Investigations on Damage Potential and Control of Maize Stem Borer, *Chilo partellus* (Swinhoe) on Maize, *Zea mays* (L.)

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RAJENDRA SINGH CHOUDHARY

Thesis

Master of Science in Agriculture
(Entomology)

2011

Department of Entomology
Rajasthan College of Agriculture
Maharana Pratap University of Agriculture and Technology
Udaipur-313001 (Raj.)

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Thesis

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In Partial Fulfillment of the Requirement for

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(Entomology)

By

RAJENDRA SINGH CHOUDHARY

2011

Maharana Pratap University of Agriculture and Technology, Udaipur

Rajasthan College of Agriculture, Udaipur

CERTIFICATE-I

Dated: / /2011

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Dated: / /2011

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Dated: / /2012

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Place : Udaipur
Date : **(Rajendra Singh Choudhary)**

Investigations on Damage Potential and Control of Maize Stem Borer, *Chilo partellus* (Swinhoe) on Maize, *Zea mays* (L.)

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ABSTRACT

The "Investigations on Damage Potential and Control of Maize Stem Borer, *Chilo partellus* (Swinhoe) on Maize, *Zea mays* (L.)" were conducted at Instructional Farm and Department of Entomology of Rajasthan College of Agriculture, Udaipur during *kharif* 2011. The data recorded on vulnerable stage of maize to the infestation of *C. partellus* showed that plant acquire resistance in older stage as compared to earlier stage. The release of larvae up to 11 days after germination (DAG) resulted in maximum LIR, 9.0 while, 8.33 after 13 DAG. Minimum LIR, 3.67 was obtained at 21 DAG and there was significant difference among LIR obtained at 13, 15, 17, 19 and 21 DAG. The data recorded on plant height varied from 18.53 to 160.58 cm after the release of neonate larvae at 7 to 21 DAG. Minimum plant height, 18.53 cm, was recorded at 7 DAG followed by 19.92, 22.75 and 26.48 cm at 9, 11 and 13 DAG respectively. The release of larvae at 7 to 13 DAG destroyed the plants completely and no yield was recorded while maximum yield, 102.22 g /plant was recorded at 21 DAG followed by 88.39 and 54.82 g /plant at 19 and 17 DAG respectively.

The effect of insecticide when applied immediate before or after release of larvae showed minimum LIR, 1.0, maximum plant height, 169.96 and 171.85 cm, nil tunnel length and maximum plant yield, 118.27 and 119.94 g /plant respectively. Significantly similar results were obtained when larvae were released one day before and after spray. Spray of insecticide two days before or after release also resulted in less LIR, 2.87 and 2.30, plant height, 164.36 and 167.04 cm, nil tunnel length and good plant yield, 109.99 and 113.15 g /plant respectively. The release of larvae well before (8 DBS) gave high LIR, 8.70, lowest plant height, 32.76 cm, nil tunnel length and no yield.

The results obtained on incubation period of eggs of *C. partellus* showed that storage of eggs for 3 days at 3^0C resulted in longest incubation period, 8.13 days,

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followed by 7.34, 6.73, 6.47 and 6.21 days at 5, 7, 9 and 11^0C respectively. The increase in duration of storage of eggs (5 days) of *C. partellus* resulted in varied impacts wherein 3 and 5^0C gave longest incubation period, 10.88 and 10.22 days respectively but statistically at par. Similarly, at 7 and 9^0C, incubation period was 9.30 and 9.18 days but statistically at par and significantly different to 8.45 days at 11^0C. Prolonged storage (7 days) also had the similar effect wherein longest incubation period, 13.20 days, was observed at 3^0C and shortest, 10.91 days at 11^0C. The data obtained on hatching of eggs of *C. partellus* showed that at low temperature, 3^0C, inhibited development and significantly minimum hatching, 15.0, 9.0 and 5.0 per cent was observed at 3, 5 and 7 days respectively. Maximum hatching, 73.0, 59.0 and 36.0 per cent was recorded at 11^0C when stored for 3, 5 and 7 days respectively.

The observations recorded on pupal period at different temperature *viz*., 3 to 11^0C under varied storage durations, 5 to 15 days showed decreased temperature either prolonged the pupal period or inhibited development completely. Longest pupal period, 16.42 and 22.68 days was observed at 3^0C under 5 and 10 days storage respectively while shortest duration, 13.07 to 24.92 days was recorded at 11^0C under 5, 10 and 15 days respectively. No adults were emerged at 3^0C when pupae were stored for 15 days.

Adult emergence at different test temperature under 5, 10 and 15 days ranged from 12.0 to 69.0, 7.0 to 55.0 and 9.0 to 40.0 per cent respectively. No adults were emerged at 3^0C under 15 days storage. Sex ratio exhibited at test temperatures, 3, 5, 7, 9 and 11^0C were significantly different to each other under 5, 10 and 15 days storage. Less female, 0.68 to 0.43 were observed at 3^0C while females were increased comparatively to 0.94, 0.94 and 0.91 at higher temperature, 11^0C under 5, 10 and 15 days storage respectively. Very similar trends in fecundity was observed wherein low temperature retarted the fecundity while higher temperature favoured the fecundity. Number of eggs observed at 3, 5, 7, 9 and 11^0C under 5, 10 and 15 days ranged from 49.75 to 184.75, 31.5 to 168.75 and 39.75 to 151.50, respectively and were statistically different to each other. The adults emerged from pupae stored at 3 to 11^0C for 5 to 15 days showed significant effect on adult longevity. Shortest life span of adult, 1.5 and 1.25 days, was observed at lowest temperature, 3^0C under 5 and 10 days storage respectively while longest life span, 3.75, 3.25 and 3.0 days was recorded at 11^0C under 5, 10 and 15 days respectively.

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15 fnuk d Hk.Mkj.k ij eknkvk dh l[;k e Øe'kh 0-94] 0-94 ,o 0-91 rd vi{kkÑr nt dh xbA blh rjg dh çofÙk;k] mitkÅiu ij nt vkdMk dh Fkh ftle de rkieku mitkÅiu dk vo:) djrk Fkk tcfd vf/kd rkieku mitkÅiu dk lgk;;Dr FkkA 3] 5] 7] 9 ,o 11° lfYl;l ij 5] 10 ,o 15 fnuk d Hk.Mkj.k ij v.Mk dh l[;k Øe'kh 49-75 l 184-75] 31-5 l 168-75 ,o 39-75 l 151-50 nt dh x;h tk lkf[;dh; :i l ,d nlj l fHkUu FkA dkf"kr dk 3 l 11° lfYl;l ij 5 l 15 fnuk rd Hk.Mkj.k dju ij 0;Ld nh?kk; ij vFki.k çHkko fn[kk;kA 0;Ld dk de l de thoudky Øe'kh] 1-5 ,o 1-25 fnu U;ure rkieku 3° lfYl;l ij 5 l 10 fnuk rd Hk.Mkj.k dju ij nt fd;k x;k tcfd vf/kdre thoudky Øe'kh 3-75] 3-25 ,o 3-0 fnu 11° lfYl;l ij 5] 10 ,o 15 fnuk d Hk.Mkj.k ij nt fd;k x;kA

1. INTRODUCTION

Maize is an important cereal crop which is cultivated in about 140 million hectares mainly in tropical and subtropical regions. Of which, approximately 96 m ha area is in the developing countries of the world. Although 68 per cent of global maize area is in the developing countries, which contributes to only 46 per cent of the world's maize production. Low average yield of maize in the developing countries is responsible for the wide gap between the global share of area and share of production. The average maize yield in the developed countries is more than 8 t / ha, while in the developing countries it is around 3 t / ha (Zaidi and Singh, 2005).

In India, maize is cultivated in 7 m ha with 20 m tones production during 2010-11 (http, 2011). Rajasthan ranks first in the country in respect of area with 10.96 lakh ha and production of 11.44 lakh tones (Anonymous, 2009). Often the yield realized by the farmers is much less than the potential of the crop. Inspite of taking due care of the production component, at time the insect pests take a heavy toll to the crop thus bringing crop yield very low.

Maize is attacked by over 250 species of insect and pests (Mathur, 1991). Of those four species of tissue borers *viz*., maize stem borer or spotted stem borer (*Chilo partellus* Swinhoe), pink stem borer (*Sesamia inference* Walkar), shoot fly (*Atherigona soccata* Rondani) and Asiatic corn borer (*Ostrinia furnacalis* Guenee) are regular and serious pests of maize. Among these, maize stem borer, *C. partellus*, is the principal pest in all maize growing countries. It also attacks sorghum, millets, rice, sugarcane, bajra and other graminicious grasses. It is widely distributed in tropical Asia (India, Pakistan, Bangladesh, Afghanistan, Nepal, Cambodia, Indonesia, Laos, Sri Lanka, Thailand, Vietnam, Iraq, Japan, Nyasaland and Taiwan). Asian region is probably the native place for this pest.

The injury caused by maize stem borer in maize includes leaf feeding, tunneling within stalk, disruption of the flow of nutrients to the ear, and subsequent development of "dead hearts" by damage to the central growing shoot of young plant. The first symptom of damage caused by *C. partellus* is the appearance of "shot hole" injury to whorl leaves. Plants that survive the initial attack show reduced inter-nodal length resulting in shoots 'rosetting'. Yield loss is attributed the physiological effects

on final ear size, lodging or the complete loss of ears and formation of “dead hearts” (Kfir *et al.* 2002).

Potential losses due to insect pests in maize on global basis are estimated to be of 14-18 per cent (Oerka, 2002), which is 52 million tons valued at $ 5.7 billion annually (James, 2003), while yield loss estimates for maize stem borer vary greatly depending upon the country, season, maize variety and fertilization (Kfir *et al.* 2002, De Groote *et al.* 2003). However, in studies with *C. partellus* alone, yields in East Africa were reduced by 15-45 per cent (Seshu Reddy and Sum, 1992). In South Africa, yield losses in maize and sorghum exceeded 50 per cent (Kfir *et al.* 2002). The yield losses in maize by *C. partellus* ranging from 5.14 to 91.22 per cent reported by earlier workers in India (Reddy, 1968, Chatterji *et al.*, 1969, Singh and Sajjan, 1982). At the lower limit of 25 per cent damage, the average loss in maize in the *kharif* season at a conservative estimate, comes to Rs. 1105 million annually (Siddiqui and Marwaha, 1994). The development of newer and resistant maize varieties play an important role in reduction of yield losses which are developed for their resistance through artificial release technique under field conditions against maize stem borer.

The screening of developed cultivars for their resistance against maize stem borer is done through Leaf injury rating technique (1-9 scale) (Chatterji *et al.*, 1970). The release of 15-20 black headed eggs of maize stem borer in leaf whorl after 10-12 days after germination resulted in different type of damage symptoms. These symptoms are graded according to Leaf injury technique (LIR) after one month of release for resistance of cultivar. The release of larvae in early or late plant stage drastically affect the LIR. It is therefore, essential to identify the most susceptible stage of host to maize stem borer for artificial infestation and which helps to identify the resistant cultivars.

Insecticides are playing pivotal role in the management of *C. partellus* if sprayed timely. Once larva enters the stem, it becomes difficult to control by the insecticides. It is therefore, important to know the actual stage / time of application of insecticide in crop for effective management of *C. partellus*. Hence, it was planned to study the time of application of insecticide before or after the release of neonate larvae of *C. partellus* at different time interval. The effect of insecticides can be increased manifold by judicious application at right stage.

Temperature is playing very significant role in the growth and development of any insect. Though, maize stem borer survival under varied temperature range but it undergoes aestivation. The successful and continuous multiplication of maize stem borer depends upon the availability of optimum temperature i.e. 25 ± 2^0C. However, the physiological development of eggs and pupae can be arrested for a short `while under cold temperature without interfering their viability and survival. Besides, it is also required to store eggs and pupae for synchronization of release and host plant age under screening programme. It was therefore, planned to investigate the effect of temperature on the viability of eggs and pupal development of *C. partellus.*

Keeping in view the above facts, studies on "Investigations on damage potential and control of maize stem borer, *Chilo partellus* (Swinhoe) on maize, *Zea mays* (L.)" was initiated with the following objectives:

(i) Identification of vulnerable stage of maize to *Chilo partellus.*

(ii) Standardization of time of application of insecticide against *Chilo partellus* on maize.

(iii) To study the effect of temperature on development of *Chilo partellus*.

  (a) Effect of low temperature on the viability of eggs of *Chilo partellus.*

  (b) Effect of low temperature on the pupal development of *Chilo partellus.*

2. REVIEW OF LITERATURE

The present investigation was carried out to study the "Damage potential, control and effect of temperature on development of *Chilo partellus* (Swinhoe) on maize"**.** The pertinent literature in relation to the proposed work is reviewed under following sub heads:

(i) Identification of vulnerable stage of plant to insect-pest.

(ii) Standardization of time of application of insecticide against insect-pest.

(iii) To study the effect of low temperature on the development of insect.

2.1 Identification of vulnerable stage of plant to insect-pest:

Maize germplasms were screened under field conditions for resistance to *C. partellus* by introducing 25-30 black headed eggs of maize stalk borer into the whorls of 15-19 days old plants and data on various biological parameters *viz*., per cent incidence, per cent dead hearts, leaf injury scale including dead hearts were recorded (Singh *et al.,* 1962; Kalode and Pant, 1966; Singh *et al.,* 1968; Chatterji *et al.*, 1970; Sarup *et al.,* 1978 and Reddy, 2003). Sarup *et al.* (1977) reported that increase in the LIR significantly decreased the maize grain yield. The most critical stage of maize crop growth is 10 day old plants succumb even to as low a population as 10 eggs per plant. The observations recorded for assessing the extent of damage after about 30 days of manual infestation of *C. partellus* in a wider range scale 1-9 (based on leaf injury including dead hearts) framed earlier by Chatterji *et al*. (1970) and later elaborated by Sarup *et al.* (1978) was considered to be most suitable technique.

Ampofo (1989) observed two peaks of infestation of *C. partellus* on maize in Kenya coinciding with early whorl and flowering stages of plant development. He reported that some varieties that showed high levels of resistance at the whorl stage were susceptible at the flowering stage, in terms of larval establishment, growth and development, severity of damage to the plants and loss in grain yield. Infestation of the plants near maturity resulted in minimal yield loss.

The investigation conducted by Davis and Pedigo (1990) on yield response of corn to injury during early development by stalk borer, *Papaipema nebris* (Guenee) showed significant linear relationship between leaf stage and injury rating. The injury rating declined at an average rate of 0.332+or-0.033 points per leaf stage. In an experiment conducted by Maredia and Mihm (1990) on damage by southwestern corn borer, *Diatraea grandiosella* (Dyar) on resistant and susceptible maize at three plant growth stages in Mexico, reported that leaf damage ratings were highest in all varieties when plants were infested at the 4-5 leaf stage and declined with the age of plants at infestation, the decline being less between the 4-5 and 6-8 leaf stages than between the 6-8 and 9-11 leaf stages. There was greater variation in leaf damage when infested at the 4-5 leaf stage than at the 6-8 leaf stage. Variation was lowest at the 9-11 leaf stage, but the ratings did not indicate any real differences between varieties. They reported that 6-8 fully extended leaf stage would be the best for artificial infestation with the pest.

Williams and Davis (1990) studied the response of corn to artificial infestation with fall armyworm and southwestern corn borer larvae. Infestation with 30 larvae of *Spodoptera frugiperda* (J.E. Smith) or *Diatrea grandiosella* (Dyar) per plant resulted in extensive heavy leaf feeding damage, no reduction in ear height and 13 per cent yield reduction. Infestation with 30 larvae of *D. grandiosella* per plant resulted in heavy leaf feeding damage, a 50 per cent ear height reduction and a 57 per cent yield reduction.

Maredia and Mihm (1991a) conducted an experiment on response of resistant and susceptible maize to 15, 30, 45 and 60 larvae of the *Diatrea grandiosella* (Dyar) per plant at the 6-7 fully extended leaf stage of maize at different infestation levels of southwestern corn borer (*D.grandiosella*) in Mexico. There was a small linear increase in leaf feeding ratings on resistant genotypes (Mp78:518 and P47S3 x Mp78:518) as the number of larvae increased. While it increased sharply on susceptible genotypes at 30 larvae when compared to 15 larvae. Leaf feeding was significantly less on resistant than on susceptible genotypes. Neither plant height nor yield of resistant genotypes was reduced significantly at any infestation level. The results indicate that infestation with 15 larvae per plant gives low damage ratings and does not adequately group the genotypes into resistant or susceptible. They reported that artificial infestation with 45 larvae per plant is adequate for screening under field

conditions in Mexico. In another experiment on damage caused by sugarcane borer to different varieties of maize at four plant growth stages i.e. at fully extended leaf stages 4-5, 6-8 and 9-11 and at flowering, they observed highest leaf-feeding damage when plants were infested at the 4-5 leaf stage and damage declined when they were infested at later stages in all varieties. Variation in leaf-feeding damage rating was greater when plants were infested at the 4-5 leaf stage. The resistant varieties (MBRV-SWCB and P23R) had significantly less feeding damage compared with the susceptible variety (PR7925). Stalk and ear damage in all varieties was highest when plants were infested at the 9-11 leaf stage and at flowering, respectively. Yield of infested treatments compared with that of an uninfested treatment was reduced at all stages in all varieties, the greatest reduction occurred when plants were infested at the 4-5 leaf stage. Resistant varieties had less yield reduction than susceptible variety. The results suggest that, for evaluating germplasm for leaf feeding damage, stalk damage, and ear damage resistance, the optimum stages for artificial infestation under conditions in Mexico would be the 6-8 leaf stage, the 9-11 leaf stage and the flowering stage, respectively (Maredia and Mihm, 1991b).

Davis *et al.* (1991) conducted an experiment during on growth and survival of southwestern corn borer on whorl and reproductive stage of plants of selected corn hybrids. They reported that degree of resistance or susceptibility in maize can shift with plant growth stage. There was an indication of a low level of resistance existed among maize hybrids with leaf-feeding resistance when infested in the reproductive stage of growth.

Reddy and Sum (1991) studied the economic injury level of *C. partellus* by artificially infesting maize (cv. Kutumani) plants at three growth stages (20, 40 and 60 day-old plants) with varying densities of newly hatched larvae (2, 4, 6, 8, 10 and 12/plant). The grain yield data obtained from the infested and the protected plants showed that maximum yield reduction and stalk damage occurred to the 20 day-old crop, while there was insignificant larval effect on the yield of the 60 day-old crop. A significant linear equation was used to estimate the yields per plant at different infestation levels to calculate the economic injury level at each stage. The resultant EIL was 3.2 and 3.9 larvae/plant for 20- and 40-day old plants, respectively.

Kumar (1992) observed the patterns of stem borer incidence and damage to two indigenous maize cultivars, Inbred A and Nyamula, for susceptibility/resistance

to *C. partellus* at artificial infestation levels of 10 and 20 larvae/plant. The number of *C. partellus* recorded on Nyamula was greater than on Inbred A in 10-week old crops, but the injury to foliage and stem-tunneling on the 2 cultivars was the same. At harvest, the degree of damage to the 2 cultivars varied. Cultivars suffered equal stem tunneling at an infestation level of 20 larvae/plant. There was a significant negative correlation between stem-tunneling and yield for Inbred A, but the correlation was not significant for Nyamula. At an infestation level of 10 larvae/plant, the correlation between stem-tunneling and yield was not significant for either of the cultivars.

Videla *et al.* (1992) studied the larval growth and survival of fall armyworm on susceptible and resistant corn at different vegetative growth stages and observed that the differences in larval weight on resistant and susceptible hybrids were greater when plants were infested at earlier whorl stages. No consistent differences were found among plant growth stages within either resistant or susceptible hybrids for weight or survivorship.

Kumar (1993) studied the resistance in maize to *C. partellus* in relation to crop phenology and observed that at vegetative stage of the crop, leaf feeding damage, percentage of plants showing dead heart and percentage stem length tunneled by *C. partellus* were significantly lower on resistant variety Mp704, than on the susceptible Inbred A. However at anthesis, the infestation and damage by *C. partellus* on the 2 maize genotypes was equally high. The high level of resistance in Mp704 at the vegetative stage to neonates of *C. partellus* was not found against older instars.

Kumar and Asino (1993) reported that artificial infestation of susceptible and test cultivars with *C. partellus* could not be differentiated by the extent of foliar lesions. However, when infested 3.5 weeks after germination, difference among the cultivars were clear and only the cultivar ER-29SV showed leaf feeding resistance and dead heart resistance to *C. partellus.*

Yang *et al.* (1993) examined the movement of neonate fall armyworm larvae on resistant and susceptible genotypes of corn at the mid-whorl and late-whorl stage. There was little difference in the movement of larvae when they were on resistant 'MpSWCB-4' compared with when they were on the susceptible genotype 'Pioneer 3369A'. However, larvae reached the feeding sites (whorl tissue) more quickly when

they were placed on the younger (upper) leaves than when they were placed on the older (lower) leaves. When larvae were collected from resistant and susceptible genotypes 24, 48 and 96 h after artificial infestation, there were consistently fewer larvae on the resistant genotype only after 96 h. Populations of larvae decreased more rapidly when the plants were infested in the late-whorl stage than when the plants were infested in the mid-whorl stage.

Kumar (1994a) measured the resistance in maize to *C. partellus* under artificial infestation at the whorl stage and at anthesis. When infested at the whorl stage (2.5 weeks after emergence), the cultivars MMV400, MBR8650, MBR8668, MBR8637, MMV600, ER29SVR, Poza Rica 7832, Bulk CG 4141, Katumani Composite B and ICZ2-CM showed leaf feeding resistance, dead heart resistance and stem feeding resistance to *C. partellus*. The plants of MBR8637, ER29SVR and Poza Rica 7832 caused significant adverse effects on the growth of *C. partellus*. Besides displaying a high degree of antibiosis against *C. partellus*, the plants of these three cutivars lost very little biomass per unit larval weight gain and lost little grain yield under infestation with *C. partellus* in the fields, indicating that tolerance mode of resistance also contributed to their overall resistance. When the cultivars were infested at anthesis, the cultivar MBR8637, MMV400 and Poza Rica 7832 showed stem feeding resistance to *C. partellus*. The rate of larval development on MBR8637 and Poza Rica 7832 was significantly lower than the other cultivars.

Kumar (1994b) reported that the artificial infestation by 1st generation of *C. partellus* on maize during the early whorl stage on the Kenyan hybrids resulted in significantly greater population than released on anthesis. In another investigation, Kumar and Saxena (1994) studied infestation and damage on 3 maize cultivars Inbred A (susceptible), ICZ2-CM (resistant) and Katumani Composite by the stalk-borer *C. partellus* in relation to their yield in Western Kenya. Infestation levels (egg population density and larval-pupal population density) and damage levels (foliar damage and stalk damage) were significantly lower during the long rainy season of 1984 than in 1985. On Inbred A, oviposition by the moths during the pre-flowering and flowering stages was much more important in causing a reduction in the grain yield than that during the post-flowering stage of the crop. There was no correlation with grain yield on ICZ2-CM and Katumani. The larval-pupal population density on Inbred A (but not on ICZ2-CM or Katumani) had a significant negative correlation

with grain yield. Foliar damage and stalk-tunneling by the borer only affected the grain yield of Inbred A. Under artificial infestation, the grain yield of Katumani is reduced significantly by infestation, but under natural infestation it escapes due to its early maturity. By comparison, ICZ2-CM has inherent resistance to *C. partellus* and infestation and damage by the pest have no effect on grain yield.

Sayers *et al*. (1994) conducted an experiment to quantify the relationship between the percentage of plants infested with *Ostrinia nubilalis* (Hub.) larvae and field to establish economic injury levels for maize during 1988 and 1989. Three inbred genotypes were infested manually with neonate larvae at the mid-whorl or flowering stages of maize to simulate natural infestations by 1st or 2nd generation *O. nubilalis*, respectively. Infestation levels ranged from 0 to 84% of plants with larvae. Susceptibilities of the inbreds to infestations by *O. nubilalis* ranged from relatively susceptible to moderately tolerant, based on visual injury scores. Grain yield decreased as the percentage of plants infested increased with infestations at either stage of crop development. They reported that the EIL for whorl-stage infestation of *O. nubilalis* would be exceeded when >2-3 per cent of the plants have larvae present in the whorl, and the EIL for flowering stage infestation would be exceeded when >10-17 per cent of the plants have larvae in leaf axils.

Koc and Tusuz (1995) conducted an field experiment in Turkey during 1986-1989 for determination of suitable plant growth stage for artificial infestation in developing cultivar resistant to *O. nubilalis.* They observed that suitable plant stage for artificial infestation started just before tasseling time and continued to flowering time for evaluation of stalk resistance, and flowering time and beyond for evaluation of ear resistance.

Moyal (1995) observed stem borer larval growth and tunneling and its influence on maize vegetative growth. Early attacks by *Busseola fusca* (Fuller) (infestation until 17 days after maize emergence) resulted in dead hearts or in growth reduction. A relationship existed between the date of infestation, the level of attack and the development stage of maize.

Davis *et al.* (1996) screened maize for leaf feeding resistance to *S. frugiperda* in different planting date and plant growth stage. Each plant in experiment was infested with neonate larvae. Each plant was visually scored for leaf damage 7 and 14

days after infestation. Significant differences in rating scores within each factor (insect colony, planting date, and plant growth stage) were found for some comparisons. However, none of these factors appreciably altered the ability to distinguish between resistant and susceptible genotype which is the objective of screening.

Kumar (1997) studied the relationship among damage parameters under natural and an artificial infestation of four maize genotypes by *C. partellus.* Artificial infestation was done at the 6-leaf stage and flowering stages with 45-50 eggs at the black-head stage. For natural infestation, genotypes were grown under prevailing natural populations of *C. partellus.* At harvest, data were recorded on individual plants regarding number of holes, length of the stem tunneled and number of larvae and pupae present in the tunnels. A highly significant correlation was observed between number of holes and stem tunneling (expressed as the absolute tunnel length or the percentage of stem length tunneled). The relationships between the parameters varied with genotype and plant phenological stages at infestation. Damage by *C. partellus* to grain and stem was not consistently correlated among genotypes and phenological stages at infestation. These results indicate that number of holes can be used in place of the laborious method of splitting stalks for determining resistance.

Cardwell *et al.* (1997) calculated maize cob weight loss of 9 g per plant by borer infestation. At that time, the average plant loss from dead hearts across zones was 11 per cent.

Singh and Mishra (1997) studied the incidence of *C. partellus* in maize crop and found higher infestation in early sown crop than in late sown crop.

Ganguli *et al*. (1998) showed that the average time taken by neonate larvae of *C. partellus* to reach the whorl in maize (cv. D-823, D-819, CM-300, Kanchan, Navin and CM-600) was 26.8 minutes when plants were in the 7-leaf stage, and 24.08 minutes when plants were in the 6 leaf stage. The duration of whorl feeding varied with maize cultivar and was significantly lower on CM-300 (4.5 days). The maximum duration of feeding was recorded on Kanchan (12.25 days). Variation in feeding rates was attributed to levels of antibiosis.

Haile and Hofsvang (2001) investigated the influence of sowing date and fertilizer application on the incidence and damage of the stem borer (*Busseola fusca*

Fuller) in sorghum and found that sowing date had a significant effect on stem borer incidence and damage levels. Early sowing dates (1 and 15 April) had a significantly lower number of larvae, infestation and dead heart, and gave higher yields compared with the other sowing dates while late sowing dates (mid-May to mid-June) resulted in significantly higher infestation and damage. The highest infestation and damage were recorded from mid-May sowings. High stem borer infestations in delayed sowing was due to the coincidence of the susceptible stage of the crop (3-6 weeks after germination) with high populations of stem borer larvae from the first generation in late June and July. Mid- and late sown crops were also later attacked by the second generation at the grain-filling stage in September-October. These results indicate that early planting (April) is effective in reducing stem borer damage on sorghum in the highlands of Eritrea.

Songa *et al.* (2001) reported that *C. partellus* damage greatly reduced maize grain yield, with tunnel length greater than 20 cm caused a 40 per cent reduction in potential yield. A 33 per cent yield loss was found in plants with more than one stem borer exit hole. Each stem borer hole / larvae was correlated with 8-10 per cent yield loss. Good plant physical characteristics significantly increased grain yield. Principle component analysis showed that stem borer damage, plant height and stem diameter were key factors affecting maize grain yield. Regression analysis indicated that one cm of stem borer tunnel reduced yield by 3g / plant. Multiple regression analysis implied a 13.3 ± 1.5 g yield loss (8-10 per cent of potential yield) due to the damage of a single stem borer.

Sadek and Metwally (2002) assessed losses in maize yield and larval survival due to different timings of infestation by *O. nubilalis* in lower Egypt. They found considerable number of larvae on the plants infested at the age of 60 days and counted 6, 10, 18 and 35 days after egg hatching. Maize plants during anthesis were highly susceptible to European corn borer moths oviposition. An artificial infestation made at anthesis stage of maize plant growth resulted in the highest infestation and the lowest grain yield obtained. The average yield reduction relative to the control was 33.3, 15.9 and 7.2 per cent for maize plants infested with ECB egg masses at the age of 60, 45 and 30 days-old, respectively. Weight of 100 kernels were highly affected by the borer infestation and consequently caused yield losses.

Lourencao and Santos (2005) observed that maize plants at the V8 and V10 stages (8 and 10 leaf) were more susceptible to *S. frugiperda,* with losses of 11.1 and 15.4 per cent respectively. In the second crop, losses varied from 2.5 to 9.8 per cent. Spike insertion height, stem diameter and spike weight were reduced, and the most susceptible stage was V10 (10 leaf).

Arabjafari and Jalali (2007) reported positive correlation between leaf injury score caused by *C. partellus* and stem diameter of maize. while, negative correlation was found between leaf injury score and internodal distance.

Daves *et al.* (2007) studied the impact of plant resistance on southwestern corn borer damage. The susceptible hybrid sustained significantly more leaf damage and stalk tunneling than either resistant hybrid. The number of tunnels and the length of tunneling were significantly lower on the resistant hybrids. In 2003, up to 15 times more tunneling was observed on the susceptible hybrid. Larvae feeding on the resistant hybrids were delayed in their movement from the whorl to the stalk and larval survival was 50% lower on the resistant hybrids than on the susceptible hybrid.

Espino *et al.* (2007) investigated the most susceptible stage of rice panicle development to *Oebalus pugnax* (Fabricius). Plants were infested during one of three stages of panicle development (heading, milk and soft dough). Insects were allowed to feed on the plants for the duration of each stage and then killed. After maturation, panicles were harvested, and grain was hulled and milled. No differences were found in the weight of rough, brown or milled rice infested with *O. pugnax* during different stages of panicle development. Higher percentage of peck was found in grain from panicles infested during dough and milk than in grain from panicles infested during heading. Adult *O. pugnax* caused higher percentage of peck than nymphs in all stages of panicle development.

Farid *et al.* (2007) studied on maize stem borer, *C. partellus* in maize and observed that most of the borer damage occurred when the crop was in early vegetative stage and by the time it reached tasseling, no further increase in damage was observed.

Jindal and Hari (2010) reported that testing maize cultivars for resistance to *C. partellus* could be better done by infesting them at 2.5 week after germination as different components of resistance expressed at this stage. The infestation with

neonate larvae resulted in higher foliage damage and greater dead hearts than with egg masses.

2.2 Standardization of time of application of insecticide against insect-pest:

Insecticides have been in use for the control of *C. partellus* since 1940. Rahman (1944) advocated the use of inorganic insecticides for the control of *C. zonellus*. Various workers including Chatterji *et al*. (1972), Joya and Deshmukh (1973), Agarwal *et al*. (1977) and Mathur and Rawat (1977) found that the maize stem borer was effectively controlled and grain yield was significantly increased by 1 to 3 applications of endosulfan, diazinon and ultra acid.

Halimie *et al*. (1989) reported that carbofuran as a whorl treatment at 0.75 kg a.i. / ha at 25 and 45 days after sowing reduced infestation by *C. partellus* to 6.77 per cent and resulted in the greatest yields and the greatest cost benefit ratio in comparison with other methods of application.

Sekhon *et al*. (1989) observed that seed treatment of maize with carbofuran or spray of deltamethrin or endosulfan at 10 and 25 day old crops or whorl application of carbaryl granules were very effective in controlling the *C. partellus*. Similarly, Moallim (1990) reported that two applications of carbofuran (i.e. at sowing and 20 days after germination) gave good control of the *C. partellus* on sorghum.

The single applications of endosulfan against *C. partellus* at different times in the pre-flowering stages of maize and from early whorl to soft dough stage in grain sorghum were compared with multiple fractions. Based on yield and the incidence of damaged plants, late treatments were more beneficial than early ones (Berg and Rensberg, 1991).

Rensburg and Berg (1992a) investigated insect infestation prior to the early application of insecticides, at anthesis and physiological maturity of the plants. It was found that late insecticide applications were more effective than early ones in reducing insect attack on maize and sorghum at anthesis. Infestation of *B. fusca* and *C. partellus* in maize had increased since anthesis in late application of insecticide. In sorghum both species increased over the same period with both treatments. As a result, damaged sorghum increased to a larger extent up to physiological maturity than maize plant, while more maize stems were ultimately damaged with late than with early insecticide applications. In another study they observed that two

application of insecticide 7 and 8 weeks after emergence of maize and 8-9 weeks after emergence of sorghum gave the best control of *B. fusca* and *C. partellus* (Rensburg and Berg, 1992b).

Ganguli *et al.* (1997) reported that single application of carbofuran 3G @ 7.5 kg/ha in whorl stage in 15 day old day crop proved to be most effective in protecting against *C. partellus* up to 6 day after application. Similarly the spray of endosulfan @ 0.035% was highly effective in protecting the crop when applied 2 days after infestation and moderately effective when applied up to 6 days after infestation. Insecticidal spraying at later stages proved to be ineffective. Javed *et al.* (1998) investigated the economical method of furadan application against *C. partellus* in maize. The insecticide was applied at sowing and whorl application 20 days after germination, soil + whorl application at sowing and 40 DAG, 2 whorl applications 20 and 40 DAG and a control. It is concluded that soil or furrow application of furadan is the most economical and effective method of controlling maize stem borer.

Karungi *et al*. (2000) studied the effect of time and frequency of insecticide application on the field pest infestations on cowpea in Uganda. Results showed that a single spray at budding, flowering and podding had the highest marginal returns (3.12) in comparison to spraying throughout the season (1.77) and at seedling, flowering and podding stages (2.18).

Patel *et al*. (2002) observed that application of insecticides at 50 per cent pod setting of chickpea, effectively prevented the pod damage by pod borer compared to application at 15 days after 50 per cent pod setting and 50 per cent flowering stages.

Ajeigbe and Singh (2006) reported that one spray of insecticide on cowpea at flowering stage was better than one spray at podding. There was no significant difference on yield between no spray and one spray at podding stage.

Saeed *et al.* (2006) studied the efficacy of different insecticides, i.e. monocrotophos, cypermethrin, pyrethroid + methamidophos, chlorpyrifos, bifenthrin and endosulfan against the maize stem borer *C. partellus* infesting maize, Two spray of the above insecticides were administered at 20 days interval at recommended rates. Results revealed that all the insecticides were significantly effective in reducing the maize stem borer infestation compared to the untreated control.

Blandino *et al.* (2008) conducted experiments during 2006 to 2007 to investigate the effect of times of insecticide application on *O. nubilalis.* Seven times of insecticide application were compared from maize flowering to approximately 15 days after the European corn borer flight peak. The treatments applied at 7-15 days before the *O. nubilalis* flight peak showed the best efficacy to control the insect damage on ears. Overall they found that early insecticide treatment were better than treatment applied after the *O. nubilalis* flight peak. In another study on the effects of the timing of insecticide application on European corn borer damage in maize. They found that the optimum time for insecticide application is between the beginning of consistent adult flight activity and the flight peak (Blandino *et al*. 2009).

2.3 To study the effect of low temperature on the development of insect:

Conti (1987) observed that the embryonic development of coccid *Saissetia oleae* (Olivier) was nil at 13^0C and less than 20 per cent mortality was observed in between 18-28^0C. The insect could survive only up to 33^0 C.

Lu *et al*. (1988) studied the effect of temperature on the development, fecundity and multiplication of *Plutella xylostella* (Linnaeus). They reported that the development rate of eggs, larvae and pupae increased at 20-29^0 C but decreased at <16^0 C and >32^0 C. The development threshold of the eggs, larva and nymph was 3.7, 7.4 and 7.7^0 C and the effective accumulated temperature was 30.2, 173.0 and 72.1 day-degrees C, respectively. The survival rate of the eggs, larvae and nymphs, and oviposition rate were highest at 25^0 C. The adult lifespan was longest at 16^0 C and decreased with an increase in temperature.

Rodriguez *et al*. (1989) observed that the effect of temperature on development, survival and reproduction of maize pest, *Diatraea lineolata* (Walkar). They found that developmental times were inversely related to temperature, duration from eggs to adult decreased from 65 days at 22^0C to 39 days at 31^0C. Development time from egg to adult was longer for females than males at 28 and 31^0C. Fecundity, egg viability, oviposition period and adult longevity were reduced with increasing temperature.

Tomkins *et al*. (1989) found linear relationships between developmental rate and temperature for larvae and pupae of *Ctenopseustis inana* (Butler) and *Planotortrix excessana* (Walkar) reared at 11.5, 18.0 and 22.5^0C. Rate of pre-imaginal

development was affected by insect sex and species and larval food plant. *P. excessana* developed faster than *C. inana*.

Igrc (1990) investigated the influence of temperature on development of *Zygogramma suturalis* (Fab.). At a range of 6 constant temperatures between 16 and 27^0 C egg development took from 3 to 18 d. The temperature threshold was 12.5^0 and the thermal constant 56.8^0. At variable daily temperature development lasted 6.04 d with a sum of effective temperature (SET) 57.9^0. At a range of 6 constant temperatures from 19 to 27 degrees larval development took 7 to 34 d, the temperature threshold was 14.8^0 C and the thermal constant 111.1^0. At variable daily temperature the development took an av. of 16.7 d with a mean SET of 106.8^0. Fourth instar larvae enter the soil and pass through prepupal and pupal stages, and the callow adult remains in the soil until it hardens. At variable daily temperature development lasted 6.04 d with a sum of effective temperature (SET) 57.9^0. It was also found that the range of constant temperature from 19 to 27^0 development in the soil took 11 to 29 d, i.e. 4 to 12 for the callow adult. At variable daily temperature development in the soil averaged 19.4 d. The development time from egg to adult at a range of 6 constant temperatures from 19 to 27^0 C took from 25 to 59 d.

Fornasari (1995) studied the effects of temperature on the embryonic development of *Aphthona abdominalis* (Duftschmid) at constant temperatures of 12, 15, 20, 25, 30, 38 and 41^0 C and variable temperatures. Nil development was observed between 12 to 13^0 C. Embryos completed their development at constant temperatures from 15 to 38^0C. The embryo development took 32.6 days at 15^0C, while 4.5 days at 35^0C constant temperatures.

Ponsonby and Copland (1996) investigated the effect of temperature on development and immature survival in the scale insect predator, *Chilocorus nigritus* (Fabricius). They reported that the first-instar larvae did not complete development at 18^0C. However, within the range 20-30^0C, the developmental rate increased with rising temperature. Under laboratory conditions, immature survival rates were highest at 28^0C (52%) and lowest at (and below) 20^0C (17%). First-instar larvae suffered the highest mortality rates, while pupae had the lowest. Under glasshouse conditions, the survival rates were much lower (9% in the winter months and 20% throughout the remainder of the year).

Veeravel and Bhaskaran (1996) observed the temperature-dependent development, adult longevity, fecundity and feeding potential of two coccinellid predators (*Coccinella transversalis* Fabricius and *Menochilus sexmaculatus* Fabricius) under laboratory conditions. They reported that the increase in temperature from 18 to 36^0C resulted in faster development of the predators by reducing the duration of egg, larval and pupal stages at higher temperatures. Adult longevity was greater at 24^0C than at other test temperatures (18 or 30 or 36^0C). Among the adults, the females lived longer and produced more eggs at 30 than at 20^0C.

Vargas *et al*. (1996) investigated the survival and development of immature stages of four Hawaiian fruit flies reared at five constant temperatures ranging from 16 to 32^0C. They reported that species differed most conspicuously in duration of the egg stage and least conspicuously in duration of the pupal stage. Development thresholds were lower for the larval stage than for the egg and pupal stages for all species. Thermal requirements (degree-days) for development in the pupal stage were greater than those for the egg and larval stages in all species, and the requirements of *Bactrocera latifrons* (Hendel) were greater than those of the other species within each stage.

Mohamed (1997) reported that the eggs and pupae of *Pegomyia mixta* (Villeneuve) developed in the temperature range 15-35^0C. The eggs developed in 12.2 days at 15^0C and 3.0 days at 30^0C. Egg hatchability was 80 per cent at 25^0C and 24 per cent at 35^0C. The threshold of egg development was 9.2^0C. The pupal duration was 37.5 days at 15^0C and 11.5 days at 35^0C. The percentage of adult emergence ranged between 78 per cent at 25^0C and 8 per cent at 35^0 C. The threshold for pupal development was 7.5^0C.

Guo *et al*. (1997) investigated the effects of different temperatures (27.8-38^0C) on the duration of nymphal stages, egg laying, pre-oviposition period and longevity of *Nilaparvata lugens* (Stal) under laboratory. The duration of developmental stages increased above 34^0C. They reported that constant high temperature during nymphal development and female stage reduced the egg production in next generation and the shortened life span. Changing high temperature had greater effects on reproduction than constant high temperature.

Barrientos *et al*. (1998) studied on the threshold temperature and thermal constant for development of the South american tomato moth, *Tuta absoluta* (Metrick). The lower threshold temperature from egg to adult was 8.14^0C, for the egg stage averaged 6.9^0C, for larval development 7.6^0C and for pupae 9.2^0C. The thermal constant for egg, larval and pupal development was 103.8^0D, 238.5^0D and 117.3^0D, respectively.

McDonald *et al.* (1998) observed that developmental rate of *Frankliniella occidentalis* (Pergande) increased linearly as rearing temperature increased. It was estimated that 268^0 days, above a threshold temperature of 7.9^0C, were required to complete development from egg to adult.

An experiment was conducted by Pandey and Singh (1998) on effect of temperature on the development and reproduction of a cereal aphid parasitoid, *Lysiphlebia mirzai* (Shuja-Uddin). They studied the effect of different constant temperatures (12, 17, 22, 27 or 32^0C) during the entire life-span of female *L. mirzai*. It affected the longevity of female, life-table parameters, developmental rate, and mortality of developmental stages of the progeny. The parasitoid develops much faster at 32^0C than 12^0C. Higher per cent mortality occurred at 32^0C and 12^0C than at 22^0C. The adult survived much longer (17 days) at the lower extreme temperature than at the higher one. However, net fecundity (daughters/female) and total fecundity rates (progeny/female) were lowest at 12^0C.

Stevens (1998) studied the development and survival of *Chironomus tepperi* (Skuse) at a range of constant temperatures from 12.5 to 37.5^0C. Developmental rate increased with increasing temperature up to 32.5^0C, but fell at 35^0C. Low adult emergence at 37.5^0C precluded a reliable estimate of total development time at that temperature. Degree-days (DD) and developmental zero (DZ) estimates for egg to adult development are 150.5 DD and 10.5^0C for males and 167.1 DD and 10.3^0C for females.

Tsai and Hong (1998) conducted experiment on effect of temperature on development, survivorship, and reproduction of rice root aphid *Rhopalosiphum rufiabdominalis* (Sasaki). They observed that the developmental time from 1st-instar to adult varied from 20.7 days at 10^0C to 4.4 days at 30^0C. The highest net

reproduction rate was recorded at 20^0C (57.23). The optimum range of temperatures for *R. rufiabdominalis* population growth was 20-25^0C.

Yue and Rong (1998) evaluated the development of Asian corn borer, *Ostrinia furnacalis* (Guenee) at constant temperatures of 10, 12, 14, 16, 18, 22, 26, 30 and 34^0 C. The developmental time of the stages decreased as temperature increased. Lower developmental thresholds were estimated to be 10.38, 10.06 and 11.07^0C for eggs, larvae and pupae, respectively. Estimated upper developmental thresholds were 28, 32 and 31^0C for eggs, larvae and pupae, respectively.

Bai and Chen (1998) studied growth and development of *Anopheles dirus* (Peyton & Harrison) at high temperature. The results show that 33 ± 1^0C is the fatal temperature for *A. dirus* eggs. They reported that at high temperatures the life span of adult *A. dirus* is clearly shortened. At 33 ± 1^0C the average LT50 is 1.3 days, which is just 11.1 per cent of it at 25 ± 1^0C.

Torres *et al.* (1998) investigated developmental rates, egg and nymph survival and adult reproduction of *Podisus nigrispinus* (Dallas) under six fluctuating temperatures. They observed that the highest egg-adult development rate was achieved at 25-35^0C. At 10-20^0 C only 7.0 per cent of nymphs reached the adult stage, whereas at 27, 15-25 and 17-27^0 C, 93.0, 87.3 and 91.1 per cent adult emergence was achieved, respectively. The females that emerged at 10-20^0C did no laid eggs, while those at 25-35, 15-25, 17-27 and 27^0C produced a total of 92.1, 453.2, 415.0 and 325.0 eggs, respectively.

Wanderley and Ramalho (1999) investigated development time, survival and thermal requirements of the *Supputius cincticeps* (Stal) at constant temperatures (15, 18, 20, 23, 25, 28, 30, and 33^0C, 70±10 R.H. and LD 14:10). The time required for development from egg to adult ranged from 27.7 (30^0C) to 121 days (15^0C) for males, and from 30.3 (28^0C) to 114.0 days (15^0C) for females. At 33^0C the egg did not hatch. Egg survival ranged from 23.5 (30^0C) to 74.6 per cent (25^0C). Nymphal survival was highest at moderate temperatures, ranging from 3 per cent (15^0C) to 56 per cent (20^0C). Immatures had the highest survival at 20^0C. The lower development threshold temperatures for egg, nymphal development and immature phases were 10.7, 11.0, and 12.0^0C for males, and 10.0, 12.0 and 8.9^0C for females, respectively. Thermal constants for egg, nymphal development and immature phases were 84.6, 410.7 and

440.1 day-degrees C, and 88.2, 440.1 and 643.1 day-degrees C, respectively, for males and females.

Urbaneja *et al*. (1999) reported that complete development of *Phyllocnistis citrella* (Stainton) only occurred between 10 and 35^0C, but eggs and pupae could survive at lower and higher temperatures, respectively. Upper and lower development thresholds were estimated to occur at 37.8 and 8.8^0C, respectively. Maximal development rate occurred at 31.8^0C and the thermal constant was 182.0 DD.

Nagai and Yano (1999) observed development and reproduction of *Orius sauteri* (Poppius) at 4 constant temperatures (15, 20, 25 and 30^0C). Thermal constant and nil developmental for eggs and nymphs of *O. sauteri* were recorded at 62.1 day-degrees and 11.1^0C and 180.8 day-degrees and 10.3^0C, respectively. Egg mortality rate was 7.1 per cent or less. There was no significant difference in survival rate during the nymphal stage among the 4 temperatures. Longevity of female and male adults was greatest at 15^0C and shortest at 30^0C. Female lifetime fecundity reached a maximum at 25^0C. The intrinsic rate of natural increase was highest at 30^0C.

McDonald *et al*. (1999) reported that temperature and rate of development of *Thrips palmi* (Karny) from egg to adult were linearly related between 15 and 30^0 C, allowing calculation of an overall threshold of 10.1^0C, and a sum of effective temperatures of 194 degree-days.

Han *et al*. (1999) reported that development of *Spodoptera exigua* (Hubner) was significantly affected by temperature and relative humidity. The combination of 26^0C and R.H. 80 per cent or 94 per cent was optimal for the development of *S. exigua*.

Ofomata *et al*. (2000) reported that *C. partellus* had higher fecundity at 25^0C and 28^0C, but reduced at 30^0C.

Jalali and Singh (2001) studied the effect of temperature on life cycle of *C. partellus* and its natural enemies. The developmental period decreased with an increase in temperature from 18 to 35^0C and temperature around 25-30^0C was found to be the most ideal for the development and survival. *C. partellus* needed 588.34 degree-days (DD) above 17.6^0 C needed for the completion of all the developmental stages.

Jacob *et al.* (2002) reported that the development time of *C. partellus* and *Chilo orichalcociliellus* (Strant) for the egg, larval and egg-adult life stages were inversely related to temperature. The larval developmental period of *C. orichalcociliellus* reared on artificial diet was longer than the developmental period on natural diet. *C. partellus* had a higher intrinsic rate of natural increase than *C. orichalcociliellus* at all diet/temperature combinations except natural diet at 31º C.

Nishi and Takahashi (2002) observed the effects of temperature on oviposition and development of *Amphibolus venator* (Klug). They reported that the optimum temperature for multiplication and development of *A. venator* was around 32.5^0C. Pre-oviposition period decreased with increasing temperature. Temperature in the range 25-35^0C had no effect on oviposition period. The total oviposition number was highest at 35^0 C. Egg incubation period decreased with increasing temperature, however, hatchability was not affected. The development period of nymphs decreased with increasing temperature.

Jiang *et al.* (2004) examined the survival, development parameters and body growth patterns of the *C. partellus* and its parasitoid, *C. flavipes* at different temperature (22, 26 and 30ºC) using third and fourth instars of *C. partellus*. They observed that development time of *C. flavipes* immatures significantly decreased with host instar and with temperature. The increase in body weight of parasitized fourth instar *C. partellus* was higher than in non-parasitized larvae at all temperature.

The effect of storing eggs of the stalk borer, *Sesamia inferens* (Walkar) of different ages, i.e. freshly laid (<1 day), 1, 2, 3 and 4 days old, at 10^0C for 1, 2, 3, 5, 7, 10 and 15 days on egg hatchability and the extent of infestation of the resultant larvae on maize seedlings was studied under laboratory conditions. Irrespective of age, the egg hatchability was adversely affected as the storage period increased. However, the egg hatch was significantly higher when 4-day-old eggs were stored. The infestation of maize seedlings by the larvae emerging from the treated eggs was adversely affected, the infestation being minimum by the larvae that emerged from <1-day-old eggs stored at 10^0C for different durations (Reddy *et al*., 2005).

Jalali and Singh (2006) also found optimum range of temperature for development of *C. partellus* between 20º-30ºC. The natural enemies at various constant temperatures showed that 25ºC temperatures was most suitable for high

parasitism, emergence, fecundity and longevity, and that between 25º to 32º C was better for faster rate of development. Temperature of >32º C are unsuitable for survival.

Uraichuen *et al.* (2006) studied the effect of temperature on development of *Theocolax elegans* parasitizing maize weevil larvae *Sitophilus zeamais* (Westwood) in brown rice. They observed that as the temperature increased from 20 to 32^0C, the time required for development decreased from 54.4 to 16.2 days and 53.8 to 15.6 days for females and males, respectively. The developmental period at 35^0C was longer than at 32^0C. Males developed faster than females. Adult longevity was greatest at 20^0C (14.5 days for females, 20.6 days for males) and shortest at 35^0C (4.5 days for females, 3.6 days for males).

Diaz *et al*. (2008) studied the influence of nine constant temperatures (8-38^0C) on the developmental time and survival of *Ischnodemus variegates* (Signoret). Complete egg and nymphal mortality occurred at temperatures <=20.5^0C and at 38^0C. Developmental time decreased linearly with temperature until 28-30^0C and then increased at 33^0C. Mortality of first, second, and third instars was high across all temperatures. Developmental time across all temperatures was greatest for eggs, first and fifth instars compared with other stages.

Pandey and Tripathi (2008) investigated the effect of temperature on the development, fecundity, progeny, sex ratio and life table of *Campoletis chlorideae* (Uchida) on larvae of *H. armigera*. They reported that development times shortened as temperature increased from 12 to 13^0C. A reciprocal linear relationship between temperature and longevity was observed in the range of 12-17^0C. The maximum mortality of pupae occurred at 37^0C.

Pizzol *et al.* (2010) reported that *Trichogramma cacoeciae* (Marchal) showed highest fecundity at 25^0C that had been reared at 20 or 25^0C. The highest mortality occurred among wasps that laid eggs at 30^0C. Emergence rates were relatively high at all temperature, 15 to 30^0C.

3. MATERIALS AND METHODS

The materials used and methodology adopted during the present investigation on "Damage potential and control of maize stem borer, *Chilo partellus* (Swinhoe) on maize, Zea *mays* (L.)" are presented here under

3.1 General details of experiment

3.1.1 Site and location of the experiment

The present investigation was carried out at Instructional Farm and Department of Entomology, Rajasthan College of Agriculture, Udaipur, during *kharif* season 2011. Geographically, Udaipur is located at 23.4 ^{0}N longitude and 75 ^{0}E latitude at an elevation of 579.5 MSL in state of Rajasthan.

3.1.2 Climatic and weather condition of the location

The zone has a typical sub-tropical climatic condition characterized by mild winters and moderate summers associated with high humidity especially during July to September. This region provides a safe and long growing season for most of the crops. The maximum and minimum temperature during *kharif* season was 31.9 ^{0}C and 19.2 ^{0}C, respectively. Besides, the maximum and minimum relative humidity was 98.7% and 55.9%, respectively.

3.1.3 Field preparation and layout

After the harvest of previous crop, weeds and stubbles were removed from the field. The experimental field was prepared during the last week of June by ploughing followed by cross harrowing and planking. A well pulverised field was prepared for sowing the maize crop. Recommended doses of nitrogen and phosphorous (80 kg N and 30 kg P_2O_2) were applied to the crop. Half dose of nitrogen and full dose of phasphatic fertilizer were applied at the time of sowing through DAP and Urea, while remaining dose of nitrogen was applied at 30 days after sowing through top dressing with urea. To protect the crop from weeds, two hoeing and weeding was done at 20 and 30 days after sowing.

3.1.4 Meteorological data

The meteorological data for different weather parameters prevailing during the experimentation were obtained from Meteorological Observatory, Rajasthan College of Agriculture, Udaipur. The mean weekly weather parameters of the crop growing period are presented in Appendix-I.

3.2 Rearing of maize stem borer

The rearing of maize stem borer, *C. partellus* is essential to obtain the required number of egg masses, larvae and pupae for the investigation. Therefore, the rearing of *C. partellus* was done on natural food (maize stem). The larvae and pupae of maize stem borer were collected from the maize stem near by maize fields of farmers. The larvae were reared on splitted maize stem and till pupation. The pupae were taken out and kept for adult emergence. After emergence, the adults (male and female) were transferred into egg laying chambers lined with white rice paper for oviposition. Few strips of folded paper were put inside the chambers to provide more area facilitating egg laying. Five cm deep layer of fine sand properly moistened to maintain the humidity of the ovipositional chamber (R.H. 70-80 per cent) was also laid at the bottom. A small cotton swab socked in 10 per cent sugar solution was kept inside the chamber in a small petridish to fulfill the adult's food requirement. The chambers were covered with white muslin cloth and held tightly with rubber bands to prevent the adult exit. These chambers were kept in culture room maintained at 27 ± 2° C and relative humidity 70 ± 5 per cent for egg laying. The eggs laid by the females on the paper were clipped off and healthy egg masses were released on the maize whorl kept in jars (20 × 15 cm^2) for hatching and feeding in early stage.

The food was thoroughly washed with water and excessive moisture was removed by placing them on blotting paper. The glass jars were rinsed with 1 per cent formaldehyde and dried. The food was changed at an interval of 2-3 days regularly till pupation takes place. Twenty five larvae were placed per jar and larvae carefully handled with the help of camel's hair brush. To facilitate pupation 5 cm thick layer of washed and sterilized sandy soil covered with folding of blotting paper was placed at the bottom of each jar and full grown larvae were placed in it. The larvae pupated in blotting paper and splitted maize stem piece were removed and placed in glass jars lined with blotting paper at the bottom and covered with muslin cloth to avail the emergence of adults. The moths after emergence were released in ovipositional chambers for further multiplication and maintenance of culture.

3.3 Identification of vulnerable stage of maize to *Chilo partellus*

To identify the vulnerable stage of maize to *C. partellus*, an experiment was conducted at Instructional Farm, Rajasthan College of Agriculture Udaipur. Pratap Maize-5 was sown on 29th June 2011 at 60 x 60 and 25 x 25 cm row to row and plant to plant spacing. The experiment was laid down in RBD with three replications. Fifteen neonate larvae were released at 7, 9, 11, 13, 15, 17, 19 and 21 days after germination (Table-1) to achieve all categories of leaf injury rating (1-9). There were 12 plants in each row and 10 plants were selected for recording the data. One row with three replications sown were at every infestation dose. Thus thirty plants were taken in consideration for observation of each infestation level. One row was kept control after every infested row. After one month of release of neonate larvae of maize stem borer LIR was recorded (Chatterji *et al*., 1970). Further, plant height (cm) up to tassel base and yield (q/ha) were recorded at 14 per cent moisture. The cob formed on side tillers were discarded for the recording of yield.

Table-1 Plant age at release of neonate larvae of *C. partellus*

S.No.	Treatments (DAG)
T_1	7 Days after germination
T_2	9 Days after germination
T_3	11 Days after germination
T_4	13 Days after germination
T_5	15 Days after germination
T_6	17 Days after germination
T_7	19 Days after germination
T_8	21 Days after germination

Table 2 Leaf injury rating description

LIR	Damaging symptoms on maize plant
1	Apparently healthy plant.
2	Plant showing slight damage on leaf or few pin holes on one to two leaves.
3	Plant showing more pin holes or shot hole in three to four leaves.
4	Plants showing injury (pin holes, shot holes and slits) in about one third of the total number of leaves and mid-rib tunneling on one or two leaves, if any.
5	Plants showing 50 per cent leaf damage (pin holes, shot holes, slits and streaks) and mid-rib damage if any.
6	Plants showing varied type of leaf injury in about two third of total number of leaves.
7	Plant with every type of leaf injury and almost all the leaves damaged.
8	Plant showing maximum leaf injury and likely to form "dead heart" (such plants usually show stunted growth.
9	Plant showing "dead heart".

3.4 Standardization of time of application of insecticide against *Chilo partellus* on maize

To standardize the time of application of insecticide against *C. partellus* on maize, sowing of Pratap Maize -5 was done in 60 x 60 and 25 x 25 cm row to row and plant to plant spacing. This experiment was laid down in a RBD with three replications. There were 13 experimental treatments including an untreated control. The different treatments were created by releasing fifteen first instar larvae after 12 days of germination in the leaf whorl in each treatment. Quinalphos 25 EC was sprayed immediately before and after, 1, 2, 4, 6 and 8 day after the release of stem borer larvae (Table-3). There were 12 plants in each row and only 10 plants were selected for recording the data. One row was kept blank after every treatments row and after one month of release of neonate larvae of maize stem borer, leaf injury rating (1-9) was recorded. Further, plant height (cm) up to tassel base and yield (q/ha) were recorded at 14 per cent moisture. The cob formed on side tillers were discarded for the recording of yield. Tunnel length was recorded after splitting of individual plant.

Table-3 Time of application of insecticide before and after release of neonate larvae of *C. partellus*

S.No.	Treatments (DBS/DAS)
T_1	Release just before spray of quinalphos
T_2	Release one day before spray of quinalphos (1DBS)
T_3	Release two days before spray of quinalphos (2DBS)
T_4	Release four days before spray of quinalphos (4DBS)
T_5	Release six days before spray of quinalphos (6DBS)
T_6	Release eight days before spray of quinalphos (8DBS)
T_7	Immediate release after spray of quinalphos
T_8	Release one day after spray of quinalphos (1DAS)
T_9	Release two days after spray of quinalphos (2DAS)
T_{10}	Release four days after spray of quinalphos (4DAS)
T_{11}	Release six days after spray of quinalphos (6DAS)
T_{12}	Release eight days after spray of quinalphos (8DAS)
T_{13}	Untreated control

3.5 To study the effect of temperature on the development of *Chilo partellus*

3.5.1 Effect of low temperature on the viability of eggs of *Chilo partellus*

To study the effect of low temperature on the viability of eggs of *C. partellus*, a laboratory experiment was conducted at Department of Entomology, Rajasthan College of Agriculture, Udaipur. Seventy-five eggs were kept at different temperature i.e., 3, 5, 7, 9 and 11 ± 1ºC for 7 days. Out of these, 25 eggs were taken out at 3rd, 5th and 7th days and kept at 27ºC ± 1°C temperature and 75 ± 5 per cent relative humidity for larval emergence. Four replications were made for each treatment. Observations on incubation period and per cent hatching were recorded and analyzed by Completely Randomized Design.

3.5.2 Effect of low temperature on the pupal development of *Chilo partellus*

To study the effect of low temperature on the pupal development of *C. partellus,* a laboratory experiment was conducted at Department of Entomology, Rajasthan College of Agriculture Udaipur. Seventy five pupae were stored at 3, 5, 7, 9 and 11 ± 1ºC for 15 days. Out of these, 25 pupae were taken out at 5th, 10th and 15th days and kept at 27ºC ± 1°C temperature and 75 ± 5 per cent relative humidity. Four

replications were made for each treatment. Observations on pupal period, adult emergence, sex ratio, fecundity and adult longevity were recorded and analyzed by Completely Randomized Design. Adult moths generally have dark brown patterned forewings and white to gray-brown hind wings with a wing span of 25-30 mm.

4. RESULTS

The investigation on Damage potential and control of maize stem borer, *C. partellus* in maize was conducted during *Kharif* 2011 and results obtained are presented as bellows

4.1 Identification of vulnerable stage of maize to *C. partellus* / Effect of plant age on damage parameters caused by *C. partellus* and grain yield of maize

In order to identify the vulnerable stage of maize to *C. partellus*, fifteen number of neonate larvae were released at 7 DAG to 21 DAG on Pratap Maize-5 plant, resulted in varied degree of infestation to plants. The severity of infestation affected type of damage symptoms from spiral holes to dead heart. The data thus obtained after one month of release of larvae on damage symptoms (LIR), plant height and yield are presented in Table-4.

4.1.1 Effect of plant age on damage potential (LIR) caused by *C. partellus* in maize

The data on Leaf injury rating (LIR) showed that highest LIR, 9.00, was recorded in 7, 9 and 11 days after germination (T_1, T_2 and T_3)and were statistically at par followed by 8.33, 7.67, 6.67, 4.67 and 3.67 in 13, 15, 17, 19 and 21 DAG (T_4, T_5, T_6, T_7 and T_8) respectively. It is also clear from the table that LIR, 8.33 recorded in 13 DAG (T_4) was at par with T_1, T_2, T_3 and T_5 (7, 9, 11 and 15 DAG) respectively but significantly different from T_6, T_7 and T_8 . LIR recorded in T_5, T_6, T_7 and T_8 also differ statistically to each other.

4.1.2 Effect of plant age at release of *C. partellus* on plant height in maize

It is evident from the data that minimum plant height, 18.53 cm was recorded in T_1 (7 DAG) followed by 19.92, 22.75 and 26.48 cm in 9, 11 and 13 DAG (T_2, T_3 and T_4) respectively. The plant height recorded in other treatments T_5, T_6, T_7 and T_8 (15, 17, 19 and 21 DAG) were 49.13, 98.82, 139.70 and 160.58 cm respectively and were statistically differ to each other.

4.1.3 Effect of plant age at release of *C. partellus* on grain yield of maize

The data on yield (g /plant) showed that maximum plant yield, 102.22 g /plant was recorded at 21 days after germination (T_8) followed by 88.39, 54.82 and 26.87 g / plant in T_7, T_6 and T_5 (19, 17 and 15 DAG) respectively. No yield was recorded in the remaining treatments, T_1 to T_4.

The data computed for total yield showed similar trends wherein maximum yield, 68.14 q/ ha was achieved in T_8 (21 DAG) followed by 58.92, 36.54 and 17.91 q /ha in T_7, T_6 and T_5 (19, 17 and 15 DAG) respectively. No yield was recorded in remaining test treatments.

4.2 Standardization of time of application of insecticide against *C. partellus* on maize

In order to standardize the time of application of insecticide against *C. partellus* neonate larvae were released before and after spray of insecticide (Quinalphos 25EC) on maize. After one month of release of larvae, data on LIR, plant height, tunnel length and yield were recorded and presented on Table-5.

4.2.1 Effect of time of application of insecticide on damage potential (LIR) caused by *C. partellus* in maize

The data recorded (Table-5) on Leaf injury rating (LIR) clearly showed similar effect of insecticide when applied immediate, before and after release. Minimum LIR, 1.00 was recorded in T_1 (release just before spray) and T_7 (release just after spray) followed by 1.07 and 1.10 either one day before or one day after spray and were statistically at par. It is visible from the data that increase in the duration of release either before or after spray increased the LIR showing 2.30 in T_9 (2 DAS) but significantly lower to 2.87 and 2.93 in T_3 and T_{10}. LIR recorded in T_3 and T_{10} was statistically at par but lower to other remaining treatments. The spray of insecticide either 6 day after spray (T_{11}) or 4 day before spray (T_4) resulted in 4.47 and 4.63 LIR, respectively but significantly at par. The intensity of infestation increased if larvae released well before spray or delayed spray of insecticide. LIR 6.54 was recorded in T_5 (6 DBS) followed by 7.77 in T_{12} (8 DAS). Maximum LIR, 9.00 was recorded in control but was statistically at par with 8.70 in T_6 (8 DBS).

4.2.2 Effect of time of application of insecticide on damage potential (plant height) caused by *C. partellus* in maize

The data recorded on plant height (cm) when larvae released before spray or after spray (Table-5) revealed that maximum plant height, 171.85 cm, was recorded in T_7 (immediate release after spray) followed by 169.96, 167.77, 169.32 and 167.04 cm in T_1, T_2, T_8 and T_9, but were statistically at par. It is also visible that plant height recorded in T_1, T_2, T_8 and T_9 were at par with plant height, 164.15 and 164.36 cm, observed in T_{10} and T_3 respectively. The delay in spray or release of larvae well before spray significantly affected the plant height and 134.77, 125.27, 111.41 and 74.59 cm in T_{11} (6 DAS), T_4 (4 DBS), T_5 (6 DBS) and T_{12} (8 DAS) was recorded respectively. Shortest plant height, 32.76 cm was recorded in T_6 (8 DBS) but was at par with 27.02 cm in control (T_{13}).

4.2.3 Effect of time of application of insecticide on damage potential (tunnel length) caused by *C. partellus* in maize

The data recorded on tunnel length in different treatments (Table-5) before or after spray of release significantly gave the impact. None of the plant in T_1, T_2, T_3, T_7, T_8, T_9 and T_{10} resulted in tunnel formation due to effect of insecticide while in T_6 and T_{13} all plants were transformed to dead hearts. Minimum tunnel length, 1.46 cm, was observed in T_{12} followed by 3.79, 3.90 and 4.12 cm in T_{11}, T_4 and T_5 respectively.

4.2.4 Effect of time of application of insecticide on damage potential (grain yield) caused by *C. partellus* in maize

The data recorded on plant yield (Table-5) showed that highest plant yield, 119.94 g /plant, was recorded in T_7 (immediate release after spray) followed by 118.27, 118.06 and 117.67 g /plant in T_1 (immediate release before spray), T_8 (1 DAS) and T_2 (1 DBS), respectively with non significant difference to each other. The yield recorded in treatments T_3, T_9 and T_{10} varied from 109.02 to 113.15g /plant and was statistically at par. It is also visible that yield observed in T_9 (2 DAS) was significantly at par with T_1, T_2, and T_8. Plant yield observed in T_{12} (42.14 g) was significantly lowest followed by 67.48, 89.31 and 90.78 g /plant in T_5 (6 DBS), T_4 (4DBS) and T_{11} (6 DAS) respectively. No yield could be harvested in T_6 and T_{13} due to complete transformation of plants in dead hearts. Similar results were obtained when plant yield was computed for total yield (q /ha). No yield could be harvested in

T_6 (8 DBS) and T_{13} (control) due to complete transformation of plants in dead hearts whereas maximum yield, 79.95 q /ha, was recorded in T_7 followed by 78.84, 78.70 and 78.44 q /ha in T_1, T_8 and T_2 respectively. Yield recorded in T_3, T_9 and T_{10} was 73.32, 75.43 and 72.67q /ha respectively. Minimum yield, 28.10 q /ha was recorded in T_{12} (8DAS) followed by 44.98, 59.53 and 60.51 q /ha in T_5 (6 DBS), T_4 (4 DBS) and T_{11} (6 DAS) respectively.

4.3 To study the effect of low temperature on development of *Chilo partellus*

4.3.1 Effect of low temperature on the viability of eggs of *C. partellus*

The eggs of *C. partellus* were stored at low temperature, 3 to 11^0C for 3 to 7 days to find out the effect on incubation period and viability of eggs.

4.3.1.1 Effect of temperature on incubation period of eggs of *C. partellus*

Eggs of *C. partellus* were stored at 3 to 11^0C temperature for 3 to 7 days to find out the effect of temperature on incubation period and data recorded are presented in Table-6. The data showed that maximum incubation period, 8.13 days, was recorded at 3^0C followed by 7.34 days at 5^0C when eggs were stored for 3 days. Minimum incubation period, 6.21 days, was recorded at 11^0C followed by 6.47 and 6.73 days at 9 and 7^0C respectively but were statistically at par. Eggs stored for 5 days at different temperature showed that maximum incubation period, 10.88 days, was recorded at 3^0C followed by 10.22 days but was statistically at par. The incubation period, 9.3 days, was observed at 7^0C followed by 9.18 days at 9^0C but no significant difference was recorded in between. Minimum incubation period, 8.45 days, was recorded at 11^0C which was statistically different to other test temperatures.

The incubation period was enhanced when stored for longer period, 7 days at different test temperature. Maximum incubation period, 13.20 days, followed by 12.76 days was recorded at 3 and 5^0C respectively but significantly different to each other. Minimum incubation period, 10.91 days, was recorded at 11^0C but statistically different to 11.72 and 11.86 days observed at 9 and 7^0C respectively. No significant difference was observed in incubation period recorded at 7 and 9^0C.

4.3.1.2 Effect of temperature on viability of eggs of *C. partellus*

Data recorded on effect of temperature on hatching are presented in Table-7. It is clear from the data that hatching of eggs are dependent on temperature. Minimum hatching 15.0 per cent, was observed at 3^0C under 3 days storage and was significantly lowest to all test temperatures. Maximum hatching 73.0 per cent, was observed at 11^0C followed by 69.0 per cent at 9^0C but was statistically at par. No significant difference in hatching was observed at 5 and 7^0C and was 49.0 and 61.0 per cent respectively.

Data recorded for hatching at different temperature stored for 5 days showed that maximum hatching, 59.0 per cent was observed at 11^0C but was statistically at par with 55.0 per cent at 9^0C. Minimum hatching 9.0 per cent, was observed at 3^0C followed by 27.0 and 42.0 per cent at 5 and 7^0C respectively and significantly different to each other.

Similar results were observed when eggs stored for 7 days at different temperature. Maximum hatching 36.0 per cent, was observed at 11^0C followed by 33.0 per cent at 9^0C but were statistically at par. Minimum hatching, 5.0 per cent was observed at 3^0C followed by 13.0 and 22.0 per cent at 5 and 7^0C respectively and were statistically different to each other.

4.3.2 Effect of low temperature on the pupal development of *C. partellus*

The pupae of *C. partellus* were stored at low temperature, 3 to 11^0C for 5 to 15 days to find out the effect on pupal period, adult emergence, sex ratio, fecundity and adult longevity.

4.3.2.1 Effect of temperature on pupal development of *C. partellus*

The pupae of *C. partellus* were stored at different temperature, 3 to 11^0C for varied duration, 5 to 15 days, to find out the effect of temperature on pupal period and data recorded are presented in Table-8. The data showed that significantly longer pupal period, 16.42 days, was recorded at 3°C followed by 15.25, 14.46, 13.58 and 13.07 day at 5, 7, 9 and 11^0C respectively. It is also apparent from the data that pupal period recorded at 5°C was statistically at par with 7 and 9^0C while pupal period observed at 9^0C was also at par with 11^0C. Pupae stored for 10 days at different temperatures showed that maximum pupal period, 22.68 days, was observed at 3^0C

followed by 21.85 days at 5^0C but was statistically at par. The pupal period, 20.94 days observed at 7^0C was also at par with 5^0C. Minimum pupal period, 18.95 days, was observed at 11^0C followed by 19.72 days and was statistically at par.

The pupal period was enhanced when stored for longer period, 15 days at different test temperature. Longest pupal period, 29.11 days, was recorded at 5^0C followed by 27.47 and 26.71 days at 7 and 9^0C respectively. It is also evident from the table that pupal period recorded at 5^0C was significantly different to each other test temperatures while at 7 and 9^0C were at par statistically. Shortest pupal period, 24.92 days, was recorded at 11^0C and was significantly different to others.

4.3.2.2 Effect of temperature on adult emergence of *C. partellus*

The data recorded on adult emergence after storage at different temperature *viz*., 3, 5, 7, 9 and 11^0C for varied durations *viz*., 5, 10 and 15 days are presented in Table-9. It is evident from the data that storage of pupae for 5 days at low temperature, 3^0C, adversely affected the adult emergence, 12.0 per cent only and was significantly low compared to 41.0, 58.0, 65.0 and 69.0 per cent at 5, 7, 9 and 11^0C respectively. The increase in the temperature i.e. 7 to 11^0C did not affected adult emergence and was found statistically at par. The storage of pupae for 10 days at test durations showed little variation on adult emergence being significantly maximum 55.0 per cent at 11^0C followed by 48.0, 38.0, 20.0 and 7.0 per cent at 9, 7, 5 and 3^0C respectively. The data also showed that adult emergence at 9^0C was at par with T_3 (7^0C) and T_5 (11^0C) while T_1 (3^0C) and T_2 (5^0C) was significantly different to each other.

The effect of temperature on adult emergence after storage of pupae for maximum duration, 15 days, showed very significant difference among test temperatures. No emergence was observed at 3^0C while 9.0, 21.0, 31.0 and 40.0 per cent was achieved at 5, 7, 9 and 11^0C respectively.

4.3.2.3 Effect of temperature on sex ratio of *C. partellus*

The data recorded on sex ratio after storage of pupae at different temperature *viz*., 3, 5, 7, 9 and 11^0C for varied durations *viz*., 5, 10 and 15 days are presented in Table-10. It is very clearly observed that sex ratio is affected significantly with temperature. Storage of pupae for 5 days at varied temperature *viz*., 3 to 11^0C had

varied sex ratio from 0.68 to 0.94 being maximum female oriented at 11^0C and minimum at 3^0C. Similar results were recorded when pupae were stored for 10 days. More female biased sex ratio, 0.94 was recorded at 11^0C followed by 0.88, 0.81, 0.65 and 0.43 at 9, 7, 5 and 3^0C respectively. Low temperature, 3^0C, for 15 days completely inhibited the pupal development with nil adult emergence while significant more female biased sex ratio, 0.91, was recorded at 11^0C followed by 0.83, 0.72 and 0.57 at 9, 7 and 5^0C respectively.

4.3.2.4 Effect of temperature during storage on fecundity of *C. partellus*

The data recorded on fecundity of females after storage of pupae at different temperature *viz*., 3, 5, 7, 9 and 11^0C for varied duration *viz*., 5, 10 and 15 days are presented in Table-11. It is evident from the data that storage of pupae for 5 days at low temperature, 3^0C adversely affected the fecundity, 49.75 eggs /female and was significantly low compared to 83.50, 127.25, 153.75 and 184.75 eggs /female at 5, 7, 9 and 11^0C respectively. Fecundity recorded at all test temperatures were significantly different to each other. The storage of pupae at different temperature for 10 days showed similar effect on fecundity of females which ranged from 31.5 to 168.75 eggs /female. The effect of temperature on fecundity after storage of pupae for maximum duration, 15 days, showed very significant difference among test temperatures. Nil fecundity was observed at 3^0C, while 39.75, 90.50, 130.25 and 151.50 eggs /female were achieved at 5, 7, 9 and 11^0C respectively. All treatments were significantly different to each other.

4.3.2.5 Effect of temperature on adult longevity of *C. partellus*

The data recorded on adult longevity after storage of pupae at different temperatures *viz*., 3, 5, 7, 9 and 11^0C for varied durations *viz*., 5, 10 and 15 days are presented in Table-12. It is visible from the data that storage of pupae for 5 days at low temperature, 3^0C adversely affected the adult longevity, 1.50 days only and significantly low as compared to 2.75, 3.0 and 3.75 days at 7, 9 and 11^0C respectively and statistically at par with 2.25 days at 5^0C. The increase in temperature from 7 to 11^0C also increased the longevity of adults. It is evident from the table that adult longevity recorded at 7^0C was statistically at par with 5, 9 and 11^0C, while, maximum longevity observed at 11^0C was at par with 7 and 9^0C only.

The adult longevity recorded at 10 days storage of pupae on different temperature showed that longest longevity, 3.25 days was observed at 11^0C but was statistically at par with 2.5, 2.25 and 2.0 days at 9, 7 and 5^0C respectively. It is also evident from the table that longevity recorded at 5^0C was at par with 7^0C also. Shortest longevity and significantly different, 1.25 days, was recorded at 3^0C. The effect of temperature on adult longevity after storage of pupae for maximum duration, 15 days showed no adult emergence resulting nil adult longevity at 3^0C, while 1.75, 2.0, 2.75 and 3.0 days longevity was achieved at 5, 7, 9 and 11^0C respectively. It is also evident from the table that longevity recorded at 5, 7 and 9^0C was statistically at par while longevity observed at 9^0C was also non-significantly different to 11^0C.

5. DISCUSSION

5.1 Identification of vulnerable stage of maize to *C. partellus* / Effect of plant age on damage parameters caused by *C. partellus* and grain yield of maize

The artificial infestation of maize plant at 7 to 21 DAG, with fifteen neonate larvae exhibited varying degree of infestation in the plants. This shows variability in resistance at different plant stages. The infestation caused by larvae was graded after one month of release as per the exhibited Leaf Injury Rating (LIR) (Chatterji *et al.* 1969). These infestations differ from spiral holes and slits in few leaves to all leaves, dead hearts and holes in the stems and the grading of these symptoms is represented as LIR scale (1-9). The plant which showed low LIR, 1-3 is considered as resistant, > 3 to 6 as moderate resistant and > 6 to 9 as susceptible against *C. partellus* under screening programme of germplasms. In the present investigation, the results obtained on effect of plant age on damage parameters caused by *C. partellus* in Pratap Maize-5 and maize yield are discussed herewith as under.

5.1.1 Effect of plant age on damage potential (LIR) caused by *C. partellus* in maize

The results obtained on LIR in Pratap Maize-5 during 2011 are presented in Table-4 and depicted in Fig-2. It is evident from the table that LIR among different plant age varied from 3.67 to 9.00. It is also apparent from the table that increase in plant age from 7 DAG to 21 DAG significantly decreased the damage symptoms and thus LIR. The release of fifteen larvae at 7 to 11 DAG resulted in complete transformation of plant to the dead heart with 9.00 LIR, while release of larvae at 13 DAG also gave high LIR 8.33 and significantly at par with 7 to 11 DAG. The LIR recorded in plants with 15 to 21 DAG (T_5 to T_8) varied from 7.67 to 3.67 and differ statistically to each other also. The results clearly show that plant develop resistance against *C. partellus* in progressive age. Release of fifteen larvae at 19 to 21 DAG did not caused much damage and ranked as moderate resistant category, while the similar number of neonate larvae released in early stage of plant up to 17 days considered as susceptible for infestation of maize stem borer.

5.1.2 Effect of plant age at release of *C. partellus* on plant height in maize

The results obtained on plant height (cm) in Pratap maize-5 during 2011 are presented in Table-4 and depicted in Fig.2. It is evident from table that plant height at different age varied from 18.53 to 160.58 cm, due to infestation of *C. partellus* and differ significantly to each other. Maximum plant height, 160.58 cm was obtained when larvae were released at oldest stage, 21 DAG, while minimum plant height, 18.53 cm was recorded at earliest plant age, 7 DAG. Though release of larvae made at 7 DAG resulted in shortest plant height but also does not differ significantly from 19.92, 22.75 and 26.48 cm at 9, 11 and 13 DAG, respectively. It showed that the release of larvae at older age of plant could not affect the height of plant due to development of resistance against maize stem borer compared to earlier stage. The plant height recorded at 15, 17, 19 and 21 DAG was 49.13, 98.82, 139.70 and 160.58 cm, respectively and differ statistically to each other.

5.1.3 Effect of plant age at release of *C. partellus* on grain yield of maize

The results obtained on grain yield (g / plant) in Pratap Maize-5 during 2011 are presented in Table-4 and depicted in Fig.-2. It is evident from table that plant does not yield any grain when neonate larvae were released at 7, 9, 11and 13 DAG because plants were transformed to dead hearts. The release of larvae at older stage of plant 15, 17, 19 and 21 DAG recorded mean yield of 26.87, 54.82, 88.39 and 102.22 g / plant and differ significantly to each other. The data recorded for yield per plant were computed for yield /hectare which show similar results being maximum yield, 68.14 q /ha, in T_8 followed by 58.92, 36.54 and 17.91 q / ha in T_7, T_6 and T_5 respectively and differ statistically to each other. The data showed that plant could yield when release was made at older stage and it would be the result of development of resistance against maize stem borer in later stage.

The present findings are in agreement with the work of Sarup *et al*. (1977) who reported that the most critical stage of maize crop growth i.e. 10 day old plants succumb even to as low a population as 10 eggs per plant. Ampofo (1989) observed that some varieties showed high levels of resistance against *C. partellus* at the whorl stage in Kenya while susceptible at the flowering stage in terms of larval establishment, growth and development, severity of damage to the plants and loss in grain yield. Infestation of the plant near maturity resulted in minimal yield loss.

Similarly, Maredia and Mihm (1990) also reported that damage caused by southwestern corn borer varies as per the plant stage. They observed that infestation was highest at 4-5 leaf stage and declined with the age of plants, the decline was less between the 4-5 and 6-8 leaf stage than between the 6-8 and 9-11 leaf stages. They also reported that 6-8 fully extended leaf stage would be the best stage for artificial infestation of southwestern corn borer. In contrary Davis *et al*. (1991) observed that degree of resistance or susceptibility in maize against southwestern corn shift with plant growth stage and found low level of resistance when infested in the reproductive stage of growth.

The investigations conducted by Reddy and Sum (1991) also confirm the present findings. They found that artificial infestation of *C. partellus* in maize crop at 20, 40 and 60 day old plants resulted in maximum yield reduction and stalk damage at 20 day old crop while there was non significant larval effect on the yield of 60 day old crop. Kumar (1994b) also of the similar opinion that artificial infestation by 1st generation of *C. partellus* on maize during the early whorl stage resulted in significantly greater population and more damage than released on anthesis. Koc and Tusuz (1995) observed suitable plant stage for artificial infestation of *O. nubilalis* started just before tasseling time and continued to flowering time for evaluation of stalk resistance and flowering time and beyond for evaluation of ear resistance. Moyal (1995) was of the similar opinion and found that early infestation until 17 days after maize emergence by *Busseola fusca* (Fuller) resulted in dead hearts or in growth reduction. Similarly, Davis *et al*. (1996) also reported significant differences in rating scores when *Spodoptera frugiperda* was released at different planting date and plant growth stage. Similarly, Sadek and Metwally (2002) reported that infestation of *O. nubilalis* made at anthesis stage of maize plant growth resulted in the highest infestation and the lowest grain yield. Lourencao and Santos (2005) supported the present investigation that maize plants at 8 and 10 leaf stages were more susceptible to *S. frugiperda* with losses of 11.1 to 15.4 per cent respectively. Similarly, Farid *et al*. (2007) also reported that early vegetative stage is most susceptible to the stem borer *C. partellus* and no increase in damage at tasseling. Jindal and Hari (2010) was also of the opinion that artificial release of *C. partellus* in maize up to at 2.5 week after germination resulted in better explanation of resistance because different components of resistance expressed at this stage.

5.2 Standardization of time of application of insecticide against *C. partellus* on maize

The release of larvae at 12 DAG in Pratap Maize-5 either before and after spray at different intervals resulted in varying degree of damage symptoms in the plants. LIR was recorded after one month of release of larvae on different treatments. Besides, plant height, tunnel length and yield was also recorded to compare the effect of time of spray of insecticide either before or after release. The data thus gathered are discussed herewith as under:

5.2.1 Effect of time of application of insecticide on damage potential (LIR) caused by *C. partellus* in maize

To find out the exact time of application of insecticide on damage potential caused by *C. partellus* spray was done at different intervals before or after release and data recorded presented in Table-5 and depicted in Fig.-3. It is evident from the Table that release of larvae either before or after spray at different interval caused significantly difference in LIR. Among the treatments related with before spray (T_1 to T_6), maximum LIR, 8.70 was recorded in T_6 (8 DBS) followed by 6.54, 4.63, 2.87, 1.10 and 1.00 in T_5 (6 DBS), T_4 (4 DBS), T_3 (2 DBS), T_2 (1 DBS) and T_1 (release just before spray) respectively. It is also clear from the data that LIR recorded in T_1 and T_2 does not differ significantly and plant apparent as free from infestation while, release of larvae well before from 4 DBS to 8 DBS in T_4 to T_6 resulted in severe infestation.

The data recorded on LIR on released plants after spray of insecticide showed that application of insecticide at duration of release adversely affected the development of *C. partellus* resulting less damage potential. Minimum LIR, 1.00 was noted when insecticide was sprayed and then after larvae were released followed by 1.07 LIR in T_8 (1 DAS) and no significant difference was observed. Delayed application of insecticide favoured the development and enhance the damage potential as maximum LIR, 7.77 was recorded in T_{12} (8 DAS) followed by 4.47, 2.93 and 2.30 in T_{11} (6 DAS), T_{10} (4 DAS) and T_9 (DAS) respectively. It is also apparent from the data that closure release either before or after spray as evidence in T_1, T_2, T_7 and T_8 was almost free from insect infestation and was at par. Similarly, LIR recorded in T_3 (2 DBS) and T_{10} (4 DAS) or T_5 (4 DBS) and (T_{11}) (6 DAS) was statistically at par. Maximum LIR, 9.00 was observed when no insecticide was applied after release of

larvae (control) but was at par with 8.70 in T_6 (8 DBS) showed nil effect of insecticide.

5.2.2 Effect of infestation of *C. partellus* on plant height either before or after spray

To find out the effect of infestation on plant height caused by neonate larvae of *C. partellus*, spray was made at different interval on before or after release and data recorded are presented in Table-5 and depicted in Fig.-3. It is evident from the table that release of larvae either before or after spray at different interval caused significant difference in plant height. Among the treatments related with before spray (T_1 to T_6), maximum plant height, 169.96 cm was observed in T_1 when release was made immediately before spray followed by 167.77, 164.36, 125.27, 111.41 and 32.76 cm in T_2, T_3, T_4, T_5 and T_6 respectively. It is also clear from the data that plant height recorded in T_1, T_2 and T_3 does not differ significantly and plant exhibited little effect of infestation on height. Minimum height, 32.76 cm, was observed in T_6 (8 DBS) showed adverse effect of damage on height and was significantly different than T_1, T_2, T_3, T_4 and T_5 but at par with control, 27.02 cm. Release of larvae well before application of insecticide helped the insect to enter in the stem and may be resulting decrease in plant height.

The delayed application of insecticide in treatments T_7 to T_{12} at different interval showed significant impact of insecticide on damage resulted in variation in plant height. The higher plant height was observed when insecticide was sprayed closure to the time of release. Maximum plant height, 171.85 cm, was recorded in T_7 but was at par with 169.32 and 167.04 cm in T_8 (1 DAS) and T_9 (2 DAS) respectively. Plant height, 164.15 cm, was observed in T_{10} (4 DAS) and was statistically at par with T_8 and T_9 but different to 134.77 and 74.59 cm in T_{11} (6 DAS) and T_{12} (8 DAS) respectively.

Among all treatments, it is imperative that release of larvae either before spray in T_1 or T_2 and after spray in T_7, T_8 and T_9 was statistically at par. This expressed that spray of insecticide closure either before or after release did not had much impact. However delayed spray either before release or after release after spray had significant effect and plant height was reduced drastically.

5.2.3 Effect of time of application of insecticide in tunnel length caused by *C. partellus* in maize

To evaluate the time of application of insecticide on damage potential in term of tunnel length, spray was done at different interval either before or after release and data recorded are presented in Table-5 and depicted in Fig.-3. It is visible from the table that insect infestation was not severe in T_1 (release just before spray), T_2 (1 DBS), T_3 (2 DBS), T_7 (immediate release after spray), T_8 (1 DAS), T_9 (2 DAS) and T_{10} (4 DAS), no tunnel was formed. However, plants in T_6 (8 DBS) and T_{13} (control) were completely transformed in dead hearts which also lead to nil tunnel length. Shortest tunnel length, 1.46 cm, was observed in T_{12} (8 DAS) but was in relation with plant height. Tallest tunnel length, 4.12 cm, was observed in T_5 (6 DBS) followed by 3.90 and 3.79 cm in T_4 (4 DBS) and T_{11} (6 DAS) respectively.

5.2.4 Effect of time of application of insecticide on damage potential (grain yield) caused by *C. partellus* in maize

To find out the correct time of application of insecticide for protection of yield loss caused by *C. partellus*, spray was made at different interval of before or after release and data recorded presented in Table-5 and depicted in Fig.-3. It is evident from the table that release of larvae either before or after spray at different interval caused significantly difference in yield. No yield was recorded in treatment T_6 (8 DBS), and T_{13} (control) respectively due to complete loss of plants in form of dead hearts. The data showed that maximum yield, 119.94 g /plant was recorded in T_7 (immediate release after spray) followed by 118.27, 118.06 and 117.67 g /plant in T_1 (release just before spray), T_8 (1 DAS) and T_2 (1 DBS) respectively and was statistically at par. It is also clear from the data that closure spray of insecticide either before or after release does not have any significant difference. Yield obtained, 113.15 g /plant, in T_9 (2 DAS) was at par with T_1, T_2, T_3, T_7, T_8 and T_{10} respectively. Minimum yield, 42.14 g /plant, was recorded in T_{12} (8 DAS) followed by 67.48, 89.31, 90.78, 109.02 and 109.99 g /plant in T_5, T_4 (4 DBS), T_{11} (6 DAS), T_{10} (4 DAS) and T_3 (2 DBS) respectively and was statistically different to each other except to T_3 and T_{10}. The data clearly indicate that either release of larvae well before spray of insecticide or delayed release did not protect the crop against the damage caused by *C. partellus*, however, spray closure at release significantly reduced the damage resulting in increase of yield. Data computed for hectare yield also showed similar

interpretation wherein maximum yield, 79.95 q /ha was recorded in T_7 followed by 78.84, 78.70 and 78.44 q /ha in T_1, T_8 and T_2 respectively and were statistically at par. Minimum yield, 28.10 q /ha, was recorded in T_{12} followed by 44.98, 59.53, 60.51, 72.67 and 73.32 q /ha in T_5, T_4, T_{11}, T_{10} and T_3 respectively. Yield recorded in T_4 and T_{11} was statistically at par while T_3 and T_{10} was at par.

The present findings are supported by many workers. Berg and Rensberg (1991) investigated the impact of single application of endosulfan against *C. partellus* at different times in the pre-flowering stages of maize and from early whorl to soft dough stage in grain sorghum. Based on yield and incidence of damaged plants, late treatments were more beneficial than early ones. The similar results were confirmed by other studies of Rensberg and Berg (1992a and 1992b). Ganguli *et al.* (1997) found that single application of carbofuran 3G @ 7.5 Kg/ha in whorl stage in 15 day old crop was very effective against *C. partellus*. Similarly spray of endosulfan 2 days after infestation was more effective than 6 days after infestation of *C. partellus* on maize crop.

Our results are also supported by the investigation of Blandino *et al*. (2008 and 2009) who compared the efficacy of insecticide from maize flowering to approximately 15 days after the European corn borer flight peak. The treatments applied at 7-15 days before flight peak of *O. nubilalis* showed best efficacy.

The effect of insecticide either before or after damage was also investigated in other crop ecosystem by several workers. Karungi *et al*. (2000) reported that single application of insecticide at budding, flowering and podding in cowpea against field pest had highest marginal returns (3.12) in comparison to spray throughout the season (1.77) and at seedling, flowering and podding stages (2.18). Patel *et al*. (2002) observed that application of insecticide at 50 per cent pod setting of chickpea effectively prevented the pod damage by pod borer compared to application at15 days after 50 per cent pod setting and 50 per cent flowering stages. Ajeigbe and Singh (2006) found that one spray of insecticide on cowpea at flowering stage was better than one spray at podding.

5.3 To study the effect of low temperature on development of *C. partellus*

5.3.1 Effect of low temperature on the viability of eggs of *C. partellus*

The eggs of *C. partellus* were stored at low temperature, 3 to 11^0C for 3 to 7 days to find out the effect on incubation period and viability of eggs.

5.3.1.1 Effect on incubation period:

The data observed on incubation period (Table-6 and Fig.- 4) of eggs of *C. partellus* clearly showed that decrease in temperature prolong the incubation period. Storage of eggs at 3^0C for 3 days significantly increase the incubation period, 8.13 days, in comparison to 7.34, 6.73, 6.47 and 6.21 days at 5, 7, 9 and 11^0C respectively. Minimum incubation period, 6.21 days, was recorded at 11^0C and was found statistically at par with 6.73 and 6.47 days at 7 and 9^0C respectively.

It is also clear from the table that effect of temperature, 5 and 7^0C, for 5 and 7 days storage of eggs were at par but were significantly different to other test treatments. Longest incubation period, 10.88 days, for 5 days storage was observed at 3^0C followed by 10.22, 9.30, 9.18 and 8.45 days at 5, 7, 9 and 11^0C respectively. It is also visible from the data that storage of eggs at 7 and 9^0C though reduced the incubation period but non significant difference was observed. Highest temperature, 11^0C, gave the shortest incubation period, 8.45 days and significantly different to each other.

Almost similar results were observed for when eggs were stored for 7 days at different temperature. Longest incubation period, 13.20 days was observed at 3^0C followed by 12.76 days at 5^0C but was statistically at par. Incubation period, 11.86 days was recorded at 7^0C was at par with 11.72 days at 9^0C. Shortest incubation period, 10.91 days, was observed at 11^0C and was statistically different to each other.

5.3.1.2 Effect on hatching of eggs:

Data observed for hatching of eggs (Table-7 and Fig.- 5) clearly showed that storage of eggs at minimum temperature affected the development adversely and resulting in lowest hatching. This effect was enhanced when stored for prolong duration. Highest temperature, 11^0C gave the maximum hatching but were at par with 9^0C for all test duration. Maximum hatching, 73.0 per cent, was recorded at 11^0C when eggs were stored for 3 days followed by 69.0 per cent at 9^0C but statistically

were at par. The hatching observed at 7^0C was 61.0 per cent but was at par with 49.0 per cent at 5^0C. Minimum hatching, 15.0 per cent, showed significant inhibitory effect on development. Similar results were observed when eggs were stored for 5 days. Minimum hatching, 9.0 per cent, was observed at 3^0C followed by 27.0 and 42.0 per cent at 5 and 7^0C and were significantly different to each other. Maximum hatching, 59.0 per cent, was recorded at 11^0C but was statistically at par with 55.0 per cent at 9^0C. The storage of eggs for longer duration, 7 days, at test temperatures resulted in varied hatching, 5.0 to 36.0 per cent. Minimum hatching, 5.0 per cent, was recorded at 3^0C followed by 13.0 and 22.0 per cent at 5 and 7^0C and were significantly different to each other. Maximum hatching, 36.0 per cent, was observed at 11^0C followed by 33.0 per cent at 9^0C and was statistically at par.

The findings of present investigation are in close conformity with the results of many workers. Lu *et al.* (1988) reported that the development rate of eggs increased at 20-29^{0}C but decreased at $<16^0$ C and $>32^0$ C and survival rate of eggs were highest at 25^0C. Similarly, Rodriguez *et al.* (1989) observed that developmental times of *Diatraea lineolata* were inversely related to temperature and egg viability was reduced with increasing temperature. Igrc (1990) also observed the similar findings against *Zygogramma suturalis* where at a range of 6 constant temperatures between 16 and 27^0C egg development took from 3 to 18 days.

In another experiment on *Aphthona abdominalis*, Fornasari (1995) reported nil embryonic development between 12 to 13^0C while embryos complete their development at constant temperature from 15 to 38^0C. The embryo development took 32.6 days at 15^0C while 4.5 days at 35^0C constant temperature. Mohamed (1997) was also of the similar opinion who observed that eggs of *Pegomyia mixta* developed in 12.2 days at 15^0C and 3.0 days at 30^0C. Egg hatchability was 80 per cent at 25^0C and 24 per cent at 35^0C. Yue and Rong (1998) reported that the developmental time of different life stages of *Ostrinia furnacalis* decreased at temperature increased. Lower inhibitory developmental thresholds for egg were 10.38 and 28^0C respectively. Wanderley and Ramalho (1999) observed that eggs survival of *Supputius cincticeps* ranged from 23.5 (30^0C) to 74.6 per cent (25^0C) and lower development threshold temperature for egg was 10.7^0C. Jacob *et al.* (2002) reported that the development time of *C. partellus* and *C. orichalcociliellus* for egg was inversely related to temperature. Nishi and Takahashi (2002) also found that egg incubation period of

Amphibolus venator decreased with increasing temperature, however, hatchability was not affected. Reddy *et al*. (2005) reported that the egg hatchability was adversely affected by temperature as the storage period increased.

5.3.2 Effect of low temperature on the pupal development of *C. partellus*

The pupae of *C. partellus* were stored at low temperatures, 3 to 11^0C for 5 to 15 days to find out the effect on pupal period, adult emergence, sex ratio, fecundity and adult longevity.

5.3.2.1 Effect on pupal period:

The data observed on pupal period of *C. partellus* at different temperatures under varied durations, 5, 10 and 15 days are presented in Table- 8 and depicted in Fig.- 6. It is evident from the data that the decrease in temperature either prolonged the pupal period or inhibited development completely. The pupal period was also prolonged when pupae were stored for longer duration as compared to shorter duration at any temperature. Storage of pupae at 3^0C for 5 days significantly increase the pupal period, 16.42 days in comparison to 15.25, 14.46, 13.58 and 13.07 days at 5, 7, 9 and 11^0C respectively. Minimum pupal period, 13.07 days was recorded at 11^0C. It is also evident from the table that pupal period observed at 5, 7 and 9^0C were dissimilar but were statistically at par. Storage of pupae for 10 days at 3^0C significantly enhanced the pupal period, 22.68 days followed by 21.85, 20.94, 19.72 and 18.95 days at 5, 7, 9 and 11^0C respectively. It is also visible from the data that 9 and 11^0C had non significant difference on pupal period while 7^0C was statistically at par with 5^0C. The prolonged storage of pupae at test temperatures significantly affected the pupal period being significantly longest, 29.11 days followed by 27.47 and 26.71 days at 7 and 9^0C and were statistically at par. Significantly shortest pupal period, 24.92 days, was recorded at 11^0C. No emergence was emerged at 3^0C under 15 days storage.

The present findings are in close conformity with the investigation of Mohamed (1997) who reported that the pupal duration of *Pegomyia mixta* was 37.5 days at 15^0C and 11.5 days at 35^0C with 7.5^0C threshold for pupal development. Similarly, Vargas *et al*. (1996) observed survival and development of immature stages of four Hawaiian fruit flies reared at five constant temperatures ranging from 16 to

32^0C. They reported that thermal requirements for development in the pupal stage were greater than egg and larval stages in all species. In contrary Urbaneja *et al.* (1999) reported that pupae of *Phyllocnistis citrella* could survive at lower (10^0C) and higher temperature (35^0C) respectively.

5.3.2.2 Effect on adult emergence:

Data recorded on adult emergence (Table-9 and Fig.-7) clearly showed that varied temperatures and durations greatly affected the adult emergence and statistically differed to each other. Adult emergence at 3, 5, 7, 9 and 11^0C under 5 days storage were 12.0, 41.0, 58.0, 65.0 and 69.0 per cent respectively while at 10 days were 7.0, 20.0, 38.0, 48.0 and 55.0 per cent respectively. No adult emergence was recorded at 3^0C under 15 days storage while at 5, 7, 9 and 11^0C was 9.0, 21.0, 31.0 and 40.0 per cent respectively. This clearly emphasized that increase in temperature significantly increase the adult emergence while increase in duration at different temperature decreased the adult emergence.

The results of present investigation were also supported by Torres *et al*. (1998) who observed that at 10-20^0C, only 7 per cent nymphs of *Podisus nigrispinus* (Dallas) could reached the adult stage, whereas at 27, 15-25 and 17-27^0C, 93.0, 87.3 and 91.1 per cent adult emergence was achieved respectively.

5.3.2.3 Effect on sex ratio:

The data recorded on sex ratio of *C. partellus* after storage of pupae at different temperature under varied duration (Table-10 and Fig.-8) clearly showed that sex ratio is affected significantly with temperature. It is evident from the data that increase in temperature favoured more female biased sex ratio. All temperatures, 3, 5, 7, 9 and 11^0C were significantly different to each other under varied durations, 5, 10 and 15 days. Maximum female biased sex ratio, 0.94 and 0.91 was observed under 5, 10 and 15 days duration while minimum, 0.43 was observed at 3^0C under 10 days storage. No adults were observed under 15 days storage at 3^0C.The data clearly showed that prolonged storage at lowest temperature inhibited the pupal development resulted in no adult emergence.

5.3.2.4 Effect on fecundity:

Data recorded on fecundity of females of *C. partellus* emerged from stored pupa at different temperatures under varied durations (Table-11 and Fig.-9) clearly showed that storage of pupae for 5 days at lowest temperature, 3^0C adversely affected the fecundity, 49.75 egg /female compared to 83.50, 127.25, 153.75 and 184.75 egg /female at 5, 7, 9 and 11^0C respectively and was significantly different to each other. The number of eggs laid by female emerged from stored pupae for 10 days were maximum, 168.75 eggs, at 11^0C followed by 136.50, 99.25, 63.75 and 31.50 egg /female at 9, 7, 5 and 3^0C and statistically different to each other.

Similar effect of temperature on fecundity of females was observed under 15 days storage which ranged from 39.75 to 151.50 eggs /female at 5 to 11^0C and also differ to each other significantly. No adults were observed at 3^0C under 15 days storage of pupae.

5.3.2.5 Effect on adult longevity:

The data recorded on adult longevity of *C. partellus* (Table-12 and Fig.-10) under varied temperatures and durations clearly showed that the storage of pupae for 5 days at low temperature, 3^0C adversely affected the adult longevity, 1.50 days and significantly low as compared to 2.75, 3.0 and 3.75 days at 7, 9 and 11^0C respectively and statistically at par with 2.25 days at 5^0C. Adult longevity recorded at 7^0C was statistically at par with 5 and 9^0C. Maximum adult longevity, 3.75 days, was observed at 11^0C but was at par with 7 and 9^0C. The adult life span observed at test temperatures, 3 to 11^0C under 10 days storage resulted in varied longevity, 1.25 to 3.25 days being maximum at 11^0C and minimum at 3^0C. The longevity observed at 11^0C was also found statistically similar to 5, 7 and 9^0C. The adult longevity observed under 15 days storage at test temperatures showed that maximum longevity, 3.0 days, was observed at 11^0C and minimum, 1.75 days, at 5^0C but no adults were emerged at 3^0C. Overall impact of temperature on adult life span after storage of pupae at different temperatures showed that increase in temperature increased the longevity while decrease in temperature drastically reduced the longevity.

Many workers have conducted the experiments on the effect of temperature on biological parameters of adult *viz.,* sex ratio, fecundity and longevity etc. The results of present investigation are in close conformity with the findings of other workers. Lu

et al. (1988) reported that adult life span of *Plutella xylostella* (Linnaeus) decreased with an increase in temperature and was longest at 16^0C. Similarly Rodriguez *et al.* (1989) reported that fecundity, oviposition period and adult longevity of *Diatraea lineolita* (Walkar) were reduced with increasing temperature. The work conducted by Veeravel and Bhaskaran (1996) also confirmed the findings of present investigation wherein increase in temperature from 18 to 36^0C resulted in faster development of the predators, *C. transversalis* and *M. sexmaculatus*. Adult longevity was greater at 24^0C than at other test temperatures (18 or 30 or 36^0C). Among the adults, the females lived longer and produced more eggs at 30 than at 20^0C. Mohamed (1997) of the opinion that adult emergence of *Pegomyia mixta* ranged between 78 per cent at 25^0C and 8 per cent at 35^0C.

Bai and Chen (1998) reported that at high temperatures, the life span of adult *Anopheles dirus* is clearly shortened. At 33 ± 1^0C, the average life time is 1.3 days, which is just 11.1 per cent of it at 25 ± 1^0C. Torres *et al*. (1998) also reported the adverse effect of temperature on *Podisus nigrispinus*. They observed that at 27, 15-25 and 17-27^0C, adult emergence was, 93.0, 87.3 and 91.1 per cent respectively. The females that emerged at 10-20^0C did not laid eggs, while those at 25-35, 15-25, 17-27 and 27^0C produced a total of 92.1, 453.2, 415.0 and 325.0 eggs, respectively. In contrary of results of present investigation Nagai and Yano (1999) observed that longevity of females and males of *O. sauteri* was greatest at 15^0C and shortest at 30^0C. Female life time fecundity reached a maximum at 25^0C. Similarly, Uraichuen *et al*. (2006) also reported that adult longevity of *Sitophilus zeamais* was greatest at 20^0C (14.5 days for females and 20.6 days for males) and shortest at 35^0C (4.5 days for females and 3.6 days for males). Pandey and Tripathi (2008) also reported that development time of *Compoletis chlorideae* on larvae of *H. armigera* shortened as temperature increased from 12 to 13^0C. A reciprocal linear relationship between temperature and longevity was observed in the range of 12-17^0C.

6. SUMMARY

The results obtained under the present study "Investigations on Damage Potential and Control of Maize Stem Borer, *Chilo partellus* (Swinhoe) on Maize, *Zea mays* (L.)" are summarized below:

The data recorded on Leaf injury rating (LIR) in Pratap Maize-5 clearly showed that plant acquire resistance against neonate larvae of *C. partellus* in older stage as compared to earlier stage. The selection of plants for artificial release of larvae at later stage withstand the infestation. It is evident from the data that release of larvae up to 11 days after germination resulted in complete transformation of plants into dead hearts with maximum LIR, 9.0. The LIR observed after release of larvae at 13 days after germination was 8.33. Minimum LIR, 3.67 was obtained at 21 days after germination followed by 4.67, 6.67 and 7.67 at 19, 17 and 15 days after germination respectively and was significantly different to each other.

The data revealed that plant height varied from 18.53 to 160.58 cm, after the release of larvae at 7 to 21 DAG. It is also evident from the table that increase in age of plant for artificial release of larvae of *C. partellus* from 7 to 21 days significantly increase the plant height. Minimum plant height, 18.53 cm, was recorded at 7 DAG followed by 19.92, 22.75 and 26.48 cm at 9, 11 and 13 DAG respectively which showed that plants were very suscepltible up to this stage to the infestation of *C. partellus*.

The data on plant yield (g /plant) showed that release of larvae after 21 DAG resulted in maximum yield, 102.22 g /plant followed by 88.39 and 54.82 g /plant at 19 and 17 DAG respectively. The release of larvae at 7 to 13 DAG destroyed the plants completely and no yield was recorded. The results clearly emphasized that maize plants are very susceptible up to 13 DAG and this stage can be used under artificial infestation for screening of germplasms.

The effect of insecticide when applied immediate before or after release of larvae showed difference in Leaf injury rating (LIR), plant height, tunnel length and yield. It is apparent from the data that release of larvae just before and immediate after spray gave minimum LIR, 1.0, maximum plant height, 169.96 and 171.85 cm, nil tunnel length and maximum plant yield, 118.27 and 119.94 g /plant respectively and

was significantly different to each other treatments. The release of larvae one days before and after application of insecticide also gave similar results wherein, 1.10 and 1.07 LIR, 167.77 and 169.32 cm plant height, nil tunnel length and 117.67 and 118.06 g /plant yield was recorded respectively. It is also evident from the data that spray of insecticide two days before or after release also had significant impact on larval development, thus resulted in less LIR, 2.87 and 2.30, plant height, 164.36 and 167.04 cm, nil tunnel length and good plant yield, 109.99 and 113.15 g /plant respectively. The release of larvae well before spray (8 DBS) gave high LIR, 8.70, lowest plant height, 32.76 cm, nil tunnel length and no yield and was statistically at par with control. Delayed in release of larvae after spray (8 DAS) also helped insect to develop comfortably and gave 7.77 LIR, 74.59 cm plant height, 1.46 cm tunnel length and 42.14 g /plant plant yield. It is clearly depicted from the data that insecticide are effective against *C. partellus* for 2 days in before spray while up to 4 days in after spray of insecticide and then after toxic effects decreased.

The results obtained on incubation period of eggs of *C. partellus* showed that it varied with storage time and temperature. It is evident from the data that increase in the temperature decreased the incubation period. Storage of eggs for 3 days at 3^0C resulted in longest incubation period, 8.13 days followed by 7.34, 6.73, 6.47 and 6.21 days at 5, 7, 9 and 11^0C respectively. Increase in temperature from 7 to 11^0C had statistically similar effect on incubation period while at 3 and 5^0C differ significantly. The increase in duration of storage of eggs (5 days) of *C. partellus* resulted in varied impacts wherein 3 and 5^0C gave longest incubation period, 10.88 and 10.22 days respectively but statistically at par. Similarly, at 7 and 9^0C, incubation period was 9.30 and 9.18 days but statistically at par and significantly different to 8.45 days at 11^0C. The storage of eggs for prolonged duration (7 days) also had the similar results as at 5^0C wherein longest incubation period, 13.20 days was observed at 3^0C and shortest, 10.91 days at 11^0C.

The data on hatching of eggs of *C. partellus* at different temperature after storage for varied duration clearly indicated that low temperature, 3^0C, inhibited development and significantly minimum hatching, 15.0, 9.0 and 5.0 per cent was observed at 3, 5 and 7 days respectively. Maximum hatching, 73.0, 59.0 and 36.0 per cent was recorded at 11^0C when stored for 3, 5 and 7 days respectively. It is indicated from the data that storage for short duration at test temperature had less effect on

hatching while it increased progressively in prolonged duration. Almost similar trends are observed in all treatments but was statistically at par with 69.0, 55.0 and 33.0 per cent at 9^0C for 3, 5 and 7 days storage respectively.

The observations recorded on pupal period at different temperatures *viz.*, 3 to 11^0C under varied storage durations 5 to 15 days showed that decrease in the temperature either prolonged the pupal period or inhibited development completely. The pupal period was also prolonged when pupae were kept for longer duration compared to shorter duration at any temperature. Longest pupal period, 16.42 days, was observed at 3^0C under 5 days storage while shortest duration, 13.07 days, was recorded at 11^0C. Though pupal period observed at 5, 7 and 9^0C were dissimilar but were at par statistically. For storage of 10 days, longest pupal period, 22.68 days, was observed at 3^0C and shortest, 18.95 days at 11^0C and were statistically different to each other. No adult were emerged at 3^0C when pupae were stored for 15 days. Among the remaining treatments, longest pupal period, 29.11 days, was observed at 5^0C while shortest, 24.92 days, at 11^0C. The effect of temperature on pupal period at 7 and 9^0C was almost similar and was statistically at par.

Adult emergence from pupae of *C. partellus* under varied temperature and duration greatly differ to each other. Adult emergence at different test temperature under 5, 10 and 15 days ranged from 12.0 to 69.0, 7.0 to 55.0 and 9.0 to 40.0 per cent respectively. No adults were emerged at 3^0C under 15 days storage. Increase in temperature is directly proportional to adult emergence.

Sex ratio exhibited at different temperature under different storage period showed that decrease in temperature favoured more female biased sex ratio. All test temperatures, 3, 5, 7, 9 and 11^0C were significantly different to each other under all test durations, 5, 10 and 15 days. Less female, 0.68 to 0.43 were observed at 3^0C while females were increased comparatively to 0.94, 0.94 and 0.91 at higher temperature 11^0C under 5, 10 and 15 days storage respectively. Very similar trends in fecundity was observed wherein low temperature retarted the fecundity while higher temperature favoured the fecundity. Number of eggs observed at 3, 5, 7, 9 and 11^0C under 5, 10 and 15 days ranged from 49.75 to 184.75, 31.5 to 168.75 and 39.75 to 151.50, respectively and were statistically different to each other.

The adults emerged from pupae stored at 3 to 11^{0}C for 5 to 15 days showed significant effect on adult longevity. Shortest life span of adult, 1.5 and 1.25 days, was observed at lowest temperature, 3^{0}C under 5 and 10 days storage respectively while longest life span, 3.75, 3.25 and 3.0 days was recorded at 11^{0}C under 5, 10 and 15 days respectively.

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Table 4: Effect of plant age on damage parameters caused by *C. partellus* and grain yield of maize

S.No.	Treatments (DAG)	LIR	Plant height (cm)	Plant yield (g/plant)	Total yield (q/ha)
T_1	**7**	9.00	18.53	0.00	0.00
T_2	**9**	9.00	19.92	0.00	0.00
T_3	**11**	9.00	22.75	0.00	0.00
T_4	**13**	8.33	26.48	0.00	0.00
T_5	**15**	7.67	49.13	26.87	17.91
T_6	**17**	6.67	98.82	54.82	36.54
T_7	**19**	4.67	139.70	88.39	58.92
T_8	**21**	3.67	160.58	102.22	68.14
SEm±		0.271	5.642		
CD (P = 0.05)		0.822	17.113		
CV (%)		6.473	14.587		

DAG = Days after germination

Table 5: Effect of time of application of insecticide on damage parameters caused by *C. partellus* in maize

S.No.	Treatments (DBS/DAS)	LIR	Plant height	Tunnel length	Plant yield	Total yield

			(cm)	(cm)	(g/plant)	(q/ha)
T_1	**Release just before spray**	1.00	169.96	0.00	118.27	78.84
T_2	**1 DBS**	1.10	167.77	0.00	117.67	78.44
T_3	**2 DBS**	2.87	164.36	0.00	109.99	73.32
T_4	**4 DBS**	4.63	125.27	3.90	89.31	59.53
T_5	**6 DBS**	6.54	111.41	4.12	67.48	44.98
T_6	**8 DBS**	8.70	32.76	0.00	0.00	0.00
T_7	**Immediate release after spray**	1.00	171.85	0.00	119.94	79.95
T_8	**1 DAS**	1.07	169.32	0.00	118.06	78.70
T_9	**2 DAS**	2.30	167.04	0.00	113.15	75.43
T_{10}	**4 DAS**	2.93	164.15	0.00	109.02	72.67
T_{11}	**6 DAS**	4.47	134.77	3.79	90.78	60.51
T_{12}	**8 DAS**	7.77	74.59	1.46	42.14	28.10
T_{13}	**Untreated control**	9.00	27.02	0.00	0.00	0.00
SEm±		0.113	2.121		1.871	
CD (P = 0.05)		0.333	6.238		5.463	
CV (%)		4.778	2.843		3.846	

DBS = Days before spray
DAS = Days after spray

Table 6: Effect of temperature on incubation period of eggs of *C. partellus*

S.No.	Treatments (^{0}C)	Mean incubation period (days) at different storage periods		
		3 Days	**5 Days**	**7 Days**
T_1	**3**	8.13	10.88	13.20
T_2	**5**	7.34	10.22	12.76
T_3	**7**	6.73	9.30	11.86

T_4	**9**	6.47	9.18	11.72
T_5	**11**	6.21	8.45	10.91
SEm±		0.236	0.229	0.226
CD(P=0.05)		0.712	0.690	0.683
CV (%)		6.779	4.769	3.747

Table 7: Effect of temperature on viability of eggs of *C. partellus*

S.No.	**Treatments (^{0}C)**	**Mean hatching (%) at different storage periods**		
		3 Days	**5 Days**	**7 Days**
T_1	**3**	22.67 (15.00)	17.39 (9.00)	12.76 (5.00)
T_2	**5**	44.42 (49.00)	31.23 (27.00)	21.10 (13.00)
T_3	**7**	51.44 (61.00)	40.38 (42.00)	27.86 (22.00)
T_4	**9**	56.42 (69.00)	47.89 (55.00)	35.03 (33.00)
T_5	**11**	58.94 (73.00)	50.23 (59.00)	36.83 (36.00)
SEm±		2.593	1.668	1.386
CD(P=0.05)		7.816	5.027	4.179
CV (%)		11.086	8.912	10.379

Figures in parentheses represent retransformed per cent values

Table 8: Effect of temperature on pupal development of *C. partellus*

S.No.	**Treatments (^{0}C)**	**Mean pupal period (days) at different storage periods**		
		5 Days	**10 Days**	**15 Days**
T_1	**3**	16.42	22.68	0.00
T_2	**5**	15.25	21.85	29.11
T_3	**7**	14.46	20.94	27.47
T_4	**9**	13.58	19.72	26.71

T_5	**11**	13.07	18.95	24.92
SEm±		0.333	0.417	0.306
CD(P=0.05)		1.005	1.258	0.923
CV (%)		4.581	4.008	2.830

Table 9: Effect of temperature on adult emergence of *C. partellus*

S.No.	Treatments (^{0}C)	Mean adult emergence (%) at different storage periods		
		5 Days	**10 Days**	**15 Days**
T_1	**3**	20.14 (12.00)	14.94 (7.00)	0.57 (0.00)
T_2	**5**	39.75 (41.00)	26.51 (20.00)	17.39 (9.00)
T_3	**7**	49.71 (58.00)	38.01 (38.00)	27.16 (21.00)
T_4	**9**	53.86 (65.00)	43.83 (48.00)	33.80 (31.00)
T_5	**11**	56.51 (69.00)	47.88 (55.00)	39.15 (40.00)
SEm±		2.855	1.96	1.649
CD(P=0.05)		8.605	5.91	4.970
CV (%)		12.978	11.46	13.964

Figures in parentheses represent retransformed per cent values

Table 10: Effect of temperature on sex ratio of *C. partellus*

S.No.	Treatments (^{0}C)	Proportion of female to male at different storage periods		
		5 Days	10 Days	15 Days
T_1	3	55.56 (0.68)	36.62 (0.43)	5.74 (0.00)
T_2	5	59.71 (0.74)	53.95 (0.65)	50.18 (0.57)
T_3	7	63.25 (0.79)	64.52 (0.81)	58.59 (0.72)
T_4	9	67.31 (0.84)	72.66 (0.88)	68.36 (0.83)
T_5	11	75.50 (0.94)	79.90 (0.94)	74.70 (0.91)
SEm±		0.054	0.117	0.104
CD(P=0.05)		0.165	0.353	0.315
CV (%)		13.740	31.617	34.607

Figures in parentheses represent retransformed values

Table 11: Effect of temperature during storage on fecundity of *C. partellus*

S.No.	Treatments (^{0}C)	Mean fecundity / female at different storage periods		
		5 Days	10 Days	15 Days
T_1	3	49.75	31.50	0.00
T_2	5	83.50	63.75	39.75
T_3	7	127.25	99.25	90.50
T_4	9	153.75	136.50	130.25
T_5	11	184.75	168.75	151.50
SEm±		3.549	4.412	3.208
CD(P=0.05)		10.697	13.298	9.668
CV (%)		5.925	8.829	7.786

Table 12: Effect of temperature on adult longevity of *C. partellus*

S.No.	Treatments (^{0}C)	Mean adult life span (days) at different storage periods		
		5 Days	10 Days	15 Days
T_1	3	1.50	1.25	0.00
T_2	5	2.25	2.00	1.75
T_3	7	2.75	2.25	2.00
T_4	9	3.00	2.50	2.75
T_5	11	3.75	3.25	3.00
SEm±		0.347	0.392	0.353
CD(P=0.05)		1.047	1.183	1.065
CV (%)		26.234	34.901	37.216