http://www.pjbs.org

PJBS

ISSN 1028-8880

Pakistan Journal of Biological Sciences

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Pakistan Journal of Biological Sciences, 2 (2): 261-276, 1999 Review Article

Rice Insect Pests of Pakistan and Their Control: A Lesson from past for Sustainable Future Integrated Pest Management

Shahid Karim and S. Riazuddin
National Centre of Excellence in Molecular Biology,
University of the Punjab, Lahore-5370, Pakistan.

1. Preamble

Rice is the world's most important food crop second to wheat, feeding over 2 billion people in Asia alone. On this continent about 90% of the world's rice is grown (International Rice Research Institute, 1993). The rice crop not only provides food for people, it also a host to over 800 species of insect herbivores. In Pakistan, rice is an important food crop as well as commercial crop. It occupies about 10 percent of the total cropped area and on average 1/3rd of its production is exported every year (Anonymous, 1995). The area (Fig. 1), production and yield of rice in each province are given in Table 1. Rapid population growth has forced to increase in rice production. Since it is not possible to extend the rice growing area infinitely, it is necessary to adopt measures to enhance yield per hectare. The national average yields in Pakistan are about half the yields in most of the developed countries. An important measure to enhance yield is to control insect pests of rice. A large number of different chemical pesticides are being used to control insect pests in Pakistan (Woodburn, 1990). Insecticide resistance is the major problem in controlling insect pests and more than 500 arthropod species has been recorded with resistance against insecticides either chemical or biopesticides (McGaughey and Beeman, 1988; Georghiou, 1990; Rodcharoen and Mulla, 1994) worldwide. Indiscriminate use of chemical pesticides not only increase the rate of resistance evolution, but is also a risk to humans health, the environmen and biological control of insect pests by predators and parasites (Hansen, 1987; Waage, 1993). The increasing awareness of the undesirable side effects of chemical pesticides, the drudgery of applying them frequently and the development of insect resistance have stirred scientific interest in alternative insect control measures. Therefore, there is a need for integrated pest management (IPM) approach to reduce the use of chemical pesticides with environment friendly methods. IPM is a process by which farmers get help from a range of different pest control methods to achieve the most effective, economical and sustainable combination for a particular local situation.

The major insect pests that cause significant yield losses are stem borers, leaffolders, plant-hoppers and leafhoppers (Inayatullah *et al.*, 1986; Mahar and Bhatti, 1986; Rehman *et al.*, 1986). Since the introduction of high yielding varieties, distinct changes have occurred in the insect pest complex of Pakistan. Several species, which were once considered minor pests, are now considered major pests in Pakistan. Examples are leaffolders and white-backed plant hopper. Stem borers are still a great threat in traditional Basmati growing areas (Kalar tract) in Punjab province. Basmati yield loss caused by yellow stem borer (*Scirpophaga incertulas*), white stem borer *(Scirpophaga innotata),* pink stem borer (*Sesamia inferens*) and striped stem borer *(Chilo suppressalis)* has been estimated at 20-25 percent (Afzal *et al*., 1977; Ahmad *et al*., 1979a; Ahmed, 1984, 1987; Mahar *et al*., 1986). The leaf folder complex, including *Cnaphalocrocis medinalis* and *Marasmia patnalis,* has become a major pest of rice with change in cultural practices like using higher amounts of fertilizers in high-yielding varieties (Dhaliwal *et al*., 1979). A complete list of rice insect pests in Pakistan is given in Table 3.

Here, we present a brief review about the major insect pests of rice in Pakistan, identification, biology, control methods and future control strategies.

2. Rice Plant

Rice, an annual grass *(Graminae),* belongs to the genus *Oryza* that includes twenty wild species and two cultivated species, *O. sativa* (Asian rice) and *O. glaberrima* (African rice). *Oryza sativa* is the most commonly grown species trirougnout the rice-growing world today. In Asia, *O. sativa* is differentiated into three subspecies based on geographic conditions; *indica, javanica* and *japonica. Indica* refers to the tropical and subtropical varieties grown throughout South and Southeast Asia, southern China. *Javanica* designates the bulu (awned) and gundil (awnless) rices with long panicles and bold grains growing alongside of indices in Indonesia. *Japonica* refers to the short and roundish grained varieties of the temperate zones of Japan, China and Korea. *Japonica*-type varieties are grown in northern California, USA due to their tolerance to low night temperatures. *Indica*-type varieties are grown in the southern USA.

The rice plant consists of the roots, stem, leaves and panicle. Rice passes through the 10 stages during its growth cycle; germination and emergence, seedling, tillering, stem elongation, panicle initiation, panicle development, flowering, milk gram, dough grain and mature grain stage (Reissig *et al*., 1986). Traditional varieties like Basmati require about 150 days for growth to reach the mature grain stage whereas the modern, high yielding, very early maturing varieties can be harvested in as few as 90 days after sowing.

3. Major Pests of Rice in Pakistan

The rice plant is vulnerable to many insects from its sowing to harvest.

Table 1: Rice area, production and yield in Pakistan

Locality	Area (h)	Production (tonnes)	Yield (Kg/h)
Baluchistan	1209000	333200	2756
NWFP	62700	118400	1888
Punjab	1300600	1488200	1221
Sindh	702900	1954900	2781
Pakistan	21871000	3994700	1826

Table 2: Registered insecticides to control insect pests of rice in Pakistan

Registered Insecticides	Common Name	Target insect pest	Company
Agree (50 WP)	*Bacillus thuringiensis*	Lepidopteran	Novartis
Condor (7.5 FS)	*Bacillus thuringiensis kurstaki*	Lepidopteran	Agrevo
MVP bioinsecticide	*Bacillus thuringiensis kurstaki*	Lepidopteran	National Pesticide
Larvo-Bt	*Bacillus thuringiensis*	Lepidopteran	National Pesticide
Bactospine (1600 WP)	*Bacillus thuringiensis*	Lepidopteran	Pakistan Agrochernicals
Thuricide (1600 WP)	*Bacillus thuringiensis*	Lepidoptera	Agrevo
Sumthion (98 ULV, 50 EC)	Fenitriothion	Lepidopteran	Granulars (Pvt.) Ltd.
Malathion (95, ULV, 57 EC, 50 WDP)	Malathion	Broad spectrum	Cynamid
Sumibas (75 EC, 4D)	Fenitrothion + BMC	Hornopteran	Agril Chem & Dyestuff
Mipcin (50 WP)	MIPC	Homoptera	Nichemin Corporation
Deltanet (400 EC)	Furathiocard	Homoptera	Novartis
Padan (10 G and 4G)	Cartao hydrochloride	Broad spectrum	Nichemin Corporation
Nuvacron (40 SCW)	Monocrotophos	Broad spectrum	Novartis
Azodrin (40 WSC)	Monocrotophos	Broad spectrum	Pakistan Burma Shell
Karate (2.5 EC, 2 ED & 0.8 ULV)	Lembda Cyhalothrin	Broad spectrum	ICI Pakistan
Rogor (40 EC & 65 ULV)	Dimethoate	Broad spectrum	Alintco Pvt. Ltd.
Sevin (85 SPO	Carbaryl	Broad Spectrum	Rhone-Poulenc Pakistan
Sevidol (4 + 4 GO	Carbaryl + BHC	Broad Spectrum	Rhone Poulenc Pakistan
Orthane (40 EC, 75 SP & 5 G)	Acephate	Broad spectrum	R. B. Avari & Co.
Lannate (90 WSP & 29 LU)	Methomyl	Broad spectrum	Du Pont Far East.
Curatter (3 G)	Carbofuran	Broad spectrum	Chemdyes Pakistan
Diafuran (3 G)	Carbofuran	Broad spectrum	Nichemin Corportion
Furadan (3 G & 10 G)	Carbofuran	Broad spectrum	FMC Pakistan
Birlane (24 EC & 10 EC)	Chlorfenvinohos	Broad spectrum	Cynamid Pakistan
Basudin (14 G, 10 G & 5 G)	Diazinon	Broad spectrum	Novartis
Diazinon (14G, 10G, 56)	Diazinon	Broad spectrum	EPAID CO.
Miral (2G)	Isazofos	Broad spectrum	Novartis
Cidial (5G)	Phenthoate	Broad Spectrum	GHR Pvt. Ltd.
Evisect (5G)	Thiocyclam hydrogenoxalate	Broad spectrum	Agrevo

Table 3: Insect pests of rice *(Oryza sativa)* in Pakistan

Common Name	Scientific Name	Order/Family	Major Host/Alternate Host Plant
Yellow Borer* Stem	*Scirpophaga incertulas* (Walker)	Lepidoptera/Pyralidae	Rice/Wild rices, Grass weed
White Borer* Stem	*Scirpophaga innotata* (Walker)	Lepidoptera/Pyralidae	Rice/None
Stripped Borer* Stem	*Chilo suppressalis* (Walker)	Lepidoptera/Pyralidae	Rice/Maize
Pink stem borer*	*Sesamia inferens* (Walker)	Lepidoptera/Noctuidae	Rice/Maize, Sugarcane Wheat
Sorghum Stem Borer**	*Chilo partellus* (Swinhoe)	Lepidoptera/Pyralidae	Sorghum/Rice, Maize
Dark-head Rice Borer* *	*Chilo polychrysus* (Meyrick)	Lepidoptera/Pyralidae	Rice/none
Leaffolder*	*Cnaphalocrocis medinalis* (Guenee)	Lepidoptera/Pyralidae	Rice/Corn, Sorghum
Leaffolder**	*Marasmia patnalis,* Bradley	Lepidoptera/Pyralidae	Rice/Corn, Sorghum
Army worm* *	*Mythimna separate.* (Walker)	Lepidoptera/Noctuidae	Maize, Cotton/Rice, crucifers, cucurbites, Potatos
Cutworm**	*Spodoptera litura* (Fabricius)	Lepidoptera/Noctuidae	Cotton, Maize/Rice
Rice Cutworm**	*Spodoptera cilium*, Guenee	Lepidoptera/Noctuidae	Rice /Maize, Cucurbetes, Legumes Okra

Rice swarming caterpillar**	*Spodoptera mauritia acronyctoides* (Guenee)	Lepidoptera/Noctuidae Lepidoptera/Noctuidae	maize/Rice, Legumes, Sorghum, Sugarcane, wheat
Grasy cutworm**	*Agrotis ipsilon* (Hfn.), *Plusia orichalcea (F.),* *Brachmia arotraea* Meyr.	Lepidoptera/Noctuidae	Cotton, Cruciferous, Lettuce/Rice
Rice Skipper**	*Parnara Guttata* B. & G., *Tephrina dispitaria* Gn., *Diacrisia oblique* Walker, *Euproctis corvine* Moore, *E. fraterna Moore, E. vurguniula*, *Psalis pennatula* F.	Pyralidae Gelechiidae Lepidoptera/Hesperiidae	Maize, Sugarcane/Rice, Wheat
		Arctiidae Lymantridae	Legumes/Rice Caman Chile
Rice Caseworm**	*Nymphula clepunctalis* Guenee	Homoptera/ Tropiduchidae	Sweetpotato/Rice
Rice Grasshopper*	*Hieroglyphus banian* (F.)	Orthoptera/Acriididae	Rice/Maize, Sorghum
Small Grasshopper*	*Oxya multidentata* (Will.), *O. velox* F.	Homoptera/Acriididae	Rice/Maize, Sorghum Wheat and Sugarcane
Short horned Grasshopper**	*Attractomorpha acutipennis* (Guer.), *Eyorepocnemis plorans* (Charp.), *Shirakiacris shirakii* (I. Bol.), *Trigonocorpha* sp.		
Surface Grasshopper**	*Aiolopus* sp., *chrotogonus* sp.	Orthoptera/Acriididae	Maize, Cotton, Sorghum/ Rice, Wild grasses
Mole cricket**	*Gryllotalpa africana* Beau	Prthoptera/Gryllotopidae	Cruciferous/Rice Solanaceous
Field cricket**	*Acheta domesticus*		
Rice Hispa*	*Dicladispa armigera Oliv.*	Coleoptera/Chrysomelidae	Rice
Whitebacked planthopper*	*Sogetella furcilera* (Horvath)	Homoptera/Cicadellidae	Rice
White leafhopper*	*Cofana spectra* (Distant)	Homoptera/Cicadellidae	Rice/Maize, Sugarcane Wheat
Green Leaf hopper**	*Nephotettix nigropictus* (Stal)	Homoptera/Cicadellidae	Rice/Cucurbitae, Sugarcane Solanaceous
Maize leafhopper**	*Cicadulina bipuntella* Mats. *Ralclutha* sp.	Homoptera/Cicadellidae	Maize/Rice
Corn leaf Aphid**	*Rhopalosiphum maidis* (Fitch)	Homoptera/Aphididae	Maize, Sugarcane, Sorghum/Rice
Rice. mealy bug**	*Ripersia oryzae* Green	Homoptera/ Pseudococcidae	Rice/Polyphagous
Rice bug**	*Leptocprisa acute* (Thunberg), *L. varicornis* F.	Hemiptera/Alydidae	Rice/Sugarcane
Green soldier bug**	*Acrosternum* (Nezara) *graminea*	Hemiptera/Pentatomidae	Cotton, Okra, Maize/Rice
Black rice bug	*Scotinophora coarctata* (Thunberg),	Creontiades pallidus Ramb.	Hemiptera/Pentatomidae Rice
Rice root weevil**	*Hydronomidius mollitor* Fst.	Coleoptera/ Carcenlionidae	Rice/Wild grasses
Rice shoot fly**	*Atherigona aoryzae* Mall	Diptera/Muscidae	Rice/Maize
Sorghum Shoot fly**	*Atherigona soccata* Rond.	Diptera/Muscidae	Sorghum/Rice
Rice gall midge**	*Pachydiplosis oryzae* (W-M), *Animala* sp. Nr. *Dilatata* Arrow, *Animala dorsalis* F.	Diptera	Rice
Flea beetle**	*Phyllotreta chotanica* Duviv, *Myllocerus discolor* Bohr.	Coleoptera/Chrysmelidae	Rice/Crucifers, Keaf

*Major pest. ** Minor pest.

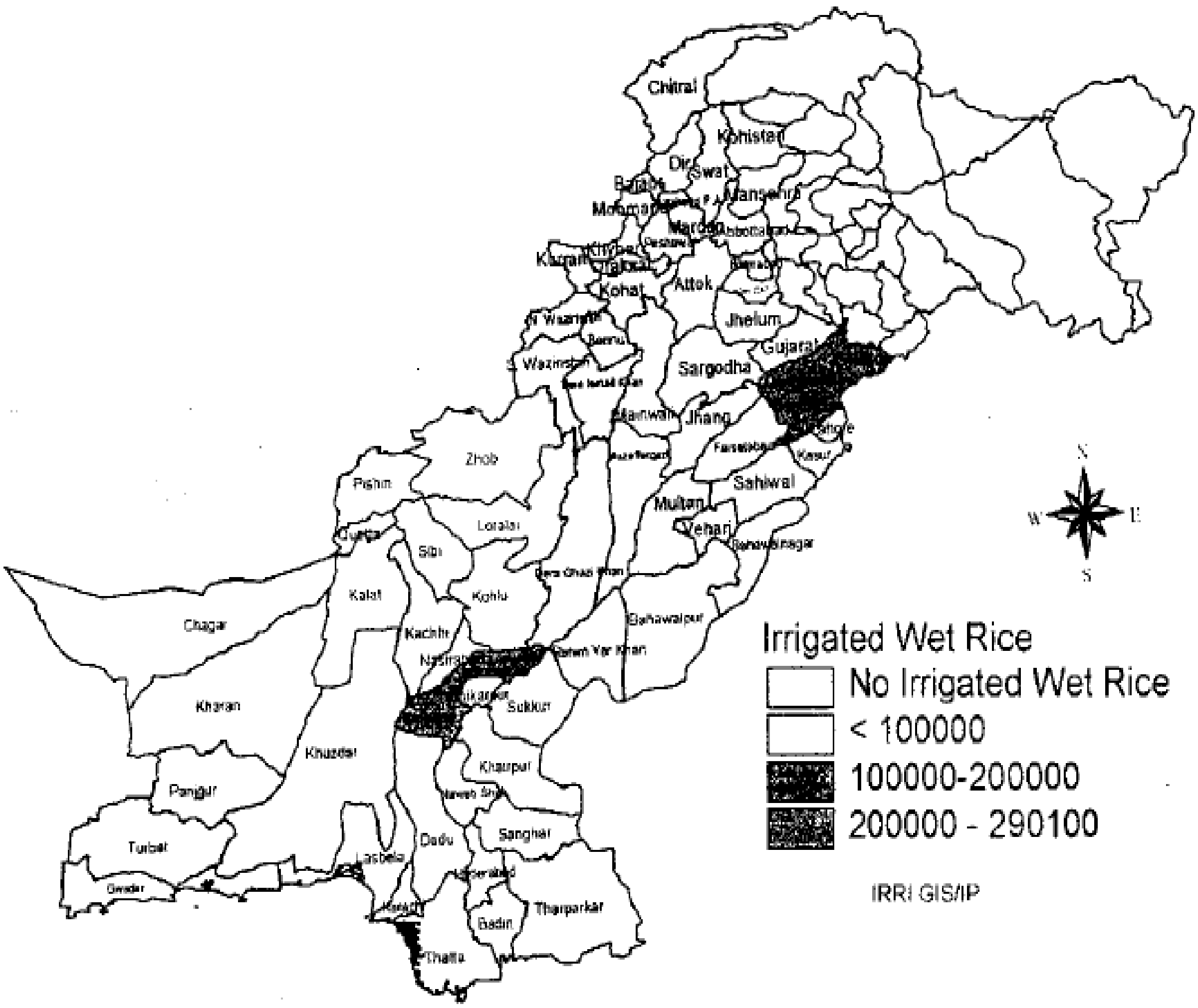

Fig. 1: Rice by culture

There are over 50 insect pest species damaging rice plant in Pakistan, although the majority does very little destruction. Only 10 species are of major economic importance and can cause economic damage of about 25-30 percent (Niaz, 1971). Few of the species that were earlier considered, as minor pests have recently become major pests like leaffolders, plant and leafhoppers. Under each major pest, its distribution, major host and alternate host plants, life cycle, symptoms and damage are given in the proceeding section. In case of few pests, little or no information on their life cycle or identification is available.

Stem borers: Rice stem borers belonging to two Lepidopteran families of Pyralidae and Noctuidae can infest rice plants from seedling to maturity. Pyralid borers are the most common and destructive of all stern borers and usually have a high degree of host specificity (Pathak, 1968). The noctuid borers are polyphagous and only occasionally cause economic losses. In Pakistan, the most important and widely distributed species are yellow stem borer, *Scirpohaga incertulas* (Walker), white stem borer, *Scirpohaga innotata* (Walker), pink stem borer, *Sesamia inferens* (Walker) and striped stem borer, *Chilo suppressalis* (Walker) (Koehler, 1971; Haque, 1970; Inayatullah *et al.*, 1989, 1990; Inayatullah and Rehman, 1990). Stem borer larvae start their attack by boring the inner portion of leaf sheaths (Moiz, 1969). At this stage, the symptom of damage is the longitudinal yellowish white patches at the feeding sites on the leaf sheath (Javed and Ahmed, 1974). The subsequent boring of the stem by caterpillars often leads to severing of the apical plant parts from the base. As a result, the central leaf whorl does not open, turns brown and dries. The lower leaves, however, may still look green and healthy. This condition is known as "dead heart" and the affected tillers do not bear panicles. if the detachment of growing plant parts takes place after panicle initiation, the panicles may not emerge, or these that have already emerged, may not produce grains (Ahmad *et al*., 1979b). Such panicles are noticeable in the field by bearing empty grains, being erect and white. They are termed "white heads".

3.1.1. *Scirpohaga incertulas* (Walker), Yellow Stem Borer:
Distribution: Pakistan- all rice growing areas, South and South East Asian Countries.

Life History: The adults of yellow stem borer are nocturnal, positively phototropic and strong fliers, are diurnal and rest in the shade when not actively flying (Loevinsohn and Bandog, 1991). Moths usually emerge in the early hours of night. The female moth is bigger than male and its forewings are bright yellowish brown with distinct black spot in the centre. The abdomen is wide, the tip being covered with tufts of yellowish hairs (Ahmad *et al.*, 1979a). The male moth is pale yellow; the abdomen is slender and the posterior end has a thin hairy covering dorsally. Spots on male moth wings are not noticeable. Mating generally occurs between 7 to 9 p.m. The sex of YSB based on light trap catches has been reported as generally more females than males (Pathak, 1968). The female moths lay eggs early at night in small masses near the tip of leaf blade. A female moth is capable of laying 100-150 eggs. They are creamy white, flattened, oval and scale like and covered with tuft of anal hairs from female moths. Before hatching, the eggs turned dark brown. The hatching larvae are negatively geotropic and crawl upward toward the tip of plants where they stay for only short time. Some spin a silken thread, suspend themselves from it and swing with the wind to land on other plants. During this roaming period, many larvae die. The survivors enter between the stem and the leaf sheath and feed on green tissues of the leaf sheath for next two to three days. The larvae then start boring in the stem, often at the nodal region and feed on its inner tissues of the plant. The full-grown sixth instar larvae are 25 mm long, white or yellowish white and with a well-divided prothoracic shield. They make a thin silken case over themselves inside the stem soon after the prepupal molt. The larval period usually lasts for 30 days. Before pupation, the larvae make an exit hole through which the adult moth later escapes. Pupation takes place inside the stem, mostly in the lowest node of the plant or just above the water level. Pupae are pale at first and turn darker brown after sometime. The pupal period is 6-10 days but may be prolonged in cooler months. In winter season, when there is no rice crop in the field and temperature is also not optimal for larval development, mature larvae diapause in rice stubble.

Damage: The extent of losses varies in time and space. The average incidence increased with the stage of crop, from early elongation phase to ripening through late elongation and booting-heading stages (Ahmad and Afzal, 1982). Reduction in yield of Basmati varieties on account of yellow stem borer has been estimated at 20-30 percent and occasionally, the crop infestation goes up to 90 percent (Mahar and Hakro, 1994; Mahar *et al*., 1986; Salim *et al*., 1991).

3.1.2. *Scirpophaga innotata* (Walker), white stem borer:
Distribution: Pakistan-all rice growing areas, Australia, South and South East Asian countries.

Life History: The white stem borer is also a major pest of rice in Pakistan. The adult WSB is similar to the YSB in appearance. The adult moths of WSB are similar in appearance. The white moth with an orange anal tuft is commonly seen in the field especially in the early stages of the crop. The adult female has a wingspan of 26-30 mm and the male of 18-24 mm. Female moth usually lay eggs in cluster of 70-260 on the underside of young leaves. The egg mass is covered with silky hairs from the anal portion of the female moth and is similar to that of the yellow stem borer. Larvae hatch from the eggs in 4-9 days. The young larvae penetrate the leaf sheath and bores down into the stem. Larvae are milky white and grow to a length of 25 mm. The larval stage varies from 19-31 days. The full-grown larva pupates within the stem after making an exit hole for the moth to emerge like *S. incertulas.* Pupae are soft bodied, pale and 12-15 mm long. They are whitish and pupate for 7-11 days. Like *S. incertulas, S. innotata* larvae also undergo diapause during winter season. White stem borers produce 3-5 generations on the rice crop depending upon the duration of the variety, time of sowing and transplanting.

Damage: Damage and nature, same as yellow stem borer. The first 3 generations cause deadhearts in nurseries and in the young crop while feeding of two subsequent generations causes whiteheads.

3.1.3. *Chilo suppressalis* (Walker), striped stem borer:
Distribution: Pakistan-all rice growing areas, Europe, South and South East Asian countries.

Life History: The adult moths are 13-16 mm long and with straw to light brown forewings. Striped stem borer moths carry a number of silvery scales and usually five black dots at the tip of the forewings; the hind wing is yellowish white. Females are lighter in color than males. Moths emerge at early night hours and become active in the early morning. During the daylight, moths remain in dense foliage. Mating usually takes place during the night of emergence but egg laying starts only on the next night. Male and female moths mate maximum 8 in their life span. A female moth may lay 100-550 eggs in batches of 50 to 80 each night over a 3-5 days period. Eggs are naked and scale like, pale to dark yellow, laid in masses formed of overlapping rows. Egg masses are found on basal half of the leaves. Eggs hatch in 3-5 days. The larvae live gregariously during the first three instars. The newly hatched larvae crawl up the rice plant and then congregate beneath the leaf sheath. All larvae enter the stem through a common hole. The fully-grown larva is approximately 26 mm long and 2.5 mm wide. It has a yellowish brown head and _three dorsal and two lateral brownish abdominal stripes. The larval stage normally lasts from 20-48 days. Pupation takes place within the stem like other stem borers. The pupa is reddish brown in color and is without a silken cocoon. Under ideal ecological conditions, there are 5-6 larval instars while under stress conditions, as many as 9 instars have been recorded. There are 1-4 generations per year depending on the availability of host plant and occurrence of favorable temperature conditions.

Damage: The pest mainly attacks rice in the middle or late stage of plant growth. In addition to causing deadhearts and whiteheads larval feeding can also cause reduced plant vigor, fewer tillers, unfilled grains and lodging of plants.

3.1.4 *Sesamia inferens* (Walker), pink stem borer:
Distribution: Pakistan-all rice growing areas, South and South Asian countries.

Life History: The pink stem borer is generally the least damaging stem borer species. The adult moth is fawn, the forewings being tan with dark brown markings from a centered point in the forewings. Grey-black lines radiate toward the wing tips ending in a thin terminal line of dark spots. There are tufts of hairs on pronotum. The hind wings are white. The wing span is 30-35 mm in female and 20-30 mm in the male. Female moth laid around 400 eggs. Eggs are creamy white to dark and are naked and hatch in a week's time. The larva has an orange-red head capsule and its body is purplish pink dorsally and white ventrally. The head is relatively large compared to the rest of the body. Larvae often come out of one stem and bore into additional stems, thus destroying several plants. The larva becomes full-grown in 4-5 weeks, undergoing 5-7 molts. At this stage, it is 20-26 mm long. Pupation takes place inside the larval tunnel within the stem but occasionally occurs outside the stem between the leaf sheath and the stem. The pupa is dark brown with a tinge of purple on the cephalic region. It is 18 mm long and 4 mm wide. The pupation usually is about for one week. There are up to six generations in a year.

Damage: Similar to other stem borers but it is leas destructive. This may be due to its polyphagus nature Outbreaks in rice usually result from a population spill ove from adjacent sugarcane fields or other alternate hosts.

3.2. Leaffolders

The rice leaffolders, earlier considered as a minor an sporadic pest of rice, appear to have become increasing! important with the spread of high yielding varieties any accompanying changes in cultural practices (Joshi, 1988) Misuse and excessive use of nitrogenous fertilizers hay been cited as the cause for high leaffolder populations.

3.2.1. *Cnaphalocrocis medinalis* (Guenee), rice leaffolder:
Distribution: Pakistan-Kalar tract and Sindh. Australia South and South East Asia.

Life History: Moths are nocturnal and in bright daylight hide themselves under surface of leaves and on stems. During the early morning hours, moths are often active bu their activity goes down as light spreads. The moths ar attracted to light. Adult moths are yellowish brown ii color, small and are 10-12 mm long with a wing expand o 13-15 mm. The wings take the shape of an equal side triangle when at rest. The forewings have three obliqu lines of varying lengths. The hind wings have a broad an area. The tibiae are tufted with black hairs, which are prominent in the male moth but not in female. The tip of the abdomen is blunt in the male but pointed in female The female attracts its mate with a pheromone any generally mates between dusk and midnight. Adul longevity is about a week. Egg laying starts after one or two days after mating. Females lay eggs single or in rows parallel to a midrib on both surfaces of young leaves, flat oval and whitish yellow eggs. The eggs are laid in batche of 10-12. Each female moth may lay about 300 egg during its lifetime. The incubation period varies from 3-6 days. The newly hatched larva is white translucent with light-brown head. The bodies however turn green once the larva starts feeding. After hatching, it crawls to the bass of the youngest unopened leaf and begins to feed. The second instar migrates to an older leaf and folds the lea together. Some of the newly hatched larvae suspen themselves by silken threads from the leaf tip and disperse to other plants by wind. There are five larval instars. The full-grown larva is about 16 mm long and 1.7 mm with across the thorax. It is yellowish green in color with a darl brown head and prothoracic shield. Larvae jump or wiggli rapidly when touched. The larval period lasts for 15-25 days. Pupation takes places inside the leaf roll in looser woven strands of silk. The newly formed pupa is slende and greenish brown and turns brown later. The molt emerges after 6-8 days.

Damage: The larvae fold the leaves and scrape the green tissues of the leaves from within and cause scorching anc leave drying (Khan and Ramachandran, 1989). Each larving is capable of destroying several leaves by its feeding

Under heavy infestation, each rice plant attacked may have several rolled leaves, which severely restricts its photosynthetic activity (Salim *et al.*, 1991). When plants are attached in the flag leaf stage, grains may be partially filled.

3.2.2. *Marasmia patnalis,* Bradley, rice leaffolder

Distribution: Pakistan-Kalar tract and Sindh, Australia and some countries of South and South East Asia.

Life History: *Marasmia patnalis* habits and biology are very similar to *C. medinalis.* The adult moth has three long, dark bands on the forewings while *C. medinalis* has two long and one short band (Barrion and Litsinger, 1985, 1994). The adult moth is about 7 mm long with a wingspan of 13 mm. Its forewings have light yellow and brown markings. The gravid female moths prefer to lay eggs on the green parts of tall rice plants. Eggs are laid singly or in-groups of 2-9 on the upper side of the leaves but sometimes eggs are also seen on leaf sheaths. The incubation period is about 4-5 days. The newly hatched larvae scrape the leaf surface. The second instar larvae fold leaves and start feeding from within. The larva differs from C. *medinalis* in that the apex of the pronotum is convex while it is straight in *C. medinalis.* The larval period is about 23 days. The pupal period is up to 9 days and takes place within a silken cocoon, most commonly between leaves that have been stitched together. Adult emerges at night.

Damage: same as *C. medinalis.*

3.3. Leafhoppers and planthoppers

The rice leaf and planthoppers have gained great economic significance in recent years. Interestingly, leaf and plant hoppers have assumed a pest status in Pakistan after the introduction of high yielding short duration varieties. Whitebacked planthopper *(Sogatella furcifera)* is the most widespread and second important rice pest after stem borers in Pakistan (Mochida *et al.*, 1982). It first appeared iii Sind province on a thousand hectares in 1952 and a 60 percent loss in grain was estimated (Ghauri, 1979; Rehman *et al.*, 1986). But Mahar *et al.* (1978) reported its outbreak in Sind first time on semidwarf varieties. Population densities of this pest are higher on high yielding varieties than on local Basmati varieties in past years (Inayatullah *et al.*, 1987; Mahar *et al.*, 1983),

3.3.1. *Sogatella furcifera* (Horvarth), whitebacked planthopper

Distribution: Pakistan-Sindh and Punjab rice growing areas, Australia, South East Asia and Far East countries.

Life History: Long-winged adults invade paddy field at first month of sowing. They prefer young seedlings and produce winged migratory forms before the flowering stage of rice. The adult hopper is 3.5-4.0 mm long. Forewings are almost uniformly subhyline with dark veins. There is a prominent white band between the junctures of the wings. The body is creamy white with the mesonotum and abdomen black dorsally and the legs, ochraceous brown. Macropterouus males and females, brachypterous females are commonly found in the rice crop where as brachypterous males are very rare. The adults prefer to stay at the upper portion of rice stems. Adults are strongly phototropic and attracted to light traps. Eggs are laid on the leaf midribs, A female can lay eggs on an average of 150-300. The egg hatch in 6 days period. Nymphs are white to a strongly mottled dark grey or black and white in color. After 5 instars, nymphs reach their adulthood in 12-17 days. During winter season, the adult emerging in grasses start laying diapaused eggs, which hatch by the middle of spring season. Nymphs prefer weed for feedings. The adult hoppers, which develop from these nymphs, infest the rice fields.

Damage: The rice plants affected by the white-backed plant hopper appear uniform in large areas throughout the field. Both nymphs and adults suck plant sap. Both adult and nymph sucks sap primarily at the base of the rice plants which leads to yellowing of lower leaves reduced vigor and stunting of plants. At the feeding sites, numerous brownish spots appear. The attacked leaves soon turned yellow and their tips dry up. As the damage increase the pale yellow plants turn brownish, reduce in vigor, become stunted and ultimately dry up with out producing ears. This condition is known as "hopper burn". Gravid females cause additional damage by making oviposition punctures in leaf sheaths. Feeding points caused by egg laying may later become potential sites for the invasion of bacterial and fungal diseases. The honeydew produced by the hopper serves as a medium for mold growth. White-hacked hopper is not a vector for any viral diseases in Pakistan or anywhere else. The ecological conditions and factors reported to be favorable for a population explosion of this pest differs in various places (Haq *at al.,* 1991). In Pakistan, a prolonged monsoon with intermittent rain and application of heavy doses of nitrogenous fertilizers were suggested as the cause for an epidemic.

3.3.2. *Cofana spectra* (Distant), white leafhopper

Distribution: Pakistan-Only in Sind, Africa, South and Southeast Asian countries like India, Philippines, Sri Lanka and Taiwan.

Life History: The body of *C. spectra* is yellowish, the forewings grey-white with prominent veins and the head bear four black spots. The female including tegmina, sized about 9.5 mm while male is shorter and around 7.5 mm long (Sam and Chelliah, 1984). The adult longevity ranges from 7-10 days respectively. Adults rest on the lower part of plant and strong phototropic behavior. The female lays eggs in rows of 10-15 after making a cut parallel to the long axis of the leaf sheath with its saw like ovipositor. A female laid eggs on an average of 50 and hatch in 5-12 days.

Damage: *C. spectra* were previously a minor pest. It causes typical sap loss. Leaf tips first dry up and later the leaf turns orange and curls. The pest causes stunting and yellowing of plants and severe infestations cause plant death.

3.4. Grasshoppers

Many grasshopper species are occasionally found in shady fields but rarely cause significant damage other than along field borders (Irshad, 1977; Zafar, 1985). They chew angular holes in leaves, causing an injury similar to that caused by leaffolder or Armyworms. Grasshoppers are polyphagous insect pests.

3.4.1. *Hieroglyphus banian* (F.), rice grasshopper

Distribution: Pakistan-Punjab and NWFP, South East Asian Countries.

Life History: The adult grasshopper is of medium size, the female measuring 34-54 mm and the male 28-40 mm in length. Its upper body color is dull green or yellow-brown while lower body surface is brownish black. The adults mate after a short pre-copulation period of 1-3 days. The longevity ranges from 1-8 months. Egg pods are laid in soil, each pod contains about 30-35 eggs. On an average, each female lays 100-150 eggs in her whole life span. Individual eggs are yellowish and covered with a gummy substance that hardens into a waterproof coating. The eggs hatch after the first downpour, young hoppers are brownish yellow and later change to dull green. The usual number of instars is 5-6 for males and 7 for females and there is only one generation in a year.

Damage: The nymphs eat newly germinated rice seedlings and, cause them to wither. Adult grasshoppers feed on the leaves and shoots and sometimes cut the earheads. If the emerging inflorescence is attacked, the resulting grains become chaffy. In the month of August and September, heavy defoliation can be caused by their attack.

3.4.2. *Oxya multidentata* (Will.), small grasshopper

Distribution: Pakistan-NWFP and Punjab, Africa, South and South East Asia.

Life History: The grasshopper is green or pale brown with a dark line running laterally from each eye through the thorax. Adult measures 30 mm. Eggs are laid in masses of 10-30 above water on stems. In dry conditions, females bury eggs below the soil surface. Eggs are enclosed in a gummy bubble that hardens to form an ootheca. The eggs hatch in 2-3 weeks time. There are six larval instars and female passes through an extra molt. Nymphal development usually takes three months time. There is only one generation a year and insect overw inters in the egg stage.

Damage: This pest was a minor pest of rice but has gained economic significance. The nymphs and adults feed on rice leaves and nurseries. Adult feed at the bases of maturing earheads causing them to dry up.

3.5. *Dicladispa armigera* (Oliver), rice hispa

Distribution: Pakistan-Rice growing areas, South and South East Asian countries.

Life History: Adult beetles emerge in early morning and laid on the lower parts of the plant during daytime. Beetles are small, shiny blacks about 5.5 mm long, with spines on their wing covers. Female beetles live for 20 days while the longevity is only fortnight. Beetles mate 3-4 days after emergence. Eggs are laid singly and a female can lay on average 50-55 eggs. Eggs hatch after 4-5 days. The newly hatched larvae are pale yellow, dorso-ventra flattened and about 2.4 mm long (Vadadia *et al.*, 1989). They start mining from the leaf tip towards the base of the leaf blade. The larval stage lasts for 7-12 days. The pupa, are flat, brown and exarate. Pupal stage takes 4-5 days and completed within the leaf mines. The adult beetles cut their way out of the rice leaf and become external feeder.

Damage: The pest causes heavy crop losses in Pakisti (Zafar, 1984). Introduction of high yielding varieties in more areas and improved agronomic practices seem to be partly responsible for increased infestation. Both grubs and adult beetles feed on rice plants. Grubs mine the leaves by feeding on the mesophyll between the veins and tunneling the tissue in the direction of main axis of the leaf advancing towards the leaf sheath. In severe cases, leaves are brown and the field presents a dried up appearance. Even replanting may not be of much avail as the pests persist the field and infest the freshly planted seedlings.

4. Control of rice pests

Naturally selected cultivation practices and resistant varieties achieved the traditional forms of rice cultivation adaptation to pests. In recent decades the need for enhanced rice production in Pakistan and worldwide has left to the adoption of more intensive production systems. It has produced increases in pest attack and a greater reliant on chemical pesticides as the major form of control. Breakthroughs in novel methodologies of control as possible but their impact on rice production is uncertain are certainly unproven. At present, there is far more potential to improve pest management by fully utilizing the control methodologies and practices currently available.

The high yielding, early maturing modern rice varieties caused major shifts in insect pest complex in Pakistan also like rest of the world. Chemical insecticide, which began during the last two decades, has become a major part of crop protection. Indiscriminate use of chemical pesticide and varietal change caused major outbreaks of insect pest such as leaffolders, plant and leafhoppers. Because of the destruction and killing of indigenous predators and parasite that had kept pest population under economic level (Hashmi *et al.*, 1983). In the present situation of insect pests in Pakistan, it is important to use integrated pest management approach that is long lasting, inexpensive an environmentally safe (Hashmi, 1985). In the last three decades, only attention has been given to chemical control in Pakistan both on public and private level. IPM and its components have been neglected in the past excel chemical control. A major constraint to implement an effective IPM in local conditions for diverse paddy culture in Pakistan is the lack of infrastructure and trained personnel. Host plant resistance and biological control are two methods of insect pest control that have attracted increasing attention as alternative to our virtual reliance on chemical pest control. Host plant resistance strategies for developing insect resistant varieties have been improved with the existing knowledge of cellular and molecular biological approaches (Panda and Khush, 1995). Biological control, the use of living organisms as pest control agents, is a ubiquitous natural process: predators, parasites and pathogens (bacterial, fungal or viral) of pests are continuously reducing pest population in the crop. Host plant resistance and biological control are two of the many methods of insect pest control that might be used as alternatives to chemical insecticides. Others include the use of attractants (pheromones), insect growth regulators, insect growth inhibitors, repellents, sterile insect release systems, cultural, mechanical and physical control.

4.1. Cultural, mechanical and physical control: A wide range of cultural, mechanical and physical methods have the potential to suppress the insect pests in paddy fields and their use will depend on existing alternatives and local conditions. These methods are generally the most economical and environment-friendly, if used properly and on wide area through community-wide cooperation. In the past, cultural practices as a method of insect pest control were not considered as high priority area but with the development of IPM philosophy, now it becomes an important strategy in paddy fields. These methods that can limit the pest populations have advantages over chemical control because they are cheap and friendly to beneficial organisms. These methods usually aim to disrupt or slow down the population build up of insects. They include sanitation, destructive tillage, planting and harvesting schedule, proper fertilizer and water management. Handpicking and netting are labor intensive but can contribute to suppress the insect population in certain situations like nurseries (Litsinger, 1994). It may be appropriate to net, armyworms, leaf folders and other caterpillars when abundant in seedbeds. Complete control is not necessary in these situations as the seedling can normally recover from moderate infestation. Stem borer egg masses pose little threat to seedbed but it may be attractive to remove them by hand from the field before stem elongation, particularly eggs of those species that can be seen. Egg masses can be seen very easily on young seedlings. Excessive use of fertilizers can attract more insects, therefore, optimal levels of fertilizer with split applications are recommended. Crop maturity is another factor that can attract different pests. Crop maturity greater than 140 days encourages stem borer and planthoppers in paddy field. Crop should not be planted at times of at least pest abundance. The stubble should be removed to control rice stem borers. It is a fact that mechanical, cultural and physical methods would not themselves present economic damaging levels but they can contribute with other control approaches to synergies their action to suppress or eliminate pest populations in paddy fields.

4.2. Chemical Control: In 1960s, modern high yielding varieties brought insecticides in a package of technologies of the green revolution in Asian agriculture. Chlorinated hydrocarbons were first used followed quickly by the organophosphates, methylcarbamates and pyrethroids-all neuroactive chemicals (Table 2). The widespread adoption of chemical methods provided users with an apparently high successful means of achieving their objectives. Following are the advantages and disadvantages of the chemical pesticides.

Potential advantages:

- highly effective in the absence of resistance: pest populations can be reduced to a very low levels often demanded by farmers and consumers
- rapid action
- economical (in terms of immediate costs of applications)
- flexible and readily available: well organized marketing network
- application technology can be simple and readily handled by farmers

Potential disadvantages:

- resistance
- insufficient selectivity: damage to unintended recipients
- inappropriate persistence
- induction of secondary pest problems
- transient effectiveness; requirement for repeated applications in many pest control situations
- performance may be weather dependent

Although, it is well documented that chemical control is incompatible with the ecological approach to pest management, pesticides still remain the first line of defense against all insect pests and are used freely when insect outbreaks occur. In Pakistan, national rice production progressively increased following the wide use of chemical pesticides by Government of Pakistan and subsequent use of other pesticides by multinationals (Table 2). Although pesticides have effectively controlled many insect pest species but 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 poisoning, particularly in developing countries. Pest resurgence associated with insecticidal destruction of natural enemies and the development of insecticide resistance lead to increased doses or more powerful insecticides. In Pakistan, aerial spray for pest eradication in paddy fields exercised by plant protection department, GOP in 70s and afterward. Even where farmers can afford insecticides the health hazard may outweigh the economic benefits. Due to the cost of pesticides, toxicity to man and the environment, the secondary pest problems caused such as the resurgence of the leafhoppers and because of the death of natural predators, the recent trend in rice crop has been toward the integration of insect resistant varieties with the conservation of natural enemies. Although the judicious use of selective chemical pesticides in rice is necessary in certain cases. The IPM strategy emphasizes need-based use of chemical insecticides rather than prophylactic treatment.

4.3. Host Plant Resistance

4.3.1. Conventional Breeding: For the 9000 years during which rice has been grown as a crop, farmers have selected the high yielding varieties. Such selection has tended towards cultivars that show resistance to insects and diseases and have the capability to compete with weeds. However, the traditional rice systems were relatively low yielding. To meet the food needs of the increasing populations dependent on rice, the situation was transformed by Green revolution. A major feature of this revolution was breeding for high yields. Breeding is the most economic, least complicated and environmentally friendly approach to protect rice from insect pests. Good germplasm collections are the prerequisite for the success of breeding programs in rice. Breeding methods and breeding strategies for developing insect resistant varieties have been improved with the existing knowledge of cellular and molecular biological approaches (Panda and Khush, 1995). The rice breeding programs of Pakistan aim at incorporating their improved germplasm genes for resistance to different insect pests with the collaboration of International Rice Research Institute (Zafar and Qayyum, 1986; Riaz *et al*., 1993; Rustamani *et al*., 1995). The rice breeding programs of Pakistan like other rice growing countries aim at incorporating into their improved germplasm genes for resistance to stem borers from many donors. However, none of the rice varieties developed so for have more than a moderate level of resistance. In plant breeding methods involving sexual hybridization where large segments of the genome are transferred from one parent to the other, genetic techniques permit the introduction of single gene into economically important crop. Selection of improved variants from among the progeny of sexual hybrids is followed standardized phenotypic test procedures in multilocation trials in greenhouse and field. This approach has been extremely successful in the past in enhancing insect resistance (Khush, 1995) and will continue to be important in the future. Two phases of plant breeding, Phase 1, production of novel genetic variation and Phase 2, selection of improved variants have been elegantly described. Four biotechnological approaches are contributing to enhancement of insect resistance in rice, wide hybridization/embryo rescue, transformation, DNA markers and DNA fingerprinting. Wide hybridization (Khush and Brar, 1992) and transformation contribute to the production of novel genetic variants by increasing the gene pool available to breeders while DNA markers and DNA fingerprinting of insects help to make selection and phenotypic analysis more efficient and powerful.

4.3.2. Transgenic Plants: The most significant breakthroughs in plant molecular biology in this decade is the development of techniques to transfer genes from unrelated sources into economically important crop plants. In the past, plant breeders could manipulate only the primary and secondary gene pools of the cultivated species for crop improvement. However, recent advances in tissue culture, genetic transformation and molecular biology have made it possible to introduce genes from diverse sources such as bacteria, viruses, animals and plants into crop plants. These developments provide the opportunity to develop transgenic crops with novel genes for insect resistance. In Pakistan, only national Centre of Excellence in Molecular Biology has reported the transformation of rice with genes for insect resistance from the bacterium *Bacillus thuringiensis* (Bt) (see section 4.4.1A). The first successful use of transgenic plant technology was reported by a Belgian biotechnology company, Plant Genetic Systems, in July of 1987 (Vaeck *et al*., 1987). Using a gene from *Bacillus thuringiensis,* this group developed tobacco plants that produced enough of the endotoxin to kill first-instar *Manduca sexta* larvae. The ability to incorporate genes into crops like rice to confer insect resistance has already been demonstrated. Following are the advantages of transgenic Plants over chemical and other control measures;

- Season long built-in resistance.
- Insects pests are controlled at the early stages.
- Plant protection is independent of weather conditions.
- It confers protection against the borers, which are difficult to treat using insecticides.
- transgenic plants only kill crop eating insects and beneficial organisms synergies its toxicity.
- Environment safe and friendly approach.
- Choice of suitable genes that are not toxic to man and animals.
- Considerable financial savings.

Potentially this approach offers dramatic advantages over conventional methods and these advantages ought to drive its adoption as a major new technology for control of insect pests like stem borers. However, uncertainties about the rates at which insects will overcome the new resistance deserve careful attention. Today, two different strategies for producing such plants have been successfully used. One approach is to use *Bacillus thuringiensis* δ-endotoxins as a source of resistance genes and other is to identify and use the insect resistance genes present in plants or other bacterium for plant protection. Following are the available sources of resistance for plant protection;

- Inhibitors of proteolytic enzymes.
- Protease inhibitors as insecticidal agents.
- Thiol protease inhibitors as insecticidal agents.
- α-Amylase inhibitors as insecticidal agents.
- Chitinases as insect control agents
- Cholesterol exidases
- Peroxidases
- Plant lectins as insecticidal agents.
- *Bacillus thuringiensis* δ-endotoxins as insecticidal agents.
- *Bacillus thuringiensis* vegetative insecticidal proteins.

Local biotypes of striped stem borer exist in Japan (Litsinger, 1994) and there is not any information about the biotypes of insect pests in Pakistani populations, This area needs attention of researchers also to design sustainable resistance strategies. Transgenic plant technology should complement, rather than replace other forms of crop protection and it is envisaged that it will have a major impact on agricultural system in Pakistan.

4.4. Biological Control: Biological control is the action of living organisms as pest control agents. For insect pests, these control agents or natural enemies include predators, parasitoids (parasitic wasps and flies), parasites (nematodes) and pathogens. Natural enemies of rice pests are commonly observed in paddy fields in Pakistan, their value in pest control is not well understood, where most species of natural enemies remain undescribed and unstudied. Biological control is a major factor in the control of many insect pests' species and indeed prevents many non-pest insects from achieving pest status. It is evident from basic ecological studies that natural enemies are key factors in the life of a range of insect pests in natural and agricultural ecosystems (Lawton and McNeill, 1979; Crawley, 1992). Further, the selective elimination of natural enemies by the use of pesticides (insecticides, fungicides and herbicides) has resulted in the resurgence of a great variety of pest insects around the world and the creation of many new, secondary pests (De Back, 1974; Waage, 1989). Pesticides can eliminate important natural enemies of target pests and non-target species, which then become secondary pests. Generally, natural enemies are more susceptible to chemical pesticides than insect pests because of their smaller size, greater mobility on plants, less concealed habits and, perhaps their relatively poor ability to detoxify chemical toxins (Jepson, 1989). By reducing the use of pesticides to a minimal necessary level, the action of natural enemies is often restored and the farmer can sometimes move from a costly chemical strategy to free, biological control with little change in yield. Most recently, registered products for insect control are produced in developing countries and include bacteria (104 products in the market, mostly *Bacillus thuringiensis),* nematodes (44 products), fungi (12 products), viruses (8 products), protozoa (6 products) and arthropods natural enemies, including *Trichogramma,* predatory mites-, lady birds, parasitoids and others (107 products).

4.4.1 Insect Pathogens: Insect pathogens offer an alternate and important control strategy to chemical insecticides. Microbial pesticides are widely used in crop protection and the present knowledge regarding the action mechanism of pathogens has also increased (Samson, 1981). Microbial control agents are easy to manipulate for aerial spray than predators and parasites and their augmentation is also easy. Progress in the cheap industrial production and enhanced shelf life of microbial products has been established in different countries. Insect pathogens are safe to humans and non-target species so they can be used harmoniously with other control agents. The only major disadvantage of pathogens is their slow speed of action in comparison with chemicals.

4.4.1A: Bacteria: Microbial pesticides or biopesticides have gained momentum in the pesticide market as alternative to chemical pesticides. *Bacillus thuringiensis* (80 accounted 90 percent of the biopesticide market in USA in the period of 1988-1995 (Zechendorf, 1995; Lal and Lal, 1993). Bt has been used for decades to control lepidopterous larvae and was supplemented recently by strains selected for potency to additional target pests but overall they represent only 1 percent of the insecticide market worldwide (Hopkins, 1996). In Pakistan, presently, only 4 Bt products are registered with Plant Protection Division for the control of insect pests (Table 2). Bt is a gram positive, aerobic, soil bacterium, produces proteinaceous parasporal crystalline inclusions composed of insecticidal crystal proteins (1CP) or 6-endotoxins. Bt 6-endotoxins, are oral toxicants and have no demonstrated contact activity. Mode of action of δ-endotoxins can be described by the following steps; ingestion, solubilization, proteolytic activation, passage through peritrophic membrane, receptor binding, membrane insertion, ion channel formation and cell lysis (Karim and Riazuddin, 1997). The disadvantage of Bt as biopesticide is that ultraviolet light of the sun can easily inactive the toxin towards insect pests. Resistance is a major potential problem on selection of pest populations with Bt endotoxins and this will also probably hold for other insecticidal proteins because of the extreme selection pressure in transgenic plants. Thus, Bt endotoxin (Natural or genetically engineered) and synthetic chemical insecticides must be used in concert to achieve adequate control of a pest complex with minimal selection for resistance. Other toxic proteins (protease inhibitors, lectins etc.) expressed in crop plants and of potential value have less proven field efficacy.

4.4.1B. Fungi: Entomopathogenic fungi most commonly collected in agricultural crops include species of *Metarhiziuium, Beauveria, Hirsutella, Nomuraea* and *Paecilomyces* (Samson, 1981). They have considerable potential as biological pesticides. In recent years, there has been a resurgence of exploration of their potential, due to the hazardous effects of chemical pesticides. Entomopathogenic fungi are unlikely to capture a major part of pesticide market, but they do have a future in specialized applications and integrated approaches to insect pest control. Future development should base on the rice ecosystem in Pakistan and less on one pest or pathogen. Successful inundative augmentations in the future are likely to be limited owing the limited number of quick damage pathogens and the unsuitability of slow pathogens, unless genetic manipulations increase the number. In Pakistan, there is only one registered product based on *Beauveria* species marketed as Natural L.

4.4.1C. Viruses: Insects are susceptible to a wide variety of virus infections. Baculoviruses are specific to a few lepidopterous pests and have no known adverse health or ecological effects. They have been used as control agents, but factors such as slow action and photosensitivity limit the effectiveness and potential economic importance of the natural, unimproved biologicals. Several attempts have been made to modify baculoviruses for enhanced potency and speed to kill by incorporation of various genes to express them, including juvenile hormone esterase, toxins, insect hormones and chitinase, but thus far without any practical success. There is not a single report of insect control by baculovirus in Pakistan so far.

4.5. Parasites and Predators: More than 150 species of natural enemies are known to attack the rice stem borers. Parasitoids and predators caused >90 of the >98 percent mortality from egg to pupa in common stem borer species attacking traditionally grown rice and even 100 per cent egg parasitism (Heinrichs, 1994a, b). Severe outbreaks of stem borer attacks has reported in regions where insecticides were used but not where natural enemies remained unharmed. In recent decade, elevated awareness of the impacts of pesticide use on the environment and human health have resulted in efforts to reduce reliance on chemical control. Many countries including Pakistan have instituted more stringent regulation of pesticide manufacture registration and use, thereby increasing the cost and decreasing the availability of these tools. In many cases, the pests themselves have indicated the need for change, with pesticide resistance now a common reality in many pests. The use of natural enemies to reduce the impacts of pests has a long history. There are three general approaches to biological control; importation, augmentation and conservation of natural enemies. Each of these techniques can be used either alone or in combination in a biological control program. Importation of natural enemies, sometimes referred to as classical biological control, is used when a pest of exotic origin is the target of the biocontrol program. Pests are constantly being imported in countries where they are not native, either accidentally, in some cases, intentionally. Due to a lack of natural enemies to suppress their populations, these introduced organisms become pests. In such cases, importation of natural enemies can be highly effective (Caltagirone, 1981). Augmentation is the direct manipulation of natural enemies to increase their effectiveness. Either mass production of periodic colonization; or genetic enhancement of natural enemies can accomplish this. The most commonly used approach is in which natural enemies are produced insectaries, then released either inoculatively or inundating. In Pakistan, there is not a single insectary to rear natural enemies for suppression of rice pests.

In the rice ecosystem, one of the most important approaches to biological control is conservation of the natural enemy complex. It is a critical component biological control. This involves identification of the factors, which may limit the effectiveness of a particular natural enemy and modifying them to increase the effectiveness of the beneficial species. In general conservation of natural enemies involves either, reducing factor which interfere with natural enemies or provide resources that natural enemies need in their environment. Minimal disruption of natural enemies can be attained by reduction of the impact of pesticides; selective use of pest resistant plant varieties; changes in cultural practice including maintenance of refuge for natural enemies through the use of strip-plantings, field borders, or con crops or alteration of regional landscapes.

In short, conservation, importation and augmentation of natural predators and parasites in numero agroecosystems, but further application have enhanced biological control and refinement of these technologies needed in Pakistani system.

Insect Growth Regulators and Pheromones: The insect growth regulators (IGRs) were at one time considered to the third generation of insecticides with great potential for curtailing agricultural toxicant use. The first IGRs, modeling on natural insect juvenile hormones, have outstanding potency under contained conditions and examples such the closely related methoprene and the more distant related fenoxycarb and pyriproxyfen find use in special but not broad markets. A newer development involving hormonal regulations the ecdysone agonist tebfenozide are analogs with adequate potency and outstanding selectivity which provide a new and effective approach to the use developmental inhibitors for insect pest control. Despite outstanding potency and apparent safety for mammal these compounds are still limited in agricultural application by slow action and a narrow range of sensitive stages in the life cycle. Other IGRs include the plant system cromazine, which inhibits larval development by unknown mechanism and azadiractin, the major limonoid in neem which has antifeedant and antimolting properties. Pheromones and other attractants play a significant role in monitoring pest populations and manipulating insect behavior at extremely low levels without toxic chemical residues; they are important components of pest control programs that usually also require a chemical insecticide.

5. Integrated Pest Management: A golden age: In recent decades, elevated awareness of the impacts of pesticides use on the environment and human health has resulted of efforts to reduce reliance on chemical controls. The need for alternatives to pesticides is clear, but where will these solutions come from? Effective non-insecticide management of the rice key pests is essential for a significant reduction of insecticide applications. Historically, extensive use of chemical insecticides to control key pests on field crops has led to the creation of additional secondary pests (rice leaffolder in Pakistan) by eliminating the activities of arthropods natural enemies that normally keep these secondary pests below damaging a levels.

Several approaches used alone or in concert, show promise for reducing insecticide use not only on rice but widely by IPM of many agricultural crops. A 50 percent reduction might readily be achieved through wider adoption of the following practices.

- ♦ Improved scouting and monitoring, together with application of sophisticated and accurate crop simulations, to predict injury levels accurately.
- ♦ Application of insecticide at reduced rates and with more efficiency.
- ♦ Improved crop rotations, including modified tillage practices and efficient handling of crop residue.
- ♦ Improved crop varieties that resist insect attack more readily, including transqenic plants.
- ♦ Biological control.

The use of natural enemies to reduce the impacts of pests has a long history. The greatest potential for Integrated Pest management (IPM) lies in the inoculative augmentation and introduction and establishment approaches, including introduction of new strains of pathogen species already present. Importation, augmentation and conservation of natural enemies, insect pathogens constitute the three basic approaches to biological control of insects. These approaches have been effective, yet have received only a fraction of the research devoted to similar approaches with parasitoids and predators. These approaches minimize certain entomopathogen weaknesses such as slow debilitation of pest individuals and populations and take advantage of ecological strengths such as recycling, persistence and rapid generation times. Continued refinement and adaptation of biological control approaches and applications are necessary if the full potential of this biologically based pest management strategy is to be fulfilled.

The most important audience for the evaluation results is the group of individuals who must implement IPM. These include agricultural policy makers, extension agents, pest control advisors and farmers. Unless the member of this audience appreciate and build on the central importance and immunse economic impact of biological control in their decision making, all efforts are academic exercises.

6. The Future: What is required, is a better understanding of farmers' problems that will enable key constraints to be reduced and more appropriate control strategies to be designed. Prospects for the development of biological control products in Pakistan are good and encouraging technologies are not complex, labor is available and the incentive to internalize pest control economics is great given the foreign exchange currently expended to import chemical pesticide (Table 2). In IPM different approaches have their merit and application, the more participatory approach may be more suitable to the solution of complex, local problems faced by small scale, risk prone farmers in rice growing areas. In Pakistan, making the best use of integrated approaches of biological control and host plant resistance (traditional and transgenic) to the development of IPM that will be useful to the farmers.

Acknowledgements

Financial assistance by World Bank is greatly appreciated to Shahid Karim. We thank Dr. Mike Cohen for his critical comments to improve manuscript. Authors thank IRRI GIS (Cornelia Alforja, Nestor Fabellar), library and CPS staff for their help in the preparation of this manuscript. Research on rice biotechnology in our laboratory is supported in part by Rockefeller Foundation, New York, USA. Mention of a proprietary product does not constitute an endorsement or a recommendation for its use by authors.

References

Afzal, M., I. Ahmad and M.A.M. Khan, 1977. Estimation of infestation due to paddy stem borers in lower Sind. Chemosphere, 6: 645-550.

Ahmad, I. and M. Afzal, 1982. Seasonal abundance and population trends of yellow rice stemborer *Schoenobius incertulas* (Walker) (Pyralidae: Schoenobiinae) in major rice growing areas of upper and lower Sind and Punjab. Chemosphere, 11: 521-524.

Ahmad, I., M. Afzal and M.A.M. Khan, 1979a. Aspects of larval morphology and larval and adult keys to the rice stem borers (Insecta: Lepidoptera) and a new record of a rice stem borer *Niphadoses gilviberbis* (Zell.) from Pakistan. Pak. J. Scient. Ind. Res., 23: 40-45.

Ahmad, I., M. Afzal and S.S. Shaukat, 1979b. A reliable measure for the estimation of yield loss in different stages of rice crop due to stem borer incidence in lower Sind. Chemosphere, 8: 575-580.

Ahmed, M., 1984. A sample study of stem borer infestation on rice crop and its expected effects on yield of rice at Gujjo Sind Pakistan 1981. Pak. J. Scient. Ind. Res., 27: 33-37.

Ahmed, M., 1987. Serious attack of stem borers of rice crop at Gujjo Sind, Pakistan. Pak. J. Agric. Res., 8: 355-355.

Anonymous, 1995. Economic survey, 1994-95. Agriculture, Government of Pakistan, Finance Division, Economic Adviser's Wing, Islamabad, Pakistan, pp: 9-17.

Barrion, A.T. and J.A. Litsinger, 1985. Identification of rice leaffolders (LF) by wing markings. Int. Rice Res. Newslett., 10: 24-24.

Barrion, A.T. and J.A. Litsinger, 1994. Taxonomy of Rice Insect Pests and their Arthropod Parasites and Predators. In: Biology and Management of Rice Insects, Heinrichs, E.A. (Ed.), Wiley Eastern Limited, New Age International Limited, New Delhi, pp: 13-359.

Caltagirone, L.E., 1981. Landmark examples in classical biological control. Ann. Rev. Entomol., 26: 213-232.

Crawley, M.J., 1992. Natural Enemies: The Population Biology of Predators, Parasites and Diseases. Blackwell Scientific Publications, Oxford, UK.

De Back, P., 1974. Biological Control by Natural Enemies. Cambridge University Press, Cambridge, UK.

Dhaliwal, G.S., H.N. Shahi, P.S. Gill and M.S. Maskina, 1979. Field reaction of rice varieties to leaf folder at various nitrogen levels. Int. Rice Res. Newslett., 4: 7-7.

Georghiou, G., 1990. Overview of Insecticide Resistance. In: Managing Resistance to Agrochemicals, Green, M.B., H.M. LeBaron and W.K. Moberg (Eds.). American Chemical Society, Washington, DC., pp: 18-41.

Ghauri, M.S.K., 1979. Whitebacked planthopper attacks before introduction of new rice varieties in Pakistan. Int. Rice Res. Newslett., 4: 11-11.

Hansen, M., 1987. Escape from the Pesticide Treadmill Alternatives to Pesticides in Developing Countries. Institute for Consumer Policy Research, New York, ISBN-13: 978-0890432815, Pages: 185.

Haq, E., A. Mohsin and A.A. Hashmi, 1991. Efficacy of botanical and organophosphate pesticides against white backed planthopper *Sogatella furcifera* (Horv.). Proc. 11th Pak. Congress Zool., 11: 149-152.

Haque, H., 1970. Hand Book of Agricultural Pests of Pakistan and their Control. Pakistan Central Department of Plant Protection, Pakistan, Pages: 125.

Hashmi, A.A., 1985. Pest management models in annual crops. Progressive Farming, 5: 30-32.

Hashmi, M.A., M. Naeem-Ullah and M. Arshad, 1983. Economic threshold relation between population density and profitability of control-an inconsistent parameter in pest. Progressive Farming, 3: 23-30.

Heinrichs, E.A., 1994a. Host Plant Resistance. In: Biology and Management of Rice Insects, Heinrichs, E.A. (Ed.). Wiley, New York, ISBN: 0470218142, pp: 517-547.

Heinrichs, E.A., 1994b. Rice. In: Biology and Management of Rice Insects, Heinrichs, E.A. (Ed.). Wiley, New York, ISBN: 0470218142, pp: 1-11.

Hopkins, W.L., 1996. Global Insecticide Directory. 1st Edn., Ag Chem Information Services, Indianapolis, Pages: 183.

Inayatullah, C. and A. Rehman, 1990. Incidence of rice Stem Borers (SB) in Sind. Int. Rice Res. Newslett., 15: 30-30.

Inayatullah, C., A. Majid and M.S. Moughal, 1990. Fluctuations in rice stem borer density in the Punjab. Int. Rice Res. Newslett., 15: 24-24.

Inayatullah, C., A. Rehman and M. Ashraf, 1986. Management of insect pests of paddy in Pakistan. Progressive Farming, 6: 54-62.

Inayatullah, C., Ehsan-Ul-Haq, N. Tanweer and N. Mahmood, 1989. Incidence of rice Stem Borer (SB) in the Punjab. Int. Rice Res. Newslett., 14: 38-38.

Inayatullah, C., M. Ashraf and L. Khan, 1987. Whitebacked planthopper (WBPH) damage in Pakistan. Int. Rice Res. Newslett., 12: 18-18.

International Rice Research Institute, 1993. Rice Almanac 1993-95. International Rice Research Institute, Manila, Philippines..

Irshad, M., 1977. Grasshoppers on rice in Pakistan. Int. Rice Res. Newslett., 2: 8-9.

Javed, S. and M. Ahmed, 1974. Some remarks on the stem borer infestation of the rice crop in the Southern part of Sind (Pakistan) in 1973. Folia Biol. (Krakow), 22: 399-403.

Jepson, P.C., 1989. Pesticides and Non-Target Invertebrates. Intercept Ltd., Wimborne, UK.

Joshi, R.C., 1988. The leaffolder of rice. Antenna, 12: 39-39.

Karim, S. and S. Riazuddin, 1997. *Bacillus thuringiensis*-endotoxins: Molecular mechanism of action and pest management. Proc. Pak. Acad. Sci., 34: 135-156.

Khan, Z.R. and R. Ramachandran, 1989. Studies on the behaviour of rice leaffolders *Cnapffalocrocis medinalis* and *Marasmia patnalis*. Seventeenth Annual Reports, International Centre of Insect Physiology and Ecology, ICIPE Science Press, Nairobi, Kenya, pp: 19-24.

Khush, G.S. and D.S. Brar, 1992. Overcoming the Barriers in Hybridization. In: Distant Hybridization of Crop Plants, Kalloo, G. and J.B. Chowdhury (Eds.). Springer-Verlag, Berlin, pp: 47-61.

Khush, G.S., 1995. Modern varieties-their real contribution to food supply and equity. GeoJournal, 35: 275-284.

Koehler, C.S., 1971. Stem borer problems in west Pakistan. Proceedings of the International Rice Research Conference, April 19-23, 1971, Los Banos, Laguna, Philippines, pp: 9.

Lal, R. and S. Lal, 1993. Genetic Engineering of Plants for Crop Improvement. CRC Press, USA., ISBN: 9780849364242, Pages: 246.

Lawton, J.H. and S. McNeill, 1979. Between the Devil and the Deep Blue Sea: On the Problem of Being a Herbivore. In: Population Dynamics, Anderson, R.M., B.D. Turner and L.R. Taylor (Eds.). Blackwell Publication, USA., pp: 223-244.

Litsinger, J.A., 1994. Cultural, Mechanical and Physical Control of Rice Insects. In: Biology and Management of Rice Insects, Heinrichs, E.A. (Ed.). Int. Rice Res. Inst., Wiley Eastern Ltd., New Delhi, India, ISBN: 978-0-470-21814-3, pp: 549-584.

Loevinsohn, M.E. and J.P. Bandong, 1991. Correlations between light trap catches, field populations of Yellow Stem Borer (YSB) and lunar phase. Int. Rice Res. Newslett., 16: 25-26.

Mahar, M. M. and I.M. Bhatti, 1986. Control of rice insects in Sind. Progressive Farming, 6: 3-64.

Mahar, M.M. and M.R. Hakro, 1994. The prospects and possibilities of yellow stem borer eradication under Sind conditions. Rice Research Institute, Dokri, Research Publication 1969-1983, pp: 211-222.

Mahar, M.M., I.M. Bhatti and A.H. Dhuto, 1986. Stem borer infestations and yield-loss relationship in rice and cost benefits of control. Rice Research Institute, Dokri, Research Publication 1983-1985, pp: 133-150.

Mahar, M.M., I.M. Bhatti and M.R. Hakro, 1978. Whitebacked planthopper appears on rice in Sind, Pakistan. Int. Rice Res. Newslett., 3: 11-11.

Mahar, M.M., M.R. Hakro and I.M. Bhatti, 1983. Some field studies on whitebacked planthopper *Sogatella furcifera* (Horvath), under Sind conditions. Proceedings of the 4th National Seminar on Rice Research and Production, April 2-4, 1983, Islamabad, Pakistan, pp: 11.

McGaughey, W.H. and R.W. Beeman, 1988. Resistance to *Bacillus thuringiensis* in colonies of indianmeal moth and almond moth (Lepidoptera: Pyralidae). J. Econ. Entomol., 81: 28-33.

Mochida, O., T.J. Perfect, V.A. Dyck and M.M. Mahar, 1982. The whitebacked planthopper *Sogatella furcifera* (Horvath) (Horn., Delphacidae), its pest status and ecology. Proceedings of the International Rice Research Conference on Rice Cropping Systems, April 19-23, 1982, International Rice Research Institute, Los Banos, pp: 72.

Moiz, S.A., 1969. Ecology of the Rice Stem Borer, *Tryporyza incertulas* Walker, in West Pakistan: Preliminary Studies. In: Insect Ecology and the Sterile-Male Techniques, IAEA (Ed.). International Atomic Energy Agency, Vienna, pp: 147-156.

Niaz, N.S., 1971. Rice production falls. Press Conference, Secretary Agriculture Punjab, The Pakistan Times, April 2, 1971.

Panda, N. and G.S. Khush, 1995. Host Plant Resistance to Insects. CABI International, UK., ISBN: 9780851989631, pp: 324-355.

Pathak, M.D., 1968. Ecology of common insect pests of rice. Ann. Rev. Entomol., 13: 257-294.

Rehman, A., C. Inayatullah and M. Ashraf, 1986. White-backed plant-hopper: A major pest of paddy. Progressive Farming, 6: 65-67.

Reissig, W.H., E.A. Heinrichs, J.A. Litsinger, K. Moody, L. Fielder, T.W. Mew and A.T. Barrion, 1986. Illustrated Guide to Integrated Pest Management in Rice in Tropical Asia. International Rice Research Institute, Los Banos, Laguna.

Riaz, M., M. Ahmad and A. Butt, 1993. Screening rice varieties and lines for resistance to Yellow Stem Borer (YSB) based on preference or nonpreference and antibiosis. Int. Rice Res. Newslett., 18: 26-26.

Rodcharoen, J. and M.S. Mulla, 1994. Resistance development in *Culex quinquefasciatus* (Diptera: Culicidae) to *Bacillus sphaericus*. J. Econ. Entomol., 87: 1133-1140.

Rustamani, M.A., M.H. Solangi, M.A. Talpur, M.M. Khan and T. Hussain, 1995. Screening of rice genotypes for relative resistance to yellow stem borer, *Scirpophaga incertulas* (Walk.). Pak. J. Zool., 27: 345-348.

Salim, M., A. Rehman and M. Ramzan, 1991. Leaffolder (LF) outbreak in Punjab, Pakistan. Int. Rice Res. Newslett., 16: 22-22.

Sam, M.D. and S. Chelliah, 1984. Biology of the white leafhopper on rice. Int. Rice Res. Newslett., 9: 22-22.

Samson, R.A., 1981. Identification: Entomopathogenic Deauteromycetes. In: Microbial Control of Pests and Plant Diseases, 1970-1980, Burges, H.D. (Ed.). Academic Press, New York, pp: 94-106.

Vadadia, L.D., A.H. Shah and H.V. Pandya, 1989. Biology of rice hispa. Oryza, 26: 206-208.

Vaeck, M., A. Reynearts, H. Hofte, S. Jansens and M. DeBeuckleer *et al*., 1987. Transgenic plants protected from insect attack. Nature, 328: 33-37.

Waage, J.K., 1989. The Population Dynamics of Pest-Pesticides Natural Enemy Interaction. In: Pesticides and Non-Target Invertebrates, Jepson, P.C. (Ed.). Intercept Ltd., Wimborne, UK., pp: 81-94.

Waage, J.K., 1993. Making IPM Work: Developing Country Experiences and Prospects. In: Agriculture and Environmental Challenges, Srivastava, J.P. and H.I. Alderman (Eds.). World Bank, Washington, DC., USA., pp: 119-134.

Woodburn, A.T., 1990. The Current Rice Agrochemicals Market. In: Pest Management in Rice, Grayson, B.T., M.B. Green and L.G. Cupping (Eds.). Elsevier, New York, pp: 15-30.

Zafar, M.A. and H.A. Qayyum, 1986. Susceptibility of some rice varieties to *Sitophilus oryzae* (Linn.) and *Tribolium castaneum* (Hbst.) during storage. Pak. J. Agric. Res., 24: 67-72.

Zafar, M.A., 1984. Chemical control of rice Hispa. Int. Rice Res. Newslett., 9: 18-19.

Zafar, M.A., 1985. Chemical control of grasshoppers in Pakistan. Int. Rice Res. Newslett., 10: 16-16.

Zechendorf, B., 1995. Biopesticides as Integrated Pest Management Strategy in Agriculture. In: Novel Approaches to Integrated Pest Management, Reuveni, R. (Ed.). Lewis Publishers, Boca Raton, FL., pp: 231-260.