during September 2011 to February 2012. The study was conducted under two separate experiments. In first experiment, five botanicals along with one untreated control were used viz. (i) T_1 = Dried neem leaf powder @ 2.5 g/kg rice, (ii) T_2 = Dried bishkatali leaf powder @ 2.5 g/kg rice, (iii) T_3 = Dried marigold leaf powder @ 2.5 g/kg rice, (iv) T_4 = Dried dholkolmi leaf powder @ 2.5 g/kg rice, (v) T_5 = Dried mahogany leaf powder @ 2.5 g/kg rice, (vi) T_6 = Untreated control. While in second experiment, three fumigants along with untreated control treatments were used viz. (i) T_1 = Camphor @ 1 gm/kg rice, (ii) T_2 = Phostoxin tablet @ 200 mg/kg rice, (iii) T_3 = Naphthalene @ 500 mg/kg rice and (iv) T_4 = Untreated control. Both the experiments were laid out in Completely Randomized Design (CRD) with 4 replications. Data were collected on grain infestation by number and weight, survibility of weevil larvae and pupae on stored rice during the storing period.

SUMMARY

Considering the efficacy of five botanicals and three fumigants applied against *S. oryzae*, the findings of the results have been summarized below:

In case of botanical based management practices

In terms of grain infestation by number, among five botanicals, dried neem leaf powder @ 2.5 gm/kg rice performed best results in reducing the grain infestation (65.81%) over control during the management of rice weevil in storage than dried leaf powder of bishkatali, marigold, dholkalmi and mahogany; whereas, the dried mahogany leaf powder showed the least performance in reducing the percent grain infestation (32.14%) by number over control. As a result, the order of trend of efficiency among five botanicals and one untreated control in terms of percent reduction of grain infestation by number was T_1 (dried neem leaf powder) > T_2 (dried bishkatali leaf powder) > T_4 (dried dholkalmi leaf powder) > T_3 (dried marigold leaf powder) > T_5 (dried mahogany leaf powder) > T_6 (untreated control).

In terms of grain infestation by weight, among five botanicals, dried neem leaf powder @ 2.5 gm/kg rice performed best results in reducing the grain infestation by weight (57.42%) over control than dried leaf powder of bishkatali, marigold, dholkalmi and mahogany; whereas, the dried mahogany leaf powder also showed the least performance in reducing the percent grain infestation (26.76%) by weight over control. As a result, the order of trend of efficiency among five botanicals and one untreated control in terms of percent reduction of grain infestation by weight was T_1 (dried neem leaf powder) > T_2 (dried bishkatali leaf powder) > T_4 (dried dholkalmi leaf powder) > T_3 (dried marigold leaf powder) > T_5 (dried mahogany leaf powder) > T_6 (untreated control).

Considering the larval survibility, among five botanicals, dried neem leaf powder @ 2.5 gm/kg rice performed best results in reducing the larval incidence by number (64.63%) over control than dried leaf powder of bishkatali, marigold, dholkalmi and mahogany; whereas, the dried mahogany leaf powder showed the least performance in reducing the percent larval incidence (30.61%) by number over control. As a result, the order of trend of efficiency among five botanicals and one untreated control in terms of percent reduction of larval incidence by number was T_1 (dried neem leaf powder) > T_2 (dried bishkatali leaf powder) > T_4 (dried dholkalmi leaf powder) > T_3 (dried marigold leaf powder) > T_5 (dried mahogany leaf powder) > T_6 (untreated control).

In terms of pupal survibility, among five botanicals, dried neem leaf powder @ 2.5 gm/kg rice performed best results in reducing the pupal incidence by number (64.92%) over control than dried leaf powder of bishkatali, marigold, dholkalmi and mahogany; whereas, the dried mahogany leaf powder showed the least performance in reducing the percent pupal incidence (30.28%) by number over control. As a result, the order of trend of efficiency among five botanicals and one untreated control in terms of percent reduction of pupal incidence by number was T_1 (dried neem leaf powder) > T_2 (dried bishkatali leaf powder) > T_4 (dried dholkalmi leaf powder) > T_3 (dried marigold leaf powder) > T_5 (dried mahogany leaf powder) > T_6 (untreated control).

In case of fumigant based management practices

Considering the grain infestation by number, among three fumigants, Camphor showed best performance in reducing grain infestation (73.34%) over control than Phostoxin tablet and Naphthalene, where Naphthalene @ 500 mg/kg rice showed the least performance in reducing grain infestation by number (55.15%) over control. As a result, the order of trend of efficiency among three fumigants including one untreated control in terms of percent grain infestation by number was T_1 (camphor) > T_2 (phostoxin tablet) > T_3 (naphthalene) > T_4 (untreated control).

In terms of grain infestation by weight, among three fumigants, Camphor showed best performance in reducing grain infestation by weight (76.19%) over control than Phostoxin tablet and Naphthalene, where Naphthalene @ 500 mg/kg rice showed the least performance in reducing grain infestation by weight (59.96%) over control. As a result, the order of trend of efficiency of three fumigants including one untreated control in terms of percent grain infestation by weight was T_1 (camphor) > T_2 (phostoxin tablet) > T_3 (naphthalene) > T_4 (untreated control).

Considering the larval survibility, among three fumigants, camphor @ 1 gm/kg rice performed best results in reducing the larval incidence by number (75.67%) over control than phostoxin and naphthalene; whereas, the naphthalene showed the least performance in reducing the percent larval incidence (59.90%) by number over control. As a result, the order of trend of efficiency among three fumigants and one untreated control in terms of percent reduction of larval incidence by number was T_1 (camphor) > T_2 (phostoxin tablet) > T_3 (naphthalene) > T_4 (untreated control).

In terms of pupal survibility, among three fumigants, camphor @ 1 gm/kg rice performed best results in reducing the pupal incidence by number (79.52%) over control than phostoxin and naphthalene; whereas, the naphthalene showed the least performance in reducing the percent pupal incidence (66.01%) by number over control. As a result, the order of trend of efficiency among three fumigants and one untreated control in terms of percent reduction of pupal incidence by number was T_1 (camphor) > T_2 (phostoxin tablet) > T_3 (naphthalene) > T_4 (untreated control).

CONCLUSION

Based on the above findings of the study, the following conclusions have been drawn:

In case of botanical based management practices

- Dried neem leaf powder @ 2.5 gm/kg rice performed best results in reducing the grain infestation by number (65.81%) and weight (57.42%) over control during the management of rice weevil, *S. oryzae* in storage than dried leaf powder of bishkatali, marigold, dholkalmi and mahogany; whereas, the dried mahogany leaf powder showed the least performance in reducing the percent grain infestation by number (32.14% and weight (26.76%) over control.

- Considering the larval and pupal survibility of rice weevil, among five botanicals, dried neem leaf powder performed best results in reducing the incidence of weevil larvae (64.63%) and pupae (64.92%) over control than dried leaf powder of bishkatali, marigold, dholkalmi and mahogany; whereas, the dried mahogany leaf powder showed the least performance in reducing the percent incidence of larvae (30.61%) and pupae (30.28%) over control.

In case of fumigant based management practices

- Among three fumigants, Camphor performed the best results in reducing grain infestation by number (73.34%) and weight (76.19%) over control than Phostoxin tablet and Naphthalene, where Naphthalene @ 500 mg/kg rice showed the least performance in reducing grain infestation by number (55.15%) and weight (59.96%) over control.
- Considering the larval and pupal survibility of rice weevil, camphor performed the best results in reducing the incidence of larvae (75.67%) and pupae (79.52%) over control than phostoxin and naphthalene; whereas, the naphthalene showed the least performance in reducing the percent incidence of larvae (59.90%) and pupae (66.01%) by number over control.

RECOMMENDATIONS

Considering the findings of the study the following recommendations can be drawn:

1. Dried neem leaf powder and camphor should be applied against rice weevil infesting rice in storage as an effective and human health hazard free control measures.
2. More number of botanicals, their derivatives and fumigants should be included in further elaborative research for controlling rice weevil and other insect pests in stored products.

Further intensive laboratory studies should be done.

CHAPTER VI

REFERENCES

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

Abivardi, C. (1976). Additional studies on insecticidal activities of camphor to stored product insects, Zeitschrift fur Pflanzenkrankheiten und pflanzenschutz. **83**(7-8): 119 - 121.

Abivardi, C. and Benz, G. 1984. New observation on camphor an old insect repellent as a relatively safe candidate fumigant against nine insect species. *Mitteilunger der Schweizerischen Entomologischan Gesellschaft*. **57**(2-3): 179-187.

Adgesh, B.J. and Rejesus, B.M. (1991). Residual Toxicity of three plant materials against three storage insect pests. College Leguna Philippines. Dept. of Entomology. p. 29.

Aggarwal, K.K., Tripathi, A.K., Prajapati, V. and Kumar, S. (2001). Toxicity of 1,8- cineole towards three species of stored product coleopterans. *Int. J. Trop. Insect Sci.* **21**: 155-160.

Ahmed, S.M. and Eapea, M. (1986). Comparative efficacy of indigenous plant materials as repellent against *Sitophilus oryzae* Linn. *Bangladesh J. Agril. Res*. **5**(2): 31 - 35.

Alam, M.Z. (1971). Pest of stored grains and other stored products and their control. The Agricultural Information Service, Dhaka. p. 7 - 9.

Amin, M.R., Shahjahan, M., Eltaj, H.F., Iqbal, T.M.T. and Alamgir, M.H. (2000). Leaf extracts of Shiyalmutra (*Blumea lacera*) as botanical insecticides against lesser grain borrer and rice weevil. B*angladesh J. Entomol*. **10**(1-2): 1 - 13.

Amoore, J. E. and Hautala, E. (1983). Odor as an aid to chemical safety: Odor thresholds compared with threshold limit values and volatiles for 214 industrial chemicals in air and water dilution. *J. Appl. Toxicology*. **3** (6): 272–290.

Anand Prakash. (1980). Influence of age on fecundity and fertility of lesser grain borer *Rhizopertha dominica* (F.) and rice weevil *Sitophilus oryzae* (L.) in stored rice. *Bulletin of Grain Tech.* **18**: 119-121.

Andrada, M.G., Alingod, C.G., Lim, M.E.S., Cosico, M.F.A., and Martinez E.M. (2001). Field evaluation of aluminum phosphide formulations as a fumigant for the control of storage infestations. *Phytoparasitica*. **29**: 32.

Anonymous. (1933), Entomological and Zoological investigations. *Report of South Carolina Experimental Station.* **46**: 69-93.

Anonymous. (1934). Entomological and Zoological investigations. *Report of South Carolina Experimental Station*. **47**: 56-64.

Anonymous. (1981). Insect anti-feedant action of some essential oils. *Pesticides*. **15**(7): 15 - 18.

Anonymous. (2009). Rice weevil *Sitophilus oryzae* (L.) Canadian Grain Commission.

Arbogast, R.T. and Throne, J.E. (1997). Insect infestation of farm-stored maize in South Carolina: towards characterization of a habitat. *J. Stored Prod. Res*. **33**: 187 - 198.

Asmanizar, D.A. and Idris, A.B. (2008). Effect of selected plant extraction on mortality of adult *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae), a pest of stored rice grains. *Malaysian Applied Biol.* 3**7**: 41 - 46.

Azmi, M.A., Naqvi, S.N.H., Akhtar, K., Jahan, M., Habib, R. and Tabassum, R. (1993). Toxicological studies of solfac and neem formulation against *Sitophilus oryzae. National Academy Sci. Letters.* **16**(5 - 6): 187 - 190.

Banarjee, G.M. and Nigam, S.K. (1985). Role of indigenous plant materials in pest control. *Pesticides.* **19**: 33 - 38.

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.

Bazzoni, E., Sanna-Passino, G. and Moretti, M.D.L. (2002) Essential oils and other control techniques against stored product insects. In: Recent Progress in Medicinal Plants, (D.K. Majumdar, J.N. Govil, V.K. Singh, Eds.), Phytochemistry and Pharmacology II, Houston, TX, Sci Tech Publishing LLC. **8:** 313-342.

BBS (Bangladesh Bureau of Statistics). (2010). Statistical Yearbook of Bangladesh (26^{th} ed.). p. 149-156

Bheemanna, M. (1986). Studies on biology of rice weevil *Sitophilus oryzae* Linnaeus (Curculionidae : Coleptera) and host resistance in sorghum. *M. Sc. (Agri.)Thesis*, University of Agricultural Sciences, Dharwad.

Bhuiah, M.I.M. and Quinones, A.C. (1990). Use of leaves lagundi, *Vitex negundo* L. as corn seed protectant against the corn weevil *Sitophilous zeamais* Motsch. *Bangladesh J. Zool*. **18**(1): 127 - 129.

Bhuiyah, M.I.M., Islam, N., Begam, A. and Karim, M.A. (1990). Biology of rice weevil, *Sitophilus oryzae* Linnaeus. *Bangladesh J. Zool.* **18**: 67-74.

Bishop, W. P. and Sanders, K. D. (2000). Camphor hepatotoxicity. *South Med. J.,* **93** (6): 596–598.

Bowry, S.K., Pandey, N.D. and Triparthi, R.A. (1984). Evaluation of certain oilseed cake powders as grain protectant against *Sitophilous oryzae* Linn. *Indian J. Entomol*. **46**(2): 196 - 200.

BRRI (Bangladesh Rice Research Institute). (1984). Annual Report. Bangladesh Rice Research Institute, Joydebpur, Gazipur. p. 135 - 139.

BRRI (Bangladesh Rice Research Institute). (1985). Annual Report. Bangladesh Rice Research Institute, Joydebpur, Gazipur. p. 185 - 191.

Bryn, C. (2002). Study on stored grain pests and industrial use of chemicals. *Bangladesh. J. Training Develop*., **16**(2): 108-110.

Campbell, J.F. (2002). Influence of seed size on exploitation by the rice weevil, *Sitophilus oryzae. J. Insect Behav.* **15**(3): 420-445.

Catherine, A.W. and Wendell, E.B. (1987). Mating Behavior of the Maize Weevil, *Sitophilus zeamais* (Coleoptera: Curculionidae). Entomol. Soc. America. 80(5): 578-583.

Chander, H. and Ahmed, S.M. (1983). Potential of some new plant products as grain protectants against insect infestation. Bull. Grain Technol. **21**: 179 - 188.

Chander, H., Kulkarni, S.G. and Berry, S.K. (1991). Effectiveness of turmeric powder and mustard oil as protectant in stored milled rice against the rice weevil, *Sitophilus oryzae* Linn. *Int. pest con.* **33**(4): 94 - 97.

Chandra, S., Khare, B.P. and Sharma, V.K. (1978). Efficacy of some selected fumigants on rice-weevil, *Sitophilus oryzae* Linn. *Indian J. Agril. Res.* **12**(2): 79 - 84.

Charles, J.G. (1998). Rice and Grain Weevils Life Cycle. The Horticulture and Food Research Institute of New Zealand Ltd.

Chauvin, G. and Vannier, G. and Vernon, P. (1994). Insecticidal properties of paradichlorobenzene and camphor: A preliminary study on *Tineola bissellieolla* (Lepidoptera: Tineidae). First European workshop on invertebrate Eco-physiology held on 21-25, September, 1994. France. *Acta Oecologica,* **15**(1): 23-29.

Chiasson, H., Vincent, C. and Bostanian, N.J. (2004). Insecticidal properties of a Chenopodium based botanical. *J. Econ. Entom.* **97**:1378–1383.

Chu, S.S., Du, S.S., Liu, Q.Z., Liu, Q.R. and Liu, Z.L. (2012). Composition and insecticidal activity of the essential oil of *Artemisia igniaria* flowering aerial parts against *Sitophilus zeamais*. *J. Med. Plants Res.* **6**: 3188–3192.

Chu, S.S., Liu, Q.R. and Liu, Z.L. (2010). Insecticidal activity and chemical composition of the essential oil of *Artemisia vestita* from China. *Biochem. Syst. Ecol.* **38:** 489–492.

Cogburn, R.R. and Vick, K.W. (1981). Distribution of Angoumois grain moth, almond moth, and Indianmeal moth in rice fields and rice storages in Texas as indicated by pheromone-baited adhesive traps. *Environ. Entomol.* **10**: 1003 - 1007.

Cotton, R.T. (1921). Four Rhychophora attacking corn in storage. *J. Agril. Res.* **20**(8): 605-614.

Cotton, R.T. (1963). Pests of Stored grains and grain products. Burgess Publ. Co. Minnesota, 4th Edition. pp. 35 - 40.

Dakshinamurthy, A. (1988). Effect of certain plant products on storage pests of paddy. *Trop. Sci.* **28**(2): 119 - 122.

Das, G.P. (1986). Pesticidal efficacy of some indigenous plant oils against the pulse beetle, *Callosobruchus chinensis* L. (Coleoptera: Bruchidae). *Bangladesh J. Zool.* **14**(1)**:** 15 - 18.

Das, G.P. and Karim, M.A. (1986). Effectiveness of neem seed kernel oil as surface protectant against the pulse beetle, *Callosobruchus chinensis* L. (Coleoptera: Bruchidae). *Rev. Appl. Entomol.* **76**(8): 30 - 31.

Deshpande, A.D. (1967). Neem as a seed protectant against storage pests. *M. Sc. (Agri.)Thesis*, Post-Graduation Section, IARI, New Delhi.

Dey, D. and Sarup, P. (1993). Feasibility of protecting maize varieties with vegetable oils to save losses in storage due to *Sitophilous oryzae.* L. *J. Entomol. Res.* **17**(1): 1-15.

Dilwari, V.K., Dhaluiwal, D.G. and Maha, M.S. (1991). Toxicity of allylisothiocyanate to rice weevil, *Sitophylus oryzae* Linn. *J. Ins. Sci.* **4**(1): 101 - 102.

Dix, D.E. and All, J.N. (1986). Population density and sex ratio dynamics of overwintering maize weevils (Coleoptera: Curculionidae) infesting fields corn. J. *Entomol. Sci.* **21**: 368 - 375.

Duncan, D.B. (1951). A significance test for differences between ranked treatments in an analysis of variance. *Virginia. J. Sci.* **2**(9): 171 - 189.

Facknath, J. and Sunita, D. (2006). Combination of neem and physical disturbance for the control of four insect pests of stored products. *Intern. J. Trop. Insect Sci.* **26**(1):1 6 - 27.

Fava, A. and Springhetti, A. (1991). Egg distribution of Sitophilus granarius L. (Col., Curculionidae) in *Triticum aestivum* caryopses. *J. Applied Entomol*. **111:** 406-411.

Flay, C.D., He, X.Z. and Wang, Q. (2010). Influence of multiple mating on female reproductive fitness in the rice weevil, *Sitophilus oryzae*. *New Zealand Plant Protect*. **63:** 201-207.

Gelosi, A. (1982). Rice weevil, (Sitophilus oryzae Linn.). *Informatore Fitopatologico.* **32**(12): 31 - 34.

Girish, G.K. and Jain, S.K. (1974). studies on the efficacy of neem seed kernel powder against stored grain pests. Bull. Grain Technol. **12**: 226 - 228.

Hagstrum, D.W. (1985). Preharvest infestation of cowpeas by the cowpea weevil (Coleoptera: Bruchidae) and population trends during storage in Florida. *J. Econ. Entomol.* **78**: 358 - 361.

Halstead, D.G.H. (1963). External sex differences in stored products Coleoptera. *Bulletin of Entomological Research*, **54**: 119-134.

Hamed R. K. A., Ahmed S M.S., Abotaleb A.O.B. and ELSawaf B. M. (2012). Efficacy of certain plant oils as grain protectants against the rice weevil, *Sitophilus oryzae* (Coleoptera: Curculionidae) on wheat. Egypt. Acad. J. Biolog. Sci. **5**(2):49-53.

Hiremath, I.G., Ahn, Y.G. and Kim, S.I. (1997). Insecticidal activity of Indian plant extracts against *Nilaparvata lugens* (Homoptera: Delphacidae). *Appl. Entomol. Zool.* **32**(1): 159 - 166.

Honek, A. (1993). Intraspecific variation in body size and fecundity of insects: a general relationship. *Oıkos*. **67:** 483-492.

Hussain, M. (1995). Controlling rice borers under Bangladesh conditions. *Pestology*. **8**(8): 28 - 30.

Igantowicz, S. (1997). Repellency of powered plant materials of the ribbed melilot and the white melilot to the grain weevil and the rice weevil. *Prog. plant prot.* **37**(2): 46 - 49.

Igantowicz, S. and Wesolowska, B. (1996). Repellency of powered plant material of the Indian neem tree, the Labrador tea, and the Sweetflag to some stored product pests. *Plolskie-Pismo-Entomologiczene.* **65**(1-2): 61 - 67.

Imtiaz, A., Farzana, S., Azmi, M.A., Rizvi, S.A., Muzaffer, A. and Shakoori, A.R. (2001). Comparative toxicological studies of neem leaf extract and cyhalothria (pyrethroid) against *Sitophilous oryzae* and their effects on alkaline phosphatase activity. *Proc. Pakistan congr.* **21**: 255 - 261.

Islam, B.N. (1984). Pesticidal action of neem and certain other indigenous plants and weeds of Bangladesh. In Proc. 2nd Int. Neem Conf. *Ranischhlolzhausen.* pp. 263 - 290.

Islam, B.N. (1987). Use of some extracts from Meliaceae and Annonaceae for control of rice hispa, *Dicladispa armegera* and the pulse beetle *Collosobruchus chinensis.* Proc. 3rd Int. Neem Conf., Nairobi, Kenya. pp. 217 - 242.

Ivbijaro, M.I., Ligan, C. and Youdeowei, A. (1985). Control of rice weevil, *Sitophilus oryzae* Linn. in stored maize with vegetable oils. *Agric. Ecosystem and Env.* **14**(3- 4): 237 - 242.

Jacobson, M. (1986). The neem tree: natural resistance par excellence. In Natural resistance of plants to pests (ed. Green, M.B. and Hedin, P.A.). American Chemical Society, Washington, DC. ACS Symp. Ser. 296.

Jiang, G.H., Liu, Q.R., Chu, S.S. and Liu, Z.L. (2012). Chemical composition and insecticidal activity of the essential oil of *Artemisia eriopoda* against maize weevil, *Sitophilus zeamais*. *Nat. Prod. Commun.* **7**: 267–268.

Jilani, G. and Su, M.C.F. (1983). Laboratory studies on several plant materials, as insect repellents for protection of cereal grains. *J. Econ. Entomol.* **76**: 154 - 157.

Jilani, G. (1986). Use of botanicals for protection of stored food grains against insect pests : A review. *Work Done at Grain Storage Research Laboratory*. PARC, Karachi, Pakistan. pp. 30 - 35.

Jilani, G. and Saxena, R.C. (1987). Derivatives of neem, turmeric and sweetflag as grain protectant against stored grain insect pests. International Rice Res. Inst. Los Nanos, Manila (Philippines). p. 1.

Jotwani, P. and Sirkar. (1965). Studies on the incidence and extent of damage due to insect pests in stored seeds. *Indian J. Entomol.* **30**(1): 61-65.

Juneja, R.P. and Patel, J.R. (1994). Botanical materials as protectant of greengram *Vigna radiata* (L.) against pulse beetle *Callosobruchus analis* Fabricus- I. *Gujarat Agricultural University Res. J.* **20**: 84 - 87.

Kabir, K.H., Raman, M.A. and Ahmed, M.S. (2003). Utilization of different containers, chemicals and indigenous materials for the management for the management of pulse beetle (*Callosobruchus chinensis* L.) in storage. *Annual Report*, Entomology Division, Bangladesh Agricultural Research Institute, Joydebpur, Gazipur. pp. 67 - 71.

Kalasagond, P.R. (1998). Management of beetle pests in stored wheat by non-insecticidal approaches. *M. Sc. (Agri.) Thesis*, University of Agricultural Sciences, Dharwad.

Karim, A.N.M.R. (1986). The hispa episode. Modern rice cultivation workshop, BRRI, Joydebpur. pp. 125 - 160.

Kashyap, N.P., Bhagat, R.M., Sharma, D.C. and Suri, S.M. (1992). Efficacy of some useful plant leaves for the control of potato tuber moth, *Phthorimaea operculella* Zell. in stores. *J. Entomol Res.* **16**: 223 - 227.

Ketkar, C.M. (1976). Utilization of neem *(Azadirachta indica* A. Juss) and its byproducts. VIC, Bombay, India. p. 234.

Ketkar, C.M. (1989). Modified neem cake manurial project, utilization of neem (*Azadirachta indica* A. Juss) and its by products. Khadi and Village Industries Commission, Bombay, India.

Khalequzzaman, M. and Islam, M.N. (1992). Pesticidal action of Datura, *Datura metel* Linn. Leaf extracts on *Tribolium castaneum* Herbst. *Bangladesh J. Zool.* **20**(2): 223 - 229.

Khalequzzaman, M. and Osman Goni, S.H.M. (2009). Toxic Potentials of Some Plant Powders on Survival and Development of *Callosobuchus maculatus* (F.) and *Callosobuchus chinensis* L. *J. Life Earth Sci.* **(3,4)**: 1 - 6.

Khan, M. and Shahjahan, R.M. (1998). Evaluation of eucalyptus leaf extracts as repellent for adult of *Sitophilous oryzae* (L.) (Coleoptera: Curculionidae) and attractant for *Callosobruchus chinensis* (L.) (Coleoptera: Bruchidae) *Bangladesh J. Entomol.* **8**(1-2): 81 - 88.

Khosla, R.K. (1997). Techniques for assessment of loses due to pest and diseases of rice. *Indian J. Agric. Sci.,* 47(4): 171-174.

Kim, S., Ahn, Y.J. and Kwon, H.W. (2010). Toxicity of aromatic plants and their constituents against Coleopteran stored products insect pests. New perspectives in plant protection. p: 94 -120.

Kiritani, K. (1965). Biological studies on the *Sitophilus* complex (Coleoptera: Curculionidae) in Japan. *J. Stored Products Res.* **1**: 169-176.

Koehler, P.G. (2008). Rice weevil, *Sitophilus oryzae* (Coleoptera: Curculionidae). University of Florida IFAS Extension.

Kordali, S., Aslan, I., Calmasur, O. and Cakir, A. (2006). Toxicity of essential oils isolated from three *Artemisia* species and some of their major components to granary weevil, *Sitophilus granarius* (L.) (Coleoptera: Curculionidae). Ind. Crops Prod. **23**: 162-170.

Kumari, K., Sinha, M.M., Mehto, D.N. and Hammed, S.F. (1990). Effect of some vegetable oils as protectants against pulse beetles *Callosobruchus chinensis.* Bull Grain Technol. **28**(1): 58 - 60.

Kundu, B.R., Ara R., Begum, M.M. and Sarker, Z.I. (2007). Effect of Bishkatali, *Polygonum hydropiper* L. plant extracts against the red flour beetle, *Tribolium castaneum* Herbst. *Univ. j. zool. Rajshahi Univ*. **(26)**:93 – 97.

Latif, M.A., Ali, M.Y. and Ali, M. (2009). Effect of Some Containers, Chemicals and Indigenous Materials on Incidence of Wheat Pests in Storage. *Agric Rural Dev*. **7**(1&2): 107-113.

Latif, M.A. and Rahman, M.M. (2000). Efficacy of camphor in protecting rice grains infested by rice weevil (*Sitophilus oryzae* Linn.) in storage. *J. Agric. Sci. Tech.* **1**(1): 65-69.

Latif, M.A., Rahman, M.M. and Alam, M.Z. (2004). Efficacy of camphor in protecting rice grains infested by rice weevil (*Sitophilus oryzae* Linn.) in storage. *J. Agric. Educ. Technol.* **7**(1-2): 75 - 78.

Lee, B.H., Annis, P.C., Tumaalii, T. and Choi, W.C. (2004) Fumigant toxicity of essential oils from the *Myrtaceae* family and 1,8-cineole against 3 major stored-grain insects. *J. Stored Prod. Res*. **40**: 553–564.

Lee, S.E., Kim, J.E. and Lee, H.S. (2001). Insecticide resistance in increasing interest. *Agricl. Chem. Biotech.* **44**: 105–112.

Lefevre, P.C. (1953). Etude de *Calandra oryzae* (L.) sur sorgho (*Sorghum vulgare* Bert). *Bulletin of Agricultural Congress Belge*. **44**: 1001-1046.

Lin, T. (1958). Bionomics studies of rice weeil, *Sitophilus oryzae* Linnaeus. *Agril.l Res.* **8**: 44-54.

Liu, Z.L., Liu, Q.R., Chu, S.S. and Jiang, G.H. (2010). Insecticidal activity and chemical composition of the essential oils of *Artemisia lavandulaefolia* and *Artemisia sieversiana* from China. *Chem. Biodiv.* **7**: 2040–2045.

Longstaff, B.C. (1981). Biology of the grain pest species of the genus *Sitophilus* (Coleoptera: Curculionidae): A critical review. *Protect. Ecol.* **2**: 83-130.

Lopez-Cristobal, U. (1953). The preservation of stored grain: A new technique with a synthetic insecticide. *Rev. Fac. Agron. Eva. Peron*. **29**: 85-106.

Mahanti, V. (2002). Ecology and management of stored grain pests of maize. *Ph. D. Thesis*, Acharya N. G., Ranga Agricultural University, Hyderabad.

Makanjuloa, W.A. (1989). Evaluation of extracts of neem, *Azadirachta indica* A. Juss. For the control of some stored product pests. *J. Stored prod. Res.* **25**(4): 231 - 237.

Malik, M.M. and Mujtaba Naqvi S.H. (1984). Screening of some indigenous plants as repellents or antifeedants for stored grain insect. *J. Stored Prod. Res.* **20**(1): 41 - 44.

Mamun, M.S.A., Shahjahan, M. and Ahmad M. (2009). Laboratory evaluation of some indigenous plant extracts as toxicants against red flour beetle, *Tribolium castaneum* Herbst. J. Bangladesh Agril. Univ. **7**(1): 1 – 5.

Mann, J., Davidson, R.S., Hobbs, J.B. and firbornc, J.B. (1994). Natural products, Addison Wesley Longman ltd, Harlow, UK. pp. 309-311.

Martin, D., Valdez, J., Boren, J. and Mayersohn, M. (2004). Dermal absorption of camphor, menthol, and methyl salicylate in humans. *J. Clin. Pharmacol.,* **44** (10): 1151–1157.

Mason, L.J. (2003). Grain Insect Fact Sheet, E-237-W: Rice, Granary, and Maize Weevils *Sitophilus oryzae* (L.), *S. granarius* (L.), and *S. zeamais* (Motsch). Purdue University, Department of Entomology.

Mishra, B.K., Mishra, P.R. and Mohapatra, H.K. (1992). Studies on some plant product mixtures against *Sitophilus oryzae* (L.) infesting wheat seeds. *Indian J. Plant Protec.* **26**: 178 - 182.

Mordue (Luntz), A.J. and Blackwell, A. (1993). Azadirachtinan update. *J. Insect Physiol.* pp. 903 – 924.

Moreno, E. C. B. and Ramirez, J. 1988. The influence of hermetic storage on the behaviour of maize seed germination. Seed Science and Technol.16: 427-434.

Nakayama, S. (1931). Biology studies on the rice weevil, *Calandra oryzae* (L.). *J. Agric. Experimen. Stat. Govt. Gen. Chosen.* **18**: 25-69.

Nawrot, J. (1985). Principles for control of grain weevil, *Sitophilous granaries* L. (Coleoptera: Curculionidae) using natural plants compounds affecting the behaviour of the beetles. *J. Appl. Entomol.* **24**(2): 173 - 197.

Nawrot, J. (1983). Principles for grain weevil (*Sitophilus granarius* L.) (Coleoptera: *Curculionidae*) control with use of natural chemical compounds affecting the behavior of beetles. Prace Naukowe Instytutu Ochrony Roslin. **24**: 173-197.

Newman, L.J. (1927). Grain weevils. *J. Dept. Agril. W. Australia.* **45**: 538-545.

Niber, B.T., Helenius, J., Nairs, A.L. and Tierto Niber, B. (1992). Toxicity of plant extracts to three storage beetles (Coleoptera). *J. Appl. Entomol.* **113**(2): 202 - 208.

Okuni, T. (1924). Insect pests of stored grains in Formosa Part I. Res. Ins. Agric. **6**: 1-16.

Perez-Mendoza J., Throne, J.E. and Baker J.E. (2004). Ovarian physiology and age-grading in the rice weevil, *Sitophilus oryzae* (Coleoptera: Curculionidae). *J. Stored Products Res.* 179–196.

Perveen, B., Malek, M.A., Talukder, D., Khanam, L.A.M., Dey, K.C. and Rafiqul, I. (1998). Effectiveness of two indigenous plant extracts against three stored product insect pests, Bangladesh. *J. Sci. Ind. Res.* **33**(2): 287 - 289.

Pittendrigh, B.R., Huesing, J.E., Shade, R.E. and Murdock, L.L. (1997). Monitoring of rice weevil, *Sitophilus oryzae*, feeding behaviour in maize seeds and the occurrence of supernumerary molts in low humidity conditions. *Entomologia Experimentalis et Applicata*, **83**: 225-231.

Prakash, A and Mathur, I.C. (1981). Plant products in insect pests management of stored grains. *Bull. Grain Technol.* **19**(3): 213 - 219.

Prakash, A, and Rao, J. (1983). Insect pests and their management in rice storage in India, presented in National Symposium on Maximising and Stabilising of yields on rain fed rice production system held at CSRRI, Cuttack (India) on

Feb. pp. 23 - 25.

Prakash, A., Rao, J., Gupta, S.P. and Behra, J. (1993). Evaluation of botanical pesticides as grain protectants against rice weevil, *Sitophilus oryzae* Linn. *Botanical pesticides in integrated pest management.* **17**: 360 - 365.

Prakash, A., Rao, J., Pasalu, I.C. and Mathur, K.C. (1987). Rice Storage and insect pest management. B. R. Publishing Corporation, Delhi. p. 15 - 60.

Rahman, L.M. (1998). Laboratory evaluation of urmoi, neem and turmeric for controlling the rice weevil. M.S. Thesis, Dept. of Entomology, BAU, Mymensingh. p. 115.

Rahman, M.L., Hossain, M. and Ahmad, M. (1999). Repellent effect of urmoi, neem and turmeric extracts against rice weevil and granary weevil. *Bangladesh J. Entomol.* **9**(1-2): 9 - 16.

Rai, L., Sarid, J.N. and Pingalc, S.V. (1963). Fumigation of food grains in India with hydrogen phosphide, Series I, Tests in concrete bins. *Bull. Grain Technol.* **1**(1-2): 3 - 15.

Rajapakse, R.H.S., Senanayake, S.G.J.N. and Patnasekara, D. (1998). Effect of the five botanicals on oviposition, adult emergence and mortality of *Callosobruchus maculatus* Fab. (Coleoptera: Bruchidae) infesting cowpea *Vigna unguiculata* L. Walp. *J. Entomol. Res.* **22**: 117 - 122.

Rama Rao, C.V. and Sarangi, P.K. (1998). Control of *Sitophilus oryzae* (L.) through certain plant products. *Indian J. Plant Protec.* **26**: 183 - 184.

Rani, P.U. and Jamil, K. (1989). Effect of water hyacinth leaf extract on mortality, growth and metamorphosis of certain pests of stored products. *Sci. Appl.* **10**(3): 327 - 332.

Rees, D. (2004). Insects of stored products. CSIRO Publishing, Collingwood, Australia. P: 192.

Rouf, F.M.A., Sardar, M.A. and Ahmed K.S. (1996). Individual and combined effects of some plant materials for protection of lentil seeds against pulse beetle, *Callosobruchus chinensis* L. *Bangladesh J. Entomol.* **6**(1-2): 13 - 21.

Rowe, L. (1994). The costs of mating and mate choice in water striders. *Animal Behav.* **48:** 1049-1056.

Rozman, V., Kalinovic, I. and Korunic, Z. (2007). Toxicity of naturally occurring compounds of Lamiaceae and Lauraceae to three storedproduct insects. *J. Stored Prod. Res.* **43**: 349 - 355.

Rozman, V., Kalinovic, I. and Korunic, Z. (2007). Toxicity of naturally occurring compounds of *Lamiaceae* and *Lauraceae* to three stored-product insects. *J. Stored Prod. Res*. **43**: 349–355.

Rozman, V., Kalinovic, I. and Liska, A. (2006). Bioactivity of 1,8-cineole, camphor and carvacrol against rusty grain beetle (*Cryptolestes ferrugineus* Steph.) on stored wheat. *Proceedings of the 9th International Working Conference onStored Product Protection,Campinas, Sao Paulo, Brazil.* 687–694.

Russel and Mercer, P. (1962). Effects of Sorghum Varieties on the Rice Weevil, *Sitophilus oryzae* (L.) I. Oviposition, Immature Mortality, and Size of Adults. *Entomol. Soc. America.* **55**(6): 678-685.

Ryoo, M.I. and Cho, H.W. (1992). Feeding and ovipositional preferences and demography of rice weevil (Coleoptera: Curculionidae) reared on mixtures of brown, polished and rough rice. *Environ. Entomol*. **21**(3): 549 - 555.

Sahayaraj, K. and Paulraj, M.G. (1998). Screening the relative toxicity of some plant extracts to *Spodoptera litura* Fab. of groundnut. *Fresenius. Environ.* **7**(9-10): 557 - 560.

Saim, N. and Meloan, C.E. (1986). Compounds from leaves of Bay (*Laurus nobilis* L.) as repellents for *Tribolium castaneum* (Herbst) when added to wheat flour. *J. Stored Pro. Res.* **22**: 141 - 144.

Salama, S.L. (2008). Efficiency of some plant extracts as seed protectants against *Sitophilus oryzae* (L.) and *Callosobruchus maculatus* (F.). Cairo, Egypt: Faculty of Agriculture, Ain Shams University. *Arab Univ. J. Agric. Sci*. **12** (2): 771-781.

Sanguanpong, U. (1996). Using the neem oil pelletes in controlling the rice weevil *Sitophilus oryzae. J. National Res. Council*, Thailand. **29**(1-3): 6 - 15.

Sanguanpong, U., Kongkathip, N. and Sombatsiri, K. (2001). Reproductive inhibition of rice weevil, *Sitophilus oryzae* (L.) induced by vapor of formulated neem-oil based pellets. 20th ASEAN/2nd APEC Seminar on Postharvest "Quality Management and Market Access", Lotus Pang Suankaew Hotel, Chiangmai, Thailand.

Sarac, A. and Tunc, I. (1995). Toxicity of essential oil vapours to stored- product insects. *Zeitschrift fiir Pflanzenkrankleiten und Pflan-Zenschhutz.* **102**(1): 69 - 74.

Sattigi, H.N. (1982). Studies on the biology, chemical control of *Sitophilus oryzae* Linnaeus (Curculionidae : Coleoptera) and *Rhizopertha dominica* Fab. (Bostrychidae : Coleoptera) and residue analysis of insecticides. *M. Sc. (Agri.) Thesis*, University of Agricultural Sciences, Dharwad.

Saxena, R.C. (1986). Antifeedant in tropical pest management. *Insect Sci. Appl.* **8**(4-6): 731 - 736.

Saxena, R.C. (1989). Insecticides of plant origin. American Chemical Society, Washington, DC. ACS Symposium Series 387. pp. 110 – 135.

Schmutterer, H. (1990). Properties and potential of natural pesticides from the neem tree, *Azadirachta indica*. *Annu. 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 major storedproduct insects. *J. Chem. Ecol.* **17**: 499 – 504.

Sharaby, A. (1988). Evaluation of some Myrtaceae plant leaves as protectant against the infestation by Sitophilus oryzae L. and Sitophilus granarius L. *Insect Sci. Appl.* **9**: 465 – 468.

Sharaby, A. (1989). Some Myrtaceae leaves of protectants of rice against the infestation of *S. oryzae* L. and *S. granaries* L. *Polskie-Pesmo-Entomologiczene*. **59**(2): 337 - 382.

Sharifi, S. and Mills, R.B. (1971). Developmental activities and behaviour of the rice weevil, *Sitophilus oryzae* (L.), within the kernels of wheat. *J. Econ. Entomol.* **64**: 1114-1118.

Sharma, R.K. (1995). Suppression of insect reproductive potential by neem in stored maize. *Annals of Plant Prot. Sci.* **3**: 113 - 114.

Sharma, R.K. (1999). Efficacy of neem products against storage pests in maize. *Annals of Agric. Res.* **20**: 198 - 201.

Sharvale, T. G. and Borikar, P. S. (1998). Laboratory evaluation of plant products and grain protectants for prevention of damage by *Callosobruchus* *chinensis* (Linnaeus) in stored chickpea. Agricultural Science Digest. **18**: 234 - 236.

Shazali, M.E.H. (2000). Control of insect pests in bagged sorghum under gas-proof sheets by two phosphine releasing products. *Sudan J. Agril. Res*. **3**:41-47.

Shazali, M.E.H. and Smith, R.H. (1985). Life history studies of internally feeding pests of stored sorghum: *Sitotroga cerealella* (Ol.) and *Sitophilus oryzae* (L.). *J. Stored Products Res.* **21**(4): 171-178.

Siddika, A. (2004). Efficacy of some additives for suppressing Rice moth (*Sitotroga cerealella*) in stored rice. M.S. Thesis Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur. p: 64.

Singh, D., Siddiqui, M.S. and Sharma S. (1989). Reproduction retardant and fumigant properties of essentials oils against rice weevil (Colleoptera: Cuuculionidae), in stored wheat. *J. Econ. Ent.* **82**(3): 727 - 733.

Singh, K. (1987). Seasonal variations in the population of insect pests of stored products in West Bengal. *Indian J. Ecol.* **4**(2): 66 - 77.

Singh, K., Agrawal, N.S. and Girish, G.K. (1974). The oviposition and development of *Sitophilus oryzae* (L.) in different high-yielding varieties of wheat. *J. Stored Products Res.* **10**: 105-111.

Singh, R.P., Chari, M.S., Raheja, A.K. and Kraus W. (1996). Neem and Environment. Oxford and IBH publishing, New Dehli, India. pp. 1 - 1198.

Sivasrinivas. (2001). Evaluation of indigenous products and boric acid against stored grain pests. *M. Sc. (Agri.) Thesis*, University of Agricultural Sciences, Dharwad.

Smith, L.B. and Barker, P.S. (1987). Distribution of insects found in granary residues in the Canadian prairies. *Can. Entomol.* **119**: 873 - 880.

Smith, R.H. (1986). Oviposition, competition and population dynamics in storage insects. Proceedings of the 4th International WorkingConference on Stored-Product Protection, Tel Aviv, Israel. 427-433.

Sowunmi, O.E. and Akinnusi, O.A. (1983). Studies on the use of the neem kernel in the control of stored cowpea beetle *Callosobruchus maculatus*. Trop. Grain Leg. Bull. **27**: 28 - 31.

Srivastava, S., Gupta, K.C. and Agarwal, A. (1989). Effect of plant product on Callosobruchus chinensis L. infestation on red gram. *Rev. Appl. Entomol.* **77**(9): 781.

Stejskal, V. and Kucerova, Z. (1996). The effect of grain size on the biology of Sitophilus granarius L. (Coleoptera: Curculionidae). I. Oviposition, distribution of eggs and adult emergence. *J. Applied Entomol*. **120:** 143-146.

Stoyanova, S. and Shikerenov D. (1983). Use of phosphene preparation for the de-infestation of wheat and flour. *Rasticina Zaschita.* **31**(2): 30 - 33.

Su, H.C.F. (1989). Laboratory evaluation of dill seed extract in reducing infestations of rice weevil in stored wheat. *J. Entomol. Sci.* **24**(3): 317 - 320.

Su, H.C.F. (1991). Toxicity and repellency of chenopodium oil to four spccies of stored-product insects. *J. Entomol. Soc.* **26**(1): 178 - 182.

Sunil kumar. (2003). Survey of indigenous technologies and evaluation of botanicals against major storage pests. *M. Sc. (Agri.) Thesis*, University of Agricultural Sciences, Dharwad.

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 Prod. Res.* **47**: 222-230.

Talukdar, F.A. and Howse, P.E. (1993). Deterrent and insecticidal effect of extract of pithraj, *Aphanamixis polystacha* against *Tribolium Castaneum*. *J. Chem. Ecel.* **9**: 2463 - 2471.

Talukder, F.A. and Howse, P.E. (1994). Laboratory evaluation of toxic and repellent properties of the pithraj tree, *Aphanamixis polystachya* Wall and Parker against *Sitophilus oryzae* L. *Int. J. Pest Management*. **41**(3): 274 - 279.

Talukder, F.A. and Howse, P.E. (1995). Efficasy of pithraj, *Aphanamixis polystachya* seed extracts against stored product pests. Proc. 6th Int. Working Conf. Stored Product Protect, Canberra, Australia.

Tanzubil, P.B. (1987). The use of neem products in controlling the cowpea weevil, *Callosobruchus maculates* Fab. *Nyankpala Agric. Exp. Sta. Crops Res. Inst.* pp. 517 - 523.

Timothy, T.E. and Odili, E.O. (2009). Biocidal activity of selected plant powders against *Tribolium castaneum* Herbst in stored groundnut (*Arachis hypogaea* L.). *African J. Environ. Sci.Tech*. **3**(1): 1-5.

Treiman, F.S. (1937). On the morphology and biology of *Calandra oryzae* (L.). *Travaux Institute for Academic Sciences.* **14**: 256-277.

Urrelo, R. and Wright, V.F. (1989). Oviposition preference of *S. zeamais* (M.) (Coleoptera : Curculionidae) on resistant and susceptible maize accessions. *J. Kansas Entomol. Soc.* **62**: 23-31.

Valsamma, G. and Patel, J.R. (1992). Mint, *Mentha spicata* – A promising botanicals protectant for greengram against pulse beetle *Callosobruchus analis* F. *Indian J. Plant Prot.* **20**: 66 - 69.

Walker, K. (2008b). Rice weevil (*Sitophilus oryzae*). Pest and Diseases Image Library.

Watson, P., Stallmann, R. and Arnqvist, G. (1998). Sexual conflict and the energetic costs of mating and mate choice in water striders. *The American Naturalist.* **151:** 46-58.

Weaver, D.K., Dunkel, F.V., Potter, R.C. and Ntezurubanza, L. (1994). Contact and fumigant efficacy of powdered and intact *Ocimum canum Sims* (Lamiales: Lamiaceae) against *Zabrotes subfasciatus* (Boheman) adults (Coleoptera: Bruchidae). *J. Stored Prod. Res.* **30**: 243 – 252.

Weaver, D.K., Phillips, T.W., Dunkel, F.V., Weaver, T., Grubbe, R.T. and Nance, E.L. (1995). Effect of camphor on embryonic and post-embryonic development *citikbobruchus chinensis* (L.). *J. Chemical Ecol.* **21**(2): 127 - 142.

Wenholz, H. (1927). Storage of maize in coastal districts. Agriculture Coloniale, *New South Wales.* **38**: 255-261.

Wille, J. (1923). Contribution to the biology of rice weevil *C. oryzae Zeitschift Fuer Angewandte.* **9**: 333-342.

William F.L. (1991). Granary and Rice Weevils. Ohio State University Extension Fact Sheet. Kenny Road, Columbus. OH 43210-1000.

Xie, Y.S., Fields, P.G. and Isman, M.B. (1995). Repellency and toxicity of azadirachtin and neem concentrates to 3 stored product beetles. *J. Econ. Entomol.* **88**: 1024 - 1031.

Xu Hanhong and Zhao Shanhuan. (1994). Studies on insecticidal activity of cassia oil and its toxic constituent analysis. *J. South China Agric. Univ.* **15**(1): 27 - 33.

Yadav, T.D. (1983). Seed fumigation as an aspect to seed storage technology. *Seed Res.* **11**(2): 240 - 247.

Yevoor. (2003). Biology and management of rice weevil, *Sitophilus oryzae* (Linn.) in maize grains. *M. Sc. (Agri.) Thesis*, University of Agricultural Sciences, Dharwad.

Zhang and Zhao. (1983). The Use of Spices and Medicinals as Bioactive Protectants for Grains by P. Golob. p. 137.