2.1 TAXONOMY OF THE GRAIN MOTH

The Angoumois grain moth *Sitotroga cerealella* (Oliv.) belongs to the family: Gelechiidae, order: Lepidoptera. According to Sattler (1973), the genus *Sitotroga* was erected by Heimann in 1870. In 1879 Olivier first described this insect under the name *Alucita cerealella*. Meyrick (1927 and 1928) subsequently placed this insect under the genera *Nesolechia* and *Syngonomictis*. However, as the generic name proposed by Heimann (loc. cit.) was universally accepted, this insect is now known as *Sitotroga cerealella* (Olivier) (as quoted by Sundararajan, 1986).

The insect was noticed infesting wheat in 1736 in the province of Angoumois, France, due to which it obtained the common name Angoumois Grain Moth (AGM) (Cotton, 1941). In India, this insect is known variously as grain moth, paddy moth and rice moth. In Tamil Nadu the Vernacular name for the insect is "Andhu poochi".

2.2 DISTRIBUTION AND HOST RANGE

The Angoumois grain moth *Sitotroga cerealella* (Olivier) also known as paddy moth, is world-wide in distribution and found in abundance in coastal and mountainous areas where the climate is humid (Prakash and Rao, 1986). In India,
this insect infests paddy, rice, maize, wheat, jowar, barley, oats and a wide variety of other grains (Mookerji et al., 1968; Sone Lal and Doharey, 1992). It causes considerable damage to all the cereal grains including Chickpea and Cowpea (Back, 1929; Doggett, 1957, 1958).

2.3 FIELD INCIDENCE

Most of the insect pests of stored products begin their destructive feeding before the grain is harvested (Painter and Rett, 1951; Cotton, 1963). Usman (1957) reported that the pests of stored products infest the grains in the field and later become established in storage. They include the weevil *Araecerus fasciculatus* (De Geer), the pulse beetle *Callosobruchus chinensis* (Linn.), the potato tuber moth *Phthorimaea operculella* (Zell.), the rice weevil *Sitophilus oryzae* (Linn.), and AGM *Sitotroga cerealella* (Oliv.). Hariprasad (1984) reported the field infestation of pigeonpea by pulse beetle *Callosobruchus chinensis* in Orissa.
As regards *Sitotroga cerealella*, the earliest report on field incidence on wheat dates back to 1762 by Monceau and Tillet (as given in Simmons and Ellington, 1927). Simmons and Ellington (*loc cit.*) calculated that even an infestation level of 0.2 per cent at the time of harvest leads to total infestation in the next season. Their study, in which 60 per cent of samples were infested just before harvest, showed the potential preharvest infestation. In Japan, a low level of harvest infestation by AGM led to heavy losses in storage (Harukawa and Kumashiro, 1938). Douglas (1941) reported that out of the 125 varieties harvested, 117 samples were infested by the grain moth (93.8%). Giles (1965) has pointed out that the attack of the stored product pest both in the field as well as in the threshing yard were of major importance. According to Prevett (1971) AGM infests only the husked grain of mature standing crop in the field. It also infests the grain during post harvest processes like threshing, drying and storage (Douglas, 1941 and Cotton, 1947). The grain moth infested the standing paddy crop in the field irrespective of the distance from the stores (Howlader and Matin, 1988). Cogburn (1974) reported that AGM is a major pest of rice in the field. The field incidence of this insect on the ripe panicles of the rice was observed by Ganesalingam and Krishnarajaiah (1979) in Sri Lanka.
In India, the first report on field infestation by AGM on the ripening ears of paddy was reported by Fletcher and Ghosh (1919). While investigating on the possible origin of AGM infestation of stored paddy, Israel and Vedamoorthy (1956) found that the grain moth attacked the ripe earheads of the paddy in the field. Occasionally this insect was found to attack the milky stages of the crop. A serious attack by *S. cerealella* on the standing crops of cholam and ragi was observed by Subramaniam *et al.*, (1959). A few surveys have been conducted to assess the field incidence of storage pests with particular reference to AGM. Agarwal *et al.*, (1978) conducted a survey in various villages of Ludhiana district of Punjab and observed the incidence of *Sitotroga cerealella* and *Sitophilus oryzae* on the standing wheat crop.

In places where rice is grown in a particular season, the pest AGM survives on alternate hosts in other seasons to reinfect the next rice crop (Dakshinamoorthy and Regupathy, 1988). Ragumooorthy and Gunathilagaraj (1988) conducted a survey on the field incidence of AGM on rice in the fields at the Agricultural college, Madurai and the Tamil Nadu Rice Research Institute, Aduthurai. They observed the emergence of AGM from 124 of 212 samples at Madurai and 59 of 151 samples at Aduthurai. Subramaniam *et al.*, (1959) reported
the field incidence of AGM for the first time on sorghum and finger millet at Tamil Nadu Agricultural University, Coimbatore and the neighbouring fields. Singh et al., (1978) reported that infestation of AGM was more in samples collected from short distances upto 1000 metres from the villages. A survey to trace the source of infestation in stored grains was conducted by Lallanrai and Singh (1979) who observed that *S. oryzae*, *R. dominica* and *S. cerealella* infested the grains from matured crop standing in the field. AGM infests the mature standing crop in paddy fields and also during post harvest processes like threshing and storage. Infestation is acquired by external invasion either at the crop stage or at the threshing yard or in storage (Prakash and Rao, 1986). The AGM also infests the grain during post harvest processes (Ganesalingam and Krishnarajaiah, 1979). Maduravalli (1989) reported field infestation of AGM on IR 50, IR 20 and Ponni varieties in Pudukkottai town.

2.5 INCIDENCE IN STORAGE

Paddy is stored by farmers for varying lengths of time. During such storage, the top layers get infested by the grain moth. The grain moth is one of the major insect pests of stored paddy (Cogburn, 1977). The AGM causes substantial damage to stored rice resulting in reduction of viability of grains, rendering them unsuitable for seeding and human consumption (Cotton, 1963). Cogburn (1974) has
experimentally assessed the weight losses during rice storage and concluded that one gravid female of *Sitotroga cerealella* in 50 gms of stored rice could destroy the grains completely in three subsequent generations.

Rice in storage is being damaged by a number of agents like insects, rodents, mites and birds. The storage insects cause considerable damage every year. These insects develop or multiply inside or among the stored grains. The larvae and adults feed in or on the grains and cause losses of different types. The losses include the qualitative loss or loss of seed viability and quantitative loss or weight loss.

The grain moth is one of the major insect pests of stored paddy in India (Sardar, 1976; Abraham and Nair, 1986 and Khare and Johari, 1979). The infestation of AGM begins in the field and later gets established in storage (Israel and Vedamoorthy, 1956). Rice is generally stored in husked form in rural India in order to avoid the possibilities of infestation. Despite measures adopted, AGM causes severe damage in storage (Chellappa and Chellaiah, 1976; Chatterjee et al., 1977).

2.6 ABIOTIC FACTORS

Moisture, humidity, temperature, light and nature of the storage structures are the abiotic factors that influence infestation (Prakash and Kauraw, 1982). Simwal
and Chahal (1970), Bains (1971) and Boldt (1974) reported the influence of temperature on insect infestation. According to them, 28°C to 33°C is the optimum temperature for insect infestation, a range for storage insects. Cogburn et al., (1980) reported correlations of infestibility of AGM with several agronomic and physicochemical characteristics to be statistically significant. Difference in farm practices and climate would account for the degree of infestation by AGM (Greening, 1981).

Singh (1977) and Prakash et al., (1981) reported that AGM multiplied in large numbers in North India during rainy season and high humidity. According to Lall (1944) the infestation was high during the monsoon months of July to September in Allahabad. The development period was long in January and short during June while the insect population was maximum in June and minimum in January in storage complex (Shajahan, 1975). Prakash et al., (1981) reported that 28°C to 32°C is the optimum temperature for insect infestation. This difference is significant depending upon the grain type and the nature of the experimental design. The population was maximum during April/May when the temperature ranged from 12°C to 27.4°C (Singh, 1977).
2.7 SCREENING OF RICE VARIETIES FOR THEIR SUSCEPTIBILITY / TOLERANCE TO AGM

A number of studies have been carried out on the susceptibility of several rice varieties to AGM. Cogburn (1977) found the commercial varieties to be more susceptible to insect attack than the experimental varieties. Grains with imperfect hulls were preferred by the insect (Robert et al., 1983). Rice with intact husks reduced infestation (Breese, 1960). Varieties of rice differed in their susceptibility to the attack of AGM (Russell and Cogburn, 1977).

Abraham and Nair (1966) reported that the grains were more resistant if the developmental period of the insect was long with less fecundity. Short bold varieties were found less suitable for infestation than the long slender varieties (Prakash et al., 1979). Khare and Johari (1979) observed the existence of a positive relationship between the grain weight and resistance. The varieties with strong odour were highly resistant than the odourless varieties (Chatterjee et al., 1977). Dhotimal and Dumbre (1983) reported that fine varieties were more susceptible than coarse varieties. Gailad et al., (1990) reported a clear-cut relationship between the susceptibility and the
developmental period. The higher seed weight and the quality of the grain are the factors for higher susceptibility (Chellappa, 1975). Prakash et al., (1982) reported a positive correlation between LB ratio, grain hardness and adult emergence. The susceptibility of IR 50, IR 20 and Ponni varieties of Pudukkottai town has been reported by Maduravalli (1989).

2.8 RICE GRAIN PROPERTIES AND RESISTANCE TO AGM

Recent reviews reflect very little study of systematics that correlates varietal resistance of rice to storage insect pests with physico-chemical properties of the grain (Russell and Cogburn, 1977). Most of the studies used regional samples which represent only a fraction of the wide range of grain properties. Composition of insect resistance on rice is complicated as the bio-assay technique used by entomologists are variable (Russell and Cogburn, 1977). Moreover the physico-chemical properties have seldom been analysed simultaneously. The developmental time of insects, number of F₁ progeny, ovipositional preference, weight loss of rice grain and loss due to milling are the properties that decide the susceptibility index. The results are least variable when eggs rather than the adults were used for screening the rice varieties (Russell, 1976).
2.8 PHYSICAL PROPERTIES

2.8.1 Hull or Husk

The hull comprises 18 to 25 per cent of the rough rice. An intact hull contributes to resistance to rice weevil *Sitophilus oryzae* and lesser grain borer *Rhizopertha dominica* (Breese, 1960). Cohan and Russell (1970) have noted that varieties with imperfect hulls have more damage by AGM. Cogburn (1974) confirmed hull intactness as a factor for resistance to lesser grain borer and AGM.

2.8.2 GRAIN TYPES

Rice grains are classified into different grades by various workers based on their length and breadth (L/B) ratio, which has been reviewed by Battacharya and Sowbhagya (Anand Prakash *et al.*, 1982). Grains have been graded into five types namely long slender, long bold, medium slender, short slender and short bold. *S. cerealella* and *R. dominica* showed different ovipositional and developmental responses on different grain varieties. Though long slender grains were better suited for development, they were less preferred by *S. cerealella* for egg laying (Prakash *et al.*, 1981).

2.8.3 DIMENSIONS AND HARDNESS

The insect larvae live inside the endosperm. The varietal susceptibility seems to be related to grain weight
and width. A positive but insignificant correlation between the L/B ratio and mean percentage of damage to rough rice by AGM was reported by Abraham and Thomas (1969). Sikder (1965) reported that AGM reared on large grain varieties were bigger than those reared on small grain varieties. Brown rice width and weight correlated positively with susceptibility index to AGM (Dobie, 1974).

2.10 CHEMICAL PROPERTIES

Food grains are stored over a period of time in most places both for personal consumption and public distribution. Inspite of the best care, both qualitative and quantitative losses were reported in these storages due to both environmental factors and contamination. Several studies have been carried out to assess the quantitative losses of food grains. The losses vary from 2 to 50 per cent depending upon the food grain, period and method of storage and the type of insects that infest the stored grains (Tyagi and Girish, 1977). The stored grain insect pests are one of the major biological agents which attack the stored grains and inflict quantitative and qualitative losses. They deteriorate the quality of seeds by denaturing and decreasing the solubility of the proteins (Pingale et al., and Subramaniam et al., as reported by Sharma et al., 1979). There is a wide variation in the type of qualitative losses of stored grains caused by different
insect species (Sharma et al., 1979). Pandey and Pandey (1977) observed changes in the chemical constituents of various maize varieties due to insect infestation. Sharma et al., (1979) assessed the biochemical losses in stored wheat due to infestation by some stored grain insect pests.

Rice is a major food of Indians, especially the South Indians. The reports on the qualitative losses of rice due to AGM infestation are meagre. Starch in the form of polysaccharides, fats and proteins are the major constituents of rice. The total sugars and the reducing sugars are the simpler and free forms of starch. The proteins on breakdown give rise to free amino nitrogen which is the simpler form. Phenol is another component of rice, which inhibits the microbial action. Singaravadivel and Anthoniraj (1983) reported that the starch and proteins are rapidly converted into sugars and amino nitrogen due to microbial action and high moisture content. More heat is generated during such conversion. The conversion and the heat cause decolouration of rice in storage. The decolouration is called Maillard browning. This has been observed and reported by Anthoniraj and Singaravadivel (1990) in rice, which according to them is due to microbial action.
2.11 STORAGE LOSSES

Paddy and rice are stored for varying lengths of time. Pruthi (1950) noted that about 50 per cent of the kernel is destroyed by a single larva of AGM. Infestation in the upper layer of stored paddy for a prolonged period may reach 4 to 5 per cent (Ghosh, 1940). Infestation of 67 varieties of rice by AGM was studied during 1967-69 after 2 years of storage in the laboratory. It was 3.26 per cent after a year and 6.73 per cent after 2 years of storage (Kittur and Patel, 1972).

2.12 BIOLOGY OF THE ANGOUMOIS GRAIN MOTH

2.12.1 FECUNDITY

Barnes and Grove (1916) reported that a female on an average laid 100 eggs in clusters. King (1918) observed 92 white eggs per female. The eggs were laid in grain grooves or holes made by other insects. They also reported that the white coloured eggs turned red at the time of hatching. Simmons (1924) reported that the fecundity averaged 100 eggs per female and the pre oviposition period was less than 24 hours in summer. Candura (1950) observed that about 5 to 6 eggs were laid between grooves on grains of standing wheat, while the insect laid 20 to 50 eggs in clusters in the stored wheat. In some females, although the oviposition lasted upto 9 days, 40 per cent of the eggs were laid on the next day after mating (Schieferdecker, 1969). The egg
laying was more during winter seasons (Shajahan, 1975). Sundararajan (1978) reported that the fecundity was high in cooler months.

2.12.2 INCUBATION

According to several authors, the incubation period is variable. It ranged between 2 to 15 days. King (1918) observed the incubation period to be 7 to 9 days and Simmons (1933) noted it to be 4 to 12 days. According to Crombie (1943) it was 2 to 7 days with a mean of 3 days. The incubation period was observed to be 4 to 15 days with a mean of 6.1 days (Shajahan, 1975) and 4 to 9 days with a mean of 5.5 days (Sundararajan, 1978).

2.12.3 LARVAL PERIOD

According to the studies by previous authors, AGM passed through four larval instars. Simmons (1933) based on studies on wheat kernels reported that this insect had a total period of 30-35 days and passed through four larval instars. Crombie (1943) confirmed this through his studies on wheat flour. Mills (1965) claimed that this insect passed through 4 to 7 larval instars based on mandibular counts when reared on maize kernels. He also reported that the sexes of fully grown larvae and pupae can be distinguished by their colours. There were four larval instars each with an average span of 6 days at 30°C and 76 per cent relative humidity (Thomas et al., 1960). The insect when reared on unbroken rice passed though 5 larval
instars (Shajahan, 1975). Sundararajan (1978) reported four instars when reared on unbroken rice. Maduravalli (1989) reported that AGM passed through five instars.

2.12.4 PUPAL PERIOD

Like the larval life, the pupal life span was also variable. King (1918) reported that the pupal period lasted for 10 to 17 days with an average of 13 days. The pupal period was also reported to be 5 to 10 days (Simmons, 1933), 4 to 7 days (Crombie, 1943). Thomas et al., (1960) reported the pupal period to last for 7 days on wheat. The pupal life span was 6 to 11 days with an average of 8 days on rice (Shajahan, 1975). Sundararajan (1978) observed the pupal period to last for 5 to 11 days with an average of 8 days.

2.12.5 ADULTS

Flanders (1930) reported that the adults were negatively phototropic. The sex ratio of male and female was 1:1 (Candura, 1950) and 1:2 (Sundararajan, 1978).

According to the various reports, the adult longevity between male and female varied. It was 3 to 8 days (King, 1918), or 8.1 for males and 9.2 days for females (Simmons, 1933) or 6 to 9 days (Candura, 1950) or 3 days for male and 4.4 days for female (Shajahan, 1975) or 3 to 7 days with a mean of 5.5 days for males and 5 to 10 days with a mean of 6.5 days for females (Sundararajan, 1978).