

**INVESTIGATIONS ON THE EGG REMOVAL DEVICE FOR PULSE  
BEETLE (TNAU PATENT, 198434) FOR OTHER IMPORTANT  
PESTS OF STORAGE GRAINS**

Thesis submitted in part fulfillment of the requirements for the award of the degree of  
**MASTER OF SCIENCE (AGRICULTURE) IN AGRICULTURAL ENTOMOLOGY**  
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**By**

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## CERTIFICATE

This is to certify that the thesis entitled “**INVESTIGATIONS ON THE EGG REMOVAL DEVICE FOR PULSE BEETLE (TNAU PATENT, 198434) FOR OTHER IMPORTANT PESTS OF STORAGE GRAINS**” submitted in part fulfillment of the requirements for the award of degree of **MASTER OF SCIENCE (AGRICULTURE) IN AGRICULTURAL ENTOMOLOGY** to the Tamil Nadu Agricultural University, Coimbatore is a record of bonafide research work carried out by **Mr. S.A. JAYAPRAKASH**, under my supervision and guidance and that no part of this thesis has been submitted for the award of any other degree, diploma, fellowship or other similar titles or prizes and that the work has not been published in part or full in any scientific or popular journal or magazine.

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**(S.A. JAYAPRAKASH)**

*Abstract*

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## ABSTRACT

### INVESTIGATIONS ON THE EGG REMOVAL DEVICE FOR PULSE BEETLE (TNAU PATENT, 198434) FOR OTHER IMPORTANT PESTS OF STORAGE GRAINS

By

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Investigations were carried out to assess the efficiency of egg removal device for pulse beetle (TNAU Patent, 198434) in the removal of eggs of other major stored product insects. The egg removal device for pulse beetle was also upgraded as a power-operated mechanical unit and its efficiency in the removal of eggs and adults were evaluated.

The egg removal efficiency of hand-operated egg removal device was proved to be effective in the removal of eggs of major stored grain pests. Better egg removal was achieved in the case of rice moth, *Corcyra cephalonica* Stainton, when the device was operated for 3 days (15 minutes/day). It was also found effective in the removal of eggs of Angoumois grain moth, *Sitotroga cerealella* Olivier, from infested sorghum, paddy and wheat grains. Among the grains a higher percentage of control was observed in wheat followed by sorghum and paddy.

A significant reduction in the number of offspring adults were noticed when the grains (sorghum, wheat, maize and paddy) artificially infested with the maize weevil, *Sitophilus zeamais* Motsch; the red flour beetle, *Tribolium castaneum* Herbst. and the lesser grain borer, *Rhyzopertha dominica* Fab. were subjected to 3 days treatment

(15 minutes/day). Among the insects tested a higher percentage of reduction in the emergence of offspring adults were noticed in *R. dominica*, followed by *T. castaneum* and *S. zeamais* in sorghum and wheat grains, whereas in maize grain it was in the order of *R. dominica* followed by *S. zeamais* and *T. castaneum* and in paddy it was in the order of *R. dominica* followed by *S. zeamais*.

It was observed that the egg removal device was also effective in the removal of eggs of cigarette beetle *Lasioderma serricornis* F.

To avoid variation in the speed of rotation and for the practical application of the egg removal device, the prototype was upgraded as power-operated mechanical unit.

The power-operated mechanical unit was also proved to be effective in the removal of eggs of major stored product insects. It was found that the power-operated mechanical unit was effective in the removal of eggs of *S. zeamais*, *T. castaneum* and *R. dominica* from infested sorghum, wheat, maize and paddy grains.

The power-operated mechanical unit was also tested and found effective in the removal of adults of *S. zeamais*, *T. castaneum* and *R. dominica* from artificially infested sorghum, wheat, maize and paddy grains. It was noticed that the maximum number of adults were removed in a duration of 60 minutes. A high percentage of adults of *T. castaneum* were removed followed by *S. zeamais* and *R. dominica* at the same time duration. With respect to the various grains tested the insect removal percentage was higher in maize grains.

It was observed that there was no much mechanical impact of rotation on germination and the grain damage was also very meagre.

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## *Introduction*

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# CHAPTER I

## INTRODUCTION

Storage, in its comprehensive connotation, performs some complex and critical functions. Firstly, it provides for the physical safety of food grains for long periods underlining the need for good covered storage accommodation. Secondly, it safeguards the quality of grains so stored including its nutritional value resulting from a package of practices for proper preservation and suitably trained man power to implement it. Thirdly, storage is the kingpin for a sound food security system. Thus storage management lies at the heart of the management of the food economy (Kamla Prasad, 1980). The problem of feeding the ever increasing human population does not end with production of food grains. It involves a variety of functions right from the protection from deterioration and wastage of all what has been produced to their equitable distribution to the needy which have not received sufficient attention in many countries of the world. Unless the problems of storage are satisfactorily solved, the problem of feeding hungry millions may continue even with substantial increase in food production.

( The stored grains are attacked by more than a dozen of stored grain insect pests (Simwat and Chahal, 1982). These insects develop or multiply among the stored grains. The larvae and adults of some species feed in/on the grains and cause losses of different types i.e. quantitative or weight loss, qualitative and loss of seed viability. Quantitative damage is due to grain weight loss caused by insect feeding (Golebiowska, 1969). Qualitative damage is due to product alterations such as loss of nutritional and aesthetic value, increased levels of rejects in the grain mass and loss of industrial (baking) characteristics. Insects are also important pests of stored seed and may damage the seed embryos, causing a decrease in germination (Monino *et al.*, 1998). )

✓ ( Insects in grains are undesirable not only from an aesthetic point of view, but also from the point of view of public health (Gupta, 1983). The major economic loss caused by grain infesting insect is not always the actual material they consume, but also the amount contaminated by them and their excreta which makes food unfit for human consumption.) In India, post-harvest losses caused by the unscientific storage, rodents, insects, micro-organisms, moisture etc. account for about 10 per cent of total food grains

(Bhargava *et al.*, 2007). A world survey by F.A.O. indicated about 5 per cent loss of cereals, in storage annually (Herford, 1952). In India only 10 per cent of the total produce is handled by public agencies. The other 90 per cent is handled by farmers and the private trade both for seed and consumption purposes (Kamla Prasad, 1980). The most vulnerable point is the farmers storage both in farm and at home where 60 to 70 per cent of produce is retained (Vimala and Pushpamma, 1983). Even the most conservative estimate of 3 per cent loss in farm storage would almost be a loss of about 4 million tonnes of grain annually (Kamla Prasad, 1980).

Stored product insects assume greater importance as they start their damage in the field itself (Mohan and Subba Rao, 2000). Generally stored product insects fly from nearby farms, farm store houses or cultivators store and start laying eggs on the maturing grains. Then this problem is further complicated as the infestation is invariably carried over from field to storage. This field infestation paves way for the further development of the insects during storage of grains and cause heavy loss.

Use of pesticides and fumigants are the most frequently followed methods to prevent some losses during storage. However, the choice of pesticides for storage pest control is very limited because of the strict requirements imposed for the safe use of synthetic insecticides on or near food (Padin *et al.*, 1997). The continuous use of chemical pesticides for control of stored grain pests has resulted in serious problems such as insecticide resistance (Pacheco *et al.*, 1990; Sartori *et al.*, 1990). Further more the efficacy of insecticides against storage pest varies greatly after treatment (Suchita *et al.*, 1989).

Thus it is evident that the insect pests and use of insecticides on insect pests pose a very serious threat to stored grains. Hence, an all-round effort should be made to keep the grains safe under storage employing the recent techniques and fully exploiting the various principles of pest control based on ecology-cum-economics.

In this context physical removal of eggs and adults from grain in storage is one of the best alternative methods for the reduction of damage by insects and insect's progeny. Insect removal devices play a vital role in the removal of stored product insects from food grains (Mohan, 1994). As like insect removal devices, TNAU patented (Patent number: 198434) "Egg removal device for pulse beetle" assumes importance to

remove insect eggs from grains. As the TNAU patented device has been tested only for pulse beetle, assessing the efficacy of the device for other important pests will enable to recommend the device for major stored product insects attacking stored commodity. Hence, investigations were carried out on the egg removal device on the removal of eggs of major stored product insect pests of food grains with the following objectives:

- 1) To study the efficiency of egg removal device (TNAU Patent, 198434) in the removal of eggs of insect pests like,
  - i) Rice moth (*Corcyra cephalonica* Stainton)
  - ii) Angoumois grain moth (*Sitotroga cerealella* Olivier)
  - iii) Red flour beetle (*Tribolium castaneum* Herbst.)
  - iv) Lesser grain borer (*Rhyzopertha dominica* Feb.)
  - v) Maize weevil (*Sitophilus zeamais* Motsch)
  - vi) Cigarette beetle (*Lasioderma serricorne* F.)
- 2) To scale up the patented egg removal device (TNAU Patent, 198434) into a power-operated mechanical unit and testing its efficiency for the removal of stored product insects from infested grains.

## *Review of Literature*

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## CHAPTER II

### REVIEW OF LITERATURE

Insect pests cause heavy losses to stored grains quantitatively and qualitatively throughout the world (Madrid *et al.*, 1990). The protection of stored grains from insect pests is considerable importance to their severe infestation and damage in a short period (Allotey, 1991). The damage starts from the field itself (Mohan and Subba Rao, 2000). This problem is further complicated as the infestation is invariably carried over from field to storage. Currently fumigation or synthetic insecticides are largely used to manage the stored product insects. Mechanical handling of grain may be a more practical means of controlling stored product insects than using insecticides which introduce the risk of residues or buildup of resistant strains of insects (Loschiavo, 1978).

#### 2.1. Sources of infestation

The occurrence of insects in stored food was considered natural, but with the development of technology, insect infestations are no more taken for granted. It has been realized that infestation is of external origin. Sources of infestation are also well defined. Insect outbreak and damage in stored food commodities could be due to the infestation from various sources (Cotton *et al.*, 1960). Infestation, through field migration, conveyance, storage building or structures, birds, ant nests and rodent were found to be the main sources of infestation of stored product insects (Khare, 1963). Some insects may be carried from the field. For example the Angoumois grain moth, *Sitotroga cerealella* (Oliv.) moth infests husked rice grains on mature standing crop in the field, migrates horizontally in storage and causes considerable losses (Anand Prakash and Jagadiswari Rao, 1986).

The field infestation by the maize weevil, *Sitophilus zeamais* (Motsch.) was observed to be about 300 meters from the villages which were source of infestation (Singh *et al.*, 1978).

Threshing yard, container, transport and stores are other sources of infestation. On the threshing yard, insects capable of flying invariably get access to the harvested grain. Angoumois grain moth infests grains during post-harvest processings like

harvesting, threshing, drying and storage. Khare and Agrawal (1964) while studying sources of infestations nearby floors, godowns observed that rodent burrows had on an average of 2.05 kg of grain in the living galleries harboring various insect pests of stored grains.

Cracks and crevices, residues and sacks provide required shelter to insects. Coombs and Freeman (1955) have given an account of insect survival in a warehouse and flour mill.

Sharangapani and Pingale (1950) on bagged grain observed that the insects either entering or emerging from existing immature stages move layer to layer of the bags.

Sarid *et al.* (1967) studied the development of infestation in a bag stack of wheat. A tightly build bag-stack was observed to behave like a bulk in respect of infestation.

## **2.2. Field carryover infestation**

Field carryover infestation served as one of the important sources as it paves way for the development of insects during storage (Lallan Rai and Singh, 1979). The infestation of *S. cerealella* starts from the field on the standing crop of paddy (Fletcher, 1921; Usman and Puttarudriah, 1955), sorghum (Puttarudriah and Raju, 1953), ragi (Subramanian *et al.*, 1959), maize (Singh *et al.*, 1978) and wheat (Khare *et al.*, 1970). The earliest field infestation of *S. cerealella* on standing wheat crop dates back to 1762 (Simmons and Ellington, 1927). A field infestation of 0.26 per cent at harvest could lead to a total loss in storage (Simmons and Ellington, 1925; 1927).

The extent of field infestation was found to be 60 per cent in wheat and 33.60 per cent in rice in the USA (Douglas, 1941). The number of moths carried from field to store ranged from 0.25 to 69/0.45 kg of threshed paddy (Israel and Vedamoorthy, 1956). Giles (1969) indicated that the attack by this pest in the field as well as in the threshing yard were of major importance. *S. cerealella* being a good flier (Girish and Pingale, 1968), can infest the standing crop in the field even upto one km form the source of infestation (Singh *et al.*, 1978). *S. cerealella* was found to infest paddy in the field which helped to create a suitable environment for infestation by other insects during storage (Cogburn, 1977; Doharey *et al.*, 1979). *S. cerealella* not only infests paddy in storage but also in

field conditions which enhanced its ability to damage (Ganesalingham and Krishnarajah, 1979; Prakash *et al.*, 1981).

The field incidence of *S. cerealella* was surveyed in Tamil Nadu by Ragumoorthy and Gunathilagaraj (1988). They reported that *S. cerealella* emerged from 124 of 213 samples at Madurai and from 59 of 151 samples at Aduthurai.

Singh *et al.* (1978) reported *S. zeamais* infesting standing maize crop for first time in India. They found that the number of adults emerged per infested sample at a distance of 200 and 800 meters away from the stores were 7.5 and 1.0, respectively.

Pulse beetle (*Callosobruchus chinensis* L.) was found to lay eggs on developing seeds or pods of growing plants in the field which lead to severe infestation in storage (Mookharjee *et al.*, 1970). Yellow pods were the most preferred ones for oviposition by *C. chinensis* in the field and served as the main source of infestation (Raina, 1970). Pulse beetles were found to be serious pests of stored pulses which breed in the field and the primary infestation got carried over to the storage (Arora, 1977). Pulses suffer losses both qualitatively and quantitatively due to the attack by the pulse beetles.

The field infestation by the pulse beetle (*Callosobruchus maculatus* F.) was found to act as a potential source of initiation of population build up during post-harvest period in stores (Khanvilkar and Dalvi, 1984). They also inferred that the population of *C. maculatus* multiplied by 83.9 and 61.7 times from the basic per cent infestation of 0.5 and 1.0 respectively, within a period of two months in stored green gram as a result of field infestation.

Singal and Kalra (1991) reported that infestation by *S. cerealella*, the rice weevil (*Sitophilus oryzae* L.) and *C. chinensis* starts from the field itself. Hill (1993) inferred that both *C. chinensis* and *C. maculatus* were of greater significance as they damage the pulses both in the field as well as during storage.

Mohan and Subba Rao (2000) concluded those fields carried over infestation form the potential source of inoculum during storage. They also reported that the carry-over of *C. chinensis* from field to store revealed a very low level of field infestation and caused heavy grain losses in storage due to the subsequent build up of insect population.

### 2.3. Losses in stored grain due to insect pests attack

Losses of growing crops are immediately apparent because there is less produce to harvest. On the other hand, losses of stored grains are not always apparent and the extent of deterioration in the quality of grain (produce) is seldom appreciated. Post harvest losses during storage alone are estimated to be 6.58 per cent (Gahukar, 1994).

#### 2.3.1. Quantitative losses

Quantitative losses are mostly concerned with the amount of food the insects consume causing a total loss in the food (Vimala and Pushpamma, 1983). Insects during storage mainly cause quantitative/weight losses by direct feeding on grain kernels (Anand Prakash and Jagadiswari Rao, 1985).

##### 2.3.1.1. Grain damage

Rajan *et al.* (1975) observed 8, 56 and 68 per cent damage in cowpea grains infested by *C. chinensis* after a period of 2, 4 and 5 months of storage, respectively. Daniel *et al.* (1977) reported 11, 25 and 56 per cent damage in Bengal gram and 10, 24 and 49 per cent in red gram after 1, 3 and 6 months of infestation by *C. chinensis*, respectively under controlled conditions. The corresponding values for damage to green gram were 8, 38, 48 and 52 per cent after 1, 2, 3 and 4 months of infestation.

Singh and Sharma (1982) estimated the grain damage in moong or green gram varieties (ML 5, G 65 and Shining Moong No.1) and mash or black gram varieties (T 9 and Mash 1-1) by *C. maculatus* (Fab.). They reported that, the range of damaged grains varied from 42.53 to 57.77 and 7.97 to 10.20 per cent in moong and mash varieties, respectively. The damage was significantly higher in green gram varieties than black gram varieties.

Quantitative losses occurring in four pulses, namely, green gram, red gram, black gram and bengal gram stored for one year in rural families of three agro climatic regions of Andhra Pradesh have been assessed by Vimala and Pushpamma (1983). Irrespective of the regions highest mean percentage of kernel damage for twelve months storage was found in green gram followed by red gram, black gram and bengal gram.

Khanvilkar and Dalvi (1984) reported 8, 38, 48 and 52 per cent damage to green gram caused by *C. maculatus* after 1, 2, 3 and 4 months of infestation, respectively, under controlled conditions. Borah and Mohan (1985) reported 11.2 per cent infestation to paddy after 6 months for storage in Assam.

Giga *et al.* (1991) recorded a loss of 0.06 to 9.7 per cent of food grains in the farm stores in different regions of Uttar Pradesh during six months storage period. Infestation by *S. cerealella* was very high to the tune of 82.7 per cent in stored paddy (Pathak and Jha, 2003).

Darshan Punia *et al.* (1992) reported the percentage damage in wheat over different storage periods. After 3 months of storage 2 to 4 per cent damage were observed and the samples stored for 6 and 9 months contained 2 to 20 and 4 to 60 per cent damage, respectively.

### **2.3.1.2. Weight loss in stored grain**

Losses to food grains caused by storage insects have been investigated in the laboratory mainly using wheat infested with the granary weevil, *Sitophilus granarius* (L.) (Golebiowska, 1969; Howe, 1963), *Sitophilus oryzae* (Golebiowska 1969; Singh *et al.*, 1972; White, 1953) and *Rhyzopertha dominica* F. (Golebiowska, 1969; Rao and Wilbur, 1972).

FAO survey (1977) on post-harvest crop losses in developing countries showed 8.5 per cent weight loss in legumes in Central Storage in India.

The storage losses caused by pulse beetles *C. chinensis* (L.) and *C. maculatus* (F.) in whole pulses, *viz.*, green gram, red gram, Bengal gram and black gram stored at farm level in different storage structures were assessed by Doharey *et al.* (1992) in few districts of Uttar Pradesh. A maximum of 13.8 per cent loss in weight was recorded in green gram stored in gunny bags, 12.02 per cent in red gram stored in brass pot and minimum (1.13 per cent) in tin container after 6 months of storage. In case of Bengal gram, 3.15 per cent loss in weight was recorded in the grain stored in gunny bags after 5 months of storage while in black gram 0.90 to 3.15 per cent loss was recorded in tin container after 7 months of storage period.

### 2.3.2. Qualitative losses

Loss of quality for a food man is important from the availability of nutritional constituents whereas for seed-man, it is germinability of a kernel. Food grains also undergo metabolic activities as other living organisms, and are governed by the presence of moisture, temperature, insects and fungi. Qualitative losses include the degradation of carbohydrates, fats and protein, reduction in B group of vitamins and reduction in digestibility of the food grain (Vimala and Pushpamma, 1983). Increase in fat acidity and change in non-reducing sugars are two main deteriorating indices (Anderson and Alcock, 1954). Fats, carbohydrates and proteins are proximate principles that determine the nutritive value of food grain. Fat acidity during storage was considered to be deteriorating the quality (Fenton and Swanson, 1930 and Pomeranz *et al.*, 1956).

#### 2.3.2.1. Biochemical changes

Gupta *et al.* (1981) observed an increase in FFA from 28.2mg KOH/100g of grain to 128.6mg KOH/100g grain in infested kernels of Bengal gram by *C. maculatus* after six months, but it increased in control too but to a lesser extent. They also reported that the FFA increased as the percentage of weeviled kernels and storage period increased. They also observed an increase in reducing sugars by 1.65 per cent, whereas the non-reducing sugars and starch decreased by 0.95 and 28.69 per cent in Bengal gram after 6 months infestation by *C. maculatus*. They also reported an increase in uric acid content of Bengal gram infested by *C. maculatus*. The increase in infested samples was reported to be 2320mg/100g of grains after six months of infestation.

Ndhine and Rawat (1985) reported that *C. phaseoli* infestation in field bean led to increase in moisture, protein, amino acid, phosphorus, potassium calcium, magnesium, iron, zinc, sulphur, total ash, alcoholic, acidity, free fatty acids and decrease in total carbohydrate, reducing sugar, non-reducing sugar, oil and vitamin C.

Darshan Punia *et al.* (1992) studied the nutritional changes in wheat grains due to insect infestation. After 9 months of storage a loss as high as 53 per cent in starch, 47 per cent in protein, 42 per cent in fat, 17 per cent in total sugars and 21 per cent in reducing sugars was observed in 100 grains. They also observed that uric acid in stored wheat

grains increased with an increase in storage period; there was two fold increase in its content after nine months of storage.

### **2.3.2.2. Loss in germination**

Insect infestation in stored seeds directly affect their germination. Grains bored by insects fail to germinate. Germination of stored seed tends to decrease with the increase of insect infestation (Anand Prakash and Jagadiswari Rao, 1985).

Agrawal *et al.* (1981) reported that loss of germination in wheat due to infestation was about 77.33 per cent which was stored for maximum of 8 months.

Germination loss of moong and mash varieties due to *C. maculatus* was observed by (Singh and Sharma, 1982). Loss in germination varied from 47.53 to 70.60 per cent in moong varieties and 14.13 to 19.76 per cent in mash varieties after five months of storage.

The population build-up of *S. oryzae* (L.), *T. granarium* (Overts) and *T. castaneum* (Herbst) at 2, 4 and 8 pairs per 500g wheat/species of initial infestation and resultant germination loss was studied by Simwat and Chahal (1982). The germination loss of wheat ranged from 2.5 to 49.8 per cent from first to sixth month.

## **2.4. Mechanical impact on the control of stored product insects**

Mechanical impact on grain is one of the best stored product insect management methods among physical control methods. Insects are more susceptible to impact than acceleration. However, insects are highly susceptible to the combination of acceleration followed by deceleration (Rudy Plarre and Franz Reichmuth, 2000).

Mechanical control acts as one of the important strategies in the management of stored product insects (Freeman, 1973). Frequent application of chemical insecticides lead to the development of insects population which became increasingly resistant to several insecticides (Dyte, 1974). And also the concern about chemical residues in food stuffs has focused attention on physical methods to control stored product insects. Mechanical handling of grain may be a more practical means of controlling stored grain pests than using insecticides which introduce the risk of residues or build-up of resistant strains of insects (Loschiavo, 1978).

Physical disturbances like rotation, tumbling and especially impact of infested grain adversely affects various life stages of stored product insects. The adverse effects of mechanical impact depend on the species and life stages of the insect species (Bailey, 1962; Joffe, 1963; Joffe and Clarke, 1963; Bailey, 1969; Loschiavo, 1978; Ungsunantwiwat and Mills, 1979).

#### 2.4.1. Effect of impact on pre-emergent stages of insects

Different developmental stages vary in their susceptibility to the mechanical impact. The most sensitive stages of *S. oryzae* was found to be the egg and fourth larval and pupal stages. Repetitive treatment carried out by Joffe and Clarke (1963) on effect of disturbances on pre-emergent stages of *S. oryzae* resulted in the death of almost all of the most advanced immature stages; that they survived the first three larval instars and were killed during the fourth instar larvae and pupae found in the dissected grain. They reported that dropping infested maize from 36 feet during the fifth week after oviposition caused a significant reduction of more than 50 per cent in emergence. The height of the most commercial elevator bins varies between 80 and 120 feet and infested grain entering these bins and falling on the solid bottom would presumably be subjected to sufficient mechanical shock to cause the death of a large proportion of the immature stages of *Sitophilus* contained within the grain.

Richards (1947) noted that frequent disturbing of weevils by shaking produced a depressing effect on oviposition which was similar to overcrowding.

Bailey (1962) found that the unprotected immature stages of the granary weevil were killed by relatively small impact forces but destruction of all immature insects inside the kernels required forces that caused up to 20 per cent damage to kernels.

Turning process has a direct and deleterious physical effect on the development of both adult and immature stages of certain primary and secondary grain pests (Joffe, 1963).

Bailey (1969) stated that physically disturbing wheat containing immature stages of *S. granarius* (L.) might prevent many or all of them from developing successfully, especially if the wheat were disturbed two or more times a week.

Impact machines are very effective in controlling insect eggs (Rudy Plarre and Franz Reichmuth, 2000). Stratil and Wohlgemuth (1989) have shown complete control of *Ephestia kuehniella* (Zeller) eggs, when impacting rye flour at throughput rates 7-8 metric tons per hour. Similar results were obtained with adults of *Oryzaephilus surinamensis*, *Tribolium castaneum*, and *S. granarius*.

Quentin *et al.* (1991) reported, brief daily tumbling of beans held in half filled jars, buckets and gunny sacks reduced *Acanthoscelides obtectus* (Say) populations of 97 per cent relative to stationary control. *A. obtectus* larvae takes 24 hours to bore into dry red kidney bean and boring can occur only at particular sites where a bean abuts some other surface, by daily tumbling. They also observed smashed eggs and larvae were visible on the walls of the glass jars.

#### **2.4.2. Effect of impact on adult stage of insects**

Richards (1947) in his study on the biology of *Sitophilus* mentioned that the young weevil after shedding the pupal skin, spends a number of days inside the grain and that mechanical stimuli, such as shaking of the grain play an important part in deciding when the weevil will actually emerge.

Bailey (1962) found that relatively small impact forces killed adults of the granary weevil, *S. granarius* with less grain damage.

Joffe (1963) found that the turning of maize grain from one bin to another bin killed the adults of *S. oryzae*. Joffe and Clarke (1963) reported that relatively slight disturbance could cause the death of free living adults.

Bryan and Elvidge (1977) found that rusty grain beetles suffered a higher mortality than saw toothed grain beetles, red flour beetles and granary weevils subjected to the physical stress of a sample delivery system used in terminal elevators. They suggested that physical contact with the delivery equipment during operation of the system caused damage to insects.

Mortality of rusty grain beetle adults occurred when wheat was dropped through a tube from a height of 14.1m and mortality ranged from 4 to 98 per cent for 1 and 7 drops, respectively (Loschiavo, 1978). He also reported that the mortality of adult granary

weevils dropped 14.1m ranged from 0.3 to 5.4 per cent, while the number of dead weevils recovered by tapping the tube immediately after each drop was 0.3 per cent.

The effect of impact was higher when the adult beetles were dropped in sacks filled with grain probably due to further collision with kernels at the movement of impact as compared to being dropped with free falling grain where additional impact is less, likely. Tumbling and rotation of sacks increased fewer rusty grain beetles larvae emerged as adults, indicating increased mortality inside the kernel. After 50 and 60 min of disturbance, adult emergence 25 days later was approximately 3 per cent (Loschiavo, 1978).

Mechanically disturbing infested samples to remove newly emerged adult weevils every 48 hours reduced numbers of progeny surviving to the adult stage of *S. granarius* (Ungsunantwiwat and Mills, 1979). Bahr (1990) showed that passing grain four times through an industrial vacuum system produced 99.6 and 100per cent mortality in *Trogoderma granarium* and *O. surinamensis*, respectively.

Marriot (1999) found that adults of *T. castaneum*, the drug store beetle (*Stegobium paniceum* L.), *O. surinamensis* and *S. granarius* subjected to impact machines had broken legs and antenna, damaged elytra or demolished body parts that resulted in an immediate or delayed mortality.

The free-living adults are killed at velocities below 20-25 meters per second suggest that grain may be effectively treated by multiple passes through a percussion or impact machine at specific time intervals (Rudy Plarre and Franz Reichmuth, 2000).

#### **2.4.3. Effect of frequency and velocity of impact on insect**

Joffe and Clarke (1963) showed that the type, timing and frequency of disturbance play a significant role in determining the extent of damage to *S. oryzae*. There was a clear relationship between frequency of disturbance and the reduction in the number of progeny.

Bailey (1969) showed a clear additive effect as the number of impacts increased even at very low impact speeds when the infested wheat was dropped several times. Regular turning of grain from one bin to another could, therefore be lethal to insects.

He demonstrated that mortality of granary weevils increased with increasing velocity and number of impacts in infested grain.

Mortality of larvae and adults of the rusty grain beetle, *Cryptolestes ferrugineus* (Stephens), and the red flour beetle, *T. castaneum*, embedded in wheat grain increased with increasing number of rotations, tumbling, and drops, followed by impact. Moreover, the kernels were not damaged and germination was not impaired. Species exposed to rotation and tumbling suffered little mortality. However, when dropped several times from a height of 14.1 meters with a resulting velocity of 16.6 meters per second, mortality of the granary weevil, *S. granarius* (L.) and the rice weevil, *S. oryzae* increased significantly (Loschiava, 1978).

In impact machine, insect mortality increases with increasing velocity of the steel pegs. Species-specific susceptibilities at different velocities for a given throughput rate occurred only at velocities between 25 and 33 meters per second. Differences in susceptibility among species were less obvious at velocities of 50 – 65 meters per second (Rudy Plarre and Franz Reichmuth, 2000).

#### **2.4.4. Effect of impact on grain damage and germination**

Pest control by mechanical impact has not been widely adopted for stored products probably because of concern over damage to seeds receiving adequate impact forces needed to kill most pests with few iterations of the treatment (Quentin *et al.*, 1991). The main disadvantage of turning as a control measure in practice, apart from any considerations of cost, appears to be the increase in the percentage of broken kernels. This however, mainly depends on the type of grain being transferred and the extent and method of turning (Rudy Plarre and Franz Reichmuth, 2000).

Joffe (1963) noticed that, when compared to undisturbed maize, regularly turned bulks of grain were relatively cooler and in overall better conditions. There was less spoilage of grain due to moisture accumulation.

The experiments conducted by Loschiavo (1978) showed that physical disturbance like dropping, rotation and tumbling in the control of rusty grain beetle and granary weevil, there was a negligible damage to grains and no loss of germination and

bean tumbling experiment on the control of *A. obectus* by Quentin *et al* (1991) indicates that there was no damage to the beans.

Entoleters were found to be the most extensively used direct means of mechanical control (Watters, 1991). Banks and Fields (1995) inferred that moving or handling grain could play a significant role in the control of many stored product insects. Sahay and Dakshinamurthy (1995) designed an entoleter which would exclusively break infested wheat grain, while not affecting sound grain. They also inferred that the system removed 95 per cent of *S. granarius* infestations.

Fields and Muir (1996) reported that by the use of entoleters, wheat kernels infested with primary feeders such as *S. oryzae* or *R. dominica* broke apart and were separated from the intact kernels.

Stratil *et al.* (1987) determined the amount of broken wheat kernels before and after impacting at different throughput rates ranging from 1 to 10 metric tons per hour at velocities of 25 – 55 meters per second in impact machine. The amount of broken kernels were proportional to the velocity of the steel peg. However, kernel breakage depended very much on the wheat variety, with soft wheat breaking more easily than hard wheat. The moisture content also determined kernel breakage during impacting (Zwingelberg, 1988). Wheat at moisture content of 14 per cent was more likely to break than wheat conditioned for milling (about 17 per cent moisture content).

Bailey (1962) found wheat at moisture content of 14 per cent was more resistant to breakage. For wheat intended for storage the upper limit for impact machine velocity that provides an acceptable percentage of broken kernels were determined to be around 30 – 35 meters per second. Taking insect mortalities and product alteration into consideration, it appears that impacting stored wheat of 14 per cent moisture at velocities of 654 meters per second is not feasible. At this speed uninfected kernels may be damaged. The free living adults were killed at velocities below 20 – 25 meters per second.

Eric Lucas and Jordi Riudavets (2000) studied the mechanical impact of rice polishing on the rice weevil, *S. oryzae* (L.) and the subsequent post polishing effects associated with rice quality. Polishing corresponding to a weight loss of 11 % in rice generated an immediate mortality of 40 per cent; the subsequent mortality caused by rice

quality was also 40 % (total 80 %). A polishing process corresponding to 14 and 16 % of rice weight loss generated a drastic mortality of more than 95 % in the weevil population.

#### **2.4.5. Combined effect of mechanical impact**

The combined effect of neem and physical disturbance are more effective in reducing populations and disturbing growth and development of *A. obtectus* (Say), *S. oryzae* (L.), *O. surinamensis* (L.) and *C. ferrugineus* (Stephens) (Sunita Facknath, 2006). Neem leaf powder or neem oil added to beans and tumbled daily produced reduction of 98 per cent and 97.7 per cent, respectively, in *A. obtectus*. In case of *S. oryzae* the reduction ranged from 65.2 per cent with only twice weekly tumbling to a maximum of 97.8 per cent when the rice grains were mixed with neem oil and turned over daily.

In case of *O. surinamensis* the reduction ranged from 46.0 per cent with only twice weekly tumbling to a maximum of more than 95 per cent where the rice grains were mixed with the neem leaf powder and neem oil and turned over daily. As in the case of *C. ferrugineus* tumbling alone is effective. Daily and twice weekly grain tumbling significantly reduced the population of 76.2 and 39.8 per cent, respectively.

#### **2.5. Mechanical removal of insects**

Physical or mechanical methods like rotation, tumbling and impact of infested grains will be effective in the removal of stored product insects. Mechanical removal of insects from grain in storage could be sorted as one of the important pest control strategy (Bailey, 1969).

Wandering behavior of stored product insects is well exploited by the entomologists in the development of devices for trapping the stored product insects (Barak and Harein, 1982).

In bulk stored grains probe traps were used for detecting and trapping of stored product insects (Loschiavo, 1967; Mohan and Gopalan, 1992). *S. oryzae*, *R. dominica* and *T. castaneum* could be effectively trapped and monitored by the use of probe traps (Mohan, 1993).

These probe traps were effective only in the early detection of stored product insects and it got a limited success in mass trapping of stored product insects.

Hence a new concept namely 'container concept' was introduced in the place of 'trap concept' with the aim to remove the insects as quickly as possible so that a significant effect may be seen in the produce stored with respect to damage and progeny production. As a result, Mohan (1994) invented a device named TNAU automatic insect removal bin which exploits wandering behavior of stored product insects, as well as the moving habit of them towards well aerated regions. It was found that 83 to 94 per cent of stored product insects were removed within a period of 10 days and there was a substantial reduction in damage as well as progeny production.

Insects in automatic insect removal bin, while wandering, enter the perforation to reach the aerated part and while doing so, get slipped off and fall into the collection vessel through a pitfall mechanism as reported by Mohan (1995).

*S. oryzae*, *R. dominica*, *T. castaneum* and *O. surinamensis* which were commonly found attacking stored grains would be automatically removed within a period of 20 days with more than 90 per cent efficiency (Mohan, 1996). Studies conducted by Mohan revealed that 94.0 per cent of the adults of *S. oryzae* were removed within a period of 10 days when the artificially infested milled rice was stored in the automatic insect removal bin. Also 75.34 per cent of *R. dominica* adults were removed from the infested paddy which were stored in the automatic insect removal bin for a period of 10 days and the effect of mass removal resulted in the substantial reduction in damage and progeny production in the grains stored in the insect removal bin as reported by Mohan (1997).

Weller *et al.* (1998) observed in their studies that the reduction in infestation by the use of grain scanner which involves the combined effects of physical shock and removal varied from 89 to 98 per cent for *T. castaneum* and 51 to 94 per cent for *R. dominica* depending on life stage.

Mohan (2001) observed that indicator device and pit fall traps were very useful in the timely detection of the emergence of field carryover beetles in stores. They also studied the effect of pitfall traps in the removal of bruchids from green gram. Results showed that the pitfall traps removed substantial number (491 insects after 5 months of storage) of adults resulting in reduced damage by pulse beetle during storage.

Mohan (2004) reported that probe trap, pit fall traps, two-in-one model trap, indicator device and automatic insect removal bin will be very much useful in the early detection and mass trapping of stored product insects.

Mohan and Raghavan (2005) found that pit fall trap was very effective in the early detection of *S. cerealella*.

Mohan *et al.* (2006) reported the efficiency of the probe traps increased when the wheat grains were treated with protein-enriched pea flour. The repellent property of protein-enriched pea flour is exploited to increase the efficiency of the probe trap by treating the grain with flour. They found that more number of rusty grain beetles *Cryptolestes ferrugineus* (Stephens) were collected by probe traps in protein-enriched pea flour treated wheat.

## *Materials and Methods*

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## CHAPTER III

### MATERIALS AND METHODS

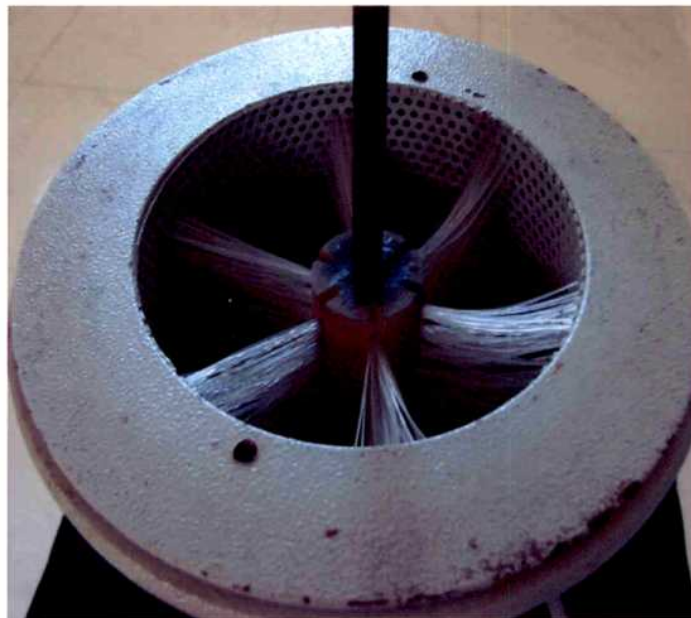
Investigations on the “Egg removal device for pulse beetle” was carried out to assess its efficiency in the removal of the eggs of major stored grain insects with the aim of preventing field carry over infestation. Attempts were also made to scale up the prototype of the egg removal device into a power-operated mechanical unit. The particulars of the materials tested, observations recorded and the methods employed in different experiments are presented here under.

#### 3.1. Description of the hand-operated egg removal device

Egg removal device for pulse beetle (Plate 1 a & b) patented by Dr. S. Mohan of Tamil Nadu Agricultural University, Coimbatore, India, has been used to assess the efficiency of its egg removal against other important stored product insects namely, the rice moth, *Corcyra cephalonica* Stainton, the Angoumois grain moth, *Sitotroga cerealella* Olivier, the red flour beetle, *Tribolium castaneum* Herbst, the maize weevil, *Sitophilus zeamais* Motsch, the lesser grain borer, *Rhyzopertha dominica* Feb., and the Cigarette beetle, *Laisoderma serricornis* F. The patented egg removal device comprise of an outer container enclosing an inner perforated container. The outer container (18.5 cm high and 21 cm diameter) is made up of aluminium and the inner perforated container made up of GI sheet with a diameter of 15 cm. The outer container and inner perforated container (3 mm perforation) is arranged in such a manner that a gap of 3 cm exists between them. The containers were provided with a lid at the top, the lid having an opening at its centre. A rotatable rod is provided with smooth brushes of length 4.5 cm fixed equispaced. The sides of brushes touch the inner walls of the inner perforated container. The rotatable rods are fixed to the bottom of the inner container and pass through the opening, connecting the lid at the top. The other end of the outer container is provided with a transparent container to collect the insects which fall down from the inner perforated container.



**a. Outer view**



**b. Inner view**

**Plate 1. Hand-operated egg removal device**

### **3.1.1. Mass culturing of test insects**

The test insects used for the various experimental studies, namely, *C. cephalonica*, *S. cerealella*, *T. castaneum*, *S. zeamais*, *R. dominica*, and *L. serricornis* were mass multiplied in plastic containers in the laboratory and used for experiments (Plates 2 and 3).

#### **3.1.1.1. Rice moth**

Rice moths were mass cultured in broken cumbu grains. The eggs were obtained from the biocontrol laboratory, Tamil Nadu Agricultural University, Coimbatore, India. Further the cultures were maintained on a diet comprising pearl millet and groundnut powder mixed in the ratio of 4: 1 (Ananthakrishnan *et al.*, 1991).

#### **3.1.1.2. Red flour beetle**

Sorghum grains which were infested with *T. castaneum* were collected from Millet Breeding Station, Tamil Nadu Agricultural University, Coimbatore, India, and were cultured on whole wheat flour at 30° C and 70 per cent R.H (White, 1982).

#### **3.1.1.3. Maize weevil and lesser grain borer**

Maize and sorghum grains which were infested with *S. zeamais* and *R. dominica* collected from Millet Breeding Station, Tamil Nadu Agricultural University, Coimbatore, India, and were reared in the laboratory at 28° C and 70 per cent R.H. on organic whole wheat kernels (Mohan *et al.*, 2007).

#### **3.1.1.4. Angoumois grain moth**

Methods developed at the Kansas State University (Pedersen *et al.*, 1974) and the University of California (Strong *et al.*, 1967) was followed for mass culturing of Angoumois grain moth. The insects were mass cultured in culture medium which contains half a kg each of paddy (IR 20), sorghum (CO 9) and cumbu (KM 2) grains.

#### **3.1.1.5. Cigarette beetle**

Coriander seeds, turmeric powder and chilli powder which were infested with cigarette beetles were collected from local markets for initiating culture. The insects were reared at 27 ± 1°C and 60 ± 5 per cent RH with a 12-h photoperiod on a diet of whole wheat flour (10 parts), white cornmeal (10 parts), and brewers' yeast (1.5 parts) (Arbogast *et al.*, 2003).



**Plate 2. Laboratory setup of experiments**



**Plate 3. Mass culturing of insects**

### **3.1.2. Efficiency of egg removal device in the removal/damage of eggs of rice moth from sorghum grains**

Sorghum grains which were obtained from Millet Breeding Station, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India, were sieved to remove dust and then kept in a deep freeze at  $-18^{\circ}\text{C}$  in 1 kg batches sealed in polythene bags for 10 days to destroy any prior infestation by insects (Shazali and Smith, 1986). Then these disinfested grains were used for the experimental purpose. The experiment was designed as a factorial experiment with these factors: (1) Number of grains with eggs (i.e. 10, 20 and 30) and (2) Duration of operation (1 day, 2 days, 3 days and no operation). So it includes 12 treatments and each treatment was replicated five times. For each replicate one kg of sorghum grains were used.

The inner perforated container of the egg removal device was filled with sorghum grains. 10, 20 and 30 seeds with one day old single egg was introduced into the inner container and thoroughly mixed.

Circular rotation involving clockwise and anticlockwise movements were given in an alternate manner for 15 minutes in a day to remove the eggs of *C. cephalonica*. After rotating for 15 minutes sorghum grains were taken out and kept in a separate plastic container for a period of 40 days to observe for the emergence of offspring adults. After 20 days of operation the grains were observed for larval webbings and the number of webbings were counted.

The offspring adults were removed and counted thrice between 40 and 60 days and the total number of offspring adults were expressed.

### **3.1.3. Efficiency of egg removal device in the removal/damage of eggs of Angoumois grain moth from infested sorghum, paddy and wheat grains**

Sorghum, paddy and wheat grains were sieved to remove dirt and foreign matter from the grains and the grains were properly disinfested as done in sorghum grains for rice moth experiment. Then the grains were taken in plastic containers and 20 pairs of adult moths were introduced into the plastic container in every one kilogram of grains and covered with khada cloth, secured with rubber band. The grains were kept without disturbance for 5 days for oviposition. On 6<sup>th</sup> day the adults were removed from the grain.

Then the grains were placed in the inner perforated container of egg removal device. Circular rotation involving clockwise and anticlockwise movements in an alternate manner were given for 15 minutes per day, likewise for 1, 2 and 3 days, respectively, by which the eggs have been removed (Plate 5) from the grain and collected in the collection container.

The grains were taken out and kept without disturbance for a period of 30 days to observe for the emergence of offspring adults. The offspring adults were removed and counted thrice between 30 and 60 days and the total number of offspring adults were expressed.

#### **3.1.4. Efficiency of egg removal device in the removal/damage of eggs of maize weevil, red flour beetle and lesser grain borer from infested sorghum, wheat, maize and paddy grains**

Sorghum and maize grains were obtained from the Millet Breeding Station, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India and the paddy grains were procured from Paddy Breeding Station, TNAU, Coimbatore, Tamil Nadu, India, whereas, wheat grains were obtained from Horticultural Research Station, Ooty, Tamil Nadu, India. The grains were sieved to remove dust and insects and the grains were properly disinfested as that of sorghum grains in rice moth experiment.

Unsexed adults of *S. zeamais*, *T. castaneum* and *R. dominica* were released to the grains of sorghum, wheat, maize or paddy (*T. castaneum* was not used for paddy) at the rate of 100 adults per kilogram of grains (Mohan, 1993). The grains were placed in plastic containers, covered with khada cloth. The grains were kept as such for 7 days for oviposition. Then the adult insects were removed from the grains after 7 days. After removal, the grains were placed in the inner perforated container of the egg removal device. Circular rotation involving clockwise and anticlockwise movements in an alternate manner were given for 15 minutes per day, likewise rotated for 1, 2 and 3 days, respectively.

The grains were taken out and kept without disturbance for a period of 40 days to observe for the emergence of offspring adults. The offspring adults were removed and counted thrice between 40 and 60 days and the total number of offspring adults were expressed.

### **3.1.5. Efficiency of egg removal device in the removal/damage of eggs of cigarette beetle from coriander**

Coriander seeds were bought from the local shops and it was sieved and the dusts and insects if any were removed from the coriander seeds and were disinfested by giving cold treatment. The coriander seeds were taken in plastic containers and unsexed adults of *L. serricornis* were added to the coriander seeds at the rate of 50 adults for 500 gram of seeds. The plastic containers were covered with khada cloth and secured with rubber band. The seeds were kept as such for 7 days for oviposition. After 7 days the adult insects were removed from the seeds. Then, the coriander seeds were placed in the inner perforated container of egg removal device. Circular rotation involving clockwise and anticlockwise movements in an alternate manner were given for 15 minutes per day, likewise for 1, 2 and 3 days, respectively.

The seeds were taken out and kept without disturbance for a period of 40 days to observe for the emergence of offspring adults. The offspring adults were removed and counted thrice between 40 and 60 days and the total number of offspring adults were expressed.

### **3.2. Scaling up of the prototype of “Egg removal device for pulse beetle” into a “Power-operated mechanical unit”**

The prototype of hand-operated “Egg removal device for pulse beetle” has been upgraded as a “Power-operated mechanical unit” (Plate 4) to speedup the process of removal of eggs and adults of major stored product insects. The unit consists of the basic components, namely, outer container, inner perforated container, brushes, brush supporting arm, grain outlet, insect outlet, central grid, supporting unit, control unit, motor (0.25 H.P) and stand (5 cm). The outer container and inner perforated container were made up of galvanized iron sheet. The inner perforated container is attached in such a manner that it gets coincided with the outer container at the upper portion and has the capacity to hold 10 kilogram of grains and the perforation size is 2 mm. The base of the outer container is attached with a rotatable central grid and this will rotate clockwise and anticlockwise. The inner perforated container is provided with smooth brushes (Plate 4b) of length 6 cm fixed equispaced and the brush is attached with the supporting arm.



**a. Outer view**



**b. Inner view**

**Plate 4. Power-operated mechanical unit**

The container and the brush supporting arm are held by the supporting unit and this supporting unit is covered by steel plates. The supporting unit consists of control unit comprising of timer and speed indicator knob. The timer can be used to set the time duration, until which the device could be allowed to operate.

When the unit is operated, the container rotates clockwise and anticlockwise. Due to clockwise and anticlockwise rotation, the grains are shuffled and the insect eggs attached to grains get detached by means of brushing mechanism and get removed through the perforation. There is also a possibility that eggs which were not removed would have been crushed due to the impact of rotation. The rotation also create physical disturbance to the adult insects present in the grains. Due to the disturbance, the insects tend to move towards the aerated region, enters the perforation and while doing so, gets slipped off and were collected in the insect outlet.

### **3.2.1. Efficiency of power-operated mechanical unit in the removal/damage of eggs of maize weevil, red flour beetle and lesser grain borer from infested sorghum, wheat, maize and paddy grains**

Unsexed adults of *S. zeamais*, *T. castaneum* and *R. dominica* were added to the grains of sorghum, wheat, maize or paddy (*T. castaneum* was not used for paddy) at the rate of 200 adults for 5 kilogram of grains. The grains were placed in plastic buckets, covered with khada cloth. The grains were kept as such for 7 days for oviposition. Then the adult insects were removed from the grains after 7 days. After removal, the grains were placed in the inner perforated container of power-operated egg and adult removal device and the device was operated for 15 minutes per day. Likewise operated for 1, 2 and 3 days, respectively.

The grains were taken out and kept without disturbance for a period of 40 days to observe for the emergence of offspring adults. The offspring adults were removed and counted thrice between 40 and 60 days and the total number of offspring adults were expressed.

### **3.2.2. Efficiency of power-operated mechanical unit in the removal of adults of stored product insects from infested grains**

Unsexed adults of *S. zeamais*, *T. castaneum* and *R. dominica* were added to separate grain masses (5 kilograms each) of sorghum, wheat, paddy or maize at the rate of 500 adults for every 5 kg of grains. Infested grains containing insects were placed in the inner perforated container and the device was operated. Observations on the number of insects collected in the collection container were recorded at 10, 20, 30, 40, 50 and 60 minutes of operation of the device and the results were expressed in percentage (Pretheep Kumar, 2004). Each test was replicated five times and the studies were conducted at room temperature of 28°C with 75 per cent RH.

### **3.2.3. Impact of hand-operated egg removal device and power-operated mechanical unit on germination**

Test food grains, viz., sorghum, wheat, paddy and maize were subjected to roll towel method to assess the impact of egg removal device on germination problem if any. 25 seeds, each of maize, paddy, sorghum and wheat, which were subjected to rotational impact by the use of device and control were taken and placed over a blotting paper after providing sufficient moisture. After a period of 7 days, they were observed for the progress in terms of germination.

### **3.2.4. Impact of hand-operated and power-operated egg removal device on the mechanical damage to food grains**

Grains subjected to impact both by the use of hand-operated and power-operated egg removal device were assessed for the mechanical damage caused to them. For this purpose, 100 grains, each of sorghum, maize, wheat and paddy, were observed for the presence of damaged grains due to mechanical action and the mean damage was expressed in percentage. Four replications were maintained in all the experiments.

## **3.3. Statistical analysis**

The data pertaining to the observations in the laboratory were analysed in a Completely Randomized Design (CRD) and Factorial CRD (Gomez and Gomez, 1984). Wherever necessary, suitable transformations were made before analysis.

*Results*

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## CHAPTER IV

### RESULTS

The results of investigations carried out on the efficiency of “egg removal device for pulse beetle” for the control of other major stored product insects along with the efficiency of the “Power-operated mechanical unit” are presented below.

#### **4.1. Efficiency of egg removal device in the removal of eggs of rice moth from sorghum grains**

The hand-operated egg removal device has been used to remove the eggs of *Corcyra cephalonica* Stainton. Observations on the number of webbings and adult emergence showed that the eggs were removed effectively from infested grains (Plate 5) (Tables 1 and 2).

##### **4.1.1. Counting of webbings**

The efficacy of egg removal device in the removal of eggs of *C. cephalonica* has been assessed on the basis of counting of webbings in the sorghum grains (Plate 7a and b) and it has been presented in table 1. The number of webbings in 10 eggs added treatment were 1.4, 1.0, 0.2 and 9.6 in 1, 2, 3 days rotated grains and in untreated control, respectively, whereas it was 2.0, 1.2, 0.4 and 12.4 in the case of 20 eggs added treatment and 3.2, 1.8, 0.6 and 15.2 in the case of 30 eggs added treatment, respectively. Compared to control there was less number of webbings in all the treatments and among the treatments there was significantly less number of webbings in 3 days rotated grains. There was no significant difference in the number of webbings between different densities of eggs added in all the treatments (1, 2 and 3 days rotated grains). Hence it was found that 3 days rotated grains showed higher reduction in the number of webbings irrespective of different densities of eggs added.

##### **4.1.2. Adult emergence**

The adult emergence of *C. cephalonica* was also observed after 40 days of rotation and the data given in table 2. The mean number of offspring adults noticed in 1 day rotated grains were 1.2, 1.8 and 3.0 in 10, 20 and 30 eggs added, respectively, whereas it



**Plate 5. Eggs of *Corcyra cephalonica* Stainton removed by using hand-operated egg removal device**



**Plate 6. Eggs of *Sitotroga cerealella* Olivier removed by using hand-operated egg removal device**



**a. Treated grains**



**b. Control**

**Plate 7. Larval webbings of *Corcyra cephalonica* Stainton observed in sorghum grains**

**Table 1. Efficiency of egg removal device in the removal of eggs of *Corcyra cephalonica* by way of counting the webblings from infested sorghum grains**

No. of eggs mixed in 1 kg grain	1 Day rotation		2 Days rotation		3 Days rotation		Control
	No. of webblings	% reduction of webblings over control	No. of webblings	% reduction of webblings over control	No. of webblings	% reduction of webblings over control	
10	1.4 (1.22)	85.41	1.0 (1.12)	89.58	0.2 (0.81)	97.91	9.6 (2.99)
20	2.0 (1.50)	83.87	1.2 (1.19)	90.32	0.4 (0.91)	96.77	12.4 (3.44)
30	3.2 (1.82)	78.94	1.8 (1.50)	88.15	0.6 (1.02)	96.05	15.2 (3.87)

Values are the means of five observations.

CD (P = 0.05) Values,

1. Density of eggs 0.28431
2. Frequency of rotation 0.32830

CV = 23.60%, Figures in parentheses are square root (X+0.5) transformed values.

**Table 2. Efficiency of egg removal device in the removal of eggs of *Corcyra cephalonica* by way of counting the adult emergence from infested sorghum grains**

No. of eggs mixed in 1 kg grain	1 Day rotation		2 Days rotation		3 Days rotation		Control
	No. of adults emerged	% reduction of adults emergence over control	No. of adults emerged	% reduction of adults emergence over control	No. of adults emerged	% reduction of adults emergence over control	
10	1.2 (1.32)	86.36	0.8 (1.19)	90.90	0.2 (0.81)	97.72	8.8 (3.13)
20	1.8 (1.55)	84.74	1.0 (1.26)	91.52	0.4 (0.91)	96.61	11.8 (3.53)
30	3.0 (1.89)	79.72	1.8 (1.50)	87.83	0.6 (1.02)	95.94	14.8 (3.91)

Values are the means of five observations.

CD (P = 0.05) Values

1. Density of eggs 0.28877
2. Frequency of rotation 0.33345

CV = 23.73 %, Figures in parentheses are square root (X+0.5) transformed values.

was 0.8, 1.0 and 1.8 in 2 days rotated grains and 0.2, 0.4 and 0.6 in 3 days rotated grains, respectively. The observations showed that there was significantly less number of offspring adults emerged in 3 days rotated grain.

#### **4.2. Efficiency of egg removal device in the removal of eggs of Angoumois grain moth from infested sorghum, paddy and wheat grains**

The observation on the mean number of offspring adults of Angoumois grain moth showed that the egg removal device effectively removed the eggs of *Sitotroga cerealella* Olivier (Plate 6). The data on mean number of offspring adults and percentage reduction in adult emergence were given in table 3. Observations on the mean number of offspring adults of *S. cerealella* in paddy grains were found to be 21.80, 13.60, 8.40 and 39.20 in 1, 2, 3 days rotated grains and in untreated control, respectively, whereas it was 18.60, 11.40, 6.20 and 31.80 in the case of sorghum grains, respectively. The results showed that there was significant difference between the treatments. Compared to control there was a less number of offspring adults in all the treatments. The pattern of emergence of offspring adults revealed that the number of offspring adults were significantly less in 3 days rotated grain. In wheat grain also, the similar pattern of offspring adults were observed. A higher percentage of reduction in the emergence of offspring adults were noticed in wheat grain followed by sorghum and paddy.

#### **4.3. Efficiency of egg removal device in the removal/damage of eggs of maize weevil, red flour beetle and lesser grain borer from infested sorghum, wheat, maize and paddy grains**

Investigations carried out to assess the efficiency of egg removal device in the removal of eggs of *Sitophilus zeamais* Motsch, *Tribolium castaneum* Herbst. and *Rhyzopertha dominica* Feb. from infested sorghum, wheat, maize and paddy grains showed that the eggs were effectively removed from the grains (Tables, 4, 5, 6 and 7).

##### **4.3.1. Sorghum**

The data on mean number and percentage reduction of offspring adults of *S. zeamais*, *T. castaneum* and *R. dominica* was given in table 4. Observations on the mean number of offspring adults of *S. zeamais* were found to be 169.20, 140.00, 109.60 and

**Table 3. Impact of egg removal device on the egg stage by way of assessing the emergence of *Sitotroga cerealella* adults from infested paddy, sorghum and wheat grains**

Frequency of rotation (15 min/day)	Mean number of adults emerged in different commodities					
	Paddy	% Reduction of adult emergence over control	Sorghum	% Reduction of adult emergence over control	Wheat	% Reduction of adult emergence over control
1 day	21.80 (4.64)	44.38	18.60 (4.27)	41.50	15.80 (4.00)	44.75
2 days	13.60 (3.65)	65.30	11.40 (3.39)	64.15	9.20 (3.10)	67.83
3 days	8.40 (2.96)	78.57	6.20 (2.53)	80.50	4.40 (2.17)	84.61
Control	39.20 (6.28)		31.80 (5.63)		28.60 (5.32)	
CD (P = 0.05)	1.0647		1.1300		0.8866	
CV%	18.39		21.71		18.53	

Values are the means of five observations.

Figures in parentheses are square root ( $X+0.5$ ) transformed values.

**Table 4. Impact of egg removal device on the egg stage by way of assessing the emergence of *Sitophilus zeamais*, *Tribolium castaneum* and *Rhyzopertha dominica* adults from infested sorghum grains**

Frequency of rotation (15 min/day)	Mean number of adults emerged					
	<i>Sitophilus Zeamais</i>	% Reduction of adult emergence over control	<i>Tribolium castaneum</i>	% Reduction of adult emergence over control	<i>Rhyzopertha dominica</i>	% Reduction of adult emergence over control
1 day	169.20 (13.02)	9.71	508.2 (22.55)	24.26	441.6 (21.02)	17.82
2 days	140.00 (11.79)	25.29	419.4 (20.49)	37.55	304.8 (17.47)	43.28
3 days	109.60 (10.48)	41.51	306.2 (17.51)	54.36	230.4 (15.18)	57.12
Control	187.40 (13.69)		671.0 (25.91)		537.4 (23.19)	
CD (P = 0.05)	1.1122		0.4471		0.6998	
CV%	6.78		1.54		2.72	

Values are the means of five observations.  
 Figures in parentheses are square root ( $X+0.5$ ) transformed values.

**Table 5. Impact of egg removal device on the egg stage by way of assessing the emergence of *Sitophilus zeamais*, *Tribolium castaneum* and *Rhyzopertha dominica* adults from infested wheat grains**

Frequency of rotation (15 min/day)	Mean number of adults emerged					
	<i>Sitophilus zeamais</i>	% Reduction of adult emergence over control	<i>Tribolium castaneum</i>	% Reduction of adult emergence over control	<i>Rhyzopertha dominica</i>	% Reduction of adult emergence over control
1 day	171.20 (13.10)	22.10	587.60 (24.25)	16.67	437.40 (20.92)	28.59
2 days	136.40 (11.69)	37.94	420.80 (20.52)	40.33	316.20 (17.78)	48.38
3 days	97.60 (9.90)	55.6	218.40 (14.79)	69.03	187.40 (13.70)	69.40
Control	219.80 (14.84)		705.20 (26.56)		612.60 (24.76)	
CD (P = 0.05)	0.5817		0.4654		0.6587	
CV%	3.51		1.61		2.55	

Values are the means of five observations.  
 Figures in parentheses are square root ( $X+0.5$ ) transformed values.

Table 6. Impact of egg removal device on the egg stage by way of assessing the emergence of *Sitophilus zeamais*, *Tribolium castaneum* and *Rhyzopertha dominica* adults from infested maize grains

Frequency of rotation (15 min/day)	Mean number of adults emerged			% Reduction of adult emergence over control	% Reduction of adult emergence over control
	<i>Sitophilus zeamais</i>	<i>Tribolium castaneum</i>	<i>Rhyzopertha dominica</i>		
1 day	287.40 (16.96)	498.60 (22.33)	432.00 (20.79)	5.39	16.03
2 days	158.20 (12.57)	364.20 (19.09)	302.60 (17.41)	47.92	38.66
3 days	81.20 (9.04)	169.00 (13.01)	123.40 (11.12)	73.27	71.53
Control	303.80 (17.44)	593.80 (24.38)	517.20 (22.75)		
CD (P = 0.05)	0.7730	0.6859	0.6284		
CV%	4.12	2.60	2.60		

Values are the means of five observations.  
 Figures in parentheses are square root ( $X+0.5$ ) transformed values.

**Table 7. Impact of egg removal device on the egg stage by way of assessing the emergence of *Sitophilus zeamais* and *Rhyzopertha dominica* adults from infested paddy grains**

Frequency of rotation (15 min/day)	Mean number of adults emerged			
	<i>Sitophilus zeamais</i>	% Reduction of adult emergence over control	<i>Rhyzopertha dominica</i>	% Reduction of adult emergence over control
1 day	118.20 (10.83)	13.34	502.60 (22.43)	26.88
2 days	103.60 (10.20)	24.04	364.20 (19.08)	47.01
3 days	85.20 (9.24)	37.53	161.20 (12.67)	76.54
Control	136.40 (11.66)		687.40 (26.23)	
CD (P = 0.05)	1.2240		1.0205	
CV%	8.73		3.79	

Values are the means of five observations.

Figures in parentheses are square root (X+0.5) transformed values.

187.40 in 1, 2, 3 days rotated grains and in untreated control, respectively, whereas, it was 508.20, 419.4, 306.20 and 671.00 in the case of *T. castaneum*, respectively. Compared to control there was less number of offspring adults in all the treatments. The pattern of emergence of offspring adults of *S. zeamais*, and *T. castaneum* revealed that the number of offspring adults were significantly less in 3 days rotated grains. A similar trend was also noticed in *R. dominica*. The percentage reduction in the emergence of offspring adults of all test insects showed a higher percentage of reduction in 3 days rotated grains. With reference to different insects tested it was in the order of:

$$R. dominica > T. castaneum > S. zeamais$$

#### 4.3.2. Wheat

The mean number of offspring adults of *S. zeamais* were found to be 171.20, 136.40, 97.60 and 219.80 in 1, 2, 3 days rotated grains and in untreated control, respectively (Table 5). The results showed that there was a significant difference between the treatments and control. Number of offspring adults of *S. zeamais* were found to be significantly less in 3 days rotated wheat grains. Percentage reduction in adult emergence in 3 days rotated wheat grains were, 55.6, 69.03 and 69.40(%) in *S. zeamais*, *T. castaneum* and *R. dominica*, respectively. A higher percentage of reduction in the emergence of offspring adults were noticed in 3 days rotated grains and among different insects tested, a higher percentage of reduction was found in *R. dominica* followed by *T. castaneum* and *S. zeamais*.

#### 4.3.3. Maize

Investigations carried out to assess the efficiency of egg removal device in the removal of eggs of *S. zeamais*, *T. castaneum* and *R. dominica* on maize grains have revealed that there was a significant reduction in the emergence of offspring adults in treated grains. The data on mean number of offspring adults and percentage reduction in adult emergence of *S. zeamais*, *T. castaneum* and *R. dominica* was given in table 6. The mean number of offspring adults of *S. zeamais* in maize grains were found to be 287.40 158.20, 81.20 and 303.80 in 1, 2, 3 days rotated grains and in untreated control, respectively. Compared to control there was a less number of offspring adults in all the treatments and the 3 days rotated grains showed significantly less number of offspring

adults. Similar trend was also observed in *T. castaneum* and *R. dominica*. The percentage reduction in the emergence of all test insects showed a higher percentage reduction in 3 days rotated grains. With reference to different insects tested it was in the order of:

$$R. dominica > S. zeamais > T. castaneum$$

#### 4.3.4. Paddy

The data on mean number of offspring adults of *R. dominica* in paddy grains were found to be 502.60, 364.20, 161.20 and 136.40 in 1, 2, 3 days rotated grains and in untreated control, respectively. The results of *R. dominica* showed that there was significant difference between the treatments and control. The mean number of offspring adults of *S. zeamais* noticed were 118.20, 103.60, 85.20 and 136.40 in 1, 2, 3 days rotated grains and in untreated control, respectively. A higher percentage of reduction in the emergence of offspring adults were noticed in *R. dominica* followed by *S. zeamais*.

#### 4.4. Efficiency of egg removal device in the removal of eggs of cigarette beetle from coriander

Observations on the mean number of offspring adults of *Lasioderma serricornis* F. showed that the egg removal device efficiently removed the eggs (Table 8). The mean number of offspring adults of *L. serricornis* in coriander seeds were found to be 72.6, 38.2, 26.4 and 116.8 in 1, 2, 3 and in untreated control, respectively. The observation showed that there was a significant difference between the treatments and control. Compared to control there was less number of offspring adults in all the treatments and among the treatments it was significantly less in 3 days rotated coriander seeds.

#### 4.5. Scaling up of the prototype of “Egg removal device for pulse beetle” to a power-operated mechanical unit

The power-operated mechanical unit was designed and fabricated and investigations were carried out to assess the efficacy of the unit in the removal of eggs and adults of stored product insects from infested food grains.

**Table 8. Impact of egg removal device on the egg stage by way of assessing the emergence of *Lasioderma serricorne* adults from infested coriander seeds**

Frequency of rotation (15 min/day)	Mean number of adults emerged	% Reduction of adult emergence over control
1 day	72.6 (8.54)	37.84
2 days	38.2 (6.21)	67.29
3 days	26.4 (5.15)	77.39
Control	116.8 (10.79)	
CD (P = 0.05)	1.2498	
CV%	8.86	

Values are the means of five observations.

Figures in parentheses are square root (X+0.5) transformed values.

#### 4.5.1. Efficiency of power-operated mechanical unit in the removal/damage of eggs of maize weevil, red flour beetle and lesser grain borer from infested sorghum, wheat, maize and paddy grains

Studies carried out to assess the efficiency of egg removal device in the removal of eggs of *S. zeamais*, *T. castaneum* and *R. dominica* from infested sorghum, wheat, maize and paddy grains showed that the eggs were effectively removed from the grains (Tables 9, 10, 11 and 12).

##### 4.5.1.1. Sorghum

The data on mean number and percentage reduction of offspring adults of *S. zeamais*, *T. castaneum* and *R. dominica* was given in table 9. Observations on the mean number of offspring adults of *S. zeamais*, were found to be 352.20, 290.00, 224.60 and 396.00 in 1, 2, 3 days rotated grains and in untreated control, respectively, whereas, it was 816.20, 722.40, 416.20 and 1086.40 in *T. castaneum*, respectively. Compared to control there was a less number of offspring adults in all the treatments. The pattern of emergence of offspring adults of *S. zeamais*, and *T. castaneum* revealed that the number of offspring adults were significantly less in 3 days rotated grains. A similar trend was also noticed in *R. dominica*. Percentage reduction in adult emergence in 3 days rotated maize grains were found to be, 43.28, 61.68 and 64.75 in *S. zeamais*, *T. castaneum*, and *R. dominica*, respectively. The percentage reduction in the emergence of offspring adults of all test insects showed a higher percentage of reduction in 3 days rotated sorghum grains. With reference to different insects tested the insect removal was in the order of:

$$R. dominica > T. castaneum > S. zeamais$$

##### 4.5.1.2. Wheat

The mean number of offspring adults of *S. zeamais* were found to be 282.4, 234.8, 150.8 and 394.2 in 1, 2, 3 days rotated grains and in untreated control, respectively (Table 10). Number of offspring adults of *S. zeamais* was significantly less in 3 days rotated wheat grains. The results showed that there was a significant difference between the treatments and control. A higher percentage of reduction in the emergence of offspring adults were noticed in *R. dominica* followed by *T. castaneum* and *S. zeamais*.

Table 9. Efficiency of power-operated mechanical unit in the removal of eggs of *Sitophilus zeamais*, *Tribolium castaneum* and *Rhyzopertha dominica* from infested sorghum grains

Frequency of rotation (15 min/day)	% Reduction of adult emergence over control			Mean number of adults emerged		
	<i>Sitophilus zeamais</i>	<i>Tribolium castaneum</i>	<i>Rhyzopertha dominica</i>	<i>Sitophilus zeamais</i>	<i>Tribolium castaneum</i>	<i>Rhyzopertha dominica</i>
1 day	352.20 (18.78)	11.06	24.87	816.20 (28.58)	674.6 (25.98)	31.33
2 days	290.00 (17.04)	26.76	33.5	722.40 (26.89)	498.2 (22.33)	49.28
3 days	224.60 (15.00)	43.28	61.68	416.20 (20.41)	346.2 (18.62)	64.75
Control	396.00 (19.91)			1086.40 (32.96)	982.4 (31.35)	
CD (P = 0.05)	0.5363			0.7651	0.6036	
CV%	2.26			2.10	1.83	

Values are the means of five observations.  
 Figures in parentheses are square root ( $X+0.5$ ) transformed values.

Table 10. Efficiency of power-operated mechanical unit in the removal of eggs of *Sitophilus zeamais*, *Tribolium castaneum* and *Rhyzopertha dominica* from infested wheat grains

Frequency of rotation (15 min/day)	Mean number of adults emerged					
	<i>Sitophilus zeamais</i>	% Reduction of adult emergence over control	<i>Tribolium castaneum</i>	% Reduction of adult emergence over control	<i>Rhyzopertha dominica</i>	% Reduction of adult emergence over control
1 day	282.4 (16.81)	38.36	994.6 (31.54)	26.23	762.0 (27.61)	32.23
2 days	234.8 (15.31)	40.43	694.2 (26.36)	48.51	542.4 (23.29)	51.76
3 days	150.8 (12.26)	61.74	425.2 (17.46)	68.46	324.8 (18.02)	71.11
Control	394.2 (19.86)		1348.4 (36.71)		1124.4 (33.53)	
CD (P = 0.05)	1.1492		0.9945		1.0253	
CV%	5.34		2.65		2.99	

Values are the means of five observations.  
 Figures in parentheses are square root ( $X+0.5$ ) transformed values.

Table 11. Efficiency of power-operated mechanical unit in the removal of eggs of *Sitophilus zeamais*, *Tribolium castaneum* and *Rhyzopertha dominica* from infested maize grains

Frequency of rotation (15 min/day)	Mean number of adults emerged					
	<i>Sitophilus zeamais</i>	% Reduction of adult emergence over control	<i>Tribolium castaneum</i>	% Reduction of adult emergence over control	<i>Rhyzopertha dominica</i>	% Reduction of adult emergence over control
1 day	416.8 (20.42)	24.60	816.8 (28.59)	20.12	674.6 (25.98)	23.75
2 days	246.6 (15.65)	55.39	594.6 (24.39)	41.85	432.8 (20.80)	51.08
3 days	98.2 (9.85)	82.23	267.8 (16.35)	73.81	128.4 (11.26)	85.48
Control	552.8 (23.52)		1022.6 (31.98)		884.8 (29.74)	
CD (P = 0.05)	1.5899		1.0990		1.4777	
CV%	6.84		3.24		5.03	

Values are the means of five observations.  
 Figures in parentheses are square root ( $X+0.5$ ) transformed values.

Table 12. Efficiency of power-operated mechanical unit in the removal of eggs of *Sitophilus zeamais* and *Rhyzopertha dominica* from infested paddy grains

Frequency of rotation (15 min/day)	Mean number of adults emerged			
	<i>Sitophilus zeamais</i>	% Reduction of adult emergence over control	<i>Rhyzopertha dominica</i>	% Reduction of adult emergence over control
1 day	198.6 (14.09)	28.66	836.8 (28.93)	31.67
2 days	167.8 (12.90)	39.72	648.6 (25.47)	47.04
3 days	156.6 (12.53)	43.75	258.4 (16.04)	78.90
Control	278.4 (16.69)		1224.8 (34.99)	
CD (P = 0.05)	1.2865		1.3714	
CV%	6.84		3.88	

Values are the means of five observations.

Figures in parenthesis are square root (X+0.5) transformed values

#### 4.5.1.3. Maize

Observations on the mean number of offspring adults and percentage reduction in adult emergence of *S. zeamais*, *T. castaneum* and *R. dominica* was given in table 11. In *S. zeamais* the mean number of offspring adults noticed were, 416.80, 246.60, 98.20 and 552.80 in 1, 2, 3 days rotated grains and in untreated control, respectively. The observation showed that there was a significant difference between the treatments and control. Among the treatments 3 days rotated grains showed significantly less number of offspring adults. The similar trend was also observed in *T. castaneum* and *R. dominica*. Percentage reduction in the emergence of offspring adults in 3 days rotated grains were found to be 82.23, 73.81 and 85.48 in *S. zeamais*, *T. castaneum* and *R. dominica*, respectively. A higher percentage of reduction was observed in *R. dominica* followed by *S. zeamais* and *T. castaneum*.

#### 4.5.1.4. Paddy

The mean number of offspring adults of *S. zeamais* noticed were 198.6, 167.8, 156.6 and 278.4 in 1, 2 and 3 days rotated grains and in untreated control, respectively, whereas it was 836.8, 648.6, 258.4 and 1224.8 in *R. dominica*, respectively. The results on *R. dominica* showed that there exists a significant differences between the treatments. The percentage reduction in emergence of offspring adults was higher in 3 days rotated grains. With regard to different insects tested, a higher percentage of reduction in the emergence of offspring adults were noticed in *R. dominica* followed by *S. zeamais*

#### 4.5.2. Efficiency of power-operated mechanical unit on the removal of adults of maize weevil, red flour beetle and lesser grain borer from infested sorghum, wheat and maize grains

The power-operated mechanical unit put to the test with sorghum, wheat, maize and paddy which were artificially infested with known number of adults of *S. zeamais*, *T. castaneum* or *R. dominica* showed that the insects were removed effectively from the infested grains (Table 13, 14, 15 and 16).

##### 4.5.2.1. Sorghum

The results of investigations on insect removal by the use of power-operated mechanical unit was found to be very effective in the removal of adults of *S. zeamais*,

*T. castaneum* and *R. dominica* from artificially infested sorghum grains. Removal of *S. zeamais* adults from infested sorghum were found to be 6.20, 20.40, 31.20, 43.80, 55.00 and 71.80 per cent after 10, 20, 30, 40, 50 and 60 minutes of operation of the device, respectively. The recovery of *T. castaneum* and *R. dominica* from infested sorghum grains were observed to be 74.40 and 65.40 per cent when the device was operated for a duration of 60 minutes. The results showed that the insects were removed significantly after 60 minutes of operation. The recovery pattern in sorghum grains indicates that a higher percentage of *T. castaneum* was removed followed by *S. zeamais* and *R. dominica*.

#### 4.5.2.2. Wheat

The percentage of *S. zeamais*, *T. castaneum* and *R. dominica* removed from artificially infested wheat by operating the power-operated mechanical unit for different time duration is presented in table 14. The observations on the percentage adult removal of *S. zeamais* from artificially infested wheat grains were found to be 9.80, 26.40, 38.60, 52.40, 63.80 and 84.00 per cent after 10, 20, 30, 40, 50 and 60 minutes of operation of the device, respectively. The device when operated for 60 minutes resulted in the removal of 88.80 and 75.00 per cent of *T. castaneum* and *R. dominica*, respectively. The maximum number of insects were removed significantly at the operation duration of 60 minutes. A higher percentage of adults of *T. castaneum* was removed followed by *S. zeamais* and *R. dominica* at the same time duration.

#### 4.5.2.3. Maize

Recovery of *S. zeamais* from artificially infested maize were found to be 10.40, 28.20, 40.20, 56.00, 68.20 and 87.20 per cent after 10, 20, 30, 40, 50 and 60 minutes of operation of the device, respectively (Table 15). The results showed that the insects were removed significantly after 60 minutes of operation. A similar trend was also observed in *T. castaneum* and *R. dominica*. The removal pattern in maize grains revealed that a higher percentage of *T. castaneum* was removed followed by *S. zeamais* and *R. dominica*.

#### 4.5.2.4. Paddy

Observations on the insect removal by the use of power-operated mechanical unit was found to be effective in the removal of adults of *S. zeamais* and *R. dominica* from

**Table 13. Efficiency of power-operated mechanical unit in the removal of *Sitophilus zeamais*, *Tribolium castaneum* and *Rhyzopertha dominica* adults from infested sorghum grains**

Duration of operation (min)	Per cent insect removal		
	<i>Sitophilus zeamais</i>	<i>Tribolium castaneum</i>	<i>Rhyzopertha dominica</i>
10	6.20 (14.39)	7.40 (15.77)	4.60 (12.30)
20	20.40 (26.84)	23.80 (29.18)	11.40 (19.70)
30	31.20 (33.92)	34.60 (36.01)	22.00 (27.92)
40	43.80 (41.43)	49.20 (44.54)	37.20 (37.58)
50	55.00 (47.87)	62.60 (52.31)	48.80 (44.31)
60	71.80 (57.95)	74.40 (59.64)	65.40 (53.99)
CD (P = 0.05)	2.0845	2.5860	2.7995
CV%	4.31	5.01	6.57

Values are the means of five observations.

Figures in parentheses are arcsine ( $\text{Sqr}(X/100)$ ) transformed values.

**Table 14. Efficiency of power-operated mechanical unit in the removal of *Sitophilus zeamais*, *Tribolium castaneum* and *Rhyzopertha dominica* adults from infested wheat grains**

Duration of operation (min)	Per cent insect removal		
	<i>Sitophilus zeamais</i>	<i>Tribolium castaneum</i>	<i>Rhyzopertha dominica</i>
10	9.80 (18.23)	10.40 (18.79)	5.80 (13.92)
20	26.40 (30.91)	34.80 (36.13)	15.00 (22.71)
30	38.6 (38.40)	44.60 (41.89)	26.40 (30.91)
40	52.40 (46.38)	60.40 (51.05)	41.60 (40.16)
50	63.80 (53.02)	74.20 (59.54)	55.80 (48.34)
60	84.00 (66.48)	88.80 (71.61)	75.00 (60.32)
CD (P = 0.05)	2.2430	5.0523	1.9647
CV%	4.07	8.32	4.18

Values are the means of five observations.

Figures in parentheses are arcsine ( $\text{Sqr}(X/100)$ ) transformed values.

**Table 15. Efficacy of power - operated mechanical unit in the removal of *Sitophilus zeamais*, *Tribolium castaneum* and *Rhyzopertha dominica* adults from infested maize grains**

Duration of operation (min)	Per cent insect removal		
	<i>Sitophilus zeamais</i>	<i>Tribolium castaneum</i>	<i>Rhyzopertha dominica</i>
10	10.40 (18.68)	12.20 (20.33)	7.40 (15.63)
20	28.20 (31.88)	36.60 (37.18)	17.80 (24.76)
30	40.20 (39.31)	48.40 (44.08)	29.20 (32.54)
40	56.00 (48.48)	63.80 (53.03)	44.60 (41.89)
50	68.20 (56.02)	77.00 (61.39)	60.40 (51.02)
60	87.20 (69.22)	92.40 (75.10)	79.60 (63.51)
CD (P = 0.05)	6.0690	5.2542	1.9647
CV%	10.58	8.30	4.18

Values are the means of five observations.

Figures in parentheses are arcsine ( $\text{Sqr}(X/100)$ ) transformed values.

**Table 16. Efficiency of power operated mechanical unit in the removal of *Sitophilus zeamais* and *Rhyzopertha dominica* adults from infested paddy grains**

Duration of operation (min)	Per cent insect removal	
	<i>Sitophilus zeamais</i>	<i>Rhyzopertha dominica</i>
10	7.60 (15.97)	5.00 (12.87)
20	22.60 (28.36)	13.80 (21.77)
30	34.30 (35.82)	23.40 (28.90)
40	47.80 (43.74)	40.12 (39.26)
50	59.00 (50.21)	51.60 (45.92)
60	80.20 (63.64)	70.20 (57.00)
CD (P = 0.05)	2.6158	3.4216
CV%	5.06	5.94

Values are the means of five observations.

Figures in parentheses are arcsine ( $\text{Sqr}(X/100)$ ) transformed values.

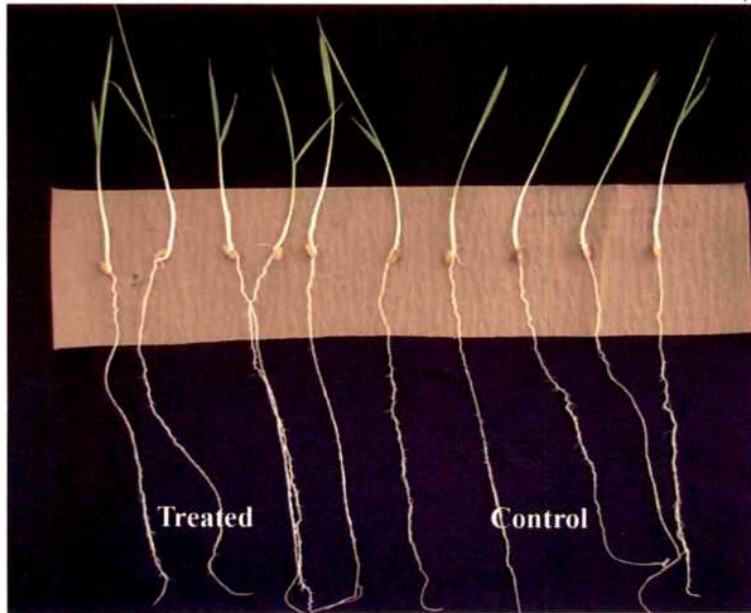
artificially infested paddy (Table 16). The removal of *S. zeamais* adults from infested paddy were found to be 7.60, 22.60, 34.30, 47.80, 59.00 and 80.20 per cent after 10, 20, 30, 40, 50 and 60 minutes of operation of the device, respectively. A higher percentage of insects were removed after 60 minutes of operation. The pattern of recovery in paddy grains indicates that a high percentage of *S. zeamais* was removed followed by *R. dominica* at the same time duration.

#### **4.5.3 Impact of hand operated egg removal device and power-operated mechanical unit on germination**

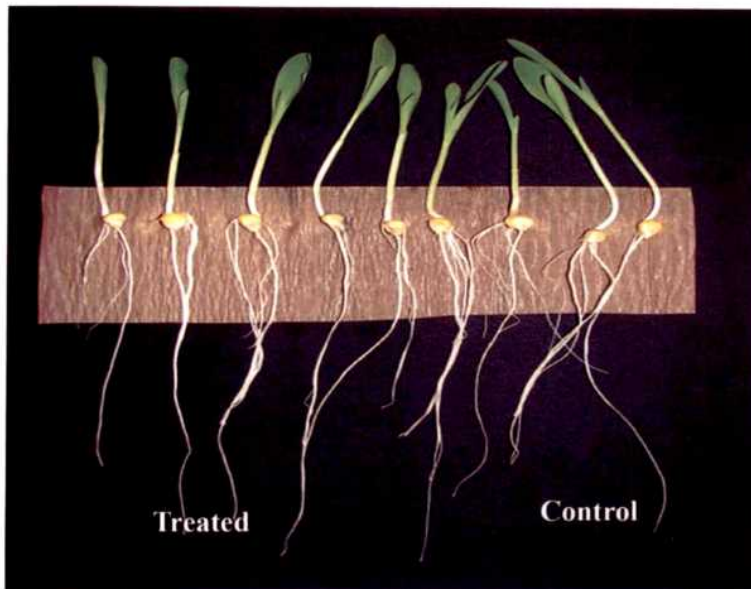
Impact of hand-operated egg removal device/power operated mechanical unit on the germination aspects were assessed by germination test (Roll towel method). The germination percentage of all grains showed that there was no much impact of mechanical rotation on the germinability of grains both in hand-operated and power-operated mechanical devices (Table 17). The germination percentage of grains which were subjected to the hand-operated unit was found to be 98, 97, 100 and 99 per cent for sorghum, wheat, paddy and maize, respectively. Whereas, the grains which were subjected to the power-operated unit were found to be 96, 93, 98, and 97 per cent for sorghum, wheat, paddy and maize, respectively. Among the grains tested, paddy was found to be less affected in terms of germination (Plate 8a and b).

#### **4.5.4. Impact of hand-operated egg removal device and power-operated mechanical unit on the mechanical grain damage**

Grains subjected to rotational impact by the use of both hand-operated egg removal device and power-operated mechanical unit were assessed for the damage caused to them. The mechanical impact of rotation on grain damage was recorded and it showed that there was very less damage to the grains (Table 18). The mechanical damage caused to the grains which were subjected to hand-operated egg removal device were found to be 1.5, 2.0, 0.5 and 1.0 per cent in sorghum, wheat, paddy and maize, respectively. The mechanical damage on grains which were subjected to power-operated egg and adult removal device were found to be 3.0, 4.5, 1.5 and 2.0 in sorghum, wheat, paddy and maize, respectively. A maximum percentage of damage was caused to wheat grain and the damage was very less in paddy grain.



**a. Paddy**



**b. Maize**

**Plate 8. Germination of paddy and maize grains subjected to mechanical impact**

**Table 17. Impact of the egg removal device on germination**

S. No.	Commodity	Germination percentage (%)	
		Hand-operated	Power-operated
1.	Sorghum	98.00	96.00
2.	Wheat	97.00	93.00
3.	Paddy	100.00	98.00
4.	Maize	99.00	97.00

**Table 18. Impact of egg removal device on grain damage**

S. No.	Commodity	Mechanical damage (%)	
		Hand-operated	Power-operated
1.	Sorghum	1.5	3.0
2.	Wheat	2.0	3.5
3.	Paddy	0.5	1.5
4.	Maize	1.0	2.0

*Discussion*

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## CHAPTER V

### DISCUSSION

Investigations were carried out to assess the efficiency of egg removal device for pulse beetle in the removal of eggs of stored grain insects. The egg and adult removal ability of the power operated mechanical unit was also evaluated. The results thus obtained are discussed in this chapter.

#### **5.1. Efficiency of egg removal device in the removal of eggs of rice moth from sorghum grains**

Studies conducted to evaluate the efficiency of egg removal device in the removal of eggs of *Corcyra cephalonica* Stainton was done by way of assessing the number of offspring adults. The reduction in progeny production was estimated based on number of larval webbings and offspring adults emerged. The egg removal device was found to reduce the progeny markedly either by removing or damaging the eggs.

*C. cephalonica* is most significant lepidopteran pest of stored products in many tropical locations and survives on a wider range of food materials such as whole cereals, processed product of cereals, nuts and dry fruits. Controlling this pest is of utmost importance as it causes severe damage in a very shortspan of time. Mechanical impact is one of the important strategies of physical control method in managing the stored grain insects.

The results of this investigation showed that the egg removal device was highly effective in the control of *C. cephalonica*. Operating the egg removal device for 3 days (i.e. 5 min/day) resulted in less number of webbings and higher reduction in the emergence of offspring adults. This could be due to the fact that rotating the grains for 3 days provides ample chance for the grains to get themselves subjected to physical disturbances which inturn would result in more removal or damage to eggs present in grains, finally, ending in a significant reduction in progeny. Increase in the number of rotations leads to increase in the mortality of larvae of stored product insects (Loschiavo, 1978). Moreover, the larval stages present inside the grain could have been killed due to the physical impact caused by rotation. No significant difference was observed among the density of eggs used for the experiments. Hence, this egg removal device would prove to be very effective both under mild and severe infestation.

## 5.2. Efficiency of egg removal device in the removal of eggs of Angoumois grain moth from infested sorghum, paddy and wheat grains

Investigations conducted to assess the efficiency of egg removal device in the removal of eggs of Angoumois grain moth from infested sorghum, paddy and wheat grains indicates that the egg removal device significantly removed the eggs of Angoumois grain moth.

Angoumois grain moth is found world wide in a variety of stored grains including paddy, wheat, maize, oat, sorghum, barley, etc. (Anand Prakash and Jagadiswari Rao, 1986). Field carry over infestation of this pest becomes most serious during storage. It is well documented that *S. cerealella* infest grain in the field prior to harvest (Singh *et al.*, 1978). The eggs laid in the grains of standing crops will emerge during storage and cause severe damage to the grains. So this mechanical rotation of grains after harvest of grains or before bringing to storage will remove the eggs and facilitate the pest free storage of grains.

Observations on the emergence of offspring adults showed that rotating the grains for 3 days resulted in the control of *S. cerealella*. Increasing the frequency of rotation would make the grains exposed to physical disturbance for a longer time resulting in the removal of more number of eggs.

The results of investigations carried out in different grains showed that the higher percentage of control was observed in wheat grains followed by sorghum and paddy. This could be due to the differential habit of host preference. Paddy is the most preferred grain for *S. cerealella* followed by sorghum (Ragumoorthi, 1987). So there is a chance to lay more number of eggs in paddy than sorghum and wheat. This could be the reason for lesser control of this pest in paddy. It may require more number of frequency of rotation or duration of operation.

Grain texture is also one of the important factors which determines the efficiency of egg removal. Generally the adult females lay their eggs on the grooves of grain surface (Khare, 1993). Female adult moths prefer rough surface for egg laying than smooth one in stored rice (Anand Prakash and Jagadiswari Rao, 1986). The surface of the paddy grain

is rough compared to sorghum and wheat. So the removal of eggs from paddy grain is difficult. The smooth surfaces of the sorghum and wheat grains facilitate the easy detachment and removal of eggs.

### **5.3. Efficiency of egg removal device in the removal/damage of eggs of maize weevil, red flour beetle and lesser grain borer from infested sorghum, wheat, maize and paddy grains**

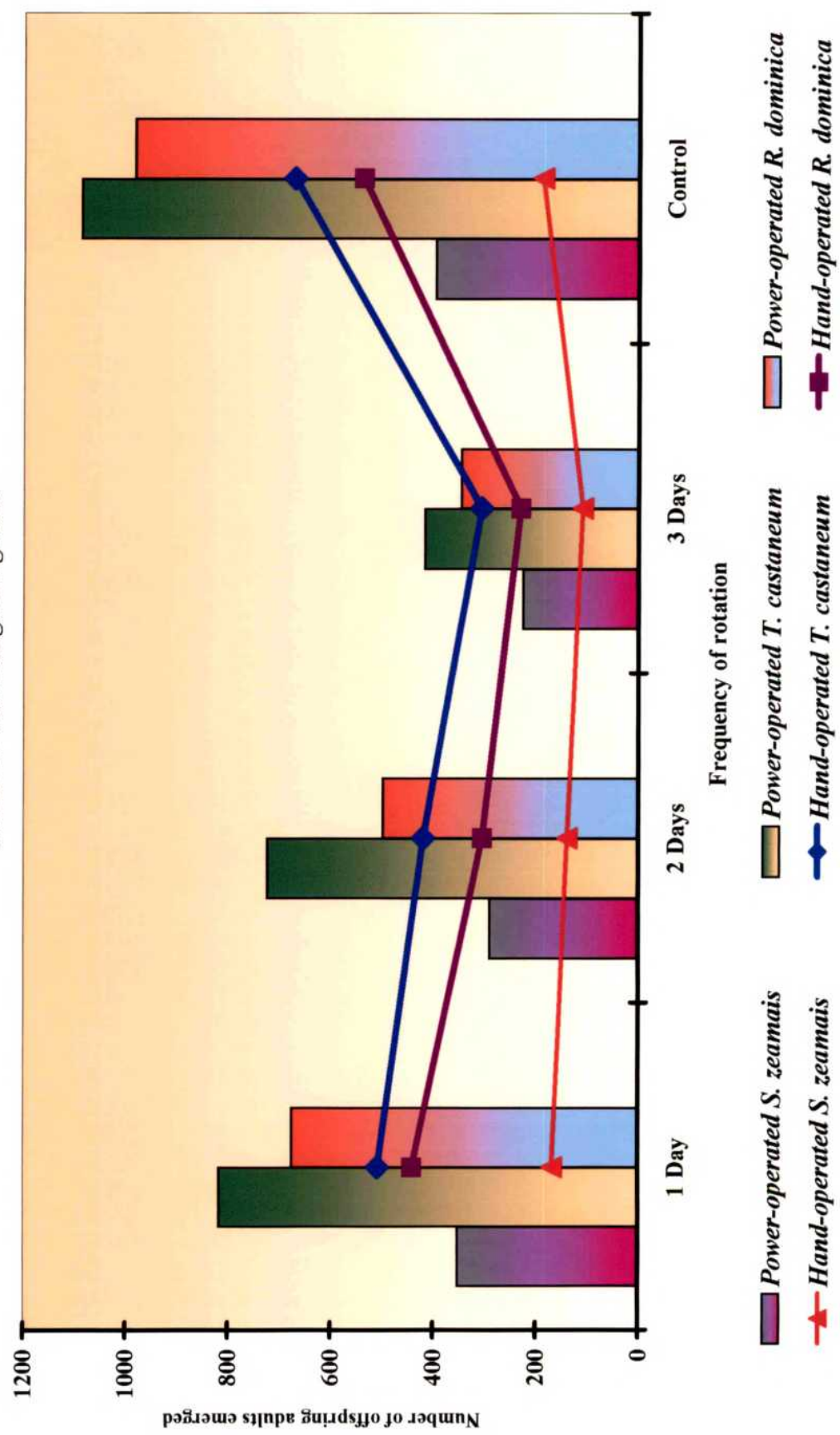
Investigations carried out to find out the efficiency of egg removal device in the removal of eggs of maize weevil, red flour beetle and lesser grain borer revealed that the eggs were effectively removed. These insects have been tested against the important food grains like, wheat, maize, paddy and sorghum grains. Wheat and paddy grains were chosen as they are staple food in Northern and Southern India, respectively. Maize ranks third in position next to wheat and rice in the world with respect to area while its productivity surpasses all other cereal crops. Major areas in the European countries are occupied by maize cultivation. Majority of the rainfed lands in India and in South Africa is cultivated with sorghum. These grains are infested by many of the stored product insects when brought to storage and cause significant loss. So preventing the loss of these grains during storage will help to feed the stomachs of poor.

#### **5.3.1. Sorghum**

The percentage of control was found out on the basis of emergence of offspring adults from treated grains. Among 1, 2 and 3 days rotated grains, a higher percentage of reduction in emergence of offspring adults were observed in 3 days rotated grains (Figure 1). This could be due to more frequency of disturbance or impact of rotation caused to the eggs attached to the grains of stored grain pests. The regular bean tumbling dramatically lowered the bean weevil *Acanthoscelides obtectus* (Say) populations by approximately 97 per cent in kidney bean (*Phaseolus vulgaris* L.).

Among the insects tested in sorghum grains a higher percentage of reduction in adult emergence was noticed in *Rhyzopertha dominica* Feb. followed by *Tribolium castaneum* Herbst. and *Sitophilus zeamais* Motsch. There was no much variation in the percentage of control of *T. castaneum* and *R. dominica*. The eggs of *T. castaneum* is more sticky when freshly laid (Khare, 1993). So the removal of eggs of *T. castaneum* is

Fig. 1. Impact of egg removal devices on the emergence of adults of *S. zeamais*, *T. castaneum* and *R. dominica* from sorghum grains



more difficult. Maize weevils make a slit like opening on the grain surface and lay their eggs and cover them with some gelatinous material. So the removal of eggs of *T. castaneum* and *S. zeamais* is very difficult compared to the eggs of *R. dominica*. This could be the possible reason for the higher percentage of reduction in offspring adults of *R. dominica*.

### 5.3.2. Wheat

Studies carried out to assess the efficiency of egg removal device in the removal of eggs of *S. zeamais*, *T. castaneum* and *R. dominica* from wheat grains revealed that, the eggs were effectively removed from the grain. Among the insects tested, a higher percentage of egg removal was observed in 3 days rotated grain (Figure 2). This could be due to more number of physical disturbances on the grains. The mortality of rusty grain beetle *Cryptolestes ferrugineus* (Stephens) adults generally increased with increasing number of drops in wheat (Loschiavo, 1978) There is no much variation in the percentage reduction of offspring adults between *T. castaneum* and *R. dominica* and a lesser control was observed in *S. zeamais*. This may be due to the specific egg laying pattern of *S. zeamais* which lays the eggs inside the grain and cover them with gelatinous secretions over it (Richards, 1947).

### 5.3.3. Maize

The mean number of offspring adults of *S. zeamais*, *T. castaneum* and *R. dominica* in maize grains support the greater efficiency of egg removal by the use of hand-operated egg removal device (Figure 3). The results showed that there was a significant difference between the treatments. The 3 days rotated grains showed better removal/damage of eggs. Joffe and Clarke (1963) showed that the type, timing and frequency of disturbance play a significant role in determining the extent of damage to *S. oryzae*. They reported that the daily disturbance of maize grains resulted in a higher percentage of control of *S. oryzae*. There was a clear relationship between frequency of disturbance and the reduction in the number of progeny. A higher reduction in offspring adults were noticed in *R. dominica* followed by *S. zeamais* and *T. castaneum*. Eventhough the eggs of *S. zeamais* were plugged with secretions, the eggs get damaged by physical disturbance or rotation, because the egg stage is most sensitive stage for physical disturbance (Joffe and Clarke, 1963).

Fig. 2. Impact of egg removal devices on the emergence of adults of *S. zeamais*, *T. castaneum* and *R. dominica* from wheat grains

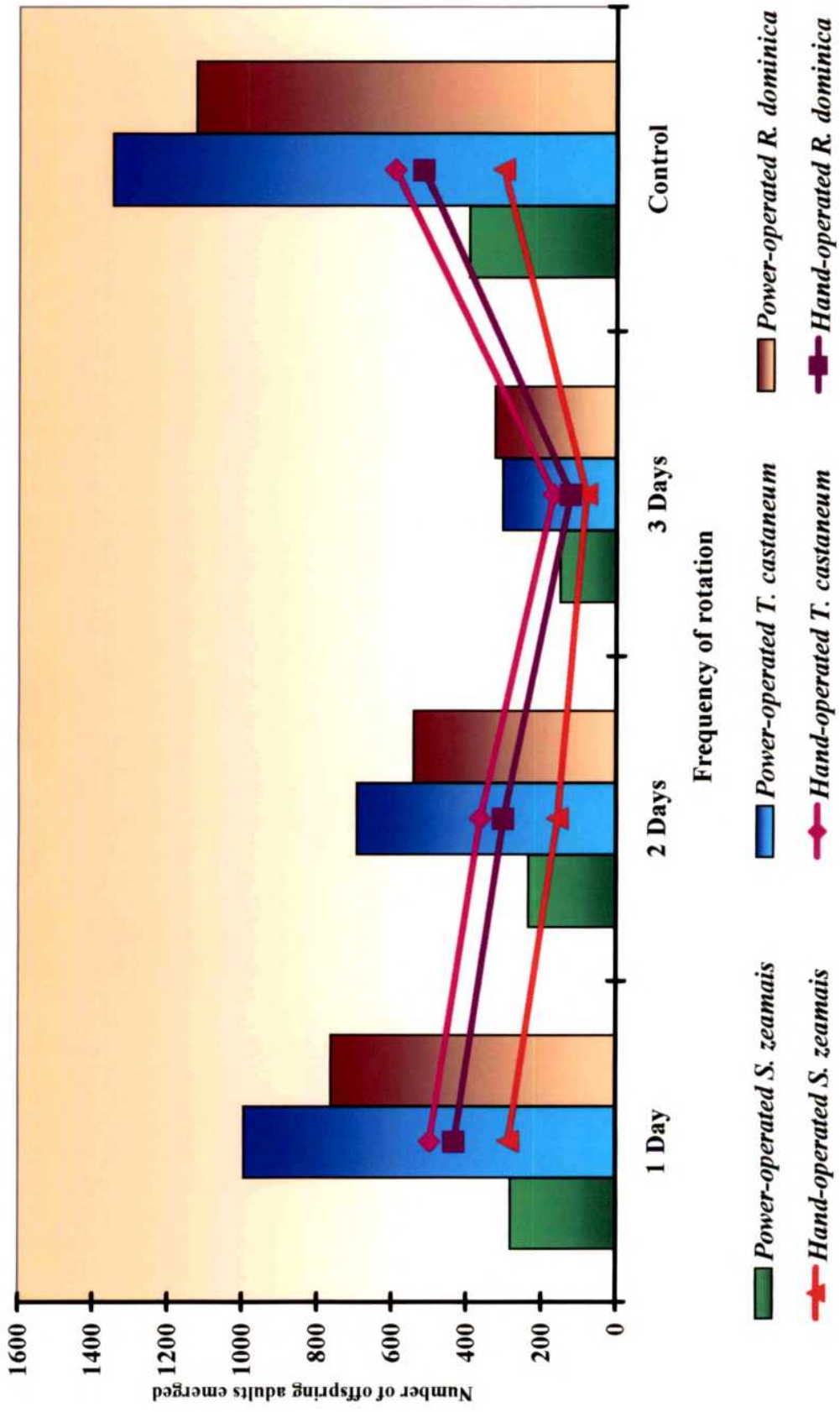
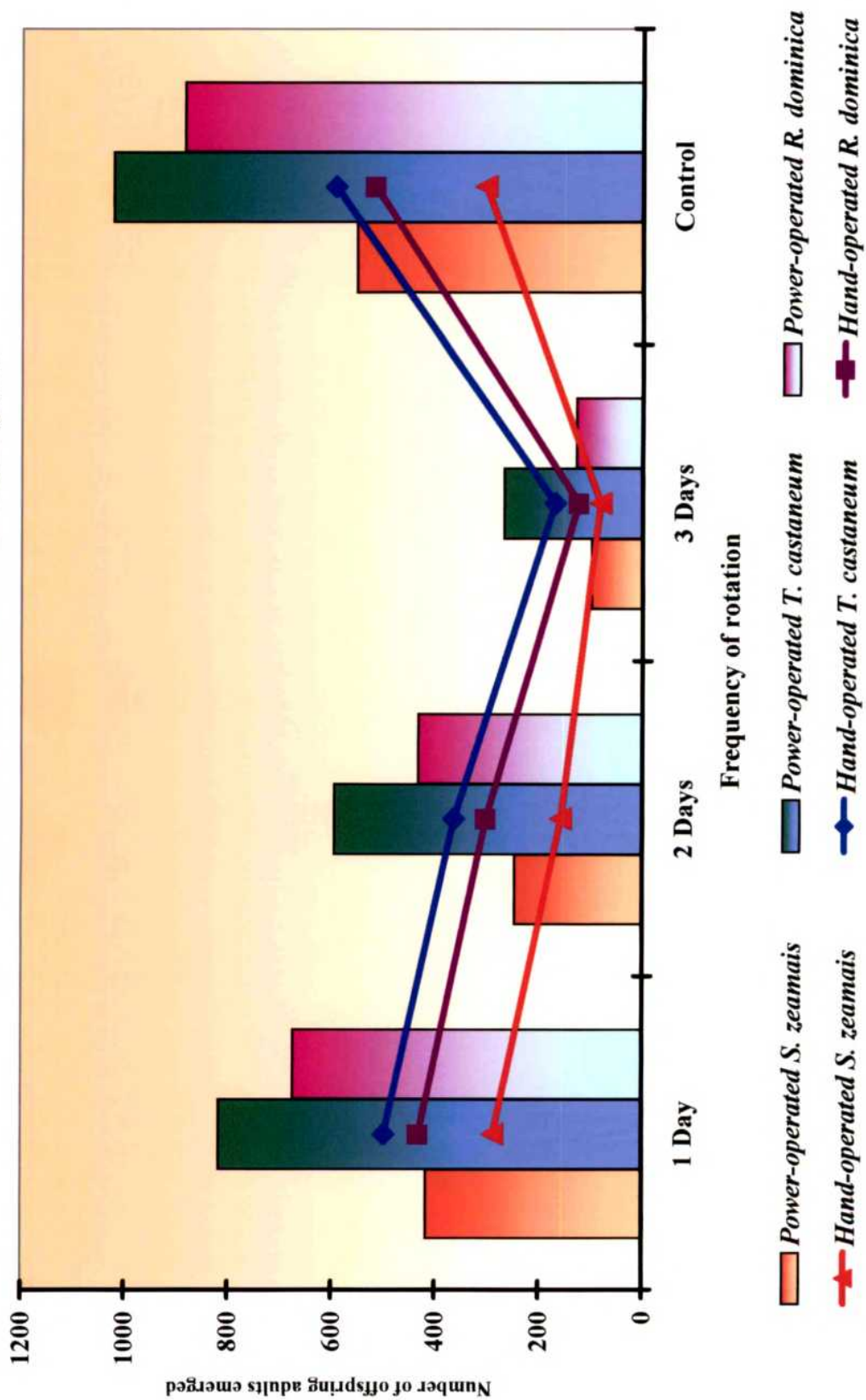


Fig. 3. Impact of egg removal devices on the emergence of adults of *S. zeamais*, *T. castaneum* and *R. dominica* from maize grains



#### 5.3.4. Paddy

Investigations carried out to assess the efficiency of egg removal device in the removal of eggs of *S. zeamais* and *R. dominica* in paddy grains showed that the eggs were effectively removed from the paddy grains. Both in *S. zeamais* and *R. dominica* the 3 days rotated grains showed significantly less number of offspring adults indicating that the effective removal of eggs. This could be due to the more number of impacts or physical disturbance on the eggs which would remove or damage the eggs. In paddy grains a lesser number of offspring adults of *R. dominica* was observed which indicates the removal of eggs significantly (Figure 4). Due to the process of plugging of eggs of *S. zeamais*, egg removal efficiency was reduced.

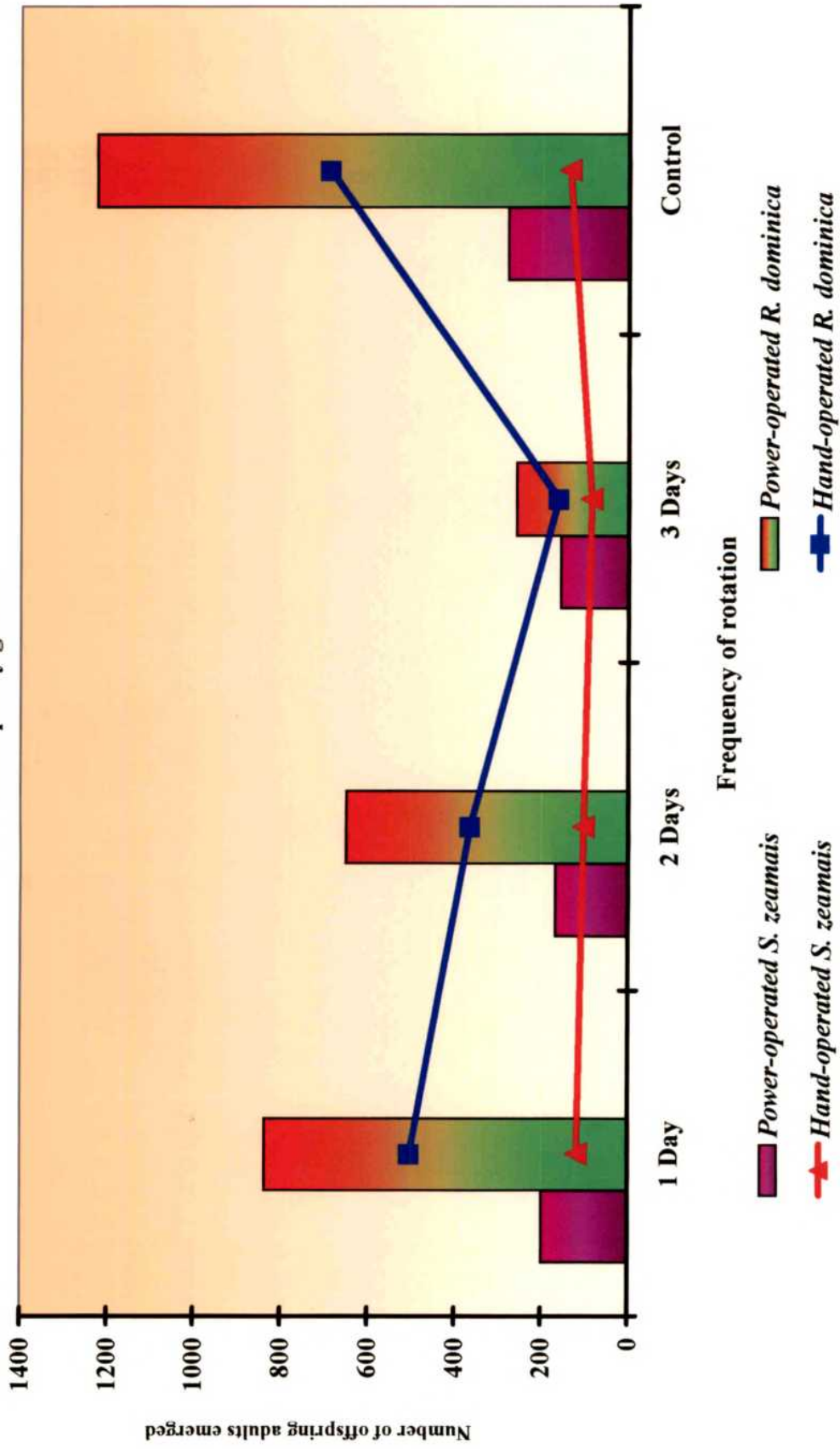
#### 5.4. Efficiency of egg removal device in the removal of eggs of cigarette beetle from coriander

Studies conducted to assess the efficiency of egg removal device in the removal of eggs of *Lasioderma serricornis* F. from coriander seeds revealed that the device is effective in egg removal.

Coriander is one of the important spices in India. It is used along with other spices in our daily diet and has also got some medicinal value. Coriander is stored as whole seed as well as in powder form. During storage, whole coriander seed is infested by cigarette beetle causing considerable damage and deteriorates the quality (Agrawal and Srivastava, 1984). So the present investigation in the removal of eggs of *L. serricornis* will be effective in the control of cigarette beetle.

The results showed that the significant difference exists between the treatments and control. Among 1, 2 and 3 days rotated grains, 3 days rotated grains showed less number of offspring adults. A reduction in the emergence of offspring adults was achieved. Generally, the females of *L. serricornis* oviposit directly on the dried surface of the grains (Ashworth, 1993). Hence, the brush present in the device might have cleared the eggs easily from the surface.

Fig. 4. Impact of egg removal devices on the emergence of adults of *S. zeamais* and *R. dominica* from paddy grains



### **5.5. Efficiency of power-operated mechanical unit in the removal/damage of eggs of maize weevil, red flour beetle and lesser grain borer from infested sorghum, wheat, maize and paddy grains**

Investigations carried out to assess the efficiency of power-operated mechanical unit in the removal of eggs of major stored product insects from infested food grains revealed that the unit is effective in the removal. The power-operated mechanical unit is advantageous, because, the speed of rotation would remain uniform throughout the duration of operation. Whereas, in the case of hand-operated egg removal device the speed of rotation may vary as it is operated manually. The power-operated mechanical unit could be installed in grain storage godowns and used as it would facilitate insects free grain storage. There was a little increase in the mechanical damage caused to grains and decrease in germination percentage over hand-operated egg removal device. This could be due to the increase in the speed of rotation, thereby causing more damage to the grains. In impact machines insect mortality increases with increasing velocity of the steel pegs (Rudy Plarre and Franz Reichmuth, 2000).

#### **5.5.1. Sorghum**

Studies carried out to assess the efficiency of power-operated mechanical unit in the removal of eggs of maize weevil, red flour beetle and lesser grain borer from infested sorghum grains revealed that a significant number of eggs have been removed. The results showed that, among, 1, 2 and 3 days rotated grains the higher percentage of reduction in emergence of offspring adults were observed in 3 days rotated grains (Figure 1). The more the disturbance or impact of rotation more the removal of eggs resulting in a lesser number of offspring adults. Mortality of insects embedded in grain increased with increasing number of rotations, tumbling and drops, followed by impact (Loschiavo, 1978).

Among the tested insects, a higher percentage of reduction in adult emergence was noticed in *R. dominica* followed by *T. castaneum* and *S. zeamais*. There is no much variation on percentage of control in *T. castaneum* and *R. dominica*. Sticky nature of the eggs of *T. castaneum* and eggs covered with gelatinous secretion in the case of maize weevil would have reduced the efficiency of the power-operated mechanical unit in removing the eggs from the grains.

### 5.5.2. Wheat

A higher percentage of egg removal of *S. zeamais*, *T. castaneum* and *R. dominica* was observed in 3 days rotated wheat grains (Figure 2). Bailey (1969) showed a clear additive effect, as the number of impacts increase, even at very low impact speeds, when the infested wheat was dropped several times. A less control was achieved in *S. zeamais*, which might be due to the egg laying behaviour, i.e. laid eggs were covered with gelatinous secretions.

### 5.5.3. Maize

The results showed that there exists a significant difference between the treatments. Three days rotated grains showed better removal of eggs of *S. zeamais*, *T. castaneum* and *R. dominica* from infested maize kernels. An increase in the frequency of operation results in an increase in the efficiency of egg removal. A clear relationship exists between the frequency of disturbance and the reduction in the number of progeny. A higher reduction in offspring adults were noticed in *R. dominica* followed by *S. zeamais* and *T. castaneum* (Figure 3). The egg stage is more sensitive against physical disturbance; even the eggs of *S. zeamais* which are normally covered with gelatinous secretions were even removed or damaged due to the agitation caused by rotation.

### 5.5.4. Paddy

In paddy grains, *R. dominica* showed less number of offspring adults indicating the effectiveness of egg removal by the use of power-operated mechanical unit (Figure 4).

## 5.6. Efficiency of power-operated mechanical unit in the removal of adults of maize weevil, red flour beetle and lesser grain borer from infested sorghum, wheat and maize grains

The prototype of egg removal device scaled up as power-operated mechanical unit, proved more efficient in terms of removal of stored product insects from infested grains.

The power-operated mechanical unit was tested against *S. zeamais*, *T. castaneum* and *R. dominica* in cereals like, sorghum, wheat, maize and paddy. The operation time was fixed as 60 minutes and the insects which got collected in the collection device was

counted once in every 10 minutes. Many of the stored product insects are involved in mating immediately after emergence and lay their eggs on the grains. Hence, 60 minutes rotation would help in the prevention of matting and oviposition by the insects.

Investigations carried out to assess the efficiency of the power-operated mechanical unit in the removal of adults of *S. zeamais*, *T. castaneum* and *R. dominica* revealed that the device effectively removed the adults. The results showed that there was a significant variation in the recovery of insects at different time duration. The maximum number of insects were removed at 60 minutes time duration. The pattern of recovery indicates that a high percentage of *T. castaneum* were removed followed by *S. zeamais* and *R. dominica* at the same time duration. This could be due to the fast moving behaviour of *T. castaneum* than other insects. Comparatively the density of sorghum grain is more, so the insect removal percentage was less in sorghum than in wheat, maize and paddy.

Compared to all the grains the insect removal percentage was higher in maize grain. This could be due to the less density of maize grains that makes more space for the movement of insects.

In paddy the removal of insects were less compared to other grains, as the grain density is more and texture is coarse. The coarse texture of grains gives a grip to grasp during the physical disturbance.

The concept of physical removal of insects from stored grains could be sorted as one of the important pest control strategy (Banks and Fields, 1995). The power-operated mechanical device exploits the wandering and air loving behaviour of the stored product insects. By operating the device for a duration of 60 minutes, a major proportion of the insects could be removed and the mechanical damage to grains were very meagre which tends to increase the value of the grain.

Merits of the mechanical device over traditional insect control are that it is residue free, it offers no advantage to insecticide resistant insect strains and it can be used to remove stored product insects attacking food grains simultaneously. The equipment is easy to maintain and run and therefore remains more suited for removing the insects from the grains at a faster pace. This device resulted in flushing out the insect in a very short time.

Physical disturbance (White *et al.*, 1997) associated with the wandering behaviour of insect towards aerated region have contributed to the removal of adult insects from the infested grains. Most farmers in the small scale community do not normally have facilities to prevent storage losses due to insect pests. They could be benefited by using this mechanical device. The design of the device is in such a manner that it facilitated the rapid removal of insects from mild and severely infested grains. Unlike chemical and biological control, the use of physical control, especially mechanical force applied to commodities does not result in toxic residues or insect filth (Vincent *et al.*, 2003). Employing physical control methods like the use of mechanical devices do not endanger human health or safety of the environment. Hence, the power-operated mechanical unit developed for the removal of insects from mild and severely infested grains could be of greater value to the farmers and grain-handlers.

#### **5.7. Impact of hand operated egg removal device and power-operated mechanical unit on germination**

Germination of the test grains namely, sorghum, wheat, maize and paddy was not affected when they were subjected to rotational impact both by the use of hand-operated and power-operated mechanical unit for egg and adult removal.

#### **5.8. Impact of hand-operated egg removal device and power-operated mechanical unit on the mechanical grain damage**

Mechanical damage observed was very meagre (less than 3.0 %) in the test grains namely, sorghum, wheat, maize and paddy when they were subjected to rotational impact both by the use of hand-operated and power-operated mechanical unit for egg and adult removal.

*Summary*

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## CHAPTER IV

### SUMMARY

The results of investigations carried out on the efficiency of “Egg removal device for pulse beetle” in the removal of eggs of major stored product insects and testing the efficiency of a scaled up “Power operated mechanical unit” in the removal of eggs and adults of major stored product insects are summarized below:

- 1) The egg removal device proved effective in the removal of eggs of *C. cephalonica* when the hand-operated egg removal device was rotated for a period of 3 days (15 minutes/day).
- 2) Eggs of *S. cerealella* were removed effectively from the infested sorghum, wheat and paddy grains. The 3 days rotation was found effective and maximum number of eggs were removed from wheat grains followed by sorghum and paddy.
- 3) The egg removal device was found effective in the removal of eggs of maize weevil, red flour beetle and lesser grain borer from infested sorghum, wheat, maize and paddy grains. The maximum percentage of reduction in the emergence of offspring adults were noticed in 3 days rotated grains.
- 4) Among the insects tested in wheat and sorghum grains, the maximum control was observed in *R. dominica* followed by *T. castaneum* and *S. zeamais*
- 5) In the case of maize, the maximum control was noticed in *R. dominica* followed by *S. zeamais* and *T. castaneum*
- 6) In the case of paddy, the egg removal efficiency was in the order of *R. dominica* > *S. zeamais*
- 7) The egg removal device also proved effective in the removal of eggs of *L. serricornis* from coriander seeds and 3 days rotation was found to be more effective.
- 8) The prototype of “Egg removal device for pulse beetle” upgraded as “Power operated mechanical unit” effectively removed the eggs of *S. zeamais*, *T. castaneum* and *R. dominica* from infested sorghum, wheat and maize grains when rotated for 3 days (15 min/day).

- 9) A very short time duration of 60 minutes, the power-operated mechanical unit removed the maximum percentage of adults of *S. zeamais*, *T. castaneum* and *R. dominica* from artificially infested sorghum, wheat, maize and paddy grains.
- 10) A higher percentage of adults of *T. castaneum* were removed followed by *S. zeamais* and *R. dominica* at the same time duration of 60 minutes.
- 11) The mechanical impact created by the both unit (hand-operated egg removal device and power-operated mechanical unit) did not affect the germination of the treated seeds.
- 12) There was no grain damage due to the operation of both hand and power-operated mechanical unit.

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