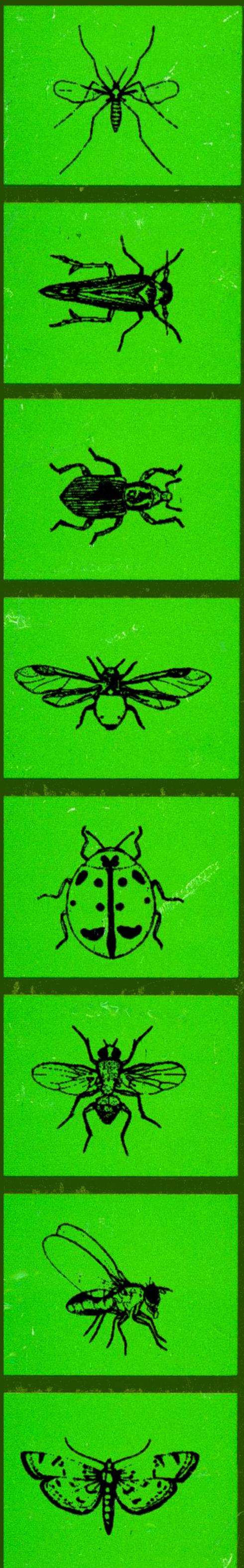

Insect Pests of Rice

M. D. Pathak and Z. R. Khan

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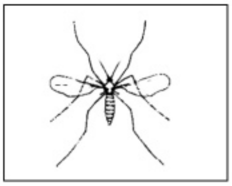
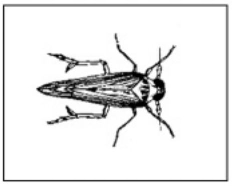
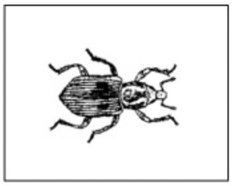
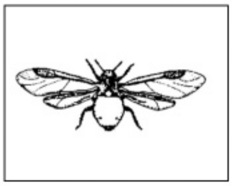
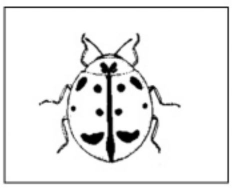
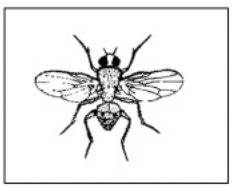
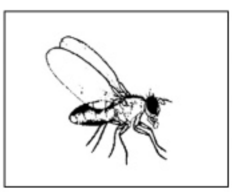
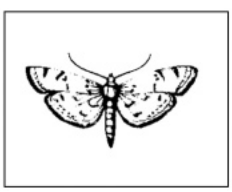

1994

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Contents

Foreword

The world rice crop is attacked by more than 100 species of insects; 20 of them can cause economic damage. Insect pests that can cause significant yield losses are stem borers; leafhoppers and planthoppers (which cause direct damage by feeding as well as by transmitting viruses); gall midges, a group of defoliating species (main1y lepidopterans); and a grain-sucking bug complex that feeds on developing grains.

Average yield loss due to various insect pests in Asia — where more than 90% of the world's rice is produced—is about 20%. Any decrease in pest damage means a corresponding increase in needed rice production.

Reduction in insect pest damage should come from incorporating genetic resistance into new genotypes and from the development of suitable cultural and biological control methods. The first edition of this book, published in 1967, contained basic information on the biology and factors of abundance of common insect pests of rice. Since then, due to the introduction of high-yielding modern varieties, distinct changes have occurred in the insect pest complex of rice. Several species, once considered minor pests, have become major pests. Also, much information on various aspects of control, including integrated pest management, has become available.

This new edition includes updated information on biology, damage, seasonal history and factors of abundance, and control measures of the major insect pests of rice. IRRI hopes this expanded content will prove useful to researchers, extension workers, and students everywhere.

Many people were involved in the production of this book. N.J. Fernandez, A.D. Tan, and F.F.D. Villanueva helped compile the text, references, and tables; A.T. Barrion validates scientific names of insect pests; E. Panisales provided artwork; and M.L.P. Abenes provided photographic services. The volume was edited by W.H. Smith and G.S. Argosino.

Klaus Lampe

Introduction

Rice, the staple diet of over half of the world's population, is grown on over 145 million ha in more than 110 countries, and occupies almost one-fifth of the total world cropland under cereals. Classified primarily as a tropical and subtropical crop, rice is cultivated as far north as 53° N latitude on the border between the USSR and China and as far south as 39° S latitude in Central Argentina, and from sea level to altitudes of 3,000 m. The crop is established either by direct sowing (broadcast or drilled) or by transplanting. Rice grows under diverse water regimes: it is an upland crop where there is no standing water and rains are the sole source of moisture, or a lowland crop under conditions in which water, derived either from rain or irrigation systems, is impounded in the fields. Rice is cultivated on terraces, on slopes, and in valleys or other low-lying sites. Floating rice may be grown in several meters of standing water.

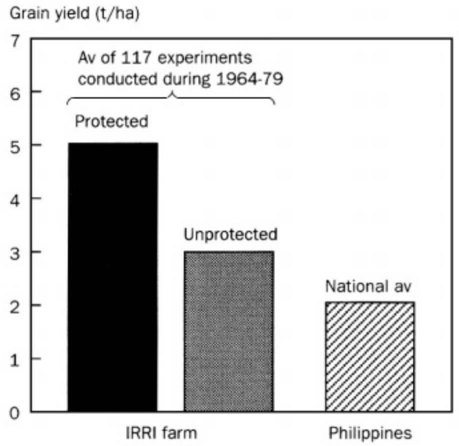
As many as 80,000 rice accessions (cultivated and wild varieties) have been collected at the International Rice Germplasm Center of the International Rice Research Institute (IRRI). The traditional tropical rice varieties are tall and leafy; they often lodge during the later stages of growth. Modern varieties (MVs) are short—usually about 1 m high—stiff-strawed, erect-leafed, and lodging resistant. The plant characters of the MVs are commonly associated with high yields.

Two major factors are responsible for low yields: adverse weather (floods, drought, typhoons, etc.) and pest epidemics.

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

Average rice yield varies from less than 1 t/ha in some tropical countries to more than 6 t/ha in Japan, Republic of Korea, and the USA. Rice yields in South and Southeast Asia, the world's rice bowl, fluctuate widely, averaging around 2 t/ha.

Most of the world's rice production is from irrigated and rainfed lowland ricefields where insect pests are constraints. The warm and humid environment in which rice is grown is conducive to the proliferation of insects. Heavily fertilized, high-tillering MVs and the practice of multicropping rice throughout the year favor the buildup of pest populations. The intensity of the insect problem in such an area can be illustrated by the experience at IRRI. In 117 experiments conducted over 15 yr, plots protected from insects yielded almost twice as much as unprotected plots (Fig. 1). Average rice yield loss due to various insect pests was estimated to be 31.5% in Asia (excluding mainland China) and 21 % in North and Central America in



1. Magnitude of rice crop loss due to insect pests in the Philippines. The average yield from plots protected with insecticides was 4.9 t/ha whereas that from unprotected plots was 3.0 t/ha, suggesting a loss of 40% (modified from M.D. Pathak and G.S. Dhaliwal, 1981, Trends and strategies for rice insect problems in tropical Asia, IRRI Res. Pap. Ser. 64, International Rice Research Institute, P.O. Box 933, Manila 1099, Philippines).

1967.[1] Estimates for tropical South and Southeast Asia are considerably lower. In a 1989 survey of 50 rice entomologists from 11 countries, average yield losses due to insect pests were estimated at 18.5%. Yield increases of this magnitude frequently result from effective insect control in the different South and Southeast Asian countries.

The rice plant is subject to attack by more than 100 species of insects; 20 of them can cause economic damage. Together they infest all parts of the plant at all growth stages, and a few transmit viral diseases. The major insect pests that cause significant yield losses are leafhoppers and planthoppers, which cause direct damage as well as transmit viruses; stem borers; and a group of defoliator species (Table 1). As in many other agroecosystems, the rice agroecosystem has a few primary pests that may actually limit production under certain conditions. In addition to the primary pests are numerous species that cause periodic losses, and a few species that may occur in such low numbers that no damage occurs.

Since the introduction of high-yielding varieties, distinct changes have occurred in the insect pest complex of rice in Asia. Several species, which once were considered minor pests, are now considered major (Table 2). Examples are the brown planthopper, whitebacked planthopper, green leafhopper, and leaffolders. Until the 1960s, the stem borers were considered the most serious pests of rice throughout the tropics. In recent years, however, damage from them has declined. In Japan, the population densities of stem borers have steadily declined since the mid-1960s (Fig. 2).

Table 1. Insect pests and stages at which they attack the rice crop.

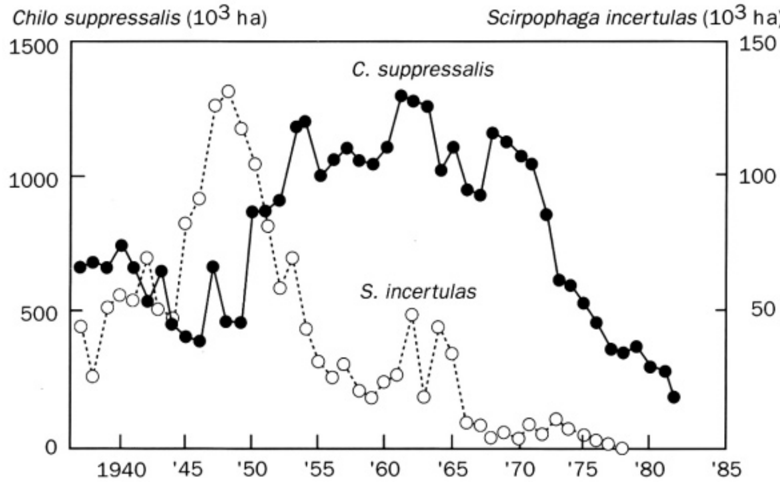
Insect pests (order:family)
Vegetative sfage
Seedling maggots (Diptera: Muscidae)
Rice whorl maggots (Diptera: Ephydridae)
Rice caseworms (Lepidoptera: Pyralidae)
Rice green semiloopers (Lepidoptera: Noctuidae)
Rice leaf beetles (Coleoptera: Chrysomelidae)
Rice thrips (Thysanoptera:Thripidae)
Rice gall midge (Diptera: Cecidomyiidae)
Armyworms and cutworms (Lepidopera: Noctuidae)
Grasshoppers, katydids, and field crickets (Orthoptera: Acrididae, Gryllidae, and Tettigoniidae)
Rice leaffolders (Lepidoptera: Pyralidae)
Rice stem borers (Lepidoptera: Pyralidae and Noctuidae)
Stalked-eyed flies (Diptera: Diopsidae)
Black bugs (Hemiptera: Pentatomidae)
Rice hispa (Coleoptera: Chrysomelidae)
Mealybugs (Homoptera: Pseudococcidae)
Reproductive stage
Greenhorned caterpillars (Lepidoptera: Satyridae)
Rice skippers (Lepidoptera: Hesperiidae)
Planthoppers (Homoptera: Delphacidae)
Leafhoppers (Homoptera: Cicadellidae)
Ripening stage
Ripening seed bugs (Hemiptera: Alydidae)
Stink bugs (Hemiptera: Pentatomidae)
Soil-inhabiting pests
Ants (Hymenoptera: Formicidae)
Termites (Isoptera: Termitidae and Rhinotermitidae)
White grubs (Coleoptera: Scarabaeidae)
Field crickets (Orthoptera: Gryllotalpidae)
Mole crickets (Orthoptera: Gryllotalpidae)
Root weevils (Coleoptera: Curculionidae)
Root aphids (Homoptera: Aphididae)
Wire worms (Coleoptera: Elateridae)
Root-feeding mealybugs (Homoptera: Pseudococcidae)

[1] Cramer H H (1967) Plant protection and world crop production. Bayer Pflanzenschutz Leverkusen 20(1):1-524.

Other insect pests are reportedly becoming serious on rice in many countries. Examples are thrips in India and China, rice bugs in Malaysia, and mealybugs in India and Bangladesh. In addition, new pests are recorded in several areas: sugarcane leafhopper *Pyrilla perpusilla* Walker and rusty plum aphid *Hysteroneura [=Carolinaia] setariae* (Thomas). These pests were recently recorded to have attacked the crop in India.

Another important example is the rice water weevil *Lissorhoptrus oryzophilus* Kuschel in Japan. This pest, originally distributed in the Mississippi River basin in the USA, is now the most destructive rice pest in Japan. The weevil was first recorded in 1976 in Aichi Prefecture and is believed to have been transported to Japan with hay imported from the USA. The insect is presently regarded as the most destructive rice pest in Japan and the most difficult to control.

Insect pests attack the rice crop from the time the nursery bed is prepared until harvest. The actual species complex varies in abundance and distribution from locality to locality and from year to year. Only the most common and specific insect pests of rice in Asia are discussed in this book.



2. Annual changes in hectarage of ricefields infested with two stem borer species in Japan (from K. Kiritani, 1988, Jpn. Agric. Res. Q. 21:264).

Table 2. Changes in economic importance of various insect pests during the last 15 yr with the introduction of modern varieties and improved crop production practices.[a]

Country	Major insect pests becoming less important	Minor insects becoming more important
Bangladesh	Stem borers, armyworms	Green leafhopper, brown planthopper, grasshoppers, rice leaffolders, whitebacked planthopper
China (mainland)	Stem borers, small brown planthopper, armyworms	Brown planthopper, whitebacked planthopper, rice hispa
China, Taiwan Province	Stem borers	Rice leaffolders, small brown planthopper, whitebacked planthopper
India	Stem borers, swarming caterpillars, brown planthopper, gall midge	Whitebacked planthopper, rice leaffolders, rice root weevil, rice bug, rice whorl maggot, rice hispa
Indonesia	Stem borers	Brown planthopper, rice leaffolders
Japan	Stem borers, brown planthopper	Rice bugs, rice water weevil
Korea, Republic of	Stem borers, zigzag leafhopper, brown planthopper	Whitebacked planthopper, rice leaffolders, rice water weevil
Pakistan	Stem borers	Whitebacked planthopper, rice leaffolders
Philippines	Brown planthopper, stem borers	Rice bugs, rice leaffolders, whorl maggots
Sri Lanka	Stem borers	Whitebacked planthopper, brown planthopper, green leafhopper
Thailand	Green leafhopper	Rice leaffolders, caseworm

[a]Data obtained from 50 rice entomologists in different countries.

Stem borers

The stem borers, generally considered the most serious pests of rice worldwide, occur and infest plants from seedling stage to maturity. Fifty species in three families—Pyralidae, Noctuidae (Lepidoptera), and Diopsidae (Diptera)—are known to attack the rice crop (Table 3). Thirty-five pyralids belonging to 12 genera, 10 noctuid species belonging to 3 genera, and 5 diopsid species belonging to the genus *Diopsis* have been recorded as rice stem borers. The pyralid borers are the most common and destructive, and usually have high host specificity. The noctuid borers are polyphagous and only occasionally cause economic losses to the rice crop. In Asia, the most destructive and widely distributed are yellow stem borer *Scirpophaga incertulas* (Walker), striped stem borer *Chilo suppressalis* (Walker), white stem borer *Scirpophaga innotata* (Walker), dark-headed stem borer, *Chilo polychrysus* (Meyrick), and pink borer *Sesamia inferens* (Walker). In Asia, *Scirpophaga incertulas* and *Chilo suppressalis* are responsible for a steady annual damage of 5-10% of the rice crop, with occasional localized outbreaks of up to 60%.

Scirpophaga incertulas, distributed primarily in the tropics, also occurs in the temperate areas where temperature remains above 10 ºC and annual rainfall is more than 1,000 mm. It is the predominant species in Bangladesh, India, Malaysia, Pakistan, the Philippines, Sri Lanka, Thailand, Vietnam, and parts of Indonesia. *Chilo suppressalis* and *Scirpophaga innotata* follow close behind. In Bangladesh, *Scirpophaga incertulas* is

Table 3. Stem borers of rice worldwide.

Order	Family	Species[a]	Distribution
Lepidoptera	Pyralidae	*Acigona ignefusalis* (Hampson)	
		Adelpherupa flavescens Hampson	Africa
		Ancylolomia chrysographella (Kollar)	Asia
		Catagela adjurella Walker	China
		***Chilo agamemnon* Bleszynski**	Middle East/North-East Africa
		Chilo aleniellus (Strand)	Africa
		***Chilo auricilius* Dudgeon**	Asia
		Chilo diffusilineus (J. de Joannis)	Africa
		Chilo luniferalis Hampson	Africa
		Chilo mesoplagalis (Hampson)	Africa
		Chilo partellus (Swinhoe)	West Asia/Africa
		***Chilo plejadellus* Zincken**	North America
		***Chilo polychrysus* (Meyrick)**	Asia
		Chilo psammathis (Hampson)	Africa
		Chilo sacchariphagus indicus (Kapur)	Asia
		***Chilo suppressalis* (Walker)**	Europe/Middle East/Asia/ Oceania
		***Chilo zacconius* Bleszynski**	Africa
		Diatraea lineolata (Walker)	Central/South America
		***Diatraea saccharalis* (Fabricius)**	North/South America
		***Elasmopalpus lignosellus* (Zeller)**	North/South Amerlca
		Eldana saccharina Walker	Africa
		***Maliarpha separatella* Ragonot**	Africa/West Asia
		Niphadoses palleucus Common	Australia
		***Rupela albinella* (Cramer)**	North/South America
		Scirpophaga aurivena (Hampson)	Asia
		Scirpophaga fusciflua Hampson	Asia
		Scirpophaga gilviberbis Zeller	Asia
		***Scirpophaga incertulas* (Walker)**	Asia/Australia
		= *Schoenobius incertulas* (Walker)	
		= *Tryporyza incertulas* (Walker)	
		***Scirpophaga innotata* (Walker)**	East Asia/Australia
		= *Tryporyza innotata* (Walker)	
		Scirpophaga lineata (Butler)	Asia
		Scirpophaga nivella (Fabricus)	Asia/Australia/Oceania
		***Scirpophaga occidentella* (Walker)**	Africa
		***Scirpophaga subumbrosa* Meyrick**	Africa
		Scirpophaga virginia Schultze	Asia
	Noctuidae	*Bathytricha truncata* (Walker)	Australia
		Busseola fusca Fuller	Africa
		***Sesamia botanephaga* Tams & Bowden**	Afrlca
		***Sesamia calamistis* (Hampson)**	Africa
		Sesamia cretica Lederer	Africa/Europe/Middle East
		Sesamia epunctifera Hampson	Africa
		***Sesamia inferens* (Walker)**	Asia/Australia/Oceania
		***Sesamia nonagrioides* (Lefebre)**	Africa
		Sesamia penniseti Tams & Bowden	Africa
		Sesamia uniformis Dudgeon	Asia
Diptera	Diopsidae	***Diopsis apicalis* Dalman**	Africa
		Diopsis circularis Macquart	Africa
		Diopsis ichneumonea Linnaeus	Africa
		***Diopsis macrophthalma* Dalman**	Africa
		Diopsis servillei Macquart	Africa

[a] Species printed in boldface are those commonly occurring on rice.

of major importance followed by *Sesamia inferens.* In the Republic of Korea, *Chilo suppressalis* is the only stem borer damaging rice; *Scirpophaga incertulas* does not occur. In Japan, *Chilo suppressalis* and *Scirpophaga incertulas* are the two economically important rice borers. Because *Scirpophaga incertulas* is restricted to southern Japan, the maximum area of ricefields it infests is one-tenth of that of *Chilo suppressalis.* Moreover, *Scirpophaga incertulas* in Japan has been steadily decreasing since 1948 and *Chilo suppressalis* since 1960. *Scirpophaga incertulas* is also a major pest of deepwater rice in eastern India, Bangladesh, and Thailand, causing more than 20% yield loss in many fields.

Chilo suppressalis is highly tolerant of low temperature. Full-grown larvae exposed to −14°C for 1-3 h do not exhibit significant mortality. *Scirpophaga innotata,* a tropical species, occurs in regions with distinct dry and wet seasons. *Chilo polychrysus,* initially reported as the most common and destructive in Asia, has been recorded in several other countries in recent years and its importance is being increasingly recognized.

In Africa, sorghum stem borer *Chilo partellus* (Swinhoe), *Chilo diffusilineus* J. de Joannis, white stem borer *Maliarpha separatella* Ragonot, and African pink borer *Sesamia calamistis* (Hampson) are serious rice pests. In eastern Africa, the principal stem borer of upland rice is *Chilo partellus. Maliarpha separatella* and *Sesamia calamistis* are more abundant in lowland rice. In Central and West Africa, *Maliarpha separatella* and Sesamia calamistis are dominant stem borers of upland rice. *Chilo diffusilineus* and *Chilo partellus* are important pests in upland savannas. Stalk-eyed stem borers *Diopsis* spp. are also important rice pests in Africa.

In North and South America, *Diatraea saccharalis* (Fabricius) is the most widespread species, followed by *Rupela albinella* (Cramer) and *Elasmopalpus lignosellus* (Zeller).

Because stem borers are the most important rice pests in Asia and other parts of the world, their bionomics has been widely studied. Except for some investigations in Japan, most studies have been conducted under natural environmental conditions and any ecological conclusions drawn are more generalized than specific.

Life history

Adults

The adults of lepidopterous stem borer species (Fig. 3a-3f) are nocturnal, positively phototropic, and strong fliers; diopsid flies (Fig. 4a, b) are diurnal and rest in the shade when not actively flying. *Scirpophaga incertulas* moths usually emerge between 1900 and 2100 h; *Chilo suppressalis* moths emerge from 1500 to 2300 h, peaking between 1900 and 2000 h, and become active again toward dawn. During the day, *Chilo suppressalis* hides among the grasses while *Scirpophaga incertulas* and *R. albinella* remain in nurseries or ricefields.

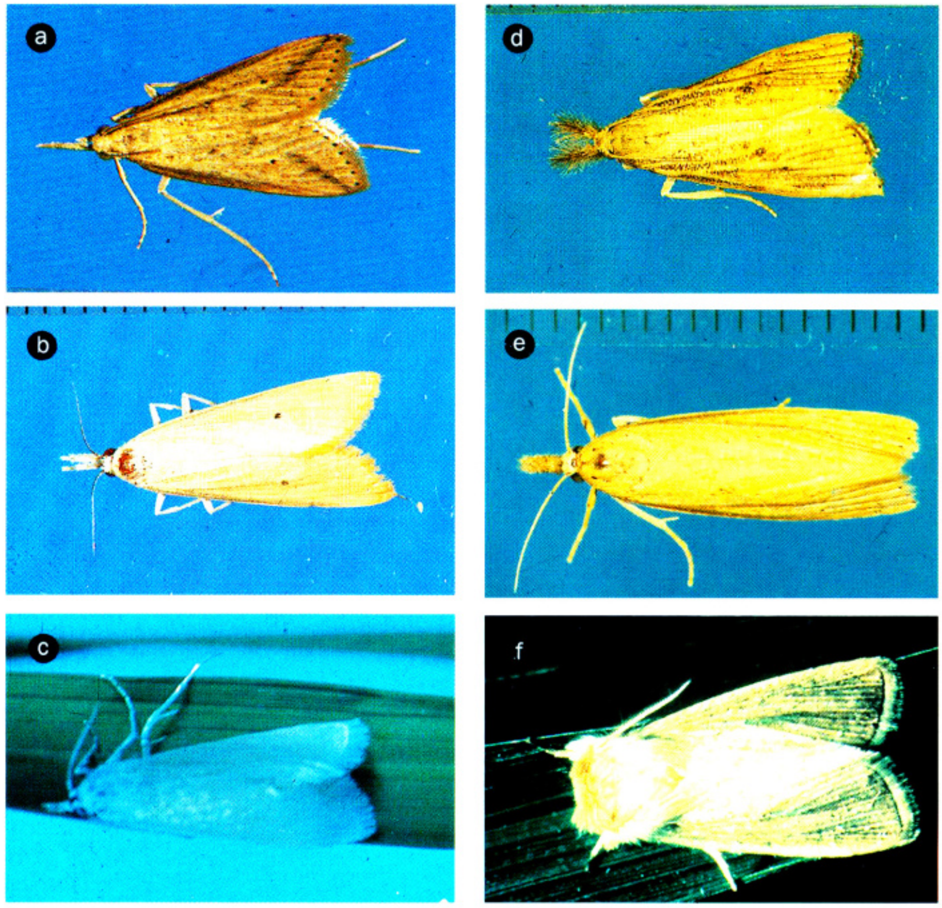
The strong phototaxis of these species in earlier years was used to attract them to light traps for monitoring and control. In Japan, however, even with one light trap installed in every 80 ha of rice, only 50% of the moth population could be attracted. The moths are most attracted to UV and green fluorescent lights. Light traps are now used only for studying population fluctuations.

Most borer species can fly 5-10 miles, but can cover longer distances if carried by winds. The distance covered per second has been reported as 0.6-3.4 m for *Chilo suppressalis* males, which fly in an irregular or circuitous course, and 0.48-2.15 m for females, which usually fly in straight lines.

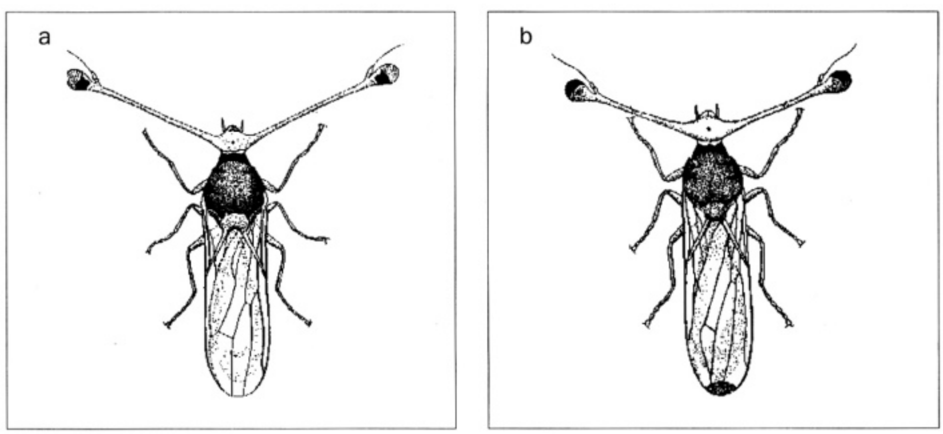
Mating in most species generally occurs between 1900 and 2100 h. The sex ratio of different species, based on light trap catches, has been reported as generally more females than males, except for a 1:l ratio for *Maliarpha separatella.* In the absence of data on phototropism of different sexes in these experiments, the validity of light trap catches to represent sex ratios in nature is questionable.

In experiments at IRRI, field-collected females of *Chilo suppressalis* and *Sesamia inferens* mated many times; those of Scirpophaga incertulas and Scirpophaga innotata mated only once. In laboratory tests using varying sex ratios of *Chilo suppressalis,* individual females mated as often as four times and males as often as eight times. The male moths were strongly attracted to the virgin females. Attraction was maximum on the evenings of female emergence, but declined on subsequent days. Virgin females used as baits 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 airstreams from containers of virgin females.

Oviposition by most stem borer species occurs in the evening. *Chilo suppressalis* moths start oviposition the night after emergence and continue up to 3 d, usually from 1700 to 2200 h with a peak at about 2000 h. *Scirpophaga incertulas* females oviposit between 1900 and 2200 h in summer and 1800 and 2000 h in spring and autumn. The moths deposit only one egg mass per night and oviposition occurs up to five nights after emergence. Oviposition usually takes 10-35 min. *Chilo suppressalis* moths are most active between 19 and 33 °C; no flight or oviposition occurs below 15 °C. The maximum number of eggs is laid at 29 °C and 90% relative humidity (RH). The moths exhibit strong preference for oviposition on certain host plants, but eggs within a field are generally randomly distributed.



3. Adults of lepidopterous stem borers: ***a) Scirpophaga incertulas*** **male,** ***b) Scirpophaga incertulas*** **female,** ***c) Scirpophaga innotata, d) Chilo auricilius, e) C. suppressalis, f) Sesamia inferens.***



4. ***Diopsis*** **adults:** ***a) Diopsis macrophthalma, b) D. apicalis.***

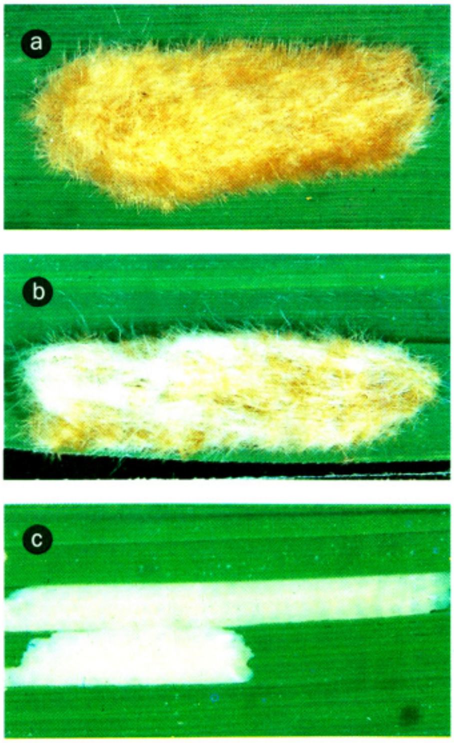
Eggs

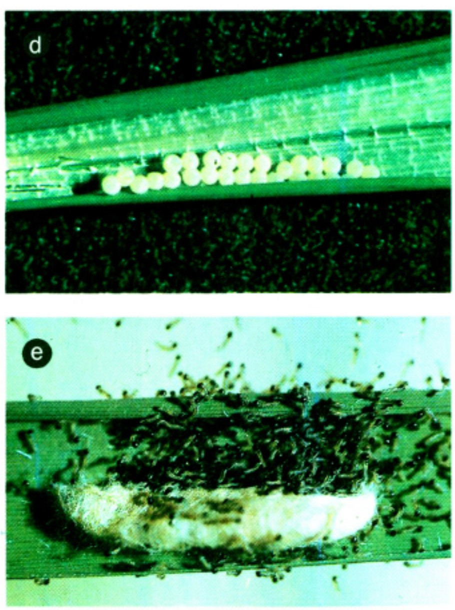
Lepidopterous stem borers lay eggs in masses (Fig. 5a-5e); diopsid flies lay isolated eggs. The eggs of *Scirpophaga incertulas and Scirpophaga innotata* are laid near the tip of the leaf blade, while those of *Chilo suppressalis* and *Chilo polychrysus* are found at the basal half of the leaves or, occasionally, on leaf sheaths. *R. albinella* and *Chilo polychrysus* oviposit on the lower surface of the leaf blade. Several workers in Japan have reported that first-generation *Chilo suppressalis* moths normally oviposit on the upper surface of the leaves and that moths of subsequent generations deposit eggs on the lower surfaces. For several thousand field-collected eggs at IRRI, no distinct difference in position on either leaf surface was recorded, except that the eggs on the upper leaf surface of hairy varieties were laid in the glabrous area along the midrib.

Egg masses of lepidopterous stem borers usually contain 50-80 eggs, and a single female is capable of laying 100-200 eggs. Diopsid females lay about 30 eggs each in a span of about 2 wk. Pyralids oviposit openly on the leaf blades, noctuids oviposit behind leaf sheaths. The eggs of *Scirpophaga incertulas, Scirpophaga innotata,* and *R. albinella* are covered with pale orange-brown hairs from the anal tufts of the female moths (Fig. 5a, b). Those of *Chilo suppressalis* and *Chilo polychrysus* have no such cover (Fig. 5c). *Maliarpha 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, forming a case that encloses the egg mass. Among eggs of all species, those of *Sesamia inferens,* laid between the leaf sheath and the stem, are probably the most effectively protected (Fig. 5d).

The threshold temperature for development of *Chilo suppressalis* eggs is reported to be 10-12 °C. Although *Scirpophaga incertulas* eggs show some development at 13 °C, hatching normally occurs at 16 °C or higher. In both species, the incubation period decreases with temperature increase, beginning at 30 °C and continuing up to 35 °C. Although embryonic development can be completed at 35 °C, the larvae die within the egg shell. In *Chilo suppressalis* eggs, cholinesterase activity starts at about 60 h after oviposition. This could be the reason for the ineffectiveness of organophosphate insecticides on freshly laid eggs. Egg development duration in diopsids is 2-3 d; that in lepidopterous moths, 5-9 d.

The optimum egg hatching temperature is 21-33 °C for *Chilo suppressalis* and 24-29 °C for *Scirpophaga incertulas.* Both species require 90-100% RH; hatching is severely reduced below 70% RH. The eggs usually hatch during daytime. In *Chilo suppressalis,* maximum hatching is from 0500 to 0600 h, followed by another peak from 1400 to 1600 h. In *R. albinella,* hatching usually occurs in the evening. Generally, all eggs in a mass hatch simultaneously (Fig. 5e). Larvae emerged from a large egg mass of *Chilo suppressalis* in about 13 min, but those from a small egg mass lacked synchronization and took longer.





5. Eggs of lepidopterous stem borers: *a) Scirpophaga incertulas, b) Scirpophaga innotata, c) Chilo suppressalis,* d) *Sesamia inferens,* e) hatching of an egg mass.

Larvae

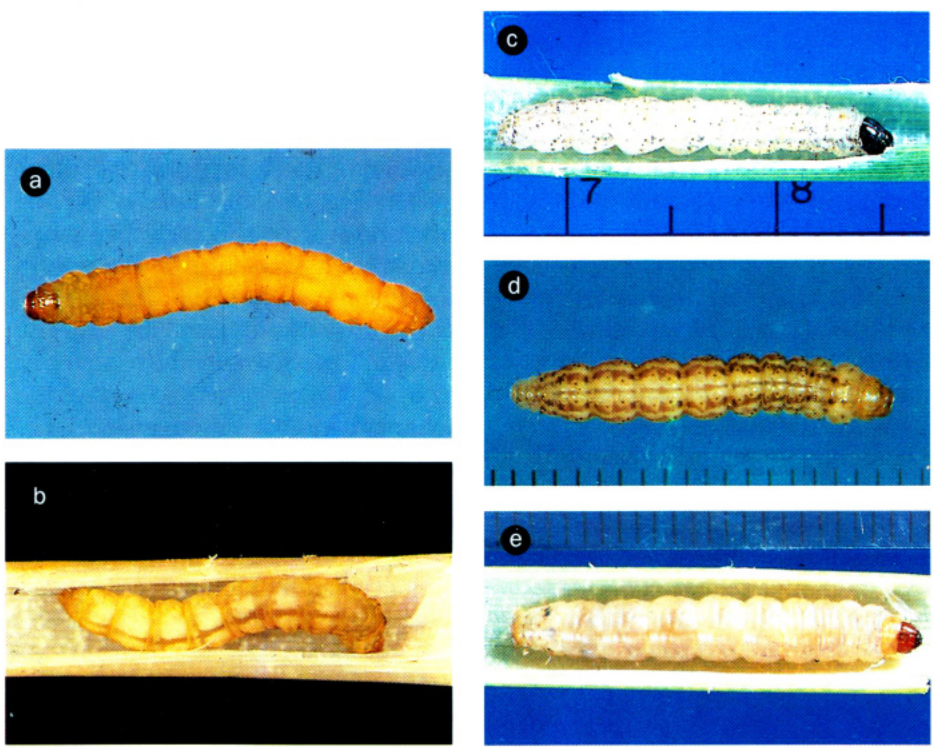
The larvae of lepidopterous stem borers are shown in Figure 6a-e. The hatching larvae are negatively geotropic and crawl upward toward the tip of the plants where they stay for only short periods. Some spin a silken thread, suspend themselves from it, and swing with the wind to land on other plants. Those that fall on water can swim because of an air layer around their body. Most of those remaining on the tip descend toward the base and crawl between the leaf sheath and stem. They congregate and enter the leaf sheath through a common hole bored by one of them. They then feed on the leaf sheath tissues for about a week, and then bore into the stem, mostly through the nodal regions at the point of attachment of the leaf sheath to the stem.

The first-generation larvae require 1.5 h from hatching to enter the leaf sheaths; the second generation require a somewhat longer period.

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. During later instars, crowding results in high mortality, slower growth rate, smaller size, and reduced fecundity of the emerging female moths. The newly hatched larvae in the second and third broods normally enter either the third or fourth leaf sheath without moving to the plant tip. They live there together for about a week before migrating to adjoining plants. Early migration of the first-generation larvae is probably an adaptation to the limited food available on young plants rather than a reflection of inherent behavioral differences between larvae of different generations.

Scirpophaga incertulas larvae rarely feed gregariously, but their initial orientation and establishment for feeding are much the same as those of *Chilo suppressalis* larvae. On a 30-day-old plant, the larvae take about 30 min to migrate to the leaf sheath after hatching. Usually, 75% of these larvae bore in, but only 10% reach the adult stage. They seldom enter seedlings, but if they do, boring takes longer and survival is low. During the vegetative phase of the plants, the larvae generally enter the basal parts, usually 5-10 cm above the water; on older plants, they bore through the upper nodes and feed their way through the nodal septa toward the base. On a crop at heading stage, boring usually occurs at the peduncle node or internode, which results in whiteheads even with slight feeding. At this stage the larvae cause maximum damage.

From the second instar onward, the *Scirpophaga incertulas* larvae migrate by using body leaf wrappings, 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. The length of this tube approximates that of the larval body. In 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. *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.



6. Larvae of lepidopterous *stem* borers: *a) Scirpophaga incertulas, b) Scirpophaga innotata, c) Chilo auricilius, d) C. suppressalis, e) Sesamia inferens.*

They usually feed individually. Upon hatching at dawn, diopsid larvae move down the stem and behind the leaf sheath on a film of dew. The eggs are dispersed and, normally, only one larva per tiller occurs.

Chilo auricilius Dudgeon is primarily a pest of sugarcane and only occasionally infests rice. Generally larvae infest grown-up canes only, as the mature larvae cannot make exit holes through several leaf layers of young canes.

The threshold temperature for development of *Chilo suppressalis* larvae is 10.5-12 °C, but optimum development is between 22 and 33 °C. The threshold temperature for *Scirpophaga incertulas* larvae, however, is a minimum of 16 °C. When reared at 12 °C, the second- and third-instar larvae cannot molt and so die. The rate of larval development is positively correlated with temperature between 17 and 35 °C.

In identifying stem borer instars, many workers consider the width of the mandibles a better indicator than the width of the head capsule because the mandibles are contiguous in different instars. *Scirpophaga incertulas* larvae usually undergo four to seven larval instar stages to become full grown. Most larvae undergo five instars when reared at 23-29 °C, but only four at 29-35 °C. The number of molts decreases in larvae feeding on maturing plants compared with those feeding on tillering plants. Molts increase where few host plants are available.

Under optimum conditions, *Chilo suppressalis* has five to six larval instars. Under adverse conditions, such as those discussed above, as many as nine instars have been recorded. In lepidopterous and diopsid species, the larval period usually lasts from 20 to 30 d.

Most stem borer species can pass an unfavorable period in dormancy. Drought during the larval period can induce a temporary slowing down of body metabolism to prolong the developmental period. A more profound physiological change that enables stem borers to live for months in suspended development is called diapause. Diapause can be either hibernation (overwintering in temperate climates) or aestivation (dry season dormancy in the tropics). *Scirpophaga incertulas* and *Scirpophaga innotata* hibernate or aestivate. Depending on the site, *Scirpophaga incertulas* is more prone to diapause than *Scirpophaga innotata,* particularly in the tropics. Stem borers, including diopsids, diapause as last-instar larvae. Some diopsids diapause as adults in swarms.

Hibernation is broken by warm weather and longer daylengths; aestivation is broken by rainfall or flooding. In the Philippines, with multiple rice crops, *Scirpophaga incertulas* is nondiapausing; in Pakistan, with only a wet season crop, it overwinters in rice stubble. In Indonesia, *Scirpophaga innotata* does not aestivate in double-cropped irrigated areas.

Pupae

Pupae of lepidopterous stem borers are shown in Figure 7a-d. Pupation in lepidopterous rice stem borers usually takes place in the stem, straw, or stubble. Diopsids pupate within the stem. Sometimes *Sesamia inferens* also pupate between the leaf sheath and stem. Before pupating, the full-grown larvae cut exit holes in the internodes through which the emerging moths escape. Usually the external opening of the exit hole is covered with fine web and cannot be easily detected before the moths have escaped. *Chilo suppressalis* pupae are without cocoons, but pupae of *Scirpophaga* spp., *Rupela* spp., and *Maliarpha* spp. are covered with whitish silken cocoons. The anterior extremity of the 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 waterproof.

7. Pupae of lepidopterous stem borers: *a) Scirpophaga incertulas, b) Scirpophaga innotata, c) Chilo suppressalis, d) Sesamia inferens.*

Since the full-grown larvae of *Scirpophaga* spp., *Rupela* spp., and *Maliarpha* spp. tend to feed in the basal parts of the plants, all the larvae are usually left in the stubble after harvest. Some *Chilo suppressalis* larvae feeding aboveground are removed with the straw. During dormancy or diapause, larvae in the stubble move down into the plant base and most stay 3-5 cm below ground level. Overwintering *Scirpophaga innotata* larvae move into the roots and construct tunnels up to 10 cm deep. On return of optimum conditions, they pupate at the hibernation sites. Thus, in all these species overwintering larvae pupate in the stubble. In addition to the stubble, harvested straw is another pupation site of some *Chilo suppressalis* larvae. Since conditions of straw and stubble differ, the rate of larval development is affected. Therefore pupation and emergence of *Chilo suppressalis* are less synchronized than those of other species.

The pupal period in lepidopterous and diopsid species lasts for 9-12 d. The threshold temperatures for pupal development are 15-16 °C for *Scirpophaga incertulas* and 10 °C for *Chilo suppressalis.* The rate of pupal development for *Chilo suppressalis* increases linearly from 15 to 30 °C, but slows down above 35 °C. Above 35 °C the pupae suffer high mortality and emerging moths are often deformed. When pupae that had been kept at a temperature between 20 and 36 °C for 2-4 h a day were exposed to a low temperature near the developmental threshold (12-15 °C), the development rate was faster. Also, when *Chilo suppressalis* larvae were exposed to continuous illumination, pupation was accelerated. Continuous darkness delayed pupation and reduced its percentage. Daily exposure to light for even a minimum of 30 min was adequate to mask the effect of continuous darkness.

Seasonal occurrence and abundance

In general, stem borers are polyvoltine, but the number of generations in a year depends on environmental factors, primarily temperature, rainfall, and crop availability. In different geographical areas, the borers hibernate, aestivate, or remain active throughout the year, and occur in different seasonal patterns. In areas of short optimum environmental conditions, such as in northern Japan, they appear in only one generation; in Central Japan and the Republic of 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 different 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 year-round, 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 tropical rice where moths have been caught in light traps throughout the year. Their population peaks have often been misinterpreted as different broods. A critical evaluation of the data shows that these peaks in light trap catches are reflections of major planting seasons and brief environmental variations rather than distinct seasonal effects.

In temperate areas, and in the tropics where only one rice crop is grown a year, the borers aestivate or hibernate. Detailed studies of the hibernation of *Chilo suppressalis* have established that the full-grown larvae undergo diapause, which is a hormonal reaction. In Japan, two distinct ecotypes have been recorded: Shonai in the north, Saigoku in the southwest. A possible third ecotype, Tosa from Kocha Prefecture, has been reported. The intensity of diapause is weak in the Shonai ecotype, which is more tolerant of lower temperature than the Saigoku ecotype. The stem borer population between the areas distinctly occupied by these ecotypes is intermediate in character. Although it has not been fully established, evidence suggests that *Scirpophaga incertulas* larvae diapause. Records of suppression in the growth of a yellow muscardine fungus on hibernating *Scirpophaga incertulas* larvae (a reaction normally considered characteristic of diapausing *Chilo* larvae) and differences in the diapausing tendency of *Scirpophaga incertulas* larvae, even when exposed to the same temperature, also suggest that this species diapauses. Although there is frequent mention of diapause for almost all other species, available data are inadequate to differentiate diapause from hibernation or aestivation.

Temperature, daylength, and growth stage of the host plants are principal factors inducing diapause. *Chilo suppressalis* larvae hatching from eggs incubated at temperatures below 22 °C usually undergo diapause; the temperature exposure during advanced embryonic development is particularly effective. Although total darkness or continuous illumination does not bring about diapause, exposure to short daylengths (8-14 h) induces it, whereas long daylengths (14.5-16 h) prevent it. Such effects are more evident during the larval than during the egg stage. Various ecotypes show sensitivity to daylengths, depending on other local conditions. Under total darkness, high temperature (33 °C) prevents diapause and low temperature (28 °C) induces it. Both *Chilo suppressalis* and *Scirpophaga incertulas* larvae that fed on mature plants tend to enter diapause. However, as the number of generations of both species is governed largely by the number of crops grown in a particular area, especially in the tropics, the role of mature plants in inducing diapause is somewhat uncertain. The diapause of *R. albinella* and *Scirpophaga innotata* terminates with higher precipitation.

In places having distinct generations, the first generation usually 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 often the ones that 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. Besides the seasonal fluctuations, distinct annual fluctuations also occur in stem borer populations. Although the factors responsible for such fluctuations are not fully understood, some of the possible causes are the following.

Generally, all borer larvae suffer low mortality during winter. In Japan, where the winter temperature is much lower than in most other rice regions, mortality of *Chilo suppressalis* and *Scirpophaga incertulas* has been low even during severe winters. *Chilo suppressalis* is more tolerant of low temperatures than *Scirpophaga incertulas.* In years of high precipitation during autumn, higher percentages of larvae hibernate, and if the winter or spring is warm, more of these successfully pupate and emerge as adult moths. These conditions, however, also accelerate pupation and emergence. Oviposition then occurs on seedlings, on which the larvae suffer high mortality and the population is reduced. However, if late spring is somewhat cooler and delays moth emergence, or if the rice is planted slightly earlier, the population builds up rapidly and heavy damage may occur. Warm weather is essential for population buildup; the moths in cool areas are generally smaller and lay fewer eggs. If the weather stays warm during the remaining rice crop seasons, the larvae develop rapidly and the total number of generations may increase. The problem is exacerbated particularly in areas of multiple rice crops.

Larvae suffer high mortality on seedlings. Some workers in Japan attribute this to high water temperature. Increased larval mortality is recorded whenever the average temperature of floodwater exceeds 35 °C for any 5 d in July. Measurements of the temperature of the floodwater and within the rice stem suggest that temperature itself is not directly lethal. Rather, high temperature might reduce larval vitality, thereby increasing their vulnerability to bacterial diseases or other natural hazards.

Larvae on seedlings used for mass rearing have high survival, and it is unlikely that the greater larval mortality in the field is due to nutritional deficiency. However, because the early-instar larvae feed gregariously, the food available on the seedlings is inadequate and the larvae are forced to migrate much earlier, probably resulting in high mortality. In areas of double cropping, the seedlings of the second crop carry a heavy egg load, leading to subsequent high larval mortality. Such regulation of the population may not be operative, however, where planting seasons are not distinct.

Both in tropical and subtropical regions, the population has been reported to decline drastically during the summer months after the second crop harvest. The decline has frequently been attributed to high temperature, but the fact that most ricefields have been harvested and often plowed during that time is equally important.

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

For oviposition, stem borer moths prefer ricefields receiving high rates of nitrogenous fertilizers. Rice plants containing higher levels of N are more suitable for larval growth.

The stem borer problem is more intense in areas with soils deficient in silica. Both field and laboratory studies have shown that larval survival is significantly reduced if silica is applied to these soils. It has also been demonstrated that the soil itself renders rice plants less attractive to the insect, and 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 recorded in larvae reared on varieties containing different percentages of silica. Silica level also significantly affects lodging and disease incidence in the rice plant.

Damage

The initial boring and feeding by larvae in the leaf sheath cause broad, longitudinal, whitish, discolored areas at feeding sites, but only rarely do they 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 severs the apical parts of the plant from the base. When this occurs during the vegetative phase of the plant, the central leaf whorl does not unfold, but turns brownish and dries off, although the lower leaves remain green and healthy. This condition is known as deadheart (Fig. 8a), and the affected tillers dry out without bearing panicles. Sometimes deadhearts are also caused by larval feeding above the primordia; if no further damage occurs, the severed portions are pushed out by new growth.

After panicle initiation, severance of the growing plant parts from the base dries the panicles, which may not emerge; panicles that have emerged do not produce grains. Affected panicles later become conspicuous in the fields. Being empty, they remain straight and are whitish. They are usually called whiteheads (Fig. 8b). When the panicles are cut off at the base after spikelet filling is partially completed, shriveled grains are observed. The plants can compensate for a low percentage of early deadhearts, but for every 1% of whiteheads, 1-3% loss in yield may be expected.

Although stem borer damage becomes evident only as deadheart and whitehead, significant losses are also inflicted by 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 spikelets.

Diopsid larvae have small mouthparts and can penetrate only a young tiller. Usually, only one generation per crop develops. The larva cuts through the tiller at a slanting angle about 10 cm aboveground and the leaf sheath is not cut. After the deadheart develops and the tiller rots, the larva moves on to another tiller. On average, one larva can damage three tillers. Diopsids seldom cause whiteheads. The synchrony of emergence of the flies with the onset of the wet season concentrates the attack on a newly planted crop. Damage from succeeding generations is more spread out over time.

The damage potential is also related to the inner diameter of the stem in relation to the diameter of the larvae. If the tiller is wider than the larva, damage is less. There may be differences between species in this regard. Although high levels of infestation can occur with *R. albinella* and *Maliarpha separatella,* recorded yield loss is minimal.

Plant type, crop vigor, and the pest complex can play a large role in determining eventual yield loss by stem borers. Low-tillering varieties have less opportunity to compensate for deadhearts than high-tillering varieties. A high-tillering variety can produce a replacement tiller for a deadheart. Similarly, a vigorous, well-nourished crop can tolerate higher levels of deadhearts and whiteheads than can a stressed crop.

8. Damage caused by stem borers: *a)* deadheart, *b)* whitehead.

Control methods

Cultural control

Crop cultural practices have a profound bearing on the stem borer population. Some methods are effective only if carried out through communitywide cooperation; others are effective on a single field. Communitywide practices act to prevent colonization and have the greatest potential to minimize infestation. China and prewar Indonesia developed effective cultural practices, often in combinations that isolate the rice crop through time and space. Practices that can be carried out on a single field include using optimal rates of N fertilizer in split applications. Applying slag increases the silica content of the crop, making it more resistant.

Since the eggs of *Scirpophaga incertulas* are laid near the tip of the leaf blade, the widespread practice of clipping the seedlings before transplanting greatly reduces the carryover of eggs from the seedbed to the transplanted fields. However, this control method has merit only if older seedlings are transplanted. Similarly, the height at which a crop is harvested is an important factor in determining the percentage of larvae that are left in the stubble. At harvest, *Chilo suppressalis* larvae are usually about 10 to 15 cm aboveground. Although *Scirpophaga incertulas* larvae are located somewhat lower, most of them are aboveground as well. Therefore, harvesting at ground level can remove a majority of the larvae of all species. To destroy those remaining in the stubble, burning or removing the stubble, decomposing the stubble with low rates of calcium cyanide, plowing, and flooding have been suggested. Burning is only partially effective because after harvest the larvae generally move below ground level. It is also difficult to uniformly burn stubble in a field. Plowing and flooding are apparently most effective. Since stubble is the major source of the overwintering stem borer population, proper stubble management cannot be overemphasized.

In several countries, delayed seeding and transplanting have been effective in evading first-generation moths. This practice has not been highly effective against *Chilo suppressalis* in Japan since emergence is delayed if planting is delayed. It has been effective, however, against *Scirpophaga incertulas,* the appearance of which is not affected by planting dates. The number of generations of this species is determined by the growth duration of the crop. 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 crops should significantly reduce the borer population.

Changing planting time may not always be feasible because of other agronomic considerations. In Pakistan, the planting date has been regulated by releasing canal water only after the first brood *Scirpophaga incertulas* moths have emerged. This late-planted crop is far less infested than fields planted early with private irrigation systems. 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 at several sites, resulting in high survival of first-generation *Scirpophaga incertulas* larvae. Also, the first and second broods of *Chilo suppressalis* moths appeared earlier, possibly introducing a distinct third generation in the warmer sections of the country. Light-trap catches of moths reveal a change from a unimodal to a bimodal pattern in both the first and second broods.

Biological control

Most biological control of stem borers in tropical Asia and Africa comes from indigenous predators, parasites, and entomopathogens. The conservation of these valuable organisms is the key to development of stable and successful integrated pest management (IPM) systems. Over 100 species of stem borer parasitoids have been identified. The three most important genera are the egg parasitoids *Telenomus, Tetrastichus,* and *Trichogramma. Tetrastichus* wasps have elongated ovipositors and can lay their eggs in stem borer eggs, even if the latter are covered with a mat of hair. *Telenomus* wasps, however, parasitize stem borer eggs while the moth is in the act of oviposition—before the eggs are covered with hair. The wasp locates the female moth, possibly by the sex pheromone, attaches itself to the tuft of anal hair near the ovipositor, and waits for the moth to lay eggs.

Egg masses are also the food of several predators. The longhorned grasshopper *Conocephalus longipennis* (Haan) preys voraciously on eggs of the yellow stem borer. Other orthopteran predators such as the crickets *Metioche vittaticollis* (Stål) and *Anaxipha longipennis* (Serville) feed on eggs of *Chilo suppressalis.* The predatory mirid *Cyrtorhinus lividipennis* Reuter also attacks eggs of *Chilo suppressalis.*

A wide range of predatory species attacks the small larvae of stem borers before they enter the stem of the rice plant. Some important predators are coccinellid beetles *Micraspis crocea* (Mulsant), *Harmonia octomaculata* (Fabricius), and carabid beetles such as *Ophionea* spp. When young larvae fall on the water, they are preyed upon by *Microvelia douglasi atrolineata* Bergroth and *Mesovelia vittigera* (Horváth). Ants and a dozen other predators prey upon stem borer larvae.

The larval and pupal stages are attacked by a large number of parasites, but parasitization rates are often low.

The adult moths are attacked by several spiders while resting on foliage or are caught in webs while flying. Dragonflies and birds are also effective daytime predators; bats are active at dusk.

Several species of fungi can infect the larval stage and consume stem borer larvae at the base of stems when they are about to pupate. The fungus *Cordyceps* sp. grows long, noodle-like arms on the stem borer's body. Pathogen activity is greatest against larvae resting over winter or summer, particularly when the stubble has decayed and is moist.

Varietal resistance

Rice varieties vary in their susceptibility to stem borers. In field and laboratory experiments, several varieties are known to be rejected by the moths for oviposition. On resistant varieties stem borer larvae suffer high mortality, are smaller, and have a slower growth rate. In field experiments, susceptible varieties harbor more borers and suffer more damage than resistant varieties. During the last 25 yr, local and introduced germplasm have been extensively screened for resistance to stem borers in several countries. At IRRI, more than 17,000 rice varieties have been screened for resistance to *Chilo suppressalis* and more than 39,000 varieties to *Scirpophaga incertulas.* Common resistance sources such as TKM6, Chianan 2, Taichung 16, Ptb 10, Su-Yai 20, and WC1263 have been identified. However, varieties resistant to one stem borer species are not necessarily resistant to others. The differences in varietal resistance are only quantitative in nature. Very high levels of resistance have not been found in rice, and resistance scores vary from highly susceptible to moderately resistant. Even varieties classified as resistant suffer some damage under high insect populations. However, several wild rices have high levels of resistance to stem borers. Genetic analysis has shown such resistance to be polygenic in nature.

The nature of resistance to *Chilo suppressalis* has been studied in detail. Several morphological and anatomical characteristics of the rice plant show a general association with resistance to stem borers. Generally, tall varieties with long, wide leaves and large stems are more susceptible. Varieties containing more layers of lignified tissue, a greater area under sclerenchymatous tissue, and a large number of silica cells are more resistant. Although each of these characteristics appears to contribute to borer resistance, none by itself appears to be the main cause of such resistance. A rice plant biochemical oryzanone (*p*-methylacetophenone) was identified as an attractant to ovipositing moths and to larvae. The resistance of TKM6 and other resistant rice varieties was mostly due to allomones, which inhibit oviposition and disturb the insect's growth and development. IRRI in collaboration with the Tropical Development Research Institute, London, recently identified this biochemical resistance factor, coded as Compound A, as a pentadecanal. Compound A in resistant plants inhibits oviposition and adversely affects eggs and larval and pupal stages.

On the other hand, differences in nonpreference for oviposition of *Scirpophaga incertulas* are not distinct in screenhouse tests. But larvae feeding on resistant varieties were smaller, had low survival, and caused lower percentages of deadhearts than those feeding on susceptible varieties.

At IRRI, breeding for resistance to *Chilo suppressalis* started in 1965. Selected resistant varieties have been used in a hybridization program to improve their resistance to *Chilo suppressalis* and to incorporate their resistance into plants with desirable agronomic characters. TKM6 has been used extensively in breeding for borer resistance in several countries. IR20, the first borer-resistant, improved-plant-type variety, was developed by crossing TKM6 with Peta/TN1. It has moderate resistance to *Chilo suppressalis* and *Scirpophaga incertulas;* resistance to green leafhopper, tungro virus, and bacterial leaf blight; and tolerance for several adverse soil conditions.

Subsequent studies on breeding for resistance to *Chilo suppressalis* involved the diallel selective mating (DSM) system using seven rice varieties moderately resistant to *Chilo suppressalis.* DSM for three generations has produced progenies distinctly more resistant than any parent.

The breeding program for *Scirpophaga incertulas* resistance was initiated at IRRI after 1972. Three improved plant types — IR1721-11, IR1917-3, and IR1820-52-2 — were found resistant. A series of multiple crosses was also made to accumulate resistance from several breeding lines. Breeding lines such as IR4791-80 and IR4791-89, which emanated from this system, had a higher level of resistance than IR1820-52-2. A new approach to upgrade the level of *Scirpophaga incertulas* resistance was adapted in 1980, using the male-sterile-facilitated recurrent selection scheme. Genetic male sterile IR36 used as female parent was crossed with 26 donor parents.

The rice breeding programs of many countries aim at incorporating into their improved germplasm genes for resistance to *Chilo suppressalis* and *Scirpophaga incertulas* from many donors. However, none of the rice varieties developed so far have more than a moderate level of resistance. Some wild rices such as *Oryza officinalis* and *O. ridleyi* have very high levels of resistance to stem borers. Their resistance needs to be transferred to cultivated rice, using appropriate distant hybridization techniques.

Chemical control

Stem borers are difficult to control with insecticides. After hatching, the larvae are exposed only for a few hours before they penetrate a tiller or enter the plant. Successful control involves repeated foliar applications with spray volumes more than 400 liters/ha. In temperate climates, stem borer populations are more synchronized, and well-timed applications have a greater degree of control than in the tropics where generations overlap. The decline in stem borer abundance in Japan and the Republic of Korea is attributed to the frequent use of insecticides over many years, even though the stem borers have developed insecticide resistance.

Foliar sprays, which act on the larvae and on the adult moths and eggs, also come into greater contact with natural enemies of the stem borer. Cases of stem borer resurgence are not evident, although secondary pest outbreaks have been reported in areas of heavy insecticide usage against stem borers.

Granular formulations, particularly gamma BHC and diazinon, give higher control than foliar sprays or dusts, particularly in high rainfall environments. Granules broadcast into irrigation water are particularly effective in preventing deadhearts in a young crop. Gamma BHC has a fumigant action that kills resting moths. The insecticide is partly dissolved in the water and moves by capillary action between the leaf sheath and stem to come into contact with young larvae: the nonsystemic insecticide granules act as though they were systemic. The limitation to using granules is cost—they are more expensive to transport. Stable water supply and deep water levels are also necessary for high levels of control. As the water level falls, the capillary activity progressively declines. If the field dries out, insecticide efficacy ceases. Flooding from heavy rains also washes the insecticide out of the field. Dosage levels have declined, consistent with the relatively higher costs of insecticides.

Systemic granules have an advantage in that the chemical can enter the plant even with low water levels. The chemical percolates into the soil and is taken up by the roots. From the roots, the chemical is transmitted through the xylem tissues to the stems and eventually to the tips of the leaves. Carbofuran exudes in droplets of water from leaf hydathodes and evaporates into the air. If systemic granules are broadcast into the irrigation water, high dosages are necessary because much of the chemical is absorbed in the soil. The dosage needed increases with plant biomass. If granules are broadcast during the last harrowing or leveling operation before planting, dosages can be cut in half. Effectivity lasts more than a month because the granule is protected from rapid degradation. Heavy use of granules, however, can lead to microbial degradation. Several species of soil bacteria respond to and rapidly consume the insecticide, rendering it ineffective. The process can be slowed by using lower dosages in rotation with foliar sprays. The problem with soil incorporation of insecticides before planting is that the stem borer population cannot be assessed—it might not be large enough to warrant control.

A combination of sex attractant (pheromones) and chemosterilant could also be a promising control tactic. High moth populations in overlapping generations, however, and the difficulties involved in mass rearing some stem borer species are major limitations to the mass release of artificially irradiated sterile male moths as a control measure. Exploratory experiments on mass rearing have shown that, when provided with 1% tepa, apholate, or tretamine, or 20% hempa as food, the moths mated normally but deposited 50% fewer eggs. Of the eggs deposited, 20% of those laid by moths exposed to tepa and apholate were sterile.

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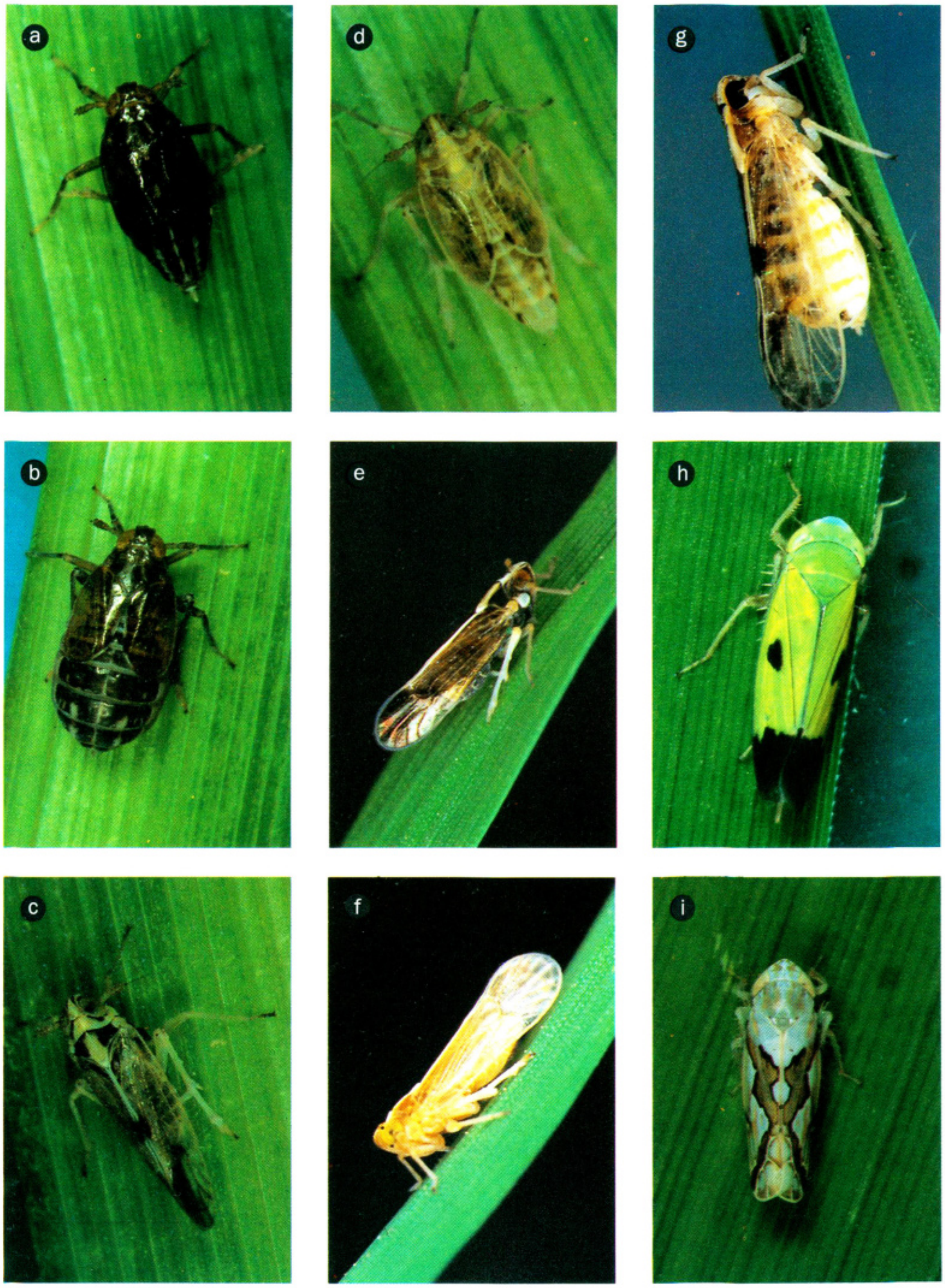
Rice leafhoppers and planthoppers

Several species of leafhoppers and planthoppers are serious pests of rice worldwide (Table 4). In many areas, they frequently occur in numbers large enough to cause complete drying of the crop, but even sparse populations reduce rice yields. In addition to direct feeding damage, leafhoppers and planthoppers are vectors of most of the currently known rice virus diseases. The more damaging species are green leafhoppers *Nephotettix* spp., the zigzag leafhopper *Recilia dorsalis* (Motschulsky), the brown planthopper *Nilaparvata lugens* (Stål), the small brown planthopper *Laodelphax striatellus* (Fallen), the whitebacked planthopper *Sogatella furcifera* (Horváth), and the rice delphacid *Tagosodes (=Sogatodes) orizicolus* (Muir) (Fig. 9a-i). The first five species occur in Asia. *Tagosodes orizicolus* is found in the southern USA and in the north central region of South America. Among several *Nephotettix* species, three are important. *Nephotettix cincticeps* (Uhler) is distributed in temperate areas. *Nephotettix virescens* (Distant) and *Nephotettix nigropictus (=apicalis)* (Stål) are distributed in temperate and tropical Asia. *Nephotettix nigropictus* is mainly distributed in tropical Asian rice-growing areas.

In Africa, leafhoppers and planthoppers do not cause serious loss, probably because lowland rice is not widely planted. The only reported hopperburn in Nigeria was

Table 4. Major planthopper and leafhopper pests of rice.

Name	Common name	Distribution	Vector of
Delphacidae (Planthoppers)			
Laodelphax striatellus (Fallen)	Small brown planthopper	China, Japan, Republic of Korea, Palearctic regions	Rice stripe, rice streaked dwarf
Nilaparvata lugens (stål)	Brown planthopper	South and Southeast Asia, China, Japan	Grassy stunt, ragged stunt
Sogatella furcifera (Horvith)	Whitebacked planthopper	South and Southeast Asia, northern Australia, China, Japan, Republic of Korea, South Pacific Islands	
Tagosodes orizicolus (Muir)	Rice delphacid	Caribbean Islands South America, southern United States	Hoja blanca
Cicadellidae (Leafhoppers)			
Cofana spectra (Distant)	White leafhopper	South and Southeast Asia, Australia, Africa, China	
Nephotettix cincticeps (Uhler)	Rice green leafhopper	China (including Taiwan), Japan, Republic of Korea	Rice dwarf, yellow dwarf
Nephotettix virescens (Distant)	Rice green leafhopper	South and Southeast Asia	Yellow dwarf, tungro, penyakit merah, yellow-orange leaf
Nephotettix nigropictus (Stål)	Rice green leafhopper	South and Southeast Asia, China	Rice dwarf, yellow dwarf, transitory yellowing, tungro, yellow-orange leaf, rice gall dwarf
Recilia dorsalis (Motschulsky)	Zigzag leafhopper	South and Southeast Asia; Taiwan, China; Japan	Rice dwarf, yellow-orange leaf



9. Adults of rice leafhoppers and planthoppers: ***a) Nilaparvata lugens*** **male,** ***b) Nilaparvata lugens*** **female,** ***c) Sogatella furcifera*** **male,** ***d) S. furcifera*** **female,** ***e) Tagosodes orizicolus*** **male,** ***f) T. orizicolus*** **female,** ***g) T. cubanus, h) Nephotettix virescens, i) Recilia dorsalis.*** **Photos** ***e, f,*** **and** ***g*** **courtesy of CIAT.**

from the planthopper *Nilaparvata maeander* Fennah in breeder plots receiving high N rates. Hoppers are serious problems in Latin America, where polyphagous hopper species such as *Graphocephala* spp., *Hortensia* spp., *Exitianus obscurinervis* (Stål), *Balclutha* spp., and *Draeculacephala* spp. breed in large grassland areas.

Hopperburn is rare in upland ricefields because leafhoppers and planthoppers prefer lowland rice to upland rice. Generally, fields receiving large amounts of nitrogenous fertilizers and subjected to indiscriminate use of pesticides are more heavily infested. The abundance of leafhoppers and planthoppers is also attributed to high temperature and high humidity. In the tropics, these pests remain active throughout the year and their population fluctuates according to the availability of food plants, presence of natural enemies, and environmental conditions.

Generally, the leafhoppers feed on the leaves and upper parts of the plants, whereas the planthoppers confine themselves to the basal parts. However, *Tagosodes orizicolus* males stay in the upper portions of the plants and only the female planthoppers stay in the basal parts.

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. Brachypterous forms have very much smaller wings, particularly the hind wings, which are rudimentary.

The macropterous forms are adapted to migration and develop with crowding and the shortage of host plants. The brachypterous forms are generally larger and have longer legs and ovipositors. Their preoviposition period is usually shorter than that of macropterous forms.

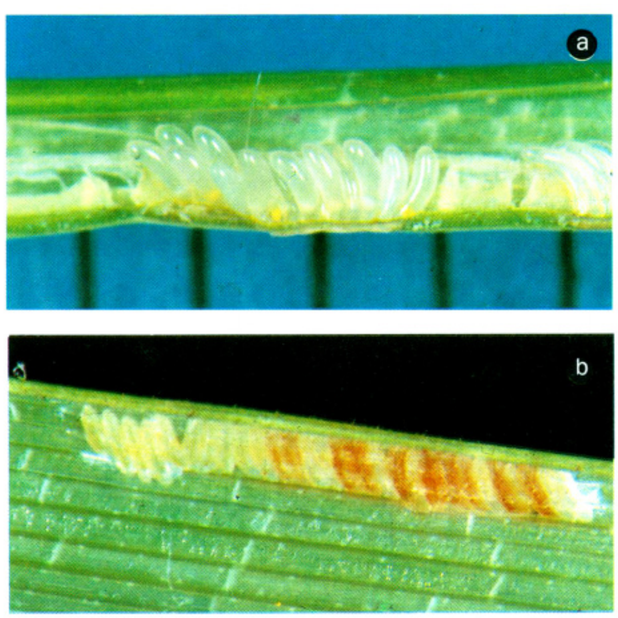
In *Nilaparvata lugens,* more brachypterous forms develop at low temperature. In males, short daylength and high temperature increase the percentage of brachypterous forms, but daylength has no effect on the development of winged female forms. In *Laodelphax striatellus,* macropterous as well as brachypterous forms are found in both sexes, but in *Sogatella furcifera* no brachypterous males have been recorded. Both *Tagosodes orizicolus* and *Tagosodes cubanus* (Crawford) have alate and brachypterous forms, but the latter are more common in *Tagosodes orizicolus* males.

Planthopper infestation in a ricefield starts with macropterous immigrants, which spread randomly and produce brachypterous females. The flight dispersal of *Nilaparvata lugens* and *Sogatella furcifera* takes place during the preoviposition period, generally in the evenings of hot humid days. The population builds up continuously for two generations when different patches of infestation tend to join together. At this stage, macropterous forms develop and the insects migrate to another area.

Life history

Adult *Nilaparvata lugens* remain active from 10 to 32 °C and *Sogatella furcifera* from 8 to 36 °C. In both species, the macropterous females are somewhat more tolerant of temperature than are the males. *Nilaparvata lugens* adults usually live for 10-20 d in summer and 30-50 d during autumn. Females kept at 20 °C have an oviposition period of 21 d, which is reduced to 3 d if they are kept at 30°C.

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 tissue (Fig. 10a, b). The number of eggs varies in different species. *Tagosodes orizicolus* usually lays eggs in multiples of 7, which is attributed to the 14 ovarioles in each ovary of the females. In Japan, eggs per mass number 4-8 for *Sogatella furcifera* and 2 or 3 for *Nilaparvata lugens.* Observations at IRRI show that the number of eggs in these species is 7-19 for *Sogatella furcifera* and 4-10 for *Nilaparvata lugens.* In *Nephotettix* spp., each mass has 8-16 eggs and each female lays 200-300 eggs. The females of *Recilia dorsalis* lay 100-200 eggs; those of *Tagosodes orizicolus, Nilaparvata lugens,* and *Sogatella furcifera* lay 300-350. Brachypterous *Nilaparvata lugens* females usually lay more eggs than



10. Eggs of *a) Nilaparvata lugens, b) Nephotettix virescens* (parasitized).

the macropterous forms, but no such difference is evident in *Sogatella furcifera.*

The eggs are usually cylindrical with their micropyle ends protruding from the leaf tissue. They are whitish when freshly laid, but later become darker with two distinct spots. The spots vary in color between species and represent the eyes of the developing embryo. The incubation period is 4-8 d. In most species, egg and nymph develop fastest at 25-30 °C. *Nilaparvata lugens* eggs usually do not hatch if incubated at 33 °C, but more eggs hatch and growth is faster at 27 °C than at 25 °C. A temperature of 33 °C is lethal to freshly hatched nymphs and greatly reduces the life span of the adults.

Most species undergo four to five molts, and the nymphal period is 2-3 wk. *Nilaparvata lugens* nymphs exhibit a positive relationship between rate of nymphal development and temperature of 11.6-27.7 °C. The rate of egg and nymphal development of both *Nilaparvata lugens* and *Sogatella furcifera* is highest at 27-28 °C. The fourth- and fifth-instar nymphs of *Nilaparvata lugens* remain active at 12-31 °C. For *Tagosodes orizicolus,* the developmental threshold is 8.2 °C and the thermal constant is 25.6 °C.

Seasonal occurrence and abundance

In the warm and humid tropics, different species of leafhoppers and planthoppers remain active year-round, and populations fluctuate according to the availability of food plants, presence of natural enemies, and environmental conditions. After the rice crop is harvested, the insects may transfer to some weeds and grasses, but do not hibernate. In areas of wide temperature variations, however, they hibernate or aestivate. In Japan, *Nilaparvata lugens* and *Recilia dorsalis* hibernate as eggs, and *Nephotettix* spp. and *Laodelphax striatellus* as fourth-instar nymphs. *Sogatella furcifera* has been observed to hibernate as eggs just before hatching or at the young nymphal stage. *Nilaparvata lugens* overwinters either as eggs or as fifth-instar nymphs. *Tagosodes orizicolus* and *Tagosodes cubanus* diapause in the egg stage.

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

Thus, seasonal occurrence varies distinctly between areas where the insects undergo dormancy and diapause on the one hand, and where they remain active year-round on the other. In the latter case, but with exceptions, the insects are usually more abundant during the dry season than during the wet. Also, *Nephotettix* spp. and *Sogatella furcifera* are usually more common during early crop stages; *Nilaparvata lugens* and *Recilia dorsalis* become more prevalent during later stages. The population of *Tagosodes orizicolus* also increases toward the maturity of the crop. In Vietnam, *Sogatella furcifera* is prevalent from July to August, together with *Nephotettix virescens.*

In Japan, *Laodelphax striatellus* and *Nephotettix cincticeps,* which hibernate as fourth-instar nymphs, appear in March. The former passes one generation on wheat and the latter one generation on grasses; then both migrate to ricefields. Direct migration to ricefields also occurs if the crop is established at the time of the insects' emergence. *Nephotettix* spp. complete three generations on rice from June to August and in the fourth generation hibernate as nymphs in late September to October. *Recilia dorsalis* also occurs in four generations. In Amami Oshima Island (South Japan), no diapause in *Nephotettix* spp. occurs and adults can be collected year-round as in tropical areas. The population of *Sogatella furcifera* generally increases up to July and August and decreases in September and October; *Nilaparvata lugens* increases in September and October. During the later part of the cropping season, *Nilaparvata lugens* is known to occur in overlapping generations.

In hibernating generations of *Nephotettix* spp. in Japan, females have been recorded to deposit an average of 300 eggs each. The number of eggs laid in subsequent generations, however, is reduced to one-half, even though there is no significant difference in the number of eggs contained in the ovarioles of *Nephotettix* spp. of different generations. It is apparent then that the difference in the number of eggs laid is due to environmental conditions affecting the developmental process of the oocytes, rather than to any inherent difference between the insects themselves. It is widely accepted that for most rice leafhopper and planthopper species, the optimum temperature is 25-30 °C. Insects reared at higher temperatures do survive, but they are less fertile and often many eggs do not hatch.

The abundance of *Nephotettix* spp. has been attributed to high temperature, low rainfall, and abundant sunshine. Review of data on light-trap catches from several experiment stations in southern Japan reveals a positive correlation between population buildup and the amount of sunshine (r = 0.931, and a negative correlation with average RH (r = 0.67).

When exposed to strong sunlight at 22 °C, many *Sogatella furcifera* nymphs die, but the adults survive. Below 22 °C, solar radiation is essential for oviposition of *Sogatella furcifera,* but excessive solar and UV radiation prevent the buildup of the *Nilaparvata lugens* population. Exposure to short-wave radiation is actually deleterious to both species.

Planthoppers prefer lowland to upland rice and, since thick vegetation is a better habitat for them, direct-sown fields are often preferred to transplanted ones. Since various species have distinct preferences for plants at different growth stages, they proliferate when rice plants of different ages are available. The shortage of host plants results in overcrowding, which adversely affects the population buildup. It reduces the rate of nymphal development, increases the percentage of macropterous adults, lengthens the preoviposition period, and decreases the number of eggs laid.

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.

Damage

Leafhoppers and planthoppers damage 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. Excessive oviposition may produce similar effects. The feeding and ovipositional marks predispose plants to fungal and bacterial infection, and the honeydew encourages sooty molds.

Except for minute leaf galls found on plants infested with *Cicadulina bipunctella* (Matsumura), said to be due to a toxin injected by the insect while feeding, there is no other record of leafhopper or planthopper species injecting toxin to rice plants.

In addition to damaging plants by direct feeding, planthoppers and leafhoppers are also vectors of most currently known rice viral diseases. *Nilaparvata lugens* transmits grassy stunt and ragged stunt viral diseases in South and Southeast Asia. *Laodelphax striatellus* is the vector of rice stripe, the most serious disease of rice in East Asian countries, and also transmits the black-streaked dwarf virus. *Tagosodes orizicolus* is the only significant vector of hoja blanca virus in Central America, northern South America, and the Caribbean Islands. *Nephotettix virescens* has caused heavy crop losses throughout South and Southeast Asia as a vector of tungro viruses. *Sogatella furcifera* does not transmit any disease.

In greenhouse experiments, 400 newly hatched *Nilaparvata lugens* nymphs infesting susceptible rice plants at 25 and 50 d after transplanting (DT) caused complete drying in 3 and 15 d, respectively. Under field conditions, plants nearing maturity develop hopperburn if infested with about 400-500 *Nilaparvata lugens.* However, distinct differences in tolerance of various varieties for hopperburn have been recorded. Infestation with smaller populations during early stages of plant growth reduces the number of tillers, plant height, and general vigor. But after panicle initiation, similar populations greatly increase the percentage of unfilled spikelets.

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 plant. Under favorable conditions, such as high N application, high humidity, optimum temperatures, and little air movement, the population rapidly increases and hopperburn occurs. Sometimes hopperburn is also caused by large numbers of planthoppers migrating from adjacent areas.

Control methods

Cultural control

Sanitation of ricefields for control of leafhoppers and planthoppers is recommended. Ratoons and volunteer rice may serve as inoculum sources for viral diseases.

Rotation of rice with another crop often provides an effective and economical control measure, especially in areas of one rice crop a year. In some parts of Asia, legumes are recommended after rice for reducing leafhopper and planthopper infestations. Simultaneous cropping and rotation with other crops minimizes *Nilaparvata lugens* populations.

Judicious use of fertilizer with split N applications (three times) and draining the field for 3 or 4 d during infestation have been recommended for reducing *Nilaparvata lugens* and *Sogatella furcifera* populations.

Detailed studies on the use of a trap crop to control *Nilaparvata lugens* and *Nephotettix virescens* have been conducted at IRRI. One-fourth of the total crop area transplanted as a trap crop 20 d ahead of the main crop attracted more colonizing *Nilaparvata lugens* than the main crop. Similarly, two, three, or four border rows, transplanted 15 d earlier than the main crop and sprayed with an insecticide weekly for up to 60 DT reduced incidence of *Nephotettix virescens* and its transmitted tungro virus in the main crop.

For *Nilaparvata lugens,* closer spacing of rice plants is believed to be one factor that induces hopper buildup. The basal portion of plants receives less sunshine, is slightly cooler and more humid, and provides a suitable microclimate for the buildup of the pest population. However, wider spacing cannot be recommended because it significantly reduces yields.

Biological control

Several parasites, predators, and pathogens attack the planthopper and leafhopper at all stages, and effectively control them under most situations. Improper use of insecticides, however, can kill the natural enemies and thus lead to dramatic pest outbreaks.

Nilaparvata lugens eggs are parasitized by mymarid *Anagrus optabilis* (Perkins), trichogrammatid *Paracentrobia andoi* (Ishii), and eulophid *Tetrastichus formosanus*

(Timberlake) wasps. Mirid bug *Cyrtorhinus lividipennis* Reuter and phytoseiid mite *Amblyseius* nr. *calorai* Corpuz & Rimando prey on the eggs.

Nymphs and adults of *Nilaparvata lugens* are parasitized by elenchid strepsipteran *Elenchus yasumatsui* Kifune & Hirashima (Elenchidae), dryinid wasp *Echthrodelphax bicolor* Esaki & Hashimoto, nematode parasite *Hexamermis* sp., and fungal pathogens *Beauveria bassiana* (Balsamo) Vuillemin and *Hirsutella citriformis* Speare.

Underwater aquatic predators (e.g., *Hydrophilus affinis* (Sharp) and *Cybister* sp.), and those that swim on the surface (e.g., *Ranatra dimidiata* (Montadon), *Microvelia douglasi atrolineata* Bergroth, and *Mesovelia vittigera* (Horváth)) prey on hoppers that feed near the water or fall into the water.

The beetle *Ophionea [=Casnoidea] iskii iskii* Habu and the spider *Pardosa (=Lycosa) pseudoannulata* (Boesenberg & Strand) actively search the foliage for *Nilaparvata lugens* nymphs and adults. Dragonflies and damselflies prey on moving adults and nymphs. In laboratory tests, a single *Pardosa pseudoannulata* consumed an average of 45 planthoppers/d.

Green leafhopper eggs are parasitized by trichogrammatid wasps *Paracentrobia andoi* (Ishii) and *Oligosita naias* Girault, and by mymarid wasps *Anagrus optabilis* (Perkins) and *Gonatocerus* sp. The eggs are also preyed upon by *Cyrtorhinus lividipennis.*

Nymphs and adults are parasitized by pipunculid flies *Pipunculus mutillatus* Loew and *Tomosvaryella oryzaetora* Koizumi, dryinid wasp *Echthrodelphax fairchildii* Perkins, strepsipteran *Halictophagus munroei* Hirashima & Kifune, and *Hexamermis* spp. nematodes. Parasitization of green leafhoppers by pipunculids is reportedly greater than 50% and seems to be an important mortality factor for this pest complex.

An array of predators also attacks nymphs and adults: *Microvelia douglasi atrolineata, Stenonabis tagalicus* (Stål), *Drapetis* sp., damselflies, dragonflies, and spiders.

Nematodes and fungal pathogens also infect nymphs and adults. *Beauveria bassiana,* a white fungus, grows from the inside and covers the body of dead leafhoppers.

Varietal resistance

The use of resistant rice varieties is an ideal method of controlling leafhoppers and planthoppers. Various studies have demonstrated natural resistance to these pests in several rice varieties. That resistance has been transferred to several modern varieties (MVs). Breeding for planthopper and leafhopper resistance has now become a major research objective in most of the rice-growing countries of Asia, and Central and South America. Current breeding programs include developing resistance to *Nilaparvata lugens, Sogatella furcifera, Laodelphax striatellus,* and *Nephotettix virescens* in Asia, and to *Tagosodes orizicolus* in Central and South America.

Studies on varietal resistance to leafhoppers and planthoppers were started at IRRI in 1966 when 1,400 rice varieties, selected from an evaluation of 10,000 rice varieties and collections for their resistance to stem borers, were field-tested for susceptibility to *Nilaparvata lugens* and *Nephotettix virescens.* The selected varieties were tested more intensively for the consistency and the nature of their resistance. Subsequently, these and a large number of other lines were evaluated against the major leafhopper and planthopper pests of rice. Varietal screening for *Sogatella furcifera* started at IRRI in 1970. Several national rice improvement programs in Bangladesh, China, India, Indonesia, and Thailand are also screening a large number of varieties and types of germplasm for resistance to these pests. At IRRI, more than 50,000 rices from the germplasm collection have been screened against *Nephotettix virescens, Nilaparvata lugens,* and *Sogatella furcifera.* Many useful resistance sources have been identified and their resistance incorporated into MVs.

Dramatic progress has been made in the development of rice varieties with resistance to leafhoppers and planthoppers, and rice varieties resistant to these pests are now grown on millions of hectares in South and Southeast Asia, and in Central and South America. However, the full potential of resistant varieties in insect control has often been limited by the development of new biotypes of leafhoppers and planthoppers, which can survive on resistant varieties.

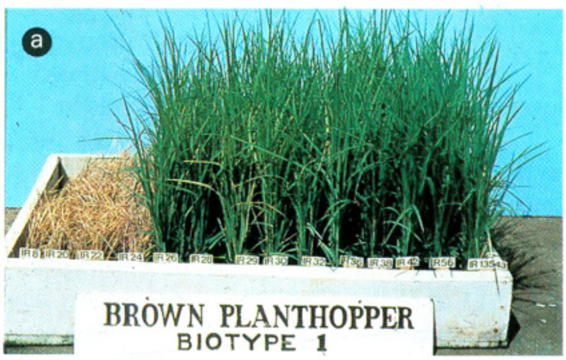
Leafhopper and planthopper resistance is generally governed by major genes (Table 5). Eight genes for resistance to *Nephotettix virescens* have been identified. Of the eight, six are dominant *(Glh 1, Glh 2, Glh 3, Glh 5, Glh 6,* and *Glh 7)* and two recessive *(glh 4* and *glh 8). Glh 1-Glh 5* and *glh 8* convey resistance to the *Nephotettix virescens* population in the Philippines; *Glh 6* and *Glh 7* convey resistance to Bangladesh populations.

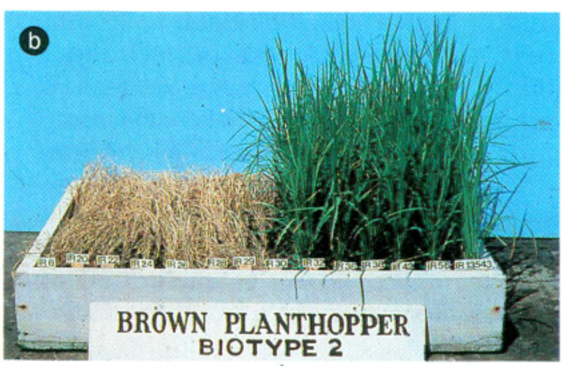
Although there are no confirmed reports of biotypic variation, virulent *Nephotettix virescens* populations were selected at IRRI on resistant rice varieties Pankhari 203 (*Glh 1*), IR8 (*Glh 3*), Ptb 8 (*glh 4*), TAPL796 (*Glh 6*), Moddai Karuppan (*Glh 7*), and DV85 *(glh 8*). However, no such population could be selected on ASD7 (*Glh 2*) and ASD8 (*Glh 5*) rice varieties. *Nephotettix virescens* populations in different countries also show differences in virulence to resistant rice varieties. High levels of resistance to *Nephotettix virescens* have recently been reported in many wild rices. There is no information, however, regarding resistance of these wild rices to rice tungro virus.

Nilaparvata lugens is a persistent and prolific species. So far, four biotypes are known. Biotype 1, biotype 2, and biotype 3 are identified in the Philippines and biotype 4 occurs in the Indian Subcontinent. Genetic analysis of resistant rice varieties revealed nine major genes that convey resistance to different biotypes of the pest (Table 5). Biotype 1, the general and predominant field population, can infest only those varieties that lack genes for resistance, e.g., IR5, IR8, IR20, IR22, IR24, TN1 (Fig. 11a). Biotype 2 can survive on and damage varieties carrying the *Bph* 1 resistance gene, e.g., IR26, IR28, IR29, IR30, IR34, and Mudgo, in addition to those susceptible to biotype 1 (Fig. 11b). Biotype 3 can infest rice varieties IR32, IR36, IR42, IR54, ASD7, carrying the *bph* 2 gene and varieties vulnerable to biotype 1 (Fig. 11c). Recently a population of *Nilaparvata lugens,* which equally damages rice varieties with *Bph* 2 and *bph* 2 resistance genes, was collected in Mindanao, southern Philippines. However, none of the Philippine biotypes survive on varieties with genes *Bph* 3, *bph* 4, *bph* 8, or *Bph* 9. Three genes — *bph* 5, *Bph* 6, and *bph* 7 — convey resistance to biotype 4 only. The possibility of the occurrence or evolution of more biotypes cannot be excluded if resistant varieties with new genes for resistance are planted intensively. In such an eventuality, the sequential release of resistant varieties with varying genetic background would assume great importance. Fortunately, several wild rice accessions have high levels of resistance to all the three

Table 5. Present knowledge on the genetics of leafhopper and planthopper resistance in rice.

Insect	Resistance gene	Varietal source of resistance gene
Green leafhopper	*Glh 1*	Pankhari 203
	Glh 2	ASD7
	Glh 3	IR8
	glh 4	Ptb 8
	Glh 5	ASD8
	Glh 6	TAPL#796
	Glh 7	Moddai Karuppan
	glh 8	DV85
Zigzag leafhopper	*Zlh 1*	Rathu Heenati
	Zlh 2	Ptb 21
	Zlh 3	Ptb 33
Brown planthopper	*Bph 1*	Mudgo
	bph 2	ASD7
	Bph 3	Rathu Heenati
	bph 4	Babawee
	bph 5	ARC10550
	Bph 6	Swarnalata
	bph 7	T12
	bph 8	Chin Saba
	Bph 9	Pokkali
Whitebacked planthopper	*Wbph 1*	N22
	Wbph 2	ARC10239
	Wbph 3	ADR52
	wbph 4	Podiwi A8
	Wbph 5	N'Diang Marie





11. Resistance of rice to different biotypes of *Nilaparvata lugens.* a) Biotype 1 damages varieties with no gene for resistance, b) Biotype 2 damages varieties with *Bph* 1 gene, and c) Biotype 3 damages those with *bph* 2 gene.

Nilaparvata lugens biotypes. Recently, such resistance was successfully transferred from the wild species *Oryza officinalis* into cultivated rice. Several progenies were highly resistant to all the four biotypes.

Studies of inheritance of rice resistance to *Sogatella furcifera* were initiated in 1979 at IRRI. Genetic analysis of several rice varieties identified five resistance genes (Table 5). Recent reports showed that, in addition to major genes, minor genes are also responsible for imparting resistance to this pest in some rice varieties. It is believed that minor genes can delay the selection of *Sogatella furcifera* biotypes. There is no IR cultivar highly resistant to this pest. However, IRRI researchers are incorporating *Wbph* 3, *wbph* 4, and *Wbph* 5 genes into improved breeding lines.

All tropical American land races and all japonica rice varieties are highly susceptible to rice delphacid. All known resistant varieties are indica varieties from Southeast Asia where the insect is not known to occur. Resistance to *Tugosodes orizicolus* is apparently not associated with any morphological trait in the rice plant, including height, pubescence, or any other plant character. Insects caged on resistant varieties suffered high mortality, had slower growth, and laid fewer eggs. Resistance to the rice delphacid was found to be inherited independently of resistance to the hoja blanca virus. Varieties resistant to the vector and susceptible to the virus show low infection in the field. Several resistant varieties (CICA 4, CICA 6, and CICA 8) were released jointly by the Centro Internacional de Agricultura Tropical (CIAT), Colombia, and the Instituto Colombiano Agropecuario. Presently, CIAT and Cuba have an excellent breeding program for resistance to *Tagosodes orizicolus.* CIAT also has a breeding program for resistance to hoja blanca virus.

Chemical control

The most common method of controlling rice virus disease spread is by the application of insecticides to control planthopper and leafhopper vectors. Insecticides prevent not only the spread of viral diseases but also direct damage by insect pests. The tactics used in successful chemical control of the vector are related to vector behavior and biology and to the characteristics of virus transmission. With *Nilaparvata lugens,* feeding damage is more common than damage due to transmission of grassy stunt and ragged stunt viral diseases. With *Nephotettix virescens,* the tungro virus transmitted by the vector is much more damaging than direct feeding damage. Tungro, a nonpersistent virus, is transmitted during a short feeding period, whereas transmission of persistent ragged stunt and grassy stunt viruses requires more time. Therefore, prevention of feeding and rapid knockdown of the leafhopper are important in preventing virus transmission. In tungro epidemic areas, prophylactic measures are sometimes recommended to ensure protection against virus infection. However, the cost of protection must be sufficiently low to be economically attractive. For control of *Nilaparvata lugens,* insecticides should be applied only when the insect population reaches the economic threshold. Applying insecticides when macropterous adults are numerous in a field will kill natural enemies and not the eggs. Applying insecticide when the population is mostly young nymphs is wasteful because young nymphs cannot damage the crop. Moreover, natural enemies normally control nymph numbers.

Leafhoppers are generally more sensitive to insecticides than planthoppers. Studies on selective toxicity of organophosphates, carbamates, and chlorinated hydrocarbons against planthoppers in Japan and the Republic of Korea show that organophosphates have maximum selectivity, i.e., the highest LD_{50} values against *Nilaparvata lugens, Sogatella furcifera,* and *Laodelphax striatellus.* On the other hand, the carbamates have a generally higher level of ovicidal activity than the organophosphates.

Insecticide-induced resurgence of *Nilaparvata lugens* has been reported in every country in tropical Asia. Although several other factors have been implicated in inducing resurgence, it is generally recognized that the primary cause is the destruction of natural enemies. Insecticides causing high levels of resurgence should not be recommended for control of rice pests. Buprofezin (2-tert-butylimino-3-isopropyl-5-phenyl-tetrahydro-l,3,5-thiadizin-4-one) is a highly selective molting-inhibitor for control of *Nilaparvata lugens, Sogatella furcifera, Laodelphax striatellus, Nephotettix virescens,* and *Nephotettix cincticeps.* Buprofezin is reported to be nontoxic to natural enemies, mammals, or fish.

For control of tungro virus, systemic granules are recommended for incorporation into the soil before sowing the seedbed. Soil-incorporated granules are more efficient than broadcast granules or sprays in the seedbed. Soaking the seedlings in insecticide solution for 6-12 h before transplanting gives protection for 20 d, whereas soil incorporation or broadcasting of systemic granules protects the crop for 40 d. For control of *Nilaparvata lugens,* granules are less effective than sprays or dusts, particularly when applied to older plants with a greater biomass.

Insecticide resistance of leafhoppers and planthoppers has been most common in Japan where the insecticide use rate on rice is much higher than in any of the tropical countries. *Nephotettix cincticeps* was the first hopper species to become resistant to organophosphates and carbamates. Resistance of *Nephotettix cincticeps* and *Laodelphax striatellus* to several organophosphates and carbamates has also been reported in the Republic of Korea. *Nilaparvata lugens* has also developed resistance to carbofuran in South and Southeast Asia.

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Rice gall midge

The rice gall midge *Orseolia oryzae* (Wood-Mason) is a serious pest of rice in South and Southeast Asia. It is widely distributed in several parts of India and in Cambodia, southern China, Indonesia, Laos, Myanmar, Nepal, Pakistan, Sri Lanka, northern Thailand, and Vietnam. The pest has not been reported in the Philippines, Malaysia, or southern Thailand.

In Africa, another species of gall midge—*Orseolia oryzivora* Harris and Gape—damages the rice crop, but it is not considered a major pest. It is reported to occur in Cameroon, Ghana, Ivory Coast, Liberia, Mali, Niger, Nigeria, Senegal, and Sudan.

Since the fly requires high humidity, lowland crops are more often infested than upland crops. Both gall midge species prefer lowland to upland rice. Damage on upland rice in China and on deepwater rice in India has also been recorded.

Life history

Adults

The adult flies of both *Orseolia oryzae* and *Orseolia oryzivora* are about the size of a mosquito (wing length is 3.5-4 mm for females and 3.0-3.5 mm for males). They are nocturnal and phototropic (Fig. 12). The females have a bright red, stout abdomen; the abdomens of males are darker. The field population of *Orseolia oryzae* has generally a 4:1 female-to-male ratio, but *Orseolia oryzivora* has 1:1. The adults feed on dewdrops and live for 2-5 d. Copulation usually takes place soon after emergence and lasts for about 5 min. Oviposition starts a few hours later. The females mate only once and no parthenogenesis has been recorded; unmated females lay sterile eggs.

12. Adult of rice gall midge *Orseolia oryzae.*

Eggs

A single female is capable of laying 100-200 eggs, either singly or in groups of 3-4 near the base of the plants, on the ligules or in their vicinity on the leaf blade, or on the leaf sheath. In the seedbed as well as after transplanting, about 60-70% of the eggs are laid on the leaf blade, and most of the rest on the leaf sheaths, except for occasional oviposition on the central whorl of the plants. Eggs laid on the leaf blade are on the undersurface. In captivity, the females oviposit on almost any surface they come in contact with. The eggs (elongate tubular, 0.5 mm long and 0.12 mm wide) are shiny white with pinkish, red, or yellow shading, and turn shining amber before hatching. The incubation period is 3-4 d.

Larvae

The newly hatched larvae of both species are about 1 mm long and can live in water up to 3 d without any harmful effect. They creep down the leaf sheath to the growing points of the tillers and reach the interior of the bud. There they lacerate the tissues and feed until pupation. Their feeding stimulates the tillers to grow into a tubular gall that resembles an onion leaf. The average larval period of *Orseolia oryzae* is 15-20 d; that of *Orseolia oryzivora* is 6-22 d. The full-grown larva of *Orseolia oryzae* is about 3 mm long, pale red, with a pointed anterior end. It feeds at the base of the gall where it pupates. Generally only one maggot per tiller is found. The full-grown larva of *Orseolia oryzivora* is whitish pink and 4.4 mm long. Under high population pressure, multiple and simultaneous infestations occur.

Pupae

Pupation occurs inside the gall near the base. The pupa of *Orseolia oryzae* is about 2-2.5 mm long and 0.6-0.8 mm wide; that of *Orseolia oryzivora* is 5.8 mm long. The pupae are adorned with a series of subequal spines pointed backwards. These spines enable the pupae to wriggle their way to the tip of the gall. When the adults are ready to emerge, the pupae pierce the tip and project halfway out. The skin of the pupa then bursts and the midge crawls out. Emergence generally takes place at night. The pupal period is 2-8 d.

Seasonal occurrence and abundance

The fly becomes active at the onset of the monsoon when it completes one to two generations on grasses before rice is planted, and then transfers to the ricefields. It usually takes 9-14 d to complete one life cycle on grasses, but about 9-26 d on rice. The fly 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. In multi-cropped rice areas, the fly seldom infests the second crop and has not been observed infesting the third one. Usually it occurs in five to eight overlapping generations in one season.

The insect has been reported to hibernate in underground dormant buds of grasses serving as alternate hosts and becomes active again when the buds start growing after rains. Larvae overwinter in a short tube in the stubble. The midge also multiplies on sprouting rice stubble in unplowed ricefields. In the Cameroons, after rice is harvested, the pest migrates to wild rice *Oryza barthii,* where it remains active until the plants dry up in summer. Several alternate host plants recorded in India and Thailand include wild rice *Oryza officinalis* and several graminaceous weed plants such as *Ischaemum aristatum, Echinochloa colona, Paspalum* sp., and *Leersia* sp.

The most serious gall midge infestation occurs when early rains make the flies active. Subsequent dry periods delay rice planting; 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 the fast buildup of gall midge populations. The favorable condition for fly development is 26-30 °C and 82-88% RH. Heavy rains or storms cause high mortality. The insects are less abundant in crop years preceded by a warm and dry spring.

Low RH may be the cause of the decline in gall midge during the second rice crop even though there is no distinct lack of suitable hosts. Because the larvae can live under submergence for several days, changes in water levels in the ricefields do not seem to have a distinct effect on fly incidence.

Damage

Damage 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 these new tillers often become infested and very few, if any, bear panicles. Even these panicles are less vigorous and are often stunted.

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

The exact nature of the development of galls is not fully understood. Either direct feeding in the developing primordia or the secretion of some compound by the maggot stimulates the growth of the leaf sheath around the larvae 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 the same color as the leaf sheath but somewhat shiny. Several earlier workers regarded galls as elongated rice stems. But later anatomical studies of the galls established that they are 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 3-7 d after the larvae enter the growing point of the plants. A fully developed gall is generally 1-2 cm wide and 10-30 cm long, although galls as long as 50 cm have been recorded. By the time galls become visible, the adults have generally emerged. However, tiny galls (about 2 mm long) can be easily detected in the field; most of them contain maggots or pupae.

Control methods

Cultural control

Removal of grassy weeds or wild rice alternate hosts from ricefields and surrounding areas helps reduce the pest population. Plowing fields after harvest and keeping fallow land free of off-season alternate host plant is recommended.

Delaying wet season planting of photoperiod-sensitive varieties helps reduce infestation because plants at the vegetative stage are more susceptible to gall midge attack. Planting of photoperiod-insensitive varieties as early as possible after the beginning of wet season allows the crop to complete the vegetative stage before the gall midge population transfers from alternate hosts.

The use of moderate amounts of N fertilizer and split applications over three growth stages is recommended. Neighboring fields should not be planted within 3 wk of other fields to avoid crops of staggered ages.

Biological control

Numerous parasitoids and predators attack different life stages of rice gall midges. The natural enemy complexes controlling the Asian rice gall midge and African gall midge are different.

A predatory phytoseiid mite *Amblyseius imbricatus* Corpuz & Rimando attacks eggs of Asian rice gall midge *Orseolia oryzae.* Several platygasterid wasps (e.g., *Platygaster oryzae* Cameron) are gregarious larval parasitoids. These parasitoids lay eggs on the walls of silver shoot after first stinging the larva inside. The wasp larvae that hatch out feed on the gall midge host. Several solitary larval parasitoids, e.g., *Obtusiclava oryzae* (Subba Rao) and pupal parasitoids, e.g., *Neanastatus* oryzae Ferriere and *Neanastatus cinctiventris* Girault, are also known.

Numerous species of spiders, e.g., *Tetragnatha mandibulata* Walckenaer, *Argiope catenulata* Doleschall, and *Neoscona theisi* (Walckenaer), prey on the adult midge.

Tetrastichus pachydiplosisae Risbec is reported as a major parasitoid of African gall midge *Orseolia oryzivora,* and is considered an important natural control factor for the pest. Among other parasitoids of *Orseolia oryzivora,* important ones are *Platygaster pachydiplosisae* Risbec, *Bracon* sp. aff. *annulicornis* Granger, *Neanastatus tenuis* Ferriere var. *platygasteri* Risbec, and *Anisopteromalus camerunus* Risbec.

Varietal resistance

Planting a resistant variety is the most effective means of preventing gall midge damage. Differences in varietal susceptibility to this pest were reported as early as 1922 in Vietnam and 1927 in India. Several national rice improvement programs in Bangladesh, India, Indonesia, Sri Lanka, and Thailand are currently screening germplasm for resistance to the gall midge and have identified several hundred resistant varieties. In India, several rice varieties such as Eswarakora, HR42, HR63, Ptb 18, Ptb 21, Siam 29, and the Thai variety Leuang 152 were found highly resistant and were used in several breeding programs. The Indonesian program evaluated more than 6,000 local varieties, but found none of them resistant.

Existence of gall midge biotypes in India was suspected during the early stages of development of resistant rice varieties. Since then, many regional, national, and international collaborative studies have been undertaken to detect, define, and recognize different biotypes of gall midge. Morphological variations were also noted in gall midge adults collected in India and Thailand, which are believed to be representatives of two biotypes.

Inheritance of resistance studies identified two major genes for resistance: *Gm1* conveying resistance in Eswarakora derivatives, *Gm2* in Siam and Leuang 152 derivatives. After 15 yr of national and international coordinated trials, three biotypes of rice gall midge were recently identified in India. Biotype 1, which is incapable of overcoming resistance conferred by either of the two identified genes, is confined to the states of Andhra Pradesh, Madhya Pradesh, and probably northwestern Orissa. Biotype 2, which can overcome resistance of rice varieties with *Gm1* resistance gene, is scattered in parts of Orissa, Karnataka, and Maharashtra. Biotype 3, capable of infesting rice varieties with resistance gene *Gm2,* is found in Bihar and Manipur.

The resistance to gall midge is reported to be primarily due to antibiosis. Larval development is retarded on resistant varieties, but is normal on susceptible varieties. On several wild rices, the adult is ill-formed and does not emerge. Although significant advances have been made in the development of rice varieties resistant to gall midge in Asia, new resistance sources have not been included in breeding programs. Identification of new resistance genes and development of isogenic lines are necessary to properly characterize the biotypes. A close monitoring of increasingly virulent populations of gall midge in India and Thailand is also needed.

Chemical control

It is difficult to control the gall midge with insecticide because the larvae are protected inside the plant or gall. At any rate, granular insecticide applications are usually more effective than sprays, but only if there is standing water in the field.

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Rice leaffolders

Eight species of pyralid moths, whose larvae roll or fold leaves of graminaceous plants, comprise the leaffolder complex. They are *Cnaphalocrocis medinalis* (Guenée), *Marasmia patnalis* Bradley, *Marasmia (=Susumia) exigua* (Butler), *Marasmia bilinealis* Hampson, *Marasmia ruralis* (Walker), *Marasmia suspicalis* (Walker), *Marasmia trapezalis* (Guenée), and *Marasmia venilialis* (Guenée).

Leaffolders are widely distributed in the rice-growing tracts of 29 humid tropical and temperate countries in Asia, Oceania, Australia, and Africa between 48° N and 24° S and 0° E to 172°W. Currently, only three species, *Cnaphalocrocis medinalis, Marasmia patnalis,* and *Marasmia exigua,* have attained pest status on rice.

Cnaphalocrocis medinalis traditionally has been accepted as a sole leaffolder pest in the lowland ricefields of Asia. But the discovery of *Marasmia patnalis* in 1981 has complicated the interpretation of past results. *Marasmia patnalis* has often been confused with *Cnaphalocuocis medinalis* in South and Southeast Asia (Fig. 13a, b). The individuals belonging to the two genera could be differentiated from each other by forewing venation. *Cnaphalocrocis* has R2 and R1 (veins 10 and 11) stalked, with R2 set close to the trunk of R3 and R4 (veins 8 and 9). *Marasmia,* on the other hand, has R2 and R1 free. These and other morphological as well as genitalial features are used to separate the leaffolder species.

Several alternate hosts are reported for the rice leaffolders. Aside from rice, they attack various grasses, sedges, and cultivated crops such as maize.

Life history

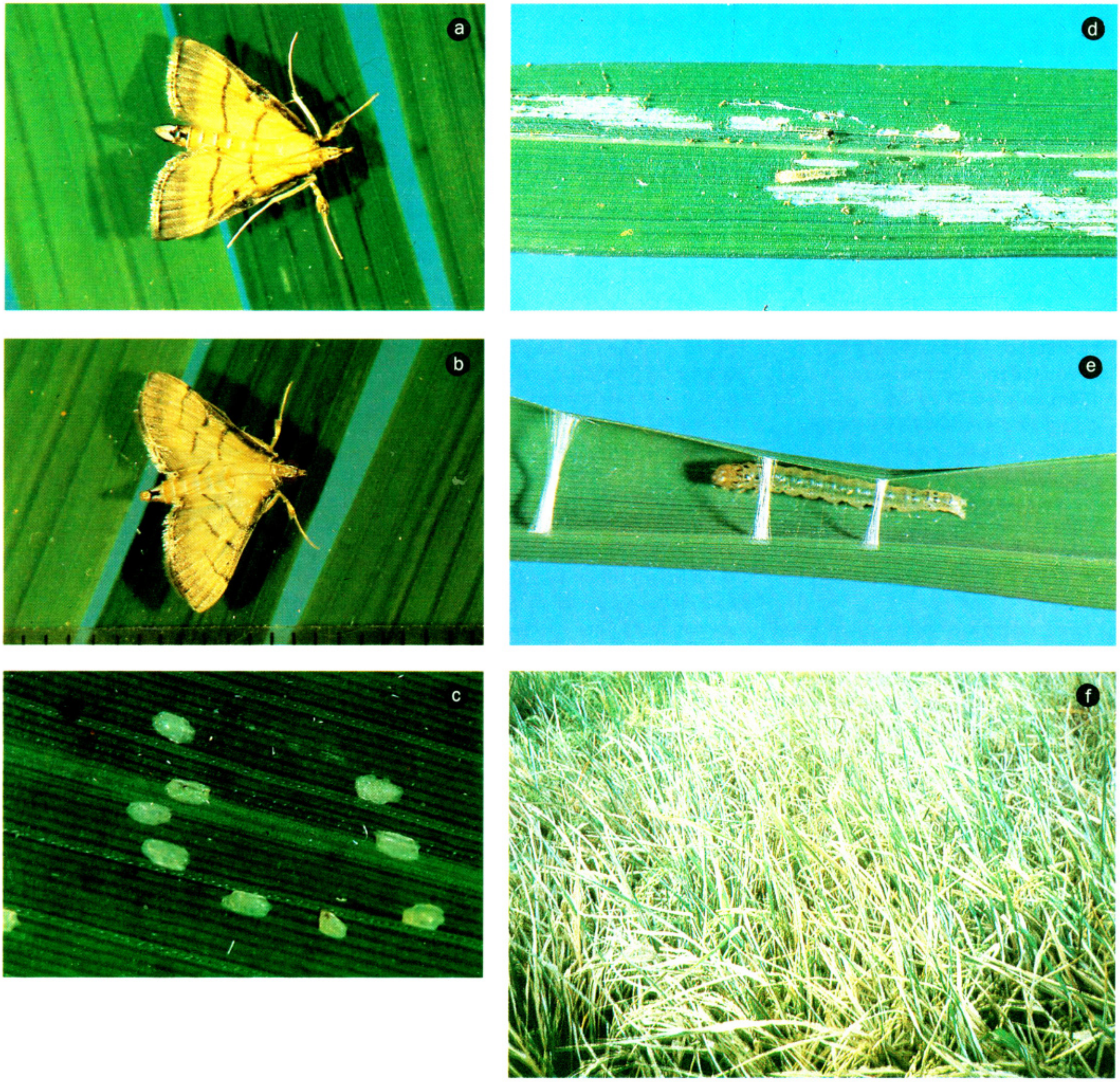
The life history of rice leaffolder species is more or less similar. *Cnaphalocrocis medinalis* is the best known leaffolder species in Asia. The adult moths are 10-12 mm long. They are light brown with shiny, brownish yellow wings adorned with dark, broad margins, and two to three dark vertical stripes. Wing expanse is 13-15 mm. The moths are nocturnal; they hide during the day and usually emerge at night. They generally mate between dusk and midnight.

Oviposition starts two-three nights after mating. The female moth usually lives for as long as 8-9 d and lays 50-300 eggs. The eggs are laid on different nights in batches of 10-12 arranged linearly along the midrib on either surface of the leaf blade (Fig. 13c). The biggest batches are laid on the fourth-seventh night after the moths emerge.

The individual eggs are translucent, yellowish white, oval, 0.90 mm long and 0.39 mm wide, and almost flat with a slightly convex surface. The eggs hatch 3-4 d after oviposition.

The freshly hatched larva is 1.5-2 mm long and 0.2-0.3 mm wide, has a shiny translucent body and a light-brown head. The body turns green after the larva begins feeding. The first-instar larva feeds on the young leaves by scraping the leaf surface, but it does not cause the leaves to fold (Fig. 13d). Its body usually is covered with a silky material. Five larval instars are completed in an average period of 20-30 d. The larvae from the late second instar onward can cause the leaves to fold (Fig. 13e). The caterpillar secretes a series of threads and uses these to connect the two margins of a leaf blade. The threads contract as they dry and bring the two leaf margins together, turning the leaf blade into a tubular structure. The larva remains within the leaf blade and feeds on it by scraping the leaf surface, thus causing longitudinal, white, transparent streaks on the leaf blade. If a blade is severely damaged, the larva migrates to other leaves.

The full-grown larva is yellowish green with a dark brown head and is 20-25 mm long and 1.5-2 mm wide. It undergoes pupation inside the leaf roll in loosely woven strands of silk thread. The newly formed pupa is light brown, but turns reddish brown toward moth emergence in 6-10 d.



13. Rice leaffolders: *a) Cnaphalocrocis medinalis* adult, *b) Marasmia patnalis* adult, *c) C. medinalis* eggs, *d)* damage by a second-instar larva of *C. medinalis, e)* rice leaf rolled by a third-instar larva of *C. medinalis, f)* a ricefield damaged by leaffolders.

Seasonal occurrence and abundance

Although moths are recorded in the warm tropics year-round, they usually are most abundant during the rainy season. In places with cool winters, the insect is active from May to October, during which it completes four to five generations; the later generations usually overlap. High humidity and optimum temperature appear to be important factors in the insect's abundance.

The distribution of leaffolders can be seasonal. *Cnaphalocrocis medinalis* is a long distance migrant into temperate China (including Taiwan) and Japan inasmuch as it does not overwinter in those areas. Every year the initial population migrates to these temperate countries from tropical regions. The insect migrates northward in the spring and southward in the fall, and undergoes a reproductive diapause at the onset of seasonal emigratory periods. In the Philippines, *Cnaphalocrocis medinalis* remains active year-round in irrigated multicropped rice areas, but disperses tens of kilometers to colonize the rainfed rice areas in the wet season. Long distance dispersal is unknown in the other leaffolders.

Leaffolders have increased in importance both in upland and lowland ricefields in the last decade, particularly in areas where modern varieties are extensively grown. Expanded rice areas with new irrigation systems, multiple rice cropping, reduced genetic variability of the modern semidwarfs, application of high levels of nitrogenous fertilizers, and insecticide-induced resurgence have further compounded the leaffolder problem.

Damage

Several outbreaks of leaffolders have been reported in Bangladesh, China, Fiji, India, Japan, Republic of Korea, Malaysia, Nepal, Philippines, Sri Lanka, and Vietnam. Most of the rice leaffolder literature relates to *Cnaphalocrocis medinalis.* Sometimes, other species, primarily *Marasmia patnalis,* could be more dominant. Under favorable conditions, leaffolders produce several generations. During high insect population densities, rice plants dry up and appear scorched (Fig. 13f). Before feeding, the larvae fold the leaves longitudinally and fasten leaf margins with stitches of threadlike silk.

The larvae feed by scraping the green mesophyll from within the folded leaves. This results in linear, pale white stripe damage to the leaf. First- and early second-instar larvae are gregarious and generally feed within the slightly folded basal regions of the young leaves in a tiller. Starting with the late second instar, when larvae regularly roll up leaves, they become solitary. Generally, only one larva per leaf roll is found; after feeding on one fold for about 2-3 d, it moves to another leaf. Thus, each larva destroys a number of leaves during its growth.

Feeding greatly reduces the general vigor and photosynthetic ability of an infested rice plant. The damaged leaves also serve as entry points for fungal and bacterial infections. The maximum yield loss caused by leaffolders is reportedly due to feeding on the flag leaf. Unfortunately, N fertilizer, which generally contributes to the high yield of modern varieties, also enhances the nutritional status of the rice plant, leading to greater insect survival, reproduction, and feeding rates, which, in turn, lead to greater damage.

Control methods

Cultural control

Judicious use of nitrogenous fertilizer in split applications is recommended. Removal of grassy weeds from ricefields and surrounding borders prevents the buildup of rice leaffolders on alternate hosts.

Biological control

Numerous natural enemies normally push rice leaffolders below economic threshold levels. Several species of Diptera (e.g., *Megaselia* spp. and *Argyrophylax* spp.), Hymenoptera *(Goniozus* spp., *Trichogramma* spp., *Apanteles* spp., and *Bracon spp.),* Coleoptera *(Chlaenius* spp. and *Coccinella* spp.), Orthoptera *(Anaxipha* spp. and *Metioche* spp.), Araneae *(Argiope* spp., *Pardosa* spp., and *Tetragnatha* spp.), and nematodes *(Agamermis* spp.) have been reported as parasites and predators of leaffolders in Asia. A few fungal, bacterial, and viral pathogens are also known to parasitize the larvae, particularly when the pest population is high. Microbial insecticides, particularly *Bacillus thuringiensis* Berliner, are effective against larvae. Among the vertebrates, frogs and toads are considered important predators of leaffolders in some countries.

Varietal resistance

More than 18,000 rice accessions from the germplasm collection of IRRI have been screened for resistance to *Cnaphalocrocis medinalis.* Nearly 115 were found resistant or moderately resistant. Several traditional rice varieties such as Ptb 21, Ptb 33, TKMI, TKM2, TKM6, Muthumanikam, and WC1263, are resistant to *Cnaphalocrocis medinalis* and have to be reevaluated in light of the discovery of the overlapping *Marasmia patnalis* species complex. Selected rice varieties resistant to *Cnaphalocrocis medinalis* are also resistant to *Marasmia patnalis.* Several wild rices— *Oryza brachyantha, O. nivara, O. rufipogon,* and *O. perennis* — also show resistance to *Cnaphalocrocis medinalis* and *Marasmia patnalis.* Research centers with several national rice improvement programs are also screening rice varieties and wild germplasm for resistance to *Cnaphalocrocis medinalis;* several rice varieties and breeding lines with potential for resistance have been identified. Unfortunately, all IR rice varieties (IR5 to IR72) are susceptible to leaffolders. Improved varieties with resistance to the leaffolder complex are needed because varietal resistance is one of the more promising tactics in the integrated control of this pest in tropical Asia.

Chemical control

Chemical control is the only practical method to control increasing leaffolder infestation during crop growth. However, socioeconomic constraints in tropical developing countries and insecticide-induced resurgence of *Nilaparvata lugens* present obstacles to effective chemical control. Numerous insecticides that have been identified for control are most effective as foliar sprays. But foliar sprays have to be repeated because they are often washed off by frequent rains. Granular insecticides broadcast into water are ineffective. Economic thresholds, used to make decisions on insecticide application, are based on egg counts, damaged leaves, or larval densities. Since leaffolders can attack the crop during any growth stage, fields should be monitored weekly.

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Grain-sucking insects

Several hemipterous bugs belonging to the families Alydidae and Pentatomidae (Table 6) that feed by sucking the sap of developing spikelets cause serious rice crop losses. Usually, they live either in the ricefields or on grasses in the vicinity where they feed and multiply during the vegetative phase of the rice crop. They then migrate to flowering ricefields, which strongly attract them. In Asia, several species of *Leptocorisa* are the most important grain-sucking pests; in the USA, the rice stink bug *Oebalus pugnax* (Fabricius) is of major importance.

Table 6. Grain-sucking insects of rice.

Common name	Family	Scientific name	Distribution
Rice bug	Alydidae	*Leptocorisa acuta* (Thunberg)	Asia, Australia
		L. biguttata (Walker)	Asia
		L. chinensis (Dallas)	Asia
		L. palawanensis Ahmad	Asia
		L. oratorius (Fabricius)	Asia, Australia
		L. solomonensis Ahmad	Asia
		Riptortus linearis Fabricius	Asia
		Stenocoris southwoodi Ahmad	Africa, South America
		S. claviformis Ahmad	Africa, South America
Stink bug	Pentatornidae	*Oebalus pugnax* (Fabricius)	Southern USA
		O. poecila (Dallas)	Latin America
		O. ypsilon-griseus (De Geer)	Latin America
		O. grisescens (Sailer)	Latin America
		Eysarcoris (=Stollia) *ventralis* (Westwood)	Asia
		Pygomenida varipennis (Westwood)	Asia
		P. benghalensis (Westwood)	Asia
		Nezara viridula Linnaeus	Asia, Africa

Rice bugs

The most important rice bugs in the subtropical and tropical rice areas belong to the genus *Leptocorisa.* Another genus, *Stenocoris,* which was previously a subgenus of *Leptocorisa,* also contains several species known to be present in ricefields, but their economic significance is not fully known. *Stenocoris* occurs in Ethiopian, Nearctic, and Neotropical regions; *Leptocorisa* is distributed in the Orient-Australian region and includes some of the most serious rice pests in this area. The species of major economic significance are listed in Table 6.

Rice bugs concentrate on small-scale upland ricefields that they can actively search out. They are also common in rainfed lowland rice environments. In irrigated rice, yield loss from rice bugs that feed on grains is normally minimal because their populations are diluted in vast areas of rice planted more or less at the same time.

The rice bug populations in a ricefield are highly variable and damage occurs only during a short period of crop growth. The lowland rice crops of Asia are dominated by *Leptocorisa oratorius* (Fabricius).

Life history

The adult insect is long and slender, about 14-17 mm long and 3-4 mm wide (Fig. 14a). On the average it lives for 30-50 d, but some individuals have been observed to survive for 110-115 d. It is phototropic and diurnal, but is most active during early mornings and evenings 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 females start mating only 7-14 d after becoming adults. *L. oratorius* lays its eggs high on foliage. *L. acuta* (Thunberg) and *L. solomonensis* Ahmad oviposit at ground level, the former on litter and the latter on the ground. These egg-laying habits explain their environmental preferences. Oviposition generally commences 3-4 d after mating. A single female lays an average of 200-300 eggs in batches of 10-20, usually arranged in two or three straight rows along the midrib on the upper surface of the leaf blade. The eggs are oval, slightly flattened on the top (Fig. 14b). They are creamy white when freshly laid, but become darker as they approach hatching in 5-8 d. During hatching, the upper half of the egg breaks away, leaving a distinct hole.

The freshly emerged nymphs are tiny and green, but become brownish as they grow. They blend with the foliage and are often undetected. They start feeding 3-4 h after hatching, and undergo five nymphal instars in a total period of 25-30 d to become adults. The feeding habits of adults and nymphs are similar.

A number of alternate host plants, all in the family Gramineae, have been recorded. The insects live on grasses but prefer flowering rice.

Both nymphs and adults are difficult to see in the ricefields because their color resembles that of rice plants. Infested fields, however, can often be detected, even from a distance, because they emit a typical rice bug odor produced by scent glands on the abdomen of the insect.

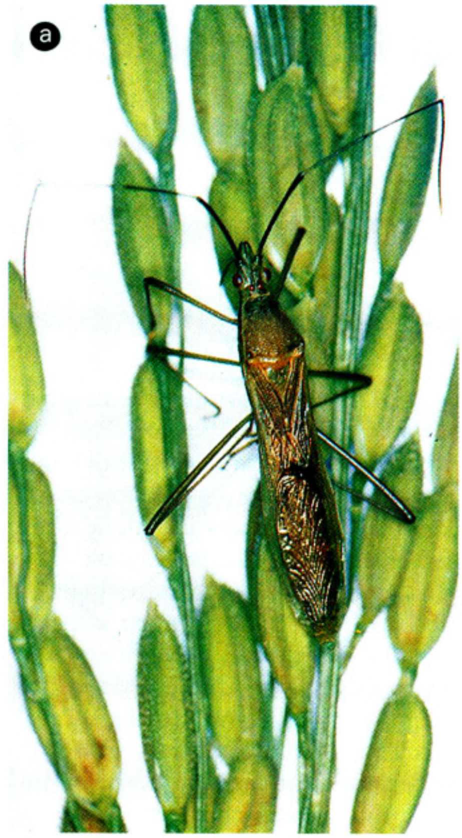
When disturbed, adults fly and give off the typical rice bug odor. Adults are active in late afternoon and early morning. They rest in grassy areas during periods of bright sunshine. During the dry season, adults move to wooded areas where they remain dormant.

Seasonal occurrence and abundance

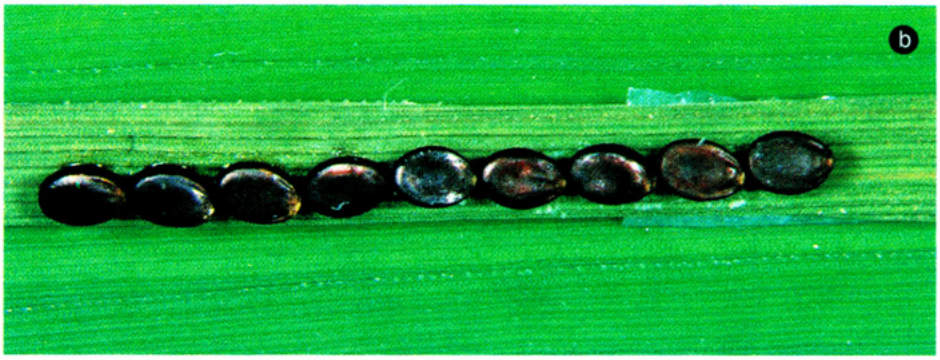
All stages of the rice bug are especially vulnerable to changes in temperature and humidity. The bugs are most abundant at 27-28 °C and 80-82% RH. During flowering of the rice crop, warm weather, overcast skies, and frequent drizzles favor population buildup, but heavy rains reduce it. The population usually increases at the end of the rainy season and declines rapidly during dry months and when temperature is unfavorable. When temperature declines from October onward, the insects hibernate in grasses. In such areas, late rice crops escape rice bug infestation. The hibernating adults become active with the onset of summer rains. Intermittent rains and high temperature during summer are conducive to terminating the diapause.

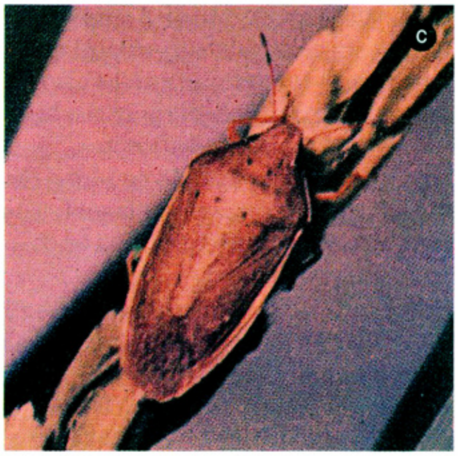
Factors that cause high rice bug populations are nearby woodlands, extensive weedy areas near ricefields, and staggered rice planting.

After diapause, the adults feed on weeds and other available alternate hosts on which they pass one to two generations before migrating to the rice crop now at flowering stage. In Japan, the postdiapause adults of *L. chinensis* migrate from mountainous areas to upland ricefields during flowering. In single-cropped areas, the insect usually has four overlapping generations. But at places where temperatures are optimum and rice is grown year-round, the bugs remain active throughout the year without a distinct diapause. In such areas, fields that mature earlier or later than the usual crops become heavily infested. Insect abundance becomes especially high where rice planting is staggered, leading to an extended ripening period over several crops. The strong phototropic nature of the insect has led some workers to explore light traps as a control method, but the results have been erratic. Large rice bug populations can also be trapped in early planted ricefields.



14. Grain-sucking insect pests of rice:
a) *Leptocorisa oratorius* adult, b) *L. oratorius* eggs, c) adult of a pentatomid bug.





Stink bugs

Pentatomid bugs or stink bugs (Fig. 14c) are important rice pests in Asia, Africa, Latin America, and southern USA (Table 6). Both adults and nymphs feed on developing grains of rice in the milk and dough stage, resulting in partially or entirely unfilled grains. This damage is characteristic of the species.

Nezara viridula Linnaeus occurs worldwide and is often more abundant in uplands. It is a polyphagous pest and often causes serious damage to rice. The bug is of great significance in southern Japan because of the cultivation of early rice, which reaches heading in mid-June to early July, coinciding with the emergence of first-generation adults. The coincidence is particularly favorable for the insect because not only is flowering rice more suitable for its survival and development, but at this time hosts other than rice are scarce. Furthermore, since their dispersal ability is greater than that of their parasites, a population migrating to ricefields suffers only low parasitization. The population developed on an early rice crop increases on the medium- and late-maturing crops, but even in double-cropped areas, the bug population usually remains fairly low. This is not true in grassy or orchard areas where adequate alternate hosts are available.

Pentatomid bugs belonging to *Oebalus* species are another group of important rice pests in Latin America and southern USA.

Life history

The adult insects of the southern green stink bug or *Nezara viridula,* typically pentatomid, are about 13-17 mm long. They occur in four distinct color phenotypes. Females start mating 1 wk after emergence and the preoviposition period varies from 2 to 3 wk. Both male and female bugs are capable of repeated matings. The average life span of females is about 30 d.

The eggs are laid on the lower surface of leaves in masses of 20-130 in five to eight parallel rows. Each female usually lays two to eight yellow egg masses that turn red just before hatching. The first-instar nymphs congregate around the egg shells; at the second instar, they start feeding gregariously; they scatter to solitary feeding beyond the fourth instar. The nymphs undergo five molts in an average period of 35-45 d to become adults. The nymphal population is considerably heterogeneous in color pattern.

The adults of rice stink bug *O. pugnax* are 1.0-1.25 mm long and slightly less than half as wide. They are straw-colored, shield-shaped, and have two sharply pointed shoulder spines, which project forward and possess the typical stink bug smell. Males usually live for about 30 d. Females live an average of 40 d, laying about 70-80 eggs each. The eggs are barrel-shaped (0.85 x 0.65 mm) and laid in masses of 10-47 in double rows. The eggs of one row alternate with those of the other. They are deposited on leaves of panicles of different grasses. Newly laid eggs are green, but they become reddish before hatching 4-8 d after oviposition. The newly hatched nymphs congregate around the empty egg shells for about 24 h, after which they disperse to feed. The nymphs undergo five molts over a total average period of 16-23 d to become adults.

Seasonal occurrence and abundance

In southern Japan, *Nezara viridula* occurs in three overlapping generations with a partial fourth. In warm years, the hibernating insects become active during March to June, and complete the fourth generation.

The adult insects hibernate in dry, shady areas. In hibernation, the males are quiescent while the females diapause. During years with a severe winter, the hibernating insects, particularly those which have fed on grasses, are smaller and suffer high mortality.

Adults emerging from hibernation 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 ricefields over several kilometers.

In nature, the population is, to some degree, density dependent. With increased population density in the second and third generations, the females exhibit reduced fecundity and the eggs and larvae suffer higher mortality. Strong winds also reduce the nymphal population. In Japan, several egg parasites play an important role. Substantial biological control of this insect has been achieved in Hawaii and Australia.

The adult insects of *O. pugnax* 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 ricefields and move to the ricefields later. A severe winter reduces the population of overwintering adults, and high temperature during summer causes high nymphal mortality.

Another species, *Oebalus* (=*Solubea*) *ornata* (Sailer), has been reported to cause serious losses to rice in the Dominican Republic. It frequently occurs in large numbers, causing up to 50% crop loss.

In general, the bionomics of this pest resembles that of *O. 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 extremely active up to 1000 h when they feed on the panicles and copulate. They migrate to the base of the plants when the sun becomes brighter. On cloudy or light rainy days, the adults and nymphs remain on the panicles all day and feed extensively. In the Dominican 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. The population is at its lowest ebb in May.

Damage

The damage to the rice crop is caused by the feeding of nymphs and adult bugs on the endosperm of the developing grains. Growing rice bug nymphs are more active feeders than adults, but adults cause more damage because they feed for a longer period. Although they also feed on other parts of the rice plant, they prefer grains at the milk stage and even ripening grain. Both nymphs and adults feed by inserting their proboscises at points where palea and lemma meet. Diffused brown spots caused by the exudation of the sap mark the points of insertion. Grains damaged during milk stage remain empty. The panicles in heavily infested fields contain many shriveled and unfilled grains and usually remain erect. In severe cases of infestation, most grains in a field are sucked empty and the straw has an off-flavor, which is unattractive to cattle. When rice bugs feed in soft or hard dough endosperm in a solid state, they inject enzymes to predigest it. Damage during the dough stage causes discoloration of mature grain and causes weakness in the kernel. Such rice has lower milling quality or is pecky rice of inferior grade. Partially damaged grains also have an off-flavor even after cooking. Injury during the milk stage causes yield loss; damage during the dough stage impairs grain quality.

The southern green stink bugs feeding on rice are generally larger than those feeding on grasses and other hosts.

Control methods

Control measures for all grain-sucking insects are similar.

Cultural control

Various cultural and mechanical control measures are being adopted to control grain-sucking bugs. Delayed, but synchronous, planting of early-maturing varieties is suggested so that all crops ripen at the same time. Weed sanitation and eradication of alternate hosts from ricefields, levees, and surrounding areas also prevent the multiplication of the bug in rice-free periods. Mechanical control measures such as smoking the field, hand-picking of adults and nymphs, and the use of sticky traps have been suggested.

Varietal resistance

All cultivated rice varieties are susceptible to grain-sucking pests. IRRI attempts to find resistance to *Leptocorisa* spp. located a rice from India in a group of coarse-ground, low-yielding rice called Sathi. In this rice, the panicle remains enclosed in the leaf sheath and offers a sort of mechanical resistance to insect sucking. However, the compatibility of this character with yielding ability and ease of threshing is uncertain. In India, varieties Mundagakutty from Tamil Nadu and Soma from Bihar also show similar resistance.

Pentatomid bugs bore through the lemma or palea, but hairy seeds or seeds with awns that deter bugs draw complaints from threshers. Although screening for resistance to rice bug has been limited, moderate levels of resistance to the rice stink bug has been reported in some rice varieties such as Bluebelle, Nortai, PI 9810, and RU7603069.

Biological control

A number of natural enemies including parasites and predators are known to attack the rice bug at various stages. Small scelionid wasps *Gryon nixoni* (Masner) parasitize the eggs of *Leptocorisa* spp. Several species of parasitic wasps attack stink bugs. The meadow grasshopper *Conocephalus longipennis* (Haan) preys on rice bug eggs; several species of spiders, e.g., *Neoscona theisi* (Walckenaer), *Argiope catenulata* (Doleschall), and *Tetragnatha javana* (Thorell) prey on nymphs and adults. *Beauveria bassiana* (Balsamo) Vuillemin, a fungus, attacks both nymphs and adults. The assassin bug *Nabis stenoferus* Hsiao is a common natural enemy of stink bug.

Chemical control

Grain-sucking bugs are readily controlled with spray or dust formulations. Granular insecticides are generally ineffective. The use of poison baits against *Leptocorisa* spp. has been suggested.

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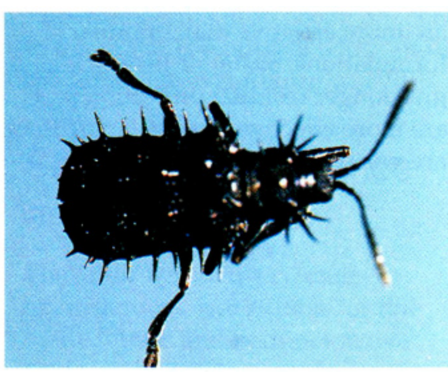
Rice hispa

Rice hispa *Dicladispa armigera* (Oliver) frequently causes extensive damage to lowland rice crops in Bangladesh, China (including Taiwan), India, Indonesia, Japan, Myanmar, Nepal, Pakistan, West Malaysia, and southern Thailand. The pest is not reported on upland rice and prefers more aquatic habitats. In Central Africa, a species of rice hispa *Dicladispa viridicyanea* (Kraatz) attacks upland rice in the vegetative stage as well as in lowland seedbeds. *Trichispa sericea* (Guerin), an African species, damages upland rice in West Africa and Madagascar. Three other hispid insects—*Dactylispa dilaticornis, Rhadinosa lebongensis* Maulik, and *Leptista pygmaea* Baly—damage the rice crop in several states of India. *Dicladispa gestroi* (Chapuis) is another important hispid insect reported from the Malagasy Republic.

Life history

The adult of *Dicladispa armigera* is a small (5.5 mm long), shiny, blue-black beetle with a spiny body (Fig. 15). Adult beetles of *Didadispa viridicyanea* are metallic blue-green, about 5 mm long, with five lateral spines on each side of the thorax and a series of alternately long and short lateral spines on the elytra. The females of *Dicladispa armigera* live an average of 20 d and the males, 14 d. They mate 3 or 4 d 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 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 is 4-5 d.

The pale yellow grubs, dorsoventrally flattened and 2.4 mm long, hatch and mine immediately into the leaf blades between the epidermal membranes and feed on the green tissue. The larval period is 7-12 d; the pupal stage is 4 or 5 d. Both stages are completed without migration to any other leaf. The adult beetles cut their way out of the leaf and begin to lay eggs 3 or 4 d later. Adults are external feeders.



15. Adult of rice hispa *Dicladispa armigera.*

Seasonal occurrence and abundance

The pest occurs throughout the year in tropical areas, but is generally more numerous during the rainy season. In places having cool winters, the insect remains active from May to October and completes four or five generations.

Heavy rains, especially in premonsoon or earliest monsoon periods, followed by abnormally low precipitation, minimum day-night temperature differential for a number of days, and high RH favor rapid buildup of hispa populations. Incidence is generally higher in fields treated with higher rates of N and where plants grow thickly under shade. The leaves of semidwarf varieties are more heavily infested than are those of conventional local varieties.

At initial infestation the adult beetle prefers the young rice crop. In India, the adults generally appear in ricefields in February and the population increases until June or July when the grubs as well as the beetles cause heavy losses to young crops. After August the population declines and the pest is usually of no economic significance. Adult beetles in small numbers can be collected from ricefields up to September or October. During this period, the pest completes six overlapping generations.

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. 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. The affected parts of the leaves usually wither off. In severe infestations, the leaves turn whitish and membranous and finally dry off. In Kenya, *Trichispa sericea* can transmit rice yellow mottle virus.

Infested plants have reduced leaf area, become less vigorous, and are often stunted. In recent years, hispa has been a perpetual problem in Bangladesh, infesting several thousand hectares annually and causing affected areas to suffer a significant yield loss. The insect also attacks sugarcane and some wild grasses.

Control methods

Cultural control

Close plant spacing results in greater leaf densities that can tolerate higher hispa numbers. Bunds and vicinities should be kept free from grassy weeds on which these beetles can maintain their population. Stubble should be uprooted after harvest to avoid ratooning. In some countries, leaf tips are clipped off before transplanting to eliminate early stages of the pest. Excess N application should be avoided. Planting early at the beginning of the monsoon allows a field to escape hispa buildup. Handpicking damaged leaves removes larvae from the field and prevents hispa buildup. Damaged leaves can be removed up until booting.

Biological control

The role of natural enemies in controlling hispa has not been fully assessed. However, several braconid wasps such as *Bracon hispae* (Viereck), *Bracon* sp., *Campyloneurus* sp., and *Macrocentrus* sp. are known to parasitize the larvae. Likewise, the ichneumonid wasp *Isotima* sp. and two unidentified species of eulophid are also larval parasites. Pupal parasites include three pteromalid species: *Eupteromalus* sp., *Trichomalopsis apanteloctena* (Crawford), and *Serotenus* sp. An unidentified *trichogrammatid* species parasitizes the eggs of this pest. A reduviid *Rkinocoris fuscipes* (Fabricius) is a recorded predator of hispa adults.

Varietal resistance

At present there are no varieties with proven resistance to hispa, but OR165-94-1 and KAU1945 have been reported as moderately resistant. Indications are that some cultivars such as MTU6637, RNR1446, IET26889, Norin B, IR579, and Manoharsali are less preferred than others.

Chemical control

Chemicals play an important role in rice hispa control. Adults are more exposed and susceptible to insecticide than are the larvae, which are protected in leaf mines. Sprays and dusts are more effective than granular formulations. Systemic insecticides give longer residual protection and are more effective against larvae than are nonsystemic chemicals.

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Rice water weevil

The rice water weevil *Lissorhoptrus oryzophilus* Kuschel, which was originally distributed in the Mississippi River basin in the USA, is now one of the most destructive rice pests in Japan. The weevil was recorded for the first time in 1959 in California. Only females were found and the weevil reproduced parthenogenetically. The pest was found in Cuba and the Dominican Republic in 1972. The Dominican Republic strain also consists only of parthenogenic females.

In Japan, the weevil was first recorded in 1976 in Aichi Prefecture. Only parthenogenic females with triploid chromosomes are found. They are probably derived from the California population. The Nayoga Plant Quarantine Station suggests that the insect arrived in Japan with hay imported from the USA. By the end of the year, the insect was confirmed to have occurred in 730 ha of ricefields in three cities and two towns in the Prefecture.

Since 1976 the rice water weevil rapidly spread. By the end of 1986, more than 1 million ha, or 46% of the total ricefields in Japan were infested. The insect is now regarded as the number one pest of rice in Japan and the most difficult one to control.

Life history

The adult weevil is about 3 mm long and is greyish brown 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 plant parts, but oviposit on submerged plant parts. Cylindrical, pearly white eggs, about 0.8 mm long, are individually inserted 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. Under field conditions, the eggs hatch in an average of 8 d. 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 remain there to feed. There are four larval instars, and it takes 30-40 d for the larvae to reach adulthood. The larger third-instar larvae feed externally among the roots and sometimes up into the crown. Several larvae are often found in the roots of a single plant. The larvae can migrate up to 15 cm through the soil to other roots. Pupation occurs in a cocoon attached to the roots. The pupa is white and of the same size as the adult weevil.

Seasonal occurrence and abundance

The adult weevil overwinters in Spanish moss, rice stubble, or fine matted grass and becomes active again as the weather warms up from March to June. The survival rate of the overwintering adults is high in favorable hibernating sites such as groves, but low in dry leaves. Overwintering adults can survive even under deep snow and at very low temperature. In Japan, 60% of the adults survive until April under −18.6 °C (minimum) air temperature and −6 °C (minimum) soil temperature. Laboratory experiments on overwintering adults exposed to various low temperatures for 3 mo showed that the critical minimum temperature ranges from −5 to −10 °C. The supercooling point of overwintering adults under wet conditions is from −6.2 to −17.6 °C. The adults move into the fields with young rice plants 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. Oviposition usually occurs after the field is irrigated. Newly emerged adults usually fly at night to adjacent fields of younger rice.

Larval population density varies considerably with time of transplanting and with time when rice is first flooded. When rice seedlings are transplanted in mid-May in Japan, adult females are most abundant and yield loss is highest. In the USA, ricefields flooded very early or late are less infested than those flooded in between. In addition, young rice plants are more heavily infested than older plants. Larval, pupal, and adult populations are generally higher in fields with standing water throughout the cropping season than in fields flooded 1 mo after transplanting.

Damage

Adults feed on leaves of young rice plants. The resulting longitudinal strips on the leaf surface usually are not 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 producing loss of vigor, lodging, and reduced yields. The most important factor for yield loss is the decrease in number of tillers and panicles.

Control methods

Cultural control

Intermittent draining and flooding of ricefields at 15-d intervals considerably reduce the damage caused by rice water weevil. However, this procedure is prohibitive in many areas because of limited water supply and loss of fertilizers. In Japan, transplanting rice seedlings early in April significantly reduces yield loss. Damage can also be reduced by transplanting mature or middle-age seedlings. Plots receiving greater amounts of fertilizers are more severely infested. Removal of aquatic grasses, which are alternate hosts, reduces the pest population.

Biological control

An undescribed mermithid almost exclusively parasitized female weevils in the USA. Several bird species and frogs are known to ingest the weevils. Tettigoniid grasshoppers such as *Conocephalus fasciatus* (De Geer), *Neoconocephalus triops* (Linnaeus), and *Orchelimum agile* (De Geer) prey upon adult weevils. The fungus *Beauveria bassiana* (Balsamo) Vuillemin is known to infect the rice water weevil in Japan.

Varietal resistance

High levels of resistance to rice water weevil are not found in any rice genotype. Several rice varieties with moderate or low levels of resistance are known. Varieties with moderate levels of resistance are Ae Guk Ai Koku, Iljin, and Mit Dari from the Republic of Korea; Toyokuni and Mogami mochi from Japan; IR269-1-1-3, IR404-1-3-1-1, IR404-3-2-7, IR404-6-3-10-1, and IR455-5-5-1-2 from the Philippines; and CI 9903 and CI 8900 from the USA.

Chemical control

Granular insecticides applied at the proper time control the rice water weevil.

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Rice thrips

Thrips have been recorded as pests of rice from most of the rice-growing countries of the world in all rice environments. The two most common species associated with rice are *Stenchaetothrips (=Baliothrips, =Thrips) biformis* (Bagnall) (Thripidae) and *Haplothrips aculeatus* (Fabricius) (Phlaeothripidae). In Bangladesh, China, India, Indonesia, Japan, and Sri Lanka, *S. biformis* is now considered a major rice pest. It attacks rice seedlings in nurseries as well as small, newly transplanted plants. Unlike other thrips, it apparently does not attack more mature plants and is not found in the panicles.

S. biformis is also known as rice leaf thrip, paddy thrip, or oriental rice thrip. The first specimens were collected in 1913 in Oxford, England, from sedge stacks, accumulations of plant materials consisting mainly of *Phragmites* and *Phalaris,* removed from water courses. The species is one of the very few thrips that live only on plants growing in water. The abundance, host plant preference, and distribution of other thrip species associated with rice are given in Table 7.

Table 7. Common thrips pests of rice.

Species	Abundance	Host plant	Distribution
Haplothrips aculeatus (Fabricius)	Very common	Polyphagous: grasses, cereals, many kinds of flowers	Taiwan and northeastern China, India, Indonesia, Japan, Republic of Korea, Philippines, USA, northern USSR, Thailand, Africa, Europe
Stenchaetothrips biformis (Bagnall)	Very common	Primarily rice, maize, sugarcane; other graminaceous crops and weeds	Bangladesh, Cambodia, India, Indonesia, Japan, Malaysia, Myanmar, Philippines, Sri Lanka, Thailand, Vietnam
Anaphothrips obscurus (Muller)	Less common	Tobacco, rice, other graminaceous plants	Japan, Europe
Chirothrips manicatus (Haliday)	Less common	Polyphagous: oat, barley, wheat	Japan, USSR, Europe, North America
Frankliniella intonsa (Trybom)	Less common	Clover, alfalfa, flowers of graminaceous and other plants	Taiwan, China; Japan; Europe
Frankliniella tenuicornis (Uzel)	Less common	Flowers of graminaceous plants, e.g, wheat and rye	Germany, England, Finland, Japan, Scandinavia, Sweden
Aelothrips fasciatus[a] (Linnaeus)	Less common	Polyphagous	Northeastern China, India, Japan, Republic of Korea, USA, northern USSR, Europe

[a]Status as a rice pest doubtful; the species has been recorded to feed on other thrips, aphids, mites, and various other small insects.

Life history

S. biformis is a minute, fragile-looking insect, usually 1-2 mm long, with well-pronounced five- to eight-segmented antennae (Fig. 16a). The adults can be winged or wingless. Both pairs of wings are elongated, narrow, and fringed with long hairs. It is this latter character that gives the order the name thrips. These hairs arise from sockets, except in the family Phlaeothripidae (such as *H. aculeatus),* as extensions of the wing membrane. Parthenogenetic reproduction, with haplodiploidy process of sex determination, is common in thrips.

Thrips have a relatively short life cycle and can multiply rapidly. The life history of each species features an egg, two active larval instars that feed, followed by two or three (as in the case of Phlaeothripidae) relatively inactive pupal instars that probably do not feed, and adult. Adults are found inside rolled leaves on the upper parts of the plant.

Female thrips lay an average of 93 and a maximum of 147 eggs at 25 °C. The eggs of *S. biformis* are tiny, usually 0.25 mm long by 0.1 mm wide, and pale yellow. They are laid singly in slits cut in the leaf blade tissue by the saw-like ovipositors of the female. The upper half of the egg is exposed on the leaf surface. The incubation period is about 3 d. The optimum temperature for incubation is 25 to 30 °C, and for nymphs, 26.5 °C.

The freshly hatched larvae are colorless but turn pale yellow in the second instar. First- and second-instar larvae feed actively on the soft tissue of the unopened young leaves or within leaves rolled by thrip adults. The entire larval, prepupal, and pupal periods are completed at these sites. Most of the time, mobile adults are also found hidden within the rolled leaves; in some instances both nymphs and adults may be found feeding on the outer surfaces of these areas. The duration of the various life stages is greatly influenced by existing environmental conditions, especially temperature. Duration from the newly hatched nymph to the adult was 9 d at 23.3 ºC and 4 d at 36 ºC.

Seasonal occurrence and abundance

Despite their small size and fragile appearance, thrips can travel long distances. They migrate during the day and seek out newly planted ricefields. They are day-flying insects and are not attracted to light traps. In areas of cool winters, *S. biformis* adults migrate to graminaceous weeds after the flowering of rice and hibernate. They become active again in spring and multiply on these weeds or on other graminaceous crops such as wheat, barley, and oats. From these crops they move to rice nurseries or transplanted fields. Infestation in the nursery is frequently carried over to transplanted fields. Occasionally, overwintering *H. aculeatus* adults have been found in stored unhulled rice. With multirice cropping in the tropics, thrips have been reported to be more abundant in ricefields from July to September and in January. These periods coincide with the seedling stage of the rice crop.

Both *S. biformis* and *H. aculeutus* have been recorded throughout crop growth but are more abundant during the seedling and flowering stages. Thrips are frequently reported as more serious during dry periods; this could be due to a reduced tolerance of rice plants under drought stress.

In India, thrips infestation is generally recorded during the first week of August, with peak infestation during the second and third weeks. The population declines in early September and disappears by mid-September.

Damage

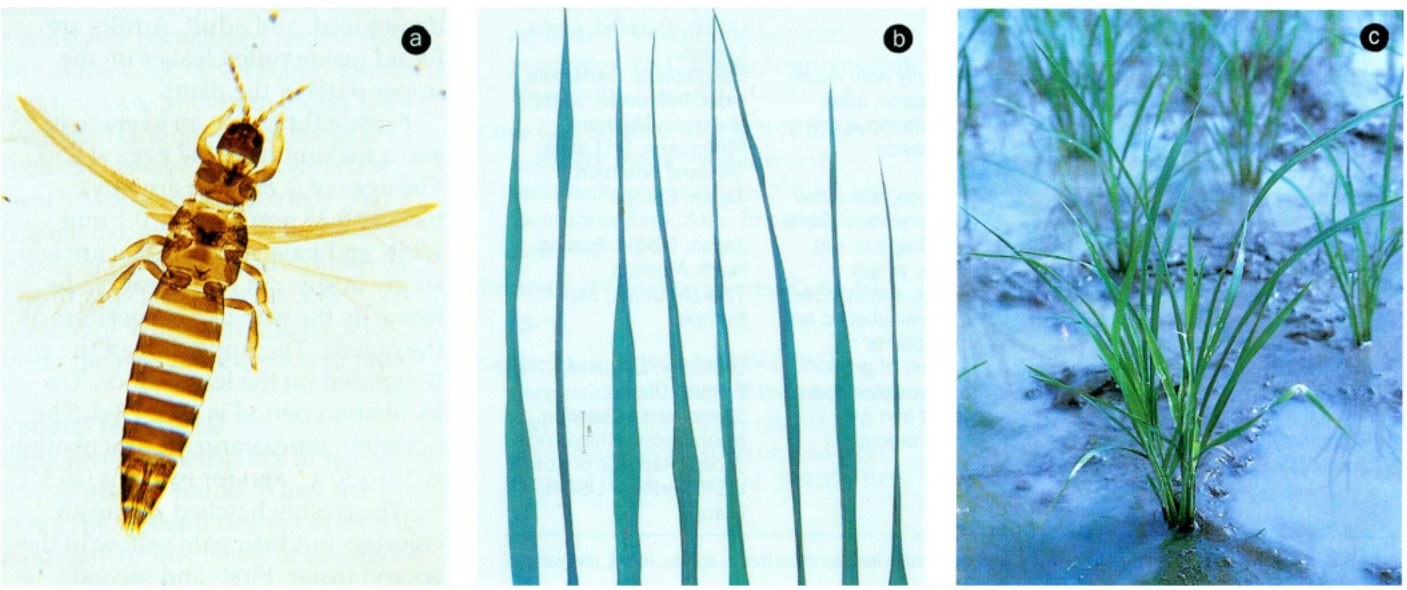
Larvae and adults have rasping type mouthparts and only one mandible, the left one. Leaf-feeding thrips species exhibit a punch-and-suck feeding technique: the single mandible punches a hole in the plant surface through which the paired maxillary stylets are then inserted to imbibe the plant sap. Typical symptoms of thrip damage include inward rolling of the leaves along the margins, wilting, and stunting (Fig. 16b). There are also fine, yellowish or silvery streaks developing from the margin to the midrib. In severe infestation, seedlings may die resulting in a low number of plants per unit area (Fig. 16c). The damage is most evident if there is no standing water in the ricefields.

Control methods

Cultural control

Flooding the field to submerge plants for 2 d effectively controls thrips.

16. Rice thrips: *a)* adult, *b)* damaged leaf, *c)* damaged plants in a field.



Varietal resistance

Several rice varieties and wild rices with resistance to thrips have been identified. Among the rice varieties are IR62, IET1444, and traditional varieties Ptb 21 and Ptb 33 from India. Wild rices with resistance to thrips include *Oryza eichingeri, O. glaberrima, O. minuta, O. nivara, O. officinalis, O. perennis, O. rufipogon,* and *O. sativa f. spontanea.* No resistant varieties are commercially available.

Biological control

The role of natural enemies against thrips has not been determined.

Chemical control

Insecticides in the form of dusts, systemic granules, or sprays control population buildup of the pest.

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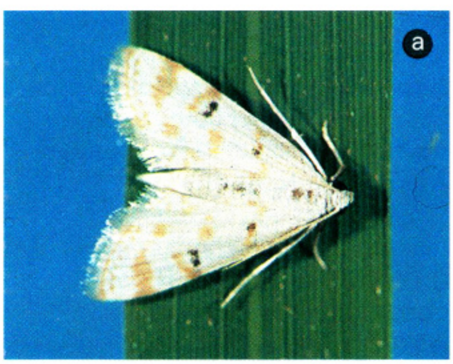
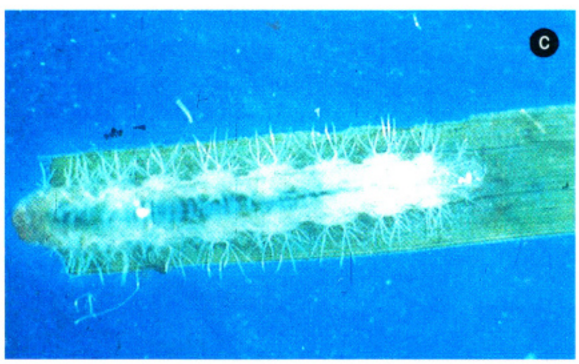
Rice caseworm

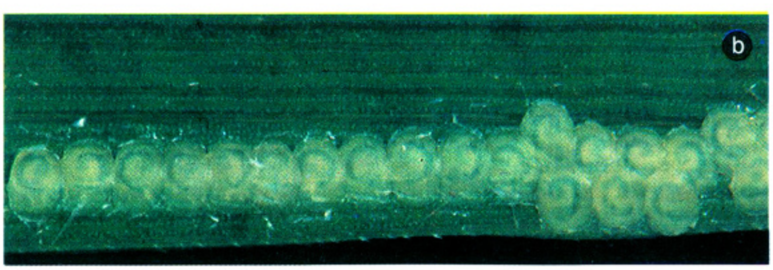
The rice caseworm *Nymphula depunctalis* (Guenée) (Pyralidae-Lepidoptera) is an important insect pest of rice. It occurs in Australia, many tropical countries (India, Indonesia, Malaysia, Philippines, Sri Lanka), and in Africa, and South America. *N. depunctalis* was previously known as *N. stagnalis* (Zeller) 1852, *Hydrocampa depunctalis* (Guenee) 1854, and *Zebronia decussalis* (Walker) 1954. Among related species are *Nymphula vittalis* Bremer and *Nymphula fengwhanalis* (Pryer), which occur in China; *Paraponyx (=Nymphula) fluctuosalis* Zeller, which occurs in some African countries and in Australia, China, India, Japan, Malaysia, Philippines, Sri Lanka, and Thailand; and *P. diminutalis* (Snellen), which occurs in China, India, Indonesia, Japan, Philippines, Sri Lanka, and Thailand. *N. depunctalis* occurs regularly in low populations, except for some occasional buildup in small areas where it may severely defoliate the plants. Its common name, caseworm, refers to the larval habit of forming the leaves of rice plants or grasses into tubes or cases and enclosing itself within them during feeding. The leaf cases protect the larvae from natural enemies and act as floats to carry the larvae from one plant to another. Rice at the seedling and vegetative stages is its preferred host. It also infests millet and various grasses such as *Panicum, Eragrostis,* and *Paspalurn.*

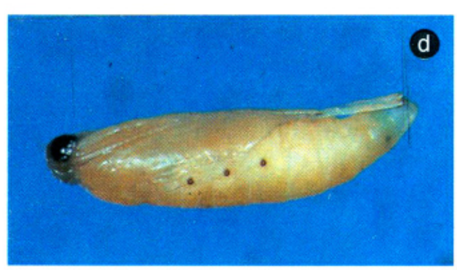
Life history

The adult moths are snowy white, about 6 mm long, and have a wing expanse of about 15 mm. The white wings are marked with a few light brown to black specks and two or three submarginal fulvous bands (Fig. 17a). The adults are nocturnal, hiding in ricefields during the day and laying eggs at night. Females oviposit an average of 2.5 d after emergence, usually starting within 1-4 d. Eggs, 10-20 in a batch, are laid in one or two adjacent rows on the undersides of leaves floating on water (Fig. 1%). A single female lays an average of about 50 eggs in her lifetime. Mated females die 1 d after









17. Rice caseworm *Nymphula depunctalis:* *a)* adult, *b)* eggs, *c)* larva, *d)* pupa·

oviposition; unmated females can live up to 1 wk. The egg is light yellow, circular, about 0.5 mm in diameter, and somewhat flattened with a smooth surface. Before it hatches, the egg turns darker with two purplish dots, which represent the eyes of the developing larva. Average incubation period is 4 d.

The freshly hatched larva is pale cream, about 1.2 mm long and 0.2 mm across the head. The head is light yellow. The second instar larva is somewhat greenish. Five larval instars are completed in an average of 20 d. The full-grown larva is about 14 mm long and 1.6 mm in diameter. It is pale green with a semitransparent skin and light brown prothoracic shield and head. A characteristic feature that becomes visible only at the start of the second instar is six rows of gills with tubes connected to the main trachea (Fig. 17c). The five pairs of spiracles on the larva's body are considered nonfunctional and the larva breathes through its gills. During the day, larvae float on the water; at night they climb plants to cut off leaves to make new cases, or feed on severed leaves on the water surface. In making a case, the larva moves to the tip of a young leaf, cuts the leaf blade on one side of the midrib, then secretes a silken thread to bind the two margins of the leaf blade into a tubular structure. The larva detaches this tube from the leaf by severing the other part of the leaf blade. The larva replaces these leaf casings with new ones after each molt and undergoes pupation within the leaf case.

The pupa, about 5.5 mm long and 1.5 mm wide, is cream colored when freshly formed, but turns silvery white toward moth emergence (Fig. 17d). The pupal period lasts for about 1 wk. The adult usually emerges during the night through an opening at the upper end of the case. The life cycle is completed in 1 mo.

Seasonal occurrence and abundance

The caseworm occurs only in ricefields with standing water. It is found in irrigated and rainfed lowland environments and is more prevalent in the rainy season. The pest is usually abundant July to November, when it infests rice plants and other grasses in the ricefields. After November, it migrates to grassy areas. No hibernation is recorded in the Philippines and the insect occurs in overlapping generations. Irrigation, which ensures prolonged standing water in the vegetative stage, increases the pest's abundance.

Damage

Larvae begin to feed shortly after hatching and start making leaf cases 2 d later. The freshly hatched larvae feed on the surface of the tender leaves, but later instars feed from within the case or on the surface of even the older leaves. Damage is caused by larvae feeding and cutting off the leaf tips for making leaf cases.

Damage is characterized by ladder-like appearance of the removed leaf tissue, leaving the upper epidermis somewhat papery. Damaged plants occur in patches in the field. Heavily infested plants may still recover in 1 mo, but are already stunted. They produce fewer tillers and smaller panicles, and maturity is delayed. Yield loss occurs if, during the first 30 d after transplanting, other pests such as whorl maggot or stem borer infest the crop, reducing the plants' ability to recover.

Control methods

Cultural control

Cultural methods involving water management are effective in controlling the rice caseworm larvae. A nonflooded seedbed is protected from caseworm attack. Draining the field for at least 3 d will kill most of the larvae because they are highly dependent on water for oxygen. However, this practice favors weed growth. Transplanting older seedlings may also help in limiting the period of caseworm larvae attack.

Biological control

Trichogramma minutum Ashmead is reported as a parasite of caseworm eggs. While foraging for algae, snails such as Pila sp. and *Radix* sp. (Lymnaeidae) may dislodge caseworm eggs from rice leaves. A braconid wasp *Dacnusa* sp. and a tabanid fly Tabanus sp. parasitize the caseworm larvae. The larvae of hydrophilids [e.g., *Hydrophilus affinis* (Sharp), *Sternolophus rufipes* (Fabricius), and *Berosus* sp.] are reported predators of the caseworm larvae, as are dytiscids *Laccophilus difficilis* (Sharp) and Cybister tripunctatus orientalis Gschwendther. The common red ants *Solenopsis geminata* (Fabricius) attack the larvae and pupae of the pest, especially when the infested ricefields become dry. Several spiders prey on the moth. They include three species of Araneidae—*Neoscona theisi* (Walckenaer), Argiope catenulata (Doleschall), and Araneus inustus (L. Koch); one species of Oxyopidae—*Oxyopes javanus* (Thorell); one species of Lycosidae Pardosa pseudoannulata (Boesenberg and Strand); one species of Tetragnathidae—*Tetragnatha nitens* (Audouin); and one species of Clubionidae—*Clubiona japonicola* Boesenberg and Strand.

Varietal resistance

No varieties resistant to the pest have been identified. Results of varietal screening done in Africa and India, however, revealed several promising varieties: ARC6626, ARC10651, ARC10696, BKN6323, Brengut, BW78, CO 28, Laki 396, and ROK2.

Chemical control

Rice caseworm larvae are highly sensitive to insecticidal treatment. They are readily controlled with foliar sprays or the application of granules in the floodwater. Insecticide application through foliar sprays should be carried out not later than 1 wk after transplanting.

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Rice mealybugs

Mealybugs are plant-sucking, relatively immobile insects belonging to the family Pseudococcidae. They secrete white filaments of wax to cover themselves. They are widely distributed throughout the world and are considered economically important pests of a variety of host plants that include horticultural crops. Among them are coffee, cacao, and citrus; root and tuber crops such as cassava, potato, and yam; and cereals such as sorghum and rice. Mealybugs are stem, leaf, or root feeders. More than half of the mealybug species feed on rice roots. *Brevennia (=Heterococcus,=Ripersia)rehi (=oryzae)* (Lindinger) is the main foliar feeder found in Asia. *B. rehi* occasionally causes heavy losses to rice crops in Bangladesh, India, and Thailand. The mealybug is found primarily in the rainfed rice environment and is not prevalent in irrigated rice. Well-drained soils help mealybugs survive underground. Recently, the sugarcane mealybug *Pseudococcus saccharicola* Takahashi has begun to attack upland and lowland irrigated rice (Fig. 18). High density (>100 mealybugs/hill) caused plants to wilt and die.

18. Rice mealybug *Pseudococcus saccharicola.*

Life history

Adult females of *B. rehi* are wingless, elongate-oval or broadly ovate, pinkish, and soft-bodied with a distinct waxy or powdery coating. The males are smaller and yellowish white, have a single pair of wings and a waxy style-like process at the end of the abdomen, but lack mouthparts. Reproduction is parthenogenetic and the females are extremely prolific, laying eggs and depositing nymphs simultaneously. A single female usually lays a total of 60-280 eggs and nymphs during its 2-wk lifetime. Mature females can survive for long periods without food and still lay eggs.

The eggs are yellowish white, about 0.3 mm long, and are laid in chains. The incubation period is 3-6 h. The nymphs are white, turning to pale yellow and later to pale pink. They are about 0.4 mm long. The eggs and nymphs are protected by waxy threads spun by the females. At first, the nymphs stay under the body of the female for about 2 d; later, at crawling stage, they move to the upper parts of the plant or are dispersed in the wind.

The nymphs establish themselves in groups, in virtually immobile positions between the leaf sheath and the stem where they feed. They complete three nymphal stages, which last for about 15 d. The adult females remain stationary and feed at the sites of nymphal development. The winged adult males do not feed but fly off. The insect completes its life cycle in 17-37 d. The biology of *P. saccharicola* is similar to that of *B. rehi.* However, no male was obtained from mass rearing despite the 13 generations of females in 1 yr at IRRI.

Seasonal occurrence and abundance

In the Philippines, the pest occurs in high numbers during the rainy season from the end of April to early July. During this period, it completes two generations. Dry spells result in a large population buildup, and damage to drought-stressed plants can be high.

Damage

Nymphs and adult females infesting the leaf sheath damage the plant by sucking sap from the rice stem. That results in smaller leaves, yellowing, abnormal tillering, and stunted plants. Under heavy infestation, either no panicles are formed or they do not fully exsert from the boot; the plants may even dry off. The damage is in patches since the young nymphs have rather limited migrating ability. Likewise, mealybug numbers vary greatly between hills. This causes the field to have several spots of depressed growth, which are known by various names such as chakdhora, soorai disease, etc. Damage is intense during drought conditions when rice plants can least tolerate sap loss.

Control methods

Cultural control

Cultural control measures include timing of planting dates to escape peak infestation, continuous flooding of the field at 5-cm depth throughout the crop growth period, and removal and destruction of infested plants at the first sign of mealybug damage.

Biological control

Lady beetles such as *Coccinella repanda* Thunberg, *Menochilus sexmaculatus* Fabricius, and *Harmonia octomaculata* (Fabricius) are the main natural enemies of the mealybug. Hymenopterous parasites of *B. rehi* recorded from India include Ceraphronidae *(Cerapkron* sp.), Encyrtidae *(Adelencyrtus* sp., *Cheiloneurus* sp., *Doliphocerus* sp., *Gyranusa* sp., *Mayeridia* sp., *Parasyrphophagus* sp., and *Xanthoencyrtus* sp.), Eulophidae *(Aprostocetus* sp., *Chrysocharis* sp., *Desostenus* sp., and *Tetrastichus* sp.), Mymaridae *(Lymaemon* sp.), Pteromalidae *(Callitula* sp. and *Diparini* sp.), and Thysanidae *(Thysanus* sp.). Recorded dipterous predators of B. rehi are two chloropids *[Anatrichus pygrnaeus* Lamb and *Mepachymerus ensifer* (Thompson)] and one drosophilid *[Gitona perspicax* (Knab)].

Varietal resistance

No varieties resistant to *B. rehi* are commercially available.

Chemical control

The waxy secretion covering the mealybugs and their habit of living behind leaf sheaths protect them from insecticide. Foliar sprays are effective, however, if the nozzle is directed to the bases of plants. Granular insecticides are effective in fields with standing water. If damaged fields have no standing water, broadcasting granules is impractical.

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Whorl maggots

Whorl maggots constitute a complex of several species belonging to the genus *Hydrellia* in the family Ephydridae and order Diptera. All members of the genus are stem or leaf miners. They prefer an aquatic habitat, usually living near water or in damp areas. Rice whorl maggots are difficult to identify because they resemble other flies in the field such as *Psilopa* and *Paralimna* whose larvae feed on rice, and *Notiphila* spp. that live on decomposing organic matter in ricefields (Fig. 19a, b). Three important species of *Hydrellia* are known to infest rice plants.

Rice whorl maggot

The rice whorl maggot *Hydrellia philippina* Ferino was first recorded as a serious pest of rice in the Philippines in 1962. The insect is semi-aquatic and attacks only rice plants, particularly those in irrigated fields. It is usually observed at the vegetative stage of the rice plant, feeding on the central whorl leaf. Its common name, rice whorl maggot, reflects its feeding habit.

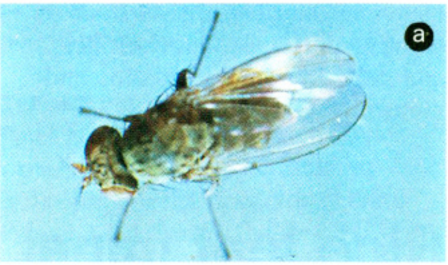
Life history

The adults are dull grey. The females are 1.5-3.0 mm long, but the males are slightly smaller. Adults prefer places with abundant calm water and lush vegetation. During the early and later parts of the day, they float on the water or perch on floating vegetation. During midday, they are sedentary, clinging on upright vegetation. The average egg-laying capacity is 20 eggs/female. The egg-laying period lasts for 1-8 d.

The eggs are laid singly on either surface of the leaves. They are cylindrical, whitish, and are 0.65-0.85 mm long and 0.15-0.20 mm wide. When freshly laid, the entire egg yolk mass is opaque, but later the anterior half shows the black cephalopharyngeal skeleton of the developing embryo. The incubation period is 2-6 d.

The freshly hatched larvae are transparent to light cream colored, but turn yellowish after they start feeding. The hatching maggots migrate to the unopened central leaves where the entire larval period is completed. The full-grown larva is cylindrical with the posterior end tapering to a pair of pointed spiracles. It is about 4.4-6.4 mm long and 0.5- 0.7 mm wide. Under low magnification, the heavily sclerotized mouth hook and cephalopharyngeal skeleton can be easily identified. The larval period lasts for 10-12 d.

The full-grown maggots pupate outside the feeding stalk. The puparium is 4.8 mm long on the average. It is light to dark brown, ovoid, subcylindrical, with the posterior end tapering gradually to the last segment, which bears two terminal respiratory spines. The pupal period lasts for 5-10 d. The egg-to-adult period is normally 25-28 d.



19. Rice whorl maggot: *a) Hydrellia* philippina adult, *b) Notiphila* sp. adult.

Seasonal occurrence and abundance

In the Philippines, the pest occurs on rice throughout the year, but is most prevalent from September to November. The pest completes about 13-17 overlapping generations in 1 yr.

The rice whorl maggot is abundant during the early stages of crop growth, but generally ceases to be a problem after the plants reach the booting stage. This is probably due to the lack of suitable habitat for the maggots, which feed on the central whorl leaf. No infestation after panicle emergence has been recorded.

Damage

The fly maggots feed on the inner margins of unfurled leaves. The newly hatched larvae migrate to the central whorl and feed on the mesophyll tissue.

Damage is characterized by small, chewed-up, discolored areas on the innermost margin of the central whorl. These areas eventually dry up and damaged leaves usually droop. Heavy infestation causes a marked stunting of the plant, fewer tillers, and delayed panicle initiation and maturity.

Rice leaf miner

Hydrellia griseola (Fallén) is not a true whorl maggot but a leaf miner. It is an important pest in California, USA, and northern Japan. It has also been recorded in northern USA, Europe (France, Italy, and Germany), and South America. This species is primarily a pest of rice, but is also known to infest barley, oat, timothy, and wheat, in addition to aquatic plants. It is also referred to by various common names such as rice leaf miner, smaller rice leaf miner, gray barley fly, and gray mining fly.

Life history

The adult fly, about 2 mm long and 0.7-0.8 mm wide, is light grey and looks like a small housefly. It usually lives for 3-4 mo and prefers high-moisture areas. The flies are hydrofuge, i.e., they can float on the water surface if submerged and also walk on the water surface. It has been recorded feeding on dead organisms.

The adults are positively phototropic. They exhibit optimum activity at 11-31 °C, and are fairly tolerant of cold weather (showing some activity even at –2 °C), but suffer thermal mortality above 40 °C. Mating starts 3 d after emergence, and within the temperature range of 13-37 °C, emergence and mating occur at any hour of the day. Both males and females multimate. The preoviposition period is about 5 d. Optimum temperature for oviposition is 10-32 °C when a single female lays about 50-100 eggs. High winds and abundant algal growth cause several of the lower leaves to remain on the water surface; these leaves are preferred for oviposition and are suitable for larval growth. Eggs are laid singly on the leaves, but a single leaf may contain several eggs. Oviposition usually occurs on horizontal leaves near the water surface, but with dense foliage and high RH, eggs have been recorded at 15-20 cm above water level. The eggs hatch between 6 and 32 °C and above 50% RH; hatching is highest at 98% RH. The average incubation period of about 5 d between 21 and 32 °C is considerably prolonged at higher temperature.

The freshly hatched larvae are tiny, usually 0.10-0.17 mm wide and 0.33-1.13 mm long, and nearly transparent to light cream colored. They have well-developed mouth hooks, which they use to mine inside the leaf tissue. The larvae start mining soon after hatching, either with their caudal segments still within the egg shell or after a short migration from the oviposition sites. Mining usually lasts for 2-3 h. Under limited food supply, crowding, or submergence of the affected leaves, the larvae may leave the mines and migrate to newer leaves. They can crawl on a submerged surface; later instar larvae usually take 0.5-1.5 h to bore into the leaves. The maggots undergo three larval instars. The total larval period is 7-10 d at 21-32 °C, but is considerably prolonged at lower temperature. The entire larval and pupal periods are completed within the mines.

Pupation occurs either within the original mines or, more frequently, the full-grown larvae form a new mine for pupation. The pupae are visible within the translucent mines. Pupae from soils have also been recorded.

Seasonal occurrence and abundance

In California, the adult flies occur throughout the year, but their population is usually highest from March to June. No oviposition has been recorded from November to February. The pest occurs in 11 generations, and beyond the first generation the broods usually overlap. In northern Japan, eight generations have been recorded. The first generation occurs in the second half of April. Adults of the second generation oviposit on rice leaves in May. The flies overwinter in the pupal stage.

Optimum temperature, adequate humidity, and availability of host plants regulate fly populations. Temperatures below 0 °C for a short duration cause no harm. The insect's activity increases from the beginning of spring because of warmer temperature and availability of standing water.

Low temperatures in the preceding summer provide favorable conditions for insect survival and multiplication, and result in an increased fly population in the fall. Higher temperatures than usual during winter, accompanied by an early thaw, cause low mortality of the overwintering population. These conditions, augmented by synchronism of the oviposition period with transplanting, deep water in the fields, and slow growth of the plants because of low temperature, increase the damage. A combination of these factors resulted in a severe outbreak of the fly in northern Japan in 1954.

Damage

The hatching larvae usually mine the leaf blade directly from the egg shell or after a short migration. The entire larval stage is passed within the leaf blade where the larvae feed on the mesophyll tissue. The early mine is 0.1- 0.2 mm wide and is usually linear, appearing as a whitish streak when viewed by reflected light. The mine extends in a linear fashion for about half the larval life and gradually widens as the maggot becomes larger. Toward the later part of development, the mine may take on a blotch-like appearance as the larva moves up and down the sides and excavates an increasing amount of tissue. The full-grown larvae consume all mesophyll tissue in the mine, leaving only the upper and lower epidermal cells. Occasionally, the larvae also infest leaf sheaths and stems. They prefer leaves near the water surface.

Damage from the pest is similar to that caused by another agromyzid fly, *Pseudonapomyza asiatica* Spencer. The damaged leaves shrivel and lie prostrate on the water surface. Such conditions, particularly during seedling stage, significantly reduce rice yields. A 10-20% loss of the total rice crop was reported in California in 1953 when pest incidence was serious. In 1954, a severe infestation and heavy damage by this pest was recorded in northern Japan.

Paddy stem maggot

The paddy stem maggot *Hydrellia sasakii* Yuasa and Isitani occasionally causes economic losses to the late-planted rice crop in Japan. It occurs throughout Japan, but its distribution in other countries has not been studied. Besides rice, *Leptochloa chinensis* Ness, *Leersia sayanuka* Ohwi, and *Leersia japonica* Makino have also been infested.

Life history

The females start ovipositing in ricefields shortly after transplanting. The eggs, laid individually on either side of the leaf surface, hatch in 2 d on the average. The freshly hatched larvae migrate to the central whorl of the plant and feed on the unopened leaves or, occasionally, on the developing grains in the boot. The larvae become full grown in an average 2-3 wk and pupate between the leaf sheath and the stem. The average pupation period is 5-8 d during summer and fall, but about 17 d during spring.

Seasonal occurrence and abundance

In southwestern Japan, the insect produces five generations in a year from late April to early November. It is most numerous in the third and fourth generations, and ricefields transplanted during late July to early August are heavily infested.

During winter, the insect hibernates in the larval stage on *Leersia sayanuka* and other graminaceous weeds. The adults are fairly tolerant of wide temperature variations and exhibit normal activity at 18-39 °C.

Damage

The paddy stem maggot is primarily a pest of the rice plant and is usually abundant in ricefields only up to 30 d after transplanting (DT). Maggots feeding on the leaf blades cause the damage. Freshly hatched maggots usually feed on the unopened young leaves. Feeding by young larvae results in small spotted and striped marks all over the laminae. The older larvae enter the central whorl to feed on the inner margins of the unopened leaves, causing large marginal spots on the leaves. Larvae also occasionally infest panicles in the booting stage and damage the developing grains. Heavy infestations result in stunting of the crop, nonuniform maturity of rice plants, and reduced grain yield.

Control methods

Control measures for all whorl maggots are similar.

Cultural control

Since adults are attracted to standing water, recommended cultural control is draining of the ricefields at intervals of 3-4 d during the first 30 DT to reduce egg laying. Drained fields, however, allow more weeds to grow.

Crop establishment methods that enable the plants to cover the water surface most rapidly result in insignificant damage from whorl maggot. Covering the water surface with azolla helps to prevent infestation. Direct seeding is advisable since direct-seeded fields or seedbeds are not highly attractive to adults. When transplanting, it is better to use older seedlings to shorten the vegetative stage of the crop.

Biological control

Exposed eggs on leaves are parasitized by *Trichogramma* sp. wasps and preyed upon by *Dolichopus* sp. flies. *Metioche vittaticollis* Stål also preys on the eggs of *N. philippina.* Eulophids (e.g., *Tetrastickus* sp.) and braconids (e.g., *Opius* sp.) parasitize whorl maggot larvae. The braconid *Chaenusa conjugens* (Nees) parasitizes *H. griseola* larvae. Adult whorl maggots are preyed upon by ephydrid flies *Ochthera brevitibialis* de Meijere. Spiders that prey upon adults include oxyopid *Oxyopes javanus* (Thorell), lycosid *Pardosa pseudoannulata*

(Boesenberg and Strand), and araneid *Neoscona theisi* (Walckenaer). Fungus of the genus *Entomophthora* is also recorded as parasite of whorl maggot.

Varietal resistance

Only one rice cultivar (IR40) and two wild rices (*Oryza brachyantha* and *O. ridleyi*) have been identified as resistant to whorl maggots.

Chemical control

Broadcasting of nonsystemic granules on standing water in the field, or soil incorporation of systemic granules during the last harrowing before transplanting is usually more effective than foliar sprays. Foliar sprays can, however, be applied 1 or 2 wk after transplanting.

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Ladybird beetle

The ladybird beetles (Coleoptera: Coccinellidae) are brightly colored, small, oval, convex insects, and comprise about 5,000 species. The greater number of these species are predaceous, both as larvae and adults, and feed on a wide variety of soft-bodied insects such as leafhoppers, planthoppers, mealybugs, and aphids, and on the eggs of various insects. A comparatively small number of species are of economic significance as plant pests. Most predaceous species can be broadly distinguished by their mandibles, which have simple or bifid apices, each with a basal tooth, lacking in most phytophagous species. In phytophagous insects, the apices of the mandibles are multidentate.

Some ladybird beetles recorded as feeding on rice plants are listed in Table 8. The most common and widely distributed are *Micraspis discolor* (Fabricius) and *M. crocea* (Mulsant).

Table 8. Ladybird beetles recorded feeding on rice.

Name	Feeding on	Distribution
Coccinella repanda (Thunberg) [= *Coccinella transversalis* Fabricius]	Rice pollen, panicle	Australia; Bangladesh; Bhutan; Taiwan, China; India; Melanesia, Micronesia; Nepal; New Zealand; Sri Lanka; Tasmania; Thailand
Exochomus nigromaculatus (Goeze)	Leaf	Malaysia
Micraspis afflicta (Mulsant)	Panicle	Indonesia, Malaysia
Micraspis crocea (Mulsant)	Rice pollen, leaf, panicle	Philippines
Micraspis discolor (Fabricius)	Rice pollen, leaf	South and Southeast Asia, China, Japan (including Ryukyu Islands)
Micraspis lineata		Indonesia
Micraspis vincta (Gorham)	Rice pollen	India, Malaysia, Myanmar, Pakistan, Thailand

Life history

Adults

Beetles of *M. discolor* are about 3.2-3.8 mm long and 2.8-3.2 mm wide (Fig. 20). They have oval convex bodies with bright orange to red-orange elytra. The males are usually slightly smaller than the females. The beetles are cannibalistic, feeding on their own eggs, larvae, and pupae, but usually prefer soft-bodied insects. They are diurnal and live on various plant parts as predators. They select their feeding location according to the presence of hosts, and are numerous at the bases of plants and on the upper leaves and panicles. After harvest, they congregate in the stubble. Adults live 25 to 40 d.

20. Ladybird beetle *Micraspis discolor.*

Eggs

The preoviposition period is 6-10 d. Females lay 14-26 eggs/d in a cluster on the upper and lower leaf surfaces. Eggs within a cluster are not attached to each other. The egg is about 0.99-1.05 mm long and 0.41-0.44 mm wide, elongate-oval, and shiny yellow-orange, which gradually changes to pale brown and later to brown. Reddish eye spots develop just before hatching. Egg incubation is 2-4 d.

Larvae

The hatching larva cuts an irregular hole through the upper end of the egg shell. Eggs from a single batch usually hatch simultaneously and the larvae remain clustered for almost a day. Larvae are soft-bodied, brownish black, elongate, somewhat flattened, and covered with minute tubercles or spines. They have the general body shape of an alligator. They are very active and are seen moving about the whole plant, preying on various insects or feeding on the exposed pollen. They undergo four larval instars in an average of 15-20 d. The full-grown larva is 5-6 mm long. It becomes sedentary before pupation, attaching itself to the rice plant by means of a suction disc located at the abdominal tip.

Pupae

The newly formed pupa is pinkish, but later turns orange to reddish orange. The pupation period is 3-8 d.

Seasonal occurrence and abundance

Occurrence of the beetles depends on prey. At IRRI, studies on the life cycle and occurrence of the beetles revealed that *M. crocea* is most abundant during rice flowering and during outbreaks of its prey *Nilaparvata lugens* (Stål). In India, adults of *M. discolor* occur throughout the crop year in aphid-infested fields and then disperse to weeds. By the end of March, the beetles undergo reproductive diapause, which ends within 6-8 d of aphids' appearance on the crop.

Temperatures of 16-26 °C and RH of 60-80% favor faster larval development.

Damage

Ladybird beetle pests of rice have mixed feeding habits. Adults and nymphs prefer to prey upon various aphid, leafhopper, and planthopper nymphs and adults; stem borer eggs; and other soft-bodied, small insects such as thrips and mealybugs. In the absence of prey, however, they feed on leaf blades (leaving small chewed areas), pollen, and frequently damage developing grains. They gnaw a hole through the rice hull to feed on the soft grain during the dough stage.

Control method

Micraspis spp. can be readily controlled by organophosphate insecticides used as sprays. However, since these beetles are predators of numerous harmful insects, controlling the prey population helps to control the beetles.

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Rice black bugs

The two most common species of black bugs (Hemiptera: Pentatomidae) attacking rice plants are the Malayan rice black bug *Scotinophara coarctata* (Fabricius) and the Japanese rice black bug *Scotinophara lurida* (Burmeister). They are also commonly known as rice pentatomid bugs. *Scotinophara coarctata* is an important pest of rice in Cambodia, China (including Taiwan), India, Indonesia, Malaysia, Philippines, Thailand, and Vietnam. *Scotinophara lurida* occurs in China (including Taiwan), India, Japan, and Sri Lanka.

The occurrence of *Scotinophara coarctata* on rice was first recorded in Indonesia in 1903. In West Malaysia the pest was first recorded on rice in 1918. Since 1983 its numbers have increased because of the staggered planting of the rice crop. In the Philippines, the pest was first recorded in September 1979 in southern Palawan; it later spread to central and northern Palawan. The black bug problem in Palawan is partly related to double cropping of irrigated rice since the introduction of high-yielding cultivars and high N levels. Black bug infestation is most serious in poorly drained ricefields around marshes. Except for Palawan, no other parts of the Philippines have reported severe black bug infestation.

Scotinophara lurida is a major pest of rice in China and Japan. Before 1940 the pest was recorded as an occasional rice pest in Sri Lanka. Since then it has become economically important, occurring periodically in large numbers and causing extensive damage to rice crops in most parts of the country.

Black bugs are known to attack the rice crop at various growth stages from seedling to maturity. Heavy damage is usually seen after heading or maturing, especially when irrigation is stopped during the maturation period. Large populations of the pest are more common on lowland than on upland rices, and on continuously irrigated or continuously rice-cropped fields than on rainfed or single-cropped fields. They are also more common in direct-seeded paddies than in transplanted fields because of their preference for densely planted fields.

Aside from rice, other hosts are *Zea mays* (L.), *Alocasia indica* (Roxb.) Schott, *Colocasia esculenta* (L.) Schott, *Lecrsia hexandra* (L.) Sw., *Echinochloa crus-galli* (L.) P. Beauv., *Rottboellia cochinchinensis* (Lour.) W. D. Clayton, *Echinochloa* colona (L.) Link., *Fimbristylis miliacea* (L.) Vahl, *Cyperus rotundus* L., *Cyeperus iria* L., *Sacciolepis lnyurus* (Lam.) A. Chase, *Scirpus grossus* L.f., *Scleria sumatrensis* Retz., and *Hymenachne acutigluma* (Steud.) Gilliland.

Life history

The adult of *Scotinophara coarctata* has a black head, collar, and cicatrices; yellowish brown antennae; reddish to dark brown abdomen; and reddish brown legs with yellowish tibiae and tarsi. Average size is 9 mm from the anterior margin of the head to the apex of the abdomen and 4.5 mm across the prothorax. Black bugs are regarded as noisome insects with a bad smell. They are strongly attracted to light, but not to yellow electric bulbs. Their flight activity to light traps coincides with the lunar cycle. Adult females lay their eggs in clusters, each containing 29-34 eggs, on the basal parts of the rice plants near the water surface. The egg is about 1.0 mm long and 0.65 mm wide; shiny, pale greenish grey; cylindrical; and finely reticulated. The top is greyish white—indicating the cap, which splits to allow the nymph to emerge. The female guards the eggs by staying on top of the mass. Average incubation period is 4-7 d. There are five nymphal instars, which last for 26-34 d. Adult bugs survive for 4-7 mo.

Seasonal occurrence and abundance

Eggs hatch and nymphs develop optimally at temperatures of 25-28 °C and 75% RH.

In Sri Lanka, *Scotinophara lurida* has three or four overlapping generations in a year. The first generation and part of the second generation occur on the first crop; the remainder of the second, the third, and part of the fourth generation occur on the second crop. There are two overlapping generations in aestivation at each period between crops. At aestivation sites, fourth- and fifth-instar nymphs and adults are most commonly found.

In Japan, *Scotinophara lurida* develops only one generation a year. The first generation bugs that develop on the rice crop hibernate in the winter in adult stage and invade the next year's crop in the seedling stage.

Damage

Black bug nymphs and adults are usually found at the basal part of the rice plant and damage is caused by their feeding on the plant sap. At the early hours of the day, the bugs are found feeding on the upper parts of the rice seedlings and on the upper surfaces of the leaves. Later, when sunlight intensity increases, they move to the undersides of the leaves and stems and continue to feed there. They are very sluggish in the day, rarely taking wing. At night they become very active, are often seen in flight, and feed continuously throughout the night. Older nymphs and adults are sometimes found on cracks in the soil during the day.

Heavy infestation during the tillering stage kills the central shoots, resulting in deadheart. Rice plants show slight stunting, yellowing, chlorotic lesions, and fewer tillers. During the booting stage, plants show stunted panicles, no panicles, or incompletely exserted panicles, and unfilled spikelets or whiteheads. During crop maturation, incomplete and unfilled spikelets increase. Heavy damage at any stage causes the plants to wilt and dry, a condition known as bug burn.

Control methods

Cultural control

Since black bugs remain in the rice stubble after harvest, plowing the field helps to kill the pests and destroy their host plants. Removing weeds from the field to allow more sunlight to reach the bases of the rice plants is another cultural control method.

Biological control

Natural enemies of the rice black bug include the scelionid egg parasitoid *Telenomus triptus* Nixon; the gryllid predators *Metioche vittaticollis* (Stål) and *Anaxipha* sp.; the coccinellid predator *Micraspis crocea* (Mulsant); the carabid predator *Agonum daimio* Bates; the nabid bug *Stenonabis tagalicus* (Stål); the spider predators *Pardosa pseudoannulata* (Boesenberg and Strand), *Oxyopes javanus* (Thorell), *Tetragnatha virescens* Okuma, and *Camaricus formosus* Thorell; and the entomopathogenic fungi (Deuteromycotina) *Beauveria bassiana* (Balsamo) Vuillemin, *Metarhizium anisopliae* (Metschnikoff) Sorokin, and *Paecilomyces lilacinus* (Thompson) Samson.

Varietal resistance

Two rice cultivars, IR10781-75-3-2-2 and IR13149-71-3-2, are resistant to rice black bugs.

Chemical control

Directly spraying insecticides at the base of the plants where the black bugs stay provides the most effective control.

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Armyworms and cutworms

The larvae of several species of grassland-adapted noctuids, popularly called armyworms and cutworms, feed gregariously on the leaves and stems of rice plants. They are similar in habits, but can be broadly distinguished according to the portion of the plant attacked. The armyworm larvae feed on the aboveground parts of the plants, mostly on the leaves, often leaving only the midribs. The cutworm larvae feed on the roots and shoots, which are often cut off at ground level or at various other levels, or leaves or panicles may be detached. Cutworms can defoliate ricefields, generally in patches, from early vegetative growth to harvest. The cutworms are nocturnal; during the day, they hide in the upper layer (3-5 cm) of soil or occasionally on plants on cloudy days. Otherwise they hide under trash near the base of the plants, in leaf folds, or behind the leaf sheath.

The armyworms get their name from the larval habit of appearing in enormous numbers. As food supplies become exhausted, they assume a gregarious marching habit seeking fresh fields. Several cutworm species also exhibit armyworm habits and are included in the broad category of armyworms. Some of the common armyworm species that infest rice are listed in Table 9. The basic bionomics of a few selected species are presented in this chapter.

Common armyworm

The common armyworm or ear-cutting caterpillar *Mythimna [=Pseudaletia] unipuncta* (Haworth) occurs sporadically, but occasionally causes serious losses. It is a common pest of rice and was formerly known as *Cirphis unipuncta.* Although this species is the most common of various armyworms in Asia, other species such as *Mythimna loreyi* (Duponchel), *M. venelba* (Moore), *M. separata* (Walker), and *M. irregularis* (Walker) occasionally infest rice. Their outbreaks are usually characterized by the sudden appearance of larvae in immense numbers; severe losses are inflicted even before the worms are detected. Frequently, they disappear just as suddenly.

M. unipuncta is a polyphagous insect and has been recorded as a serious pest of rice, wheat, oats, barley, and other cereals. It also infests other grasses and may occasionally feed on nongraminaceous crops. The species is rather cosmopolitan in distribution and has been recorded throughout Asia, the Australian region, Europe, and North America where it is indigenous.

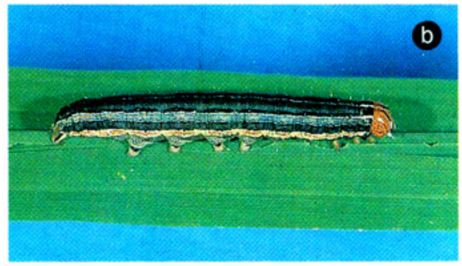
Table 9. Some common armyworms and cutworms that attack rice.

Species	Distribution
Spodoptera mauritia acronyctoides (Guenée)	Asia, Australia
Spdoptera exempta (Walker)	Africa, Asia, Australia
Spodoptera exigua (Hubner)	Africa, Asia, Australia, Europe
Spodoptera frugiperda (J. E. Smith)	Latin America, North and Central USA
Spodoptera litura (Fabricius)	Africa, Asia
Spodoptera ornithogalli (Guenee)	Latin America
Spodoptera (= Prodenia) eridania (Crampton)	Latin America, southern USA
Mythimna (= Pseudaletia) irregularis (Walker)	Southeast Asia
Mythimna (= Pseudaletia) separata (Walker)	Africa, Asia, Australia
Mythimna (= Pseudaletia) unipuncta (Haworth)	Asia, Europe, central and southern USA
Mythimna (= Pseudaletia) venalba (Moore)	Southeast Asia
Mythimna loreyi (Duponchel) (= *Pseudaletia loreyi* Duponchel)	South and Southeast Asia, Africa
Mythimna (= Pseudaletia) latifascia (= *adultera)* (Walker)	Latin America
Mythimna (= Pseudaletia) sequax (Fabricius)	Latin America
Mythimna roseilinea (Walker)	Asia
Mythimna yu (Guenée)	Latin America
Platysenta (= Spodoptera) compta (Walker) [= *Spodoptera pecten* Guenée]	Asia

Life history

Adults

The adult moths are pale and brick-red to pale brown, and have a very hairy body covered with dark specks and patches (Fig. 21a). They are about 2-3 cm long and have a 3-5 cm wing-spread. The adult moths are nocturnal, strongly phototropic, and are quiescent during the day. The moths feed on dewdrops and other sugary substances, and start mating 1-3 d after emergence (DE). Mating and oviposition usually occur after dark and during early evening hours. The male moths live an average of 3 d; the females live for 7 d. Generally, the males die shortly after mating. The females have an oviposition period of about 5 d.



21. Armyworm and cutworm pests of rice: *a) Mythimna separata* adult, *b)* armyworm larva, *c) Spodoptera mauritia* egg mass, *d) S. litura* adult, *e) S. litura* larva.

Eggs

The eggs are laid between the leaf sheaths and the stem near the joint of the leaf sheath and the leaf blade. They are deposited in clusters of several rows, a cluster consisting of 90-230 eggs, with an average of about 100. The eggs within an egg mass are generally covered with a white adhesive substance that glues them together. The individual eggs are spherical, measuring 0.6-0.7 mm in diameter with a finely ridged surface when freshly laid. They are whitish to pale yellow but become dark brown toward hatching. Unfertilized eggs do not hatch. The average incubation period is 7-9 d.

Larvae

The freshly hatched larvae are dull whitish with a brown-black head, and average 1.8 mm long and 0.35 mm wide. They undergo six instars and become full grown at 30-35 mm long and 6-6.5 mm wide. They are usually dark or greenish grey.

The first-instar larvae have only two pairs of prolegs and move with a looping motion. At this stage, they usually inhabit the young leaves of rice and other hosts. Their feeding results in skeletonizing the leaf blades. Both the looping movement and skeletonizing feeding habit are lost in the third instar when they have well-developed prolegs and feed by cutting big holes in the leaves of their host plants. The larvae are nocturnal, remaining hidden under foliage or debris in the day but feeding actively from dusk to dawn (Fig. 21b). The fifth- to sixth-instar larvae become gregarious and are voracious feeders.

The sixth-instar larvae require about 80% of the total food eaten during the entire larval period. The full-grown larvae also cut off the rice panicles from the peduncle—the reason they are also called ear-cutting caterpillars. The gregarious nature of the larvae during the later instars and their increased feeding capacity are the apparent causes of their becoming suddenly noticeable. The total average larval period is about 28 d.

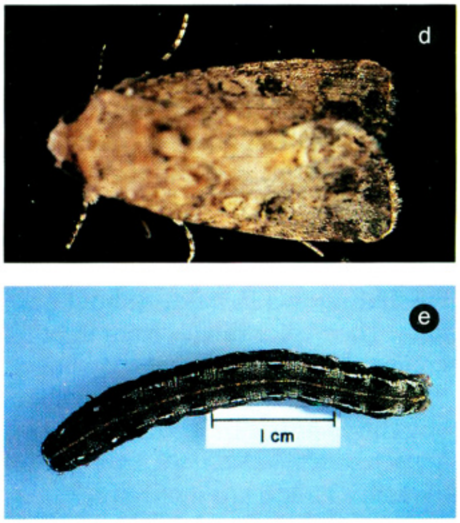
Pupae

The full-grown larvae crawl down into the soil where they form individual pupal earthen cells, molt, and undergo pupation. The pupae measure 15-19 mm long and 5-6 mm wide. They are light amber at pupation, but become dark brown toward moth emergence. The pupal period is 7-29 d, with an average of 16 d.

Seasonal occurrence and abundance

The insect hibernates as a full-grown larva. The duration of hibernation and the number of generations in a year are governed by temperature. In Bangladesh, the hibernation period is from December to March. In April, the larvae start pupating and adult moths are recorded from mid-April to mid-May. There are five generations every year.

The insects' habit of pupating in the soil limits their multiplication in lowland ricefields. In such areas, the population invariably develops on upland graminaceous crops or in the



neighboring grassy areas. Usually they multiply in grasses up to the third brood before migrating to the ricefields, either in swarms of caterpillars or as moths for oviposition.

Damage

Crop damage is caused by the larvae or caterpillars. Partly grown larvae feed on the young leaves, producing skeletonized leaf blades. They often devour plants down to the ground. Most serious damage is caused by nearly full-grown larvae that attack the crop at heading. They feed rapidly and consume large amounts of foliage in a short time as well as detach rice panicles. These insects are more active at night, and may nearly destroy a crop before their presence is detected.

Rice swarming caterpillar

The rice swarming caterpillar *Spodoptera mauritia acronyctoides* (Guenée) is another sporadic pest, which occasionally causes serious losses to rice crops. The insect is polyphagous and infests various graminaceous crops and weeds. Upland rice is its preferred host. It is widely distributed throughout the Indian subcontinent, East and Southeast Asia, and the Australian region. It is one of the most serious insect pests in South India, and possibly the most serious of the armyworms in other rice areas of Asia. The pest is particularly serious during the rainy season, although it has been recorded occurring year-round in the tropics. Another closely related species is *Platysenta compta* (Walker), which also occasionally infests ricefields. It is considered only a minor pest of rice, although it causes economic losses to maize and other grasses. The black armyworm *Spodoptera exempta* (Walker) is another serious but sporadic pest of rice. This species is polyphagous, but prefers rice and maize. The general life history and nature of damage resemble those of *S. mauritia.*

Life history

Adults

The adult insect of the swarming caterpillar is a greyish black moth with a white blotch on its forewings. The moth is nocturnal—hiding during the day in crevices in the soil or under other cover—but is active after dark. Generally, it is not attracted to light. The moths mate 1-2 d DE and females start ovipositing shortly after mating. Usually, 4- to 20-d-old seedlings in flooded seedbeds or direct-sown fields with standing water are preferred for oviposition. Plants older than 20 d and growing in dry fields are rarely infested.

The moth is a strong flier and can move great distances for oviposition. Usually, females tend to congregate and oviposit in the same area. They die shortly after oviposition.

The first-generation moths usually appear when the seeds are germinating in the seedbeds or in direct-sown fields.

Eggs

The eggs are laid in batches on the lower surface of the leaves of rice and other grasses and are covered with greyish hairs from the anal tuft of the female moths (Fig. 21c). A single moth lays about 5-6 egg clusters, each containing 150-200 eggs. The egg incubation period is 5-9 d. (The eggs of the black armyworm, *S. exempta,* are laid in masses on the leaves and hatch in an average of 2 or 3 d.) Hatching usually occurs during the morning hours. The newly hatched larvae are very active and feed by scraping the green matter from the leaf tips. They rest within the rolled edges of young leaves where they are almost invisible. Occasionally they spin a silken thread and suspend themselves from the plants. They then drift by wind to other plants.

Larvae

The larvae undergo five instars in an average 22 d to become full grown. (*S. exempta* undergoes six larval instars and the larval period is 11-12 d.) Those beyond the third larval instar are strictly nocturnal and hide during the day. During cloudy weather, however, they remain active during the day. Full-grown larvae are about 38 mm long, dark to pale green, with dull dorsal and subdorsal stripes. Their colors vary greatly and show a phase variation pattern as in locusts. When disturbed, the full-grown larva curls into a ring, which is a characteristic common to all cutworms and armyworms.

Pupae

Pupation takes place in earthen cells slightly below ground level. The pupa is dark brown and about 13 mm long. The pupal stage lasts for 10-14 d. (*S. exempta* pupation occurs in the soil and lasts 5-10 d.) The total life cycle is 20-30 d.

Seasonal occurrence and abundance

This insect is essentially a seedling pest and rarely infests a crop more than 6-7 wk after transplanting. The larvae are generally found on crops less than 20-25 d old. They migrate from older ricefields to grassy areas where subsequent broods cause severe damage. The larvae suffer high mortality from heavy rains, and are victims of various bacterial diseases, parasites, and predators. The inability of the larvae to swim is a weakness. In flooded fields they are forced to stay on the plants, which they defoliate. They are thus exposed to birds and other predators.

Although the pest has been recorded year-round in multicropped areas, it occurs in high numbers only during May and July. Outbreaks occur after periods of prolonged drought followed by heavy rainfall. Drought kills their natural enemies and flooding allows them to concentrate on rice plants.

Damage

The swarming caterpillars cause severe damage to rice plants in nursery beds. They appear suddenly in masses and move like an army from field to field so that seedbeds or the direct seeded fields look as if grazed by cattle. Generally, a transplanted crop is not severely affected. Newly hatched larvae cause the plants to look sickly with withered tips and cut leaves, but older larvae (more than 10 d old) feed voraciously and almost completely defoliate the plants. They migrate from field to field and extensive losses are often caused within 1 wk. The absence of standing water in the fields facilitates migration.

Fall armyworm

The fall armyworm *Spodoptera frugiperda* (J.E. Smith) is another species that causes economic losses to rice crops although it occurs only sporadically. It is polyphagous and attacks many crops including grasses, cereals, legumes, cotton, cabbage, and tobacco. It has been recorded throughout North and Central America, but is more common in the southern USA, Central America, and neotropical areas. The fall armyworm is so-called because it does not appear in the northern parts of the USA until late summer or fall. It is also variously known as grass worm, overflow worm, and southern armyworm.

Life history

Adults

The adult moths are ash grey; their forewings are mottled with irregular white or light grey spots near the tips. They are about 2 cm long and approximately 4 cm across their wingspread. They are nocturnal, are strongly attracted to light, and live for 2-3 wk.

Eggs

The eggs are deposited in clusters on the leaf blades of the various hosts. Each egg cluster contains 50 to several hundred eggs. The eggs are round, about 0.5 mm in diameter, dull white, and have a ridged surface. The egg masses are covered with mouse-colored scales from the body of the female moths. The incubation period is 4-10 d.

Larvae

The newly hatched larvae have black heads and white bodies, but become darker in subsequent instars. They are active feeders and may curl up in the leaf sheaths, suspend themselves from plants by a thread, or move about on the ground. They become full grown about 2-3 wk from hatching. Full-grown larvae are about 4 cm long. Their color ranges from light green to almost black and they have three yellowish white longitudinal lines on their back. On each side (next to each outer dorsal line) is a wide dark stripe with an equally wide, wavy, yellow stripe splotched with red below.

Pupae

The full-grown larvae move down to the soil where they burrow 2.5 to 5 cm and make small cells in which they individually undergo pupation. The pupae are yellowish brown when freshly formed, but darken as they approach moth emergence. The pupal stage lasts for 10-14 d.

Seasonal occurrence and abundance

The fall armyworm hibernates as full-grown larvae. In the USA, overwintering occurs only in the extreme south. In successive generations, the moths move northward. As many as six generations usually occur in the extreme southern states, but in northern states there is only one generation a year. Because the larvae require dry soil for pupation, they cannot maintain subsequent generations in flooded ricefields. Therefore, pupation usually occurs in other upland crops or in grassy areas, and the adult moths migrate to the ricefields where they deposit their eggs. Occasionally, large numbers of larvae from grassy areas or other upland crops also migrate to the ricefields.

Damage

Young larvae feed on the lower surfaces of leaves, leaving the epidermis intact. At first, they eat only tender parts of leaves, but as they grow they devour all foliage, leaving only the tough plant stems. If food becomes scarce, the larvae move in hordes to nearby fields of abundant foliage.

Fall armyworms cause different kinds of injury to different plants. In rice and other grasses, they eat the leaves or may cut off heads by chewing through the stem. Damage becomes noticeable about 3-4 d after infestation, and heavy defoliation becomes visible after the larvae congregate on the plants.

Common cutworm

The common cutworm *Spodoptera litura* (Fabricius), also known as grass cutworm, vegetable cutworm, tobacco cutworm, or tobacco caterpillar, is a polyphagous insect and a common pest of various agricultural crops. Although occurring only sporadically, it frequently causes great economic losses to cabbage, castor, maize, jute, rice, smaller millets, sweet potato, tobacco, and a wide variety of other crops. It has a wide distribution and has been recorded in Australia, the Indian subcontinent, Southeast and East Asia, China, Turkey, and several African countries. This pest was first described by Fabricius in 1775 as *Noctua litura.* The name *Prodenia litura,* proposed by Hampson in 1909, was used until recently when the pest was transferred to genus *Spodoptera.*

Life history

Adults

The adult moths (Fig. 21d) are nocturnal, remaining quiet and generally staying concealed in dark places during the day. They become active during the night when they fly about to feed on the nectar of flowers. They live 5-10 d and copulation occurs soon after emergence. The female moths start ovipositing 2-3 d after emergence and oviposition occurs early in the evening and at night.

Eggs

The individual egg is pearly white, round, and has a ridged surface. Eggs are laid in clusters on either surface of the leaves of various plants. A single female is capable of laying up to five clusters of eggs, each cluster containing an average of 300 eggs. The eggs within a cluster are arranged in rows up to three layers deep. The clusters are covered with short yellowish brown hairs from the abdominal tips of the female moths. The eggs hatch in an average of 3 d. There is a considerable uniformity in the time of hatching of the eggs in each egg mass.

Larvae

Newly hatched larvae are tiny, about 1 mm long, and are greenish with a cylindrical body. They feed gregariously for 3-5 d from the base of the leaf toward the apical area. At this stage, they feed on the epidermis of the leaf and may sclerotize the entire leaf surface. Sclerotization of leaves is a typical symptom of *S. litura* damage to thick-leaved plants such as castor, but the larvae devour the entire leaves of rice and other graminaceous plants. After the third instar, the larvae may still feed gregariously if food is abundant; others may disperse to feed individually. Beyond this stage, the larvae are very active and cause extensive losses.

The larvae pass through five instars to become full grown. During different instars, there are considerable changes in larval colors. After the third instar, dark transverse bands start appearing on their bodies (Fig. 21e). The full-grown larva has a cylindrical body and is brown or brownish black tinged with orange. The thoracic segments have one to two dark spots near the base of the legs. The abdominal segments have generally two light, brownish lateral lines on each side—one above and one below the spiracles. Above the top lines is a broken line composed of velvety semicrescent patches that vary in color between individuals. The larval period is 20-26 d.

Pupae

Pupation occurs in an earthen cell about 7-8 cm below the soil surface. The cells average 22.5 mm long and 9.28 mm wide. The pupal stage lasts for 8-11 d.

Seasonal occurrence and abundance

In India, the outbreak of *S. litura* occurs earlier in semiarid regions, usually by the end of July or the first week of August. In humid regions, it occurs in the second week of September. These variations are correlated with climatic conditions. Rainfall indirectly affects the initiation of the outbreak. Heavy rainfall after a dry spell initiates the outbreak, generally by second- or third-generation larvae. By the time the first-instar larvae hatch, the wild vegetation is tender and capable of supporting the initial population. After wild food plants have been exhausted, the larvae migrate to cultivated fields where extensive damage is usually caused by the second generation emerging in large numbers.

Damage

The common cutworm is a problem generally on upland rice only because it needs dry soil for pupation and for completion of its life cycle. Lowland rice usually suffers heavy damage from larvae migrating from adjacent grassy areas. Young caterpillars eat the soft leaves of the rice plant, but full-grown caterpillars can devour the entire plant. They are most serious during the seedling stage of rice when they sever the seedlings at the base. When abundant during late crop growth, they may severely defoliate the rice crop.

Control methods

Control measures for all armyworms and cutworms are similar.

Cultural control

Seedbeds should be established far from large areas of weeds and grasses so that armyworms and cutworms cannot migrate from alternate hosts. Removing weeds from areas outside of fields and plowing all fallow land help to control armyworms and cutworms.

Biological control

Natural enemies play a key role in keeping armyworm and cutworm numbers below economic injury levels. Cutworms, which have large numbers of natural enemies, colonize the crop soon after land preparation at the beginning of the rainy season when natural enemy populations are low. Armyworms are also normally held in check by egg and larval parasites. When these parasites fail, usually because of drought, armyworms become epidemic.

Eggs of armyworms and cutworms are parasitized by scelionid wasps (*Telenomus* sp.) and trichogrammatid wasps (*Trichogramma ivelae* Pang & Cheng). Larvae are parasitized by braconid wasps (*Cotesia* sp.), eulophid wasps [*Euplectrus chapadae* (Ashmead)], and chalcid wasps [*Brachymeria lasus* (Walker)]. Tachinid flies [*Palexorista lucagus* Walker, *Argyrophylax nigrotibialis* Baranov, and *Zygobothria atropivora* (Robineau-Desvoidy)] also parasitize the larvae. *Chelonus formosanus* Sonan is reported as a parasite of *S. litura* eggs and larvae. Ants *Odontoponera transversa* (Smith) and wasps *Ropalidia fasciata* Fabricius prey on eggs and larvae. The spiders *Pardosa pseudoannulata* (Boesenberg & Strand) and *Oxyopes javanus* (Thorell) prey on moths.

A polyhedrosis virus attacks larvae. Dead, virus-infected larvae turn black and hang limply from plants.

Varietal resistance

Several wild rices possess moderate levels of resistance to *Spodoptera mauritia acronyctoides* and *Mythimna separata.* Moderate resistance to *Spodoptera frugiperda* is also reported in plant introductions (PI) 160842, 346830, 346833, 346833, and 346853. Moderate levels of resistance are also detected in *Oryza glaberrima* Steud. accessions 101800, 102554, and 369453.

Chemical control

Sprays are more effective than granules. High dosages are required to kill large armyworm and cutworm larvae, because insecticide toxicity is positively related to insect body weight. Since insecticides break down rapidly in sunlight and high temperature, spraying should be done late in the afternoon before the larvae leave their resting places to climb up the plants. Because damage is normally concentrated in discrete areas of a ricefield, only areas where damage occurs should be sprayed.

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Soil-inhabiting pests

Soil-inhabiting insect pests are not a serious problem in irrigated ricefields. Well-drained, nonpuddled upland rice soils favor these pests. Soil pests feed on underground plant parts. Soil pests include ants, e.g., *Solenopsis geminata* (Fabricius), *Monomorium pharaonis* (Linnaeus), and *Pheidologeton diversus* Jerdon; termites, e.g., *Macrotermes gilvus* (Hagen), *Heterotermes philippinensis* (Light), and *Coptotermes formusanus* Shiraki; mole cricket *Gryllotalpa orientalis* (=*africana*) Burmeister; field crickets, e.g., *Gryllus* assimilis (=*bimaculatus*) (Fabricius) and *Teleogryllus testaceous* (Walker); white grubs, e.g., *Leucopholis rorida* (Fabricius), *Holotrichia serrata* Fabricius; root aphids, e.g., *Tetraneura nigriabdominalis* (Sasaki) and *Geoica lucifuga* (Zehntner); and rice root weevils, e.g., *Echinocnemus squameus* Billberg, *Echinocnemus oryzae* Marshall, and *Hydronomidius molitor* Faust.

Ants

The ant (Hymenoptera: Formicidae) is a social insect that can easily be distinguished from other insects by the presence of a pedicel, a stalk-like structure serving as a support between its thorax and abdomen. Ants are widely distributed and commonly occur in upland rice environments and in dry seeded ricefields in rainfed wetlands. The most common species of ants that inhabit the soil and thereby cause considerable damage to upland rice plants in Asia are *Solenopsis geminata* (Fabricius), *Munomorium pharaonis* (Linnaeus), *Pheidologeton diversus* Jerdon, and *Pheidole* sp. These fire ants and harvester ants cause damage to rice plants by feeding on ungerminated rice seeds carried by foraging worker ants into their nests, which are constructed below the soil surface in upland fields or in levees in rainfed wetland fields. If the supply of ungerminated seeds is low, they feed on germinated seeds. Damage is characterized by reduced, usually patchy, plant stand. Ants also tend root aphids in their nests especially during unfavorable weather, and help these aphids tunnel along the root systems to penetrate the soil.

Control methods

Cultural control

Increasing the seeding rate helps to compensate for losses caused by ants.

Chemical control

Treatment of seeds with insecticides in powder form is the most effective method of controlling ants.

Termites

Termites (Fig. 22a) are generally known as white ants because of their overall similarity to ants in body shape, wings, and the caste system of workers, soldiers, king, and queen. Termites belonging to family Termitidae, are subterranean, and lack symbiotic protozoans, which help digest cellulose. This family of termites cultures fungi, which break down cellulose, in special underground cells.

Termites are a problem in upland rice, but can also occur in light-textured soils in rainfed wetland areas. Infestations are severe on light-textured soils with low moisture content.

Some grassland termites make nests composed of many tunnels deep in the soil. They attack living rice plants only when dead plant material is not available. They attack a drought-stressed crop, but prefer older plants having greater cellulose content. They tunnel through plant stems and eat roots. The plants become stunted and then wilt. Damaged plants can easily be pulled by hand.

Termites are more serious in Latin America and Africa than in Asia. The common Asian species that attack rice plants are *Macrotermes gilvus* (Hagen), *Heterotermes philippinensis* (Light), and *Coptotermes formusanus* Shiraki. In Africa, *Microtermes* and *Macrotermes* termites have been reported as pests of rainfed upland rice.

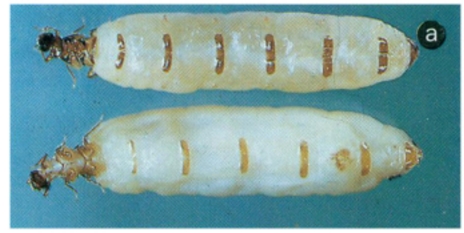
Control methods

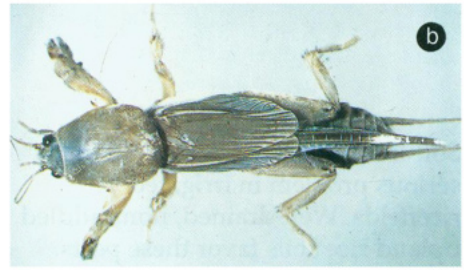
Cultural control

Placing crop residues in the field at planting time can divert the pest from the growing crop.

Chemical control

Chemical control includes treating seeds with insecticides at planting or applying granular insecticide in the seed furrows or hills. The decision to use insecticides should be based on the history of termite damage in a particular field.





22. Soil-inhabiting pests of rice: a) queens of termites, b) *Gryllotalpa orientalis* adult, c) adult of field cricket *Plebeiogryllus plebejus,* d) adult of white grub, e) white grub larva, f) root aphid.

Crickets

Several species of mole crickets (Gryllotalpidae) and field crickets (Gryllidae) feed on the underground parts of all upland crops including rice (Fig. 22b, c). Four species of mole crickets are reported to attack rice: *Gryllotalpa orientalis (=africana)* Burmeister in Asia, *Gyllotalpa africana* Palisot de Beauvois in Africa, and *Neocurtilla hexadactyla* (Perty) and *Scapteriscus didactylus* (Latreille) in Latin America. Several species of field crickets are reported as rice pests: *Gryllus assimilis (=bimaculatus)* (Fabricius), *Gryllus (=Liogyllus) bimaculatus* de Geer, *Brachytrupes portentosus* (Lichtenstein), *Plebeiogryllus plebejus* (Saussure), *Teleogryllus testaceous* (Walker), *Teleogryllus occipitalis* (Serville), *Loxoblemmus haani* Saussure, and *Velarifictorus aspersus membranaceus* (Drury) in Africa.

Life history

Mole crickets are brownish and very plump insects, usually 2.5-3 mm long, with short antennae. Their front legs are classical examples of modification for digging. The foretibia are modified into spade-like structures resembling the feet of a mole, the character that gives them the common name of mole cricket. The insect uses these modified legs to burrow into the soil where it feeds on tender roots of growing plants. Mole crickets generally live in burrows 8-10 cm below the soil surface, but during unfavorable weather they burrow deeper. Adults aestivate or hibernate. They are strong fliers. They are attracted to light and are often recorded near street lights or in light traps.

The eggs are white, oval, and are laid in hardened cells or chambers constructed in the soil by the females. One cell generally contains 30-50 eggs. Depending on the temperature, the incubation period is 15-40 d. The hatching nymphs feed on the roots, damaging the crop in patches. The nymphs have limited migrating ability and generally suffer heavy mortality. The nymphal period lasts 3-4 mo. The insect has only one generation per year in temperate areas.

After ricefields have been flooded, mole crickets are usually seen swimming on the water, particularly when the flooded fields are being plowed and puddled. In areas where mole crickets are eaten, people may be seen collecting them while a field is being plowed. Cannibalism is apparently the most important factor regulating mole cricket populations.

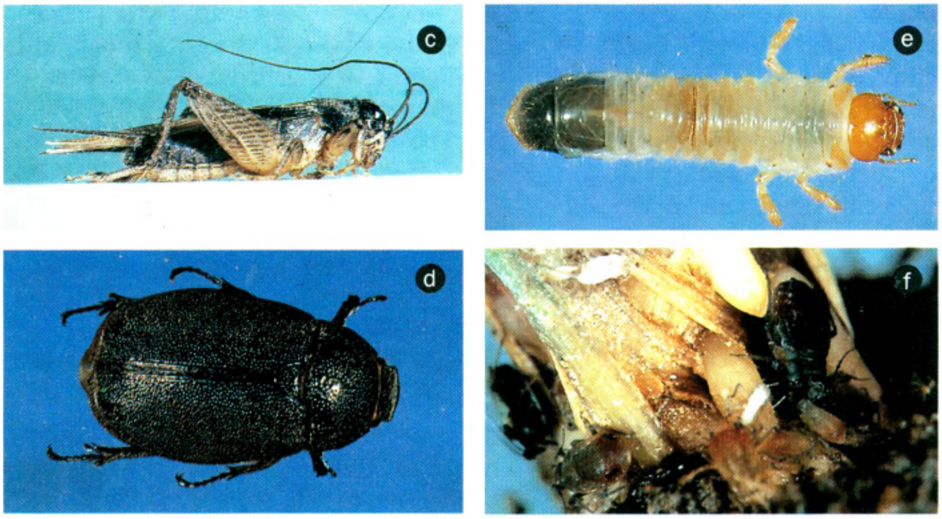
The mole cricket cannot live in flooded fields, so they swim across the water to the levees. They burrow into the levees and lay eggs. When the water level recedes, they migrate to the field to feed.

Field cricket nymphs and adults have similar nocturnal habits and damage rice as much as do mole crickets. Piles of weeds remaining on fields attract them. They also make subterranean nests and tunnel through the soil to feed on roots. Some species prefer seed to roots; others feed at the base of stems.

Like mole crickets, field crickets cannot survive in standing water and are therefore more prevalent in upland fields.

Damage

Both mole crickets and field crickets live in ramifying underground burrows, generally 8-10 cm below the surface. One mole cricket can burrow a distance of several meters in one night. Under upland conditions the burrows are more abundant in moist patches, but in lowland fields they are common near the levees and in areas that are not submerged. These burrows run close to the soil surface



and the crickets feed on the roots of the plants or even the base of the seedling, resulting either in complete severing of the aerial parts from the root or heavy root pruning. Mole crickets cannot kill older plants with large root systems.

Some species of field crickets defoliate rice plants by removing the central portion of leaves.

Control methods

Cultural control

Maintaining standing water in the field prevents mole crickets and field crickets from tunneling into the soil and damaging the crop.

Biological control

Mole crickets are cannibalistic, thus regulating their own numbers. *Pheropsophus jessoensis* Morawitz (Carabidae) larvae prey on the eggs of *Gryllotalpa africana.* Sphecid wasps *Larra carbonaria* (Smith), *Larva luzonensis* (Rohwer) and *Larva sanguinea* Williams parasitize nymphs and adults by paralyzing them and dragging them into wasp nests as food for the young.

Other sphecid species — *Liris aurulenta* (Fabricius), *Motes manilae* (Ashmead), *Motes subtessellatus* (Smith), and *Motes loboriosus* (Smith)—parasitize field crickets.

A nematode, *Mermis nigrescens* (Dujardin), parasitizes adults and nymphs of mole crickets.

In China, the fungus *Beauveria bassiana* (Balsamo) Vuillemin parasitizes nymphs and adults of *Gryllotalpa africana.* The earwig *Labidura* sp. preys on both nymphs and adults of the pest.

Chemical control

Poisoned bait made from moistened rice bran and liquid or powdered insecticide can be placed in the field or on rice bunds to kill night-foraging mole crickets and field crickets. In deepwater areas, the main control measure is chemical treatment of soil or seeds at planting.

White grubs

The term white grub refers to the large larva of a scarab beetle. White grub species are known either as the chafers, in which only the larvae feed on roots, or the black beetles, in which only the adults feed on roots. White grubs are widely distributed and are considered important pests causing serious damage to rice crops. They are polyphagous and infest roots of various crops such as cereals, millets, sugarcane, vegetables, and other plantation crops. There are many species of white grubs, but none is widely distributed in Asia. *Holotrichia serrata* Fabricius is the most common species of white grub of the chafer type that attacks the roots of rice plants. This species of white grub has been causing serious damage to rice crops in several parts of India since 1973.

Life history

The beetle is reddish, blackish red, or dark tan, about 2 cm long and 1 cm wide (Fig. 22d). Antennae have 10 segments. Female beetles are usually bigger than males. Females prefer to lay eggs in moist sandy soil, to a depth of 7-12 cm. A single female lays a maximum of 14 eggs/d and about 50-60 eggs throughout its adult life. The eggs are laid singly and are covered with a jelly-like white substance. The freshly laid egg is smooth, milky white, oval, and is about 3.7 mm long and 2.2 mm wide. As the egg grows, a part of it becomes hyaline white and other parts remain milky white. The developing embryo becomes visible about 7 d after oviposition. Before hatching, the egg is smooth, elliptical, and is about 5.3 mm long and 4.05 mm wide. The incubation period is 8-10 d.

Immediately after hatching, the grub eats the egg shell then remains inactive for 2-3 h. It is milky white with a dirty-white head, and is about 9.8 mm long and 2.3 mm wide at the head. After 3-4 h, the body expands, the head becomes brownish, and the grub starts feeding on organic matter. At this stage, the grub requires a higher quantity of organic matter than of roots.

The second-instar grub has morphological characters and color pattern similar to those of the first instar, but the last abdominal segment is enlarged. It is 36.5 mm long and 3.85 mm wide at the head. The second instar is more curved, active, and cannibalistic. At the first half of the second instar, the food requirement is the same as that of the first instar, but at the later part, the grub requires a higher quantity of roots than of organic matter. The second-instar period lasts 14-62 d, with an average of 37 d.

The third-instar grub is creamy white and is about 46.5 mm long and 6.60 mm wide at the head. This period lasts for 143 d (Fig. 22e).

Pupation takes place in earthen cells in the soil 20-40 cm deep. The freshly formed pupa is creamy white and later turns brown. The pupae are exarate and the pupal period lasts 20-24 d. When adults emerge, they remain in the soil until the onset of the monsoon.

The life cycle is completed within 1 yr in the tropics. In temperate regions the life cycle is 2 yr.

Seasonal occurrence and abundance

In India, the beetles emerge from the soil after about 35 mm of rainfall in the monsoon or premonsoon season in May. Females lay eggs in June, July, and August. Pupation takes place around February, and adults that emerge remain under the soil until the onset of the monsoon.

Soil moisture is an important factor in egg incubation and survival of white grubs. The most suitable soil moisture is 10-15% for the hatching of eggs and 15-25% for survival.

Damage

Adults of black beetles burrow in the soil and feed on the roots; larvae feed only on organic matter.

Chafer adults, on the other hand, are foliage feeders. Larvae feeding on the roots cause the plants to become stunted and then wilt. Damage to rice crops is higher during drought conditions because plants are less able to produce new roots. Damage is in patches since white grubs are unevenly distributed in the soil because of their strict moisture requirement.

Control methods

Cultural control

Cultural control methods that help reduce field population of the pest include delaying land preparation until most chafer adults pass their egg-laying phase or die. Weeding also reduces egg laying by females since they are attracted to thick vegetation.

Biological control

Several specialized scoliid wasps such as *Campsomeris marginella modesta* (Smith) can parasitize white grubs in the soil. Mermithid nematodes such as *Psammomermis* sp. also parasitize the larvae.

Chemical control

The only practical insecticidal control measure against white grubs is the application of granular insecticides in crop furrows or hills at sowing.

Rice root aphids

The rice root aphid *Tetraneura (=Tetraneurella) nigriabdominalis* (Sasaki) (Homoptera: Aphididae) is considered a major pest of upland rice. It occurs in Australia, Bangladesh, Fiji, India, Indonesia, Japan, Republic of Korea, Malaysia, Nepal, New Zealand, Pakistan, Philippines, Sri Lanka, Tonga, and the USA. It has also been recorded in Africa, Central America, and the Caribbean. The pest is also known as the grass root aphid because it infests the roots of other graminaceous plants aside from rice. These other hosts include species of *Agropyon, Cenchrus, Chloris, Cynodon, Echinochloa, Eleusine, Eragrostis, Panicum, Saccharum,* and *Setaria.* The pest has been recorded under different names in several countries. In the Philippines and Taiwan, China, it was previously known as *Dryopeia hirsuta* Baker.

Other root aphids known to infest rice plants are *Rhopalosiphum rufiabdominalis* (Sasaki), *Anoecia fulviabdominalis* (Sasaki), *Paracletus cimiciformis* Heyden, and *Geoica lucifuga* (Zehntner).

Life history

The rice root aphid *Tetraneura nigriabdominalis* is small, greenish or brownish white, plump, and oval-bodied (Fig. 22f). It is not so globose compared with most *Tetraneura* species. Rice root aphids usually cluster on roots of rice plants. There are two adult forms: winged and nonwinged. Winged adults are 1.5-2.3 mm long and nonwinged forms are 1.5-2.5 mm long. The rice root aphids reproduce by viviparous parthenogenesis and no male aphids have been recorded. There are four nymphal instars, each lasting an average period of 2.2, 2.7, 3.8, and 5.7 d. The adult aphids live 15-20 d, and each female produces 35-45 nymphs in its lifetime. The first nymphs are usually born shortly after the aphids have reached the adult stage.

Seasonal occurrence and abundance

In the Philippines, the occurrence of both apterous and alate adults has been recorded. Alate forms make up 2-3% of the population from June to

November, but increase to 10-16% in April and May. The high percentages of alate adults in April and May may be due to high temperatures and low humidity, factors considered detrimental to the survival and reproduction of the aphid in dry soils.

In China, soil type was observed to be an important factor in pest incidence. Rice planted in lateritic soil was more susceptible to aphids than that planted in muddy or sandy soil. The number of aphids per plant in lateritic soil was seven times as high as that in sandy soils.

Damage

The rice root aphids *Tetraneura nigriabdominalis* and *R. rufiabdominalis* generally cause light damage at the seedling stage and heavy damage at the tillering stage. Symptoms of rice root aphid infestation is characterized by yellowing and distorted growth of the plants. When these plants are pulled out, a large number of aphids are seen on the roots. The damage is caused by the feeding of the adults and nymphs, which suck the plant sap from the roots. In many cases, the aphids are found in irregular cavities (about 1.5 cm in diameter) with fairly smooth walls, which surround the succulent rice roots. The aphids feed on the roots, staying within these cavities, which are possibly made by certain species of ants that live in symbiosis with the aphids.

Control methods

Biological control

Several natural enemies are recorded: a braconid wasp *Aphidius* sp. and a mermithid nematode *Mermis* sp. are recorded parasites of nymphs and adults. Lady beetles such as *Coccinella repanda* (Thunberg), *Menochilus sexmaculatus* (Fabricius), and *Harmonia octomaculata* (Fabricius) prey on nymphs and adults.

Chemical control

The usual prophylactic soil or seed treatment with appropriate chemicals should prevent the buildup of rice root aphids.

Rice root weevils

Rice root weevil (Coleoptera: Curculionidae) has recently become one of the most destructive rice pests in Asia. The grubs attack young rice plants and feed on the roots and rootlets. The three most widely distributed rice root weevils known to occur in Asia are *Echinocnemus squameus* Billberg in Japan, Republic of Korea, and China, and *Echinocnemus oryzae* Marshall and *Hydronomodius molitor* Faust in India.

Life history

The life cycle of the three species are similar. The adults are small black beetles densely clothed with chalky grey scales. They emerge from underground pupal cells after the onset of rains. Adult female weevils feed on the leaves before depositing their eggs on the submerged portion of rice plants. The freshly laid eggs are pear-shaped and chalky white. They are laid singly under the soil next to newly transplanted rice seedlings. The freshly hatched larvae are creamy white. There are four larval stages lasting for about 40 wk. The larvae remain submerged underground and feed on rice roots. They pupate in underground cells in the early monsoon or spring. The pupal stage lasts about 2 wk.

Damage

Adults feed on leaves of newly transplanted rice, but seldom cause economic damage. What causes enormous damage are the larvae or grubs feeding on the roots and rootlets of young rice plants. The grubs keep feeding on the regenerating roots and, as long as they feed, prevent the development of new and healthy roots. The attacked plants become stunted and produce few tillers. The leaves turn yellow and develop a rusty appearance, and the plants eventually die. Heavy attack results in large patches of dry plants in the field. Plants at tillering stage show more damage symptoms than plants after tillering. A general survey of a heavily infested field revealed that the number of root grubs varied from 1 to 248/plant, with an average of 39-45 larvae.

Control methods

Cultural control

Double cropping of flooded rice can kill most of the larvae in their pupal cells. Delayed planting of the crop to escape peak larval attack is another possible cultural control method.

Chemical control

Granular insecticides efficiently control larvae and are more efficient than foliar sprays to control the adults. In chronically infested areas, soaking the roots of rice seedlings in insecticide 6 h before transplanting effectively controls larvae.

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Rice stem maggot

The rice stem maggot *Chlorops oryzae* Matsumura (Diptera: Chloropidae) is an important pest of rice in several parts of Asia. The insect is also known to infest wheat, barley, rye, and about 12 species of graminaceous weeds. It is not known to infest nongraminaceous plants. Outbreaks of large populations occurred in Japan from 1935 to 1942 and from 1945 to 1955. The fly has been considered an important pest of rice in China since the 1970s.

Life history

The adult insects look like small houseflies. Adult life-span averages 2 wk, during which the female lays 50-100 eggs. The eggs are minute, shiny white, elongate, and are laid singly on the leaf blades. The average incubation period is 7 d.

The freshly hatched maggots are whitish and translucent. Each measures about 1 mm long. Maggots migrate to the central whorl of the rice plants to feed on the leaves near the growing points. The larvae also infest rice panicles within the boot and feed on the developing grains. The larval stage lasts for about 6 wk. The final instar larvae then move to the upper part of the rice stem and pupate on the upper and inner parts of the leaf sheath. The pupal stage lasts for about 14 d.

Seasonal occurrence and abundance

In Japan, the pest occurs in five distinct broods: two in the north and three in the south. In two-generation areas, first-brood flies appear in June and the second-brood flies in September. The first-brood flies oviposit on rice seedlings in the seedbed; those of the second brood oviposit on various grasses on which the insects overwinter as full-grown larvae. In three-generation areas, the first-brood flies emerge at the end of May and second-brood flies the second half of July. Both broods oviposit on the rice plants. The third-brood flies appear in September, oviposit on grasses and other hosts, and overwinter as full-grown maggots. The flies from two- and three-generation areas behave as distinct races, but those in mixed population areas freely interbreed. The maggots of three-brood populations develop faster than those of the two-brood populations.

In the Republic of Korea, the pest also has three generations a year with population peaks in the second half of May, early July, and mid-September.

In China, the pest also has three generations a year. Larvae overwinter in areas below 700 m, mainly in the grasses *Alopecurus japonicus, A. equalis,* and *Leersia hexandra,* and in wheat. Overwintered larvae pupate during mid- to late March, and adults emerge from mid- to late April. Larvae of the first generation feed on rice seedlings and pupate from late May to early June. Adults emerge from mid- to late June, and most of them migrate to rice areas above 800 m. Larvae of the second generation damage rice crops and pupate from early to mid-September. Adults emerge from mid-September to mid-October and migrate to lower, warmer areas where oviposition occurs. The hatching peak of third-generation larvae is in mid-November and these larvae overwinter.

Damage

Damage is caused by the maggots boring near the growing points and feeding on the leaf blades. Usually, they feed from the margin toward the midrib, causing broad, chewed patches along the sides of the leaf blades. Occasionally, they also puncture the leaves. Heavy infestation during the vegetative stage causes stunting. Second- and third-brood maggots also feed on developing grains within the boots, causing substantial losses. The damaged grains do not develop and the panicles have blank spots.

Rice varieties vary in their susceptibility to the stem maggot. Frequently, 10-20% of the panicles in susceptible varieties are infested during booting. A 10% infestation results in about 4% yield loss. Early-heading varieties usually have panicles damaged at the bottom; later varieties have panicles damaged at the top.

Control methods

Cultural control

Effective control measures include the use of irrigation against the overwintering generation and delayed sowing of the crop to escape peak damage by the pest.

Biological control

No natural enemies of this pest have been recorded so far, but spiders are considered probable predators in the Republic of Korea.

Varietal resistance

Several rice varieties from Japan are sources of resistance to the rice stem maggot. Among them are Aichi-asahi, Ashai, Joshu, Kanan-nansen, Ou 187, Ou 188, Ou 230, Ou 231, Sakaikaneko, Sin 4, Sin 5, Tohoku 64, Tugaru-asahi, Tyosen, Tyusin 203, Norin 10, and Obanazawa.

Chemical control

Rice stem maggot populations can be effectively controlled by insecticide treatment.

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Strategies for managing insect pests of rice

The high-yielding, early-maturing, modern rice varieties (MVs) developed since the 1960s caused major shifts in the insect pest complex. Insecticide use, which began during the widespread adoption of MVs, has become a major part of crop management recommendations in many developing countries. Indiscriminate use of these chemicals caused major outbreaks of insect pests such as brown planthopper (BPH) and green leafhopper (GLH) because of the destruction of indigenous predators and parasites that had kept pest populations in check most of the time. In addition, many MVs have resistance to insects, particularly to leafhoppers, planthoppers, and gall midge.

During the past three decades, considerable progress has been made on various methods of pest control in the tropics and subtropics. It is important to use all of these measures in developing an integrated pest management (IPM) program that is long-lasting, inexpensive, and environmentally safe. In most cases, this means using nonpesticidal methods of pest control, and resorting to pesticides only when the pest causes economic loss. IPM will require farmers to be trained to identify pests and their biological control agents, to do pest surveillance in their fields, and to apply various control measures.

A major constraint to implementing an effective IPM program for rice in tropical Asia and Africa is the lack of infrastructure, trained personnel, and an active program to demonstrate IPM to farmers and extension workers. Modification and adaptation of insect management programs to a particular socioeconomic situation are equally important.

The various components of IPM are host plant resistance, cultural control, biological control, and, finally, chemical control when pest damage exceeds or threatens to exceed the economic injury level.

Components of integrated pest management

Host plant resistance

Plant resistance as an approach to pest management in rice confers many advantages. Resistant rice varieties provide an inherent control that involves no expense nor environmental pollution problems, and are generally compatible with other insect control methods. The cultivation of resistant rice plants is not subject to the vagaries of weather as are chemical and biological control measures, and in certain circumstances it is the only effective means of control. Resistant varieties control even a low pest density whereas insecticide use is justifiable only when the density reaches the economic injury level. In some cases, resistance developed in plants for one insect pest species may also be effective against several others. Earlier concerns that resistance is frequently associated with poor grain quality and low yield have been overcome largely by incorporating resistance into high-yielding varieties of good quality. Depending on resistance levels, resistant varieties can be used either as the principal method of control or as a supplement to other methods of insect pest management. For example, rice varieties resistant to BPH and gall midge generally do not need supplementary control measures to protect them against these insects, but those resistant to stem borer (SB) need additional protection from infestation beyond the booting stage, or even earlier if the borer population is large.

Varietal resistance to insect vectors of plant diseases also often limits the spread of the viral diseases they transmit. In Colombia, fields of IR8, which is resistant to the rice delphacid *Tagosodes orizicolus* but susceptible to its transmitted hoja blanca virus, remains virtually virus-free, while other insect-susceptible rice varieties are heavily infested.

Fortunately, the world's rice germplasm is well endowed with sources of insect and disease resistance. Identification of sources of stable resistance is a major objective of rice improvement programs throughout the world. Rice varieties with multiple resistance to insect pests and diseases are now grown on more than 20 million ha in Asia and Central and South America.

Sources of resistance. Screening methods for more than 30 rice insect pests throughout the world have been developed and sources of resistance to most were identified over the past two decades (Table 10). Major emphasis has been on leafhopper, planthopper, SB, and gall midge. All the major rice-producing countries in South and Southeast Asia have breeding programs for BPH and GLH resistance. BPH-resistant varieties alone occupy about 25% of the irrigated lowland rice area in Southeast Asia. Strong breeding programs for gall midge resistance have been established in India, Sri Lanka, and Thailand, and several resistant rice varieties are available to farmers. Many rice varieties with moderate levels of resistance to SB have been released in Asia.

Plant resistance for occasional and secondary pests offers advantages, which are often overlooked. Resistance sources for leaffolders, rice hispa, rice bugs, and whorl maggots are available, but are not widely used in hybridization programs. On the other hand, the levels of resistance to many insect pests in cultivated rice are too low for breeding purposes. For most insect pests, only a small portion of the world's germplasm collection has been screened. Screening of the entire germplasm collection may identify varieties with higher levels of resistance.

Several wild rices have high levels of resistance to insect pests and diseases. With the development of innovative breeding techniques, those useful genes could be used to broaden the primary gene pool of cultivated rice. Genes for resistance to grassy stunt virus have been successfully transferred to rice from *Oryza nivara,* and resistance to BPH from *O. officinalis.* The world collection of more than 2,200 wild rice accessions at IRRI is being evaluated for resistance to various major and minor rice pests. Several accessions with high levels of resistance have been identified and may be used in wide hybridization breeding programs.

Breeding for resistance. Breeding for insect resistance in rice has been a focus of rice research programs only during the last two decades. Although differences in varietal susceptibility to pest infestations had been recorded for the last 50 yr or more, until 1962 scientists did not believe there was sufficient insect resistance in rice to be of practical value in breeding programs.

In the early screening at IRRI for genetic resistance to the striped stem borer (SSB), 10,000 rice accessions from IRRI's rice collection were evaluated in the field and in greenhouse experiments. Several types of germplasm were identified as resistant. Most of those resistant to SSB were susceptible to other pests and diseases and had limited practical value in a breeding program. Fortunately TKM6, a cultivar from India, was not only resistant to SSB, but was less damaged by other common pests

Table 10. Status of screening and breeding for varietal resistance to major insect pests of rice.

Insect	Status of resistance [a]					
	Screening methods developed	Resistance sources identified	Resistant breeding lines available	Resistant varieties released	Genes for resistance identified	Biotypes encountered
Scirpophaga incertulas (Walker)	+	+	+	-	-	-
Chilo suppressalis (Walker)	+	+	+	-	-	-
Maliarpha separatella Ragonot	+	+	-	-	-	-
Diopsis macrophthalma Dalman	+	+	-	-	-	-
Orseolia oryzae (Wood-Mason)	+	+	+	+	+	+
Nilaparvata lugens (Stål)	+	+	+	+	+	+
Sogatella furcifera (Horvath)	+	+	+	+	+	?
Laodelphax striatellus (Fallen)	+	+	+	+	-	?
Tagosodes orizicolus (Muir)	+	+	+	+	-	?
Nephotettix virescens (Distant)	+	+	+	+	+	+
Nephotettix cincticeps (Uhler)	+	+	+	+	-	?
Nephotettix nigropictus (Stål)	+	+	-	-	-	-
Recilia dorsalis (Motschulsky)	+	+	+	+	+	-
Cofana spectra (Distant)	+	+	-	-	-	-
Hydrellia philippina Ferino	+	+	-	-	-	-
Lissorhoptrus oryzophilus Kuschel	+	+	-	-	-	-
Dicladispa armigera (Olivier)	+	+	-	-	-	-
Spodoptera mauritia mauritia Boisduval	+	-	-	-	-	-
Mythimna separata (Walker)	+	-	-	-	-	-
Nymphula depunctalis (Guenée)	+	+	-	-	-	-
Leptocorisa spp.	+	+	-	-	-	-
Oebalus pugnax (Fabricius)	+	+	-	-	-	-

[a] + = yes, - = no, ? = biotypes suspected.

such as GLH and yellow stem borer YSB), and diseases such as bacterial blight (BB) and bacterial leaf streak (BLS). However, TKM6 had a low yield potential. To combine improved plant type with the desired characteristics, TKM6 was crossed with IR262-24-3 in 1965. This cross produced many promising breeding lines. One of these was released for cultivation in 1969 as IR20. IR20 possessed a moderate to high level of resistance to SSB, GLH, rice tungro virus, BB, BLS, and rice blast. It was the first high-yielding rice variety that had resistance to several of the common insect pests and diseases combined with good grain quality.

IR20 elicited much interest among rice scientists, and insect resistance became an important part of rice breeding programs of most national and international organizations. All IRRI varieties developed subsequent to the release of IR20 have resistance to common pests and diseases and are the most important elements in the integrated control of rice insect pests.

Genetics of resistance. Information on the mode of inheritance and the number of genes involved in the resistance of plants to particular pest species, although not essential for breeding resistant plants, has great practical significance for identifying donors of resistance, developing isogenic lines, and breeding broad-based resistant varieties. The completeness of the information available on the number of genes conferring resistance depends on the thoroughness with which the germplasm has been screened. Genes for resistance to several rice insect pests have been identified (Table 10).

Insect resistance in rice plants is governed by major genes [either a single gene (monogenic) or a few genes (oligogenic)] or minor genes [many genes (polygenic)]. Most of the known high levels of resistance are either monogenic or oligogenic, which are also easy to incorporate in improved plant types. Such resistance, however, is often short-lived. The erosion of monogenic resistance (conferred by *Bph 1* gene) in IR26 within 2 yr of its intensive cultivation in the Philippines and Indonesia in mid-1970s is a classic example of the inherent weakness of monogenic resistance. On the other hand, there are a few examples of major gene resistance remaining effective for long periods. Some rice varieties with major genes have retained their resistance to GLH over the last 40 yr.

Polygenic resistance is moderate, but is more stable and longer lasting than major gene resistance. This type of resistance is biotype-nonspecific because several minor genes are involved. The resistance to SB is polygenic. No biotype of any of these insects has been reported so far.

Nature of resistance. Although the exact mechanism of insect resistance in crop plants is not always known, the nature of resistance to some major insect pests of rice has been studied in detail. A general association between several morphological and anatomical characteristics of the rice plant (height, stem diameter, and length and width of flag leaf) and resistance to SB has been recorded. None of these characters, however, appeared to be the main cause of borer resistance.

A rice plant biochemical oryzanone (p-methylacetophenone) was identified as an attractant to ovipositing moths and larvae. Resistance of TKM6 and other resistant rice varieties was due mostly to production of allomones, which inhibit oviposition and disturb the insect's growth and development. This biochemical resistance factor, coded as Compound A, has recently been identified as a pentadecanal at IRRI in collaboration with the Tropical Development Research Institute, London. Compound A in resistant plants inhibits oviposition and adversely affects eggs, larvae, and pupal stages.

Resistance to leafhoppers and planthoppers does not seem to be associated with any morphological or anatomical peculiarities of the rice plant. It has been demonstrated that volatile allelochemicals from rice plants play an important role in imparting resistance or susceptibility to leafhoppers and planthoppers. These allelochemicals include a large group of low-molecular-weight compounds such as essential oils, particularly terpenoids, alcohols, aldehydes, fatty acids, esters, and waxes. A mixture of 14 esters, 7 carbonyl compounds, 5 alcohols, and 1 isocynurate has been identified in volatile attractant fractions of the BPH-susceptible Japanese rice cultivar Nihonbare.

Insect biotypes. Much genetic variation also occurs within the populations of various species of rice insect pests. When varieties resistant to these pests are grown, insect populations that are not able to survive and multiply on them are eliminated. But the population of surviving individuals or biotypes builds up. The development of new biotypes capable of surviving on resistant varieties limits the role of resistant varieties in insect control. For example, the threat of BPH biotypes to the stability of resistant rice varieties is considered serious. So far, three BPH biotypes (biotype 1, biotype 2, and biotype 3) have been identified in the Philippines and one biotype (biotype 4) in the Indian subcontinent. Genetic analysis of resistant varieties revealed nine major genes that convey resistance to the different BPH biotypes (Table 5).

Biotype 1, the general and predominant field population in the Philippines, can infest only the susceptible varieties—those that lack genes for resistance—such as IR5, IR8, IR20, IR22, IR24, and TN1. Biotype 2 can survive on and damage varieties carrying *Bph 1* resistance gene (e.g., IR26, IR28, IR29, IR30, IR34, Mudgo) in addition to those susceptible to biotype 1. Biotype 3, a laboratory biotype produced in the Philippines, can infest rice varieties carrying the *bph 2* gene (e.g., IR32, IR36, IR42, IR54, ASD7) and varieties vulnerable to biotype 1. Recently, a population of BPH collected from Mindanao, southern Philippines, equally damaged rice varieties with *Bph 1* and *bph 2* resistance genes. None of the BPH in the Philippines survive on varieties with *Bph 3, bph 4, bph 8,* and *Bph 9* resistance genes; *bph 5, Bph 6,* and *bph 7* convey resistance to biotype 4 of the Indian subcontinent. Several rice varieties that are resistant in the Philippines are susceptible in India and Sri Lanka because the allopatric biotypes of the pest in South Asia are more virulent than the Southeast Asian biotypes. The possibility of the occurrence or evolution of the more virulent BPH biotypes cannot be excluded if resistant varieties with new genes for resistance are planted intensively.

Although there are no confirmed reports of biotypic variation in the species *Nephotettix virescens,* virulent populations were selected at IRRI on the resistant Pankhari 203 (*Glh 1*), IR8 (*Glh 3*), Ptb 8 *(glh 4*), TAPL796 (*Glh 6*), and Moddai Karuppan (*Glh 7*). However, no such population could be selected on ASD7 (*Glh 2*) and ASD8 (*Glh 5*) rice varieties at IRRI.

GLH populations in different countries, however, show clear differences in their virulence to resistant rice varieties. Populations of *N. virescens* in Bangladesh and India have virulence patterns different from those of the Philippine populations. Pankhari 203, a rice variety with *Glh 1* resistance gene, is resistant to *N. virescens* in Indonesia and the Philippines but susceptible in Bangladesh, India, and Malaysia. Biotypic variations in GLH species *N. cincticeps* have been reported in Japan. Two distinct populations showing significant intraspecific variations in their responses to rice varieties were collected from Joestsu and Chikugo.

The existence of gall midge biotypes in India was suspected during the early stages of development of resistant rice varieties. Since then, many regional, national, and international collaborative studies have attempted to detect, define, and characterize biotypes of gall midge. Morphological variations were also noted in gall midge adults collected from India and Thailand. The insects were believed to represent two biotypes. Even within India, four gall midge biotypes occur.

The stability of insect resistance in rice varieties depends largely on the occurrence of these biotypes. Therefore, an important breeding objective is to incorporate stable resistance into high-yielding varieties. Many of the varieties bred at IRRI for resistance to BPH were not resistant to the South Asian biotype. That is one reason why IR36 is not as popular in India as in Southeast Asia. Gall midge-resistant varieties developed at the Central Rice Research Institute in Cuttack, Orissa, are susceptible to gall midge populations in the territory of Manipur, about 2,000 km from Cuttack.

The increasing importance of several insect pests and their biotypes in recent years points to the need for varieties with multiple resistance.

Wild relatives of cultivated rice, which are rich sources of several useful genes for insect resistance, should be identified and used in breeding programs. Resistance genes can be transferred to cultivated rice varieties using the embryo rescue technique. These genes from distant relatives can broaden the primary gene pool of *O. sativa.* Sequential release of resistant varieties with varying genetic background and the multiline approach will help combat insect biotype problems.

Cultural control

Changes in cropping practices of rice directly affect the dynamics of plant/insect associations. In the past, cultural practices as a method of pest suppression were a low research priority. With the development of the IPM philosophy, however, cultural control of insect pests is now an important strategy in rice production. Cultural practices, however, are usually dictated by agronomic and economic considerations. Unless insect pests are obviously a production-limiting factor, growers are unlikely to change cultural practices merely because of pest control recommendations.

Cultural control methods that suppress insect pest populations have advantages over chemical control because they do not require costly inputs, nor do they pose threats to nontarget organisms. Several cultural practices have a profound influence on insect pest survival, persistence in a particular environment, and crop damage. Sometimes, even a slight population reduction brought about by these practices prevents insect populations from reaching damaging levels. Cultural methods aim to disrupt or slow down population buildup of pests. They include sanitation (destruction [or use] of crop residue, of alternate hosts including weeds, and of habitats for aestivation or hibernation), tillage and flooding of fields to destroy insect pests in stubble, crop rotation, mixed cropping, timing of planting and harvest to escape pest infestations, use of trap crops, and proper fertilizer and water management. Although many of these practices are simple and easy to follow, they have greater impact when practiced community-wide.

Removal and destruction of stubble effectively minimize overwintering populations of many insect pests such as SB. Fall plowing results in high mortality of overwintering pupae and eggs. In China, plowing and flooding of large areas of ricefields before transplanting constitute a standard practice to reduce SB population in the subsequent crop. Proper crop rotation has helped to control BPH.

The proper timing of planting and harvesting dates helps many crops escape pest damage. In many countries, timing is regulated by ordinances or simply by the availability of irrigation water. Adjustment of planting or harvesting time is practical only in areas with distinct cold or winter seasons. Delayed planting to evade insect pests that emerge from overwintering populations has been practiced in temperate areas for many years. In the tropics and subtropics, however, the life cycle of many insect species revolves around the availability of host plants. Therefore delayed planting is effective only in minimizing pest outbreaks. In Laguna Province, Philippines, for example, a 2-mo moratorium on rice in May and June helped to control a 1973 epidemic population of BPH.

A successful example of the use of cultural practices for control of SB is reported in Japan. The major factor responsible for earlier outbreaks of YSB was the staggered planting of rice. The pest was controlled by simultaneously planting late rice. The decline in the population of SSB in Japan must have been influenced by a change in cultural practices that included planting early rice, which permitted mid-season harvest 2-3 wk earlier; straw destruction; and increasing the rate of slag application by 2-3 times. The area infested by YSB and SSB has continuously decreased since these cultural controls were adopted.

Although cultural practices are important in minimizing pest incidence, each one needs to be evaluated as part of the total crop production system. While some practices such as good land preparation are compatible with production technology, others such as change of planting dates may not be acceptable because of adverse effects on yields or the creation of conditions favorable for other insect pests. Growers who adopt cultural practices should understand their impact on insect pests. Several cultural practices suggested for controlling major insect pests of rice are given in Table 11.

Biological control

In the rice ecosystem, one of the most important approaches to biological control is conservation of the natural enemy complex. Although this tactic is much older than ones involving imported species, the importance of these communities of naturally occurring species was little known until broad-spectrum insecticides reduced their numbers to ineffective levels, resulting in the resurgence of pest populations.

Most research related to biological control in rice is confined to studies of seasonal and relative abundance, and on taxonomic surveys of natural enemies.

Rich communities of biological control agents attack rice insect pests in the absence of chemical insecticides (Fig. 23a-p). The predator and parasite complex present in most undisturbed rice ecosystems is diverse. At least 98 species of parasites have been reared from SB alone.

Table 11. Suggested cultural control measures for selected insect pests of rice.

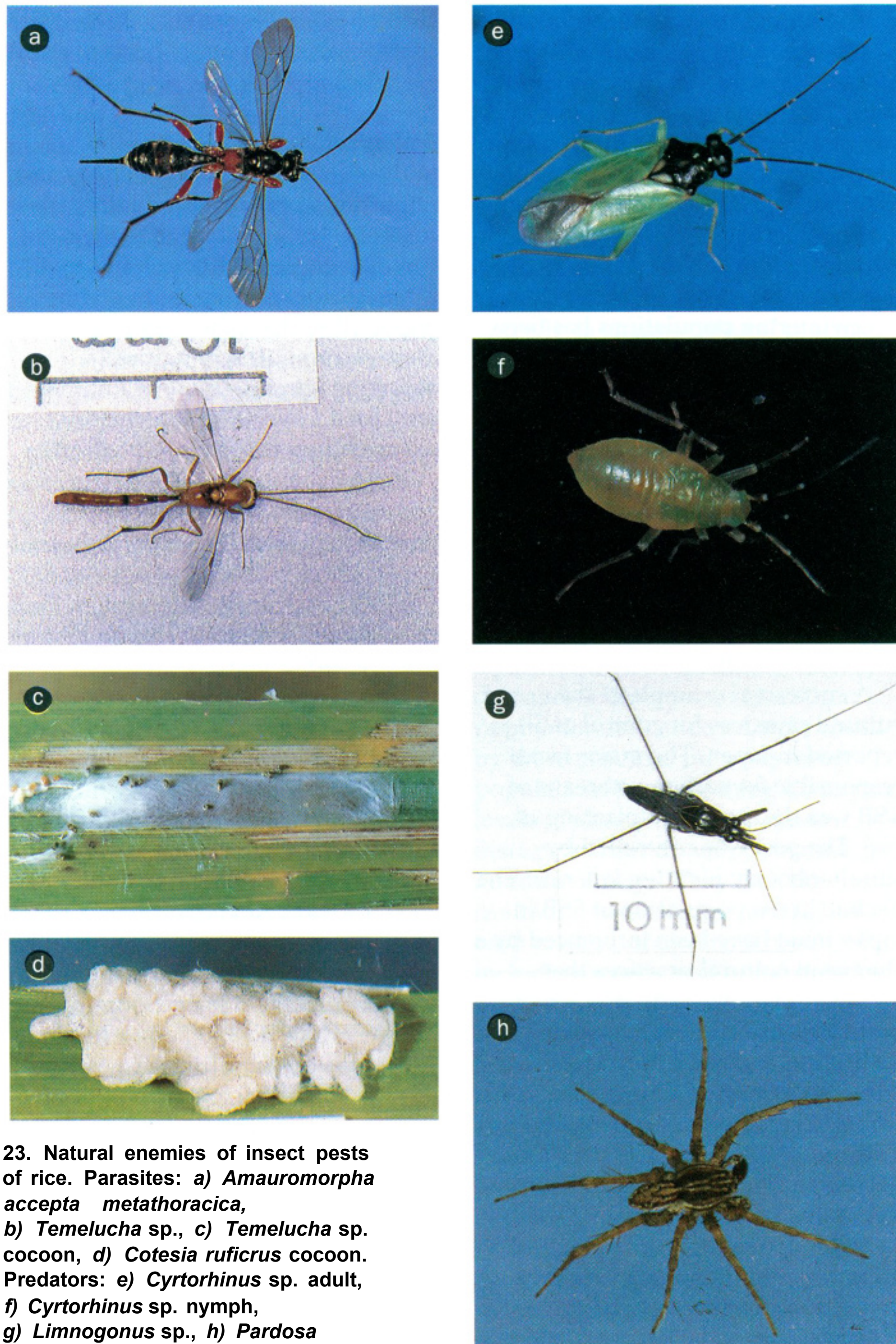
Insect pests	Measures
Stem borers	Planting early-maturing varieties Synchronous planting Early planting Delayed planting Cutting rice stalks at ground level and destruction of stubble, plowing Application of calcium cyanamide to enhance stubble-rotting and stem borer larval mortality Increased amount of slag ($CaSiO_3$) Trap crops Judicious use of fertilizer, split N applications Removal of egg masses from seedlings before transplanting Field drainage
Brown planthopper, whitebacked planthopper	Sanitation of field, plowing of volunteer ratoon Crop rotation with no more than two crops per year Draining of the field Judicious use of fertilizer, split N applications
Green leafhoppers	Growing no more than two rice crops and plowing stubble after harvest Early planting Trap crop
Gall midge	Removal of grassy weeds and wild rices from surrounding areas and ricefields Judicious use of fertilizers, split N applications Late planting Early planting Wide spacing
Whorl maggots	Early planting Field drainage
Leaffolders	Judicious use of fertilizer, split N applications Early transplanting Removal of grassy weeds
Rice bugs	Weed sanitation and eradication of alternate hosts No staggered planting Early-maturing varieties No very early or very late planting

In addition, many species of generalist predators feed on the immature and adults of most pest species.

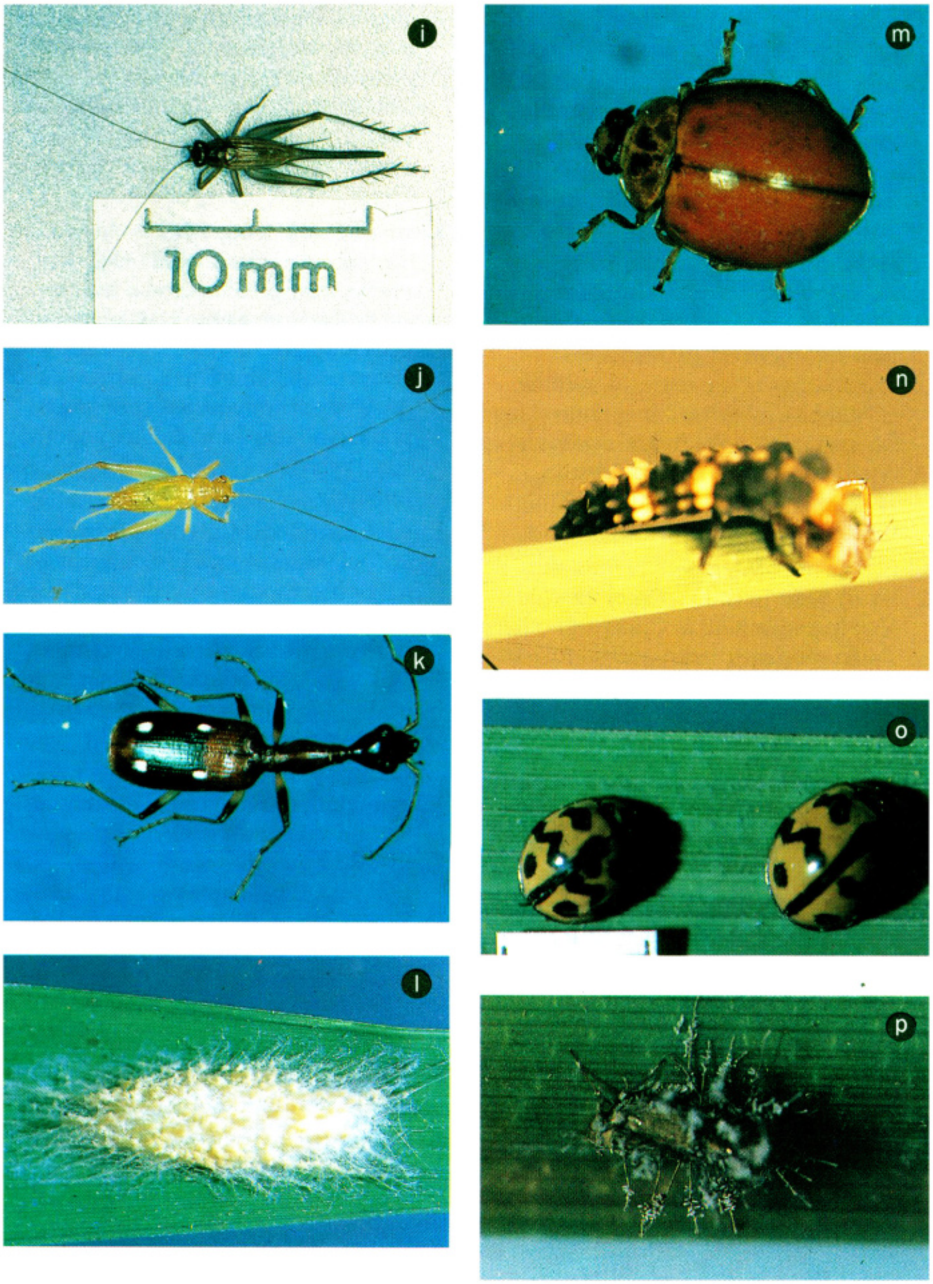
The parasite complex of leafhoppers and planthoppers is somewhat less diverse, but positive correlations have been found between percentage of egg parasitization and increasing hopper density. That suggests a density-dependent response by the parasites. Likewise, there is a strong correlation between the density of BPH and lycosid spiders. *Cyrtorhinus lividipennis* Reuter is usually the most abundant predator of BPH in ricefields. Correlations between numbers of this predator and hoppers have been found in Malaysia and recently in the Philippines. Numerous other parasitic and predatory species add to the overall mortality of insect pest species on rice. Any disruption of these communities often causes pest resurgence.

Like other insects, rice pests such as BPH, rice bug, rice black bug, and various lepidopteran pests are susceptible to entomopathogenic microorganisms. Of these, the emphasis has been given historically to the entomopathogenic fungi. Impressive epidemics of these fungi in insect populations are observed in the field. The key factors that trigger these epidemics are not known. However, environmental factors such as temperature, humidity, and the presence or absence of harmful pesticides undoubtedly play an important role.

Insect viruses have recently been identified as another group of important entomopathogenic microorganisms of insect populations in rice. High levels of infection have been recorded, especially in populations of lepidopteran larvae (e.g., leaffolder, armyworm). Research on this important group of natural enemies has recently been initiated at IRRI. In relation to the conservation of natural enemies, the specific pesticide containing spores of the entomopathogenic bacterium *Bacillus thuringiensis* Berliner is currently being tested against several lepidopterous pest



23. Natural enemies of insect pests of rice. Parasites: *a) Amauromorpha accepta metathoracica, b) Temelucha* sp., *c) Temelucha* sp. cocoon, *d) Cotesia ruficrus* cocoon. Predators: *e) Cyrtorhinus* sp. adult, *f) Cyrtorhinus* sp. nymph, *g) Limnogonus* sp., *h) Pardosa pseudoannulata, i) Metioche* sp., *j) Anaxipha* sp., *k) Ophionea nigrofasciata, l)* Egg cocoon of *Tetragnatha virescens, m) Harmonia octomaculata, n) Harmonia octomaculata* larva feeding on BPH nymph, *0) Menochilus sexmaculatus.* Pathogen: *p) Hirsutella* sp.



species. If effective against these pests, wider use of this product will be advocated and should result in further conservation of the predator, parasite, and entomopathogen complexes. Recently, IRRI initiated a project on transfer of *B. thuringiensis* gene to rice varieties for control of lepidopterous insect pests.

Nematodes have also been identified as an important group of microorganisms attacking rice pests.

Few attempts have been made to introduce natural enemies of rice insect pests from one country to another. The few have had rice SB as the primary target. The introduction of parasites from China and Japan to control *Chilo suppressalis* in Hawaii is the only known importation effort successful in rice.

Chemical control

Although it is well known that chemical control is incompatible with the ecological approach to pest management, pesticides still remain the first line of defense against many rice insect pests and are used freely when insect outbreaks occur. In Japan, national rice production progressively increased following the wide adoption of parathion in 1953 and the subsequent use of other insecticides.

Although insecticides have effectively controlled many insect pest species, their extensive use has led to serious social and environmental repercussions. The poisoning of livestock, fish, wildlife, and other beneficial organisms has been linked with pesticide use. Likewise, there has been a disturbing increase in human poisonings, particularly in developing countries. A recent survey in a major rice-growing area of the Philippines showed that, after widespread adoption of insecticides by farmers on small holdings, there was a 27% increase in mortality from causes other than trauma.

Pest resurgence associated with insecticidal destruction of natural enemies and the development of insecticide resistance lead to increased doses or more powerful insecticides. The IPM strategy emphasizes need-based use of insecticides rather than prophylactic treatment.

Insecticide-induced resurgence of BPH has been reported in every country in tropical Asia. Other examples of insecticide-induced outbreaks include those of GLH and leaffolder. Although several other factors have been implicated in inducing resurgence, it is generally recognized by most rice scientists that the primary cause is destruction of the insect pests' natural enemies by insecticides. Rice entomologists have recently begun to look at the interactions between resistant plants and chemical insecticides. There is strong circumstantial evidence that chemical insecticide applications accelerate adaptation of insect pests to previously resistant rice varieties. Thus the importance of natural enemies could be masked where farmers do not realize their importance.

Sometimes chemical insecticides are still needed on rice in tropical Asia to arrest damaging populations of insects, but their safe and effective use is still not practiced. Several selective chemicals such as buprofezin, the molting inhibitor for BPH, are available; they could greatly improve insecticide safety and selectivity. Identifying such selective chemicals and modifying application methods can make insecticide use more compatible with other IPM components.

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