Chapter-V

DISCUSSIONS

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5.1 Occurrence of insect pests, nature of infestation and their bio-control agents

Storage facilities at the village and assembling centre is still very poor. At the farm level the big growers store pulses in 'gola' made of bamboo and mud. The small and marginal farmers have no storage facilities due to which they forced to sell the produce immediately after harvest. The farmers of Terai Agro-ecological region West Bengal, India do not find any impetus for large scale production of pulses due to poor storage facility and suitable safe management. This becomes possible by undertaking a survey which involves the identification of the different species occurring over an area. India (8^0 - 30^0 North and 60^0 -97.5^0 East) has been recognized as one of the worlds' top mega-diversity nation and is very rich in faunal wealth. It has nearly 75,000 animal species where 80% of are insects (Agarwal,1999). The coleopteran includes some 2,50,000 species of beetles and weevils. Approximately 1,02,000 species of hymenopterans have been recorded and some 50% of these, primarily wasps, are parasitic (Narendran, 2001).The country demanded a clear comprehensive bio-safety under the conversions on biodiversity particularly, which are potential economic and scientific value. Insect pest and natural enemies of stored pulse of this Agro-ecological Region is still unexplored. The main objective of survey is to record different species of pests and their parasitoids on stored pulses, assess the levels of damaged of the pests, study the biological control potentiality of the natural enemies to define new species of pests and their control agents, marked endemic areas (here different district under Terai region) and finally launch timely protection measures.

The main objectives of pest survey is to detect species of pest on storage pulses and their natural enemies, assess the levels of infestation caused by the the pests, know new species of pests and their control agents. Another bruchid pest, *C. analis* which have already been reported from different countries likely India, (Lafrey,1909) island group of pacific (Archibald,1988), Kenya (Warni, 1984), Burma (Ghosh, 1939), Germany (Zascher, 1930), South Africa (Evans, 1939), Japan (Miyake, 1939), Bangladesh (Begum et al, 1984), Bulgaria (Sodomov, 1984), Australia (Whightman *et al*, 1982) South Africa (Evans,1939) and South Rodesia (Jack, 1936) but still it is not a dominant pest of storage pulses like *C. chinensis and C. maculatus.* Common and almost cosmopolitan insect pests of storage pulse namely *C. chinensis* Linn. is found to the most destructive pests of legume seeds like other countries including India as reported previously by Goncalves (1939), Colderon (1958), Morimota (1939), Pruthi and Singh (1950), Raina (1970), Southgate (1982) and many others. This species caused damaged to almost all pulses, which are cultivated locally except soybean, French bean, field pea and black gram (Table 2). The pea beetle, *Callosobruchus (=Bruchus) pisorum* Linn. was also recorded only on pea and their infestation occurred in the field and adult emerged out after few months in the storehouses. The insect, however, couldn't complete its life cycle in stored peas (Arora , 1977). Bruchids are an interesting world widely distributed group, most abundant in the tropics, whose larvae develops inside seeds, most preferred hosts belonging to the leguminous family and all together other 24 families have been recorded as host by Southgate (1978). Approximately 1300 species of bruchids have been recorded, mostly attack the growing crops, but they get carried into stores in the ripe pods and seeds and some species are successfully able to continue their development in the dry seeds (Hill, 1990). The Pulses are badly damaged by pulse beetles of the genus *Callosobruchus* (Coleoptera: Bruchidae) during storage throughout the world and this discourages the poor farmers from large-scale production and storage of pulses. In India, stored pulses are damaged by pulse beetles such as *C. chinensis* Linn.,*C. maculatus* Fab., *C. analis* Fab., *C. affinis* Frol., *C. emerginatus* All., *C. phaseoli* Gyll., *C. albacallosus* Pic., and *C. pisorum* Linn. Among these, *C. chinensis* is the most serious pest in India and also abroad.

The common and most destructive bruchid pest of stored pulses in India found to be *C. chinensis* (Goncalves, 1934; Colderon, 1958; Pruthi and Singh, 1950; Raina, 1970; Southgate, 1982 and many others). It is almost cosmopolitan and globally distributed. This species is distributed to all the districts of this region and egg-infestation occurred on green gram, grass pea, cow pea, lentil, black gram, chick pea, thakri kalai, pea, moth bean, horse gram, soy bean, kidney bean and small pea (Table 1). It caused damage to almost all the important pulses cultivated locally except the soybean, kidney bean and small pea. Black gram (*Vigna mungo*) and thakri kalai (*V. mungo silvestris)* is susceptible to this pests.

Another bruchid pest, *C. analis* which have already been reported from different countries likely Indian (Lefroy, 1909), Bangladesh (Begum *et al.,* 1984), Burma (Ghosh, 1937), Japan (Miyake, 1939), South Africa (Evans, 1939), Germany (Zachir, 1930), Australia (Whightman *et al.,* 1982), Kenya (Warni, 1984), Bulgeria (Sadonov, 1984) and South Rhodesia (Jack, 1936) but still it is not a notorious pest like *C. chinensis.* No mution of this species from terai region and from North Eastern part of India is found in the literature. During the survey it has observed that the beetle could not damage red gram, horse gram, chick pea, lentil, pea, cow pea, grass pea, soybean, kidney bean, moth bean and small pea (Table 9). They preferred to oviposit on the stored pulses – and damaged green gram, black gram and thakri kalai mostly in the indigenous store houses of this area.

C. maculatus is wide spread almost throughout the world and now almost cosmopolitan insect pest of stored pulses like *C. chinensis*. It was also reported from soybean (Howe and Currie, 1964) and kidney bean (Edward *et al.*, 1973). Oviposition and development of *C. maculatus* on nine legume seeds was studied during a survey in the Central part of India by Roy and Roy (1994). Chick pea is found to be most preferred followed by green gram, cow pea, lentil and red gram only. In the present survey, the occurrence of *C. maculatus* restricted only in Siliguri sub-division of Darjeeling and Islampur sub-division of Uttar Dinajpur only (Table 8). It is not a serious pest of stored pulses like that of *C. pisorum, Sitophilus* sp., *Corcyra cephalonica* and mention to be the minor pests of stored pulses. Pea beetle, *C. pisorum* has been collected only from pea seed and their biology could not evaluate in the laboratory. The infestation occurred in the field and adult emerged out in the laboratory. It is very uncommon race and host specific pest of peas in fields and distribution restricted to India (Arora, 1977), Russia, U.S.A., Africa (Smith *et al.*, 1982) and Bulgaria (Sadomov, 1988). All pests mentioned here are not reported previously from this region and no such extensive survey on stored pulses was done previously in North Eastern part of India.

A large number of biological control agents were collected but only few were identified till today. Among the natural enemies of stored pulses *Dinarmus vagabundus* and *Dinarmus* sp. (Hymenoptera: Pteromalidae), *Uscana mukerjii* (Hymenoptera : Trichogrammatidae), *Cerocephala dinoderi* (Hymenoptera : Pteromalidae) and *Bracon* sp. (Hymenoptera : Braconidae) have been recorded. *D. vagabundus, Dinarmus* sp. and *U. mukerjii* were the key parasitoids of bruchid pests whereas *C. dinoderi* and *Bracon* sp. were the minor parasitoid of *Sitophilus* sp. and *C. cephalonica* respectively. *Dinarmus vagabundus* was recorded as an important, gregarious larval-pupal ectoparasitoid of bruchid pests. Furthermore, *Uscana mukerjii* was a very minute, rare solitary potent egg parasitoid of bruchids (Mani, 1989 and Pajni *et al*,1976). These two are naturally occurring key parasitoids of Terai Agro-ecological Region of West Bengal, India.

The bio-control agent *Dinarmus vagabundus* (Hymenoptera : Pteromalidae) is a gregarious ecto-parasitoid of bruchid pests (Kundra, 1976) and their abundance is restricted to Hawaii Island of U.S.A., Brazil, India, Sri Lanka, Pakistan and French only (Timberlake, 1926; De Luca, 1966; Mani, 1939 and Rojas *et al.*, 1988). It was only reported from Northern zone of India and southern zone of India as a potential peresitoid of bruchids (Mani, 1989).

Cerocephala diondiri Gahan (Hymenoptera: Pleromalidae) is found once during the study and is a minor bio-control agent of stored pulses. *Bracon* sp. (Hymenoptera: Bracohidae) is also a minor control agent because *Corcyra cephalonica* rarely infested pulses (Baker *et al.*, 1995). *Uscana* *mukerjii* (Hymenoiptera : Trichogrammatidae) is a solitary potential egg parasitoid of bruchids (Pajni *et al.,* 1996) and appears to be a naturally occurring bruchids infesting stored pulses in this area. All the bio-control agents of stored pulses infesting different pests are reported for the first time from this agro-climatic region of W.B., India. Among them *Uscana mukerjii* and *Dinarmus vagabundus* was previously reported as potential parasitoids of bruchid insect pests.

5.2. Studies on bio-ecology of *Callosobruchus chinensis* on green gram (*Vigna radiata*) in the laboratory

The safety of storage from pulses depends on proper maintenance of room temperature and humidity. All these two abiotic factors are needed for the growth and development of bruchid pests. The fecundity of *C. chinensis* tends to increase from the period January- February. A study increase is maintained till July- August generation followed by a noticeable decline in fecundity in the next generation of August-September and ending at the generation of September- October the fecundity is minimum in the area of study. Obviously the population build up during the period of minimum fecundity can be arrested at a subthreshold level by adopting suitable control measure.

Hatchability percentage has been declined during June-September which is the rainy season and relative humidity has been the highest (above 80%) at this time. The correlation studies also proved that hatchability has a highly significant positive correlation with rrelative humidity. The emergence of adult also shows a some what similar kind of result although the best suitable months for the emergence of adults are November to May (r.h. was above 40%). The moisture above 80% disrupts the development of the beetle. The sex-ratio differs in different months, an almost 1 : 1 ratio was observed in January-February and July-August. Number of male adults emerged out were noticed to be higher than female except June-July, August-October and November-December (1994) studied the sex ratio in Bangladesh which was recorded 1 : 1. He could not mention the environmental conditions of that area.

The present investigation has been carried out round the year in the laboratory where temperature (°C) and relative humidity (%) varied in different seasons. Rearing protocol in the laboratory remained the same except the natural variations of temperature and relative humidity. Therefore, the differences in respect of the life history criteria of different generations in a year have been influenced by prevailing temperature and humidity. This observation is corroborates somewhat with Han and An (1990) and Pandey and Singh (1997). Han and An (1990) studied the bio-ecology of *C. chinensis* in Korea. The developmental duration increased as temperature decreased from 30 to 20°C. There were 4 generations in a year, with peak adult emergence in

May and over wintering took place in stored pulses. Pandey and Singh (1997) studied the biology of *C. chinensis* on *Vigna mungo* and *Cicer arietinum*. The incubation period lasted for 4-5 days and combined larval-pupal period for 20-28 days where temperature was $28^0C \pm 5$. *C. chinensis* is polygamous. The adult male mated several times (Begum *et al.*, 1987). The mated females started egg laying within 6-12 hours and usually laid single egg on single green gram seed when the seeds are sufficient in number (Utida, 1942).

Ovipositional period, incubation period, combined larval-pupal period, developmental period and life span of adult beetles varied significantly in different months. No such work on the biological periods has been periods were increased as temperature decreased (Parajulee *et al.*, 1989). Incubation period (9-12 days), larval-pupal period (34-37 days) and developmental period (43-51 days) was observed to be prolonged during January-February (Winter) followed by November to December (Winter) in this area. Shortest period of incubation, larval-pupal and developmental was observed during May (summer) followed by April-May (summer) and June-July (rainy season). Rajak and Pandey (1965) reported that the life cycle varied from season to season of with minimum 27 days and maximum 114 days. Moreover, the grabs hibernated during winter months from November-February. All mentioned parameters in this study are negatively correlated and developmental period was highly significant with both temperature and relative humidity (Table 13). Significant variations in the above mentioned biological parameters during different months might be due to climatologically differences especially temperature and relative humidity in the laboratory.

Information on growth index (GI) of the *C. chinensis* is not available for any month/season and from any area/place. As rebealed from growth index data provided in Table 11, the favourable environmental conditions for *C. chinensis* infestation has been March-May (1.83-2.19) (summer) followed by October-November (1.38) respectively. The number of generations of *C. chinensis* completed in a year is eleven. However, Parajulee *et al.* (1989) have recorded 13 overlapping generation/year at Chitwan district of Nepal. Han and An (1990) have obtained only 4 generations in a year in Central Korea where temperature ranged 12-30^{0}C. In the present area of study the optimum temperature (23.97-30.55^{0}C) and r.h. (52.11-68.91) for fecundity and development of *C. chinensis* was appeared to be during March-April (summer). Lhaloui *et al.* (1988) recommended optimal temperature for fecundity and development of stored product insect ranged 25-30^{0}C. Prevailing temperature (26.26-30.42^{0}C) as well as r.h. (72.11-85.21%) during rainy season of this area was not susceptible for the growth and development of *C. chinensis*. Atmospheric humidity during these periods (June-October) is considerably higher in comparison to that of other months. Humidity and grain moisture contents are closely related factors. Even though stored green gram seeds are dried to reach the safe moisture level before storage, moisture content in due course comes to equilibrium with humidity in the air.

5.3. Studies on bio-ecology of *Callosobruchus analis* on green gram (*Vigna radiata*) in the laboratory

Biology of *C. analis* is less known from the works of few researchers namely de Luca (1965), Howe and Currie (1964), Begum *et al.* (1984), Sadomov (1984) and Singh and Pandey (1997). Its distribution is still restricted to few countries and biology in relation to climatic condition is the warrant of research.

It is evident from Table 11 that the growth and development was somewhat similar to *C. chinensis* (De Luca, 1965). Total generation in a year has been noticed to be twelve. After the termination of over wintering of ovipositional, incubation, combined larval-pupal and development period was investigated during November-April, where March and April is the summer of this area. The rainy season favours the expeditions development as is evident from the developmental period (June-July). Both temperature and r.h.(%) have a highly significant positive correlation. Oviposition period, combined larval-pupal period, hatching (%) and longevity of adults show a negative correlation and significant with both temperature and relative humidity. Incubation period has a significant correlate but non-significant to r.h. (%). The fecundity is positive but non-significant. The growth and development (G.I.) have a positive correlation with temperature and negatively correlated with the r.h. (%). Adult emergence of this beetle also shows similar trend of result (Table 11). De Luca (1965) advocated that the biology of *C. analis* is similar to *C. chinensis*. Population of *C. analis* has been found to attain its optimum intrinsic rate 59-63% (Table 11) during summer (March-April) and minimum rate has noticed to be 9-13% during July-August which is the rainy season of this area. Growth index of *C. analis* also corroborates a somewhat simmilar observation. Longevity of adult male beetle is always higher than female in every generation. Sex ratio (female: male) is almost 1: 1 during the period of investigation. Optimal temperature prevails (27.12-28.39^{0}C) and r.h. (54.31-65.03%) was recorded for their growth and development during March-April. Most unfavourable temperature (28.56-30.09^{0}C) and r.h. (79.25-81.72%) has been recorded July-August which is the rainy season of this area. Heavy rain and humid atmosphere (**Appendix VI**) of this area hampered their biological activity. The present investigation is not coinciding with Begum *et al.* (1984).

5.4. Host preference and relative susceptibility of *C. chinensis* and *C. analis* to fourteen different species of stored pulses.

In free choice test, it appeared that both the species prefer to oviposit on seeds during summer in the following order green gram > red gram > pea > small pea > black gram > cow pea > soybean > moth bean > thakri kalai > grass pea > Bengal gram > kidney bean > lentil >

horse gram. Almost a similar result has been obtained during winter (Table 17). Among the host species, horse gram and lentil are the least preferred host of both the species. Observation made by Singh *et al.* (1980) was somewhat similar to the present study. Mehata and Chandel (1970) studied the host preference of *C. analis* to ten different species of stored pulses. The highest numbers of eggs were laid on cowpeas, followed by peas, green gram and black gram and a few on kidney bean, soybean, split gram and horse gram. No eggs laid were laid chick pea and lentil. The authors did not refer to the environmental condition or season of the study. Percentage of adult emergence of both the species differs significantly in respect of pulse species during summer and winter. Maximum emergence of adult beetles occurs during summer which is the suitable season than the winter. Emergence of *C. chinensis* and *C. analis* has been the highest from cowpea and the least from thakri kalai (*V. mungo silvestries*) and pea. A mere or less result has also been observed during winter also (Table 18). Both the species are unable to complete their growth and development in the soybean, kidney bean and small pea (Srivastava and Pant, 2000). It is to be mentioned that black gram (*V. mungo*) and thakri kalai (*V. mungo silvestries*) which are locally cultivated, are susceptible to *C. chinensis* whereas lentil of this area is also susceptible to *C. analis*. On the who;e, soybean, kidney bean and small pea are highly susceptible to both the species.

In case of no choice test, it has been observed that during summer *C. chinensis* lays the highest number of eggs on green gram and the lowest on kidney bean. Both the species lay maximum number of eggs during summer. Green gram is the most preferred host while least preferred host of both the species is kidney bean. However, both the species are unable to complete their life cycle on soybean, kidney bean and small pea as is evident from the total absence of adult emergence.

Ovipositional performance of *Callosobruchus* spp. on pulse species has been attributed to the seed weight (Raghupathi and Rangaswami, 1970), texture, color and shape (Gupta and Sehgal, 1987). *C. chinensis* can not cause damage soybean, horse gram, small pea and black gram whereas *C. analis* could not damage soybean, kidney bean, small pea and lentil (Fuji *et al.,* 1989). Singh *et al.* (1995) evaluated the effect of various bio-chemicals such as high protein, oil, starch and ash present in the seeds. Correlation studies of both the oil and starch with fecundity observed to be positive and highly significant where protein content was negatively correlated and highly significant. Contents of sugars and ash showed no significant correlation with fecundity. Lambrides and Imrie (2000) studied the susceptibility on green gram varieties.

In case of wild green gram, small size and presence of a well-formed texture act as ovposition deterrents. Fuji *et al.* (1989) again observed a resistance gene in *Vigna sublobata* race (a wild relative of *V. mungo*) which have had complete resistance against *C. chinensis, C. maculatus, C. analis* and *C. phaseoli.* Pandey and Singh (1997) observed that the mortality of all the stages of development of *C. chinensis* and *C. analis* was 27% and 15% respectively. In the present result the seasonal variations influence their biological activities especially their developmental periods although the oviposition and emergence of adult have been higher during summer and winter. Persistency of oviposition and adult emergence of both the species have a higher significance on soybean, kidney bean and small pea due to the physico-chemical properties of the seeds. The black gram (*V. mungo mungo*) seed (a wild relative of *V. mungo*) is completely resistant against *C. chinensis.* On the other hand, lentil seeds (*Lens esculentum*) are susceptible due to their small size. *C. analis* can not complete its development due to the shortage of space and food amounts. In addition to the physco-chemical factors the variations of biological parameters during two seasons are also responsible for the fluctuation of environmental conditions, especially the temperature and relative humidity (Menuson, 1935; El Sawaf, 1956; Howe and Currie, 1964).

Bruchid pests lay egg on stored pulses directly; the larvae enter into the seed boring the seed coat, enter within the seed coat and feed on the inner content of seed. Therefore, the seed weight, thickness of the seed coat moisture percentage of the seeds and bio-chemical substances (**Appendix XIII**) of the seed should be the main factors influencing their biological activities. Roughness of seed coat was apparently related to the susceptibility (Booker, 1967; Raghupathi *et al.*, 1970; Schalk *et al.*, 1973 and Choudhury and Pathak, 1989).

Epino and Morallo (1983) advocated that *C. chinensis* preferred to oviposit on hard, large and heavy seeds. Singal (1987) reported that thick seed coat acts as a barrier for penetration of 1st instar larvae. He also supported the observation made by Epino and Morallo (1983). On the contrary, Talekar and Lin (1992) demonstrated that smaller seed size of resistant pulse was not responsible for the resistance to *C. chinensis.* Similar findings were reported by Muhammad *et al.* (1997) and Padmavathi *et al.* (1999). In the present observation (Table 21) the seed weight has a significant negative correlation with the oviposition of *C. chinensis* whereas it shows a highly significant positive correlation in case of *C. analis.* The seed weight also shows a significant negative correlation with developmental period of both the species. Thickness of seed coat with the biological characters i.e. oviposition period, adult emergence and developmental period, have shown a non significant negative correlation.

Epino and Morallo (1983) recommended that the chemical component of green gram was correlated with the varietal susceptibility to *C. chinensis.* In the last decades, Telekar and Lin (1992), Sharma (1993), De Paula (1994), Modgil and Mehta (1994), Singh *et al.,* (1995), Oigiangbe and Onigbinde (1996) studied the physio-chemical properties of pulses. However, nothing is known about the exact causes for which the pulse beetle could not complete the growth and development inside the seeds namely soybean (*Glycine max*), kidney bean (*Phaseolus vulgaris*) and small pea (*Pisum arvense*). Malick and Singh (1980) stated that aromatic compounds with hydroxyl groups are widespread in all parts of plants. Phenols are said to be resistance to disease and pests in plants. Grains containing high around of polyphenol are resistant to bird attack. In this study kidney bean, soybean, small pea, pea, black gram contain to be higher phenol contents (Table 24). Moreover, from the study of the ovipositional preference, adult emergence and developmental period it appears that both are less susceptible to the kidney bean, soy bean, small pea, pea and black gram. On the whole, the correlation studies support the low level of infestation. Both the biological parameters were positively correlated and highly significant (Table 26). Among the different bio-chemical properties illustrated in the **appendix XIII** it should be mention that the phenol contents (Table 26) of the stored legume seeds appear to be the most important and significant criteria responsible for the susceptibility and persistency of bruchid pests.

From a critical analysis of results (Table 25) it is imperative that low phenol contents accelerate the oviposition, penetration of larvae as well as combined larval-pupal growth and development of bruchids. Pulses having higher contents of phenol prolong the developmental period, prevent the growth and development and results in the low preference of *C. chinensis* and *C. analis*.

5.5. Morphological study of the egg parasitoid, *U. mukerjii*

The first record of the Trichogrammatid chalicid genus *Chacetotricha* Girault (1911) was from India, with a redecoration of the species name as *Uscana* (=*Chaetotricha*) *mukerjii* was studied by Mani (1935). Latter on, De Luca (1965) reported and gave a taxonomical including their morphological characteristics. Though, detail morphological and sexual dimorphic characters of this naturally occurring potential parasitoid have not yet been revised. In this study, a detail comprehensive morphological feature including its morphometry of different parts of adults, sexual dimorphic characters with figures and illustrated micro-photography have been provided for further study. This potential solitary naturally occurring egg parasitoid has been recorded for the time in this region as a bio-control agent of the bruchid pests. First record of the Trichogrammatid genus *Chacetotricha* Girault (1911) from India, with a description of a new species name as *Uscana* (=*Chaetotricha*) *Mukherjii* was studied by Mani (1935) and Pajni *et al.* (1973). Mani (1989) redescribed its taxonomical note although a detail morphological and sexual dimorphic characters of this potential parasitoid has not yet been revised. In this study, a detail comprehensive morphological including its morphometry of different parts of adults, sexual dimorphic characters with draw-pictures and photography has been for further study of this typical genus (Stiffan, 1954) and first report from both *C. chinensis* and *C. analis* as a potential naturally occurring bio-control agent storage pulses.

5.6. Biology and parasitization potentiality of *U. mukerjii*

According to the earlier of reports, *Uscana mukerjii* (Mani) is a solitary egg parasitoid of *C. maculatus* (Mukerjee and Bhuya, 1936), *C. analis* (Chatterjee, 1953) and *C. chinensis* (Papai *et al.*, 1996). It has been observed in the present study that the ovipositional preference is determind by the age of host' eggs. The preference decreases with the advancement of age of the eggs. The development inside the eggs is accelerated with the increase of temperature. During winter the sex ratio is the lowest. The ratio increases with the rise of temperature in the assending order of rainy > autumn > summer. This result point out that low temperature stress during winter promotes higher number of female production for perpetuation of the species. The number of eggs are no problem, because one male can mate viably with more female. Also the increased temperature shortens the adult life span. The sex ratio at a temperature of 30^0C and 70% r.h. was approximately 1: 2.7 (Pajni *et al.*, 1996) in Punjab, India. This finding differs from the present result. Almost such a ratio has been obtained at a lower temperature of 24-27 ^{0}C during autumn.

Potentiality of parasitization is the to be highest during summer followed by rainy season. The prevailing temperature in the laboratory ranged from 26-30^0C which is the optimum temperature for parasitization. The maximum parasitization took place within 0-48 hours of egg layed by the host and declined thereafter. This solitary egg-parasitoid is naturally occurring in this area and very useful and easy to apply in stored pulses infested by *C. chinensis*.

5.7. Morphological study of the larval pupal parasitoid, *Dinarmus vagabundus*

In female, front surface of head and thorax black with bluish reflection, gaster is black with brassy luster. Gaster is always longer than the combined length of head and thorax. Antennae 13 segmented: 1.1.3.5.3. (annuli 3, 3rd annulus is sub square and flagel 5). Body length (2.04 mm.), wing span (3.79 mm.), length of forewing (1.41 mm.) and hind wings (0.75 mm.) are always longer than those of male (Mani,1989). *Dinarmus vagabundus* (Timberlake) confirmed its occurrence for the first time from Eastern India as a host and larval-pupal ecto-parasitoid of *C. chinensis* and *C. analis* on storage pulse, *Vigna mungo*. In comparison to earlier descriptions, a revision with a detailed description of its morphology, mouthparts, ovipositor apparatus and sexual dimorphism has been added for easy identification. Furthermore, the morphometry of sexual dimorphic characteristics of *D. Vagabundus* (Timberlake) such as body length and width, length of antennae, forewing, hind wing, hind leg, ovipositor apparatus, stinger etc including front surface color of head, thorax and gaster of both the sexes were not adequately described earlier.

5.8. Biology and parasitization potentiality of *D. vagabundus*

The female parasitoid with the help of its sharp and pointed ovipositor reaches and oviposits on the surface of host's larvae or pupae (Dhir, 1976 and Islam, 1995). The courtship (seconds) was recorded to be four time prolonged than the mating. Mating lasted for 15-45 seconds and male can mate with up to 38 females as observed by Kundra (1976). All the biological parameters namely courtship, mating or copulation, fecundity and sex ratio (male: female) show higher values during summer and lower during winter season. Adult'longevity of female always greater than that of the adult male during both the seasons. Developmental period also prolonged during winter. The temperature and relative humidity directly influence their biological activities. Dhir (1977) observed the variation of egg laying at different sets of temperature and r.h.(%).

The highest fecundity (47) has been recorded during summer and lowest during the winter. Dhir (1977) observed 9-26 eggs/female in his study although 'the actual count of fecundity is a difficult task' as emphasized by Islam (1995). The fecundity of *D. vagabundus* has the high rate of reproduction of the host. Temperature and relative humidity have direct impact on the biology. It has been observed in France that continuous brooding, semi-natural temperature and photoperiod cause the simultaneous occurrence of diapausing and non-diapausing larval stage in the spring season (Fabres and Reymount, 1991).

The emergence of adult from a single seed varied with different species of pulses. Kapoor (1972) was probably for the first time recorded the gregarious characteristics of the parasitoid. The potentiality of parasitization has been observed to vary with different species of stored pulses. On the average, the degree of parasitization is higher in summer when the average temperature is 28^{0}C and r.h. is 64.6 %, which seem to be the most favourable for their parasitization. *D. vagabundus* is not very frequently recorded in nature, it is regarded as an important larval-pupal ecto-parasitoid of bruchid. In the north astern part of India, this parasitoid may effectively be utilized as bio-control agents for suppression of the bruchid pest of pulses.

5.9. Effectiveness different plant oils on adult *C. chinensis*

Use of botanicals especially the various plant oils is one of the important alternatives to minimize excessive chemicalization of stored foods and seeds. The pesticidal contamination of pulses found to be above forty per cent in India. The presence of residues of synthetic insecticides widely used in storages has proved toxic to humans, domestic animals, birds and non-target faunas of storage ecosystem (Dhaliwal & Arora 1998). So far over 200 plant species belonging to 60 families are known to possess pesticidal properties and they are comparatively safer to mammals due to their biodegradable nature. The work done so far by entomologists to test the pesticidal properties of different genera of plants is mainly restricted to *Azadiracta, Pongomia, Cassia, Clerondron, Eupatorium, Acorus, Chenopodium, Eucalyptus, Mentha, Ocimum, Piper, Progostemon, Callistemon, Brassica, Sesamum, Cocos, Glycine, Helianthus, Elaeis, Ricinus* etc.(Agarwal *et al* 1973; Deshpandey *et al* 1974; Deshmuk *et al* 1975; Pandey *et al* 1976; Hill & Schoonhoven 1981; Ali *et al*1983; Ketkar *et al* 1986; Stanislow *et al* 1995; Dewadi & Maheswaswari 1996; Pandey & Singh 1997; 1998; Negi *et al* 1997; Pandey *et al* 1998).

It was observed that non-edible oils at the concentration of 0.01 were very effective. The highest (100%) mortality at this concentration was the maximum in case of chaulmoogra oil (100%) followed by clove oil (90.0%), citronella (36.3%), and castor (10.0) and neem (9.00%). At subsequent lower concentrations (0.001, 0.002 and 0.005) neem and castor oils had no such effect. The death caused due to both edible and non-edible oils differed significantly at different concentrations. The non-edible oils were more effective to cause the death of adult beetles. The dose dependant efficacy of the oils in this result corroborates the earlier observation by Pandey & Singh (1997) who worked with some other oils. Among the all fourteen plant oils tested at 0.01% concentration, chaulmoogra (*Hydnocarpus kurzii*) oil appeared to express the best pesticidal effect on the adult beetle followed by clove, safflower, citronella, sesame and soybean. Uses of botanicals as protectants of stored grains have had long history of use by farmers. The actual mechanism of their toxicidal effect on insect is not known but the basis may either be physical or bio-chemical or both. The oils may affect the respiration leading to asphyxiation of the insect pest (Pandey & Singh1997). The commonly observed secondary bio-chemical compounds particularly the fatty acids, acids, esters, enzymes and alcohol's of different oils may be responsible for insects' death. These secondary metabolites of the plant oils (Table 1), which have no known function in photosynthesis, growth or other aspects of plant physiology, may be the effective protectants of the plants against the insect attack (Bell *et al* 1990). Plants oils which provide large or economic yields of these key bio-chemical secondary metabolites may responsible for insects' death. They can affect insects in several ways: they may disrupt major metabolic pathways and cause death, act as attractants, deterrents, phago-stimulants, anti-feedants and retard or accelerate development of insect biology.

Among the plant oils tested in this study, the non-edible oils were more toxic on the adult beetles than the edible oils. It has also been mentioned that the mortality of adult *C. chinensis* was directly proportional to the increase in percent concentration (v/v) of the oils (Pandey and Singh, 1997). According to Agarwal *et al.* (1973) and Despande *et al.* (1974) non-edible oils namely *Aconus calamus* and *Progostemon* sp. were more toxic to *C. chinensis.* In another laboratory experiments, essential oils of *Callistemon citrinus* and *Expatoriun capillifolium* were found to be tonic to *C. maculatus* (Misra *et al.*(1989). Non edible oils likely geranium, citronella, basil and rue had insecticidal effect against *C. chinensis* whereas lemon, eucalyptus was not toxic to adult (Richa *et al.*, 1993).

In the present study, the extracted oils at different concentrations were exposed (24 hours) to adult *C. chinensis*. Both edible and non-edible oils were significantly differed at different percent concentrations. Chaulmoogra (*Hydnocarpus kurzii*) oils found to be highest toxicidal effect on the adult beetle followed by clove, safflower, citronella, neem and soybean (Graph -). Majeed et al. (1994) studied the toxicity neem fruit extracts against C. avali and the order of efficacy was acetone extracts methanol extract. According to Stanislow *et al.* (1995) neem oil is now produced commercially and exhibits enormous potential as insecticide due to the presence of bio-chemical properties. Citronella oil has some important aromatic compounds such as geranoil, citronellol (alcohol) and their derivatives. Maity (1988) worked out the main fatty acids namely linoleic, lauric, myristic, palmitic, oleic, caprylic (ester), capric (esters), azadirachtin (ester), stearic from the vegetative oils. Chaulmoogra is a indigenous medicinal oil having two imported fatty acids namely chaulmoogric and hydnocarpic acids (Chopra *et al.*, 1994). Use of botanicals as protectants of stored grains have had long history of use by farmers. The actual mechanism of their toxicidal effect on insect is not known but it should be both physical and bio-chemical (Singh, 1997). The commonly observed bio-chemicals and their fatty acids, esters and alcohol's **(AppendixX)** may responsible for insects' mortality. The presence of so-called secondary aromatic compounds of the plant oils, which have no known function in photosynthesis, growth or other aspects of plant physiology, gave plant materials or their extracts their anti-insect activity. The mode of action of these oils is partially attributed to influence the normal respiration, resulting in suffocation.

In view of encouraging results obtained in this study, the chaulmoogra, clove, safflower, citronella, soybean and sesame oils appear to have distinct potentiality as bio-pesticides and good additives for the management of insect pests especially the most notorious bruchid pest, *C. chinensis* (Coleoptera: Bruchidae).

5.10. Efficacy of different plant oils in protecting stored green gram up to 120 days against the attack of *C. chinensis*

With a view to developing a alternative approach for the safe management of pulse beetles, several control measures (Oils, containers, ashes, synthetic chemicals, physio-chemical factors and bio-control agents) has been chosen, assessed, evaluated and documented by many researchers namely Kachare *et al.*(1994), Islam (1999), Singh *et al.* (1994), Negi *et al.* (1997), Pandey and Singh (1997), Mummigatti and Raghunathan (1997), Babu *et al.*(1989), Kahaire (1992) Begum and Quiniones (1990), Pereira (1983), Sujatha and Punnaiah (1985) and many others. For poor or small farmers plant seed oils could be better option because these are easily available, low cost device and easy to apply. On the other hand, for big farmers/traders, the use of the oils might also be advantageous to protect stored pulses from insect attack either for food or seed purposes. In the present study, among the plant oils, chaulmoogra and niger have been trialed for the first time to protect stored pulses from bruchid attack. Many researchers have studied the efficacy of various vegetable as well as non-vegetable oils as protectants of stored pulses against bruchid pests.Most of the studies involved short term observation. A long term and dose related investigation is urgently required for evolving a protection schedule. In the present study, a dose specific protection has been explored for a storage period up to 120 days.

All the observations (Table 36-38) and figures (23-25) reveal that all the treatments and experiments are found to be statistically significant. In view of encouraging results obtained in this study, the number of egg-laying and adult emergence have decrease a noticeably over control (untreated seeds). The developmental period of the beetle has been prolonged considerably than in the control. The chaulmoogra oil has appeared as the most effications and promising than all other vegetable oils. No information is available whether this oil cause any hazard to human health. Hence, it is premature to recommend for protection of pulses meant for human consumption. But this oil does not impair germination of the seeds. Hence, this oil has a distinct potentiality for storage of pulses for seed purpose. The next promising oils in respest to suppressing egg-laying and adult emergence have been the clove, soybean, neem and citronella. Soybean oil also prolongs the developmental period followed by choulmoogra, clove, neem and citronella. Considering the efficacy of chaulmoogra, a dose of 0.3 (v/w) per 100 grams of green gram seeds appears to be the best quite a long term of storage. Moreover, the oils of clove and soybean can be considered as good protectantsat least up to a period of 120 days.

D. vagabundus (Timberlake) (Hymenoptera:Pteromalidae) is gregarious ecto-parasitoid of pulse beetle (Kundra, 1976). It is very uncommon and their abundance is restricted on in India, Sri Lanka, Pakistan, Brazil and France (De Luca, 1966; Rojas, 1988; Mani, 1989). This parasitoid is first time reported from this region and also from Eastern Zone of India. It is previously reported from Punjab, Karnataka and Tamil Nadu states of India (Mani, 1989).

In female, front surface of head and thorax black with bluish reflection, gaster is black with brassy luster. Gaster is always longer than the combined length of head and thorax. Antennae 13 segmented: 1.1.3.5.3. (Annuli 3, 3rd annulus is sub square and flagel 5). Body length (2.04 mm.), wing span (3.79 mm.), length of forewing (1.41 mm.) and hind wings (0.75 mm.) are always longer than those of male. Timberlake (1926) first described and designated *D. vagabundus* from other allied species *D. acutus* which is the type species of *Dinarmus*. Latter on, Mani (1939), Boucek *et al.*(1978) and Mani (1989) redescribed and illustrated its morphological characteristics. Unfortunately, no comprehensive study of this naturally occurring potential bio-control agent of *C. chinensis* with special emphasis to their ovipositor and sexual dimorphic characters has been published so far. *D. vagabundus* confirmed its occurrence for the first time from Eastern India as a host and larval-pupal ecto-parasitoid of *C. chinensis* and *C. analis* on storage pulse, *Vigna mungo*. In comparison to earlier descriptions, a revision with a detailed description of its morphology, mouthparts, ovipositor apparatus and sexual dimorphism has been added for easy identification. Furthermore, the morphometry of sexual dimorphic characteristics of *D. vagabundus* such as body length and width, length of antennae, forewing, hind wing, hind leg, ovipositor apparatus, stinger etc including front surface color of head, thorax and gaster of both the sexes were not adequately described earlier.