CHAPTER II

REVIEW OF LITERATURE

Both paddy and polished rice are attacked by insect pests of various species. The damage caused by insect in stored grains in tropical and sub-tropical region of the world are very common (Freeman, 1973). In this regard, North Eastern Region with high humidity (70-98%) and temperature (16°-37°C) offers most favourable climate for the rapid multiplication of insect-pest in general and the stored paddy in particular. This region receives high amount of rainfall spread over 8-10 months of a year. All these factors are conducive to the rapid multiplication of insect-pest in the stored paddy. A brief review of literature related to various aspects of the stored grain pests, which throws light upon research done in India and abroad are discussed.

2.1 Sources of infestation of *Sitophilus oryzae* Linn. and *Sitotroga cerealella* Oliv.

2.1.1 Pre-harvest infestation

The Rice weevil (*Sitophilus oryzae* Linn.) and Grain moth (*Sitotroga cerealella* Oliv.) are the most serious insect pests of paddy in stores. However, little attention has so far been paid to study the pre-harvest infestation of paddy by these insect-pests. There are various records of incidence of field infestation from different countries including India.

According to Fletcher (1921) the occurrence of *S. cerealella* as pest of stored grains and on ripe ears of paddy, wheat and other cereals in the field are common, even though farmers have no knowledge about it.
Douglas (1941) reported that the extensive damage of rice grains was caused by the field population of *S. oryzae* and *S. cerealella*.

According to Caswell (1962) the damage of grains in the range of 8-10 per cent at harvest and 30-50 per cent during storage are caused by *S. oryzae* while investigation of Russell (1962) revealed that 22.2-57.1 per cent damage to standing corn caused by *S. cerealella*.

Studies conducted by Williams and Floyd (1970) and Chesnut (1972) reported that the greatest flight activity of *Sitophilus* spp. was found in the field at pre-harvest period of corn; while Giles and Ashman (1971) revealed that the weevil infestation in the preharvest stage was inversely proportional to the distance from the edge of the field and storage receptacles.

In India the crop field did not remain unattacked by *S. oryzae* and *S. cerealella*. Khare *et al.* (1970) and Khare (1972) reported field infestation by stored grain pests from U.P. Kittur and Patel (1972) also observed up to 3.19 per cent initial field infestation in rice varieties with a mean of 0.33 per cent by these stored grain pests.

Agrawal *et al.* (1977) studied the pre-harvest infestation of wheat by stored grain insects at varying distances around godowns and villages. They recorded *S. cerealella* and *S. oryzae* infesting standing wheat crop for the first time from Punjab. More infestation was recorded in samples collected around the godowns in villages.

Singh *et al.* (1978) reported that the grain moth (*Sitotroga cerealella* Oliv.) infestation in standing paddy and maize crops; while *Sitophilus* spp. was reported to infest only standing maize crop in the field.
Their investigation further revealed that the grain moth infested the crops even upto 1000 meters and maize weevil upto 800 meters from the villages. They also recorded higher infestation in the samples collected from short distances from the villages as compared to longer distances (i.e. the source of infestation). This shows that infestations were more in the fields that were nearer to the villages.

In a study conducted by Cogburn and Vick (1981) on the distribution pattern of *S. cerealella* in rice fields in Texas (USA) found their higher intensity near storage facilities, a sharp decline in their number to a distance of 250 meters and then their numbers were almost constant to a distance of 500 meters. Moreover, they reported the occurrence of the moth at a distance of 900 meters from a known source of infestation.

Prakash and Rao (1986) reported field infestation of *S. cerealella* on standing paddy crops within 1 km from source of its infestation and also stated that it migrates horizontally in storage and cause considerable losses. Latent infestation of this insect is common through its minute eggs hidden in old containers and depositions on a used structure. Since this pest infests different kinds of cereals, cross infestation from one commodity to another is also common, when more than one kinds of cereals are stored in the single storage premises.

Howlader and Matin (1988) reported pre-harvest infestation of paddy by *S. cerealella* in the paddy fields of Bangladesh. They observed more numbers of the species emerged on the days nearer to the harvest, but as the distance from the store increased their population also showed a sharp decline.
Tripathi et al. (1992) reported that *S. cerealella* as one of the important pests of stored grains as well as in the field on the ripe ears of paddy (*Oryza sativa*) and cholam (*Sorghum vulgare*).

Singh and Khare (1993) found the field infestation of *S. cerealella* and further development of this insect during storage of grains.

Sinha (1999) stated that *S. oryzae* and *S. cerealella* infest seed crops at reproductive stage in the field. They come along with the harvested produce and multiply during pre-storage or storage period. The infestation is normally detected at the time of adult emergence.

### 2.1.2 Grain residues and debris

According to Srivastava et al. (1973) rice weevil and grain moth thrived on grain residues of wall cavities, scrappings and debris. Whereas, Rao et al. (1973) stated that sweeping from the store houses are a major source of infestation of *S. oryzae*.

Dhaliwal (1977) reported that dumping of old infested gunny bags and all sorts of junk materials near the bins served as a source of cross infestation of rice weevil and grain moth.

Prakash and Rao (1983) suggested that the cracks and crevices in old traditional structures need perfect cleaning. These then become reposing for dusts and spoilage, harbour stages of insects which at later period damage the grains at storage.

Press et al. (1984) recovered a sizeable population of *S. oryzae* from the vicinity of storage and stated that one of the major sources of infestation are the scattered storage debris found near the storage.
Barker and Smith (1987) reported that the main source of infestation of stored grain insect pests including *S. oryzae* and *S. cerealella* are the grain residues present in the wall cavities of storage bins.

Singh and Khare (1993) reported that the female of *S. cerealella* prefers cracks and crevices for oviposition.

Sinha (1999) reported that the godowns and other storage receptacles are the major sources of infestation of adults and larval stages of *S. oryzae* and *S. cerealella*, as both these stages hide in the grain residues and debris of storage receptacles. He further stated that insect of both the species hide in between weavings or corners and infest the grain when stored in old gunny bags containers.

### 2.1.3 Alternate hosts /Other plants in field vicinity

There is no revealing account of alternate host / secondary host spectrum of *S. oryzae* and *S. cerealella*. But Howe (1965) reported the occurrence of *Sitophilus granarius* and *S. oryzae* in split acorns. Joubert (1966) reported heavy infestation of *Sitotroga cerealella* in *Sorghum alnum, S. halepense* and *S. verticilliflorum, S. versicolor*, wild millet along with *Setaria nigrirostris* and *Panicum deustum*. Furthermore, he stated that no species of *Sitophilus* bred on kaffir corn, millets and grasses.

Zohary (1969) reported that wild cereal grasses have formed a part of the alternate host complex of *S. oryzae*.

Cogburn and Vick (1981) searched alternate hosts among the seeds of common weed species *viz.*, morning glory, day flower, broad leaf signal grass, nash, jungle rice, hemp, sickle pod, coffee, sena and red root
pigweed. They revealed to be not alternate hosts for *S. cerealella* as none of the seeds supported development of the pest. But they recorded population of this moth species from pasture land and forests and this was attributed to the existence of some unidentified plants in nature. Cogburn *et al.* (1989) found *S. cerealella* in wild *oryzae* species.

Tripathi *et al.* (1992) studied the relative effect of different natural foods on the growth and development of *Sitotroga cerealella*. He reported that there was no development of larvae on oilseeds, dried fruits, spices and condiments.

### 2.1.4 Crevices of tree barks

Chittenden (1911), Cotton and Good (1937) and Linsley (1944) reported that the bark of trees usually provide a micro-environment for development of stored product insects.

There are very little informations on the occurrence of *Sitophilus* spp. and *S. cerealella* in the habitat of barks of trees. Presence of *Sitophilus* spp. in the bark of *Sesbania sesban* and in dry fruits as evident in the report of Mayne and Donnis (1962) and Giles and Ashman (1971).

### 2.2 Distribution of *S. oryzae* and *S. cerealella*

#### 2.2.1 Global distribution of *S. oryzae* and *S. cerealella*

The global distribution of *S. oryzae* and *S. cerealella* in different parts of the world have been reviewed and presented in Table 1.

#### 2.2.2 Distribution of *S. oryzae* and *S. cerealella* in India

Considerable informations are available on distribution of *S. oryzae* and *S. cerealella* in India. Lefroy (1906) reported *S. oryzae*
and *S. cerealella* to be major pest of cereals in India. Fletcher (1914) recorded rice weevil and grain moth as important pests of paddy, wheat, barley and jowar in West Bengal, both in fields and stores. Fletcher (1921) further reported occurrence of *S. oryzae* and *S. cerealella* as pest of stored grains and on ripe ears of paddy, wheat and other cereals in the field. Back and Cotton (1931) mentioned that the grain moth was distributed in entire India. Rahman (1942) described *S. oryzae* and *S. cerealella* as most destructive pests of rice, maize, wheat and jowar in Punjab.

Sharma and Bhalla (1964) suggested that the rice weevil and the grain moth were the most important insect pests of rice in Himachal Pradesh. Mookherjee *et al.* (1968) reported that *S. oryzae* and *S. cerealella* were the two important pests of stored rice in eastern and central parts of India.

Mazumdar *et al.* (1973) and Baruah (1976) recorded heavy damage to stored grains under different storage condition of Assam. Deka (1981) found high infestation of *S. oryzae* and *S. cerealella* in stored rice in districts of lower Assam. *S. oryzae* and *S. cerealella* were reported to be associated with stored rice, maize and wheat in North-eastern States of India (Anonymous, 1982).

Chakravarty and Das (1983) recorded *S. oryzae* and *S. cerealella* as major pests of stored rice and wheat in West Bengal. Lal and Srivastava (1985) indicated that rice weevil and grain moth were fairly widespread in Madhya Pradesh causing severe damage to stored cereals. Pandey and Das (1985) reported the abundance and extent of losses caused by *S. oryzae* and *S. cerealella* to stored rice in Tripura.
Table 1. Global distribution of *S. oryzae* and *S. cerealella*

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Barwal and Devi (1993) reported *S. oryzae* and *S. cerealella* as major pests of wheat, wheat flour and maize.

### 2.3 Storage Ecosystem

#### 2.3.1 Storage receptacles

Food grains, immediately after threshing are stored for consumption, seed, sale and feeding purposes in the farm level storage structures by the farmers. The farmers use in general low cost locally made storage structures which vary in type, shape, dimension and making raw materials. Different district or agro-climate zones within the state have different types of storage structures with varied technology.
Stahl (1950) summarized the functional requirement of storage facility to protect the grain from the excessive moisture, insects and from temperature favourable for insects, to provide convenience and safety while moving grain in and out of storage.

Pruthi and Singh (1950) described that under air tight condition, the grain remained free from insect attack and if they are present, they did not breed and ultimately died. This was apparently due to accumulation of carbon dioxide in air spaces between the grains which was produced as a result of normal respiration of insect and grains.

Pruthi and Singh (1950), Chatterjee (1956) and Pradhan & Mookherjee (1969) indicated that multiplication of insects were arrested if the storage structures were sufficiently air tight.

Pingale (1961) considered an ideal storage structure, which is capable of maintaining grain cool and free from temperature fluctuation, insects, rodent and bird and capable of being rendered airtight.

Willson et al. (1970) recorded the storage loss of 2.4 and 6.2 per cent due to insects in indigenous bulk storage after four and seven months of storage respectively and in bag storage the grains sustained 2.7 and 4.3 per cent loss for the corresponding period of storage.

Sitotroga cerealella has been found to cause a greater extent of damage to grains when stored in small sized structure. Thus, Mazumdar et al. (1973) summerized that the size of the storage structures has a great role to play in regard to extent of damage caused by S. cerealella. Srivastava et al. (1973) working with indigenous storage structures recorded 9.7 per cent weight loss and 30.1 per cent kernel damage after six months of storage.
Yadav and Pant (1976) recorded very little infestation of grains in airtight receptacles viz., polythene bag and in tin storage without significant variation in moisture content. The grains stored in an airtight compartment in underground pits lined with polythene sheet was reported to have very low infestation (Anon. 1976).

Dhaliwal (1977) reported that the insect infestation of wheat grains in airtight structure was recorded to be 0.74, 1.59, 1.61 per cent in metal bin and 0.33, 1.00, 1.33 per cent in "Pucci Kothi" during 3, 6 and 9 months of storage period. Maximum infestation of 2.33 per cent was recorded in bag storage and the low infestation level in metal bins and "Pucci Kothi" was attributed to airtightness of these structures.

Khound (1977) reported that in Assam 'tom' is extensively used by the farmers for storing paddy for seed purpose.

Mitra Mazumdar (1978) made an investigation on the degree of rice grains damage by S. oryzae in different types of storage conditions. He recorded 7.8 and 9.7 per cent grain damage during three and six months of storage in polythene bag (airtight condition) due to attack of S. oryzae. The degree of infestation reached to the tune of 15.9 and 18.5 per cent when stored in hessian cloth bag (ventilated condition) during the corresponding period. Further, he recorded 1.45 and 1.65 per cent grain damage during 3 and 6 months of storage respectively, when grains were stored in metallic bin (airtight condition). During the corresponding period of storage he reported that infestation in 'tom' was of 1.83 and 2.16 per cent respectively.
In an experiment conducted to estimate the damage caused to stored grains in ventilated condition in storage receptacles as well as in airtight condition steel bins, it was found that in the ventilated condition of rice storage there was 7.49, 13.40, 15.58 and 16.35 per cent insect infestation at 3, 6, 9 and 12 months of storage respectively. While in the airtight condition it was 1.11, 2.30, 2.60 and 2.72 per cent kernel infestation for corresponding storage periods, respectively (Anonymous, 1980).

Traditional grain storage structures in different parts of India are constructed on wide varieties of locally available raw materials. Most of the traditional storage structures do not prove suitable for long term storage (Birewar et al., 1980).

Calderon (1981) stated that the storage receptacles are important components of the storage ecosystem and the losses in grain during storage is considered as the result of interaction between biotic and abiotic variables.

In the storage of wheat grains in metal bins (airtight condition) Khound and Borah (1982) recorded 4.10 per cent and 4.39 per cent infestation during first three and six months. They further recorded an infestation of 5.13 and 6.77 per cent to grains stored in 'Juria duli' (airtight storage receptacles) during the corresponding period of storage respectively.

When the rice grains were stored in wooden box (ventilated), insect infestation was of the order of 13, 16 and 19 per cent at 3, 6 and 9 months of storage respectively. The grains stored in 'Duli' (ventilated) for the corresponding period had shown 0.60, 4.60 and 7 per cent infestation respectively. Infestation in metallic bin and polythene bag was in order of 5.50 per cent and 5.33 per cent respectively when rice grains were stored for six months (Anon. 1982).
Prakash and Kauraw (1982) recorded that rice grains stored for 3, 6 and 9 month had sustained maximum of 2.11, 2.78, 3.36 per cent weight loss in bag storage and 1.87, 2.33 and 2.79 per cent in metallic bin storage. The maximum weight loss for the corresponding period was 1.92, 2.46 and 2.96 per cent in 'duli' and 1.92, 2.57 and 2.99 per cent in straw-type structures.

Khound and Borah (1982) reported 4.10 per cent and 4.39 per cent infestation during first 3 and 6 months of storage of wheat grains stored in metal bins (airtight condition). They also recorded 5.13 and 6.77 per cent infestation to grains stored in 'Juria duli' (airtight storage receptacle) during 3 and 6 months of storage respectively.

Birewar et al. (1983) described storage structures made from paddy straw rope wherein insect infestation varied from 1.5 - 3 per cent.

Juneja (1983) reported that average farmers has no knowledge of the scientific method of storage, nor has the facilities to do so. The food grains are stored by them traditionally and locally made storage structures which donot provide complete protection against pests and rodents.

Singh et al. (1983) reported that the conventional paddy storage structures of India differ from area to area within the same state depending upon the availability of raw materials. However, most commonly found structures are gunny bag, local mud storage structures, tom, earthen containers, bamboo containers, straw structures etc.

Press et al. (1984) reported that natural enemies regulated the dynamics of pest populations of *S. oryzae* and *S. cerealella* in storage.
While working with distribution Pattern of *S. oryzae* and *S. cerealella*, Lal and Srivastava (1985) reported 39 - 230 numbers of *S. oryzae* in bag storage against only 1 number in banda (an out door structure) per 500 gms sample. 152 numbers of the weevils were recorded in metal bin (ventilated) to only 3 numbers in sealed metal bin per 500 grms sample. Under the same ecological condition they recorded 13.33 numbers *S. cerealella* in bag storage per 500 grams sample. On the contrary, no population build-up of grain moth was recorded in hermetic condition of storage.

Murthy (1986) reported that Indian farmers retain 70 per cent of the food grains for food, feed, fodder, sales or barter at their level and store in traditional ways. Modern storage structures such as metal bin, pucca kothi, RCC ring bin, high moisture paddy bin and wire mesh bin are also used presently as paddy storage structures in the different states of India (Anon., 1986).

Bathla *et al.* (1986) studied the effect of storage receptacles in the damage of grains by pest infestation. They reported that grains stored in metal bins had shown 1.56 per cent weight loss during 9 months of storage as against 3.64 per cent weight loss when grains were stored in hessian cloth bags.

Prakash and Rao (1986) reported that in paddy storage Angoumois grain moth (*Sitotroga cerealella*) is a serious pest and infest unhusked grain in bag and bulk storage structures.

According to Girish *et al.* (1990) the common food grain storage structures are gunny bag, local mud storage structures, tins etc. As per the survey reports of Tamil Nadu Agricultural University, Coimbatore, the traditional storage
structures are obsolete except some wooden structures like 'Pathayam' in Thanjavur district or 'Kalanjiuin' in Trichy district. Studies conducted by C.R.R.I. (Cuttack), the common storage structures in Cuttack district are 'doli', gunny bag, nandabins, kothi and oliya structures. The survey reports of Indian Institute of Technology (IIT) Kharagpur indicated that rice and paddy stored in Harmer, Morai and Bags are not suited for the safe storage of food grains.

Bhattacharjee (2000) reported that farmers of Assam prefer to store in ventilated storage structures like Gutibhoral, Gusibhoral, Duli. Gunny bag was also used occasionally for storing paddy for a short period.

2.3.2 Storage Practices

Howe (1951) reported that extraneous materials consisted of dust, cowdung pallets, pieces of straw and chaffs. These materials had greatly influenced the insect-pests activities in storage habitat. The low infestation level was recorded in threshed-unclean than in threshed clean practice of storage.

Giles (1965) reported that major damage are caused by rice weevil and grain moth to grains of sorghum in unthreshed condition. He registered the population of rice weevil in the range of 10-99 and 100-900 numbers per 100 heads of unthreshed sorghum at 3 and 6 months of storage, respectively.

Krishnamurthy (1972) and Islam (1976) stated that the threshed grains contain extraneous materials such as chaffs, dusts, stones etc. which influence the activities of insects in confined storage ecosystem.

Whitney (1974) reported that layers of fine saw dust or ash (uncleaned condition) on top of stored wheat grains prevented the multiplication of stored product insects.
El-Halfawy (1976) stated that powdered rice husk as grain protectant to stimulate unclean condition of storage. He asserted that the size of the rice husk particles had a pronounced effect on the rice weevil mortality giving complete effect on the adult after 15 days.

White and Sinha (1980) reported that S. oryzae was an active grain dust producer. The dust so produced by this species in S. oryzae and S. cerealella pest-complex restricted the insect movement in storage habitat irrespective of storage practices.

Fernando (1982) found that paddy husk was an effective protectant against pulse beetle during storage, while working on the effect of foreign materials on infestation of stored pulse.

Prakash and Kauraw (1982) reported that stored unthreshed paddy had sustained quantitative loss of 2.10-2.22, 2.67-2.80 and 3.21-3.87 per cent at 3, 6 and 9 months of storage due to insect infestation of S. oryzae and S. cerealella.

An investigation was carried out to assess the population pattern of stored grain insects under different storage practices. In unthreshed condition, the mean population of S. cerealella per 500 grams sample was 5 and 21 numbers at 3 and 6 months of storage while in threshed uncleaned condition it was 10 and 26 numbers at 3 and 6 months of storage. The population of grain moth recorded was 23 and 40 numbers at 3 and 6 months in threshed cleaned condition of storage (Anon. 1982).

Golob et al. (1982) reported that on mixing the grains with sand, sawdust and wood ash (stimulation of unclean condition) at the rate of 4:1 by weight restricted insect damage.
Stubb and Abood (1983) observed avoidance response of *Sitophilus* species in wheat grains contaminated by frass and dust (unclean condition) which gave protection to stored grains for a prolonged period.

Dickens (1984) reported that rice weevil produced grain dust in storage habitat. He observed minimum level of insect activities in unclean storage practice.

Imura and Sinha (1984) stated that rice weevil was an active grain dust producer in the storage habitat.

Palaniswami and Dakshinamurthy (1986) reported that the unclean practice of storage protected the grains by reducing the rate of development of stored grain insect-pests. The presence of foreign matters like cowdung pallets in the unclean grains that released methane gas and carbon dioxide which were hazardous to the rice weevil and grain moth.

Ramzan *et al.* (1988) reported that mixing of foreign materials with grains significantly affected the population build-up of stored grain insect-pests. When quantity of foreign materials increases then there is a declining trend of population of insect pest in the stored grain.

Lawrence and Pederson (1990) studied the effect of thrashing different sorghum cultivars on *Sitotroga cerealella* and *Sitophilus oryzae*. They indicated that both species of insect responded differently when breed of unthrashed sorghum grain on average unthrashed sorghum was more suitable than thrashed sorghum for the development of *S. cerealella*, whereas thrashed sorghum was found to be more suitable than unthrashed sorghum for *S. oryzae* development.
2.3.3 Infestation Percentage

Dobie (1974) recorded an infestation percentage of 1-6 per cent in maize kernels resulted due to the attack of *S. oryzae*. Simwat and Chahal (1980) reported 1.7 per cent kernel damage within a month of storage. Borah and Mohan (1981) found 14.1 per cent infestation in a high yielding rice variety due to combined attack of *S. oryzae* and *S. cerealella*. Pandey and Das (1985) recorded 8-12 per cent damage of stored rice during five months of storage.

Nigam *et al.* (1987) reported an increase in the percentage of damage grains caused by *S. oryzae*. They recorded 1.95, 4.70 and 23.26 per cent damaged grains. Singh *et al.* (1991) recorded 64.89 per cent of infestation in barley caused by *S. oryzae*. Kurdikeri *et al.* (1994) observed that percentage of infestation increased with an increase in storage period of rice. Gupta *et al.* (1999) recorded in maize a maximum of 41.77 per cent infestation as caused by *S. oryzae*.

2.3.4 Infestation in relation to grain moisture content

Grain moisture content had profound influence on the intensity of infestation of stored product insects including *S. oryzae* and *S. cerealella*. It had been illustrated by many workers with special reference to *S. oryzae* and *S. cerealella*.

The moisture content in which the weevils could develop in grains were determined to be 9.9 per cent (Mathlein, 1938) and 8.5 per cent (Mautia, 1942). Davidson (1940), Harris (1943) and Birch (1945) suggested that 10 per cent grain moisture content was the minimum requirement for development of rice weevil.
Reddy (1950) stated that *S. oryzae* did not lay eggs in wheat grains at 7.4 per cent moisture content while few eggs were laid but none hatched at 9 per cent grain moisture content. Further, he reported that shortest period of development was at 17.6 per cent grain moisture content.

Infestation of stored grains increased with increase in grain moisture content above 10 per cent and was rapid at 14 per cent level as reported by Pruthi and Singh (1950). They also recorded decreased infestation at 8 per cent grain moisture content.

Powel and Floyd (1960) reported that the initial grain moisture content had profound influence on multiplication of *S. oryzae* and higher initial grain moisture content was conducive to quick multiplication of the weevil.

Baruah (1976) reported that grains stored at low initial moisture content of 12.2 per cent sustained 21.83 per cent damage during first three months of storage. The grains stored at initial moisture content of 17.5 per cent had 47.35 per cent damage during the same period of storage.

Rout *et al.* (1976) recorded that paddy grains with 20, 10 and 8 per cent moisture content had 25, 15 and 9 per cent infestation respectively.

Pushpamma and Reddy (1979) reported that extent of kernel damage of rice grain increased with the increase in moisture content during storage. A positive correlation was found with the increase in moisture content and kernel damage.

Simwat and Chahal (1980) observed that an increase in initial moisture content of grain from 8.5 to 17 per cent increased the oviposition by *S. oryzae* significantly. He reported that the number of weevils developed
28

at 8.5 and 11.2 per cent initial moisture content was almost the same, but an
increase from 11.2 to 17 per cent resulted in enhanced weevil emergence
which ultimately was the result of increased oviposition.

Yadav and Nathan (1980) reported that initial grain
moisture played an important role in the infestation level of stored grain
insect-pests while studying on the effect of ecological changes on the
safe storage of wheat.

Prakash et al. (1981) demonstrated that the number of progeny
of *Sitophilus oryzae* and *Sitotroga cerealella* increased gradually with the
increase of grain moisture content.

Imura and Sinha (1984) stated that the rapid increase of grain
moisture content in the habitat of *S. oryzae* and *S. cerealella* was found to be
associated with the population build up of both the species.

Studies on the effect of population of *S. oryzae* and
*S. cerealella* under controlled condition of grain moisture content was carried
out by Prakash and Rao (1986). They found that the population of both the
species increased with increase of grain moisture from 14 to 18 per cent and
the highest adult population of these species were recorded at 18 per cent
grain moisture content.

Singaravadivel (1992) observed that moisture content of paddy
stored in gunny bag decreased with the increase of storage period upto 8
months, beyond this period moisture content increased in all the lots, owing
to reabsorption of moisture from the prevailing high humid air.
Juggi et al. (1992) observed the fluctuation of grain losses in stored rice during October to April due to reduction of free water (moisture content) at a faster rate from fresh rice stock, whereas the reduction of water comparatively lower in May-August due to high relative humidity and temperature.

Baker et al. (1992) found the population development by the curculionid *S. oryzae* and damage caused to some tritical genotype were maximum at 14.2 per cent grain moisture content. Padmavathamamma et al. (1993) found that the development of *S. oryzae* at a temperature range of 28°-30°C needs 13-15 per cent grain moisture. Haque et al. (1996) obtained highest grain damage on unhusked unparboiled rice by *S. oryzae* at 37°C at any of the four initial moisture levels (10, 12, 14 and 16 %) tested.

### 2.3.5 Effect of temperature and relative humidity

Temperature and Relative humidity is one of the most important factor determining the population fluctuation of rice weevil and grain moth as evidenced in the report of Richards (1947), Morrison (1963), Teotia and Singh (1968) Singh et al. (1972) and Shazali (1982).

Reddy (1950) reported that *S. oryzae* need optimum temperature for egg laying and hatching at 30°C and 84 per cent relative humidity. He observed a decreasing trend of egg laying and hatching at temperature above or below 30°C; at 35°C very few eggs were laid but none of them hatched. Further, he recorded that at 30 per cent relative humidity no eggs were laid.

At temperature above 75°F and 75 per cent relative humidity, pest infestation was reported to be rapid by Pruthi and Singh (1950).
Khare and Agrawal (1963) observed that the conditions most favourable for activity of *S. oryzae* was 30°C and 75 per cent relative humidity.

Howe (1965) determined that 17°C was the minimum temperature for development of the weevil.

Singh *et al.* (1974) found that the oviposition and development rot of *S. oryzae* were greater at 30°C and slower at 18°C than at 25°C. Hardman (1978) recorded the lower threshold temperature for development of *S. oryzae* to be 12.6°C.

Population level of *S. oryzae* in high yielding varieties of rice was studied by Sharma *et al.* (1979). They inferred that multiplication of rice weevil population was minimum and maximum at 60 per cent and 75 per cent relative humidity respectively, while the population was retarded at 80 per cent relative humidity in the temperature range of 18°C to 30°C.

Prakash and Kauraw (1982) recorded that the minimum relative humidity for development of *S. cerealella* was found to be 65 per cent at 28±1°C temperature even with less fluctuation was reported to be lethal to *S. cerealella* (Prakash, 1982).

At 30°C temperature and 80 per cent relative humidity, the minimum development period for *S. oryzae* and *S. cerealella* were registered to be 29.5 and 24.9 days by Shazali and Smith (1985). They also observed that *S. cerealella* could tolerate higher temperature (35°C) and lower humidity (40-50 per cent at 30°C) than *S. oryzae*.

While working with conditions conducive to oviposition and development of *Sitophilus* species, Okelana and Osuji (1985) recorded lowest
level of oviposition at 30 per cent relative humidity and highest emergence of weevil was found at 70 per cent relative humidity. They further recorded that 30 per cent and 50 per cent relative humidity were detrimental to survival, oviposition and development of the weevil.

Prakash and Rao (1986) reported that the rate of multiplication of *S. oryzae* and *S. cerealella* were found increased with an increase in temperature from 20±1°C to 30±1°C and thereafter declined upto 40±1°C. The lower and upper threshold temperatures for development of the rice weevil were 15°C and 34°C as reported by Ryoo and Cho (1988).

Low temperature storage of rice is extensively practiced to control insect pests in Japan and has enabled the use of conventional fumigants to be reduced since 1991. Nakakita *et al.* (1997) recorded that both hatching and metamorphosis was greatly reduced at 10°C and population increased of *S. oryzae* was completely suppressed at 15°C. Pittendrigh *et al.* (1997) found that *S. oryzae* reared in grains at 40 per cent relative humidity took longer time to develop from egg to pupation than those reared in grains at 70 per cent relative humidity.

### 2.4 Seasonal incidence of *S. oryzae* and *S. cerealella*

Season influences the life activities of storage insects through natural fluctuations of temperature and relative humidity (Prakash and Rao, 1986) and reports documenting the influence of seasonal conditions on stored grain insect pests were published by Kumari (1962), Khare (1963), Willson *et al.* (1970), Sinha (1974) and Bains *et al.* (1976).
Khare and Agrawal (1962) recorded that the peak period of occurrence of *S. oryzae* was during July-August and caused maximum damage at atmospheric temperature of 27-34°C and at 64-75% relative humidity. They also recorded the low population of the weevil from April to June.

The population of *S. oryzae* and *S. cerealella* were encountered throughout the year but the population of *S. oryzae* was observed to be most concentrated during September-October when atmospheric temperature was between 23.0° to 32.4°C (Singh, 1977). A high population of *S. cerealella* was also recorded by him during April and May when temperature ranged between 24.3 and 37.6°C.

Prakash *et al.* (1981) reported high intensity of *S. cerealella* under natural condition of storage of rice grains during July to October and it was the seasonal variation which directly influenced the occurrence of storage insects but their multiplication was severely reduced during winter or summer (Prakash, 1983).

Working on the seasonal pattern of stored grain insect-pests, Yadav *et al.* (1986) were of the opinion that the July - August were most conducive for population growth of *S. oryzae* while the September and October had a deleterious effect on their population growth.

Abrogast and Mullen (1987) suggested that under seasonal influence of temperature and humidity, *Sitophilus oryzae* and *S. cerealella* exhibited variation in density with minimum population in late summer and early fall and high population intensity in late spring or early summer.

Ryoo and Cho (1988) studied the development of *Sitophilus oryzae* in relation to temperature on rice. The total development periods on rice were
similar to those reported on wheat. He constructed a model for the temperature-dependent developmental rate of *S. oryzae* on rice. The lower and upper threshold temperatures for overall development of the weevil were estimated to be 15.0° and 34.1°C.

Sinha (1999) reported that the temperature, relative humidity and seed moisture plays an important role in the incidence of stored grain pests. At higher (>20°C) temperature most of the stored grain pests multiply and infest seed affecting its health. Like temperature, humidity is also an important ecological factor which influences pest activity. Moisture content in grain is another factor that directly affects pest multiplication and grain infestation.

2.5 Infestation of *S. oryzae* and *S. cerealella* in relation to physical characters and chemical constituents of grains

2.5.1 Infestation of *S. oryzae* and *S. cerealella* in relation to physical characters of grain

Physical grain characters in relation to insect infestation were discussed by various workers.

Russell (1962) and Khare and Agrawal (1963) suggested that larger size of wheat kernel provided more food and space for growth and greater area for egg laying. Sikdar (1965) also reported a direct relationship between grain size and insect infestation. He postulated that the grain moth developed on larger grains had a remarkable capacity to adopt themselves to available food supply to grow in.
Russell and Pink (1965) reported the grain hardness as a major physical parameters of grain to impart resistance against insect attack. Teotia and Singh (1968) reported that bigger the size of grains larger the size of the weevils produced. Abraham and Thomas (1969) ascertained the influence of fineness of the grains and husk thickness on the susceptibility to infestation of *S. cerealella*, but none of their correlations were significant.

Rough seed coat with spiny character appears to act as a deterrent to oviposition by stored product insects (Raina, 1971; Girish *et al.*, 1974; Tyagi and Girish, 1975). Sinha (1971) suggested that the fineness of the seed-coat causing glossy and slippery outer surface were impenetrable to stored grain insects. In contrast smooth grain was found to be preferred by *S. oryzae* for egg laying (Anon. 1980).

Link and Rossetto (1971) reported that most of the larvae of *S. cerealella* were unable to penetrate rice grains that had tightly closed husk, but the insect could penetrate the grains when there was a gap between the lemma and palea. Cogburn (1974) also proved the efficiency of intact hull of rice as a protective barrier for insect penetration. According to him split husk enhances the attack of *S. oryzae* larvae.

Tyagi and Girish (1975) found that the average number of egg plugs detected on a single kernel was maximum on biggest size kernels and minimum on smallest size kernels.

Chelappa and Chelliah (1976) studied the susceptibility of ten rice varieties to the attack of *S. cerealella* and attributed the higher susceptibility partly to coarseness of the grains.
Chatterjee et al. (1977) stated that there was no correlation between the size of the grain and degree of infestation of grain moth. But they inferred that longer grain type was more susceptible while short and medium grains were least susceptible. Russell and Cogburn (1977) observed that split husk enhances the attack of *S. oryzae* larvae.

Prakash et al. (1979) studied the relationship between the grain type, smoothness of the grain surface and development of *S. cerealella* and found that grain type influenced the egg laying and development of grain moth to a great extent. Hull tightness and thickness, damaged endosperm have been reported to act directly or indirectly on the resistance of grains to stored product insects. He also reported that long slender grains were found least preferred and short bold grains were highly preferred for egg laying.

Barthakur (1982) reported that the fine grain varieties of rice were more infested by grain moth than the coarse grain varieties. He further established husk thickness and grain weight in rice were the physical grain characters that showed a definite negative correlation with grain moth infestation.

Pandey and Pandey (1982) reported that hardness of grains showed significant correlation with growth index and loss in weight. The least susceptible varieties were harder as compared to the most susceptible varieties of maize to *Sitophilus*.

Sudhakar and Pandey (1982) found that hardness of wheat grain was a factor for grain resistance to weevil and negatively correlated
with the indices of susceptibility, egg laying capacity and the total numbers of progeny. Prakash (1982) observed a positive correlation between L/B ratio of grain, number of adult emergence and percentage of damage husk. Hsia and Peng (1987) reported that hardness of grain affected the boring depth by the grubs of *Sitophilus* species, whereas Tipping *et al.* (1988) were of the opinion that feeding and oviposition by *Sitophilus* species was affected by the physical and chemical nature of grains pericarp rather than the endosperm.

Pandey and Das (1985) reported that 7.8 to 12.9 per cent of grain damage in husked rice by *S. oryzae* was attributed to thickness of the husk. The result of the study carried out by Sauphanor (1988) confirmed the importance of husk tightness in providing resistance of rice against *S. oryzae* and *S. cerealella*. He remarked that mechanical damage was more important as a way of entry than lack of close joints between lemma and palea. Poor closing of the glumes influenced attack by *S. cerealella* by which larvae of the insect could enter.

Chunni-Ram and Singh (1996) found the susceptibility of wheat varieties to be positively correlated with grain size and negatively correlated with grain hardness. Leuschner *et al.* (2000) screened 15 pea-millet grain sizes and hardness in relation to resistance to *S. oryzae* and found negative correlation between weevil susceptibility and grain hardness.

### 2.5.2 Infestation of *S. oryzae* and *S. cerealella* in relation to chemical constituents of grain

Chemical constituents play an important role in offering resistance to the pest attack. Various chemical characters of grains were associated with pest damage and relationship have been well documented.
A wide degree of variation in reducing sugar content ranging from 0.06 to 0.21 per cent in dehusked rice, from 0.05 to 0.08 per cent in polished rice and from 0.14 to 0.19 per cent in parboiled rice has been reported by Williams and Bevenue (1953), Houston et al. (1957) and Sone (1959).

Increase in protein content in storage of wheat due to insect infestations has been reported by Pingale et al. (1954), Sharma et al. (1979); Jood et al. (1996) and in maize (Rajan et al. 1975; Jood and Kapoor, 1993).

Pingale et al. (1954) have found that in insect damaged wheat grain reducing sugar content is relatively greater after some period of storage.

Singh and Mc Main (1963) suggested that sugar and starch content of corn kernels increased the weevil reproduction rate and weight. They indicated that susceptibility of corn inbred lines to rice weevil attack expressed as a number of live adults after 2 months of infestation was positively correlated with the percentage of reducing sugars but not with total sugar content of grains.

Abraham and Thomas (1969), Flores (1970) found no correlation between sugars and protein content in corn varieties and infestation of S. cerealella.

A wide degree of variation in total soluble sugar content ranging from 0.51 to 1.21 per cent in twenty varieties of dehusked rice had been reported by Raghaviah and Kaul (1970). However, a slightly lower level of total soluble sugar (0.33 to 0.74%) in 18 varieties of rice were reported by Chakravorty et al. (1972).
Raghaviah and Kaul (1970) also reported the amount of non-reducing sugar in dehusked rice between 0.16 to 0.65 per cent, whereas such variations was observed in between 0.22 to 0.73 per cent by Ckakravorty et al. (1972).

Singh et al. (1972) found no significant relationship of protein content of grain with weevil infestation. Dobie (1974) found that protein content was negatively correlated to susceptibility index of the rice varieties. Decrease in protein content in rice during storage has also been reported by Beloglazona et al. (1977).

Pathak (1974) and Pande et al. (1975) reported the presence of significantly higher quantity of silica in resistant varieties than in susceptible ones. Narayan (1977) ascertained that silica deposition interfered with penetration of shootfly larvae into leafsheath in sorghum varieties.

Rout et al. (1976) found no consistent relationship between susceptibility of S. oryzae and starch and protein content of the grain.

Pant and Susheela (1977) have also shown that protein quality of sorghum grains generally, remained unaffected by moderate insect infestation.

Dutta and Baruah (1978) reported that non-reducing sugar of some of the glutinous and non-glutinous rice varieties of Assam ranges from 0.90 to 1.12 per cent as factor for infestation.

Sudhakar and Pandey (1979) observed an increase in reducing sugar content of wheat infested by S. oryzae, while decrease in reducing sugar due to insect infestation in Wheat, Bengal gram and Field bean was reported by Sharma et al. (1979), Gupta et al. (1981) and Ndhine and Rawat (1985).
Bhattaeharya et al. (1980) reported that 68 per cent of the 106 samples of rice collected from different region of India had a protein content of 8 per cent or more. Samples from Assam had a protein content of 7-8 per cent or more. Protein content of some of the glutinous rice and non-glutinous rice varieties of Assam ranges from 8.09 to 11.05 per cent.

Singh (1980) reported that in long and round kernel of rice 0.4% glucose was suitable for progeny production of S. cerealella.

Prakash (1982) stated that the thickness and silica content of husk had a negative correlation with percentage of adult emergence and percentage of damaged grains in rice.

Borthakur (1982) while working on the grain moth observed no consistent relationship of sugar and protein content of rice grain with the infestation of the moth. Pandey and Pandey (1983) reported that the correlation coefficients of protein, sugar, starch with susceptibility index of stored grain pest were not significant. Dhotmal and Dumbre (1983) reported a positive correlation between the nitrogen content of grains and the grain infestation by S. cerealella.

Increase in protein content in storage due to insect infestations in field bean, pigeonpea have been reported by Ndhine and Rawat (1985), Srivastava et al. (1988). Increase in protein content of weevilled kernels of Bengal gram has been reported by Gupta et al. (1981).

Increase in protein content of food grains in storage due to insect infestation have been reported by various workers. Sudhakar and Pandey (1987) obtained increase in protein content in raw and parboiled rice due to
insect infestation. He also reported that increase in total soluble sugar of wheat 
damaged by rice weevil during storage period, while decrease in total soluble 
sugar in jowar and wheat due to insect infestation during the period of storage 
have been observed by Sharma et al. (1979) and Charjan and Tarar (1994).

Sauphanor et al. (1988) found no significant correlation between 
protein content of rice varieties and susceptibility index of rice varieties.

Sajwan et al. (1992) observed that storage duration and 
condition did not affect the protein content of paddy stored in metal drum, 
mud plastered bamboo bin or gunny bag.

Singh et al. (1995) reported significant effect of protein 
content of rice which decreased consistently in 12 months storage. Protein 
content of milled rice decreased significantly during storage of paddy in gunny 
bag. Drying before storage significantly decreases in water soluble protein 
and act as a susceptibility factor.

Chaunni-Ram and Singh (1996) found that crude fibre and protein 
contents of wheat kernels are negatively correlated with weevil susceptibility. 
They also found grain hardness to be positively correlated with protein content.

Ali (1997) observed that with the increase of storage period, 
total soluble sugar content of semi-glutinous rice increased in different storage 
container making them positively correlated susceptibility to insect pest attack.

2.6 Life cycle of *Sitophilus oryzae* Linn. and *Sitotroga cerealella* Oliv.

2.6.1 *Sitophilus oryzae* Linn.

2.6.1.1 Fecundity and oviposition

Cotton (1920) studied the pre-oviposition, oviposition and 
fecundity of *S. oryzae* and recorded the average pre-oviposition period is
about 7 days, oviposition period during the warm months is 93.9 days and number of eggs laid per female is 380.

Back and Cotton (1924) observed that in early spring S. oryzae starts ovipositing about three weeks after emergence and in summer after one week. They found the average duration of the pre-oviposition period of S. oryzae to be from 7-39 days during warmer months. Mathlein (1938) found a pre-oviposition period of 4 days at 25°C and 10 days at 16-18°C for S. oryzae.

Khan (1949) found that at 15°C and 50 per cent RH mating takes place after six weeks and at 70-90 per cent mating takes place after four weeks. He found a minimum pre-oviposition period of 4-5 days at 25°-30°C and 70-80 per cent RH. Howe (1952) studied the biology of the rice weevil, Calandra oryzae (L.) on wheat grains. He recorded the rate of oviposition, fecundity and the length of the developmental instars under different atmospheric temperature and relative humidity.

Prevett (1959) studied on the oviposition and duration of life of a small strain of the rice weevil, Calandra oryzae (L.) in Sierra Leone. He observed that a female laid 68 eggs in all, over an oviposition period of 71 days, the peak of egg laying being reached during the third week. Usually only one egg was laid per grain, but sometimes two or three, and on one occasion even four, were laid together. It has been calculated that 81 per cent of the eggs were laid singly, 16.8 per cent were laid as one of two on a grain and 2.2 per cent as one of three.

Sharifi and Mills (1971) found an ovipositional period of 3 days and 42 per cent, 37 per cent and 21 per cent egg deposition in endosperm, germ perimeter and germ centre of wheat kernels respectively.
Sharma (1985) recorded a fecundity of 120-240 eggs per female and an optimal ovipositional period of 4-5 days in wheat kernels. Adetunji (1987) recorded a maximum number of eggs laid as 117.8 in sorghum seed cultivars.

Ryoo and Cho (1992) found maximum fecundity and oviposition in brown rice as 244 eggs per female. Povey and Sibley (1992) recorded the no oviposition plasticity of *S. oryzae* in stale wheat grain or flour after 4 weeks exposure to poor oviposition condition. Singh *et al.* (1998) recorded the greatest and lowest number of eggs laid as 30.5 and 12.5 in maize varieties.

Sinha (1999) reported that the female rice weevil makes a small excavation in the grain where it lays around 250 translucent and white eggs.

Hazarika (2001) observed the longest and shortest mating periods of 34.5±0.46 minutes and 26.2 ±1.6 minutes respectively. He also recorded pre-oviposition and average oviposition period of 7.6±1.55 days and 31.9±1.71 respectively when *S. oryzae* reared in variety Tejaswini. He found the fecundity of mated female in an average of 101.3±8.64 eggs per female.

### 2.6.1.2 Incubation

Cotton (1920) found the incubation period of *S. oryzae* to be from 3 to 5 days during warm months, although by far the majority of them hatched in 4 days.

The incubation period of *S. oryzae* is influenced by both temperature and humidity. Khan (1949) found the minimum period for
incubation of eggs of *S. oryzae* is 4 days at 25°C and at relative humidity 70 per cent and 90 per cent. He also found hatching percentage as 100 per cent, 96.1 per cent and 57.4 per cent at 30°C and 90 per cent, 70 per cent and 50 per cent relative humidity. For the same differences in humidity they recorded the hatching percentage as 91.3 per cent, 93.7 per cent and 69.5 per cent at a temperature of 25°C.

Sattigi *et al.* (1987) recorded a mean incubation period of 6.2 days at 20°C and 62.5 per cent relative humidity. Ryoo and Cho (1988) recorded the lowest and highest incubation period for *S. oryzae* as 4.5 to 9.2 days within temperature range of 15° to 35°C.

Bhuyiah *et al.* (1990) also recorded an incubation period of 5-6 days for *S. oryzae* at 23-35°C and 79-87 per cent relative humidity. Nakakita *et al.* (1997) reported that both hatching and metamorphosis of *S. oryzae* were completely inhibited at 10°C. Singh *et al.* (1998) observed an incubation period of 5 days for *S. oryzae* at 30±1°C and 75±5 per cent relative humidity. Sinha (1999) also recorded an incubation period of 4-6 days for *S. oryzae*.

### 2.6.1.3 Developmental stage

Cotton (1920) recorded 4 larval instars of *S. oryzae*. The first three larval stages last for 4 days each, while the fourth stage varies from 4-9 days. He also reported that during the cooler weather the periods are all lengthened.

Zacher (1933) recorded that at 15°-29°C the 1st instar lasts for 4-12 days, the 2nd from 4-14 days, the 3rd from 4-17 days and the 4th from 6-24 days.

Khan (1949) found the larval period varying in between 0-32 days at 15-30°C temperature and 50-90 per cent RH. Teotia and Singh (1968)
studied on the oviposition behaviour and development of *S. oryzae* in various natural foods including rice and found the average developmental period of this pest on rice to be 29.97 days. Sharifi and Mills (1971) found a mean developmental time for larvae in each of the four instars as 3.6, 4.7, 4.8 and 5.0 days respectively for *S. oryzae*. They also recorded a total developmental period of 36.3 days.

Sattigi *et al.* (1987) recorded 4 larval instars which lasts for 28.0 days. Ryoo and Cho (1988) recorded the minimum and maximum larval period as 16.7 and 37.5 days respectively at 15-35°C.

Bhuiyah *et al.* (1990) recorded the larval period of *S. oryzae* as 16-20 days at 23°-35°C and 79-87 per cent RH. Padmavathamma *et al.* (1993) found a larval period of 18-24 days at 25°-35°C and 70-90 per cent RH.

Pittendrigh *et al.* (1997) found that larvae developing in grains at 70 per cent relative humidity had only 4 instars, whereas supernumerary moults (5 instars) occurs at 40 per cent RH. Singh *et al.* (1998) found a mean larval duration of 16-27 days while studying the developmental behaviour of *S. oryzae* in different maize varieties at 30±1°C and 75±5 per cent RH.

Sinha (1999) observed that tiny young larva is white with a yellow brown head. It bores into seed and feeds on starchy contents hollowing it out to leave only the shell. The four larval instars lasts for 20 to 30 days. He also recorded one or two days as prepupal stage.

Hazarika (2001) recorded the total developmental period of *S. oryzae* as 46.7±3.08 days on an average.
2.6.1.4 Pupation

The pupal stage of *S. oryzae* is generally shorter at high temperatures, but high relative humidity prolong the period.

Cotton (1920) observed the pre-pupal stage of *S. oryzae* which lasts for 1-2 days. He also recorded the pupal stage which lasts for 5.0 days.

Khan (1949) found that the pupal stage of *S. oryzae* varies in between 11 days to 35 days at 15° to 30°C and 50-90 per cent RH. Sharifi and Mills (1971) found that the prepupal stage lasts for 1 day and pupal stage lasts for 5.3 days.

El-Halfawy et al. (1984) obtained a pupal period of 6 days at 25±1°C and 75±5 per cent RH. Sattigi et al. (1987) obtained prepupal and pupal period as 1.5 days and 8.0 days respectively at 20°C and 62.5 per cent RH.

Ryoo and Cho (1988) recorded the pupal period varying in the range of 1.6 days to 13.9 days at a temperature range of 15° to 35°C.

Buchi (1989) from Switzerland reported the pupal period of *S. oryzae* to be varying in the range of 5 to 8 days. Bhuiyah et al. (1990) from Bangladesh reported the pupal period of *S. oryzae* was 8-9 days in maize at 23°-35°C and 79-87 per cent RH. Singh et al. (1998) from Kanpur, India reported the pupal period of *S. oryzae* as 6 to 8 days at 30±1°C and 75±5 per cent RH.

Sinha (1999) reported that the matured larva pupates inside the hollow grain for 3 to 6 days depending on temperature.

2.6.1.5 Adult

Cotton (1920) recorded that the adult weevil measures from 2.1 to 2.8 mm in length and is a light brown in colour. It has the thorax
densely pitted with round punctures, and the elytra are marked with four reddish coloured spots. He also observed that the rostrum is more curved in the female than in the male.

Sattigi et al. (1987) from Mysore reported the adult longevity for male and female as 33.87 days and 39.67 days respectively. Ryoo and Cho (1988) from Korea reported the adult longevity of *S. oryzae* male and female as 32.2 days and 34.4 days respectively. Singh et al. (1998) at Kanpur, India found the longevity of adult female and male ranging from 24.21-38.32 days and 22.09-34.46 days respectively.

Sinha (1999) studied the life cycle of *S. oryzae* and recorded the average period from egg to adult as 30 days. He stated that the number of generations in a year depends on prevailing temperature and relative humidity.

### 2.6.1.6 External morphology

Cotton (1920) studied the morphology of the adult and all the developmental stages of *S. oryzae*. Khan (1949) reported the morphology of the adult and various developmental stages of the curculionid *S. oryzae* reared in wheat.

### 2.6.1.7 Body measurement

Khan (1949) found the length of the adult from the tip of rostrum to the tip of the abdomen varies from 4.1 mm to 4.5 mm and the breadth from 1.25 mm to 1.50 mm. The eggs measures as 0.5 mm in length. He recorded the highest width of head capsule as 0.221 mm, 0.325 mm, 0.481 mm and 0.646 mm for the 1\textsuperscript{st}, 2\textsuperscript{nd}, 3\textsuperscript{rd} and 4\textsuperscript{th} instar larvae respectively. He also reported the length and width of *S. oryzae* pupa as 3.74-4.0 and 1.72-1.75 mm respectively.
Hazarika (2001) studied the body measurement of different developmental stages of *S. oryzae* and recorded the length and breadth of the eggs to be $0.52\pm0.02$ mm and $0.38\pm0.01$ mm respectively. The length and width of newly emerged larva were $1.4\pm0.21$ mm and $0.69\pm0.03$ mm respectively. The length and width of matured larva were $4.5\pm0.23$ mm and $0.33$ mm respectively. The length of the head capsules of newly emerged and matured larva were found to be $0.29\pm0.01$ mm and $0.73\pm0.01$ mm respectively. The width of the head capsules of newly emerged and matured larva were $0.21\pm0.02$ mm and $0.62\pm0.02$ mm respectively. The length and breadth of matured adult males were fund to be $4.35\pm0.44$ mm and $1.48\pm0.23$ mm and that of females were $4.33\pm0.28$ mm and $1.42\pm0.43$ mm respectively.

### 2.6.2 *Sitotroga cerealella* Oliv.

Sundararajan (1978) studied the morphology of the adult and various developmental stages of *S. cerealella* while studying the biology of this pest. He found the length of the egg (along equatorial) from $0.24$ mm to $0.28$ mm and the breadth (Polar diameter) from $0.52$ to $0.66$ mm. He also recorded the highest width of head capsule as $0.16$ mm, $0.24$ mm, $0.51$ mm and $0.75$ mm for the $1$st, $2$nd, $3$rd and $4$th instar larvae respectively. He also measured the other stages of *S. cerealella* also.

Dhotmal and Dumbre (1982) reported a fecundity of $40.88-57.88$ eggs per female on different rice varieties. He also observed that the fine grain varieties were found to be more preferred for its egg laying. He recorded an ovipositional period and incubation period ranged from $3.3$ to $5.0$ days and $5$ to $5.5$ days respectively. He also recorded an average durations of larval and pupal stages ranged from $15.66$ to $19.33$ days and $6.0$ to $10.33$ days, respectively. He observed that longevity of male moths was shorter than that of females.
Germanov (1982) observed four larval stages of *S. cerealella* under conditions of mass rearing and found that larval stages I, II, III and IV on 9th, 12th, 18th and 20th days after grain infestation respectively at 65.8 per cent RH and 22.3°C temperature. He also recorded pupation on 25th day after infestation and 30 days life cycle at 22.3°C temperature and 65.8 per cent RH.

Prakash and Rao (1986) studied the biology of *S. cerealella* with special reference to paddy grains. He recorded that on paddy grains female moth lays 30-70 eggs with an average of 40 eggs. Oviposition and incubation period were recorded to be 3.3-5.0 days and 6 days respectively. While studying on the behaviour of larva he observed that all the four larval stages of *S. cerealella* lived inside a grain. Duration of larva was found to be 13.66 to 19.33 days in different varieties. Fully fed larvae spinned silken cocoons around them in hollows in the grain and become inactive 2 days before pupation. The pupal period recorded to be 4-7 days. He further recorded that *S. cerealella* completes its life cycle in 4-6 weeks but breeds from April to October in a year.

Ratnasudhakar (1987) studied the relative susceptibility of paddy varieties against *Sitotroga cerealella* Oliv. infestation during storage and reported that the variation in mean developmental period from variety to variety. He observed highest developmental period (35.22 days) in variety Gowthami and lowest in variety NLR-13969.

Mall *et al.* (1988) studied the relative resistance of wheat varieties against *Sitotroga crealella* and observed the various developmental stages. He recorded the fecundity of 111.87 to 144.93 eggs per female. The longer incubation period was observed on wheat variety HD 2285 (5.44 days),
while shorter on HD 2211 (3.38 days). The maximum larval period was recorded in variety Raj 911 (25.69 days) while minimum in HP 1102 (17.36 days). The pupal period of the pest ranged from 6.02 to 8.34 days. The developmental period was longer in variety Raj 911 (36.59 days) while it was shorter in variety HP 1102 (29.45 days).

Singh and Khare (1993) studied on the developmental behaviour of Angoumois grain moth, *Sitotroga cerealella* Oliv. on maize, sorghum and wheat and recorded shorter developmental period in sorghum (30.94 days) followed by maize and wheat.