Bio-ecology and Management of *Corcyra cephalonica* Stainton under Sub humid Southern Zone of Rajasthan

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HEMRAJ MEENA

Thesis

Doctor of Philosophy in Agriculture (Entomology)

2014

DEPARTMENT OF ENTOMOLOGY
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This is to certify that this thesis entitled **"Bio-ecology and Management of *Corcyra cephalonica* Stainton under Sub humid Southern Zone of Rajasthan"** submitted for the degree of Doctor of Philosophy in Agriculture in the subject of Entomology, embodies bonafide research work carried out by **Mr. Hemraj Meena** under my guidance and supervision and that no part of this thesis has been submitted for any other degree. The assistance and help received during the course of investigation have been fully acknowledged. The draft of thesis was also approved by the advisory committee on 19/06/2014.

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Bio-ecology and Management of *Corcyra cephalonica* Stainton under Sub humid Southern Zone of Rajasthan

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ABSTRACT

The present investigations on "*Bio-ecology and Management of Corcyra cephalonica Stainton under Sub humid Southern Zone of Rajasthan*" were carried out under laboratory condition, Department of Entomology, Rajasthan College of Agriculture, Udaipur during, 2010 to 2012.

The study conducted on extent of damage of *C. cephalonica* in maize under different storage structures in Rajsamand, Chittorgarh and Udaipur districts revealed that the maximum infested grain samples (61.53%) were recorded from grain stored in loose storage during June-July, 2011. Whereas, infested grain samples were not found from the grain stored in metal bin during November-December, 2010. The maximum weight loss (7.46%) was recorded in grain samples collected from loose storage in Udaipur district during June-July, 2011. No weight loss in grains were recorded in the samples collected from metal bin in Chittorgarh and Udaipur district during November-December 2010. In the quantitative and qualitative studies revealed that the maximum germination (78.00%) and protein content (8.60%) were recorded in the samples collected from metal bin in Chittorgarh district during November-December, 2010, while maximum carbohydrate content (72.00%) was recorded in maize samples collected from metal bin in Rajsamand district during November-December 2010. The minimum germination (62.00%) and carbohydrate content (66.50%) were recorded in maize samples collected from loose storage in Udaipur district whereas, minimum protein content (6.70%) were recorded from loose storage in Chittorgarh district during June-July 2011.

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The studies conducted on effect of host on the biology of *C. cephalonica* revealed that the minimum hatching period (4.25 days) was observed on pearlmillet and maize and maximum on groundnut (5.50 days).

The minimum larval period (32.50 days) was recorded on pearlmillet and maximum was on oat (45.25 days). The maximum larval weight was recorded with pearlmillet (52.25 mg) and minimum on oat (38.50 mg).

The minimum pupal period was recorded on pearlmillet and maize (9.50 days) and maximum on oat (11.25 days); while maximum pupal weight was recorded on pearlmillet (38.50 mg) and minimum on oat (32.00 mg). The maximum adult emergence was recorded on pearlmillet (79.00%) and minimum on groundnut (65.00%). The Growth Rate Index was maximum on pearlmillet (1.71) and minimum on groundnut (1.07). The highest fecundity of female (302.50 eggs/female) was recorded on maize and minimum was on groundnut (225.50 eggs/female). The maximum longevity period of female (7.25 days) was recorded on wheat and minimum on sorghum (4.50 days); whereas the maximum adult male longevity was (10.25 days) recorded on pearlmillet and minimum was on sorghum (8.00 days). The

minimum developmental period was recorded on pearlmillet (46.25 days) and maximum was on oat (61.25 days).

The studies conducted on effect of temperature and relative humidity on the growth and development of *C. cephalonica* revealed that the development period of male and female was minimum at 40°C temperature and 80 per cent relative humidity with a mean of 35.70 and 31.30 days, respectively. Whereas the development period of male and female was maximum with a mean of 89.50 and 92.00 days at 20°C temperature and 40 per cent relative humidity, respectively. The minimum larval period (22.70 days) was recorded at 40°C temperature and 80 per cent relative humidity, whereas the maximum larval period of (70.10 days) was recorded at 20°C temperature and 40 per cent relative humidity. The maximum weight of full grown larva (51.00 mg) was recorded at 30°C temperature and 80 per cent relative humidity and minimum larval weight (33.00 mg) was observed at 20°C temperature and 40 per cent relative humidity. The maximum pupal period of male (13.60 days) and female (14.40 days) were observed at 20°C temperature and 40 per cent relative humidity. Whereas, the minimum pupal period of male (8.40 days) and female (9.85 days) was recorded at 30°C temperature and 80 per cent relative humidity. The higher weight of male (36.00 mg) and female (38.00 mg) pupa were observed at 30°C temperature and 80 per cent relative humidity, whereas lowest pupal weight of male (21.00 mg) and female (23.00 mg) pupa were observed at 20° C temperature and 40 per cent relative humidity. The maximum adult emergence of male (61.40%) and female (80.90%) were observed at 30°C temperature and 80 per cent relative humidity and minimum were male (35.10%) and female (54.90%) at 20°C temperature and 40 per cent relative humidity. The maximum adult longevity of male (16.30 days) and female (10.50 days) were observed at 20°C temperature and 40 per cent relative humidity while minimum adult longevity of 3.05 (male) and 2.81 (female) days were observed at 40°C temperature and 80 per cent relative humidity. The maximum growth rate index of male (1.35) and female (1.64) were recorded at 30°C temperature and 80 per cent relative humidity while minimum growth rate index male (0.39) and female (0.60) were observed at 20°C temperature and 40 per cent relative humidity.

The efficacy of different grain protectants against *C. cephalonica* revealed that the highest larval mortality (82.20%), pupal mortality (10.00%) and minimum adult emergence (6.00%) were recorded in case of application neem leaf powder at 10g/kg seed, after 40 days of release. Application of wood ash at 15g/kg seed was found least effective. The studies conducted on varietal screening against *C. cephalonica* revealed that the maximum development period (68.00 days), minimum adult emergence (62.50%) and lowest weight loss (18.50%) were observed on Pratap Hybrid Maize-1. Among the different storage structures the pusa bin was most efficient storage structure where minimum quantitative losses due to *C. cephalonica* was recorded at 120 days. The gunny bag exhibited highest weight loss in stored maize due to *C. cephalonica*.

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1. INTRODUCTION

Maize (*Zea mays* L) is one of the most versatile emerging crops having wider adaptability under varied agro-climatic conditions. Globally, maize is known as queen of cereals because it has the highest genetic yield potential among the cereals. It is cultivated on nearly 150 m ha in about 160 countries having wider diversity of soil, climate, biodiversity and management practices. The worldwide production of maize was 967 MT during 2013-14. The United States of America (USA) is the largest producer of maize contributes nearly 35 per cent of the total production in the world and maize is the driver of the US economy. The USA has the highest productivity (> 9.6 tonne/ha) which is double than the global average (4.92 tonne/ha). Whereas, the average productivity in India is 2.5 tone/ ha (IMS, 2014). In India, maize is the third most important food crops after rice and wheat. According to advance estimate its production is likely to be 23 MT (2013-14) mainly during *Kharif* season which covers 80 per cent area. Maize in India, contributes nearly 9 per cent in the national food basket. In addition to staple food for human being and quality feed for animals, maize serves as a basic raw material as an ingredient to thousands of industrial products that includes starch, oil, protein, alcoholic beverages, food sweeteners, pharmaceutical, cosmetic, film, textile, gum, package and paper industries etc.

The maize is cultivated throughout the year in all states of the country for various purposes including grain, fodder, green cobs, sweet corn, baby corn and pop corn in peri-urban areas. The predominant maize growing states that contributes more than 80 per cent of the total maize production are Andhra Pradesh (20.9 %), Karnataka (16.5 %), Rajasthan (9.9 %), Maharashtra (9.1 %), Bihar (8.9 %), Uttar Pradesh (6.1 %), Madhya Pradesh (5.7 %) and Himachal Pradesh (4.4 %). Apart from these states maize is also grown in Jammu and Kashmir and North-Eastern states. Hence, the maize has emerged as important crop in the non-traditional regions i.e. peninsular India as the state like Andhra Pradesh which ranks 5^{th} in area (0.79 m ha) has recorded the highest production (4.14 MT) and productivity (5.26 tonne/ha) in the country. Although the productivity in some of the districts of Andhra Pradesh is more or equal to the USA (IMS, 2014). In Rajasthan, maize is mostly grown in Banswara, Udaipur, Bhilwara, Dungarpur, Rajsamand and Chittorgarh districts. Rajasthan ranks

first in the country in respect of area, wherein this crop occupies 10.20 lakh hectare area with production of 21 lakh tonnes and productivity of 18 q/ha (DESDAC, 2014).

Although, there are about 200 species of insects and mites are found infesting maize grains, few of which are major or primary pests. Among these, the rice moth, *Corcyra cephalonica* Stainton (Lepidoptera: Pyralidae) is one of the most important pest of stored maize, distributed in Asia, Africa, North America and Europe. It feeds on many hosts, viz., rice, sorghum, wheat, groundnut, gram, cotton seed, etc. The larvae cause damage to grain by feeding under silken webs. When infestation is high the entire stock of grain may converted into a webbed mass. Ultimately, a characteristic fowl odour is developed and the grain rendered unfit for human consumption. The pest cause both quantitative and qualitative losses. The success achieved so far in making the stored grain free from insect pests has been largely on sole reliance of pesticides, but indiscriminate use of fumigants and other toxic chemicals caused serious problems like chronic and acute toxicity, development of insect resistance, pest resurgence, residue in food, hazards to human health and the environmental pollution. The use of plant products assumed significance as an important component of insect pest management because of their economic viability and eco-friendly nature. They hold promise as alternatives to chemical insecticides to reduce pesticide load in the environment. Contrary to the insecticides, they do not have mammalian toxicity, no health hazards, surface persistence last for long time, have no adverse effect on seed germination, cooking quality milling, less expensive and easily available. Increasing awareness of the hazards in use of chemical pesticides and several reported cases of food poisoning has created renewed interest in the use of plant products as grain protectants. There are encouraging reports on the use of certain indigenous plant products as grain protectants (Jotwani and Sircar, 1965; Singh and Srivastava, 1980; Jacob and Sheila, 1990; Bhargava, 1997; and Sharma and Bhargava, 2001).

Insect infestation causing losses are the most serious problem in grain storage particularly in villages and towns in developing countries because of humid tropical conditions, poor sanitation and inappropriate storage facilities.

In order to develop economic and effective control measures for *C. cephalonica*, detailed and accurate knowledge of its bio-ecology is essential under variable macro-ecological conditions which would be helpful in the possible

prediction of population levels and study the various mortality factors regulating pest abundance so that an effective management strategy may be developed. These aspects need more intensive investigations, as abiotic factors such as temperature, relative humidity and moisture percentage of stored products play vital role in pest infestation. One of the eco-friendly and economic approaches to keep the stored food grains free from insect attack, would be using plant products, resistant varieties and good storage structures for the management of insect population in stored products.

Hence, considering the above facts, the present investigations were carried out to study the "Bio-ecology and Management of *Corcyra cephalonica* stainton under Sub humid Southern Zone of Rajasthan" with the following objectives:

1. To study the extent of damage of *C. cephalonica* in maize under different storage structures.
2. To study the effect of hosts on the biology of *C. cephalonica.*
3. Effect of abiotic factors on the growth and development of *C. cephalonica* in stored maize.
4. To develop eco-friendly modules for management of *C. cephalonica* for stored maize.

2. REVIEW OF LITERATURE

2.1 Survey:

Srivastava *et al.* (1973) carried out surveys in two villages of western Uttar Pradesh and observed that bag storage was most common method. Other structures were kachcha and pucca kothi and drums. Damage by insect pests was more in kachcha and pucca kothi than the drums.

Gupta (1990) studied the storage structures used for storing pulses in Rajasthan and observed that 24 % farmers used bags and 76% bulk storage. He divided bulk storage into bukhari (33.2%), separate store room (32.4%), heaps in living room (24.5%), Parchhati (7.2%), kothi (1.4%) and kuthla (1.4%).

Singh *et al.* (1995) carried out a field survey in 12 districts of Haryana, India, in September-October, 1990 and recorded *S. oryzae, R. dominica, T. granarium, T. castaneum, Ephestia cautella* (*Cadra cautella*), *S. cerealella, C. cephalonica and Oryzaephilus surinamensis.* The common storage structures were jute bags, metal bins, rooms, kothi, bukhari, parchhati and thekka. Average moisture content, infestation and germination were 11.1, 9.19 and 92% respectively during six months of storage. Based on the regression coefficient between percentage infestation and weight loss, 2.03 per cent weight loss was recorded.

Lal *et al.* (2001) conducted field survey in six block at kangra district, Himachal Pradesh, India during 1997-98 to assess the damage caused by insect pests on stored maize grains.The major pests were *S. oryzae, T. castaneum, R. dominica, O. surinamensis, C. cephalonica,* and *S. cerealella*. They reported that the maximum losses in stored maize was occurred during rainy season (12.24%) followed by summer (9.85%) and winter season (3.62). Local storage structures, like gunny bags and bamboo bins resulted in significantly higher weight losses (11.51and 8.87%) compared to improved structures, like drums and metal bins (7.34 and 6.57%) respectively.

Meena and Bhargava (2003[a]) studied the effect of different storage containers on the incidence of *C. cephalonica* in stored kernels of groundnut under both artificial and natural conditions and observed significant differences in damage on kernels stored in different containers under artificial and natural condition. Significantly

higher dry mass loss (5.29%) and damage kernels (29.24%) were noticed in mud pot. The number of adults varied from 2.33 in gunny bag to 4.00 in cloth bag. Under natural conditions, low dry mass and damage kernels were noticed in gunny bag followed by urea, cloth and polythene bags.

2.2 Effect of hosts on the biology *C. cephalonica*:

The rice moth, *C. cephalonica* was reported to infest paddy and milled rice (Hutson, 1920 and Kennard, 1965), millet and maize (Ayyar, 1934; Baloch, 1977 and Russel *et al.*, 1980), sorghum (Rao, 1954) and several stored agricultural products (Hodges, 1979).

Subramaniam and Rao (1940) conducted a series of breeding trials of *C. cephalonica* with various cereals and pulses and worked out the natural preference of the moth with regard to its diet. They concluded that coarsely milled jola (*jowar* or *cholam*) was the best material for *Corcyra* rearing judging from the shortest average period of development and highest percentage of adult emergence obtained in this medium. The relative fibrous texture of the kernel of this cereal as compared to that of other grain experimented with was the reason attributed by them for this preference.

Krishnamurti and Rao (1945) evaluated the dietary efficiency of 25 different powdered commodities for *C. cephalonica* and concluded that the foods in descending order of efficiency for the larvae of the pest were wheat + 5 per cent yeast, suji, wheat + 20 per cent olive oils, groundnut kernel, chillies, wheat + 20 per cent almond oil, wheat + 20 per cent shark oil, jowar, maida, rice, maize, wheat + 20 per cent turnip oil, gram, peas, and til. While; cucurbit kernels, beans, urd, mustard seed cake, til cake, cotton seed cake, wheat + 20 per cent mustard oil and wheat + 20 per cent til oil did not permit any growth of the larvae.

Rao (1954) reported that *Corcyra* thrived best on a cereal diet jola (broken jowar) was perhaps the most favoured cereal and ragi was the least. Broken or coarsely milled cereals were found to be superior to whole grains while fine flours were not as acceptable as even whole grains.

Uberoi (1961) conducted developmental studies of *C. cephalonica* larvae on a variety of cereals, millets, pulses, oil seeds and spices and found that among cereals the flour of pearl millet and broken grain of wheat proved to be best media for the growth of the larvae.

Jacob *et al.* (1966) tested number of food to find out a medium which would yield the greatest number of healthy larvae of *C. cephalonica* in the shortest time. The average duration was 29.12 days in maize to 51.48 in red gram which proved significantly better than the other media. The average larval mortality ranged from 5.0 per cent in maize, to 26.7 per cent in barley and tenai.

Punj (1967) studied the development of *C. cephalonica* on a wide range of natural powdered foods consisting of cereals, millets, pulses, spices, oilseeds and dried fruit at constant temperature. He reported that among cereals, the dietic efficiency for *C. cephalonica* in the descending order was found to be suji, wheat, maida and maize.

Chio and Ilo (1972) carried out the studies on the suitability of five different types of foods for rearing *C. cephalonica*. They observed that development was most rapid on rice husks than other foods.

Buzz *et al.* (1975) determined the effect of six diets *viz.*, whole wheat meal, wheat bran, and shifted flour alone or mixed 5 per cent yeast, 5 per cent casein or both on the biology of *C. cephalonica*. They observed that whole wheat meal appeared to be the most suitable diet for development of *C. cephalonica* .

Sharma *et al.* (1978) showed that sorghum was most preferred diet for *C. cephalonica* followed by maize, groundnut, rice and wheat.

Russel *et al.* (1980) reported that the overall performance of *C. cephalonica* was better on millet than on sorghum.

Rao *et al.* (1980) determined the effect of fortification of natural rearing media with casein, cholesterol and glucose on the fecundity and developmental period of *C. cephalonica*. They observed that sorghum flour and all the sorghum based diets supported shorter developmental cycles as compared with those based on rice bran and powdered groundnut cake. A higher level of fecundity was recorded on sorghum flour than on the other natural media. It was found that diets rich in protein were not suitable for high egg production. High protein and casein had an adverse effect on fecundity, but glucose increased fecundity.

Ambika *et al.* (1981) reported that husked rice was the suitable food for life cycle, duration, adult emergence and fecundity of the pest among five different types of diets.

Rose *et al.* (1982) reared *C. cephalonica* on different foods *viz*., *jowar*, groundnut, wheat, biscuits, walnut, gram and mixed without and with 5 per cent yeast and found that the life cycle duration of the pest ranged from 44-52 days without yeast and 40-50 days with yeast in above foods. The percentage of adult emergence was found maximum in case of *jowar*.

Osman (1986) studied the development of *C. cephalonica* in millets, sorghum, maize, wheat and rough or milled rice, both as whole kernels and as coarsely ground grits in the laboratory. He reported that the percentage of adult emergence, the average development time from egg to adult and the fresh body weight of female, ground kernels of all grains were more suitable than whole ones for rearing the pyralid. The whole kernels most favourable to growth were those of millets and the best ground kernels those of milled rice.

Senguttuvan and Kareem (1994) reported that *C. cephalonica* had varied damage potential and adult emergence in different food materials. *Corcyra* reared on cumbu (bajra) and sorghum caused higher damage and had higher adult emergence followed by groundnut and rice. Sesame was the least preferred food material with low damage and low adult emergence. Sunetra *et al.* (2006) reported that the diet containing bajra (2.5 kg) + groundnut (100 g) was found significantly superior over all the diet combinations followed by sorghum (2.5 kg) + groundnut (100 g). It was also revealed that the addition of groundnut @ 100 g to bajra and sorghum played significant role in improving all the parameters tested in respect of growth.

Haritha *et al*. (2000) studied the biology of *C. cephalonica*. The average pre-oviposition and oviposition periods of *C. cephalonica* on groundnut pots and kernels were 0.525 and 6 days, respectively. The average duration of egg, larval and pupal periods were 4.5, 49.4 and 15.62 days, respectively, on groundnut pots and 4.5, 46.54, and 13.68 days, respectively, on kernels. The total life cycle of the moth was completed earlier on groundnut kernels (65.08 days) than on pots (69.24 days). The average fecundity of the moth was higher on groundnut kernels (277 eggs) than on pots (229 eggs).

Ingle *et al.* (2000) tested twelve different diets on *C. cephalonica* and reported that bajra+mustard or groundnut or cotton seed was the most promising diet which

favourable influenced the total development period, adult emergence, fecundity, larval length, duration and weight, pupal period and weight and longevity of adults.

Sreekumar and Paul (2000) reared *C. cephalonica* on three different media viz., wheat bran, crushed maize grains and crushed sorghum grains and observed that the total number of eggs produced, total number of moths, fecundity, longevity of moths and fresh weight did not differ significantly among the rearing system and maize was the best medium for rearing.

Kumar and Jain (2001) studied the relative preference of different hosts (sorghum, maize, groundnut, rice, wheat and gram) by the first instar larvae of *C. cephalonica*. They reported that sorghum was the most preferred host on the basis of development parameters.

Kumar and Shenmar (2001) conducted study to find an alternative food to sorghum, for *C. cephalonica* and found that the life cycle was shorter and fecundity and female progeny production were higher when reared on maize.

Sahayaraj *et al*. (2001) studied the impact of four rearing media (wheat, bajra, sorghum and rice) on the development of *C. cephalonica* in the laboratory. The life table studies indicated that the bajra fed group had the highest net reproductive rate (287.26 eggs/female) with highest total developmental period. This group also had higher growth index (1.61) total adult emergence (86.83%) and minimum male and female adult longevity.

Kumar *et al*. (2002) studied the development of *C. cephalonica* on sterilized grains of rice, sorghum, maize and wheat and observed that incubation period of *C. cephalonica* ranged from 3.10 days on sorghum to 3.89 days on wheat. Larval duration was shortest on maize (23.48 days) and longest on rice (35.75 days). Similarly, pupal duration was shortest on maize (7.75 days) and longest on rice (8.23 days). In general, males lived 2-3 days longer than females, with the highest male and female longevities of 9.80 and 7.55 days, respectively, being observed on wheat. Life cycle duration ranged from 42.55 days on maize to 56.15 days on rice.

Sathpathy *et al*. (2003) determined the effect of different rearing medium on larval weight, adult female weight, emergence (%), sex ratio and fecundity of rice grain moth (*C. cephalonica*). The maximum larvae and adult female weight, emergence (%) and fecundity were resumed in the sorghum-based media. Higher the

carbohydrate and protein content of the media better was the larval growth, emergence and fecundity. The rice bran containing medium with the lowest carbohydrate and protein content was unfavourable. Sorghum, wheat or maize based media supplemented with groundnut enhanced fecundity compared to the yeast fortified media. A high positive correlation was recorded between fecundity vz larvae weight (r = 0.86) and fecundity v/s emergence (r = 0.80). The biological parameters were positively correlated with carbohydrate and protein content of the rearing media.

Ara *et al*. (2005) Studied the biology of *C. cephalonica*. Larvae of *Corcyra* were reared on various food materials, i.e. rice flour, wheat flour, maize flour, rice + wheat flour, rice + maize flour and wheat + maize flour, in the laboratory. Based on these life cycle parameters, the suitability of the tested food materials for *C. cephalonica* development ranked in the following order: wheat > wheat+rice > rice > wheat+maize > rice+maize > maize.

Prakash and Senthilkumar (2005) studied the comparative biology of *C. cephalonica* in cumbu (*Pennisetum americanum*), rice (*Oryza sativa*) and sorghum (*Sorghum bicolor*). The shortest incubation period of 4.21 days was recorded in *P. americanum*, followed by *O. sativa* (5.32 days) and *S. bicolor* (7.41 days). High number of eggs per pair was recorded in *P. americanum* (72.10 days), followed by *O. sativa* (68.11 days) and *S. bicolor* (62.12 days). Pupal period was rapid in *P. americanum* (10.11 days) and slowest in *Sorghum bicolor*. Total developmental period was shortest in *P. americanum* (39.99 days) and longest in *S. bicolor* (48.15 days).

Yadav and Bhargava (2005) studied the comparative development of *C. cephalonica* on sorghum, pearl millet, wheat, rice, maize, barely, oat and sesmum. The result indicated that sorghum was most preferred host as the larvae of *C. cephalonica* reared on sorghum had shorter incubation, larval and pupal period, less time required to complete life cycle, higher weight of larvae and pupae, higher per cent of adult emergence and maximum adult longevity. The eight hosts in order of preference were: sorghum, pearl millet, rice, barely, wheat, maize, oat and sesamum.

Nathan *et al*. (2006) studied the effects of millet, wheat, rice and sorghum diets on the development of *C. cephalonica* and observed that percentage adult emergence and food utilization indices of fifth instar larvae (consumption index,

relative growth rate and efficiencies of conversion of ingested and digested food) were significantly higher for millet-reared than for sorghum-reared larvae. The nutritional indices for wheat and rice-reared *C. cephalonica* larvae were intermediate between the indices for larvae reared on millet and sorghum.

Pallavi *et al*. (2006) studied the relative preference of different cereals grains viz. maize, rice, wheat, sorghum, bajra, nagali as sole grains and combination of all cereal grains with 50% nagali for the mass production of *C. cephalonica.* Among the various diets, bajra, bajra+nagali, maize+nagali were found most promising diet which favourable influenced the development period, moth emergence, fecundity and adult longevity of male and female moths.

Sunetra *et al*. (2006) conducted an experiment with a view to assess the influence of nine various diets on the biology of *Corcyra cephalonica* Stainton in terms of its growth and development parameters. The diet bajra (2.5 kg) + groundnut (100 g) was found significantly superior over all the diet combinations followed by sorghum (2.5 kg)+groundnut(100 g). It may also revealed that the addition of groundnut @ 100 g to bajra and sorghum played significant role in improving all the parameters tested in respect of growth.

Patel and Patel (2007) studied the biology of *Corcyra cephalonica* Stainton on broken grains of sorghum, wheat, pearl millet and rice at room temperature in the laboratory. The mean egg period ranged from 4.06 to 5.06 days. In all four host commodities, the larvae passed through 6th and 7th instars in case of male and female, respectively. The duration of 1st, 2nd, 3rd, 4th, 5th, 6th and 7th instars varied from 4.03 to 6.77, 4.10 to 7.20, 4.83 to 7.16, 5.85 to 7.41, 6.44 to 7.52, 5.75 to 7.81 and 5.76 to 8.09 days, respectively. The prepupal and pupal period was found to be 1.23 to 1.74 and 8.40 to 10.58 days, respectively. The preoviposition, oviposition and postoviposition period ranged from 1.18 to 1.45, 5.50 to 6.21 and 0.88 to 1.23 days on different host commodities. Among all the commodities, the highest fecundity (159 eggs) was observed in females reared on sorghum. The longevity of male moth was longer (9.53 days) in rice, while it was shorter (8.18 days) in wheat. The female lived longer (8.93 days) on sorghum, while it lived shorter (7.43 days) in pearl millet. The sex ratio was recorded 1:1.09 to 1:1.22. The highest growth index was observed in sorghum (1.62).

Rajulwal *et al*. (2008[a]) studied the life tables of *C. cephalonica* on different host grains (sorghum, rice, maize or groundnut). They reported that the survival of immature stages on sorghum, rice, maize and groundnut reached 0.44, 0.30, 0.38 and 0.33 per individual, within a pivotal age of 71, 84, 66 and 81 days, respectively. On sorghum, rice, maize and groundnut, the net reproductive rate of *C. cephalonica* per generation was 46.2, 27.07, 36.46 and 41.9 females per female, and the mean length of generation time was 70.98, 87.72, 65.74 and 77.34, respectively. The innate capacity for increase in numbers was greatest for maize (0.0547), followed by sorghum (0.0540), groundnut (0.0483) and rice (0.0376). The finite rate of increase in numbers per day was 1.056, 1.056, 1.050 and 1.038 females per female on maize, sorghum, groundnut and rice, respectively. The distribution of the egg stage in the stable age distribution was 24.36, 18.17, 24.80 and 22.04 per cent on sorghum, rice, maize and groundnut. The corresponding values of larvae distribution were 73.00, 78.79, 71.87 and 75.90 per cent.

Rajulwal *et al*. (2008[b]) reported that the incubation period of *C. cephalonica* was 4 days on jowar, rice, groundnut and maize. Egg hatching was greatest on *jowar* (76 per cent), followed by maize (73.0 per cent). The shortest larval duration, highest pupation rate and highest growth index were recorded for maize (34.60 days), *jowar* (82.89 per cent) and maize (2.27), respectively. Differences in pupal duration and per cent adult emergence were not significant. The shortest pupal duration (9.21 days) and highest adult emergence (69.52 per cent) were recorded for maize. Pupal length and width did not significantly vary among the food grains. Pupal weight was greatest on maize. The ovipostion period was longest on *jowar* (6.4 days) and shortest on groundnut (5.6 days). Fecundity was greatest on groundnut (255.6) and lowest on rice (177.2).

An experiment was conducted to study the biology of *Corcyra cephalonica* Stainton on foxtail millet grains with 12% moisture content, kept in plastic jars of 3 kg capacity. Freshly emerged adults were collected, transferred to egg-laying cage and released into the glass funnel covering the upper opening with muslin cloth and eggs were collected at the bottom fitted with wire mess. Egg was pear shaped and gently rounded at one end and pointed at the pedicel end with brownish tinge. Egg duration ranged from 4-7 days with average of 4.66 days. The larval development was inside the grain cluster. Larva was dirty white with brownish head. The larval period

ranged from 4 to 5, 5 to 6, 3 to 4, 3 to 4, 5 to 7 and 8 to 10 days with a mean of 4.13, 5.04, 3.73, 3.40, 5.46 and 9.69 days, respectively for six larval instars. Total larval period ranged from 28 to 36 days with an average of 31.26 days on foxtail millet. The total developmental period occupied, 41 to 59 days on foxtail millet at a temperature of 24-28^{0}C and 70% relative humidity (Jagadish *et al*. (2009).

Jat *et al*. (2009) reported that among the various medium, sorghum, sorghum+green gram and bajra was the most promising medium for *C. cephalonia* which favourable influenced the incubation period, total larval period, adult emergence, longevity of male and female, fecundity, sex ratio and growth index.

Pathak *et al*. (2010) Tested seven different type of food media on *C. cephalonia* and reported that the emergence of moths was maximum (37.02%) from sorghum followed by pearl millet and maize in which it was 31.89 and 25.12 per cent, respectively. The minimum development period of 47.62 days in pearl millet followed by 47.89, 49.23, 50.83 and 51.23 days in pearl millet + maize (9:1), sorghum + pearl millet (9:1), sorghum + maize (9:1) and sorghum + maize (8:2), respectively. The food efficiency index (FEI) was highest on sorghum (3.10) followed by 3.06, 3.04, 3.00, 2.62 and 2.52 on sorghum + maize (9:1), sorghum + maize (8:2), sorghum + pearl millet (9:1), pearl millet and pearl millet + maize (9:1), respectively.

Deulkar *et al*. (2012) studied the impact of different diets on the biology of *Corcyra cephalonica* Stainton and revealed that the least total developmental period of 38.33 days was recorded on bajra 2.5kg+Groundnut 100 g. The least larval development period of 30.86 days and pupal period of 4.70 days, along with maximum per cent pupation (85.02%) were observed on bajra based diet. Significantly more fecundity (309 eggs female-1) was recorded on diet consisting of bajra 2.5 kg+Groundnut 100 g. Whereas, the Maize based diet proved less influential among the test diets. In case of eggs, the highest per cent viability (76%) was recorded on Sorghum 2.5 kg+Groundnut, followed by diet containing bajra 2.5 kg+ Groundnut 100 g (75.33%).

Zhang *et al*. (2012) Conducted experiment to investigate the effect of different artificial diets on growth, development and fecundity of *C. cephalonica*. Artificial diets were, A. 70% corn meal + 20% wheat bran+7% white granulated sugar+3% yeast B. 94% rice bran+3% sugar+3% yeast C. 94% rice bran+3% soybean

meal+3% yeast D. 100% rice bran. There was shorter developmental time (34.0 d) and higher total number of emergence (1169 adults) for *C. cephalonica* on diet A than on diets C and D, and B and C, respectively. The female adults from diet A had the largest number of oviposition (561.9 eggs), and the accumulative oviposition in five days after emergence amounted to 92.1% of total eggs laid.

2.3 Effect of abiotic factors on the growth and development of *C. cephalonica*:

Hugar and Jairao (1985) studied the influence of temperature and relative humidity on the survival and development of *C. cephalonica* in the laboratory at intervals of 5°C) and 60, 75 and 90 per cent RH. They reported that the larval period was highest (66.4 days) at 15°C and lowest (24.5 days) at 30°C. The average period of larval development decreased with an increase in humidity. The highest larval survival (78.3%) was observed at 25^{o}C and 90 per cent RH.

Shazali and Smith (1986) studied the ecology of single species populations of the pyralid, *C. cephalonica* and the tenebrionid, *Tribolium castaneum* on sorghum at 25, 30 and 35^{o}C and 60, 70 and 80 per cent RH. The effects of 40 and 50 per cent RH on both species were also studied at 30°C and 60-80 per cent RH. While, lower humidities (40 and 50% RH.) had a small adverse effect.

Singh and Pant (1986) carried out the laboratory studies on the effect of moisture content of cashew nut kernels and relative humidity on the growth and survival of *C. cephalonica*, *O. surinamnsis* and *T. castaneum*. They found the most favourable relative humidity for growth and survival for *C. cephalonica* and *T. castaneum* were 80 and 70 per cent, respectively. Variations in relative humidity did not significantly affect growth and survival of *C. cephalonica* or *O. surinamensis*, but humidities of less than 70 per cent adversely affected growth in *T. castaneum*. The moisture content of the cashew kernel did not affect its susceptibility to insect attack.

Cheema *et al*. (1988) studied the biology of *C. cephalonica* at 32, 30 and 27°C and 70-80 per cent RH. On 5 varieties of raya (Indian mustard) and found that the growth index was greatest for larvae reared at 32°C and least for those reared at 27°C (no growth).

Etman *et al*. (1988) reported that the development of *C. cephalonica* from first instar larvae to adults in a whole wheat flour medium, took 40.9 and 43.5 days for males and females, respectively at 28°C and 65 per cent RH. Adult longevity was 9.1

and 7.0 days for mated and virgin males; 8.3 and 8.0 days for mated and virgin females, respectively.

Mbata (1989) reported that the oviposition of *C. cephalonica* at constant temperature of 30°C was influenced by relative humidity, an average of 148.9 eggs/female being laid at 70 per cent relative humidity compared with 132.8 eggs at 50 per cent RH. More eggs were retained in the ovaries of dead females at the lower relative humidity. The incubation period was about 4 days at both humidities. Larval development was fastest at 70 per cent relative humidity (34.1 days) and slowest at 50 per cent relative humidity (43.3 days) while pupal period was not affected by relative humidity.

Hugar and Rao (1990) investigated effects of temperature and relative humidity and their interaction on the incubation period and hatching of eggs of C. *cephalonica* within a temperature range of 15-40°C and 30-90 per cent RH. They found that the incubation period decreased with an increase in temperature and relative humidity and had no effect on hatching and egg development. Optimum development took place at 30°C and 90 per cent RH.

Hugar *et al*. (1990) reported that the pupal period decreased with increase in temperature and humidity, being longest at 15°C and shortest at 35°C.

Hugar and Jairao (1991) carried out laboratory studies with *C. cephalonica* at 15, 20, 25, 30, 35 and 40°C and 30, 45, 60, 75 and 90 per cent RH and showed that the optimum temperature for development was between 25 and 30°C and the optimum humidity level was 75 and 90 per cent. Generally, the incubation period decreased with increase in temperature and humidity, but temperatures of 40°C destroyed the eggs.

Ray (1991) studied the rate of multiplication of *Corcyra cephalonica* Stainton on soyabean at a constant temperature of 28± 1°C and 75 per cent RH. and found the egg, larval and pupal periods were 7, 44 and 12 days, respectively. The net reproductive rate (Ro) was found to be 246.32 and true value of intrinsic rate of increase (rm) was 0.093 female per female per day. The finite rate of increase (λ) was found to be 1.097 female per female per day and the mean duration time (T) was calculated to be 58.83 days.

Ray (1994) reported that the egg, larval and pupal periods of *C. cephalonica* on maize at 28±1°C and RH 75 per cent were, 7, 41, and 10 days, respectively. The net reproductive rate was 181.94 and the true value of intrinsic increase was 0.104 females/females per day. The finite rate of increase and the mean duration time were 1.1096 females/females per day and 50.03 days, respectively.

Sharma *et al.* (1997) exposed the pupae of *C. cephalonica*, *S. cerealella* and *S. oryzae* to temperatures of 35.45^{0}C for 24-72 h and reported that adult emergence was totally suppressed at 45^{0}C in all cases. A very high incidence of sterility was induced in the adults emerged from pupal exposures of *S. oryzae* and *C. cephalonica* at 40^{0}C, but the effect was less pronounced in *S. cerealella*.

Allotey and Azalekor (2000) studied the life cycle of *C. cephalonica* under ambient laboratory conditions (temperature range 27.5-30^{0}C and 60-73 % R.H.) on groundnut, bambara groundnut (*Voandzeia subterranean*) and cowpea. The mean developmental period ranged from 33.2 ± 0.2 to 45.3 ± 1.8 days on whole, broken and powdered forms of the food media. Egg hatchability was found to be 83%, while; adult longevity ranged from 1.5 ± 0.5 to 11.9 ± 1.3 days for males and 1.5 ± 0.5 to 16.5 ± 1.2 days for females. Sex ratio (male:female) of emerged adults ranged from 1:1 to 1:2.1. Mean fecundities ranged from 128 ± 5 to 157 ± 8 on the food media. In experiments to assess the insecticidal potential of three plant materials against *C. cephalonica*, *Eichhornia crassipes* powder showed a higher efficacy than both *Citrus sinensis* peel powder and the leaf powder of *Chromolaena odorata* at dosages of 0.5-2.0 g per 40 g of legume seed.

Meena and Bhargava (2010[a]) studied the influence of temperature and relative humidity on biological parameters of *Corcyra cephalonica* Stainton in the laboratory at the temperature levels of 20±1, 25±1, 30±1 and 35±1^{0}C and humidity levels of 60, 70, 80 and 90 per cent on broken conditioned sorghum grains. The most suitable combination of temperature and humidity levels for fecundity, weight of full grown larva and mature pupa was 30^{0}C and 70 per cent relative humidity on which maximum egg laying (164.34), weight of full grown larva (0.049 g) and mature pupa (0.0306 g) were recorded. The larval and pupal period were found to be highest (55.00 and 13.36 days) and lowest (23.86 and 5.60 days) at 20^{0}C and 30^{0}C temperature, respectively. The larvae completed their development in 18.20 days at 35^{0}C and 90 per cent relative humidity. The shortest pupal period of 5.0 days was

observed at 35^0C and 90 per cent relative humidity, while; longest pupal period of 15.25 days was observed at 20^0C and 90 per cent relative humidity.

An laboratory experiment was conducted to investigate the effects of temperature on the hatching percentage, glucose and glycogen levels and acid phosphatase activity in the eggs during embryonic development of the rice moth, *C. cephalonica* incubated at 30, 28, 26 and 24^0C. Lowering the temperature from 30 to 24^0C did not affect the hatching percentage of eggs. A significant decrease in glucose levels (mg/egg) occurred during the initial stages followed by an increase, during the later stages of embryogenesis in eggs incubated at all three temperatures, although the levels of variation decreased with decreasing temperature. Acid phosphatase activity showed a more or less, sigmoid pattern of change with a lowering rate of increase, corresponding to decreasing incubation temperature (Chaubey *et al.* 2011).

Chaubey and Mishra (2011) studied the effect of temperatures (30, 28, 26 and 24^0C) on live weight, water content and activity of alkaline phosphatase in the eggs during embryonic development of the rice moth, *C. cephalonica*. A significant increase occurred in the duration of embryonic life with decrease in temperature. Incubated at 30^0C, wet weight and water content of eggs significantly decreased up to 36-48 h and 32-40 h respectively. The rate of decrease in live weight and water content lowered with decrease in incubation temperature. The activity of alkaline phosphatase was lowest in newly laid eggs (0-6 h), but as embryogenesis proceeded, a significant and continuous increase in its activity was observed till 60, 72, 108 and 144 h followed by a continuous fall till hatching in the eggs at 30, 28, 26 and 24^0C, respectively.

2.4 Eco-friendly modules for management:

2.4.2 Efficacy of grain protactants against *C. cephalonica*:

2.4.1.1 Plant products:

Major work has been carried out in different parts of the country and abroad on the use of plant products and physical components against *C. cephalonica*. Mixing the oil before the storage of grains in an age old practice and still prevalent in most part of india. In recent past, a number of oils have been used and scientifically evaluated against various stored product insects, which have been reviewed by many workers (Hewlett, 1947; Smith and Pearce, 1948; Pruthi and Singh, 1950; Cotton,

1956; Smith and Salked, 1966; Mittal, 1971; Strong, 1973; Bhatnagar *et al*., 1974 ; Hewlett, 1975; Saxena *et al*., 1976; Pereira, 1983; Doharey *et al*., 1985; Das, 1986; Gupta *et al*., 1992 and Singh *et al*., 1993).

Jotwani and Sircar (1967) found that the pulse grains could be effectively protected from the *C. maculates* damage by mixing crushed neem seed @ 1.2-2.0 parts per 100 parts of seeds for 11 months without any adverse effect on germination of seeds.

Sharma and Verma (1971) studied the efficacy of some plant products *viz*., powdered drupes of dharek, neem seeds and costus roots and inert material of magnesium carbonate as protectant of wheat seed against *Trogoderma granarium.* They reported that magnesium carbonate 1.0 and 2.0 per cent w/w basis gave the best protection during the first two months. At the end of the 4^{th} and 5^{th} months all concentrations of neem (0.5 and 1.0 %) and 2.0 per cent costus gave comparative results to those of magnesium carbonate. Afterwards only neem yielded the most promising results. Dharek proved to be the least effective treatment and costus proved better than dharek.

Teotia and Tiwari (1971) tested dharak drupes and leaves as protectants on wheat seed against *Sitotroga cerealella* and found that the powdered drupes and leaves of dharak when mixed with wheat seed at the rate of 1 to 2 parts per 100 parts of seed and 4 to 8 parts per 100 of seed (w/w) respectively, protected the damage of *S. cerealella.* They observed that buildup of adult population was prevented for at least 135 days.

Jilani and Malik (1973) studied the repellent properties of neem (*Azadirachta indica*), dharek (*Melia azadirach*), aak (*Calotropts procera*), gardenia (*Gardenia jasminoides*) against storage insects *viz., Tribolium castaneum* and *Rhyzopertha dominica* under laboratory conditions and found that extract of neem was the most and aak the least repellent. They also reported that extract of neem seed was more repellent than extract of neem leaves and fruits.

Singh and Srivastava (1980) studied the efficacy of neem seed powder mixed with wheat grain in three doses i.e. 1.0, 2.5, and 5.0 per cent (w/w) against the lesser grain borer for three months and observed that population increased with length of time but there was significantly different in the insect population and viability of grain

at different doses in comparison to control. Maximum protection of grain by mixing 5.0 per cent neem seed powder.

Sowunmi and Akinnusi (1983) found neem kernel powder at 0.5 parts/ 100 parts of seeds effective in controlling *C. maculates* for four months but thereafter considerable damage occurred. They also observed that treatment at 1.0 and 2.0 parts per 100 parts of seed was effective for 8 months.

Verma *et al*. (1983) found that the oils and cakes of neem, castor, linseed and mustard reduced the fecundity, hatching and adult emergence of *S. cerealella*. No adverse affect of any protectant was observed on the germination.

Bowry *et al*. (1984) tested powder of neem, linseed, mustard, castor and mahua cakes for their effect on the egg laying, infestation and it's repellent action against *Sitophilus oryzae*. Their results showed that the powder of neem cake was most effective in reducing the egg laying and minimizing the damage followed by linseed, mustard, mahua and castor cakes.

Pandey *et al*. (1985[a]) a tested neem in the form of oil, powder of kernel cakes, leaves and flower by mixing them with wheat grain at the rate of 0.1, 1.0, 5.0 (w/w) and also with babul gum at the rate of 0.1, 0.5 and 1.0 (w/v). These treatments were found effective against *C. cephalonica*, by causing adversed effect on the development *viz*., increase in development period, higher mortality and less percentage of adult emergence.

Pandey *et al*. (1985[b]) reported that neem oil, powder of kernels, cake, leaves and flower and babul gum at the rate 0.1, 1.0, 5.0, 1.0, 0.5 and 1.0 parts (w/w or w/v) per 100 parts of wheat seeds affected as ovipositional deterrent for such adults *C. cephalonica*, which were developed on untreated seed. The survival period, fecundity and fertility of the adults, which were developed on treated seeds, were reduced in comparison to the adults developed on untreated seeds. The germination powder of seeds was not impaired in any case.

Rajashekaran and Kumaraswami (1985) observed that sorghum grain treated with karanj extract at 0.4 per cent v/v or with neem extract at 1.0 per cent w/w gave complete protection from *Sitophilus oryzae*, while; green gram treated with karanj and neem extract at 0.6 per cent v/v and 0.8 per cent w/w, respectively, gave significant protection from *C. chinesis*.

Yadav (1985) reported that the treatment of neem seed oil at 50 mg/10g seeds prevented oviposition of *C. maculatus*, and treatment at 10, 20 and 30 mg/10g seeds suppressed the adult emergence of *C. maculatus* and *C. analis.*

Chauhan *et al*. (1987) screened petroleum ether extracts of 5 plants for their insecticidal activity against larvae of *C. cephalonica* in the laboratory, as compared with malathion and found on the basis of the LC_{50} that extracts of Croton sparsiflorus, *Annona squamosa*, *Acorus calamus, Brassica campestris* and *Melia azedarach* were 0.0273, 0.0017, 0.0004 and 0.0003 times less toxic, respectively, than malathion.

Tanzubil (1987) conducted the experiment to evaluate the effectiveness of neem fruit dust (2, 5 and 10%), neem leaf dust (5 and 10%) and neem seed kernel oil (2 and 5ml/kg seeds) against *C. maculatus*. He found that the neem fruit dust at 10 per cent protected stored seeds for at least four months, neem leaf dust were effective for three months while seed kernel oil at 5ml/kg seeds gave effective control.

Prusty *et al*. (1989) evaluated toxicity of six plant products *viz*., bel, pudina, neem, mild sage and begonia and extract of garlic under controlled conditions of insect infestation as grain protectants against rice moth, *C. cephalonica* in milled rice grain of superfine variety CR1014 stored in plastic container. Leaves of mild sage inhibited the larval and adult population of the moth, when eggs were released in grain mixed with these products. However, in grain treated with garlic extract, only larval population was inhibited. Other plant products failed to inhibit larval as well as adult populations of moth in milled rice admixed with these products.

Agarwal (1990) tested *Azadirachata indica* and *Calophyllum inophyllum* for their ovicidal activity against eggs of *Myllocerus undecimpustulatus*. The eggs were treated by dipping for 10 second in 1.0 per cent solution of each extracts. The neem extracts caused cent per cent mortality as compared to *C. inophyllum* which caused 94.6 per cent mortality.

Bloszyk *et al*. (1990) used six natural compounds of plant origin with a high feeding deterrent activity for impregnating 3 kinds of packing materials for food stuffs to protect them from invasion by *R. dominica* and reported that rotenone and helenalin were the best for protecting wrapping and parchment papers and polyethylene sheeting from perforation by insect.

Ivbijaro (1990) reported that the neem seed oil applied to cowpea seeds @ 2.0 and 3.0 ml/kg gave 65-100 per cent mortality of *C. maculates* after 3-5 days of treatment. The oviposition of *C. maculates* was reduced from 60.75 to 49.50 eggs in neem seed oil treatment.

Jacob and Sheila (1990) reported that neem oil @ 1.0 ml/100g seeds caused cent per mortality of adult beetle of *C. chinesis* and inhibited oviposition and hence prevented development of subsequent generation. Neem oil at 0.5 ml/100 seeds did not inhibit egg laying but prevented the development of progenies in the next generation.

Singal and Singh (1990) used different plant oils *viz*., groundnut, coconut, mustard, sesamum, soybean and rapeseed at 1, 3 and 5 ml/kg of seed against *C. chinensis* chickea resulted in significant reduction in ovipositon, adult evergence, hatching and development of embryoes. Oil treatment did not adversely affect seed germination.

Satpathi *et al*. (1991) observed that two per cent methanol extracts of Pongamia glabra caused 80.00 per cent mortality of *C. cephalonica* after 48 h treatment.

Singh and Mall (1991) studied the comparative efficacy of oil and cakes of castor, neem, mustard, linseed and powder of *Ipomea carnea*, *M. azadirach* as grain protectant against *S. oryzae* infesting stored wheat under laboratory conditions and obtained significantly less number of beetles in grains treated with neem oil (7.66) followed by *I. carnea*, *M. azadirach* and neem cake being 14.33, 16.06 and 17.33 respectively. They also reported minimum grain damage and weight loss in neem oil treated grains.

Choudhary (1992) tested different vegetable oils *viz*., groundnut, sesamum, linseed, soybean, neem, castor, safflower and coconut @ 0.25, 0.50 and 1.0 nk/100g seeds against *C. chinensis* on chickpea. He found that all oil treatements showed significant reduction in the number of *C. chinensis*. Oil effectiveness increased with and increase in doses of all oils. Neem, groundnut, castor and sesamum oils were most effective whereas linseed oil was least effective.

Uvah and Ishaya (1992) conducted a laboratory experiment to determine the effect of palm and groundnut oils on oviposition, adult emergence and longevity of *C.*

maculates on cowpea seeds. They found significant reduction in oviposition, progeny emergence and longevity by a single application of groundnut or palm oil at 2.50 ml/kg seeds.

Devaraj and Srilatha (1993) tested the antifeedent and repellent properties of extracts of neem, mustard, datura, eucalyptus and lemongrass against *C. cephalonica* and found that neem extract had the greatest antifeedent activity followed by eucalyptus, lemongrass, mustard and datura extracts, respectively. Eucalyptus extract was the most repllent, followed by lemongrass, mustard, neem and datura extracts.

Rao *et al.* (1993) evaluated the efficacy of sweet flag, ginger, Jamun, neem and mango leaf powders, neem cake and sesamum, sunflower, groundnut and plam oils and ordinary ash against *C. chinensis* on pigeon pea. Sweet flag was the most effective followed by neem kernel powder, while neem cake and ash were the least effective

Velumani *et al*. (1993) tested defatted neem kernel powder at 0.05, 0.01, 0.25, 0.5 and 1.0 per cent concentrations (w/w) for the control of storage pests *viz*., pulse beetle, rice weevil and lesser grain borer. They observed defatted neem kernel powder to be cent per cent effective at a concentration of 1g/kg of seed.

Chandraletha (1994) observed that neem seed extract disruption of the growth, metamorphosis and egg production of *C. cephalonica* by neem seed extract as the abnormal adult exhibited curled wings and showed 4 grades of deformities, the older pupae were less sensitive and number of vitellognic oocytes were reduced adversely affecting the fecundity.

Kachare *et al*. (1994) tested 10 vegetable oils *viz*., sunflower, castor, mustard, safflower, groundnut, palm, sesamum, neem, karanj and corn each at 0.5, 0.75 and 1.0 per cent concentration as seed protectants of pigeonpea against *C. chinensis*. They found no hatching of eggs at 33 days storage was noticed in neem, karanj and groundnut oils.

Parsai *et al*. (1994) evaluated the efficacy of mustard, sesamum and soybean at 0.25, 0.50, 0.75 and 1.00 per cent against *C. chinensis* on pigeonpea and found that all the three oils were equally effective for the control of this pest, in term of oviposition and adult emergence. The effects were dose dependent, with maximum effects achieved at the 1.0 per cent oil concentration.

Singh *et al*. (1994) evaluated different vegetable oils namely sesamum, sunflower, soybean, linseed, mustard, safflower, karad, castor, coconut, groundnut, ricebran, taramira at the rate of 1 and 3 ml/kg seeds against *C. chinensis*. They found that the oils of taramira, coconut, sunflower, safflower and castor were significantly better in order to check the egg laying of pulse beetle on gram seeds at both the doses as compared to other oils. No adult emergence from the seeds treated with the oils of castor, mustard, soybean and taramira, was observed.

A study was conducted to evaluate the ovicidal properties of the crude extracts of 8 indigenous plants (*Azadirachta indica*, *Erythrina indica*, *Piper nigrum*, *Acorus calamus*, *Adenocalymna allicea*, *Thevetia neriifolia*, *Pachyrhizus erosus* and *Annona squamosa*) on eggs of *C. cephalonica*. There was no egg hatching at six days after treatment in 1.5% petroleum ether extract of *Azadirachta indica*, *E. indica* or *P. nigrum* or after treatment with *P. erosus* at 2.0%. The methanol extract of *A. indica* and *P. nigrum* at 2.0% also produced the same result (Ghatak and Bhusan, 1995)

Senguttuvan *et al*. (1995) tested a range of plant products for efficacy in protecting stored groundnuts against *C. cephalonica* and reported that the plant products and edible oils afforded some protection. However, nochi leaf powder, neem leaf powder and neem oil were most effective followed by neem kernel powder.

Sharma (1995) while testing efficacy of plant products namely neem leaf powder and cob ash against *R. dominica* on stored maize and found that these test compounds at different dosages were effective in reducing the per cent grain damage. They also observed that the concentration of 10:100 of neem leaf powder reduced the adult emergence of the test insect and gave protection in respect of weigh loss 32.6 per cent in nine months of storage.

Chakraborti and Chatterejee (1996) investigated the effects of four neem products (azadirachtin, azadirachtin-iodine, neem seed kernel extract and neem oil) on eggs and larvae of *C. cephalonica*. They reported that age, toxicity, mortality, concentration and growth inhibition established a dose response independent events. Azadirachtin interfered with ecdysteroid (moulting hormone) titres and produced morphogenetic effects. It also affected the reproductive potential of the initial generation.

Singh and Pandey (1996) reported that seeds of chickpea could effectively be protected from the pulse beetle, *C. chinensis* by admixing of dried neem leaf powder at the rate of 100-100 mg/50g of seed in storage.

Bhargava (1997) tested five plant extracts *viz*., neem seed extract (*Azadirachta indica*), neem oil (*A. indica*), undi extract (*Callophylum inophyllum*), karanj extract (*Pongamia glabra*) and lemongrass oil (*Cymbopogan flexuosus*) @ 0.1, 0.5 and 1.0 ml/100g seeds against *C. cephalonica*. He found that all the doses of different plant extracts reduced the fecundity but in case of lemongrass oil no egg laying took place as adult mortality occurred within 6-8 hrs. of their release. The reduction in egg viability varied from 24.63 to 59.63 per cent in different plant extracts. The longevity of male and female adults decreased when they were released in treated food.

Dwivedi and Garg (1997) tested seven plant leaf extracts *viz*., *Ricinus communis* Linn., *Lawsonia inermis* Linn., *Acacia nilotica* Linn., *Cassia fistula* Linn., *Eucalyptus rudis* Endl., *Dalbergia sisso* Roxb. and *Parthenium hysterophorus* Linn. at 25, 50, 75 and 100 per cent concentration along with a control in acetone against eggs of *C. cephalonica*. They found that *R. communis* at 100 per cent concentration caused maximum mortality (89.47%) while the least mortality (42.10%) was exhibited by *P. hysterophorus* at the same concentration.

Khan and Thakare (1997) applied different plant products *viz*., Sweetflag (*Acorus calamus* L.) rhizome powder, neem (*Azadirachta indica* A Juss.) leaves and seed powder, oils of neem, karanj (*Pongamia glabra* Vent.) and castor (*Ricinus communis* L.) at leaves i.e. 1.0 and 5.0 per cent (w/w) for powders and 0.5 and 0.1 per cent (w/v) for oils against *C. cephalonica*. They found that significant reduction in fecundity, hatchability of eggs, longevity of adults and weight of male and female adults was observed when they were raised on grains treated with different doses of plant products.

Ramamurthy and Venugopal (1997) reported that the gunny bags impregnated with malathion at 0.1, endosulfan at 0.04 and neem oil at 3 per cent were effective in avoiding the *S. cerealella* damage. Neem seed kernel extract 5 and 3 per cent and neem oil 2 per cent were also effective in avoiding *S. cerealella* damage.

Sharma *et al*. (1997) tested different concentrations (0.5, 1.0, 2.0, 3.0 and 5.0%) of five plant extracts *viz*., undi extract (*Callophyllum inophyllum*), malodorous

neem extract (*Azadirachta indica*), neem oil (*A. indica*), karanj extract (*Pongamia glabra*) and vetivre oil (*Vetivera zizaniodies*) against freshly laid eggs of *C. chinensis*. They found that undi extract at 5.0 per cent caused maximu egg hatch inhibition (98.00%) whereas in control, no egg hatch inhibition was recorded. The minimum LC_{50} value for egg mortality was 0.7483±0.2408 in undi extract followed by 1.3253±0.0530, 1.6458±0.0882, 2.1532±0.1477 and 4.1360±0.8245 in malodorous neem extract, neem oil, karanj extract and vetiver oil, respectively.

Singh and Kumar (1997) evaluated powder of six plant products against *R. dominica* infesting stored wheat and recorded lower population build up, less damage of grains and high mortality of beetles in grains treated with dharak kernel powder with dose of 5g/100g of grains. All plant products provided protection for stored wheat grains.

Behal (1998) exposed ten days old larvae of *C. cephalonica* to oils of neem, sweet flag, citronella, eucalyptus, cloves, dill, cedar, mustard, sunflowers, cotton, soybean and karanj at 0.1, 0.3 or 0.5 per cent concentrations. He reported that the sweet flag oil repelled the larvae at all the concentrations, whereas clover, cedar wood, citronella and eucalyptus oils were effective at the higher concentrations. The cotton seed oil and neem (deodorized) at 0.5 per cent attracted the larvae.

Chanda and Chakravorty (1998) reported that growth inhibition, developmental disturbances and mortality of *C. cephalonica* increased markedly with increased dose of neem oil. Deformed adults with a prolonged period of development was obtained.

Sharma and Bhargava (1998) applied different concentrations of fenoxycarb, diflubenzuron, neem extract, karanji extract, undi extract and lemon grass oil on eggs of *C. cephalonica* (0-12, 12-24 and 24-36 h age groups) through dipping method. The egg hatch inhibition increased with the increase in concentration of fenoxycarb and plant extract. The diflubenzuron had no ovicidal effect.

Sharma *et al*. (1999) tested the efficacy of some crucifers oils *viz.*, *Brassica alba*, *B. carinata*, *B. campestris* var. brown sarson, *B. campestris* var. yellows sarson, *B. juncea*, *B. napus*, *B. nigra* and *Eruca sative* on *C. chinensis* and observed that number of eggs laid on pigeonpea were comparatively low when 0.75 and 1.0 Per cent of eight rapeseed mustard oils were used. Similarly, a decrease in adult emergence

was also recorded on the grains treated with 0.50, 0.75 and 1.0 per cent of all the oils. Results showed that such treatments in no way affected the germination and vigour of pigeon pea seeds.

Bhargava and Meena (2000) used six vegetable oils *viz*., castor, mustard, groundnut, sesamum, coconut and sunflower at 0.1, 0.5 and 1.0 ml/100g seeds against *C. chinensis* and found that all the oils caused significant mortality after three days of treatment. Castor oil (1.0 ml/100 seeds) was most effective causing 80.72 per cent mortality of the adults, inhibiting oviposition, reduction in egg viability and adult emergence in F_1 generation. Longevity of male and female adults decreased with the increase in the dose. None of the oils tested had any adverse effect on the germination of cowpea seeds up to 150 days of treatment.

Jain and Kumar (2001) studied the efficacy of neem leaf and kernel powder against the rice mothbean by feeding the larvae with treated sorghum and found that neem kernel and leaf powder (2.5 and 5.0% each0 were both toxic to *Carcyra* larvae. The respective LC_{50} values were 2.698 and 2.032 per cent. Moreover, the life cycle was prolonged taking 52.81 to 62.08 days as compared to 50.98 days in control. The neem treatments reduced larval and pupal weight, larval survival, adult emergence and longevity. The efficacy of neem treatmetns in a descending order was NKP (5.0%)>NKP (2.5%)> NLP (5.0%)> NLP (2.5%).

Sharma and Bhargava (2001) tested different concentrations (0.25, 0.50, 1.0m 2.0, 3.0 and 5.0%) of plant extracts viz., neem, karanj, undi and lemongrass against eggs of *C. cephalonica*. They found that the egg hatch inhibition increased with the increase in concentration of plant extracts. The LC_{50} values for egg mortality were 0.7079±0.0581, 0.08954±0.0566, 1.1041±0.0597 and 1.4125±0.0547 in lemongrass oil, neem extract, karanj extract and undi extract, respectively.

Sundria *et al*. (2001) tested six botanical *viz*., ratanjot (*Euphorbia spp*), garlic (*Allium sativa* L.), neem (*Azadirachta indica* A. Juss.) seed kernel suspension, neem seed kernel powder, neem leaf powder and black pepper (*Piper nigrum* L.) against the bruchid, *C. chinensis* in stored green gram. They reported that the black pepper seed powder proved to be the best protectant showing no damage even after four months of storage. The next best protectant was seed kernel powder at 20 g/kg seed. Neem kernel powder suspension (20 ml), ratanjot and neem seed kernel powder also

afforded effective protection against the bruchid damage for four months as compared to control. No adverse effect on seed viability was observed even after four months of storage.

Patel and Patel (2002) determined the efficacy of neem *(A. indica)* leaf power, *Eucalyptus globules*, custard apple (*Annona reticulata*), *Lantana camara*, bael (*Aegle marmelos*), *Ipomoea*, Indian mustard oil, cotton, groundnut, sunflower and sesame under laboratory conditions as grain protectants against the rice moth, *C. cephalonica*, infesting stored rice. The effectiveness of treatment was evaluated on the basis of total numbers of adults emerged, development period and growth index of the pest as well as weight loss of grains. The results revealed that mixing of neem and eucalyptus leaf powder at 2 per cent and mustard oil at 0.5 per cent were highly effective against this pest on stored rice.

A study was conducted to determine the effect of botanical insecticides, namely neem (*Azadirachta indica*) extract, undi (*Calophyllum inophyllum*) extract, karanj (*Pongamia glabra*) extract, eucalyptus (*Eucalyptus spp*.) oil, and lemon grass (*Cymbopogon flexuosus*) oil at 0.1, 0.5, and 1.0 ml/100 g sorghum seeds, on the stored product pest *Corcyra cephalonica* Stainton. Neem extract at 1.0 ml/100 g seeds resulted in the longest total life cycle (57.8 days), highest reduction in adult emergence (85.7%), lowest number of eggs laid per female, highest reduction in egg viability (65.3%), and shortest longevity for males (3.3 days) and females (4.8 days). There was no observed adverse effect on the germination of sorghum seeds at any interval (Yadav and Bhargava, 2002).

Ansari *et al*. (2003) reported the effect of some indigenous plant products on the loss of weight in *jowar* infested with *C. cephalonica*. Seeds of *jowar*, infested with *C. cephalonica* were treated with powder and extract forms of bulb of *Allium sativum*, seeds of *Gynandropsis gynandra* and *Centratherum anthelminticum*, rhizome of *Zingiber officinale* and leaves of *Tagetes indica* at 0.5, 1.0 and 2.0%. The extract form of *A. sativum* at 2.0% was the most effective treatment (1.33%) in minimizing the loss in weight of *jowar* seeds, followed by the extract form of *G. gynandra* at 2.0% (1.64%). *T. indica* in both powder and extract forms was the most effective in lowering the egg laying rate of *C. cephalonica*.

Jadhav and Ghule (2003) pointed out that azadirachtin (10,15 and 20% v/w) supplied through diet caused a decrease in the total body and haemolymph proteins of *C. cephalonica* larvae.

A study was conducted to evaluate the effect of plant products on reproductive potential of *C. cephalonica*. The efficacy of 0.1, 0.5 and 1 ml/100 broken seeds of *Azadirachta indica*, *Pongamia glabra*, *Calophyllum inophyllum*, *Cymbopogon flexuosus*, *Lawsonia inermis*, *Cocos nucifera*, castor, Indian mustard, sesame, groundnut, soyabean and sunflower extracts or oils in controlling *C. cephalonica* infesting rice. The fecundity, egg viability and longevity of both males and female *C. cephalonica* decreased with increasing concentrations of the extracts and the oils. Male and female longevity was lowest with lemongrass oil treatment (Meena and Bhargava, 2003[b]).

A study was conducted to assess the effectiveness of various grain protectants against rice moth (*Corcyra cephalonica* Stainton) in maize. The treatments consisted of botanicals (custard apple seed powder and neem leaf and seed kernel powder), inert dusts (attapulgite [palygorskite] dust and dolomite), insect growth regulators (diflubenzuron, flufenoxuron and lufenuron), fungicides (thiram), Ayuverdic tablets (parad) and insecticides (malathion). Larval mortality was observed with all insect growth regulators at varying intensity (Veeranki and Reddy, 2004).

Meena and Bhargava (2005) studied the effects of plant powders, i.e. dharak (*Melia azadirach*) kernel and leaf, neem (*Azadirachta indica*) kernel and leaf, Karanj (*Pongamia glabra*) kernel and leaf, oak (*Calotropis procera*) leaf, datura (*Datura alba*) leaf, citrus (*Citrus limon*) leaf, podina (*Mentha arvensis*) leaf and tulsi (*Ocimum sanctum*) leaf at 1.0, 2.5 and 5.0 parts/100 parts of grain (w/w), on fecundity, egg viability and longevity of adults of *Corcyra cephalonica* stainton. The percentage reduction in fecundity of the test insect increased with the increase in the concentration of each treatment. The mean percentage reduction in egg viability varied from 17.46 to 29.41% and 13.78 to 35.17%. The longevity of male and female adults gradually decreased with the increase in the concentration of the treatments.

Rao and Sharma (2007) studied the ovicidal effect of seed extract of custard apple (*Annona squamosa*) revealed that ethyl acetate and hexane extract were

relatively more effective in causing mortality against rice moth (*C. cephalonica*) and khapra beetle (*Trogoderma granarium*) respectively.

Sahayaraj *et al.* (2007) studied the impact of three *Vitex spp*. (*Vitex leucoxylon* Linn., *Vitex negundo* Linn, and *Vitex trifolia* Linn.) leaves powder against *C. cephalonica* (0.5, 1.0, 1.5, 2.0 and 2.5 g/100 g groundnut).The results revealed that *Vitex spp*. treatment reduced the kernel damage and dry mass loss of groundnut, insect larval weight, fecundity and its survival. *V. leucoxylon* treatment recorded a minimum developmental period (35.6 days), lower weight (1.07 mg) and fecundity (178 eggs).

Meena and Bhargava (2010^{b}) tested 10 plant powders, viz., dharek (*Melia azadirach*) kernel and leaf, neem (*Azadirachta indica*) kernel and leaf, karanj (*Pongamia glabra*) kernel, aak (*Calotropis procera*) leaf, dhatura (*Dhatura alba*) leaf, citrus (*Citrus lemon*) leaf, podina (*Mentha arvensis*) leaf and tulsi (*Ocimum sanctum*) leaf @ 1.0, 2.5 and 5.0 g per 100 g of sorghum seeds to evaluate their effect on fecundity, egg viability and longevity of adults of *C. cephalonica* . The maximum and minimum reduction in fecundity were 58.53 and 20.91 per cent in the seeds treated with karanj kernel powder and tulsi leaf powder, respectively. The reduction in egg viability varied from 17.46 to 29.41 per cent and 13.78 to 35.17 per cent in different doses and treatments.

Morya *et al*. (2010) studied the effects of powdered leaves of *Lantana camara*, *Clerodendrum inerme* and *Citrus limon* on *C. cephalonica*. Seven different doses ranging from 0.05 to 2.0 g (0.05, 0.1, 0.15, 0.5, 1.0, 1.5, and 2.0 g) per 20.0 g of rice were tested against this common insect pest of rice to evaluate their effect on its life cycle and mortality. Three higher doses were further tested for their effect on physiological parameters like total haemocyte count (THC), total protein content and glycogen level along with starved insects. *L. camara* and *C. inerme* exhibited biopesticidal activity as evidenced by the high mortality rate in treated insects, while *C. limon* was ineffective against *C. cephalonica* in the tested conditions. There was also a significant reduction in the THC (39-53%), protein (30-38%) and glycogen (40-61%) content in *L. camara* and *C. inerme* treated larvae with respect to their controls. This was however similar to the results observed in starved groups (52.0, 39.0 and 82.0% respectively for THC, protein and glycogen) which mimic a physiological condition similar to them.

Pathak *et al*. (2010) an experiment was conducted to investigate the efficacy of combined action of garlic extract and mint oil volatiles against rice-moth, *Corcyra cephalonica* Stainton. Expose the eggs of *C. cephalonica* to the combined action of Garlic (*Allium sativum*) extract and Mint (*Mentha sp.*) oil volatiles for 3,6,12 or 24 hours causes a significant reduction of varying degree in eggs hatchability at 20,40,80 or 160 micro l volumes of both. Severe reduction in both egg output and egg hatchability occurred in this pest when their larvae were exposed to 80 or 160 micro l volume of extract and oil. When freshly emerged male and females were exposed to the combined action of garlic extract and mint oil volatiles for three hours a significant reduction in eggs laid/egg hatchability were observed only at 160 micro l volumes, while; significant increase in egg yield/egg hatchability were noticed at 20, 40 and 80 micro l volumes of the both.

Pathak and Tiwari (2010[a]) a study was conducted to evaluate the larvicidal and pupicidal effects of neem leaf on the third instar larvae of *Corcyra cephalonica* Stainton. The observations revealed that 3.50% dose level of neem leaf caused 100% larval mortality.

Pathak and Tiwari (2010[b]) studied the larvicidal and pupicidal effects of neem seed extract on the third instar larvae of *C. cephalonica*. Neem seed extract, 0.11% (a.i.) v/w, caused 100% larval mortality.

An experiment was conducted to investigate the Combined action of neem (*Azadiracta indica*) and eucalyptus (*Eucalyptus sp*.) oil volatiles causes a sharp reduction in percent egg hatchability in rice moth, *Corcyra cephalonica* Stainton when freshly laid eggs were exposed to these volatiles for 24 hours. A marked decline in egg output and egg hatchability in reproductive pairs was observed whose larvae were allowed to develop in a programmed manner in an environment. A significant reduction in glycogen, lipid and protein level and an increase in free amino acids was noticed in testes and ovaries of these pyralids, when breeding pairs were exposed to the selected volatiles for a period of six hours only (Pathak and Pandey, 2011).

Shukla and Tiwari (2011) studied the larvicidal and pupicidal effects of *Dryopteris filix*-mas (root and rhizome) powder on the third instar larvae of *C. cephalonica*. The observations revealed that 4% dose of *Dryopteris filix*-mas caused 100% larval mortality indicating absolute toxicity to the pest.

Yadav *et al*. (2011a) an experiment was conducted to evaluate the effect of neem (*Azadirachta indica*) based formulations on development of storage pest, *Corcyra cephalonica* Stainton. All the test formulations were found to be effective in reducing the *C. cephalonica*. Among five neem based formulations, Nimbicidine was proved to be the most effective formulation and followed by Achook, whereas Neemazal was found to possess least development of *C. cephalonica.*

Yadav *et al*. (2011[b]) an investigation was carried out to study the insecticidal property of some natural pesticides viz. Neemazal, Bioneem, Nimbicidine, Achook and Neemgold. Among neem formulations, Neemazal was most effective against *Corcyra cephalonica* Stainton followed by Bioneem, Neemgold, Nimbicidine and Achook.

Madhavi and Raja (2012) a study was conducted to investigate the effects of *Vitex negundo* on the morphogenesis of *Corcyra cephalonica* Stainton. The *Vitex negundo* treated IV and V instar larvae of *C. cephalonica* showed varied morphogenetic deformities. The treated IV instar larvae showed prolongation of the larval period. The surviving *Vitex negundo* treated larvae moulted into V instar larvae and exhibited moult disruption. Some of the IV instar larvae were unable to moult into next instar stage, however few developed into larval pupal intermediates. The treated V instar larvae developed as adults with deformed wings and unable to fly and reproduce thus ruling out the possibility of further propogation of stored pest.

Khani *et al*. (2012) a study was conducted to estimate the insecticidal effect of essential oils from peppermint, *Mentha piperita* and black pepper, *Piper nigrum* against the rice weevil, *Sitophilus oryzae* L. and rice moth, *Corcyra cephalonica* Stainton. The major compounds in these essential oils were identified using gas chromatography-mass spectrometry and their insecticidal effect was tested against adults of the rice weevil, *S. oryzae* and the 3rd instars larvae of rice moth, *C. cephalonica*. The major compounds found in peppermint were menthol, isomenthone, limonene and cineole and in black pepper were limonene, alpha and beta pinene and caryophyllene. Highest toxicities were observed against *S. oryzae* populations treated with *M. piperita* and *P. nigrum* essential oils with LC_{50} values of 85.0 and 287.7 micro L/L air after 72 hours after, respectively. In the case of *C. cephalonica* larvae, the LC_{50} values were 343.9 and 530.5 micro L/L air for *M. piperita* and P. nigrum

essential oils at 72 hours after, respectively. *M. piperita* and *P. nigrum* oils have insecticidal effects against *S. oryzae* and *C. cephalonica*.

Patnaik *et al*. (2012) studied the efficacy of five regionally available botanicals in powdered form against *Corcyra* in stored sesame. Among the treatments both karanj and *Vitex* leaf powder as admixture impaired larval feeding and resulted in minimum seed weight loss (3.0-3.2% at 2 weeks and 7.8%-8.1% at seven weeks of storage) as compared with untreated check (26.6-27.3%). However, antifeedant index showed the superiority of karanj and *Virex* leaf powders in preventing *Corcyra* damage up to 7 weeks of storage.

Pathak and Tiwari (2012) a study was conducted to evaluate the insecticidal influence of neem seed acetone extract on the third instar larvae of *Corcyra cephalonica* Stainton. This extract caused a depressive effect on the developmental stages of this moth. A dose level of 0.16% (a.i) v/w of this extract caused 100% larval mortality.

Shukla and Tiwari (2012) an experiment was conducted to evaluate the larvicidal and pupicidal effects of pyrethrum extract on the third-instar larvae of *Corcyra cephalonica* Stainton. Pyrethrum extract at an estimated concentration of 0.0010% (active ingredient, v/v) was sufficient to cause 100% larval mortality.

Khani *et al*. (2013) an experiment was conducted to evaluate the insecticidal efficacies of Petroleum ether extract of *Piper nigrum* and *Jatropha curcas* against *Corcyra cephalonica* Stainton. The *C. cephalonica* 3rd instar larvae were shown to have similarities susceptibility to petroleum ether extract of *Piper nigrum* and *J. curcas*. Both extracts showed high bioactivity at all doses against *C. cephalonica* larvae and antifeedant action was increased with increasing plant extract concentrations. The petroleum ether extract of *P. nigrum* and *J. curcas* showed strong inhibition on egg hatchabilities and adult emergence of *C. cephalonica* at the lowest concentration.

2.4.1.2 Inert Materials:

Aldryhim (1993) studied the effectiveness of amorphous silica dust (dry acid) on three classes of wheat durum, hard and soft wheat at 20 and 30^{0}C at 40 and 60 per cent relative humidity against adults and progeny of the *R. dominica*. Effectiveness was greater at 30 than 20^{0}C and at 40 than 60 per cent relative humidity. The toxicity

of silica dust was significantly higher on durum at 40 per cent relative humidity and on hard wheat at 60 per cent relative humidity. The optimum test conditions for progeny production were 30^0C temperature and 60 per cent relative humidity. The mean number of progeny produced was significantly reduced with increasing silica dust concentration from 0.50 microgram g^{-1} wheat.

Ulriche and Mewis (2000) tested diatomaceous earth (Diatomite) Fossil Sheild R and the neem product Neem Azal- T/S R as single treatment and in combination for the control of *Sitophilus oryzae* and *Tribolium castaneum.* DE applied in concentrations of 0.5, 1.0 and 2.0g/kg rice reduced number of surviving beetles significantly. A single treatment with the neem product, in concentrations of 0.01, 0.1, 0.2 and 1.0 g azadirachtin/kg rice increased the mortality rate for both species significantly. The combination of neem and diatomaceous earth (1.0 g DE with 0.2 or 1.0 g azadirachtin) was more effective than the single treatment in reducing the numbers of beetles.

Dhakshinamoorthy and Selvanarayanan (2002) evaluated the effects of different natural products on the survival of *C. maculatus* infesting stored green gram and found that the treatments comprised leaves (as dried powder) of various plants (neem, nochi [*Vitex negundo*], pungam [*Pongamia pinnata*], citrus and thulasi), fly ash, kitchen ash, castor oil, red earth, malathion (as standard control) and untreated control. Treated seeds were kept in plastic containers and 20 adult beetles were introduced into each container and kept covered with muslin cloth. The results revealed that the mortality of the beetle at 7 days after treatment was highest (100%) in castor oil, followed by neem leaf powder (91.66%).

Athanassiou *et al*. (2004) assessed the effect of the diatomaceous earth (DE) formulations Insecto, SilicoSec and PyriSec on stored Oat, Rye and Triticale against adults of *Sitophilus oryzae* and *Tribolium confusum* at three dose i.e. 0.75, 1.0 and 1.5g /kg grain. They recorded 100 percent mortality in *S. oryzae* adults after 7 days of exposure in all three types of grains All formulations were equally effective after 7 days of exposure against *S. oryzae*, but at 48 hours of exposure, PyriSec caused significantly higher mortality than the other two formulations. No progeny were recorded in the Triticale of *S. oryzae*.

Swain and Baral (2005) evaluated effect of different ashes *i.e.* wood ash, rice straw ash, bamboo ash, cow dung ash, rice husk ash and fly ash for controlling rice weevil (*Sitophilus oryzae*) and pulse beetle (*Callosobruchus chinensis*). The wheat and pulse seeds were thoroughly mixed with ash at 0.5 g/100 g seeds. The results revealed that the different ashes significantly hindered the normal growth of the insect population. Rice husk ash was considered as the best in controlling the insects in comparison to other ashes tested.

Devi and Rao (2005) reported that the pod protectants like chlorpyriphos (2.5 ml/lit.) and imidacloprid (1 ml/lit.) gave complete control of bruchid by preventing egg lying and minimizing adult development in the treated pots. Neem based insecticides and fly ash were also found promising as protectants for groundnut pots. None of the protectants affected germinability of groundnut.

Shaheen and Khaliq (2005) tested fly ash, cow dung ash, acacia bark ash, red soil powder and turpentine oil as post harvest grain protectants for their insecticidal potency against pulse beetle attacking stored chickpea. The results revealed that fly ash at 1.0 g per 50 g of grains showed the minimum days (5.06) to 100% mortality of released adults, minimum fecundity (0.86 eggs per grain), minimum holes (0.41 per grain), lowest number (3.14) of F_1 adults emerged, maximum inhibition (78.62%) of F_1 adults, minimum weight loss (9.63%) and the minimum of 2.86 days to 100% mortality of F_1 adults. Fly ash and turpentine oil were the most effective at all application rates compared to other materials and the control. However, fly ash proved to be the best in managing pulse beetle infestation to lower levels followed by turpentine oil and cow dung ash while red soil powder and kikar ash were less effective and were similar to the control at their lower application rates.

Athanassiou (2006) evaluated the insecticidal effect of beta cyfluthrin applied to wheat with or without the adition of the diatomaceous earth (DE), against adults of *Sitophilus oryzae* and *Tribolium cofusum* at three doses 0.125, 0.25 and 0.75 ppm of beta cyfluthrin and the diatomaceous earth doses was 250 ppm, adults mortality was assessed after 24, 48 hours, 7 and 14 days of exposure to the treated substrate. For *S. oryzae*, the presence of DE increased the insecticidal effect of beta cyfluthrin at 0.125 and 0.25 ppm, adults mortality ranged between 64% and 100% after 14 days of exposure.

Govindan and Nelson (2007[a]) studied the effect of *Acorus calamus* rhizome powder and its dust formulations on the oviposition, adult emergence, seed damage and seed germination on *C. maculatus*. And *A. calamus* at 2.00% rhizome powder acted as the best ovipositional deterrent wherein only 7.00 eggs were laid compared to 265.00 eggs in the control. No black gram seed weight loss was observed. Ac 10DT (talc as filler) 4.00% showed very good ovipositional deterrent effect with only 16.00 eggs compared to 204.00 eggs laid in untreated control. Few adults (7.66 Nos) were emerged from the Ac 10DT 4.00%. Seed weight loss was only 0.16% in Ac 10DT 4.00% compared to 18-38% in untreated control. In Ac 10DF (fly ash as filler) 4.00%, only 18.00 eggs were laid while in untreated control 188.00 eggs were laid. Adult emergence was less (6.66) in Ac 10DF 4.00%. Seed weight loss was minimum (0.11%) in Ac 10DF 4.00%. Germination was maximum (89.33%) in Ac 10DF 4.00%.

Govindan and Nelson (2007[b]) evaluated effect of *Piper nigrum* seed powder and dust formulation (0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5 and 4.0% with talc (Pn10DT) or fly ash (Pn10DF) used as a filler) on *Callosobruchus maculatus* infesting black gram seeds. The black gram seeds treated with 0.25, 0.5, 0.75, 1.0, 1.25, 1.5, 1.75 and 2.0% *P. nigrum* seed powder exhibited anti-insect activities. Hatchability ranged between 68.3 and 85.2% among the treatments. The minimum adult emergence was obtained with 1.5% *P. nigrum*. Seed weight loss was minimum when treated with 1.5% *P. nigrum*. For dust formulation using talc as filler, the lowest number of eggs laid (39.6), hatchability percentage (68.8), number of adults emerged (18.3) and percentage of seed weight loss after 45 days (0.8), and the highest seed germination after 90 days (90.6) was obtained with 4.0% Pn10DT. For dust formulation using fly ash as a filler, the lowest number of eggs laid (22.6) and number of adults emerged (7.0) including the highest seed germination after 90 days was obtained with 4.0% Pn10DF. On the other hand, seed treated with 2.0 and 2.5% Pn10DF gave the lowest hatchability percentage (57.1) and percentage of seed weight loss after 45 days (8.98), respectively.

Sankari and Narayansamy (2007) evaluated the bio-efficacy of fly ash (FA)-based herbal pesticides on certain insect groups and found that the eight FA based herbal pesticides showed efficacy in thwarting various groups of pests infesting rice and vegetables, thus indicating them to be potential biopesticides. Among all the

treatments, FA+10% turmeric dust and FA+10% neem seed kernel dust showed the highest efficacy against all the test insects, including *Epilachna vigintioctopunctata* on aubergine and *Spodoptera litura* on okra, followed by the FA+10% *Vitex negundo* dust and FA+10% *Eucalyptus globulus* dust and FA+10% *Ocimum sanctum* [*Ocimum tenuiflorum*] dust treatments.

Tiwari and Tiwari (2008) studied the bio-efficacy of Diatomaceous earth formulation against five major insect pests of stored cereals *viz., R. dominica, S. oryzae, T. castaneum, S. cerealella and C. cephalonica* at 0.01, 0.02, 0.05, 0.10 and 0.20 per cent (w/w) and observed that 0.02 per cent checked 93.8, 98.1, 100.0, 100.0, 100.0 percent progeny of *R. dominica, S. oryzae, T. castaneum, S. cerealella and C. cephalonica* respectively.

Matti and Awaknavar (2009) carried out a laboratory experiment to evaluate the insecticidal effect of the diatomaceous earth formulation "Protect" at 0.025, 0.05, 0.10, 0.15, 0.25 and 0.30 per cent against adults of rice weevil in stored *jowar* seeds. They noticed per cent mortality at 0.30, 0.25, 0.20 and 0.15 per cent. However no mortality was recorded in control during storage period of two months.

Vani and Brindhaa (2013) a study was conducted to evaluate the effect of silica nanoparticles against the stored grain pest *Corcyra cephalonica* Stainton. Nanoparticles are more reactive than their bulk counterpart because of their increased surface to volume ratio. Silica nanoparticles were synthesized by modified Stober's sol-gel method. They were characterized by Scanning Electron Microscope, X-ray Diffraction and Energy Dispersive X-ray Spectroscopy. Characterization studies showed silica nanoparticles of size range 70-80nm were synthesized which are spherical in shape and amorphous in nature. Amorphous silica nanoparticles were found to be highly effective against *C. cephalonica* causing 100% mortality.

1.4.2 Varietal sceening:

Singh *et al*. (1973) screened five high yielding varieties of maize *viz.*, Vijay, Ganga-2, Ganga-3 Him-123 and Amber against *Trogoderma granarium* Everts. at 35ºC temperature and 60 per cent RH and to *S. oryzae* at 30ºC temperature and 75 per cent relative humidity in laboratory. They observed Ganga-2 and Ganga-3 was relatively resistant to both species and Vijay to *S. oryzae*. Resistance in these three varieties was related to the hardness of the grains.

Singh *et al.* (1998) screened 15 maize varieties under laboratory conditions (30±1ºC temperature and 75±5% R.H.) against *S. oryzae* and reported that maximum number of eggs (30.5 eggs) were laid on Ganga-5 and minimum on Sartaj (12.5 eggs). Emergence of adult weevil was found maximum in Harsa (57.5 per cent) and minimum in Prabhat (17.3 per cent). The longevity of female and male adult ranged from 24.21-38.32 and 22.09-34.46 days, respectively, while the developmental period varied from 22.77-36.22 days. Harsa, Ganga Safed-2 and Ganga-5 were the most preferred, while Prabhat, Sartaj, Vijay and Naveen were the least preferred varieties for the development of the pest.

Gupta *et al.* (1999) reported that maize genotypes REVT, IPTT-94, D-841, Surya, D-851 and Azad-Uttam were most susceptible to *S. oryzae* with higher losses and growth index. The maize genotypes R-7, R-21, R-51, R-46 and R-49 were moderately resistant with least infestation and a poor growth index of *S. oryzae*. The genotypes 9304, 9303, 9504 and R-50 showed intermediate behaviour.

2.4.3 Efficiency of storage structures:

In India, people use different type of storage structure to store the grain for use throughout the year and to protect from insect pests (Pruthi, 1949 and Ramasivan *et al*., 1966), however, insects are causing heavy losses. Zutshi (1966) found maximum infestation and weight loss in open room, moderate in gunny bag and *thekka* and least in metal bin. Ramasivan *et al*. (1968) reported 2.0 per cent loss by storage insect in metal drum, 2.3 per cent in jute bag, 7.6 per cent in *kuthla* and 9.5 per cent in *kucha kothi*. None of the structure was found free from infestation.

Wilson *et al*. (1970) reported 1.80 per cent losses in stored wheat kept in *bhusa* while; 2.04 per cent in metal bin and 6.15 per cent in traditional bulk storage. Khare (1973) reported very heavy loss in wheat as high as 40.1 per cent after one year of storage in *khatti*, 24.87 per cent after 9 months of storage in *kuthla*, 27.68 per cent after 6 months and 50.37 per cent after one year of storage in jute bag.

Agrawal *et al*. (1981) recorded 1.07 and 6.62 per cent weight loss in wheat stored in *pucci kothi* and *bharola*. Dhaliwal and Kaur (1982) found maximum damage (6.67 %) in *bharoli* and minimum in *pucci kothi* (1.33 %) closely followed by metal bin (1.66 %) after 9 months of storage in wheat. Similarly Khound and Borah (1984) reported 4.10 and 4.39 per cent infestation after 3 and 6 months of storage of wheat in

metal bin, 11.27 and 14.65 per cent in cement bin and 5.13 and 6.77 per cent in *juria duli* for the same periods. Lal and Srivastava (1986) also found minimum weight loss in metal bin (0.06 %) while; maximum in improved *kachchi kothi* (1.7 %) after 12 months of storage period in adopted villages and in non- adopted villages, the minimum weight loss (2.7 %) was in banda (outdoor) and maximum (11.2 %) in palai after 9 months of storage. Aujha *et al*. (1990) reported that the drum was the ideal storage structure where minimum weight loss and maximum germination was found.

Singh *et al*. (1992) observed minimum losses in metal bins and *pacci kothi* as compared to those in the traditional storage structures and gunny bags and also found higher level of quality deterioration in the traditional storage structures.

Gahalawat *et al.* (1993) found maximum weight loss in wheat in bukhari (6.17%), followed by jute bags (5.77%), theka (2.33%), heap in room (1.18%), metal bin (0.68%) and Perchatti (0.54%). Ramzan *et al.* (1994) assessed losses (kernel damage) in bag storage ranged between 4.7 and 10.5 per cent and in wooden boxes suffered kernel damage between 4.8 and 2.8 per cent with the loss in weight and viability varied from 1.9 to 11.2 and 7 to 28 per cent, respectively. Similarly Kumar *et al.* (2002) reported complete mortality of *T. castaneum* in metal bin at the top level as well as bottom level, while; in mud bin only 36.66 and 30.66 per cent obtained at top and bottom level, respectively.

Pathak and Jha (2003) reported that *Sitophilus sp*. was most dominant pest among seven species in maize samples collected from polythene bags (98.5% infestation) followed by jute bags (94.3%) and the lowest infestation (65.6%) was found in cloth bags while; maximum infestation of *Sitotroga cerealella* in polythene bags (82.7 per cent) and minimum (33.3 per cent) in samples of Tom and wooden box was recorded in paddy samples.

3. MATERIALS AND METHODS

The present investigations entitled "Bio-ecology and Management of *Corcyra cephalonica* Stainton under Sub humid Southern Zone of Rajasthan" were conducted under laboratory conditions in the Department of Entomology, Rajasthan College of Agriculture, Udaipur during 2010 to 2012. The detailed methodology used for the investigation are described as under:

3.1 Maintenance of culture:

The test insect, *Corcyra cephalonica* Stainton (Lepidoptera: Pyralidae) is a serious pest of large number of stored products. The test insect eggs were obtained from Bio-control Research Laboratory, Department of Entomology, Rajasthan College of Agriculture, Udaipur. One Cubic centimeter (one c.c.) eggs were released in the containers containing 3kg of broken maize grains. These grains were conditioned for 24 hours at 28±2º C and 75±5 per cent RH before use. The culture was maintained in culture box and plastic containers consisting of glass jars lined with black folded thick paper on the sides and blotting paper at the bottom. A cotton plug soaked in 5 per cent sucrose solution was provided in the jars for feeding the adults moths to increase the fecundity of moth (Pareek and Kushwaha, 1971). The chamber was covered with double layer of muslin cloth after releasing freshly emerged active adults. The egg laying chambers were kept in an incubator at 28±2º C and 75±5 per cent RH. Most of the eggs were laid between the double layer of muslin cloth from where these were collected daily with the help of a soft brush and kept in separate Petri dishes. The time and date of egg laying were recorded in order to select the eggs of known age that ensured continuous supply of eggs needed for the present study. Eggs which were not used for experimentation were kept separately for hatching and their date of hatching was recorded. The newly hatched larvae were kept date wise in plastic containers and food was provided. The newly hatched larvae when required were taken from dated culture for further experimentation (Plate - I).

3.2 Survey:

Intensive surveys on the extent of damage of *C. cephalonica* in different storage structures were conducted in three districts *viz.*, Rajsamand, Chittorgarh and

Udaipur. Five villages were selected randomly from each district based on the availability of the storage structures. Ten farmers were selected randomly from each village. The survey were conducted during three seasons, November – December, 2010 and subsequent second and third surveys were conducted during January-February and June – July, 2011.

The average rainfall, temperature and relative humidity of the selected districts were also recorded (Table 1).

Table: 1 Average annual rainfall, temperature and relative humidity in three districts of Sub humid Southern Zone of Rajasthan.

S. No.	Districts	Rainfall (mm)		Temperature (^{0}C)		Relative humidity (%)	
		2010	2011	2010	2011	2010	2011
1.	Rajsamand	840	759	32.90	32.10	70.23	77.82
2.	Chittorgarh	793.82	859.90	32.76	31.62	70.35	78.12
3.	Udaipur	875.30	952.20	32.50	31.50	71.40	78.40

Source: KVK Rajsamand, KVK Chittorgarh and Agromet Observatory, Instructional Farm, Rajasthan college of Agriculture, Udaipur.

During the surveys samples were collected from 10 randomly selected farmers in each village. Thus samples were collected from 150 farmers belonging to 15 villages in the three districts of Sub humid Southern Zone of Rajasthan. A sample of 2 Kg of maize grains was collected from different site of storage structure with help of purkhi/sampler. The samples were mixed thoroughly and than 500g grains were taken from each sample by dividing and sub dividing it. These samples were packed in polythene bags to avoid loss of moisture and were brought to the laboratory for analysis and further studies. The basic information on type of storage structures and varieties were also collected from each farmer. A sub sample of 100g was taken from the representative sample of 500g for further studies (Plate- II).

3.3 Effect of hosts on the biology *C. cephalonica*:

For the study of effect of the hosts on the biology of *C. cephalonica* seven different hosts *viz*., maize, sorghum, rice, wheat, pearl millet, oat and groundnut were purchased from local market (Plate – III & IV). These seeds were conditioned before

use as described in maintenance of insect culture. From each host 200g of grains were taken in plastic containers with four replications, twenty newly hatched (0-24 hours old) larvae of *C. cephalonica* were released in each container. The mouth of containers was covered with muslin cloth and tightened with rubber band. The following observations were recorded to compare the effect of hosts on the biology of *C. cephalonica viz.*

1. Hatching period (days)
2. Larval period (days) and weight (mg)
3. Pupal period (days) and weight (mg)
4. Adult emergence (%)
5. Growth Rate Index
6. Fecundity (Eggs/Female)
7. Adult longevity (days)

The larval period was worked out by recording the date of hatching and date of formation of silken web in the food. The period between web formation and adult emergence was considered as pupal period. Larval and pupal weight was determined with help of electronic balance. For recording the fecundity and ovipositional period of adult which emerged from the larvae developed on treated food, were kept in separate jar for egg laying. The total number of eggs laid by each female were counted daily till the death of female in each treatment. A random sample of 50 eggs were taken from each replication and placed in separate containers and hatching period was worked out. The longevity of male and female adults and total number of adults emerged from different hosts were recorded.

3.4 Effect of abiotic factors on the growth and development of *C. cephalonica*:

Two hundred gram conditioned maize grain as described in the maintenance of insect culture were taken in plastic containers (230mmx75mm). Twenty newly hatched larvae of *C. cephalonica* was released in containers. These container were kept in different BOD incubators, which were fixed temperatures of 20^0C, 30^0C and 40^0C with variable relative humidity i.e. 40, 60, 80 per cent. Every day grains were checked. Observations were recorded on developmental period (body weight, larval and pupal period), adult emergence (male and female), adult longevity and growth

rate index. In order to obtain eggs, to study the development period, the folded black thick papers were introduced into culture jars containing one to two days old *C. cephalonica* adults moth. After 24 hours, the black thick papers were removed and unfolded. The black thick paper bearing 50 eggs was cut and kept in petri dish. The pieces of black paper was removed from the petri dish and the eggs were carefully examined for hatching under a binocular microscope. The incubation period worked out by recording the date of egg laying and date of egg hatching. The freshly hatched larvae were released in each replication for the study of development of *C. cephalonica* and observations were continued till the adult emergence ceased. The larval period was worked out by recording the date of hatching and date of formation of silken web in the food. The period between web formation and adult emergence was considered as pupal period. Larval and pupal weight was determined with help of electronic balance. Longevity of male and female adults was determined by recording the date of their emergence from pupae and the date of natural death. The growth rate index was worked out with the help of following formula:

$$\text{Growth Rate Index} = \frac{\text{Per cent adult emergence}}{\text{Total developmental period}}$$

3.5 Quantitative and qualitative losses:

The effect of insect pest infestation on different quantitative and qualitative parameters was worked out in terms of mean loss in weight, germination (%), carbohydrate content and protein content in maize sample collected from different surveys.

3.5.1 Quantitative loss:

a. Mean loss in weight:

Ten grams seeds were taken from each representative samples taken different surveys. The damages seeds were separated out from the representative samples. The damaged and undamaged seeds weighed and counted. The per cent loss in weight was worked out with the help of following formula (Adams and Schulten, 1978).

$$\text{Per cent loss in weight} = \frac{(UNd) - (DNu)}{U\,(Nd + Nu)} \times 100$$

Where,

U = Weight of undamaged grains

Nu = Number of undamaged grains

D = Weight of damaged grains

Nd = Number of damaged grains

3.5.2 Qualitative loss:

A. Germination test:

A sample of 100 grains was taken from the representative samples collected from each village during three surveys. The samples were placed separately in moist germination paper covered with another sheet of the paper than rolled and kept in polythene bags to prevent moisture loss. There were three replications for each sample. The observation on germination of seeds was recorded separately for each sample after 6 days. The effect on germination of maize worked out by following formula:

$$\text{Mean germination loss (\%)} = \frac{\text{No. of germinated seeds}}{\text{No. of seeds kept for germination}} \times 100$$

B. Protein content:

Nitrogen content of the grains was stored in different storage structure determined by micro Kjeldhal which was converted into protein content by multiplying with factor of 5.7 (AOAC, 1980). 200 mg of finely grinded flour sample was taken in kjeldhal flask containing 10ml concentrated H_2So_4 to which 1.5g of Potassium sulphate and copper sulphate mixture (10:1) was added. It was digested for about half an hour until clear solution of blue color was obtained, the volume of digested solutions was made to 100 ml by adding distilled water. To which 10ml of 30 per cent NaOH was added and than heated. Ammonia evolved was observed in 10ml N/100 H_2So_4. Excess of N/100 H_2So_4 was titrated against N/100 NaOH to find out the actual amount acid used to absorb ammonia blank were also run and its value was subtracted from the sample value.

Standard Calculation:

1. 1ml N/100 H_2SO_4 used = 0.00014g nitrogen.

   or

   0.00014 x 5.7 = 0.000798g protein content

2. Thus 200mg sample digested to make 100mlsolution, contained = 0.000798 100/10 = 0.000798g protein.

3. Protein content in 100g grain = 0.000798 x 1000/200 x100 = 3.99g protein content for 1ml of N/100 H2So4 used = 3.99 per cent protein in the grain = 3.99 x ml of N/100 H_2SO_4 used.

C. Carbohydrate content:

The amount of total soluble sugars was estimated using anthrone method.

Principle:

The anthrone reaction is the basis of a rapid and convenient method for the determination of hexoses, aldopentoses and hexuronic acids either free or present in polysaccharides. Carbohydrates are dehydrated by conc. H_2SO_4 to form furfural. Furfural condenses with anthrone to form a blue-green coloured complex which is measured colorimetrically at 630 nm.

Reagents used:

- 80% ethanol
- Anthrone reagent
- Standard glucose

Procedure:

One hundred milligram powdered sample were ground in pestle and mortar with 5 ml 80% ethanol. The homogenates were placed in sigma-centrifuge plastic tubes and then centrifuged at 10,000 rpm for 10 minutes. The supernatant solution was collected in tubes and used for estimation of soluble sugar. Then the volume was made up to 20 ml with 80% ethanol.

Estimation:

From the above 20 ml solution 0.5 ml aliquots of sample were taken. The standards were also prepared by taking 0.2, 0.4, 0.6, 0.8 and 1 ml of the standard glucose solution. ‘0’ served at blank. The volumes were made up to 2 ml in all the tubes including the sample tubes and the blank by adding distilled water. Then 4 ml anthrone reagent was added. After 8 minutes of heating in boiling water bath the samples were cooled and the green to dark green coloured solution was read at 630

nm against blank. The standard curve was drawn by plotting concentration of the standard on the X-axis versus absorbance on the Y-axis. Finally the amount of soluble sugars presented in the sample tube was calculated from the graph.

Calculation:

$$Soluble\ sugar\ \ (\%mg) = \frac{sugar\ value\ \ from\ graph\ (mg)}{Aliquot\ sample\ used\ (0.5)} * \frac{Total\ vol.\ of\ \ extract\ (ml)}{Wt.\ of\ \ sample\ (mg)} * 100$$

3.6 Eco-friendly modules of management:

Three different component of IPM viz; grain protectants, varieties and storage structure tested for their efficacy to develop an eco-friendly module for the management of *C.cephalonica*.

Table 2: List of grain protectants used for bio-efficacy against *C. cephalonica* in stored maize

S. No.	Common name	Scientific Name	Doses
1.	Neem leaf powder	*Azadirachta indica* A. Juss	10g/kg seeds
2.	Custard apple seed powder	*Annona squamosa*	10g/kg seeds
3.	Custard apple leaf powder	*Annona squamosa*	10g/kg seeds
4.	Diatomaceous earth	-	15g/kg seeds
5.	Fly ash	-	15g/kg seeds
6.	Wood ash	-	15g/kg seeds
7.	Control	-	-

Table 3: List of storage structures used for experimentation

S. No.	Name of storage receptacles	Dimension of storage structures (inch)
1.	Earthen Pots	7 X 18 (H X D)
2.	Metal bin	7 X 18 (H X D)
3.	Gunny bag	15 X 10 (L X W)
4.	Earthen Kothi	6.5 X 5.5 X 8.0 (L X W X H)
5.	Pusa Bin	15 X 9.0 X 12 (L X W X H)

L= Length, W= Width, H= Height and D= Diameter

3.6.1 Efficacy different grain protectants against *C. cephalonica*:

Grain protectants *viz.*, neem leaf powder 5g, custard apple seed powder 5g, custard apple leaf powder 5g, diatomaceous earth 7.5g, fly ash 7.5g, wood ash 7.5g. All of these were dried in shade and powdered in grinder than after passed through 60 mesh size sieves and mixed with 500g of maize grains were taken in plastic containers for each treatment. The details of the different grain protectants were used in the experiments along with their concentrations have been presented (Table 2 and Plate-V & VI).

Twenty five freshly hatched larvae of *C. cephalonica* were released in each jar. The mouth of containers was covered with muslin cloth and tightened with the help of rubber bands. Observations on larval mortality was recorded at 5 days interval; whereas, pupal mortality and adult emergence were recorded after pupal formation and adult emergence after completion of pupal period. The mortality recorded was corrected as by Abbott's (1925) formula:

$$\textbf{Corrected mortality (\%)} = \frac{\textbf{Mortality in treatment - Mortality in control}}{\textbf{100 – Mortality in control}} \times 100$$

3.6.2 Relative susceptibility of different maize varieties to *C. cephalonica:*

Five different varieties of maize (as mention below) obtained from All India Co-ordinated Maize Improvement Project, Department of Plant Breeding and Genetics, Rajasthan College of Agricultural, Udaipur (Rajasthan), were tested against *C. cephalonica* in order to find out the relative resistance/susceptibility of maize varieties (Plate- VII).

1. Pratap Makka-3
2. PEHM-2
3. Aravali Makka-1
4. Pratap Hybrid Maize-1
5. Sathi

These seeds were conditioned before use as described in the maintenance of insect culture. Moisture content of the grains of different varieties was estimated with OSAW universal moisture meter and to bring it to desired moisture of 13 per cent. Known/requisite amount of water was added as per the method described by Prakash *et al*. (1987):-

$$\text{Volume of water to be added} = \text{Weight of grains} \times \frac{\text{Required \% moisture content} - \text{Initial \% moisture content}}{100 - \text{Required \% moisture content}}$$

From each variety, 100g maize grains were kept in plastic containers with four replications of each variety and 25 freshly hatched larvae of *C. cephalonica* were released in each container. The mouth of containers was covered with muslin cloth and tightened with rubber band. The following parameters were taken to compare the varietal susceptibility of maize against *C. cephalonica*:

1. Developmental period (Days)
2. Adult emergence (%)
3. Mean loss in weight (%)

3.4 Estimation of losses caused by *C. cephalonica* under different storage structure:

The conditioned grains as with 13 per cent moisture was stored in different storage structures *i.e.* earthen pots, metal bin, gunny bags, earthen kothi, pusa bin with four replications. The dimension of the tested storage structures has been presented (Table-3 and Plate- VIII). Two kilo grams of maize grain were filled in each container. After tying the mouth of the gunny bags and closing the lid of plastic jar and bins, all the containers were arranged in completely randomized design (CRD) in the laboratory. Twenty five freshly hatched larvae of *C cephalonica* were released on some maize grains kept open in the vicinity of the experimental site to ensure infestation of stored maize. At bimonthly intervals, the samples were drawn from different depth of containers and after mixing them about 50g sample was analyzed to record the grain damage and weight loss. The weight loss in grain was calculated as described by Adams and Schulten (1978).

4. RESULTS

4.1 Extent of damage of *Corcyra cephalonica* Stainton in maize under different storage structures:

4.1.1 Survey:

The samples of stored maize grain collected from different surveys conducted during (November-December, February-March and June-July) from different storage structures (gunny bags, metal bin, kuchhi kothi and loose storage) from Rajsamand, Chittorgarh and Udaipur district of Sub-humid Southern Zone of Rajasthan. The first survey was conducted during November - December 2010 just after the harvesting of the crop. The data presented in Table 4 revealed that in gunny bags, 3 samples (5.56 %) was found infested by *C. cephalonica* out of 54 samples, while; none of the sample out of 19 samples collected from metal bin was found infested. Whereas, in case of kucchi kothi 2 samples (6.9 %) were found infested out of 29 samples. The maximum infestation of *C. cephalonica* was noticed in samples collected from loose storage in which 5 samples (10.42 %) were found infested out of 48 samples. Data further showed that out of 150 samples were collected from 15 different villages in three districts of Southern Rajasthan 10 samples (6.67 %) were found infested by *C. cephalonica*.

The infestation of *C. cephalonica* was found higher in the second survey conducted during February - March 2011 as compared to first survey conducted during November- December 2010 (Table 5). It very well clear from Table 5 the infestation of *C. cephalonica* was minimum in the samples collected from metal bin i.e. 3 samples (6.81%) out of 44 stored maize grain samples. While; 6 (15.79%), 8 (18.18%) and 11 (45.83%) samples out of 38, 44 and 24 were found infested in kucchi kothi, bages and loose storage, respectively. The data further showed that out of 150 samples collected from 15 different villages 28 (18.67%) samples were found infested by *C. cephalonica* (Table-5).

In third survey (June - July 2011) infestation of *C. cephalonica* was recorded significantly higher as compared to first and second surveys. The data presented in Table 6 shows that the infestation of *C. cephalonica* was significantly higher in maize grains under different storage structures during June- July survey as compared to

November- December and February-March surveys. The data presented in Table 6 shows that the 16 (47.06%), 9 (18.00%), 14 (26.42%) samples were found infested out of 34, 50, and 53 samples collected from gunny bags, metal bin and kucchi kothi, respectively. Highest infestation 61.53% of *C. cephalonica* was recorded in the samples collected from loose storage where 8 samples were found infested out of 13 samples. Overall 49 (32.67%) samples were found infested by *C. cephalonica* out of total 150 samples collected in 3 different districts of Sub-humid Southern Zone of Rajasthan during June- July, 2011.

4.1.2 Quantitative and qualitative losses:

4.1.2.1 Weight loss:

The data presented in Table 7 revealed that the mean weight loss ranged from 0.0 to 0.60 per cent during November-December 2010. The mean weight loss was highest in Rajsamand (0.43%) followed by Udaipur (0.25%) and Chittorgarh (0.23%). Maximum weight loss ranged from 0.20 to 0.60, 0.0 to 0.50 and 0.0 to 0.45 per cent in Rajsamand, Chittorgarh and Udaipur districts, respectively. Lowest grain weight loss was observed in metal bin and kucchi kothi 0.20 and 0.40%, 0.0 and 0.0 and 0.0 and 0.20 per cent in Rajsamand, Chittorgarh and Udaipur, respectively. The weight loss in grains stored in gunny bags was i.e. 0.50, 0.40 and 0.35 per cent in Rajsamand, Chittorgarh and Udaipur, respectively. The highest weight loss was recorded in case of grains stored under loose storage condition, i.e. 0.60, 0.50 and 0.45 per cent in Rajsamand, Chittorgarh and Udaipur, respectively.

The mean weight loss during February-March was ranged from 0.30 to 1.40 per cent. In Rajsamand the *C. cephalonica* infestation ranged from 0.40 (metal bin) to 1.40 per cent (loose storage) and on mean basis it was 0.80 per cent in the district. Similarly in Chittorgarh it ranged from 0.30 (metal bin) to 1.10 per cent (loose storage) with mean of 0.70 per cent. In Udaipur it ranged from 0.40 (metal bin) to 1.30 per cent (loose storage) and on mean basis it was 0.90 per cent. The lowest weight loss was recorded in grains stored in metal bin i.e. 0.40, 0.30 and 0.40 per cent in Rajsamand, Chittorgarh and Udaipur, respectively. The weight loss for the grain stored in kucchi kothi was observed as 0.50, 0.40 and 0.90 per cent in Rajsamand, Chittorgarh and Udaipur, respectively. While; in case of gunny bag storage the mean weight loss was 0.90, 1.00 and 1.00 per cent in Rajsamand, Chittorgarh and Udaipur,

respectively. Whereas, significantly highest weight loss was recorded under of loose storage samples i.e. 1.40, 1.10 and 1.30 subsequently, in Rajsamand, Chittorgarh and Udaipur district.

The weight loss in maize ranged from 0.40 to 7.46 per cent during June - July 2011. The mean weight loss was highest in Udaipur (3.55%) followed by Rajsamand (2.70%) and lowest in Chittorgarh (2.20%). In Rajasamand it ranged from 0.42 to 5.40 per cent, whereas in Chittorgarh and Udaipur it ranged from 0.40 to 5.30 and 0.48 to 7.46 per cent, respectively. Significantly lowest weight loss in grain was observed in metal bin and kucchi kothi (0.42 and 1.92%), (0.40 and 1.04) and (0.48 and 1.82) in Rajssamand, Chittorgarh and Udaipur, respecttively. The weight loss in gunny bags was i.e. 3.06, 2.04 and 4.42 per cent in Rajsamand, Chittorgarh and Udaipur, respectively. The highest weight loss in loose storage samples i.e. 5.40, 5.30 and 7.46 per cent in Rajsamand, Chittorgarh and Udaipur, respectively. The data presented in Table 11, showed that the irrespectively of districts, the weight loss in maize sample was lowest i.e. 0.23 per cent during November-December in Chittorgarh, which increased upto 3.55 per cent during June-July in Udaipur district.

4.1.2.2 Mean germination:

The germination per cent of grain samples carried out in the samples collected during November-December, February-March and June – July surveys are presented in Table 8. The germination per cent of grain samples ranged from 68.00 to 78.00 per cent. The mean germination of maize samples collected during November-December were 74.25, 72.25 and 71.75 per cent in Rajsamand, Chittorgarh and Udaipur district, respectively. The mean germination was highest in the samples collected during November-December followed by February-March and June-July. The highest germination of maize grains during November-December in these district showed that grains with the same farmers owing to their freshness and good amount of moisture content in grains. Similarly during February-March survey grains exhibited germination higher than those grains surveyed during June-July in all the three districts with a mean of 70.25, 71.00 and 68.25 per cent with ranging from 68.00 to 74.00, 68.00 to 75.00 and 67.00 to 74.00 per cent in Rajsamand, Chittorgarh and Udaipur district, respectively.

In Rajsamand, during November-December the highest germination i.e. 77.00, per cent was recorded in grains stored in metal bin which was remained at par to the mean germination of maize samples collected from gunny bags (74.00%) and kucchi kothi (75.00%), whereas the lowest germination was recorded from the grains stored under loose storage, i.e. 71.00 per cent. Similarly in Rajsamand, during February-March and June-July surveys the highest germination was recorded in metal bin (74.00 and 72.00%), followed by kucchi kothi (70.00 and 69.00%) and gunny bags (69.00. and 67.00%), respectively. Whereas the lowest germination was recorded in the samples collected from loose storage i.e. 68.00 and 66.00 per cent, respectively. The mean germination of grains in Chittorgarh during November-December, February-march and June-July surveys was 72.75, 71.00 and 69.00 per cent with a range of 68.00 to 78.00, 68.00 to 75.00 and 66.00 to 73.00 per cent, respectively.

In Chittorgarh, during November-December the highest germination (78.00%) was recorded in the grains stored in metal bin which was remained at par to the germination of maize samples collected from gunny bags (72.00%) and kucchi kothi (73.00%). Whereas the minimum germination was recorded in the samples collected from loose storage (68.00%). Similarly in Chittorgarh, during February-March and June-July surveys the highest germination was recorded in metal bin i.e. 75.00 and 73.00 per cent followed by kucchi kothi (71.00 and 70.00%) and gunny bags (70.00 and 66.00%), respectively. Whereas the lowest germination was recorded in the samples collected from loose storage i.e. 68.00 and 67.00 per cent in February-March and June-July surveys, respectively.

The mean germination of the maize grains samples collected from Udaipur district during all three surveys was significantly highest in metal bin i.e. 78.00, 74.00 and 72.00 per cent, respectively, followed by Kucchi kothi 71.00, 70.00 and 67.00 per cent, respectively. The mean germination of the grains in gunny bags during all the three surveys i.e. 70.00, 68.00 and 66.00, respectively. Whereas, the lowest germination of maize samples during all three surveys were recorded in the grains collected from loose storage i.e. 68.00, 67.00 and 62.00, respectively. The average germination of grains was 71.75, 68.25 and 66.75 per cent in the November-December, 2010, February – March and June – July, 2011 survey, respectively.

The mean germination of maize grains was highest in Rajsamand district during November-December survey and was at par to mean germination of the maize

grains in Chittorgarh and Udaipur district during same survey period and found significantly higher over February-March and June – July survey period. The data presented in Table 11 revealed that irrespectively of districts, the germination per cent of maize sample was highest i.e. 74.25 per cent during November-December in Rajsamand, which reduced to 66.75 per cent during June-July in Udaipur district.

4.1.2.3 Protein content:

The protein content of maize grain collected from different districts of southern Rajasthan during three different surveys was determined with a view that insect infestation leads to change in protein content of the maize grain. The data recorded on protein content during different surveys in three districts of Southern Rajasthan have been presented in Table 9 the data revealed that the protein content of the grain vary with the season and types of storage structures. The protein content of the grains in all three districts of Southern Rajasthan was highest during November-December while minimum during June-July survey.

In Rajsamand, the mean protein content of the grain during November-December was 7.73 per cent which was significantly higher than protein content of the samples taken during February-March (7.30%) and June-July (7.15%). The protein content of the maize grain samples during February-March and June-July was at par to each other. Similar trends were also obtained in Chittorgarh and Udaipur districts. In Chittorgarh, the highest mean protein content (8.25%) was recorded during November-December and lowest (6.95%) in June-July which at par to protein content recorded in February-March (7.04%) collected maize samples. Likewise, in Udaipur the maize samples collected during November-December also exhibited maximum protein content 7.85 per cent followed by 7.05 and 6.96 per cent during February-March and June- July, respectively. The data presented in Table 9 revealed that irrespective of districts, the protein content among the samples collected from different storage structures ranged from 7.40 to 8.60 per cent during November-December survey, 6.80 to 7.80 in February-March and 6.70 to 7.85 per cent in June-July survey.

In Rajsamand district during November-December the protein content in different storage structures varied from 7.40 to 8.10 per cent whereas, lowest protein content i.e. 7.40 per cent was recorded in the samples collected from loose storage

and highest 8.10 per cent recorded in metal bin. In Rajsamand, the protein content in the samples collected from gunny bags and kucchi kothi was recorded i.e. 7.50 and 7.90 per cent, respectively. Similarly in Rajsamand, during February-March and June-July surveys the highest protein content was recorded in the samples collected from metal bin i.e. 7.80 and 7.50 per cent, followed by kucchi kothi (7.40 and 7.30%) and gunny bags (7.10 and 7.00%), respectively. The lowest 6.90 and 6.80 per cent protein content was recorded from loose storage during February-March and June-July surveys, respectively.

In Chittorgarh the mean protein content (8.25%) during November-December survey was observed with a range from 8.10 to 8.60 per cent. The samples collected from metal bin recorded maximum protein content (8.60%) and loose storage recorded lowest protein content (8.10%). In Chittorgarh, the protein content in the samples collected from gunny bags and kucchi kothi was recorded i.e. 8.10 and 8.20 per cent, respectively. Similarly during February-March and June-July surveys the highest protein content was recorded in the samples collected from metal bin i.e. 7.50 and 7.40 per cent, followed by kucchi kothi (7.00 and 6.90 %) and gunny bags (6.85 and 6.80%), respectively. The lowest protein content was recorded during February-March 7.04 and June-July 6.75 per cent were recorded in the samples collected from loose storage.

Likewise, in Udaipur district, during November-December survey mean protein content was observed 7.85 per cent with lowest (7.60%) in the samples collected from loose storage and highest (8.10%) in metal bin. In Udaipur, the protein content in the samples collected from gunny bags and kucchi kothi was recorded i.e. 7.80 and 7.90 per cent, respectively. Similarly during February-March and June-July surveys the highest protein content was recorded in the samples collected from metal bin i.e. 7.30 and 7.25 per cent, followed by kucchi kothi (7.00 and 6.85 %) and gunny bags (7.00 and 6.75%), respectively. The lowest protein content was recorded in the samples collected during February-March (6.90%) and June-July (6.80%) surveys from loose storage. The data presented in Table 11 showed that the irrespectively of districts, the protein content of maize sample was highest i.e. 8.25 per cent during November-December in Chittorgarh, which reduced to 6.91 per cent during June-July in Udaipur district.

4.1.2.4 Carbohydrate content:

The data of carbohydrate content of the maize sample collected during three different survey in different district have been present in Table 10 the data revealed that the carbohydrate content of grains samples collected from different storage structures during November-December ranged from 68.00 to 72.00 per cent, 68.00 to 71.40 and 68.30 to 70.80 per cent in Rajsamand, Chittorgarh and Udaipur district, respectively. Similarly during February-March and June-July, it ranged from 67.20 to 70.00, 67.70 to 69.80 and 67.00 to 69.50 per cent and 66.50 to 70.00, 67.40 to 69.60 and 66.50 to 69.30 per cent in Rajsamand, Chittorgarh and Udaipur district, respectively.

In Rajsamand, the mean carbohydrate content in the grain samples collected during November-December was significantly higher than those of February-March survey, however it was found at par to the mean carbohydrate content in June-July. In Chittorgarh also the maize samples collected during November-December exhibited significant higher carbohydrate content (69.03%) than the February-March (68.28%) and lowest (67.98%) in June-July. Similar results were also obtained in Udaipur. In Rajsamand, the highest carbohydrate content was recorded in the samples collected from metal bin (72.00%) and lowest in loose storage (68.00%) during November-December The carbohydrate content in the kucchi kothi and gunny bags samples were 70.50 and 68.50 per cent, respectively.

Similarly in Rajsamand during February-March and June-July surveys the highest carbohydrate content was recorded in the samples collected from metal bin i.e. 70.00 and 70.00 per cent; while, in case of kucchi kothi and gunny bags the carbohydrate content of maize samples (69.00 and 68.50%) and (67.80 and 66.60%) was recorded, respectively. The lowest carbohydrate content during February-March and June-July surveys were recorded in the samples collected from loose storage i.e. 67.20 and 66.50 per cent, respectively. In Chittorgarh, the highest carbohydrate content in the samples collected from metal bin and lowest in loose storage during November-December i.e. 71.40 and 68.20 per cent was recorded, whereas, the carbohydrate content in the samples collected from kucchi kothi and gunny bags i.e. 68.50 and 68.00 per cent, respectively. Similarly in Chittorgarh during February-March and June-July surveys the highest carbohydrate content was recorded in the samples collected from metal bin i.e. 69.80 and 69.60 per cent, while; in case of

kucchi kothi and gunny bags the carbohydrate content of maize samples i.e. (67.80 and 67.50%) and (67.80 and 67.40 %) was recorded, respectively. The lowest carbohydrate content 67.00 and 67.40 per cent were recorded during February-March and June-July surveys samples collected from loose storage.

In Udaipur, the highest carbohydrate content was recorded in the samples collected from metal bin (70.80%) and lowest in loose storage (68.30%) during November-December. The carbohydrate content i.e. 69.10 and 69.00 per cent was recorded in the samples collected from kucchi kothi and gunny bags, respectively. Similarly in Udaipur during February-March and June-July surveys the highest carbohydrate content was recorded in the samples collected from metal bin i.e. 69.50 and 69.30 per cent. The lowest carbohydrate content during February-March and June-July surveys were recorded in the samples collected from loose storage i.e. 68.00 and 67.49 per cent, respectively.

The results clearly indicated that maize stored in November-December exhibited significantly higher carbohydrate per cent than the June-July in all three districts. Data further revealed that irrespective of storage structures in three districts during three surveys showed that the samples collected from loose storage structures reported lowest carbohydrate content whereas metal bins recorded significantly maximum carbohydrate content. The data presented in Table 11 revealed that the irrespectively of districts, the carbohydrate content of maize sample was highest i.e. 69.75 per cent during November-December in Rajsamand, which reduced to 67.49 per cent during June-July in Udaipur district.

4.2 Effect of hosts on the biology *C. cephalonica*:

4.2.1 Hatching period (days):

The data presented in Table 12 showed that the maximum hatching period was observed on groundnut 5.50 days, while on maize and pearlmillet with a mean of 4.25 and 4.25 days, respectively. Next in order was sorghum where *C. cephalonica* exhibits 4.50 days as hatching period. The rice, wheat and oat required 4.75 days period for hatching.

4.2.2 Larval period (days)

The data presented in Table 12 revealed that the minimum larval period (32.50 days) was recorded on pearlmillet whereas, it was maximum on oat 45.25 days and on

remaining hosts viz., sorghum, maize, rice, wheat and groundnut it required 40.75, 41.50, 42.50, 43.25 and 44.50 days, respectively, to complete larval period.

4.2.3 Larval weight (mg):

The mean larval weight ranged from 38.50 to 52.25 mg on different hosts. The maximum larval weight was recorded on pearlmillet 52.25 mg, while minimum on oat 38.50mg (Table 12).

4.2.4 Pupal period (days):

The mean pupal period ranged from 9.50 to 11.25 days on different hosts. The maximum pupal period was observed on oat i.e. 11.25 days, while it was minimum on pearl millet and maize i.e. 9.50 days (Table 12)

4.2.5 Pupal weight (mg):

The mean pupal weight ranged from 32.00 to 38.50 mg days on different hosts. The maximum pupal weight was recorded on pearlmillet (38.50 mg), while it was minimum on oat (32.00 mg). The pupal weight on sorghum and wheat, maize, rice and groundnut were 37.00, 36.00, 34.00 and 33.75 days, respectively (Table 12).

4.2.6 Adult emergence:

The data presented in Table 12 showed that the adult emergence on different host grains ranged from 65.00 to 79.00 per cent. The maximum adult emergence was recorded on pearlmillet (79.00%), followed by maize (78.00%). However minimum adult emergence was recorded on groundnut (65.00%) which was at par with oat (66.00%).

4.2.7 Growth rate index:

The data presented in Table 12 showed that the growth rate index ranged from 1.07 to 1.71 in different host being minimum in groundnut (1.07) followed by oat (1.08) rice (1.18), wheat (1.20) and sorghum (1.38). The maximum growth rate index was recorded with pearlmillet (1.71) followed by maize (1.41).

4.2.8 Fecundity:

The data on fecundity are presented in Table 12 which indicated that the hosts significantly affected the fecundity of *C. cephalonica*. The maximum number of eggs were laid by female reared on maize (302.50) followed by pearlmillet (292.75) and

sorghum (292.50). The minimum eggs laid on groundnut (225.50) followed by oat (228.75) and rice (231.00). However the fecundity on wheat was at par with sorghum and pearl millet.

4.2.9 Adult longevity (male):

The data presented in Table 12 revealed that the males lives slightly longer period as compared to females. Maximum adult male longevity recorded on pearlmillet (10.25days) while minimum on sorghum (8.00 days).

4.2.10 Adult longevity (female):

The data presented in Table 12 showed that the longevity of female was slightly shorter than males. Maximum longevity period was recorded on wheat (7.25 days); while, minimum on sorghum (4.50 days).

4.2.11 Developmental period:

The data presented in Table 12 the average developmental period of *C. cephalonica* varied significantly on different hosts grains. The minimum developmental period was recorded on pearlmillet (46.25 days) followed by sorghum (55.00 days) which was at par with maize (55.25 days), and rice (57.50 days) and wheat (57.75 days). The maize, rice and wheat were also found at par to each other. The maximum developmental period was recorded on oat (61.25 days) followed by groundnut (60.75 days).

4.3 Effect of abiotic factors on the growth and development of *C. cephalonica* in stored maize:

4.3.1 Developmental period of female:

The data on the effect of temperature and relative humidity and interaction of both the factors on the development period of female have been presented in Table 13 and depicted Fig -I The data revealed that the developmental period of test insect varied with the temperature. The maximum (87.53 days) developmental period was recorded at 20^0C and minimum (42.83 days) at 40^0C temperature. At 30^0C temperature the test insect completed their development in 46.32 days. The data obtained on the effect of relative humidity revealed that the test insect took 52.57 days for completing their development at 80 per cent relative humidity. The developmental period 56.99 days were recorded at 60 per cent relative humidity followed by 40 per

cent relative humidity, where the pest took maximum time (67.13 days) for completing their development. The combined effect of both the factors revealed that the minimum development period of the test insect i.e. 31.30 days was recorded at 40^0C temperature and 80 per cent relative humidity followed by 36.56 days when temperature was 30^0C and relative humidity was 60 per cent. The maximum developmental period of *C. cephalonica* 92.00 days was observed at temperature 20^0C and relative humidity was 40 per cent.

4.3.2 Developmental period of male:

The data on the effect of temperature and relative humidity and interaction of both the factors on the development period of male have been presented in Table 13 and depicted Fig- I. The data revealed that the developmental period of test insect varied with the temperature. The developmental period was found maximum (84.60 days) when the insects were reared at 20^0C and minimum (40.00 days) was observed at 40^0C temperature. It was followed by 30^0C where the test insect completed their development in 41.93 days. The data obtained on the effect of relative humidity revealed that the test insect took 49.30 days for completing their development at 80 per cent relative humidity. The developmental period 52.83 days were recorded at 60 per cent relative humidity. It was followed by 40 per cent relative humidity, where the pest took maximum time (64.40 days) for completing their development. The combined effect of both the factors revealed that the minimum development period of (33.70 days) was recorded at 40^0C temperature and 80 per cent relative humidity. It was followed by 35.10 days when temperature was 30^0C and relative humidity was 60 per cent. The maximum (89.50 days) developmental period of male *C. cephalonica* was observed at temperature 20^0C and 40 per cent relative humidity.

4.3.3 Larval period:

The influences of temperature and relative humidity on larval development have been presented in Table 14 and depicted Fig- II revealed that the larval period was maximum (63.73 days) when the insects were reared at 20^0C temperature. It was followed by 30^0C temperature where the larval period was only 39.18 days. The larval period was minimum (33.90 days) at 40^0C temperature. The data obtained on the effect of relative humidity revealed that the larvae took minimum time (38.60 days) for completing their development at 80 per cent relative humidity. It was followed by

60 per cent relative humidity where the larval period was only (41.17 days). Whereas, at 40 per cent relative humidity the larvae took maximum time (57.05 days) to complete their larval development. The combined effect of both the factors revealed that the minimum development period of the test insect (22.70 days) was recorded at 40^0C temperature and 80 per cent relative humidity. It was followed by (24.80 days) at 30^0C temperature and 60 per cent humidity. The maximum larval period (70.10 days) was recorded at 20^0C temperature and 40 per cent relative humidity.

4.3.4 Weight of full grown larva:

Results obtained with regard to weight of full grown larva at different levels of temperature and relative humidity have been presented in Table 15 and depicted Fig-II. The mean weight of full grown larva of test insect ranged from 37 to 46.33 and 38.33 to 44.67 mg were recorded at different levels of temperature and humidity, respectively. The larval weight was maximum 46.33 mg when the insects were reared at 30^0C temperature. It was followed by 40^0C where the larval weight was 41.33mg, whereas, the minimum larval weight (37.00 mg) was recorded at 20^0C temperature. While, in case of relative humidity the larval weight at 40 per cent relative humidity was 38.33 mg followed by 41.67 and 44.67 mg at 60 and 80 per cent relative humidity, respectively. The most suitable combination of temperature and relative humidity on which maximum weight (51.00 mg) of full grown larva was recorded at 30^0C temperature and 80 per cent relative humidity. It was followed by combination of 30^0C temperature and 60 per cent relative humidity where the weight of full grown larva was 46.00 mg. The minimum weight (33.00 mg) of full grown larva was observed at 20^0C temperature and 40 per cent relative humidity.

4.3.5 Pupal period of female:

The data obtained on the effect of temperature and relative humidity on the duration of pupal stage of female have been presented in Table 16 and depicted Fig-III. The data revealed that the pupa took minimum time of 10.50 days to complete their development at 30^0C temperature. It was followed by the 11.20 and 13.40 days of development period at 40^0C and 20^0C temperature, respectively. The data presented in Table 16 revealed that pupal took minimum time to complete their development at 80 per cent relative humidity (10.78 days). It was followed by 60 and 40 per cent relative humidity where, pupal periods were 11.72 and 12.60 days,

respectively. The data recorded on the combined effect of both the factors revealed that the shortest pupal period of 9.85 days was recorded at 30^0C temperature and 80 per cent relative humidity; whereas, the longest pupal period of 14.40 days was recorded at 20^0C temperature and 40 per cent relative humidity.

4.3.6 Pupal period of male:

The data obtained on the effect of temperature and relative humidity on the duration of pupal stage of male have been presented in Table 16 and depicted Fig- III revealed that the pupa took minimum time of 9.27 days to complete their development at 30^0C temperature. It was followed by the 10.40 and 12.30 days of development period at 40^0C and 20^0C temperature, respectively. The data presented in Table 16 revealed that pupal took minimum time (9.80 days) to complete their development at 80 per cent relative humidity. It was followed by 60 and 40 per cent relative humidity where, pupal periods were 10.50 and 11.67 days, respectively. The data recorded on the combined effect of both the factors revealed that the shortest pupal period (8.40 days) was recorded at 30^0C temperature and 80 per cent relative humidity; whereas the longest pupal period of 13.60 days was recorded at 20^0C temperature and 40 per cent relative humidity.

4.3.7 Pupal weight of female:

The mean weight of mature pupa recorded at different temperature and relative humidity have been presented in Table 17 and depicted Fig- IV. The data revealed that the mean weight of mature pupa varied from 25.67 to 35.67 mg. and 28.33 to 33.33 mg at different levels of temperature and relative humidity, respectively. The pupal weight was found maximum (35.67 mg) at 30^oC and minimum (25.67 mg) at 20^oC temperature. It was followed by 30.73mg at 40^oC temperature. The data obtained on the effect of relative humidity the maximum pupal weight of 33.33mg was recorded at 80 per cent relative humidity. It was followed by 30.33 and 28.33mg at 60 and 40 per cent relative humidity, respectively. The combined effect of temperature and relative humidity showed that the most suitable combination for weight of mature pupa was at 30^oC temperature and 80 per cent relative humidity on which maximum weight of mature pupa (38.0 mg) was recorded. It was followed by the combination of 30^oC and 60 per cent relative humidity; where

the weight of mature pupa was 35.0 mg. The minimum pupal weight of 23.00mg was observed at 20^0C temperature and 40 per cent relative humidity.

4.3.8 Pupal weight of male:

The mean weight of mature pupa recorded at different temperature and relative humidity have been presented in Table 17 and depicted Fig- IV. The data revealed that the mean weight of mature pupa varied from 23.00 to 28.00 mg. and 26.00 to 31.00 mg at different levels of temperature and relative humidity, respectively. The pupal weight was found maximum (33.00 mg) at 30^0C and minimum (23.00 mg) at 20^0C temperature. It was followed by 28.00 mg at 40^0C temperature. The data obtained on the effect of relative humidity the maximum pupal weight of 31.00 mg was recorded at 80 per cent relative humidity. It was followed by 27.00 and 26.00 mg at 60 and 40 per cent relative humidity, respectively. The combined effect of temperature and relative humidity showed that the most suitable combination for weight of mature pupa was at 30^0C temperature and 80 per cent relative humidity on which maximum weight of mature pupa (36.00 mg) was recorded. It was followed by the combination of 30^0C and 60 per cent relative humidity where, the weight of mature pupa was 32.00 mg. The minimum pupal weight of 21.00mg was observed at 20^0C temperature and 40 per cent relative humidity.

4.3.9 Adult emergence of female:

The data presented in Table 18 and depicted Fig- V showed that the female adult emergence was maximum (72.90%) when insects was reared at 30^0C. It was followed by 67.05 per cent at 40^0C temperature, whereas, minimum (66.67%) female adult emergence was observed at 20^0C temperature. The data presented in Table 18 also revealed that relative humidity of 80 per cent was found most suitable for the adult emergence where 71.92 per cent emergence was recorded. Whereas, at 60 and 40 per cent relative humidity only 69.60 and 59.20 per cent adult emergences could be obtained, respectively. The combined effect of both the factors revealed that the combination of 30^0C temperature and 80 per cent relative humidity was suitable where maximum female adult emergence (80.90%) was recorded. It was followed by 75.10 per cent female adult emergence was observed at 30^0C and 60 per cent relative

humidity. Whereas, the minimum (54.90%) female adult emergence was observed at 20^0C temperature and 40 per cent relative humidity.

4.3.10 Adult emergence of male:

The data presented in Table 18 and depicted Fig- V showed that the male adult emergence was maximum (53.40%) when insects was reared at 30^0C. It was followed by 49.93 per cent at 40^0C temperature; whereas minimum (39.73%) adult emergence was observed at 20^0C temperature. The data presented in Table 18 also revealed that relative humidity of 80 per cent was found most suitable where 52.82 per cent male adult emergence was recorded. Whereas at 60 and 40 per cent relative humidity only 50.07 and 40.23 per cent adult emergences could be obtained, respectively. The combined effect of both the factors revealed that the combination of 30^0C temperature and 80 per cent relative humidity was suitable where maximum adult emergence (61.40%) was recorded. It was followed by 56.20 per cent male adult emergence was observed at 30^0C and 60 per cent relative humidity. Whereas, the minimum (35.10%) male adult emergence was observed at temperature 20^0C and 40 per cent relative humidity.

4.3.11 Longevity of female adult:

The longevity of female adults recorded at different levels of temperature and relative humidity have been present in Table 19 and depicted Fig- VI revealed that the longevity of female adults increased with the decrease in temperature. The longevity of female adult was found maximum (9.92 days). It was followed by at 30^0C temperature where the longevity of female adults was 4.98 days. The minimum female adult longevity of 2.99 days was recorded when the insects were reared at 40^0C temperature. Humidity also seemed to have little effect on the longevity of female adults. At 80 per cent relative humidity the longevity of female adult was 5.60 days which was followed by 5.98 and 6.30 days at 60 and 40 per cent relative humidity, respectively. The combined effect of both the factors on longevity of female adult showed that the longevity of female adult was maximum (10.50 days) at 20^0C temperature and 40 per cent relative humidity. It was followed by 10.00 days at 20^0C temperature and 60 per cent relative humidity. The minimum female adult longevity (2.81 days) was observed at 40^0C temperature and 80 per cent relative humidity.

4.3.12 Longevity of male adult:

The longevity of male adults obtained at different levels of temperature and relative humidity are presented in Table 19 and depicted Fig- VI revealed that the maximum male adults longevity of 12.83 days was recorded at 20^0C temperature and the minimum adult longevity of 3.16 days was observed at 40^0C temperature. It was followed by at 30^0C temperature adult with longevity of male was 7.23 days. The observations recorded on the effect of relative humidity on the longevity of male adult indicated that the adult could survive up to 8.89 days at 40 per cent relative humidity followed by 8.05 days at 60 per cent relative humidity and 6.28 days at 80 per cent relative humidity. The combined effect of temperature and relative humidity on the longevity of male adult, showed that adult could survive up to 16.30 days at 20^0C temperature and 40% relative humidity. It was followed by 14.20 days at 20^0C temperature and 60 per cent relative humidity was recorded. Whereas, the minimum male adult longevity of 3.05 days was observed at 40^0C temperature and 80 per cent relative humidity.

4.3.13 Growth Rate Index of female:

The data recorded on the individual and combined effect of the temperature and relative humidity on the growth rate index of *C. cephalonica* have been presented in Table 20 and depicted Fig- VII revealed that the highest growth rate index (1.64) of female was recorded at 30^0C followed by 1.61 at 40^0C temperature. The minimum (0.70) growth rate index of was recorded at 20^0C temperature. The growth rate index varied from 0.95 to 1.57 at different levels of relative humidity. In case of relative humidity, maximum (1.57) growth rate index was recorded at 80 per cent relative humidity which was followed by (1.44) at 60 per cent relative humidity. The minimum (0.95) growth rate index of was recorded at 40 per cent relative humidity. The combined effect of temperature and relative humidity on the growth rate index of test insects showed that it was maximum (1.96) at 30^0C temperature and 80 per cent relative humidity. It was followed by the growth rate index of 1.93 at 40^0C temperature and 80 per cent relative humidity. Whereas the minimum (0.60) growth rate index of was observed at 20^0C temperature and 40 per cent relative humidity.

4.3.14 Growth Rate Index of male:

The data recorded on the individual and combined effect of the temperature and relative humidity on the growth rate index of *C. cephalonica* have been presented in Table 20 and depicted Fig- VII revealed that the highest growth rate index of female (1.35) was recorded at 30^0C followed by 1.31 at 40^0C temperature. The minimum growth rate index of 0.39 was recorded at 20^0C temperature. The growth rate index varied from 0.68 to 1.27 at different levels of relative humidity. In case of relative humidity, maximum growth rate index of 1.27 was recorded at 80 per cent relative humidity which was followed by (1.18) at 60 per cent relative humidity. The minimum (0.68) growth rate index of was recorded at 40 per cent relative humidity. The combined effect of temperature and relative humidity on the growth rate index of test insects showed that it was maximum (1.65) at 30^0C temperature and 80 per cent relative humidity. It was followed by the growth rate index of 1.62 at 40^0C temperature and 80 per cent relative humidity. Whereas, the minimum growth rate index of 0.39 was observed at 20^0C temperature and 40 per cent relative humidity.

4.4 To develop eco- friendly modules for the management of *C.cephalonica* for stored maize:

4.4.1 Relative efficacy of different grain protectants against *C.cephalonica*:

4.4.1.1 Larval mortality:

The data on mean larval mortality at 5, 10, 15, 20, 25, 30, 35 and 40 days after release on freshly treated maize grains with different grain protectants are presented in Table 21 and depicted Fig- VIII. The data shows that significantly higher mortality was recorded in all the grain protectants as compare to control. The larval mortality increased with the increment in the days of release. Data recorded on larval mortality at 5 days after release showed that significantly highest mortality 49.33 per cent was recorded in neem leaf powder at10g/kg seed followed by 46.00 and 45.32 per cent with diatomaceous earth and fly ash at 15g/kg seed, respectively but both the treatments were found statistically at par to each other.

The mortality recorded in the remaining grain protectants varied from 21.33 to 44.00 per cent. The order of efficacy was custard apple seed powder at 10g/kg seed > custard apple leaf powder at 10g/kg seed > wood ash at 15g/kg seed (44.00, 38.67 and 21.33%), respectively. Data recorded further revealed that maximum larval mortality

at 10 days after release in maize grain was recorded with neem leaf powder at 10g/kg seed (55.13%) which was significantly superior over the rest of the treatments followed by 49.66 and 48.29 per cent in diatomaceous earth and fly ash, respectively and both were statistically found at par to each other. The larval mortality recorded in the remaining grain protectants varied from 21.92 to 46.57 per cent. The order of efficacy was custard apple seed powder at 10g/kg seed > custard apple leaf powder at 10g/kg seed > wood ash at 15g/kg seed (46.57, 42.46 and 21.92%), respectively.

The data recorded on larval mortality after 15 days of release was maximum in neem leaf powder at 10g/kg seed (77.77%) followed by custard apple seed powder at 10g /kg seed (76.30%) and diatomaceous earth 15g/kg seed (76.30%) and all these three were remained at par to each other. Mortality recorded in the rest of the grain protectants ranged from 55.45 to 73.33 per cent and order of efficacy was fly ash at 15g/kg seed(73.33%) > custard apple leaf powder at 10g/kg of seed(66.66%) > wood ash at 15g/kg seed (50.45%). The data recorded for larval mortality at 20 days after release showed significantly highest mortality 77.77 per cent with neem leaf powder at 10g/kg seed followed by 76.30 per cent in custard apple seed powder at 10g/kg of seed and diatomaceous earth at 15g/kg seed. Mortality recorded in the rest of the grain protectants varies from 50.45 to 73.33 per cent. The per cent larval mortality was 73.33 and 66.66 per cent recorded with fly ash at 15g/kg seed and custard apple leaf powder at 10g/kg seed. The least larval mortality (50.45 per cent) was recorded in wood ash at 15g/kg seed.

Data presented in the Table 21 revealed that at 25 days after release all the grain protectants showed the increasing trends in larval mortality as recorded at 20 days after release of test insect. The data recorded for larval mortality at 25 days after release showed significantly highest mortality (79.46 per cent) with neem leaf powder at 10g/kg seed followed by diatomaceous earth at 15g/kg seed 77.40 per cent and in custard apple seed powder at 10g/kg seed i.e. 76.32 per cent. Mortality recorded in the rest of the grain protectants varies from 51.11 to 74.34 per cent. The per cent larval mortality was 74.34 and 69.18 per cent recorded with fly ash at 15g/kg seed and custard apple leaf powder at 10g/kg seed. The least larval mortality was recorded in wood ash at 15g/kg seed was 51.11 per cent. The larval mortality at 30, 35 and 40 days after release shows similar mortality trends. Data shows that maximum larval mortality (82.21%) was recorded with neem leaf powder at 10g/kg seed treatment

which was significantly higher to rest of the treatment followed by diatomaceous earth at 15g/kg seed (77.78%), custard apple seed powder at 10g/kg seed (76.33%), fly ash at 15g/kg seed (74.81%) and custard apple leaf powder at 10g/kg seed (70.37%), respectively. Minimum larval mortality (55.55) per cent was observed in wood ash at 15g/kg seed after 30, 35 and 40 days of release.

4.4.1.2 Pupal mortality:

Maize grains were treated with various grain protectants to recorded the pupal mortality. It is evident from Table 21 and Fig- IX that all the treatments were found superior over the control (6.67 to 10.00%). Maximum pupal mortality (10.00%) was recorded in neem leaf powder at 10g/kg seed followed by 8.00 per cent with each custard apple seed powder at 10g/kg of seed and diatomaceous earth at 15g/kg seed. In case of fly ash at 15g/kg seed and wood ash at 15g/kg seed the pupal mortality were 7.00 and 6.67 per cent, respectively. Minimum pupal mortality (6.00%) was recorded under custard leaf powder at 10g/kg seed.

4.4.1.3 Adult emergence:

All the treatments were found superior over control to reduce adult emergence. The minimum adult emergence (6.00%) was observed with neem leaf powder @10g/ kg seed. In the remaining treatments adult emergence was 12.00, 13.33, 15.67, 20.67 and 33.33 per cent with diatomaceous earth @15g / kg seed, custard apple seed powder @ 10g/kg seed, fly ash @ 15g/kg seed, custard apple leaf powder @ 10g/kg seed and woodash @ 15g/kg seed, respectively, (Table- 21 & Fig- IX).

4.4.2 Varietal screening:

Five varieties of maize were evaluated against *C. cephalonica* in terms of developmental period, adult emergence and weight loss under laboratory condition. None of the variety was found free from infestation of *C. cephalonica*, however there was wide variation in developmental period, adult emergence and per cent loss in weight in different varieties of maize.

4.4.2.1 Developmental Period:

The data on mean duration of life cycle of *C. cephalonica* on different maize varieties presented in Table 23 and depicted in fig- X. It was apparent from the data that the mean duration of life cycle varied from 56.00 days to 68.00 days. The shortest

developmental period was observed on variety Sathi (56.00 days) followed by PEHM-2 (59.00 days) and Aravali Makka-1 (60.00 days) but both were found statistically at par to each other. Whereas, varied developmental period of 65.00 days to 68.00 days was observed in Pratap Makka-3 and Pratap Hybrid Maize-1. It was also evident that Pratap Makka-3 at par with Pratap Hybrid Maize-1. The order of preference in relation to the duration of life cycle was Pratap Hybrid Maize-1> Pratap Makka-3> Aravali Makka-1> PEHM-2> Sathi. PEHM-2 and Aravali Makka-1 were statistically at par with each other.

4.4.2.2 Adult emergence:

The data presented in Table 23 and depicted Fig- X showed that the maize varieties had significant effect on adult emergence. The extent of emergence ranged from 62.50 to 85.00 per cent in different varieties. It is also apparent from Table 23 that all varieties were significantly different to each other for per cent adult emergence except PEHM-2 (71.00%) and Aravali Makka-1 (70.00%). Maximum adult emergence (85.00%) was observed in Sathi followed by 71.00, 70.00, 65.25 and 62.50 per cent in PEHM-2, Aravali Makka-1, Pratap Makka-3 and Pratap Hybrid Maize-1, respectively. The order of per cent adult emergence of *C. cephalonica* were Sathi > PHEM-2 > Aravali Makka-1 > Pratap Makka-3 > Pratap Hybrid Maize-1.

4.4.2.3 Weight loss (%):

The data presented in Table 23 revealed that varieties showed relative susceptibility to *C. cephalonica* in term of loss in grain weight. The average weight loss in tested varieties varied from 18.50 to 28.50 per cent. The maximum weight loss (28.50%) was recorded in Sathi (28.50%) followed by PEHM-2 (22.75%) and Aravali Makka-1 (22.00%).Minimum weight loss (18.50%) was observed in Pratap Hybrid Maize-1 and was categorized as least susceptible. The order of weight loss by *C.cephalonica* in different maize varieties were Sathi > PEHM-2 > Aravali Makka-1 > Pratap Makka-3 > Pratap Hybrid Maize-1.

4.4.3 Estimation of losses caused by *C. cephalonica* under different storage structures:

4.4.3.1 Quantitative losses:

The weight loss due to infestation of *C. cephalonica* in stored maize grains under different storage structures *viz.*, earthen pots , metal bin ,earthen kothi and pusa

bin were recorded at 30, 60, 90 and 120 days. It evident from the data that quantitative loss in maize grain in terms of weight loss differed significantly among tested storage structures. Data after 30 days of storage showed that the zero weight loss in metal bin and pusa bin has been recorded followed by 0.75, 1.25 and 2.00 per cent in earthen kothi, earthen pots and gunny bags, respectively (Table-23 & Fig- XI). The weight loss after 60 days of storage also showed the same trends where, in minimum quantitative loss 0.00 % was observed in metal bin and pusa bin storage structures followed by 4.50, 5.00 and 7.75 per cent in earthen kothi, earthen pots and gunny bags, respectively. Data recorded after 90 days of storage showed 0.20 per cent quantitative loss in pusa bin and metal bin (0.25%). Whereas, gunny bags received maximum (11.50%) quantitative loss in maize grains. The weight loss in earthen kothi and earthen pots were recorded 7.50 and 8.25 per cent that was also found statistically at par to each other. Quantitative loss after 120 days of storage varied from 0.44 to 14.00 per cent with minimum quantitative loss in pusa bin (0.44%) and maximum in gunny bags (14.00%). Other structures viz., metal bin, earthen kothi and earthen pots received 0.50, 10.50 and 11.25 per cent weight loss, respectively. Correlation analysis presented in Table 24 also revealed that there was a positive and significant correction in quantitative loss in maize grain during storage period in earthen pots, metal bin, gunny bags, earthen kothi and pusa bin the values of coefficient of correlation was 0.999, 0.944, 0.984, 0.998 and 0.938, respectively.

5. DISCUSSION

5.1 Extent of damage of *Corcyra cephalonica* Stainton in maize under different storage structures:

5.1.1 Survey:

Quantitative survey to record the infestation of *Corcyra cephalonica* Stainton in maize in different storage structures during different period of the year in different agroclimatic conditions was conducted in three districts. The survey was conducted during November - December, February-March and June-July. Mean infested samples during November-December survey was highest in loose storage (10.42%), followed by kucchi kothi (6.90%), gunny bag (5.56%) and metal bin (0.00%). Second survey was conducted during February-March 2011, from the same farmers of the 15 villages. During the second survey infested grain samples in different storage structures varied from 6.81 to 45.83 per cent. It was highest in loose storage (45.83%),followed by gunny bags (18.18%), kucchi kothi (15.79 %) and lowest in metal bin (6.81%). The infestation of *C. cephalonica*during February-March was recorded higher as compared to November-December Third survey was conducted during June-July 2011, in which, highest infested grain samples was recorded in loose storage (61.53%), followed by gunny bags (47.06%), kucchi kothi (26.42%) and lowest in metal bin (18.00%). Infestation of *C. cephalonica*during June-July was significantly highest as compared to first and second surveys. This finding is in close conformity with the findings of Ramsivan *et al*. (1968), Shankar Dass (1977) and Agrawal *et al*. (1981). Metal bin was found most effective with only 1.96 per cent infestation. Similarly, Zutshi (1966) who reported least damage in metal bin and maximum in room. Lal*et al*. (2001)who reported that the maximum losses in stored maize was occurred during rainy season (12.24%) followed by summer (9.85%) and winter season (3.62). They also observed that the local storage structures, like gunny bags and bamboo bins resulted in significantly higher weight losses (11.51and 8.87%) compared to improved structures, like drums and metal bins (7.34 and 6.57%) respectively. Gupta (1990) reported that 24 % farmers stored in gunny bags and 76% of the farmers stored in bulk storage. He divided bulk storage into bukhari (33.20%), separate store room (32.40%), heaps in living room (24.50%), Parchhati (7.20%),

kothi (1.40%) and kuthla (1.40%). Srivastava *et al.* (1973) reported that the damage by insect pests was more in kachcha and pucca kothi than the drums.

5.1.2 Quantitative and qualitative losses:

5.1.2.1 Weight loss:

As a result of quantitative survey conducted during November-December 2010, the highest mean weight loss i.e. 0.43 per cent was recorded in grain stored in Rajsamand followed by Udaipur (0.25%) and in Chittorgarh (0.23%). The minimum grain weight loss in Rajsamand, Chittorgarh and Udaipur was observed in metal bin i.e. 0.20, 0.0 and 0.0 per cent, respectively. While the maximum weight loss was recorded in the samples collected from loose storage i.e. 0.60, 0.50 and 0.45 per cent in Rajsamand, Chittorgarh and Udaipur, respectively.

During February-March 2011, the maximum mean weight loss i.e. 0.90 per cent was observed in grain stored in Udaipur followed by Rajsamand 0.80 per cent and Chittorgarh 0.70 per cent. Similarly, lowest grain weight loss was observed in grains stored in metal bin i.e. 0.40, 0.30, and 0.40 per cent in Rajsamand, Chittorgarh and Udaipur, respectively. Similarly, the maximum weight loss i.e. 1.40, 1.10 and 1.30 per cent was recorded in the samples collected from loose storage in Rajsamand, Chittorgarh and Udaipur, respectively. Similarly**,** in the third survey conducted during June-July 2011, the mean weight loss was highest in grain samples collected from Udaipur (3.55%), followed by Rajsamand (2.70%) and in Chittorgarh (2.20%). The weight loss in grain was lowest in grains stored in metal bin i.e. 0.42, 0.40 and 0.48 per cent in Rajssamand, Chittorgarh and Udaipur, respecttively. Similarly, the highest mean weight loss was recorded in loose storage samples i.e. 5.40, 5.30 and 7.46 per cent in Rajsamand, Chittorgarh and Udaipur, respectively. While, studies in this regard were made by Gahlawat *et al.* (1993), Malik *et al*. (1994) and Singh and Yadav (1995) revealed that metalbin is an efficient storage structure because grain stored in metal bin carried minimum infestation and resulted in minimum weight loss as compared to traditional storage structure viz., room, bakhari etc. Meena and Bhargava (2003a) reported significant differences in damage on kernels stored in different containers under artificial and natural condition. Significantly higher dry mass loss (5.29%) and damage kernels (29.24%) were noticed in mud pot. Under natural

conditions, low dry mass and damage kernels were noticed in gunny bag followed by urea, cloth and polythene gunny bags.

5.1.2.2 Mean Germination:

The mean germination was highest in the samples collected during November-December, 2010. The mean germination of maize samples collected during November-December from Rajsamand, Chittorgarh and Udaipur district were 74.25, 72.25 and 71.75 per cent, respectively. The highest germination i.e. 77.00, per cent was recorded in grain samples collected from Rajsamand during November-December from the grains stored in metal bin. Whereas, the lowest germination was recorded from the grains stored under loose storage, i.e. 71.00 per cent. Similarly, in Rajsamand, during February-March and June-July, 2011 surveys the highest germination was recorded in the grain samples collected from metal bin i.e. 74.00 and 72.00 per cent, respectively. While the lowest germination was recorded in the samples collected from loose storage i.e. 68.00 and 66.00 per cent, respectively. In Chittorgarh during November-December, February-march and June-July surveys the mean germination of grains was 72.25, 71.00 and 69.00 per cent, respectively. During November-December the highest germination i.e. 78.00 per cent was recorded in grains stored in metal bin. Whereas, the lowest germination was recorded in the samples collected from loose storage i.e.68.00 per cent. Similarly, during February-March and June-July, 2011 surveys the highest germination was recorded the grain samples collected from metal bin i.e. 75.00 and 73.00 per cent, respectively. While the lowest germination was recorded in the samples collected from loose storage i.e. 68.00 and 67.00 per cent, respectively. In Udaipur during November-December, February-march and June-July surveys the mean germination of grains was 71.75, 68.25 and 66.00 per cent, respectively. During November-December the highest germination i.e. 78.00, per cent was recorded in grains stored in metal bin. Whereas the lowest germination was recorded in the samples collected from loose storage i.e. 68.00 per cent. Similarly, during February-March and June-July, 2011 surveys the highest germination was recorded in grains stored in metal bin i.e. 74.00 and 72.00 per cent, respectively. While the lowest germination was recorded in the samples collected from loose storage i.e. 67.00 and 66.75 per cent, respectively. Similar, studies in this regard were made by Singh and Yadav (1995) who reported maximum germination 96.00 per cent was recorded in wheat stored in metal bin and minimum

89.00 per cent in room. Similarly, Dhaliwal (1971) recorded 85.00 per cent germination of grains stored in metal bin and 77.00 per cent germination in loose stored wheat.

5.1.2.3 Protein content:

The protein content of the grains in all three districts of Southern Rajasthan was highest during Nov-December during which the weight loss and infestation was lowest; while during June-July survey the infestation was highest and protein content was lowest. In Rajsamand, the mean protein content of the grain during November and December, 2010 was 7.73 per cent which was significantly higher than protein content of the samples taken during February-March (7.30%) and June-July, 2011 (7.15%). The protein content of the maize grain samples during February-March and June-July was at par to each other. Similarly, in Chittorgarh the highest mean protein content in grains (8.25%) was recorded during November-December and lowest i.e. (6.95%) in June-July which was at par to protein content recorded in February-March (7.04%). Likewise, in Udaipur the maize samples collected during November-December also exhibited maximum protein content (7.85%) followed by (7.05%) and (6.91%) during February-March and June- July was found at par each other. In Rajsamand district during November-December the protein content was varied under different storage structures. The lowest protein content was 7.40 per cent recorded in the samples collected from loose storage and highest 8.10 per cent recorded in metal bin followed by gunny bags and kucchi kothi. Similarly, during February-March and June-July surveys the highest protein content in maize grains was recorded in the samples collected from metal bin i.e. 7.80 and 7.50 per cent, respectively, followed by gunny bags and kucchi kothi. The lowest protein content during February-March and June-July, 2011 surveys were recorded in the samples collected from loose storage i.e. 6.90 and 6.80 per cent, respectively.

In Chittorgarh during November-December survey, samples collected from metal bin recorded maximum protein content (8.60%) and grains stored in loose storage recorded lowest protein content (8.10%) followed by gunny bags and kucchi kothi. Similarly, during February-March and June-July surveys the highest protein content was recorded in the samples collected from metal bin i.e. 7.50 and 7.40 per cent, respectively, followed by gunny bags and kucci kothi. The lowest protein content during February-March and June-July surveys were recorded in the samples

collected from loose storage i.e. 7.04 and 6.75 per cent. Likewise, in Udaipur district, during November-December survey the lowest protein content was (7.60%) in the samples collected from loose storage and highest (8.10%) in metal bin followed by gunny bags and kucchi kothi. Similarly, during February-March and June-July surveys the highest protein content was recorded in the samples collected from metal bin i.e. 7.30 and 7.25 per cent, respectively, followed by gunny bags and kucchi kothi. The lowest protein content during February-March and June-July surveys were recorded in the samples collected from loose storage i.e. 6.90 and 6.80 per cent, respectively. The present finding is in conformity with the finding of Shankar Dass (1977) who reported a direct correlation between the decrease in protein content and the level of infestation.

5.1.2.4 Carbohydrate content:

The carbohydrate content of the grains in all three districts of Southern Rajasthan was highest during November-December when the weight loss was lowest; while during June-July survey the weight loss was highest. In Rajsamand, the mean carbohydrate content in the grain samples collected during November-December, 2010 was significantly higher i.e. (69.75%) than the February-March (68.50%) and minimum (67.90%) in June-July, 2011. Similarly, in Chittorgarh the maize samples collected during November-December exhibited significant higher carbohydrate content (69.03%) than the February-March (68.28%) and was lowest (67.98%) in grain samples collected during June-July. Likewise, in Udaipur the mean carbohydrate content was (69.30%) in November-December which was significantly higher than the February-March (68.00%) and minimum (67.49%) in June-July. The carbohydrate content varied under different storage structures.

In Rajsamand, the grain stored in metal bin exhibited the highest carbohydrate content 72.00 per cent and lowest 68.00 per cent was recorded in grains collected from loose storage during November-December Similarly, during February-March and June-July surveys the highest carbohydrate content was recorded in the samples collected from metal bin i.e. 70.00 and 70.00 per cent, respectively. Whereas, the lowest carbohydrate content during February-March and June-July surveys were recorded in the samples collected from loose storage i.e. 67.20 and 66.50 per cent, respectively. Similarly, in Chittorgarh the highest carbohydrate content was in the samples collected from metal bin and lowest in grains stored in loose storage during

November-December i.e. 71.40 and 68.20 per cent was recorded. Similarly, during February-March and June-July surveys the highest carbohydrate content was also recorded in the samples collected from metal bin i.e. 69.80 and 69.60 per cent, The lowest carbohydrate content during February-March and June-July surveys were recorded in the samples collected from loose storage i.e. 67.70 and 67.40 per cent, respectively. In Udaipur, the highest carbohydrate content in the samples collected from metal bin and lowest in loose storage during November-December i.e. 70.80 and 68.30 per cent was recorded. Similarly, in Udaipur during February-March and June-July surveys the highest carbohydrate content was recorded in the samples collected from metal bin i.e. 69.50 and 69.30 per cent, while; the lowest carbohydrate content during February-March and June-July surveys were recorded in the samples collected from loose storage i.e. 68.00 and 67.49 per cent, respectively. Similar, studies in this regard were made by Singh *et al*. (1992) who reported that grain stored in traditional store viz., gunny bag and kucchi kothi had higher level of free fatty acid and alcoholic acidity because of higher insect infestation.

5.2 Effect of hosts on the biology *C. cephalonica*:

The comparative effects of seven different hosts *viz*., maize, sorghum, rice, wheat, pearlmillet, oat, and groundnut was studied on the developmental parameters of *C. cephalonica*. The ultimate purpose of this study was to find out the most preferred host by *C. cephalonica*. The preference of the host was assessed on the basis of their effects on the hatching period, larval period and weight, pupal period and weight, adult emergence, Growth Rate Index, fecundity, adult longevity of male and female and developmental period.

5.2.1 Hatching period (days):

The minimum hatching period was observed on pearlmillet and maize with a mean of 4.25 and 4.25 days, which was at par with sorghum (4.50 days), rice, wheat and oat (4.75 days). It was followed by groundnut (5.50 days). These results gets full support from the findings ofPrakash and Senthilkumar (2005) reported that the shortest incubation period of 4.21 days was recorded on *P. americanum,* followed by *O. sativa* (5.32 days) and *S. bicolor* (7.41 days).

5.2.2 Larval period (days):

In present investigation, minimum larval period (32.50 days) was recorded on pearlmillet followed by sorghum (40.75 days), maize (41.50 days), rice (42.50 days), wheat (43.25 days), groundnut (44.50 days) and oat (45.25 days). This finding is in close conformity with the findings of Deulkar *et al.* (2012) reported that the least larval development period of 30.86 days was observed on Bajra based diet.

5.2.3 Larval weight (mg):

The maximum larval weight of 52.25mg was recorded with pearlmillet followed by sorghum (46.75 mg), maize (46.00 mg), rice (43.00 mg), wheat (42.00 mg), groundnut (40.75 mg) and oat (38.50 mg). These findings are also supported by Uberoi (1961) reported that the flour of pearl millet and broken grain of wheat proved to be best media for the growth of the larvae.

5.2.4 Pupal period (days):

The minimum pupal period was recorded on pearl millet and maize viz., 9.50 days, which was at par with sorghum and wheat (9.75 days) and rice (10.25 days). It was followed by groundnut (10.75 days) and oat (11.25 days). This finding is in close conformity with the findings of Deulkar *et al.* (2012) reported that the least pupal period of 4.70 days, along with maximum per cent pupation (85.02%) were observed on Bajra based diet.

5.2.5 Pupal weight (mg):

The maximumpupal weight of 38.50 mg wasrecorded on pearlmilletwhich was at par with sorghum and wheat (37.00 mg)and maize (36.00 mg) followed byrice (34.00 mg), groundnut (33.75 mg) and oat (32.00 mg).

5.2.6 Adult emergence:

The maximum adult emergence was recorded on pearlmillet i.e. 79.00 per cent which was at par with maize (78.00 %) and sorghum (76.00 %). It was followed by wheat (69.00%), rice (68.00%), oat (66.00%) and groundnut (65.00%). This finding is in close conformity with the findings of Nathan *et al.*(2006)observed that the per cent adult emergence was significantly higher for millet-reared than for sorghum-reared larvae.Similar observations were recorded by Pallavi *et al.* (2006) reported that the

among the various diets, bajra, bajra+nagali, maize+nagali were found most promising diet which favourable influenced the moth emergence.

5.2.7 Growth rate index:

The growth rate index was maximum on pearlmillet 1.71which was at par with Maize (1.41) and sorghum (1.38). It was followed by wheat (1.20), rice(1.18), oat(1.08) and groundnut (1.07). This finding was also supported by Sahayaraj *et al*. (2001) reported that the life table studies indicate that the bajra fed group had higher growth index (1.61).

5.2.8 Fecundity:

The maximum number of eggs were laid by female when insect reared on maize (302.50) which was at par to pearlmillet (292.75) and sorghum (292.50). It was followed by wheat (268.25), rice (231.00), oat (228.75) and groundnut (225.50). This finding is in close conformity with the findings of Pallavi *et al.*(2006) observed that among the various diets, bajra, bajra+nagali, maize+nagali were found most promising diet which favourable influenced the fecundity and adult longevity of male and female moths.

5.2.9 Adult longevity of male and female:

The Maximum adult male longevity recorded on pearlmillet i.e. 10.25 days which was at par with maize and wheat (9.75 days). It was followed by oat (8.75 days), groundnut (8.50 days) and sorghum (8.00 days). Whereas, the maximum longevity period of female was recorded on wheat i.e. 7.25 dayswhich was at par with pearlmillet and rice (6.25 days). It was followed by oat (5.50 days), maize (5.25 days), groundnut (5.00 days) and sorghum (4.50days). This finding is in close conformity with the findings of Pallavi *et al.* (2006). reported that themaximum longevity of male moth was 10.1 days when reared onbajra and bajra+nagali. Whereas, the maximum longevityof female moth was 7.1 dayswhen the test insect reared on wheat.

5.2.10 Developmental Period:

The minimum developmental period was recorded on pearlmillet i.e. 46.25 days which was at par with maize 55.25 days. It was followed by sorghum (55.00 days), rice (57.50 days), wheat (57.75 days), groundnut (60.75 days) and oat (61.25 days). This finding is in close conformity with the findings of Pathak *et al*. (2010^{a})

reported that the minimum development period of 47.62 days in pearl millet followed by 47.89, 49.23, 50.83 and 51.23 days in pearl millet + maize (9:1), sorghum + pearl millet (9:1), sorghum + maize (9:1) and sorghum + maize (8:2), respectively. Similarly, Deulkar *et al.* (2012) reported that the least total developmental period of 38.33 days was recorded on Bajra 2.5kg+Groundnut 100 g.

5.3 Effect of abiotic factors on the growth and development of *C. cephalonica* in stored maize:

Temperature is an important component of the environment and the rate of metabolism, growth, development, reproduction, general behaviour and distribution of insect pests are largely controlled by it. Fields (1992) proposed lethal, sub-lethal and optimal temperature ranges for many stored product insects; 25-33°C is optimal for growth and reproduction, while; 13-25°C or 33-35°C are sub-optimal at which insects are able to complete their development and produces offspring, and lastly at < 13° or > 35°C insects eventually die. Changes in metabolic rate caused by fluctuations of temperature have a direct bearing on two important aspects of insect life cycles; one is locomotion for performing crucial activities such as mating and feeding and the other is growth represented by development and metamorphosis. Thus, temperature mediated physiological actions regulate population dynamics.

The effect of humidity on the development of storage pest is almost intimately associated with that of temperature and operates indirectly through the moisture content of grains.With regard to biology, reproductive potentiality and development of *C. cephalonica* some work has been carried out on different temperatures and relative humidities in different countries of the world (Kamel and Hassanein, 1967; Teotia and singh, 1975; Pajni *et al*., 1978; Meena and Bhargava, 2010[a]; Chaubey and Misra, 2011).

5.3.1 Developmental period of female and male:

The development period of test insect varied with the temperature. The development period was maximum of 87.53 daysat 20°C and minimum of 42.83 days was recorded at 40°C temperature. The data obtained on the effect of relative humidity revealed that the test insect took maximum 67.13 days to complete their development at 40 per cent relative humidity and it was minimum of 52.57 days at 80 per cent relative humidity. The present studies on effect of temperature and relative

humidity revealed that the developmental period of *C. cephalonica* was 92.00 days at 20°C temperature and 40 per cent relative humidity. Whereas, the minimum development period of the test insect 31.30 days was recorded at 40°C temperature and 80 per cent relative humidity. The maximum development period of male i.e. 84.60 days was recorded at 20°C and minimum 40.00 days was recorded at 40°C temperature. The data obtained on the effect of relative humidity revealed that the test insect took maximum 64.40 days to complete their development at 40 per cent relative humidity and it was minimum of 49.30 days at 80 per cent relative humidity. The present studies on effect of temperature and relative humidity revealed that the developmental period of *C. cephalonica* was 89.50 days at 20°C temperature and 40 per cent relative humidity. Whereas, the minimum development period of the test insect 33.70 days was recorded at 40°C temperature and 80 per cent relative humidity. This finding is in close conformity with the findings of Jagdish *et al.* (2009)reported the total developmenatal period of *C. Cephalonica* occupied, 41 to 59 days on foxtail millet at a temperature of 24-28°C and 70% relative humidity. Russell *et al.* (1980) reported that at 70 per cent relative humidity and 28°C temperature, developmental period were 40 and 41 days for males and females, respectively. Allotey and Azalekor (2000) observed that at temperature ranging from 27.5-30°C and relative humidity from 60-73 per cent the mean developmental period ranged from 33.2 ± 0.2 to 45.3 ± 1.8 days. Similarily, the mean developmental period of *C. cephalonica* ranged from 46.5 to 77 days at 25.5°C temperature and 75 per cent relative humidity this finding was also supported by Kamel and Hassanein (1967). reported that mean larval period was 66.40 days at 15°C which it was lowest of 24.5 days at 30°C temprature.

5.3.2 Larval period:

The larval period of test insect varied with the temperature. The larva period was maximum of 63.73 days at 20°C and it was minimum of 33.90 days at 40°C temperature. The data obtained on the effect of relative humidity revealed that the test insect took maximum 57.05 days to complete their larval period at 40.per cent relative humidity and minimum 38.60 days was taken by the test insect to complete their larval peroid at 80 per cent relative humidity. The present studies on effect of temperature and relative humidity revealed that the maximum larval period of *C. cephalonica* i.e. 70.10 days was at 20°C temperature and 40 per cent relative humidity, Whereas, the minimum larval period of the test insect 22.70 days was

recorded at 40°C temperature and 80 per cent relative humidity. This finding is in close conformity with the findings of Hugar and jai rao (1985**)**found highest larval period 66.40 days at15°C lowest larval period 24.50 days at 30°C temperature.

5.3.3 Weight of full grown larva:

The larval weight found to be highest 46.33 mg. when the insect was reared at 30°C and lowest larval weight of 37.00 mg. was observed at 20°C temperature. The data obtained on the effect of relative humidity revealed that the maximum larval weight of 44.67 mg was recorded at 80 per cent relative humidity and minimum 38.33 mg was observed at 40 per cent relative humidity. The combined effect of temperature and relative humidity showed that most suitable combination for weight of full grown larva was 30°C temperature and 80 per cent relative humidity on which maximum weight of 51.00 mg was recorded. While, the lowest larval weight 33.00 mg. was observed at 20°C temperature and 40 per cent relative humidity. Similar results were also obtained by Meena and Bhargava 2010[a]. found that temperature of 30°C and relative humidity 70 per cent was the most suitable combination of which maximum weight of full grown larva (0.09 g.) was recorded.

5.3.4 Pupal Period of female and male:

The pupal period of female varied with the temperature. The maximum pupal period of 13.40 days of female was found at 20°C and minimum of 10.50 days at 30°C temperature. The data obtained on the effect of relative humidity revealed that the test insect took maximum 12.60 days to complete their pupal period at 40 per cent relative humidity, while minimum 10.78 days was observed at 80 per cent relative humidity. The present studies on effect of temperature and relative humidity revealed that the maximum pupal period of *C. cephalonica* 14.40 days was observed at temperature 20°C and 40 per cent relative humidity, Whereas, the minimum pupal period of the test insect i.e. 9.85 days was recorded at 30°C temperature and 80 per cent relative humidity. Thepupal period of male also varied with the temperature. The pupal period of male was maximum of 12.30 days at 20°C and it was minimum of 9.27 days at 30°C temperature. The data obtained on the effect of relative humidity revealed that the test insect took maximum 11.67 days to complete their pupal period at 40 per cent relative humidity and minimum 9.80 days was observed at 80 per cent relative humidity. The present studies on effect of temperature and relative humidity

revealed that the maximum pupal period of *C. cephalonica* 13.60 days was observed at temperature 20°C and 40 per cent relative humidity, Whereas, the minimum pupal period of the test insect i.e. 8.40 days was recorded at 30°C temperature and 80 per cent relative humidity. This finding is in close conformity with the findings of Ray (1994). reported that the pupal period of *C. cephalonica* on maize at 28±1°C and RH 75 per cent was recorded 10 days.Hugar *et al*. (1990) reported that the pupal period decreased with increase in temperature and humidity, being longest at 15°C and shortest at 35°C.

5.3.5 Pupal weight of female and male:

The higher pupal weight 35.67 mg of female pupae was recorded when the insect was reared at 30°C and it was lowest of 25.67 mg at 20°C temperature. The data obtained on the effect of relative humidity revealed that the mean pupal weight was maximum of 33.33 mg at 80 per cent relative humidity and was minimum i.e. 28.33 mg at 40 per cent relative humidity. The combined effect of temperature and relative humidity showed that most suitable combination for gaining the higher weight of pupa was 30°C temperature and 80 per cent relative humidity at which maximum weight of 38.00 mg was recorded. Lowest pupal weight of 23.00 mg was observed at 20°C temperature and 40 per cent relative humidity. The pupal weight of male was highest of 33.00 mg when the insect was reared at 30°C and it was lowest of 23.00 mg at 20°C temperature. The data obtained on the effect of relative humidity revealed that the mean pupal weight was maximum of 31.00 mg at 80 per cent relative humidity and was minimum i.e. 26.00 mg at 40 per cent relative humidity. The combined effect of temperature and relative humidity showed that most suitable combination for gaining the higher weight of pupa was 30°C temperature and 80 per cent relative humidity at which maximum weight of 36.00 mg was recorded. Lowest pupal weight of 21.00 mg. was observed at 20°C temperature and 40 per cent relative humidity. Similar findings were also reported by Meena and Bhargava (2010). reported that a combination of 30°C temperature and 70 per cent was most suitable for the pupa to gain optimum weight.

5.3.6 Adult emergence of female and male:

The maximum adult emergence of female was recorded (72.90%) when insects were reared at 30°C and minimum adult emergence (60.67%) was observed at

20°C temperature. The data obtained on the effect of relative humidity revealed that the maximum adult emergence (71.92%) was at 80 per cent relative humidity and it was minimum (59.20%) at 40 per cent relative humidity. The combined effect of temperature and relative humidity showed that a combination 30°C temperature and 80 per cent relative humidity was most suitable at which maximum adult emergence (80.90%) was observed. While minimum adult emergence (54.90%) was observed at 20°C temperature and 40 per cent relative humidity. The maximum 53.40 per cent and minimum adult emergence 39.73% was recorded when insect was reared at 30°C and 20°C temperature, respectively. The data obtained on the effect of relative humidity revealed that the maximum (52.20%) and minimum adult emergence (40.23%) was recorded at 80 per cent and 40 per cent relative humidity, respectively. The combined effect of temperature and relative humidity showed that a combination 30°C temperature and 80 per cent relative humidity was most suitable at which maximum adult emergence (61.40%) was observed. While, minimum adult emergence (35.10%) was observed at 20°C temperature and 40 per cent relative humidity. These observations are in conformity with the findings of Hugar *et al*. (1990). reported that maximum adult emergence at optimum temperature (25 - 30°C) and least at 15°C and it was less pronounced by relative humidity. Allotey and Azalekor (2000)reported 67.5 per cent adult emergence at 27-30°C and 60-73 per cent relative humidity.

5.3.7 Longevity of male and female adult:

The observations recorded on the effect of different temperature and relative humidity on the longevity of male and female adults indicate that it increases with the decrease in temperature. The maximum longevity of male and female of 12.83 & 9.92 days was recorded at 20°C temperature, respectively. Longevity of male and female adults was Minimum of 3.16 and 2.99 days, respectively at 40°C temperature. The humidity also seemed to have effect on the longevity of male and female adults whereas maximum longevity of male and female 8.89 and 6.30 days was observed at 40 per cent relative humidity, respectively, whereas minimum longevity of male and female 6.32 and 5.60 at 80 per cent relative humidity, respectively. The effect of both factors on longevity of male and female adults showed that the longevity of adult was maximum at 20°C and 40 per cent relative humidity combinations, and it was minimum at 40°C and 60 per cent relative humidity. This finding is in close

conformity with the findings of Cox *et al.* (1981) reported that the life span of *C. cephalonica* increased with decreasing temperature between 20 and 35°C.

5.3.8 Growth Rate Index of female and male:

The Growth Rate Index of female varied with temperature and relative humidity. The growth rate index was maximum i.e. 1.64 at 30°C and minimum 0.70 at 20°C temperature. The data obtained on the effect of relative humidity revealed that the maximum Growth Rate Index of 1.57 was recorded at 80 per cent relative humidity and minimum i.e. 0.95 was observed at 40 per cent relative humidity. The present studies on effect of temperature and relative humidity revealed that the maximum growth rate index of *C. cephalonica* i.e. 1.96 was observed at 30°C temperature and 80 per cent relative humidity. Whereas, the minimum Growth Rate Index of the test insect i.e. 0.60 was recorded at 20°C temperature and 40 per cent relative humidity. The Growth Rate Index of male also varied with temperature and relative humidity. The Growth Rate Index of male was maximum i.e. 1.35 at 30°C and was minimum of 0.0.47 at 20°C temperature. The data obtained on the effect of relative humidity revealed that the maximum Growth Rate Index of 1.27 was recorded at 80 per cent relative humidity and minimum i.e. 0.68 was observed at 40 per cent relative humidity. The present studies on effect of temperature and relative humidity revealed that the maximum Growth Rate Index of *C. cephalonica* i.e. 1.65 was observed at 30°C temperature and 80 per cent relative humidity. Whereas, the minimum Growth Rate Index of the test insect i.e. 0.39 was recorded at 20°C temperature and 40 per cent relative humidity. This finding is in close conformity with the findings of Cheema *et al*, 1988. reported that the Growth Rate Index was greatest for larvae of *C. cephalonica* when it was reared at 32°C and least for those reared at 27°C temperature.

5.4 Eco-friendly modules for the management of *C.cephalonica* for stored maize:

The results obtained during the present investigation on the efficacy of different grain protectants i.e. plant products and inert material discussed as follows:

5.4.1 Relative efficacy of different grain protectants against *C.cephalonica*:

Different grain protectants were mixed with maize grains to evaluate their efficacy against *C.cephalonica* on the basis of larval mortality, pupal mortality and adult emergence.

5.4.1.1 Larval mortality:

During the present investigationvarious grain protectants viz., neem leaf powder at 10g/kg seed, custard apple seed powder at 10g/kg seed custard apple leaf powder at 10g/kg seed, diatomaceous earth at 15g/kg seed, fly ash at 15g/kg seed and wood ash at 15g/kg seed were evaluated against *C. cephalonica*.All the grain protectants were found superior over the control. The larval mortality increased with the increment in the days of release. At 5 days after release highest larvalmortality of49.33 per cent was recorded in neem leaf powder at 10g/kg seed followed by 46.00 and 45.32 per cent with diatomaceous earth and flyash at 15g/kg seed, respectively and both were statistically found at par to each other.Custard apple seed powder at 10g/kg seed, custard apple leaf powder at 10g/kg seed,wood ash at 15g/kg seed with (44.00, 38.67 and 21.33%) larval mortality, respectively, followed the above treatments. At 10 days after release maximum larval mortality of 55.13 per cent was recorded with neem leaf powder at 10g/kg of seed which was significantly superior over the rest of the treatments followed by 49.66 and 48.29 per cent in diatomaceous earth and flyash, respectively and both were statistically found at par to each other. Custard apple seed powder at 10g/kg of seed, custard apple leaf powder at 10g/kg seed, wood ash at 15g/kg seed (46.57, 42.46 and 21.92%) larval mortality, respectively, followed the above treatments.

After 15 days of release maximum larval mortality of 77.77 per cent was recorded with neem leaf powder at 10g/kg seed which was closely with custard apple seed powder at 10g/kg seed and diatomaceous earth at 15g/kg seed(76.30%) and all these three were remained at par to each other. The descendingorder of efficacy of the remaining treatments were fly ash at 15g/kg seed(73.33%) > custard apple leaf powder at 10g/kg seed(66.66%) > wood ash at 15g/kg seed (50.45%). At 20 days after release highest larval mortalityof 77.77 percent was recorded with neem leaf powder at 10g/kg seed followed by 76.30 per cent in custard apple seed powder at 10g/kg seed and diatomaceous earth at 15g/kg seed. The descending order of efficacy

of the remaining treatments were 73.33, 66.66 and 50.45per cent with fly ash at 15g/kg seed, custard apple leaf powder at 10g/kg seed and wood ash at 15g/kg seed, respectively.At 25 days after release neem leaf powder at 10g/kg seed exhibited significantly highest mortality 79.46 per centfollowed by diatomaceous earth at 15g/kg seed and custard apple seed powder at 10g/kg seed with 77.40 and 76.32 per cent mortality, respectively. The descending order of efficacy of the remaining treatments were fly ash at 15g/kg seed (74.34%) > custard apple leaf powder at 10g/kg seed (69.18%). The least larval mortality was recorded in wood ash at 15g/kg seed was 51.11 per cent. Larval mortality at 30, 35 and 40 days after release was similar as above.Maximum larval mortality 82.21 per cent was recorded with neem leaf powder at 10g/kg of seed treatment which was significantly higher to rest of the treatments.The descending order of efficacy of the remaining treatments were 77.78, 76.35, 74.81, 70.37 and 55.55 per cent with diatomaceous earth at15g/kg seed , custard apple seed powder at 10g/kg seed, fly ash at 15g/kg seed, custard apple leaf powder at 10g/kgseed and wood ash at 15g/kg seed, respectively. This finding is in close conformity with the findings ofPathak and Tiwari (2010a) who was reported that the larvicidal and pupicidal effects of neem leaf on the third instar larvae of *Corcyra cephalonica* Stainton. They observed 100% mortality at 3.50% dose level of neem leaf. Veeranki and Reddy (2004) reported that custard apple seed powder, neem leaf, seed kernel powder and inert dusts (attapulgite and palygorskite) as effective treatment. Tiwari and Tiwari (2008) observed that diatomaceous earth formulation at 0.02 per cent checked 93.8, 98.1, 100.0, 100.0, 100.0 per cent progeny of *R. dominica, S. oryzae, T. castaneum, S. cerealella and C. Cephalonica,* respectively.Pathak and Tiwari (2010b) reported controlled 100% larval mortality of *C. cephalonica* with neem seed extract at 0.11% (a.i.).

5.4.1.2 Pupal mortality:

All the treatments were found superior over the control (6.67 to 10.00%). Maximum pupal mortality of 10.00 per cent was recorded in neem leaf powder at10g/kg of seed followed by 8.00 per cent with each custard apple seed powder at 10g/kg seed and diatomaceous earth at 15g/kg seed. The order of efficacy of the remaining treatments were7.00, 6.67 and 6.00 per cent with fly ash at 15g/kg seed, wood ash at 15g/kg seed andcustard leaf powder at 10g/kg seed, respectively. The present findings can be compared with those ofPathak and Tiwari (2010b) observed

larvicidal and pupicidal effects of neem seed extract at 0.11% (a.i.) on the third instar larvae of *C. cephalonica*.

5.4.1.3 Adult emergence:

The minimum adult emergence i.e. 6.00 per cent was observed in case of neem leaf powder at 10g/kg seed. In the remaining treatments adult emergence was 12.00, 13.33, 15.67, 20.67 and 33.33 per cent with diatomaceous earth at 15g/kg seed, custard apple seed powder at 10g/kg seed, fly ash at 15g/kg seed, custard apple leaf powder at 10g/kg seed and woodash at 15g/kg seed, respectively. The present findings can be compared with those of Patel and Patel (2002) observed mixing of *Neem* and eucalyptus leaf powder at 2 per cent and mustard oil at 0.5 per cent were interfere with adults emergence, development period and growth index of the pest as well as weight loss of grains.

5.4.2 Varietal screening:

The five varieties of maize viz., Pratap Makka-3, PEHM-2, Aravali Makka-1, Pratap Hybrid Maize-1 and Sathi. None of the variety was found free from infestation of *C. cephalonica*, however there was wide variation in developmental period, adult emergence and mean weight loss in different varieties of maize.

5.4.2.1 Developmental Period:

The shortest developmental period was recorded on variety Sathi (56.00 days) followed by PEHM-2 (59.00 days) and Aravali Makka-1 (60.00 days). Both these varieties were found at par to each other. It was also evident that Pratap Makka-3 was at par with Pratap Hybrid Maize-1. The order of preference were Sathi, PEHM-2, Aravali Makka-1, Pratap Makka-3 and Pratap Hybrid Maize-1, respectively. PEHM-2 and Aravali Makka-1 were statistically at par with each other. Singh *et al.* (1998) screened 15 maize varieties under laboratory conditions against *S. oryzae* and reported that maximum number of eggs (30.5 eggs) were laid on Ganga-5 and minimum on Sartaj (12.5 eggs). Emergence of adult weevil was found maximum in Harsa (57.5 per cent) and minimum in Prabhat (17.3 per cent). The longevity of female and male adult ranged from 24.21-38.32 and 22.09-34.46 days, respectively, while; the developmental period varied from 22.77-36.22 days. Harsa, Ganga Safed-2 and Ganga-5 were the most preferred, while; Prabhat, Sartaj, Vijay and Naveen were the least preferred varieties for the development of the pest.

5.4.2.2 Adult emergence:

All varieties were significantly different to each other in terms of adult emergence expect PEHM-2 (71.00%) and Aravali Makka-1 (70.00%). Maximum adult emergence 85.00 per cent was observed in Sathi followed by 71.00, 70.00, 65.25 and 62.50 per cent in PEHM-2, Aravali Makka-1, Pratap Makka-3 and Pratap Hybrid Maize-1, respectively. The order of adult emergence of *C. cephalonica* were Sathi > PHEM-2 > Arravli Makka-1 > Pratap Makka-3 > Pratap Hybrid Maize-1. Singh *et al.* (1998) screened 15 maize varieties under laboratory conditions (30±1ºC temperature and 75±5% R.H.) against *S. oryzae* and reported that maximum number of eggs (30.5 eggs) were laid on Ganga-5 and minimum on Sartaj (12.5 eggs). Emergence of adult weevil was found maximum in Harsa (57.5 per cent) and minimum in Prabhat (17.3 per cent). Similarly, Gupta *et al.* (1999) reported that maize genotypes REVT, IPTT-94, D-841, Surya, D-851 and Azad-Uttam were most susceptible to *S. oryzae* with higher losses and growth index. The maize genotypes R-7, R-21, R-51, R-46 and R-49 were moderately resistant with least infestation and a poor growth index of *S. oryzae*. The genotypes 9304, 9303, 9504 and R-50 showed intermediate behaviour.

5.4.2.3 Weight loss:

The maximum weight loss 28.50 per cent was recorded in Sathi followed by PEHM-2 and Aravali Makka-1 which were found statistically to each other with 22.75 and 22.00 per cent weight loss, respectively. Minimum weight loss, 18.50 per cent was observed in Pratap Hybrid Maize-1 and was categorized as least susceptible. The order of preference in terms of weight lossin different maize varieties were Sathi > PEHM-2 > Aravali Makka-1 > Pratap Makka-3 > Pratap Hybrid Maize-1. Pant *et al.* (1964) who reported seeds of Ganga-101 hybrid, Deccan hybrid, Rudrapur D.T.C., Melon white D.T.C. and Ganga-1 hybrid were significantly less susceptible than Ranjit hybrid, Rocol V351 D.T.C., Mexican June D.T.C., Udaipur white D.T.C., Jalicose D.T.C. and K.R. 41 O.P. Singh *et al.* (1973) observed Ganga-2 and Ganga-3 was relatively resistant to *T.granarium* and *S. Oryzae* and Vijay to *S. oryzae*. Resistance in these three varieties was related to the hardness of the grains.

5.4.3 Estimation of losses caused by *c.cephalonica* under different storage structures:

5.4.3.1 Quantitative losses:

After 30 days of storage no weight was observed in the grains stored in metal bin and pusa bin followed by 0.75, 1.25 and 2.00 per cent in earthen kothi, earthen pots and gunny bags, respectively. Similarly, after 60 days of storage same results were observed. After 60 days of storage the mean losses of 4.50, 5.00 and 7.75 per cent was recorded in earthen kothi, earthen pots and gunny bags respectively.After 90 days of storage 0.20% quantitative loss was recorded in pusa bin and very slow increase in quantitative loss was observed in metal bin i.e. 0.25 per cent, whereas in gunny bags the quantitative loss of maize grains was maximum i.e. 11.50 per cent. The weight loss in earthen kothi and earthen pots were 7.50 and 8.25 per cent, respectively and was at par to each other. Quantitative loss after 120 days of storage was minimum in pusa bin (0.44%) and maximum in gunny bags (14.00%). Other structures viz., metal bin, earthen kothi and earthen pots exhibited 0.50, 10.50 and 11.25 percent weight loss, respectively. This finding is in close conformity with the findings of Lal and Srivastava (1986) reported minimum weight loss in metal bin (0.06%) and maximum in improved kachchi kothi (1.7%) after 12 months of storage period. Similarly, Aujha *et al*. (1990) reported that the drum was the ideal storage structure where minimum weight loss and maximum germination was found. Singh *et al*. (1992) observed minimum losses in metal bins and pacci kothi as compared to those in the traditional storage structures and gunny bags and also found higher level of quality deterioration in the traditional storage structures.

6. SUMMARY

The results of the investigations conducted on the Bio-ecology and Management of *Corcyra cephalonica*Stainton under Sub humid Southern Zone of Rajasthan are summarized below.

Three quantitativesurvey were conducted on the *C. cephalonica* pest of stored maize during November-December 2010, February-March and June-July, 2011, from different storage structures in Rajsamand, Chittorgarh and Udaipur district of Sub-humid Southern Zone of Rajasthan. Among different surveys the maximum infested grain samples i.e. 8 out of 13 samples (61.53%) were recorded from loose storage during June-July, 2011. Whereas, the minimum infested grain samples i.e. 0.0 out of 19 samples (0.0%) were recorded from metal bin during November-December, 2010.During different surveys quantitative and qualitative losses (weight loss, mean germination per cent, protein content and carbohydrate content) were also observed. The maximum weight loss (7.46%) was recorded from loose storage in Udaipur district during June-July 2011 and the maximumgermination (78.00%)andprotein content(8.60%) were recorded from metal bin in Chittorgarh district. The maximum carbohydrate content (72.00%) was recorded from metal bin in Rajsamand district during November-December 2010.The no weight loss was recorded from metal bin in Chittorgarh and Udaipur district during November-December 2010. The minimum germination and carbohydrate content i.e. 62.00 and 66.50 per cent, respectively, were recorded from loose storage in Udaipur district whereas, protein content (6.70%) was recorded from loose storage in Chittorgarh district during June-July 2011.

The comparative effect of different hosts *viz.*, maize, sorghum, rice, wheat, pearlmillet, oat, and groundnut on the developmental parameters of *C.cephalonica* was studied. The minimum hatching period(4.25days) was observed on pearlmillet and maize and maximum on groundnut (5.50 days). The minimum larval period of 32.50 days was recorded on pearlmilletand maximum was on oat i.e. 45.25 days, whereas the maximum larval weight was recorded with pearlmillet(52.25 mg) and minimum on oat (38.50 mg). The minimum and maximum pupal period of 9.50 and 11.25 days was recorded on pearlmillet and oat, respectively.While maximum pupal weight was recorded on pearlmillet 38.50 mg and minimum on oat i.e. 32.00 mg. The

maximum adult emergence was recorded on pearlmillet79.00 per cent and minimum on groundnut 65.00 per cent. The Growth Rate Index was maximumon pearlmillet (1.71) and minimum was on groundnut (1.07). The maximum number of eggs were laid by female when reared on maize (302.50) and minimum on groundnut(225.50). In case of adult longevity the maximum longevity period of female was recorded on wheat (7.25 days) and minimum on sorghum (4.50days); whereas the maximum adult male longevity was recorded on pearlmillet (10.25 days) and minimum was on sorghum (8.00 days). The minimum developmental period was recorded on pearlmillet(46.25 days)and maximum was on oat (61.25 days).

The effect of temperature and relative humidity on bio-ecology of *C. cephalonica* was studied. The maximum development period of male and female i.e. 84.60 and 87.53 days were recorded at 20°C and minimum 40.00 and 42.83 days was at 40°C temperature, respectively. In case of relative humidity the male and female took maximum i.e. 64.40 and 67.13 days to complete their development at 40 per cent relative humidity and it was minimum of 49.30 and 52.57 days at 80 per cent relative humidity, respectively.Thecombined effect of temperature and relative humidity where the minimum development period of male and female were 33.70 and 31.30 days, respectively, at 40°C temperature and 80 per cent relative humidity. Whereas, the maximum development period of male and female i.e. 89.50 and 92.00 days, respectivelywere recorded at 20°C temperature and 40 per cent relative humidity.The larval period of test insect varied with the temperature and relative humidity. The larva period was maximum of 63.73 days at 20°C and it was minimum of 33.90 days at 40°C temperature. While the test insect took maximum 57.05 days to complete their larval period at 40.per cent relative humidity and minimum 38.60 days was at 80 per cent relative humidity. The combined effect of temperature and relative humidity where the minimum larval period (22.70 days) was recorded at 40°C temperature and 80 per cent relative humidity, whereas, the maximum larval period of *C. cephalonica* (70.10 days) was recorded at 20°C temperature and 40 per cent relative humidity.

The larval weight found to be highest (46.33 mg) when the insect was reared at 30°C and lowest larval weight (37.00 mg) was observed at 20°C temperature. The maximum larval weight (44.67 mg) was recorded at 80 per cent relative humidity and minimum (38.33 mg) was observed at 40 per cent relative humidity. Most suitable combination of temperature and relative humidity for weight of full grown larva was

30° C temperature and 80 per cent relative humidity on which maximum weight (51.00 mg) and lowest larval weight (33.00 mg) was observed at 20° C temperature and 40 per cent relative humidity. The pupal period of male and female was found maximum of 12.30 and 13.40 days at 20°C and minimum of 9.27 and 10.50 days at 30°C temperature, respectively. In case of relative humidity the male and female took maximum 11.67 and 12.60 days at 40 per cent relative humidity and minimum of 9.80 and 10.78 days were observed at 80 per cent relative humidity, respectively. Combined effect of temperature and relative humidity where the maximum pupal period of male and female i.e. 13.60 and 14.40 days was observed at temperature 20°C and 40 per cent relative humidity, respectively,whereas, the minimum pupal period of male and female of 8.40 and 9.85 days was recorded at 30°C temperature and 80 per cent relative humidity, respectively.

The pupal weight of male and female was highest with a mean of 33.00 and 35.67 mg when the insect was reared at 30°C and it was lowest of 23.00 and 25.67 mg at 20°C temperature, respectively.The mean pupal weight of male and female were maximum of 31.00 and 33.33 mg at 80 per cent relative humidity and was minimum i.e. 26.00 and 28.33 mg at 40 per cent relative humidity, respectively. The most suitable combination for gaining the higher weight of male and female pupa was30°C temperature and 80 per cent relative humidity at which maximum weight of 36.00 and 38.00 mg were recorded, respectively, whereas lowest pupal weight of male and female pupa i.e. 21.00 and 23.00 mg were observed at 20° C temperature and 40 per cent relative humidity, respectively.The maximum adult emergence of male and female was recorded as53.40 and 72.90 per centwhen insects were reared at 30°C and minimum adult emergence 39.73 and 60.67 per cent were observed at 20°C temperature, respectively. In case of relative humidity the maximum adult emergence of male and female 52.82 and 71.92 per cent were at 80 per cent relative humidity and it was minimum 40.23 and 59.20 per cent at 40 per cent relative humidity, respectively. A combination of 30°C temperature and 80 per cent relative humidity was most suitable at which maximum adult emergence of male and61.40 and 80.90 per cent were observed. Theminimum adult emergence 35.10 and 54.90 per cent were observed at 20°C temperature and 40 per cent relative humidity, respectively.

The maximum longevity of male and female was 12.83 and 9.92 days at 20°C temperature. The minimum longevity of male and female adults was 3.16 and 2.99

days, at 40°C temperature. Themaximum longevity of male (8.89 days) and female (6.30 days) was observed at 40 per cent relative humidity; whereas minimum longevity of male (6.32 days) and female (5.60 days) at 80 per cent relative humidity. A combination of 20°C temperature and 40 per cent relative humidity was suitable at which maximum adult longevity of male (16.30 days) and female(10.50 days) were observed. Theminimum adult longevity of 3.05 (male) and 2.81(female) days were observed at 40°C temperature and 80 per cent relative humidity.The growth rate index was maximum of male (1.35) and female (1.64) at 30°C temperature and was minimum of 0.47 (male) and 0.70 (female) at 20°C temperature. The maximum growth rate index of male (1.27) and female (1.57) was recorded at 80 per cent relative humidity and minimum i.e. 0.68 (male) and0.95 (female) were observed at 40 per cent relative humidity. A combination of 30°C temperature and 80 per cent relative humidity was suitable at which maximum growth rate index of male (1.35) and female (1.64) recorded.The minimum growth rate index 0.39 and 0.60 were observed at 20°C temperature and 40 per cent relative humidity for male & female, respectively.

All grain protectants were found significantly superior over control the efficacy of different grain protectants increased with the increase in the days of release. The highest larval mortality (82.20%) pupal mortality (10.00%) and minimum adult emergence (6.00%) were recorded with neem leaf powder @ 10g/kg of seed, after 40 days of release.The minimum larval mortality (55.55%), pupal mortality (6.67%) and highest adult emergence (33.33%) were recorded with wood ash @ 15g/kg of seed, after 40 days of release. Five varieties viz., pratap makka-3, PEHM-2, aravali makka-1, pratap hybrid maize-1 andsathi of maize were evaluated against *C. cephalonica* for developmental period, adult emergence and weight loss under laboratory conditions. Among testedvarieties none of the variety was found free from infestation. The maximumdevelopment period (68.00 days), minimum adult emergence (62.50 days) and weight loss (18.50%)were observedon pratap hybrid maize-1.Whereas, the minimum development period (56.00 days), maximum adult emergence (85.00%) and weight loss (28.50%) were observed on variety sathi. The variety pratap hybrid maize-1, pratap makka-3 were found least susceptible, whereas aravali makka-1 and PEHM-2 found moderately susceptible and sathi was reported more susceptible variety of maize.Five storage structures viz., earthen pots, metal bin,

gunny bags, earthen kothi and pusa bin were evaluated for their effectiveness on the basis of quantitative losses. The minimum quantitative losses were recorded in pusa bin upto 120 days of storage. While; the maximum quantitative losses were observed in gunny bags upto 120 days of storage.

Table: 4 Survey of storage structures with respect to infestation of *C. cephalonica in maize* during November-December 2010

Districts	Villages	Storage structures			
		Gunnybags	Metal bin	Kucchikothi	Loose storage
Rajsamand	Jitawas	6 (1)	0	2	2
	Badarda	3	2	2 (1)	3
	Bhana	2	2	3	3 (1)
	Kanusa	4	1	3	2
	Gawar	4	0	1	5
Chittorgarh	Soniana	4	1	2	3 (1)
	Morvan	4	2	1	3 (1)
	Budhpura	2	2	1	5 (1)
	Arni	4	1	2	3
	Bansi	5 (1)	1	1	3
Udaipur	Bamnia	3	1	4 (1)	2
	Changeri	2	2	1	5 (1)
	Ladani	3	1	2	4
	Gadawat	5 (1)	2	1	2
	Boria	3	1	3	3
Total		54 (3)	19 (0.0)	29 (2)	48 (5)
Per cent		5.56	0.00	6.90	10.42

Figure in parenthesis shows the number of samples infested by *C. cephalonica*

Table: 5 Survey of storage structures with respect to infestation of *C. cephalonica in maize* during February-March 2011.

Districts	Villages	Storage structures			
		Gunny bags	Metal bin	Kucchikothi	Loose storage
Rajsamand	Jitawas	3 (1)	3	3	1 (1)
	Badarda	2	4	1	3 (1)
	Bhana	2	3	4 (1)	1
	Kanusa	3 (1)	2	3	2 (2)
	Gawar	4	2	2	2 (1)
Chittorgarh	Soniana	2	3(1)	3(1)	2 (1)
	Morvan	4 (1)	2	4(1)	0
	Budhpura	3	2	3	2 (2)
	Arni	3	4 (1)	2	1
	Bansi	4 (1)	2	3(1)	1
Udaipur	Bamnia	2	4 (1)	2	2 (1)
	Changeri	3	3	2(1)	2
	Ladani	2 (1)	4	2	2 (1)
	Gadawat	4 (2)	4	1	1 (1)
	Boria	3 (1)	2	3(1)	2
Total		44 (8)	44 (3)	38 (6)	24 (11)
Per cent		18.18	6.81	15.79	45.83

Figure in parenthesis shows the number of samples infested by *C. cephalonica*

Table: 6 Survey of storage structures with respect to infestation of *C. cephalonica in maize* during June-July 2011

Districts	Villages	Storage structures			
		Gunny bags	Metal bin	Kucchikothi	Loose storage
Rajsamand	Jitawas	2 (1)	5 (2)	3 (1)	0
	Badarda	1(1)	4 (1)	4	1 (1)
	Bhana	2 (2)	3	5 (1)	0
	Kanusa	3 (1)	4	2 (1)	1
	Gawar	2 (1)	4 (1)	2	2 (2)
Chittorgarh	Soniana	2 (1)	2	6 (3)	0
	Morvan	3	4 (1)	3	0
	Budhpura	2 (1)	3	4 (1)	1 (1)
	Arni	3 (1)	2	5 (2)	0
	Bansi	2	6 (2)	2	0
Udaipur	Bamnia	1 (1)	2	5 (2)	2 (1)
	Changeri	3 (2)	3	2 (1)	2
	Ladani	2 (1)	3 (1)	3	2 (1)
	Gadawat	3 (2)	3 (1)	3 (1)	1 (1)
	Boria	3 (1)	2	4 (1)	1 (1)
Total		34 (16)	50 (9)	53 (14)	13 (8)
Per cent		47.06	18.00	26.42	61.53

Figure in parenthesis shows the number of samples infested by C. *cephalonica*

Table: 7 Weight loss in stored maize grain during different surveys in three districts of Southern Rajasthan during 2010-2011

Districts	Storage structures	Weight loss (%)		
		Surveys		
		Ist (Nov.-Dec.)	IInd(Feb.-March)	IIIrd(June-July)
Rajsamand	Gunny bags	0.50(4.05)	0.90(5.44)	3.06(10.07)
	Metal bin	0.20(2.56)	0.40(2.56)	0.42(3.71)
	Kucchikothi	0.40(3.63)	0.50(4.05)	1.92(7.96)
	Loose storage	0.60(4.44)	1.40(5.13)	5.40(13.44)
	Mean	0.43(3.74)	0.80(5.13)	2.70(9.46)
Chittorgarh	Gunny bags	0.40(3.63)	1.00(4.44)	2.04(8.21)
	Metal bin	0.00(0.00)	0.30(3.14)	0.40(3.63)
	Kucchikothi	0.00(0.00)	0.40(3.63)	1.04(5.85)
	Loose storage	0.50(4.05)	1.10(6.02)	5.30(13.31)
	Mean	0.23(2.72)	0.70(4.80)	2.20(8.52)
Udaipur	Gunny bags	0.35(3.39)	1.00(5.74)	4.42(12.14)
	Metal bin	0.00(0.00)	0.40(3.63)	0.48(3.97)
	Kucchikothi	0.20(2.56)	0.90(5.44)	1.82(7.75)
	Loose storage	0.45(3.85)	1.30(6.55)	7.46(15.85)
Mean		0.25(2.87)	0.90(5.44)	3.55(10.85)
S.Em.±		0.035	0.046	0.066
CD (P=0.05)		0.102	0.133	0.194

Figure in parenthesis are angular transformed values.

Table: 8 Effect of seasons on meangermination per cent of maize grain stored in different storage structures in three districts of Southern Rajasthan during 2010-2011

Districts	Storage structures	Germination (%)		
		Surveys		
		Ist (Nov.-Dec.)	IInd(Feb.-March)	IIIrd(June-July)
Rajsamand	Gunny bags	74.00(58.05)	69.00(56.22)	67.00(54.96)
	Metal bin	77.00(61.53)	74.00(62.24)	72.00(58.12)
	Kucchikothi	75.00(56.85)	70.00(56.79)	69.00(56.21)
	Loose storage	71.00(56.17)	68.00(55.55)	66.00(54.33)
	Mean	74.25(59.51)	70.25(56.95)	68.50(55.86)
Chittorgarh	Gunny bags	72.00(56.17)	70.00(56.79)	66.00(54.33)
	Metal bin	78.00(62.05)	75.00(61.36)	73.00(58.70)
	Kucchikothi	73.00(58.70)	71.00(57.43)	70.00(56.80)
	Loose storage	68.00(55.55)	68.00(55.55)	67.00(54.94)
	Mean	72.75(58.53)	71.00(57.42)	69.00(56.17)
Udaipur	Gunny bags	70.00(56.79)	68.00(55.55)	66.00(54.33)
	Metal bin	78.00(62.44)	74.00(59.36)	72.00(58.06)
	Kucchikothi	71.00(57.42)	70.00(56.80)	67.00(54.94)
	Loose storage	68.00(55.55)	67.00(54.94)	62.00(51.94)
Mean		71.75(57.89)	68.25(55.70)	66.75(54.79)
S.Em.±		1.495	1.109	0.781
CD (P=0.05)		4.363	3.236	2.278

Figure in parenthesis are angular transformed values

Table: 9 Effect of seasons on mean protein content of maize grain stored in different storage structures in three districts of Southern Rajasthan during 2010-2011

Districts	Storage structures	Protein content (%)		
		Surveys		
		Ist (Nov.-Dec.)	IInd(Feb.-March)	IIIrd(June-July)
Rajsamand	Gunny bags	7.50(15.89)	7.10(15.45)	7.00(15.34)
	Metal bin	8.10(16.31)	7.80(16.42)	7.50(16.89)
	Kucchikothi	7.90(15.99)	7.40(15.78)	7.30(15.68)
	Loose storage	7.40(15.78)	6.90(15.23)	6.80(15.12)
	Mean	7.73(16.14)	7.30(15.68)	7.15(15.51)
Chittorgarh	Gunny bags	8.10(16.54)	6.85(15.17)	6.80(15.12)
	Metal bin	8.60(17.05)	7.50(15.89)	7.40(15.78)
	Kucchikothi	8.20(16.64)	7.00(15.34)	6.90(15.23)
	Loose storage	8.10(16.53)	6.80(15.12)	6.70(15.00)
	Mean	8.25(16.69)	7.04(15.38)	6.95(15.29)
Udaipur	Gunny bags	7.80(16.22)	7.00(15.23)	6.75(15.06)
	Metal bin	8.10(16.53)	7.30(15.67)	7.25(15.62)
	Kucchikothi	7.90(16.32)	7.00(15.34)	6.85(15.18)
	Loose storage	7.60(16.00)	6.90(15.23)	6.80(15.12)
Mean		7.85(16.27)	7.05(15.40)	6.91(15.24)
S.Em.±		0.188	0.184	0.143
C.D. (P=0.05)		0.549	0.537	0.418

Figure in parenthesis are angular transformed values.

Table: 10 Effect of seasons on carbohydrate content of maize grain stored in different storage structures surveys in three districts of South Rajasthan during 2010-2011

Districts	Storage structures	Carbohydrate content (%)		
		Surveys		
		Ist (Nov.-Dec.)	IInd(Feb.-March)	IIIrd(June-July)
Rajsamand	Gunny bags	68.50(55.86)	67.80(55.43)	66.60(54.70)
	Metal bin	72.00(57.52)	70.00(56.88)	70.00(56.88)
	Kucchikothi	70.50(56.22)	69.00(56.22)	68.50(55.89)
	Loose storage	68.00(55.55)	67.20(55.06)	66.50(54.64)
	Mean	69.75(56.63)	68.50(55.86)	67.90(55.49)
Chittorgarh	Gunny bags	68.00(55.56)	67.80(55.43)	67.40(55.18)
	Metal bin	71.40(57.68)	69.80(56.92)	69.60(56.55)
	Kucchikothi	68.50(55.86)	67.80(55.43)	67.50(55.25)
	Loose storage	68.20(55.78)	67.70(55.33)	67.40(55.18)
	Mean	69.03(56.18)	68.28(55.72)	67.98(55.53)
Udaipur	Gunny bags	69.00(56.17)	67.50(55.24)	67.00(55.94)
	Metal bin	70.80(57.30)	69.50(56.49)	69.30(56.36)
	Kucchikothi	69.10(56.24)	68.00(55.56)	67.16(55.04)
	Loose storage	68.30(55.74)	67.00(54.94)	66.50(53.73)
Mean		69.30(56.35)	68.00(55.55)	67.49(55.24)
S.Em.±		0.586	0.423	0.465
C.D. (P=0.05)		1.710	1.235	1.357

Figure in parenthesis are angular transformed values.

Table: 11 Mean loss in weight (%), germination (%), protein content (%) and carbohydrate content (%) in maize samples drawn from different storage structures surveys in three districts of Southern Zone of Rajasthan

District	Surveys	Weight loss (%)	Germination (%)	Protein content (%)	Carbohydrate content (%)
Rajsamand	Ist (Nov.-Dec.)	0.43(3.74)	74.25(59.56)	7.73(16.14)	69.75(56.63)
	IInd(Feb.-March)	0.80(5.13)	70.25(57.00)	7.30(15.68)	68.50(55.86)
	IIIrd(June-July)	2.70(9.46)	68.50(55.86)	7.15(15.51)	67.90(55.49)
Chittorgarh	Ist (Nov.-Dec.)	0.23(2.75)	72.25(58.21)	8.25(16.69)	69.03(56.18)
	IInd(Feb.-March)	0.70(4.80)	71.00(57.42)	7.04(15.38)	68.28(55.72)
	IIIrd(June-July)	2.20(8.52)	69.00(56.17)	6.95(15.29)	67.98(55.53)
Udaipur	Ist (Nov.-Dec.)	0.25(2.87)	71.75(57.89)	7.85(16.27)	69.30(56.35)
	IInd(Feb.-March)	0.90(5.44)	68.25(55.70)	7.05(15.52)	68.00(55.55)
	IIIrd(June-July)	3.55(10.85)	66.75(54.79)	6.91(15.24)	67.49(55.24)
S.Em.±		0.049	0.876	0.156	0.268
C.D. (P=0.05)		0.146	2.603	0.462	0.780

Figure in parenthesis are angular transformed values.

Table: 12 Effect of different hosts on biology of *Corcyra cephalonica* Stainton

Hosts	Hatching period (days)	Larval period (days)	Larval weight (mg)	Pupal period (days)	Pupal weight (mg)	Adult emergence (%)	Growth rate index	Fecundity (No. of eggs/ female)	Adult longevity (days)		Development period (days)
									Male	Female	
Maize	4.25	41.50	46.00	9.50	36.00	78.00 (62.07)	1.41	302.50	9.75	5.25	55.25
Sorghum	4.50	40.75	46.75	9.75	37.00	76.00 (60.69)	1.38	292.50	8.00	4.50	55.00
Rice	4.75	42.50	43.00	10.25	34.00	68.00 (55.57)	1.18	231.00	8.50	6.25	57.50
Wheat	4.75	43.25	42.00	9.75	37.00	69.00 (56.18)	1.20	268.25	9.75	7.25	57.75
Pearlmillet	4.25	32.50	52.25	9.50	38.50	79.00 (62.75)	1.71	292.75	10.25	6.25	46.25
Oat	4.75	45.25	38.50	11.25	32.00	66.00 (54.34)	1.08	228.75	8.75	5.50	61.25
Groundnut	5.50	44.50	40.75	10.75	33.75	65.00 (53.74)	1.07	225.50	8.50	5.00	60.75
S.Em. ±	0.338	0.727	0.769	0.177	0.616	0.840	0.016	5.140	0.233	0.237	0.97
C.D. (P=0.05)	0.997	2.139	2.263	0.520	1.810	2.469	0.047	15.124	0.686	0.697	2.86

Data in parentheses are angular transformed values

Table: 13 Effect of temperature and relative humidity on the development of *C. cephalonica*

Relative humidity (%)	Developmental period (days)							
	Female				Male			
	Temperature (°C)			Mean	Temperature (°C)			Mean
	20	30	40		20	30	40	
40	92.00	56.30	53.10	67.13	89.50	53.40	50.30	64.40
60	90.30	36.56	44.10	56.99	87.40	35.10	36.00	52.83
80	80.30	46.10	31.30	52.57	76.90	37.30	33.70	49.30
Mean	87.53	46.32	42.83		84.60	41.93	40.00	
S.Em. ±	**0.877**				**0.876**			
C.D. (P=0.05)	**2.546**				**2.543**			

Table: 14 Effect of temperature and relative humidity on the larval period of *C. cephalonica*

Relative humidity (%)	Larval period (days)			
	Temperature (°C)			Mean
	20	30	40	
40	70.10	55.85	45.20	57.05
60	65.10	24.60	33.80	41.17
80	56.00	37.10	22.70	38.60
Mean	63.73	39.18	33.90	
S.Em. ±	**1.361**			
C.D. (P=0.05)	**3.949**			

Table: 15 Effect of temperature and relative humidity on weight of full grown larva of *C. cephalonica*

Relative humidity (%)	Weight of full grown larva (mg)			
	Temperature (°C)			Mean
	20	30	40	
40	33.00	42.00	40.00	38.33
60	38.00	46.00	41.00	41.67
80	40.00	51.00	43.00	44.67
Mean	37.00	46.33	41.33	
S.Em. ±	**0.726**			
C.D. (P=0.05)	**2.106**			

Table: 16 Effect of temperature and relative humidity on the pupal period of *C. cephalonica*

Relative humidity (%)	Pupal period (days)							
	Female				Male			
	Temperature (°C)			Mean	Temperature (°C)			Mean
	20	30	40		20	30	40	
40	14.40	11.29	12.10	12.60	13.60	10.30	11.10	11.67
60	13.50	10.35	11.30	11.72	12.10	9.10	10.30	10.50
80	12.30	9.85	10.20	10.78	11.20	8.40	9.80	9.80
Mean	13.40	10.50	11.20		12.30	9.27	10.40	
S.Em. ±	**0.205**				**0.187**			
C.D. (P=0.05)	**0.594**				**0.542**			

Table 17: Effect of temperature and relative humidity on pupal weight of *C. cephalonica*

Relative humidity (%)	Pupal weight (mg)							
	Female				Male			
	Temperature (°C)			Mean	Temperature (°C)			Mean
	20	30	40		20	30	40	
40	23.00	34.00	28.00	28.33	21.00	31.00	26.00	26.00
60	25.00	35.00	31.00	30.33	22.00	32.00	27.00	27.00
80	29.00	38.00	33.00	33.33	26.00	36.00	31.00	31.00
Mean	25.67	35.67	30.73		23.00	33.00	28.00	
S.Em. ±	**0.538**				**0.493**			
C.D. (P=0.05)	**1.560**				**0.142**			

Table: 18 Effect of temperature and relative humidity on the adult emergence of *C. cephalonica*

Relative humidity (%)	Adult emergence (%)							
	Female				Male			
	Temperature (°C)			Mean	Temperature (°C)			Mean
	20	30	40		20	30	40	
40	54.90 (47.81)	62.70 (52.36)	60.00 (50.77)	59.20 (50.31)	35.10 (36.33)	42.60 (40.74)	43.00 (40.98)	40.23 (39.34)
60	62.30 (52.13)	75.10 (60.08)	71.40 (57.69)	69.60 (56.63)	41.52 (40.12)	56.20 (48.56)	52.30 (46.32)	50.07 (45.00)
80	65.10 (53.80)	80.90 (64.09)	69.75 (56.63)	71.92 (58.17)	42.56 (40.72)	61.40 (51.59)	54.50 (47.58)	52.82 (46.63)
Mean	60.67 (51.25)	72.90 (58.84)	67.05 (55.03)		39.73 (39.05)	53.40 (46.97)	49.93 (44.96)	
S. Em. ±	**0.541**				**0.359**			
C.D. (P=0.05)	**1.570**				**1.041**			

Figure in parenthesis shows the angular transformed values of the respective values

Table: 19 Effect of temperature and relative humidity on adult longevity of *C. cephalonica*

Relative humidity (%)	Adult longevity (Days)							
	Female				Male			
	Temperature (°C)			Mean	Temperature (°C)			Mean
	20	30	40		20	30	40	
40	10.50	5.20	3.20	6.30	16.30	7.10	3.28	8.89
60	10.00	5.00	2.95	5.98	14.20	6.80	3.15	8.05
80	9.25	4.75	2.81	5.60	8.00	7.80	3.05	6.28
Mean	9.92	4.98	2.99		12.83	7.23	3.16	
S. Em. ±	**0.242**				**0.256**			
C.D. (P=0.05)	**0.701**				**0.744**			

Table: 20 Effect of temperature and relative humidity on Growth Rate Index of *C. cephalonica*

Relative humidity (%)	Growth Rate Index							
	Female				Male			
	Temperature (°C)			Mean	Temperature (°C)			Mean
	20	30	40		20	30	40	
40	0.60	1.11	1.13	0.95	0.39	0.80	0.86	0.68
60	0.69	1.85	1.78	1.44	0.48	1.60	1.45	1.18
80	0.81	1.96	1.93	1.57	0.55	1.65	1.62	1.27
Mean	0.70	1.64	1.61		0.47	1.35	1.31	
S.Em. ±	**0.018**				**0.017**			
C.D. (P=0.05)	**0.054**				**0.049**			

Table: 21 Relative efficacy of different grain protectants against *Corcyra cephalonica* Stainton

Treatments	Dose (g/kg.)	Per cent larval mortality at								Pupal mortality (%)	Adult emergence (%)
		5 DAR	10 DAR	15 DAR	20 DAR	25 DAR	30 DAR	35 DAR	40 DAR		
Neem leaf powder	10	49.33 (44.63)	55.13 (47.95)	77.77 (61.94)	77.77 (61.94)	79.46 (63.14)	82.21 (65.18)	82.21 (65.18)	82.21 (65.18)	10.00 (18.39)	6.00 (13.53)
Custard apple seed powder	10	44.00 (41.55)	46.57 (43.03)	76.30 (60.97)	76.30 (60.97)	76.32 (60.89)	76.35 (61.00)	76.35 (61.00)	76.35 (61.00)	8.00 (16.43)	13.33 (21.19)
Custard apple leaf powder	10	38.67 (38.45)	42.46 (40.67)	66.66 (54.73)	66.66 (54.73)	69.18 (56.28)	70.37 (57.02)	70.37 (57.02)	70.37 (57.02)	6.00 (14.15)	20.67 (27.03)
Diatomaceous earth	15	46.00 (42.31)	49.66 (44.80)	76.30 (60.87)	76.30 (60.87)	77.40 (61.62)	77.78 (61.88)	77.78 (61.88)	77.78 (61.88)	8.00 (16.41)	12.00 (20.23)
.Fly ash	15	45.32 (42.31)	48.29 (44.02)	73.33 (58.91)	73.33 (58.91)	74.34 (59.57)	74.81 (59.87)	74.81 (59.87)	74.81 (59.87)	7.00 (15.34)	15.67 (23.32)
Wood ash	15	21.33 (27.50)	21.92 (27.91)	50.45 (45.26)	50.45 (45.26)	51.11 (45.64)	55.55 (48.19)	55.55 (48.19)	55.55 (48.19)	6.67 (14.95)	33.33 (35.26)
Control		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	90.00 (71.57)
S.Em. ±		0.586	0.826	1.078	1.070	1.102	1.149	1.148	1.148	0.520	1.589
C.D. (P=0.05)		1.779	2.505	3.269	3.246	3.343	3.485	3.482	3.482	1.576	4.822

Data in parentheses are angular transformed values
DAR- Days after release

Table: 22Screening of maize varieties against *Corcyra cephalonica* Stainton

Treatments	**Developmental period (days)**	**Adult emergence (%)**	**Weight loss (%)**
Pratap makka -3	65.00	65.25 (53.89)	20.50 (26.91)
PEHM -2	59.00	71.00 (57.43)	22.75 (28.48)
Arawalimakka -1	60.00	70.00 (56.81)	22.00 (27.97)
Pratap hybrid maize -1	68.00	62.50 (52.24)	18.50 (25.47)
Sathi (local)	56.00	85.00 (67.27)	28.50 (32.26)
S.Em. ±	1.08	0.82	0.39
C.D. (P=0.05)	3.27	2.46	1.19

Data in parentheses are angular transformed values

Table: 23 Estimation of losses caused by *Corcyra cephalonica* Stainton under different storage structures

Treatments	**Quantitative losses in maize grain (%)**			
	30 days	**60 days**	**90 days**	**120 days**
Earthen pots	1.25 (6.34)	5.00 (12.99)	8.25 (16.68)	11.25 (19.59)
Metal bin	0 (0)	0 (0)	0.25 (1.43)	0.50 (2.87)
Gunny bags	2.00 (8.13)	7.75 (16.16)	11.50 (19.82)	14.00 (21.97)
Earthen kothi	0.75 (4.97)	4.50 (12.25)	7.50 (15.89)	10.50 (18.90)
Pusa bin	0.00 (0)	0.00 (0)	0.20 (2.56)	0.44 (3.80)
S.Em. ±	0.10	0.14	0.56	2.87
C.D. (P=0.05)	0.31	0.41	1.69	8.66

Data in parentheses are angular transformed values

Table 24: Rate of quantitative loss by *C. cephalonica* in stored maize grains under different storage structures

Storage structures	Weight loss	
	Correlation coefficients	Regression equation
Earthen pots	0.999**	Y= - 1.875 + 0.111 X
Metal bin	0.944**	Y= 0.250 + 0.006 X
Gunny Gunny bags	0.984**	Y= - 1.125 + 0.133 X
Earthen kothi	0.998**	Y= -2.250 + 0.108 X
Pusa bin	0.938**	Y= -0.220 + 0.005 X

** Significant at 1 % level

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