ECOLOGY OF COMMON INSECT PESTS OF RICE[1]

By M. D. Pathak

The International Rice Research Institute, The Philippines

Rice, the staple diet of over half the world's population, is grown over about 124 million hectares and occupies almost one fifth of the total world area under cereals. Classified primarily as a tropical and subtropical crop, it is cultivated as far north as 49° and as far south as 35°, and from sea level to altitudes of 3000 meters. It is established by direct sowing—broadcast or drilled—or transplanted, and under diverse water regimes: as an upland crop where there is no standing water and the rains are the sole source of moisture, or under lowland conditions whereby water, derived either from rain or irrigation systems, is impounded in the fields. On slopes it is cultivated in terraces, and in valleys or other low-lying sites, floating rice may be grown in several feet of standing water.

As many as 10,000 varieties of rice have been distinguished. The traditional tropical varieties are tall, leafy, and often lodge during the later stages of growth; whereas those grown in temperate areas are short, usually about 1 meter high, stiff-strawed, erect-leaved and lodge-resistant. The plant characters of the latter group are commonly associated with high yields and are regarded as desirable.

Low temperature is a major factor limiting rice cultivation. The optimum temperature is about 30° C but during the flowering stage temperatures of about 20° C induce sterility. Consequently, in regions of cool winters only one crop a year can therefore be grown. In warm areas as many as three crops are common.

Thus, although rice is grown under diverse cultural conditions and over a wide geographical range, it is essentially a crop of warm humid environments conducive to the survival and proliferation of insects. Of the more than 70 species recorded as pests of rice, about 20 have major significance. Together, they infest all parts and growth stages of the plant, are vectors of virus diseases, and are a major factor responsible for low rice yields—particularly in tropical Asia, the world's rice bowl.

The insect problem is accentuated in multicropping rice areas where the insects do not usually undergo a distinct diapause or dormancy but occur throughout the year in overlapping generations. The intensity of the insect problem in such areas can be illustrated by the experience at the International Rice Research Institute where, in 24 separate experiments conducted over the last six cropping seasons, plots protected from insects yielded almost twice as much as those left unprotected. Data from a large number of experiments from a number of countries which have average yields of

[1] The survey of literature pertaining to this review was completed in March 1967.

about 1300 kg/ha, have frequently shown a minimum increase of 1000 kg of rough rice per hectare as a result of insect control.

This review discusses the more common and specific insect pests of rice. Polyphagous insects, and those of minor importance, are not described.

STEM BORERS

The rice stem borers, generally considered to be most serious pests of rice, occur regularly and infest plants from seedling stage to maturity. Although of worldwide distribution, they are particularly destructive in Asia, the Middle East, Malagasi, and the Mediterranean regions. All common rice borers are lepidopterans, most of them pyralids, except those of genus *Sesamia* which are noctuids (92). The pyralid borers are the most common and destructive and usually have high host specificity, while the noctuid borers are polyphagous and only occasionally cause economic losses to the rice crop.

The common stem borer species, together with their distribution and common names, are listed in Table I. In Asia, those most destructive and widely distributed are *Tryporyza incertulas, Chilo suppressalis, Tryporyza innotata,* and *Sesamia inferens*. *Tryporyza incertulas,* often referred to as a classical example of a monophagous species, is primarily distributed in the tropics but also occurs in temperate areas where the temperature remains constantly above 10° C and the annual precipitation is more than 1000 mm (28). *C. suppressalis,* formerly common in temperate areas only, is highly tolerant of low temperatures. Its full grown larvae exposed to −14° C for one to three hours do not exhibit significant mortality, while *T. incertulas* larvae die even at −3.5° C (51). *T. innotata,* tropical in distribution, occurs in regions with distinct dry and wet seasons (155, 207). *Chilotraea polychrysa,* initially reported as most common and destructive in Malaysia, has been recorded in recent years from several other countries and its importance is being increasingly realized (112). In Africa, *Maliarpha separatella* has been reported as most common in Malagasi (19), while in Latin America and other neo-tropical countries, *Rupella albinella* and *Diatraea saccharalis* are important (209).

A considerable amount of confusion in the taxonomy of these species has been resolved by several recent studies (18, 25, 92, 184, 196), and common names for important species were approved at a symposium held at the International Rice Research Institute in 1964 (164). The morphology and anatomy of various species has been studied (46, 47, 52, 53, 73, 94, 97, 169, 184, 185, 192, 213).

Being the most important rice pests, the bionomics of stem borers have been widely studied (39, 45, 47, 87, 111, 118, 120, 155, 158, 185, 207, 208). However, except for some investigations in Japan, most studies have been conducted under natural environmental conditions and any ecological con-

TABLE I

THE COMMON SPECIES OF RICE STEM BORERS, THEIR COMMON NAMES, AND DISTRIBUTION

Species	Formerly recorded as:	Common name	Distribution
PYRALIDAE			
Chilo loftini	*C. forbesellus*		Mexico, California, Arizona
Chilo plejadellus		rice stalk borer[a]	Southern United States
Chilo suppressalis	*Crambus suppressalis* *Chilo simplex* *Chilo oryzae*	striped rice borer[a]	Indian subcontinent, Southeast and East Asia, China, Manchuria, Egypt, Spain.
Chilotraea polychrysa	*Diatraea polychrysa* *Proceras polychrysa* *Chilo polychrysa*	dark headed rice borer[a]	Malaya, India, China, Philippines
Diatraea saccharalis		small moth borer	Southern United States, South America
Zeadiatraea lineolata	*Diatraea lineolata*	Neotropical corn stalk borer	Neotropical region. Recorded infesting rice in Venezuela
Scirpophaga albinella	*Rupela albinella*	white stem borer	Neotropical region and Nearctic southern United States
Tryporyza incertulas	*Schoenobius incertellus* *S. bipunctifer* *S. punctellus* *S. minutelus*	yellow rice borer[a]	Southeast and East Asia, China Indian subcontinent, Afganistan
Tryporyza innotata	*Scirpophaga innotata*	white rice borer[a]	British Guiana, India, Philippines, Indonesia, Malaysia, Australia.
Maliarpha separatella	*Anerastia pallidicosta*		Malagasy, Burma, Ghana, Camerons, Nyasland, China, Senegal, Swaziland, Liganda.
NOCTUIDAE			
Sesamia calamistis	*Sesamia vuteria*	African pink borer[a]	Ethiopean region.
Sesamia inferens	*Leucania inferens* *Nonogria inferens*	pink borer[a]	Indian subcontinent, China, Southeast and East Asia

[a] Adopted at a symposium on Major Insect Pests of Rice held at the International Rice Research Institute, The Philippines, September 14-18, 1964 (164).

clusions drawn are more generalized than specific. Kiritani & Iwao (103) and Banerjce & Pramanik (10) reviewed the bionomics of rice stem borers in temperate and tropical areas, respectively.

DAMAGE

The initial boring and feeding by the larvae in the leaf sheath causes broad longitudinal whitish discolored areas at feeding sites but only rarely does it result in wilting and drying of the leaf blades. About a week after hatching, the larvae from the leaf sheaths bore into the stem and, staying in the pith, feed on the inner surface of the walls. Such feeding frequently results in a severing of the apical parts of the plant from the base. When this kind of damage occurs during the vegetative phase of the plant, the central leaf whorl does not unfold, turns brownish, and dries off, although the lower leaves remain green and healthy. This condition is known as "dead heart" and the affected tillers dry out without bearing panicles. Sometimes dead hearts are also caused by larval feeding above primordia but, if no further damage occurs, the severed portions are displaced by new growth (166).

After panicle initiation, severing of the growing plant parts from the base results in the drying of panicles; they may not emerge at all, and those that have already emerged do not produce grains. These later become very conspicuous in the fields as, being empty, they remain straight and are whitish. They are usually called "white heads." Where the panicles are severed at the base after grain formation is partially completed, shrivelled grains are present. The plants can compensate for a low percentage of early dead hearts, but for every per cent of white heads a 1-to-3 per cent loss in yield may be expected (71, 72).

Although stem borer damage becomes evident only as dead heart and white head, significant losses arc also inflicted by those larvae that feed within the stem without severing the growing plant parts at the base. Such damage results in reduced plant vigor, fewer tillers, and many unfilled grains.

LIFE HISTORY

Adults.—The adults of most stem borer species are nocturnal, positively phototropic, and strong fliers. The *T. incertulas* moths usually emerge between 7 to 9 p.m. while *C. suppressalis* emerge from 3 to 11 p.m. with a peak at about 7 to 8 p.m. (64, 89, 91), and become active again toward dawn. During the day they remain in hiding, *C. suppressalis* among grasses but *T. incertulas* and *Rupella albinella* remain in nurseries or rice fields (111, 210).

The strong phototaxis of these species was in earlier years utilized to attract them to light traps as a method of control. However, it was recorded that even with 80 light traps per hectare only 50 per cent of the moth population could be attracted (78). Light traps are presently used only for studying population fluctuations. The moths are most attracted to ultraviolet and green fluorescent lights (79, 219). Most borer species are capable of flying only short distances but can cover 5 to 10 miles if carried by winds. The distance covered per second has been reported to be 0.6 to 3.4 meters for *C. suppressalis* males, which flew in an irregular or circuitous course, and 0.48 to 2.15 meter for females, which usually fly in straight lines (86).

Mating in most species generally occurs between 7 to 9 p.m. (57, 89, 157, 185). The sex ratio of different species, based on light trap catches, has been recorded by various workers who, in general, have reported more females than males, except for a 1:1 ratio for *Maliarpha separatella* (19). However, in the absence of data on phototropism of different sexes in these experiments, the validity of light trap catches to represent sex ratios in nature is questionable.

Padilla (157) recorded that, in nature, the females of *C. suppressalis* and *S. inferens* were multimated, while those of *T. incertulas* and *T. innotata* mated only once. In laboratory tests using varying sex ratios of *C. suppressalis,* individual females and males mated as many as four and eight times, respectively. Also, the male moths were strongly attracted to the virgin females, the attraction being maximum on the evenings of their emergence but declining on subsequent days. Virgin females used as bait in field traps attracted several wild males, but no moths of either sex were attracted to unbaited traps or to those containing male moths. The male moths showed typical sex excitement when exposed to air streams from containers of virgin females.

The occurrence of high moth populations in overlapping generations and difficulties in mass rearing, constitute the major limitations to the mass release of artificially irradiated male moths (145). Exploratory experiments have shown that, when provided with 1 per cent tepa, apholate, tretamine, or 20 per cent hempa as feed, the moths mated normally but 50 per cent fewer eggs were deposited. Of these, 20 per cent laid by moths exposed to tepa and apholate were sterile (36, 72). The combination of sex attractant and chemosterilant could be a promising control possibility.

Oviposition by most stem borer species occurs in the evening. *C. suppressalis* starts ovipositing from the night after emergence and continues for as long as three days (114, 157), usually from 5 to 10 p.m. with a peak at about 8 p.m. (89, 90). In *T. incertulas* the oviposition occurs between 7 to 10 p.m. in summer and 6 to 8 p.m. in spring and autumn (185). The moths deposit only one egg mass per night and oviposition occurs up to five nights from emergence. Oviposition usually takes 10 to 35 minutes. *C. suppressalis* moths are most active between 19° to 33° C, no flight or oviposition occurs below 15° C (49, 111), and the maximum number of eggs are laid at 29° C and 90 per cent relative humidity (89, 199). The moths exhibit strong preference for oviposition on certain host plants (66, 71, 72), but eggs within a field are generally randomly distributed (110, 154, 218).

Eggs.—The eggs of *T. incertulas* and *T. innotata* are laid near the tip of the leaf blade, while those of *C. suppressalis* and *C. polychrysa* are found mostly at the basal half of leaves or occasionally on leaf sheaths (10, 103). *R. albinella* and *C. polychrysa* oviposit on the lower surface of the leaf blade (10, 210). Several workers have reported that the first generation of *C. suppressalis* moths normally oviposit on the upper surface of the leaves while eggs of subsequent generations are deposited on lower surfaces (103). However, from several thousand field-collected eggs at the International Rice Research Institute, no distinct difference in their position on either leaf surface was recorded except that the eggs on the upper leaf surfaces of hairy varieties were laid in the glabrous area along the midrib (166).

All rice stem borers lay eggs in masses usually containing 50 to 80 eggs per mass, and a single female is capable of laying 100 to 200 eggs. The eggs of *C. suppressalis* and *C. polychrysa* are uncovered, but those of *T. incertulas, T. innotata,* and *R. albinella* are covered with pale orange brown hairs from the anal tufts of the female moths. *S. separatella* eggs, although devoid of any such covering, are more ingeniously protected in that the glue, which the females spread on the leaf before oviposition, wrinkles the leaves, resulting in a case that encloses the egg mass (19). Probably of all species, *S. inferens* eggs, laid in between the leaf sheath and the stem, are most effectively protected.

The threshold temperature for development of *C. suppressalis* eggs is reported to be 10° to 12° C (63, 193) but, although *T. incertulas* eggs show some development at 13° C, hatching normally occurs at, or beyond, 16° C (126). In both species the incubation period decreases with an increase in temperature up to 30° C but is lengthened beyond 30° C and up to 35° C (38, 63, 126, 193, 199). At 35° C, although embryonic development can be completed, the larvae die within the egg shell (38, 193). Yushima (222) reported that, in *C. suppressalis* eggs, cholinesterase activity starts at about 60 hours after oviposition; he suggested this to be the cause of ineffectiveness of organic phosphate insecticides on freshly laid eggs.

The optimum hatching temperature for *C. suppressalis* eggs is from 21° to 33° C (103) and for *T. incertulas,* from 24° to 29° C (111). Both species require 90 to 100 per cent relative humidity and hatching is severely reduced below 70 per cent relative humidity (38). The eggs usually hatch during day time. In *C. suppressalis,* maximum hatching has been recorded at 5 to 6 a.m. followed by another peak at 2 to 4 p.m. (130), but for *R. albinella* hatching usually occurs in the evening (19). Generally, all eggs within an egg mass hatch simultaneously. Larvae from large egg mass of *C. suppressalis* hatched over about 13 minutes but those from a small egg mass lacked synchronization and took longer (178).

Larvae.—The hatching larvae are negatively geotropic and crawl upward toward the tip of the plants where they stay only for short periods. Some suspend themselves with a silken thread, which they spin, and swing with the wind to land on other plants (187). Those which fall on water can swim because of an air layer around their body (133). Most of those remaining on the tip descend toward the base and crawl in between the leaf sheath and stem; they congregate and enter the leaf sheath through a common hole bored by one of them (111, 185). The larvae then feed in the leaf sheath tissues for about a week, after which they bore into the stem, mostly through the nodal regions at the point of attachment of the leaf sheath to the stem (37).

The first generation larvae require one and one-half hours from hatching to enter the leaf sheaths (140), but a somewhat longer period is required by the second generation (216).

The *Chilo suppressalis* larvae live gregariously during the first three instars but disperse in later instars. If the early instar larvae are isolated from each other they suffer high mortality (139), but during the later instars crowding is detrimental and results in high mortality, slower rate of growth, smaller size, and reduced fecundity of the emerging female moths (55, 103). The newly hatched larvae in the second and third broods normally enter one of the third or fourth leaf sheaths without moving to the plant tip. They live there together for about a week before migrating to adjoining plants (96, 140, 146). Early migration of the first generation larvae is probably in adaptation to the limited food available on young plants rather than a reflection of inherent behavior differences of larvae between generations.

Tryporyza incertulas larvae rarely feed gregariously but their initial orientation and establishment for feeding is much the same as that of *C. suppressalis.* On a 30-day-old plant about 30 minutes is required for the larvae to migrate to the leaf sheath after hatching and, although usually 75 per cent of these larvae bore in, only 10 per cent reach the adult stage (111). The larvae seldom enter seedlings but if they do boring takes longer and there is low survival. During the vegetative phase of the plants, the larvae generally enter the basal parts usually 5 to 10 cm above the water level, but on older plants they bore through the upper nodes and feed their way through the nodal septa toward the base (10). On a crop at heading stage, boring usually occurs at the peduncle node, forming white heads even with slight feeding (166). At this stage the larvae cause maximum damage.

The *T. incertulas* larvae, from second instar onward, migrate by using body leaf wrappings. These are made by webbing the two margins of a leaf blade into a tube. The larva encases itself in this tube and detaches it from the leaf to fall on the water. Staying within this case and with its head and thorax protruding, the larva swims to other rice plants where it attaches the case perpendicularly to a tiller slightly above water level and bores into the plant (168). *Sesamia inferens* larvae, hatching from eggs laid between the leaf sheath and stem, generally bore into the stem or leaf sheath without coming to the surface of the plant. Usually they do not feed in groups (10).

Chilotraea auricilia larvae, which are primarily a pest of sugarcane and only occasionally infest rice, generally infest full-grown canes only, as the mature larvae cannot make exit holes through several leaf layers of young canes (61).

The threshold temperature for development of *C. suppressalis* larvae ranges from 10.5° to 12° C but the larvae show optimum development between 22° to 33° C (50). The *T. incertulas* larvae, however, require a minimum of 16° C as the threshold temperature. When reared at 12° C, the second and third instar larvae cannot molt and they die. The rate of larval development is positively correlated with temperature between 17° and 35° C (126).

Various workers consider the width of mandibles of stem borers a better criterion for identifying larval instars than the width of the head capsule because the latter overlaps in different instars. The *T. incertulas* larvae usually undergo four to seven larval instar stages to become full-grown. When reared at 23° to 29° C, most larvae undergo five instars but at 29° to 35° C there are four only (126). The number of molts is reduced in larvae feeding on maturing plants compared with those in the tillering phase, but increases where available host plants are limited, and in hibernating larvae (103).

Under optimum conditions there are five to six larval instars in *C. suppressalis* but under adverse conditions, such as those discussed above, as many as nine instars have been recorded (103). In all species, the total larval period usually lasts from 20 to 30 days.

Pupae.—Pupation in rice stem borers usually takes place in the stem, straw, or stubble. Sometimes *S. inferens* also pupates between the leaf sheath and stem (10). The full-grown larvae, before pupating, cut exit holes in the internodes through which the emerging moths escape. Usually the external opening of these exit holes are spun with fine web and cannot be easily detected before the moths have escaped. While *C. suppressalis* pupae are without cocoons, those of *Tryporyza, Rupella,* and *Maliarpha* are covered with whitish silken cocoons. The anterior extremity of these cocoons is tubular and attached to the exit holes; often one or two horizontal septa are webbed by the larvae in this tubular area to make the cocoons water-proof.

Since the full-grown *Tryporyza, Rupella,* and *Maliarpha* larvae have a tendency to feed in the basal parts of the plants, in a harvested crop all of the larvae are usually left in the stubble, whereas some *C. suppressalis* larvae feeding above are removed with the straw. During dormancy or diapause the larvae in the stubble move down into the plant base and stay mostly one to two inches below the ground level. Li (122) reported that overwintering *Tryporyza in*
tunnels to depths of four inches. On return of optimum conditions, these pupate at the hibernation sites. Thus, in all of these species, overwintering larvae pupate in the stubble, whereas in *C. suppressalis,* in addition to the stubble, most larvae pupate in the harvested straw. Since conditions of

straw and stubble are different, the rate of larval development is affected and hence the pupation and emergence of *C. suppressalis* are less synchronized than in other species (74).

The threshold temperatures for pupal development is 15° to 16° C for *T. incertulas* (126) but 10° C for *C. suppressalis* (136). The rate of pupal development for *C. suppressalis* increases linearly from 15° to 30° C (38, 63, 200), but slows down beyond 35° C, when the pupae suffer high mortality and emerging moths are often deformed (38, 63). When pupae, which had been kept at a constant temperature between 20° to 36° C for two to four hours a day, were exposed to a low temperature near the developmental threshold (12° to 15° C) the development rate was faster (200). Also, when exposed to continuous illumination, *C. suppressalis* pupation was accelerated, but continuous darkness delayed and reduced the percentages of pupation. Even a minimum daily exposure to light of 30 minutes was adequate to mask the effect of continuous darkness (69).

Seasonal Occurrence and Factors of Abundance

In general, stem borers are polyvoltine, but the number of generations in a year depends on environmental factors, primarily temperature and crop availability (51, 160). According to the area, they hibernate, aestivate, or remain active throughout the year, and occur in different seasonal patterns. In areas of short optimum environmental conditions, such as are found in northern Japan, they appear in only one generation, in central Japan and Korea in two generations, and in most of the comparatively warm places, with a single rice cropping regime, in three to four generations. The moths of these generations are frequently referred to as respective broods. During periods when there is no rice crop and the temperatures are not optimum for larval development, the full-grown larvae undergo dormancy or diapause. But wherever two or more rice crops are grown in a year, the borers remain active throughout the year, undergoing only a temporary quiescent stage or weak diapause in the last larval instar during brief periods of nonavailability of host plants. This is apparently true for most of the tropical rice where moths have been caught throughout the year in light traps (5, 10, 23, 71, 72). Often the peaks of their population have been misinterpreted as different broods. A critical evaluation of the data shows that these peaks in light trap catches are reflections of major seasonal effects.

In temperate areas and also in the tropics where only one rice crop is grown in a year, the borers undergo aestivation or hibernation. The hibernation of *C. suppressalis* has been investigated in detail and it has been established that the full-grown larvae undergo diapause, which is a hormonal reaction (24, 51). In Japan, two distinct ecotypes—Shonai in the north, Saigoku in the southwest, and possibly a third Tosa ecotype of *C. suppressalis* from Kochi Prefecture—have been recorded. The intensity of diapause is weak in the Shonai ecotype which is more tolerant to lower temperature than the Saigoku ecotype. The stem borer population between the areas distinctly occupied by these ecotypes is intermediate in character (51). Although it is not fully established whether *T. incertulas* larvae diapause, some records of suppression in the growth of a yellow muscardine fungus on hibernating larvae (152), a reaction which has been considered characteristic of diapausing *Chilo* larvae (51, 52), and differences in the diapausing tendency of *T. incertulas* larvae even when exposed to the same temperature (175), suggest that this species also diapauses. Although for almost all other species frequent references to diapause have been made (10, 103, 118, 122), the available data are inadequate to differentiate diapause from hibernation or aestivation.

Temperature, day length, and the stage of growth of the host plants are the principal factors inducing diapause. *C. suppressalis* larvae, hatching from eggs incubated at temperatures below 22° C, usually undergo diapause (54) and the temperature exposure during advanced embryonic development is particularly effective (48). Although total darkness or continuous illumination does not effect diapause, exposure to short day lengths (8 to 14 hours) induces it, while long days (14.5 to 16 hours) prevent it (70). Such effects are more evident during the larval than at the egg stage. Various ecotypes show sensitivity to day lengths depending on conditions existing in their area of occurrence. Under total darkness, high temperature (33° C) prevents diapause and low temperature (28° C) induces it (103). Both *C. suppressalis* and *T. incertulas* larvae that fed on mature plants tended to enter diapause (51, 80). However, as the number of generations of both these species is largely governed by the number of crops taken in a particular area, particularly in the tropics, the role of mature plants in inducing diapause is somewhat uncertain. The diapause of *R. albinella* and *T. innotata* terminates with higher amounts of precipitation (208, 209).

In areas having distinct generations, usually the first generation appears when the plants are in the nursery or shortly after transplanting; the population increases in subsequent broods and the second or later generations are the ones which often cause serious damage. This is why the borers are more destructive to the late-planted crop or the second crop where double cropping is practiced. In addition to the seasonal fluctuations there have also been reports of distinct annual fluctuations in stem borer populations. Although the factors responsible for these are not fully understood, some of the possible causes are reviewed herewith.

Generally, all borer larvae suffer low mortality during winter. In Japan, where the temperature in winter is much lower than in most other rice regions, even during severe winters low mortality of *C. suppressalis* and *T. incertulas* has usually been recorded (103). The former is more tolerant of low temperatures than the latter. In years of high precipitation during autumn a higher percentage of larvae hibernate, and if the winter or spring is warmer, more of these successfully pupate and emerge as adult moths (78). But since these conditions also accelerate pupation and emergence, oviposition occurs on seedlings on which larvae suffer high mortality, thus reducing the population. However, if late spring is somewhat cooler or the rice is planted slightly earlier, the population builds up rapidly and heavy damage may occur (78, 137, 220). Warm weather is essential for population build-up as the moths in cool areas are generally smaller (56) and lay fewer eggs than large moths (89, 114). If the weather remains warm during the remaining rice crop seasons, the larvae develop rapidly and the total number of generations may increase (55, 77, 195, 198). The problem is exacerbated in multicropping areas particularly.

It has frequently been claimed that larvae suffer high mortality on seedlings (95, 136, 204). This has often been attributed to high water temperature (134, 201). Tsutsui (201) recorded increased larval mortality whenever the average temperature of paddy water exceeded 35° C for any five days in July. Subsequently, measurements of the temperature of the paddy water and within the rice stem suggested that the temperature itself was not directly lethal but might bring about reduced larval vitality, thereby increasing vulnerability to bacterial diseases or other natural hazards (54, 109). It has also been reported that larvae on seedlings used for mass rearing have high survival rates (72, 178), and it is unlikely that the greater larval mortality in the fields can be attributed to nutritional deficiency. However, as the early instar larvae feed gregariously, the food available on the seedlings is inadequate and they are forced to migrate much earlier, probably resulting in high mortality. Egg parasites also plan an important role at this stage in reducing the borer population (95). In areas of double cropping, the seedlings of the second crop carry a heavy load of eggs, leading to subsequent high mortality. Such regulation of the population may not be operative, however, where planting seasons are not distinct (166).

Both in tropical and subtropical regions the population has been reported to decline drastically during the summer months after the second crop has been harvested. This has frequently been attributed to high temperature but the fact that most rice fields have been harvested and often ploughed during this time is equally important.

The age and variety of the host plants and the level of soil fertility have a definite effect on the size of the stem borer population. Generally, rice plants in the vegetative and early heading stages receive more eggs than those nearing maturity (66, 71). The availability, for extended periods, of host plants at the more attractive stages should therefore encourage a population increase.

Rice fields receiving high rates of nitrogenous fertilizers are preferred by stem borer moths for oviposition, and rice plants containing higher levels of nitrogen are more suitable for larval growth (66, 76).

Observations have shown the stem borer problem to be more intense in several areas of soil silica deficiency (142). Both field and laboratory studies have shown that larval survival is significantly reduced if silica is applied to these soils. Sasamoto (176, 177) demonstrated that silica application to the soils rendered the rice plants less attractive to the insect and that the silica particles in the plant interfere with larval feeding, often causing excessive mandible wear. A similar effect of silica on stem borer larvae was demonstrated by rearing them on varieties containing different percentages of silica (37). Silica level is also significant for lodging and disease incidence in rice plants.

Israel & Prakasa Rao (83) recorded a higher incidence of stem borer on acid soils (pH 4.48) than on neutral and alkaline ones (pH 8.0).

Varietal Resistance

Distinct differences in the susceptibility of rice varieties to stem borers have been recorded (82, 111, 141, 153, 165). In field and laboratory experiments, several varieties have been recorded as being nonpreferred for oviposition by the moths, and on resistant varieties stem borer larvae suffer high mortality, are smaller, and have a slower rate of growth (71, 72). In field experiments, susceptible varieties harbor more borers and suffer more damage than resistant varieties (71).

Generally, tall varieties with long wide leaves and large stems are more susceptible (161). Varieties containing more layers of lignified tissue, a greater area under sclerenchymatous tissue, and a large number of silica cells have been found more resistant (37, 82, 161, 206).

Cultural Practices

Several cultural practices have a profound bearing on the stem borer population. Since the eggs of *Tryporyza incertulas* are laid near the tip of the leaf blade, clipping the seedlings before transplanting, a widely practiced procedure, greatly reduces the carryover of eggs from seedbed to the transplanted fields. Similarly, the height at which a crop is harvested can be a very important factor in determining the percentage of larvae which are left in the stubble. At harvest time, *Chilo suppressalis* larvae are usually about four to seven inches above ground level and, although *T. incertulas* larvae are somewhat lower, most of them are above ground level. Therefore, harvesting at ground level can remove a majority of larvae of all species (21, 60, 98, 118, 122). To destroy those remaining in the stubble, burning, removing, or decomposing the stubble with low rates of calcium cyanide, ploughing, and flooding have been suggested (12, 98). Burning is only partially effective because after harvest the larvae generally move below ground level; it is also difficult to burn stubble in a field uniformly. Ploughing and flooding are apparently most effective (98, 118). Since stubble is the major source of the overwintering stem borer population, the role of proper stubble management cannot be overemphasized.

In several countries delayed seeding and transplanting has been practiced effectively to evade the first generation moths (29, 98, 118, 125, 127, 113, 187, 208). In Japan, this practice has not been highly effective against *C. suppressalis* the emergence of which is delayed if planting is delayed. The practice has been effective, however, against *T. incertulas,* the appearance of which is not effected by planting dates (80). However, the number of generations of this species is determined by the growth duration of the crop (80, 205). Thus, where continuous rice cropping is practiced, a change in planting time has little effect unless practiced over large areas. In such areas, crop rotation to include some short-duration, nongraminaceous crop should significantly reduce the borer population (98).

However, change in planting time may not always be feasible because of other agronomic considerations. In West Pakistan, the planting date has been regulated by releasing canal water only after the first brood *T. incertulas* moths have emerged; this late planted crop is far less infested than those in fields planted early with private irrigation systems (118). The early planted fields, however, minimize the full impact of late planting on the stem borer population. In Japan, where highly effective insecticides are available, early planting has been reintroduced in several places, resulting in high rates of survival of first-generation *T. incertulas* larvae. Also, the dates of appearance of first- and second-brood *C. suppressalis* moths have been brought forward and possibly introduced a distinct third generation in the warmer parts (78). The light trap capture of moths has revealed, in both the first and second brood, a change from a unimodal to a bimodal pattern (151).

LEAFHOPPERS AND PLANTHOPPERS

Several species of leafhoppers and planthoppers are serious pests of rice and of worldwide distribution. In several areas, they frequently occur in numbers large enough to cause complete drying of the crops, but even sparse populations reduce rice yields. In addition to the damage resulting from direct feeding, leafhoppers and planthoppers are vectors of most presently known rice virus diseases, and have almost the same overall economic significance as stem borers. Some of the more common species, with their hosts, the viruses transmitted, and their distribution are listed in Table II. Of these, those most important are *Nephotettix* spp., *Nilaparvata lugens, Sogatella furcifera,* and *Sogatodes oryzicola.* The first three occur throughout Asia while *S. oryzicola* is found in the southern United States and in north central South America.

Considerable confusion regarding the various species of *Nephotettix* has recently been resolved by Ishihara (75), and of *Sogatella* by Fennah (42). *N. cincticeps* is temperate in distribution while *N. impicticeps* and *N. apicalis* are distributed in temperate and tropical Asia. In East Pakistan, *Nephotettix* sp. was considered to be of minor status until 1955, but since then

TABLE II

COMMON LEAFHOPPER AND PLANTHOPPER PESTS OF RICE

Name	Common name	Formerly recorded as:	Host	Distribution	Vector of:
DELPHACIDAE (Planthoppers)					
Sogatella furcifera	white back planthopper	*Sogata furcifera* *Delphacodes furcifera*	rice, millet, maize, and other grasses	Tropicopolitan Caribbean, Brazil, South and Southeast Asia, Japan, Korea.	
Sogatodes oryzicola	rice delphacid	*Sogata orizicola* *Sogata braziliensis*	rice	Southern United States, Caribbean Islands, Central America	Hoja blanca
Sogatodes cubanus		*Sogata cubana*	*Echinochloa* and other grasses	Southern United States, Caribbean Islands, Central America	Hoja blanca
Nilaparvata lugens	brown plant hopper	*Hikora formosana*	rice and grasses, sugarcane	South and Southeast Asia, China, Japan, Korea, Micronesia	Grassy stunt
CICADELLIDAE (Leafhoppers)					
Laodelphax striatellus	small brown planthopper	*Delphacodes striatella* *Laodelphax striatella*	rice, wheat, millet, barley	Japan, Formosa, Palearctic regions	Rice stripe; rice black-streaked dwarf
Nephotettix cincticeps	rice green leafhopper	*Nephotettix bipunctatus* *Nephotettix apicalis cincticeps*	cereals and weeds	Japan, Taiwan, Korea, Manchuria, China	Rice dwarf; Yellow dwarf
Nephotettix impicticeps	rice green leafhopper	*Nephotettix bipunctatus* *Nephotettix bipunctatus bipunctatus*	rice, wheat, barley, citrus	Japan, Taiwan, Indian subcontinent	Yellow dwarf; Tungro; Penyakit merah; Yellow orange leaf
Nephotettix apicalis	rice green leafhopper	*Nephotettix apicalis* *Nephotettix bipunctatus apicalis* *Nephotettix apicalis apicalis*	rice	South and Southeast Asia, Japan	Rice dwarf; yellow dwarf; transitory yellowing
Inazuma dorsalis		*Deltocephalus dorsalis*	rice	South and Southeast Asia, Japan, Taiwan	Rice dwarf; orange leaf

it has often caused 50 to 80 per cent damage to rice production in certain areas by direct feeding (6). In southern Japan and several tropical Asian countries, *N. lugens* and *S. furcifera* have frequently been reported to cause serious losses through feeding. *Sogatodes oryzicola* and *Sogatodes cubanus* are vectors of the rice virus, "hoja blanca." *S. cubanus* usually infests grasses and perpetuates hoja blanca among them, particularly *Echinochloa,* which serves as the infection source for *S. cryzicola* which infests both rice and other grasses.

Generally, the leafhoppers feed on the leaves and upper parts of the plants, whereas the planthoppers confine themselves to the basal parts

However, *S. oryzicola* males stay in the upper portions of the plants, and only the female planthoppers stay in the basal parts (41).

All adult leafhoppers have well developed wings, but the planthoppers have two distinct winged forms, macropterous and brachypterous. The macropterous forms have normal front and hind wings, but in brachypterous forms the wings are very much reduced, particularly the hind wings which are rudimentary. The brachypterous forms are generally larger and have longer legs and ovipositors (104, 107, 108). Their preoviposition period is usually shorter than in macropterous forms. The macropterous forms are adapted for migration and develop on crowding and shortage of host plants. In *N. lugens,* more brachypterous forms develop at low temperatures. In males, short day length and high temperature increase the percentages of brachypterous forms, but the day length has no effect on development of winged female forms (88). In *Laodelphax striatellus,* macropterous as well as brachypterous forms are found in both sexes, but in *S. furcifera* no brachypterous males have been recorded (107). Both *S. oryzicola* and *S. cubanus* have alate and brachypterous forms, but the latter are more common in males and *S. oryzicola* (41).

Infestation in paddy fields starts with macropterous immigrants which distribute randomly and produce brachypterous females. The flight dispersal of *N. lugens* and *S. furcifera* takes place during the preoviposition period, generally in the evenings of hot humid days (190). The population is built up continuously for two generations; these different patches of infestation tend to join together. At this stage, macropterous forms develop and the insects migrate to another area.

Damage

The leafhoppers and planthoppers damage the plants by sucking the sap and by plugging xylem and phloem with their feeding sheaths and pieces of tissue pushed into these vessels during exploratory feeding (31). Excessive oviposition may produce similar effects. The feeding and ovipositional marks predispose plants to fungal and bacterial infection, and the honey dew encourages sooty moulds. Except for minute leaf galls found on plants infested with *Cicadulina bipunctella,* which is considered to be caused by a toxin injected by the insect while feeding (1, 129), no other record of injection of a toxin to rice plants by any leafhopper or planthopper species was available to the author.

Bae (8) obtained quantitative data on yield losses caused by different levels of both nymph and adult *N. lugens* populations feeding for varying periods on plants of different ages. He recorded that 400 newly hatched planthopper nymphs, infesting plants at 25 and 50 days after transplanting, caused complete drying in 3 and 15 days respectively. Under field conditions, plants nearing maturity develop hopperburn if infested with about 400 to 500 *N. lugens* per hill (167). However, distinct differences in tolerance of various varieties to hopperburn have been recorded (8). Infestation with smaller populations during the early stages of plant growth reduces the number of tillers, plant height, and the general vigor, but after panicle initiation similar populations greatly increase the percentages of unfilled grains (8).

Since the planthoppers show negative phototaxis and prefer high humidity, they congregate in areas of more luxuriant plant growth and multiply near the basal parts of the plants. Under favorable conditions, such as with high nitrogen application, high humidity, optimum temperatures, and little air movement, the population rapidly increases and hopperburn occurs (190). Sometimes hopperburn is also caused by large numbers of planthoppers migrating from adjacent areas.

Life History

The adult *N. lugens* and *S. furcifera* remain active from 10° to 32° C and 8° to 36° C, respectively. In both species, the macropterous females are somewhat more tolerant of temperature extremes than the males (190). *N. lugens* adults usually live for 10 to 20 days in summer and 30 to 50 days during the autumn. Females kept at 20° C have an oviposition period of 21 days, which is reduced to only 3 days if they are kept at 30° C (191).

The preoviposition period under field conditions ranges from 3 to 10 days (107), but is from 1 to 6 days between 20° and 30° C (119, 138, 191).

All leafhopper and planthopper species have identical life history patterns. The females lacerate the midrib of the leaf blade or the leaf sheath to lay egg masses in the parenchymatous tissues. The number of eggs varies in different species. In *S. oryzicola* it is usually in multiples of 7 which McGuire et al. (131) and McMillian (132) attributed to the 14 ovarioles in each of the 2 ovaries of the females. Suenaga (190) reported the number of eggs per mass as 4 to 8 and 2 to 3, respectively, for *S. furcifera* and *N. lugens*, but observations at the International Rice Research Institute have shown that the number for these species ranges between 7 to 19 and 4 to 10, respectively (166). In *Nephotettix* spp. the number of eggs per mass varies from 8 to 16 and each female lays 200 to 300 eggs (5, 105). The females of *I. dorsalis* lay 100 to 200 eggs (143, 144), *S. oryzicola* (161), and *N. lugens* and *S. furcifera* 300 to 350 (190). Brachypterous *N. lugens* females usually lay more eggs than the macropterous forms, but no such difference is evident in *S. furcifera* (190).

The eggs are usually cylindrical with their micropyle ends protruding from the leaf tissue (41). When freshly laid they are whitish but later become darker with two distinct spots which vary in color between species and represent the eyes of the developing embryo. Usually the incubation period ranges between 4 and 8 days; in most species the fastest egg and nymphal developments are between 25° and 30° C (62, 190). Bae (8) showed that *N. lugens* eggs failed to hatch at 33° C but more hatched and growth was faster at 27° C than at 25° C. Thirty-three degrees Centigrade was also lethal to the freshly hatched nymphs and greatly reduced the life span of the adults.

Most species undergo 4 to 5 molts and the nymphal period ranges from 2 to 3 weeks. *N. lugens* nymphs exhibit a positive relationship between rate of nymphal development and temperature within a range of 11.6° to 27.7° C (190). The rate of egg and nymphal development of both *N. lugens* and *S. furcifera* is highest at 27° to 28° C; the fourth and fifth instar nymphs of the former remain active between 12° and 31° C and those of *S. furcifera* between 11° to 32° C (190). For *S. oryzicola* the developmental threshold and thermal constant is 8.2° C and 257.6° C, respectively (131).

Seasonal Occurrence and Factors of Abundance

In the warm and humid tropics different species of leafhoppers and planthoppers remain active the year round, and their population fluctuates according to the availability of food plants, natural enemies, and environmental conditions. After the rice crop is harvested, the insects usually transfer to weeds and grasses but do not hibernate (4, 20). However, in areas of wide temperature variations, they hibernate or aestivate. In Japan, *N. lugens*, *I. dorsalis* hibernate as eggs, and *Nephotettix cincticeps* and *L. striatellus* as fourth instar nymphs (144). *S. furcifera* has been observed to hibernate as eggs just before hatching or in the young nymphal stage, while *N. lugens* overwinters either as eggs or as fifth instar nymphs (106, 135, 190). *S. oryzicola* and *S. cubanus* diapause in the egg stage (41, 131, 171).

The hibernating insects become active when the weather warms up around March to April, and migrate to the grasses where they breed for one generation before migrating to rice fields shortly after transplanting in June or July (44). In areas where the rice crop is available at the termination of hibernation, the insects may migrate directly to the rice fields.

Thus, the seasonal occurrence varies distinctly between areas where the insects undergo dormancy and diapause on the one hand, and where they remain active throughout the year on the other. In the latter case, although there are exceptions, the insects are usually more abundant during the dry season than during the wet season. Also, *Nephotettix* species and *S. furcifera* are usually more common during the early stages while *N. lugens* and *I. dorsalis* become more prevalent during later crop stages (65, 72, 147, 194). The population of *S. oryzicola* also increases as the crop approaches maturity (41). In Vietnam, *S. furcifera* is prevalent from July to August, together with green rice leafhoppers (197).

In Japan, *L. striatellus* and *N. cincticeps*, which hibernate as fourth instar nymphs, appear in March; the former passes one generation on wheat and the latter on grasses, and both then migrate to rice fields (108). Direct migration to rice also occurs if the fields are established at the time of emergence. *Nephotettix cincticeps* completes three generations on rice from June to August and in the fourth generation hibernates as nymphs in late September to October (144). *I. dorsalis* also occurs in four generations. On

Amami Oshima Island (southern Japan), no diapause in *Nephotettix* occurs and adults can be collected at any time of year (144), which is identical to their occurrence in tropical areas (5, 20, 72). The population of *S. furcifera* generally increases up to July and August and decreases in September and October, while *N. lugens* increases in September and October (144). It has also been recorded that during the later part of the cropping season *N. lugens* occurs in overlapping generations (190).

Nasu (144) reported that hibernating generations of *Nephotettix cincticeps* deposit an average of 304 eggs per female, and the number of eggs deposited in subsequent generations is reduced to one half. However, there is no significant difference in the number of eggs contained in the ovarioles of *Nephotettix* of different generations (144). It is, therefore, apparent that the difference in the number of eggs laid is the result of environmental conditions which affect the developmental processes of the oocytes, rather than to any inherent difference among the insects themselves. Data of this nature from tropical areas should be helpful, although it is widely accepted among various workers that for most rice leafhopper and planthopper species the optimum temperature ranges between 25° and 30° C; insects reared at higher temperatures are less fertile and many eggs often do not hatch (8, 190).

The abundance of *Nephotettix* spp. has been attributed to high temperature, low rainfall, and abundant sunshine (62). Reviewing the data on light trap catches of this species from several experiment stations in southern Japan, Suenaga (190) recorded a positive correlation between the population build-up and the amount of sunshine ($r = 0.93$), and a negative correlation with average relative humidity ($r = -0.67$).

When exposed to strong sunlight at 22° C, many *S. furcifera* nymphs die but there is no such effect on the adults. Below 22° C, solar radiation is essential for oviposition by this species, while excessive solar and ultraviolet radiation prevents the population build-up of *N. lugens*. Exposure to short wave radiation is actually deleterious to both species.

The insect prefers lowland to upland rice and, since thick vegetation is a better habitat for planthoppers, direct sown fields are often preferred to transplanted ones (135, 190). Since various species have distinct preferences for plants at different stages of growth, the availability of rice plants of different ages is conducive to their proliferation. Shortage of host plants results in overcrowding which adversely affects the population build-up. It reduces the rate of nymphal development, increases the percentages of macropterous adults, lengthens the preoviposition period, and decreases the number of eggs laid (190).

Generally, fields receiving large amounts of nitrogenous fertilizers are most infested. Also, differences in oviposition and survival of hatching nymphs on different species and varieties of rice have been recorded (8, 27, 116, 190).

THE RICE GALL MIDGE

The rice gall midge, *Pachydiplosis oryzae,* is another serious pest of rice in south and southeast Asia. It may be the most important insect pest in several parts of India, Thailand, Cambodia, Vietnam, Indonesia, Ceylon, and Southern China, but apparently has not been recorded from the Philippines. In spite of its great economic importance, details of its bionomics and ecology have not been determined and at present no satisfactory control measure is known. The literature on the gall midge has been reviewed by Barnes (11) and Reddy (170). Mani (128) described its morphology and taxonomy.

Life History

The adult fly is about the size of a mosquito, is nocturnal, and phototropic. The female has a bright red stout abdomen, but the males are darker. The field population has a 4:1 female-to-male ratio (67, 123, 214). The adults feed on dewdrops and live for two to five days. Copulation usually takes place soon after emergence, lasts for about five minutes, and oviposition starts a few hours later (188). The females mate only once (214) and no parthenogenesis has been recorded; unmated females lay sterile eggs (67).

A single female is capable of laying 100 to 200 eggs, either singly or in groups of three to four near the base of the plants on the ligules or in their vicinity on the leaf blade or sheath (34, 35). Both in the seedbed as well as after transplanting, about 60 to 70 per cent of the eggs are laid on the leaf blade and not on the leaf sheaths, except some occasional oviposition on the central whorl of the plants (217). Those on the leaf blade are on the under surface (188). In captivity, the females oviposit on almost any surface they contact. The eggs are shining, white with pinkish, red, or yellow shades, elongate tubular, 0.55 long × 0.125 mm wide, but become shining amber before hatching. The incubation period ranges from three to four days.

The newly hatched larvae, which are about 1.3 mm long, can live in water without any harmful effect, usually up to three to six days. They creep down the leaf sheath to the growing points of the tillers and reach the interior of the bud which they lacerate and feed until pupation. Their feeding stimulates the tillers to grow into a tubular gall which resembles an onion leaf (170). The average larval period lasts from 15 to 20 days. The full-grown larva is about 3 mm long, pale red with a pointed anterior end. It feeds at the base of the gall on which it pupates. Generally only one maggot is found per tillers.

The pupation occurs inside the gall near the base. The pupa is about 2 to 2.5 mm long and 0.6 to 0.8 mm wide, and is adorned with a series of subequal spines which are pointed backward (128). These spines enable the pupae to wriggle their way to the tip of the gall, and when the adults are ready to emerge, the pupae pierce the tip and project half-way out. The skin of the pupa then bursts and the midge crawls out (170). Emergence generally takes place at night. The pupal period varies from two to eight days.

Damage

The damage to the plant is caused by the transformation of regular tillers into tubular galls which dry off without bearing panicles. Early infestation results in profuse tillering of the plants but also these new tillers often become infested and very few, if any, bear panicles. Even these are stunted and of reduced vigor.

The pest starts infesting the plants in the seedbed and can continue to do so until the booting stage. As the larvae can develop only on the growing primordia, they cannot survive on a crop beyond the vegetative stage (170).

The exact nature of the development of galls is not fully understood. Either direct feeding in the developing primordia, or secretion of some compound by the maggot, stimulates the growth of the leaf sheath around the larva into an oval chamber which eventually grows into a long tubular, onion leaf-like gall. It is commonly called "silver shoot" or "onion leaf" and is usually of the same color as the leaf sheath but is somewhat shiny. Several earlier workers regarded galls as elongated rice stems, but Deoras (32, 33) established by anatomical studies that the galls were modified leaf sheaths. The leaf blade is greatly atrophied and remains attached as a leaflet with tiny ligules and auricles on the tip of the gall. The galls become apparent in three to seven days after the larvae enter the growing point (44, 188). A fully developed gall is generally 1 to 2 cm wide and 10 to 30 cm long, although galls as long as 50 mm have been recorded (33, 115). By the time galls become apparent the adults have generally emerged. However, tiny galls about 2 mm long can be easily detected in the field and frequently these contain maggots and pupae.

Seasonal Occurrence and Factors of Abundance

The fly becomes active at the onset of the monsoons, when it completes one to two generations on grasses before the rice is planted, and then finally transfers to the rice fields (170). It usually takes 9 to 14 days to complete one life cycle on grasses, but about 19 to 26 days on rice (84, 93, 204). It is capable of infesting the crop only at the tillering phase, after which the population rapidly declines primarily because of limited availability of suitable hosts. Therefore, a late planted field is often severely damaged but early plantings may evade gall midge infestation. The fly seldom infests the second crop (58), and has not been observed infesting the third one (85, 159). Usually it occurs in five to eight overlapping generations in one season.

The hibernating stage of the insect and the site of hibernation have not been fully investigated. The insect has been reported to hibernate in underground dormant buds of grasses serving as alternate hosts and to become active again when the buds start growing after rains (170). Larvae overwinter in a short tube in the stubble (123).

In some areas the fly remains active the year round on available rice plants, on sprouts in the stubble (170), or on *Oryza barthi* (34). If growing tillers of these are not available, it undergoes diapause in the stubble.

The years of most serious gall midge infestation are those when early rains make the flies active but subsequent dry periods delay planting (170). In this case, the population multiplies on grasses and the flies migrate in large numbers to the late-planted rice crop. Cloudy skies and drizzling rains are conducive to fast build-up of gall midge populations. The favorable conditions for fly development are 26° to 30° C and 82 to 88 per cent relative humidity (67, 85). Heavy rains or storms cause high mortality. The insects are less abundant in the years preceded by a warm and dry spring (170). Low relative humidity may be the cause of decline in gall midge during second crop rice even though there is no distinct lack of suitable hosts.

Since the fly requires a high humidity, lowland crops are more often infested than upland ones (123). As the larvae can live under submerged conditions for several days (170), change in water level in the rice fields has not shown a distinct effect on the fly incidence (159, 162). However, as gall midge infestation is generally not recorded from deep water or floating rice areas, probably the maggots cannot survive prolonged submergence.

Distinct differences in varietal susceptibility to this insect have been reported (43, 44, 99, 156, 159, 162, 181, 215). This approach, although a somewhat long-range one, affords a promising method of reducing gall midge damage.

GRAIN-SUCKING INSECTS

Several hemipterous bugs that feed by sucking the sap of developing rice grains cause serious losses to rice crops. Usually they live either in the rice fields or on grasses in the vicinity where they feed and multiply during the vegetative phase but migrate to flowering rice fields to which they are strongly attracted. The three most common groups—rice bugs, the rice stink bugs, and the southern green stink bugs—are reviewed in this paper.

DAMAGE

Both nymphs and adults feed on and damage the rice grains. Rice bug nymphs are more destructive than the adults (7). Although they feed on other parts of the rice plant, grains at the milky stage are preferred. Both nymphs and adults feed by inserting their stylets at a point where the glumes meet (26), and a diffused brown spot caused by the exudation of the sap marks the point of insertion (203). Such grains remain empty or only partially filled. The panicles in heavily infested fields contain many shrivelled and unfilled grains and usually remain erect. In severe cases of infestation, all the grains in a field are sucked empty and the straw has an off-flavor which is unattractive to cattle (189). Partially damaged grains are believed to have an off-flavor even after cooking.

The stink bugs prefer rice at the milky stage of development but both nymphs and adults can feed and develop on ripening grains. Kiritani (102) also observed that the bugs feeding on rice were larger than those feeding on grasses and other hosts. Bowling (17) recorded that if grains were fed on at the late dough stage the usual result was broken grain with lowered milling quality, or pecky rice of inferior grade. He calculated that four stink bugs per square foot caused substantial financial loss (13).

RICE BUGS

The most important rice bugs in the subtropical and tropical rice areas belong to genus *Leptocorisa.* Ahmad (2) revised the subfamily *Lepcorisinae,* elevated the subgenus *Stenocoris* to generic rank separate from *Leptocorisa,* and regrouped the various species in these genera. *Stenocoris* occurs in Ethiopian, Nearctic, and Neotropical regions. Several species of the genus are known to be present in rice fields but their economic significance is not fully known. *Leptocorisa* is distributed in the Oriento-Australian region and includes some of the most serious rice pests in this area. The species of major economic significance are:

Name	*Formerly recorded as*	*Distribution*
L. acuta	*L. varicornis (Rhabdocoris) varicornis*	Throughout Asia except Java and Ceylon, Australian regions. Very common in India, Sarawak, and New Guinea.
L. oratorius	*L. maculiventris, L. acuta*	Far East, Ceylon, China, India, Tibet, Java, Australia.
L. chinensis	*L. corbetti*	Asia; not recorded from Australian regions.

The morphology and bionomics under field conditions of different species of rice bugs have been studied by several workers (3, 26, 189, 203).

Life history.—The adult insect is long and slender, about 14 to 17 mm long and 3 to 4.4 mm wide. On the average it lives for 30 to 50 days, although some insects have been observed to live for 110 to 115 days (189). It is phototropic and dirurnal but remains most active during early morning and evening when the sun is not strong. On sunny days, the insects hide at the basal parts of the plants. The females are stronger fliers than the males. The males are capable of mating shortly after emergence but the female, not until 7 to 14 days after becoming adults (189). Oviposition commences 3 to 4 days after mating. A single female lays an average of 200 to 300 eggs in batches of 10 to 20, arranged usually in two or three straight rows along the midrib on the upper surface of the leaf blade (3). The eggs are oval, slightly flattened on the top. When freshly laid they are creamy white but become darker as they approach hatching five to eight days later.

The freshly hatched nymphs are tiny and green but become brownish as they grow. They begin feeding three to four hours after hatching, and undergo five nymphal instars in a total period of 25 to 30 days to become adults (3). The feeding habits of adults and nymphs are similar. A number of alternate host plants, all in the family Graminae, have been recorded (189). The insects live on grasses but prefer flowering rice. Both nymphs and adults in the rice fields are difficult to see because of their color resemblance to the rice plants, but infested fields can often be detected even from a distance as they emit the typical rice bug odor.

Seasonal occurrence and factors of abundance.—All stages of this insect are very vulnerable to changes in temperature and humidity. They are most abundant at 27° to 28° C and 80 to 82 per cent relative humidity (81). During flowering of the rice crop, warm weather, overcast skies, and frequent drizzle favor population build-up but heavy rains reduce it. Therefore, the population usually increases at the end of the rainy season (203), and declines rapidly during dry months and when the temperature is unfavorable (26). In areas where temperature declines from October onward, the population is at a peak during September to October, after which the insects undergo hibernation and aestivation in grasses. In such areas, late rice crops evade the bugs. The hibernating or aestivating adults become active with the onset of summer rains. Sen (179, 180, 182) and Israel (81) reported that intermittent rains and high temperature during summer were conducive to terminating diapause.

The adults, after diapause, feed on grasses, weeds, millet, and other available alternate hosts on which they pass one to two generations before migrating to the rice crop at flowering stage. In single cropping areas the insect usually has four overlapping generations (189). But at places where temperatures are optimum and rice is grown all year, the bugs remain active throughout the year without a distinct diapause (22). In such areas, fields which mature early or later than the usual crops, become heavily infested. The insect becomes particularly abundant where rice planting is staggered, leading to an extended ripening period (221).

The strong phototropic nature of the insect has been exploited with light traps as a method of control but the results have been erratic. Cendaña & Calora (22) reported that large rice bug populations are trapped in early planted rice fields. Cleaning grassy weeds from the vicinity and destroying the insect soon after aestivation has been suggested (189). A variety of rice known as *sathi* escapes rice bug damage because the panicles do not emerge from the leaf sheath and are thus mechanically protected (183). However, the compatibility of this character with yielding ability and ease of threshing is uncertain.

RICE STINK BUGS

The rice stink bug, *Oebalus pugnax,* is an important rice pest in the southern United States. Both adults and nymphs feed on developing grains of rice in the milk and dough stage, resulting in partially or entirely unfilled grains.

Life history.—The adults are 9.3 to 12.5 mm long and slight less than half as broad (68). They are straw colored, shield-shaped with two sharply pointed shoulder spines which projecct forward and possess the typical stink bug smell. Males usually live for about 30 days, and females for an average period of 40 days, laying 70 to 80 eggs per female (148). The eggs are barrel shaped (0.86×0.65 mm) and laid in masses of 10 to 47 in double rows with the eggs of one row alternating with those of the other. They are deposited on leaves or panicles of different grasses (16). Newly laid eggs are green but become reddish before hatching in four to eight days after oviposition. The newly hatched nymphs congregate around the empty egg shells for about 24 hours after which they disperse to feed. The nymphs undergo five molts over a total average of 16 to 20 days to become adults (149).

Seasonal occurrence and factors of abundance.—The adult insects overwinter in leaf trash or bunch grasses. Emerging from hibernation in late April and early May, the insects feed on developing seeds of grasses adjacent to rice fields, moving to the rice fields later. A severe winter reduces the population of the overwintering adults, and high temperature during summer causes high nymphal mortality.

Another species, *Oebalus (Solubea) ornata,* has been reported to cause serious losses to rice in the Dominican Republic (124). It frequently occurs in large numbers and crop loss as high as 50 per cent has been recorded often. In general, the bionomics of this pest resemble *Oebalus pugnax.* The average female-to-male ratio is 1:1. Most of the eggs are laid on the upper leaf surface, and first instar nymphs congregate around the egg shells. The pests are very active until 10 a.m. when they feed on the panicles and copulate, but migrate to the base of the plants when light from the sun becomes stronger. On cloudy or light rainy days, the adults and nymphs remain on the panicles all day and feed extensively. In the Dominiccan Republic they remain active throughout the year and occur in seven generations. The population is usually highest during July, which coincides with the flowering of the first rice crop. In February, when the second crop is flowering, the population is comparatively small but still of economic significance. In May, the population is at its lowest ebb (124).

SOUTHERN GREEN STINK BUG

The southern green stink bug, *Nezara viridula,* is a polyphagous insect and occasionally causes serious losses on rice. Kiritani (102) has reviewed the biology and control of this pest in Japan. In recent years it has assumed a great economic significance in southern Japan because of the cultivation of early paddy (150, 174), the heading of which in mid-June to early July coincides with the emergence of first generation adults. This is particularly favorable for the insect because not only is flowering rice more suitable for their survival and development, but at this time hosts other than paddy are scarce. Furthermore, since their dispersal ability is greater than that of their parasites, populations migrating to paddy fields suffer only low parasitization (102). The population developed on early rice increases on the medium and late maturing crops, but even in double rice cropping areas the bug population usually remains fairly low. However, this is not true in grassy or orchard areas where adequate alternate hosts are available when there is no rice at flowering stage.

Life history.—The adult insects, typically pentatomid in shape, are about 13 to 17 mm long, and occur in four distinct color phenotypes. Females begin mating one week after becoming adult and the preoviposition period varies from two to three weeks. Both male and female bugs are capable of repeated matings. The average life span of females is about 30 days.

The eggs are laid on the lower surfaces of the leaves in masses of 20 to 130 in 5 to 8 parallel rows. Each female usually lays 2 to 4 egg masses which are yellow but turn red just before hatching. The first instar nymphs congregate around the egg shells; at the second instar they start feeding gregariously but scatter to solitary feeding beyond the fourth instar (100, 101). The nymphs undergo five molts, in an average period of 35 to 45 days, to become adults. The nymphal population is considerably heterogenous in its color pattern.

Seasonal occurrence and factors of abundance.—In southern Japan the insect occurs in three overlapping generations with a partial fourth. In years which are warm in March to June, the hibernating insects beccome active earlier and complete the fourth generation. The adult insects hibernate in dry places in shady areas. In hibernation the males are quiescent while the females diapause (102). During years with a severe winter, the hibernating insects, particularly those which have fed on grasses, are smaller and suffer high mortality. The adults emerging from hibernacula feed on grasses, orchards, and other spring and summer crops before they migrate to rice. The attraction to heading rice is so great that adults migrate to paddy fields over long distances (102).

In nature, the population is, to some degree, regulated by density-dependent factors (100). With increased population density in the second and third generations, the females exhibit reduced fecundity and the eggs and larvae suffer mortality. Kiritani (102) reported that a large percentage of females died without ovipositing. Strong winds also reduce the nymphal population. Several egg parasites play an important role in Japan. Substantial success with biological control of this insect has been achieved in Hawaii and in Australia (30).

RICE WATER WEEVIL

The rice water weevil, *Lissorhoptrus oryzophilus,* has been reported as the most common and destructive pest of rice in the United States. Earlier records showed its occurrence only in the southern states but in recent years it has also been recorded from California (117). In Louisiana, another species, *L. simplex,* has also been recorded infesting rice (40).

Damage

The feeding of adults on the leaves of young rice plants results in longitudinal strips on the leaf surface, but this is not usually of much economic significance. The major damage is caused by the maggots which feed within and upon the roots, pruning them severely in heavy infestations and resulting in loss of vigor, lodging, and reduced yields.

Life History

The adult weevil is about 3.1 mm long and is greyish with a darker area on the dorsum. It is semiaquatic and can fly or swim just beneath the water surface. The adults feed and copulate on the aerial parts but oviposit on submerged parts of the plant. No male rice water weevils have been recorded in California and females are parthenogenetic (59). Webb (212) reported that cylindrical pearly white eggs about 0.8 mm long are individually inserted longitudinally beneath the epidermis of one of the principal roots. Current investigation, however, has shown that the eggs are mostly laid in the basal half of the submerged portion of the leaf sheath and only occasionally on the submerged upper portion of the plant or in the roots (59). Under field conditions the eggs hatch in an average period of eight days. The larvae, hatching from eggs laid in the leaf sheath, mine the leaf sheath for a short period and then crawl down to the roots. The larvae hatching in the roots feed there. There are four larval instars to produce adults in 30 to 35 days. The larger third instar larvae feed externally among the roots and sometimes up into the crown (16). Often, several larvae are found in the roots of a single plant. The larvae can migrate up to 6 inches through the soil to other roots (172).

Pupation occurs in a cocoon attached to the roots. The pupa is white and the same size as the adult weevil.

Seasonal Occurrence and Factors of Abundance

The adult weevil overwinters in Spanish moss, rice stubble, or fine matted grass and becomes active again as the weather warms from March to

June. The adults move into the fields of young rice and feed on the leaves. In unflooded fields, they hide in the soil during the day and feed at night, but in flooded fields they usually feed day and night (16). Oviposition usually occurs after the water is applied. Newly emerged adults usually fly at night to adjacent fields of younger rice.

As the weevils prefer young rice, early planted rice usually escapes heavy infestation (12, 74). The amount of damage caused and the number of larvae found are reported to differ among rice varieties (14, 74, 173). Plots receiving greater amounts of fertilizers are more severely infested (15, 202).

Intermittent draining and flooding has been reported to reduce the larval population but is not practiced by farmers, as seed treatments with several insecticides effectively protect the crop from the weevil and are much cheaper and more convenient. It has been recorded, however, that the presence of aquatic grasses, which are alternate hosts, reduces the efficacy of seed treatment (172).

Rolston & Rouse (173) suggested that planting all of the fields at the same time made possible by mechanization, draining the fields before applying fertilizers, and the use of herbicides have been deleterious to the water weevil grubs.

Two other species, *Echinocnemus oryzae* (186) and *Hydronomidus moliter* (163) have been reported to cause similar damage to rice crops in India.

RICE HISPA

Rice hispa, *Hispa armigera,* frequently causes extensive losses to rice crops in India, East Pakistan, Burma, Nepal, Sumatra, Taiwan and Southern China.

Damage

Both adults and grubs feed on and damage rice plants. The adults scrape the upper surface of the leaf blade, often leaving only the lower epidermis (9). The damaged areas appear as white streaks parallel to the midrib. The tunnelling of the grubs between the two epidermal layers results in irregular translucent white patches starting from ovipositional sites near the leaf tip and extending toward the base of the leaf blades (5). The affected parts of the leaves usually wither off. In severe infestations the leaves turn whitish and membranous and finally dry off.

Thus, infested plants have reduced leaf area, become less vigorous, and are often stunted. In recent years, this insect has been a perpetual problem in East Pakistan, infesting about 150,000 to 200,000 acres every year and causing affected areas to suffer about 20 per cent loss in yield (5).

Life History

The life history of this pest has been described by Alam (5). The adult is a small (5.5 mm long), blue-black beetle with a spiny body. The females live for an average period of 20 days and the males for 14 days. They mate three to four days after emergence. The eggs are laid singly near the tip of the leaf blade, generally on the ventral surface, and are partially inserted beneath the epidermis and covered with a small quantity of a dark substance probably secreted by the female beetle. A single female lays an average total of 55 eggs; under heavy infestation as many as 100 eggs have been recorded from a single plant in the field. The incubation period under natural field conditions ranges from four to five days.

The hatching grubs mine into the leaf blades between the epidermal membranes and feed on the green tissues. The larval and pupal periods are completed in average periods of 7 to 12 and 4 to 5 days, respectively. Both stages are completed without migration to any other leaf. The adult beetles cut their way out of the leaf and become external feeders.

Seasonal Occurrence

Usually, young rice crops are preferred by the adult beetle in initiating an infestation. No ecological information is available about this pest. Alam (5) reported that it appears in rice fields in February and that the population increases until June or July when it causes heavy losses to young crops. Beyond August the population declines and is usually of no economic significance. Adult beetles in small numbers can be collected from rice fields as late as September or October (5, 9). During this period, the pest completes six overlapping generations but how the insect bridges the period from October to January is not known.

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