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Review

Integrated Insect Pest Management Techniques for Rice

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Abstract: In modern agriculture, climate change, environmental degradation, and natural resource depletion constitute one of the major potential issues for sustainable crop production and environmental management. Integrated pest management (IPM) is a promising technology for the environment. Insect pests and weeds have long posed a danger to rice production systems, resulting in severe output losses. Although insect, pest, and weed control has remained the most efficient plant protection tool, environmental risks have prompted scientists to propose alternate pest management options. The understanding of sustainable conventional agriculture prompted the broad deployment of integrated pesticide management (IPM). IPM is a multimodal pesticide management method that aims to avoid negative environmental impacts. This method is critical for delivering healthy, sustainable food to the world's rising population. Rice is a staple crop that many developing countries rely upon for national stability and economic progress. On the other hand, rice pests represent a major biotic barrier to world rice production. This review aims to provide information on major rice pests, their identification, biology, and various IPM treatments, particularly biological management strategies. To create a sustainable rice agroecosystem, continual research and training on IPM technologies will be required.

Keywords: biological control; countries; insect life history

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1. Introduction

For roughly half the world's population, rice is one of the main grain crops and staple foods. There are approximately 114 countries where it is grown, most of them in Asia and Africa. Rice cultivation is critical to the economies of these countries, and any risk that affects output has a huge impact on their economies. Farmers worldwide are increasing their crop densities, leading to a growing number of pests to fulfill the always-increasing need for higher rice grain production. As a result, insecticides and herbicides have frequently been over-optimally applied, with harsh environmental and economic consequences. Toxic pesticides, chemical fertilizers, and extensive tilling have all been recognized as key factors for soil, water, air, and environmental pollution [1,2].

Many ecosystem functions, such as nutrient cycling, environmental purification, organic matter decomposition, and incidence of disease outbreaks in aquatic and terrestrial life, including insect pest management, are influenced by intensive farming practices. The continuous use of insecticides, herbicides, fungicides, and nutrients leaching into underground water and greenhouse gas emissions from agricultural soils have severely harmed the natural ecosystem. Despite this, biotic and abiotic stressors diminish rice yield by more than 200 million megagrams per year. Viruses are responsible for the propagation of tungro and yellow dwarf illnesses. Most insects operate as carriers for these viruses, posing a substantial threat to the rice crop. There are a number of insects that can harm rice crops; among them, the rice leaf folder (*Cnaphalocrocis medinalis* Guenée (Lepidoptera: Pyralidae)) and the lepidopteran stem borer (*Scirpophaga incertulas* and *S. innotata*; Walker (Lepidoptera: Pyralidae)) cause almost 90 million megagrams of yield loss annually [3–5].

The insecticide used led to secondary outbreaks, especially *Nilaparvata lugens*, the brown plant hopper (Stal) (Hemiptera: Delphacidae). As insecticide prevents an expanding population of major secondary pesticides, further restrictions exist, such as emerging and consistent disease resistance. Moreover, insecticide toxicity in the polluted environment and infested foods has seriously threatened farmers' health and increased insecticide resistance in flooded insect-grown animals in chemical applications against rice pests. As a result of the extensive and indiscriminate use of chemical herbicides, the soil, groundwater, and air have all suffered degrading effects, and the residual impact of these herbicides is killing beneficial insects, arthropods, and bacteria. Herbicide control in modern agriculture is a problem that must be addressed as soon as possible. Its widespread use in recent decades has led to serious environmental impacts, such as increased weed resistance, changes in weed population, and small weed domination [6–8].

In the near future, herbicide resistance will be the predominant trait of cultivated crops. The problem was worsened by herbicide resistance among many weed species. In today's agriculture, non-traditional weed management tactics are critical, particularly those based on ecological principles. However, integrated pesticide management (IPM) is now the one receiving the most attention. Many synergistic approaches are employed in IPM, from the targeted utilization of chemical pesticides to biological methods of pesticide management using natural enemies. However, according to the IPM idea, the correct use of pesticides is a valuable resource that can be exploited to increase the control of natural control agents in certain conditions [8–10]. Therefore, critical insects and animals can be identified that can be effective, beneficial predatory species as well as management measures to ensure their prolificity and long-term survival. IPM is a method of integrating pest management into a plant's life cycle, adapting to the behavior of insects as well as their cycles [3,5]. Farmers are vital to developing a good IPM plan by developing their agriculture practices and understanding pest species inside the agroecosystem [8]. Understanding pesticide life cycles on the ecosystem level offers the basis for a successful IPM plan development and implementation. The rice ecosystems should be closely linked to a farmer's practices and a well-determined IPM plan [7]. Protection of beneficial insects; secondary pests; disease dissemination; air, water, and soil contamination; and pest resurgences are part of a good IPM plan [10,11]. The broad adoption of rice agroecosystems with IPM could offer farmers in several countries enormous net benefits. In this study, the new IPM program is a farmer field school model which applies worldwide to rice agroecosystems. It safeguards against the resurgence of disease generated by pesticides, which is the main focal point in any country in the world's national IPM program [7].

Overuse and abuse of pesticides in the 1950s led entomologists to discover that insects were developing resistance to them. Throughout history, environmentalists have been concerned about pesticides causing environmental damage and danger. However, it was Rachel Carson's book *Silent Spring* in the 1960s that alerted the public to the dangers of pesticides. Many areas were discontent with using a purely insecticidal approach to pest control in the 1950s, leading to the development of IPM. In the second half of the 20th century, IPM was considered one of the fundamental foundations of agriculture against the management of insect pests. IPM tactics utilize the greatest number of existing cultural, genetic, mechanical, biological, and chemical methods to manage hazardous insect plagues at an economic level of injury in a particular plant. IPM strategy relies mostly on regular visits and monitoring of the pest and is widely recognized as a method to manage agriculture's sustainability at the global level. As the number of people moving to or from different locations and the globalization of the food industry increased, more and more pest species were introduced to locations where they had not been present previously. Suitable precautions against such invasive pests and planning, progress, and strategic implementation are essential. An effective IPM plan is crucial in this setting to optimize the benefits of insect management while limiting the possible damaging environmental implications. The IPM hypothesis is widely regarded as an environmentally acceptable method of ensuring agricultural product output and quality. That is, IPM is defined as employing a superior pest control method that reduces crop output without causing lingering chemical toxicity to beneficial organisms, which is critical for the effectiveness of actual management practice. The words integrated production and pesticide management are currently applied together and simultaneously for the initiatives in place in African and Latin American countries. The fundamental concepts of the IPM are (a) healthy soils and plants are promoted, (b) natural enemies are protected, pest levels and conditions are monitored regularly, and important technical know-how and expertise are disseminated to the farming community. By combining these principles, IPM creates a system that allows farmers to monitor the activity of various pesticides that harm crops, while at the same time reducing the use of synthetic pesticides, which results in enhanced environmental protection [12–16].

In this review, identification, biology, control tactics, and future management strategies are discussed regarding Pakistan's largest rice insect pests.

Rice Plant

O. sativa (Asian rice) and *O. glaberrima* are members of the Graminae family of grasses. Among the *Oryza* species, rice is an annual plant that includes 20 wild species and two cultivars (African rice and Teff rice). A variety of rice known as *Oryza sativa* is the most commonly cultivated in the world. As a result of its geographic location in Asia, *O. sativa* can be divided into three subspecies: *indica*, *javanica*, and *japonica*. A variety of tropical and subtropical cultivars that are cultivated in Southeast Asian countries are called *indicas*. *Javanica* refers to bull (gunded) and gundyl (awnless) kinds of rice that grow beside indicas in Indonesia with long panicles and broad grain. The short and round grain varieties in Japan, China, and Korea are known as japonica. Japonica-type cultivars have been cultivated in northern California, USA, under low night temperatures. In the southern USA, the indica types are cultivated.

The rice crop includes the roots, stalk, leaves, and panicles. In its growth cycle, rice goes through 10 stages: germination and emergence, seeds, tilling, elongation of stems, panicle initiation, panicling, flora, milk gramme, fat grain, and mature grain stage. It takes approximately 150 days for traditional varieties such as Basmati to reach the ripe grain stage in their growth cycle. Crops with high yields and modern technology can also be harvested very early after seeding, as early as 90 days after the planting date [17].

2. Rice's Most Dangerous Pests

From seed through harvest, the rice plant is susceptible to a variety of insects. A variety of insect pest species harm rice plants. Only a few species are economically significant, and they can inflict a 25–30 percent economic loss. Leaf folders, plant-, and leafhoppers are only a few of the species that were once considered small pests but have now become severe problems. The following section discusses the distribution of each major pest, as well as its major characteristics and life cycle, symptoms, and potential harm of alternate host plants [18]. Some pests have a short life cycle and are difficult to identify, and there is little or no information available on them (Table 1).

Table 1. List of some dangerous rice insect pests.

Common Name	Scientific Name	Kingdom	Phylum	Class	Oder	Family	Genus	Metamorphosis	Host Range	Destructive Stage	Symptoms
							Stem borers				
Yellow stem borer	*Scirpohaga incertulas* (Walker)	Animalia	Arthropoda	Insecta	Lepidoptera	Crambidae	*Scirpophaga*	Complete	Rice (*Oryza* spp.), Cyperus, Cyanodon dactylon, and Leptochloa panicoides	Larvae	Presence of brown colored egg mass near the leaf tip.
White stem borer	*Scirpophaga innotata* (Walker)	Animalia	Arthropoda	Insecta	Lepidoptera	Crambidae	*Scirpophaga*	Complete	Rice, *Cyperus* spp., *Saccharum officinarum*, *S. spontaneum*, *S.arundinaceum*, *Eleocharis* sp., Cyanodon dactylon, and *Oryza australiensis*	Larvae	
Striped stem borer	*Chilo suppressalis* (Walker)	Animalia	Arthropoda	Insecta	Lepidoptera	Crambidae	Chilo	Complete	Rice, maize, Scirpus gressus, *Panicum crusgalli*, sorghum, *Panicum miliaceum*, *Echinochloa* spp., *Phragmites communis*, *Saccharum* sp., *Typha latifolia*, and water oats (*Zizania latifolia*, *Z. caduciflora*, and *Zizania aquatic*)	Larvae	Dead hearts or dead tillers
Pink stem borer	*Sesamia inferens* (Walker)	Animalia	Arthropoda	Insecta	Lepidoptera	Noctuidae	Sesamia	Complete	Rice, maize, sorghum, *Setaria italica*, and many other grass weeds	Larvae	Dead hearts and white heads at the vegetative and flowering stages
							Leaf Folders				
Rice leaf folder	*Cnaphalocrocis medinalis* (Guenee)	Animalia	Arthropoda	Insecta	Lepidoptera	Crambidae	*Cnaphalocrocis*	Complete	Rice, maize, millet, oats, sorghum, sugarcane, wheat, wild grasses, and sedges	Larvae	Leaves folded longitudinally
Rice leaf folder	*Marasmia patnalis*, (Bradley)	Animalia	Arthropoda	Insecta	Lepidoptera	Crambidae	*Cnaphalocrocis*	Complete	Rice	Larvae	Defoliated, and the affected leaves are scorched or white, plastic
							Leafhoppers and planthoppers				
White-backed planthopper	*Sogatella furcifera* (Horvarth)	Animalia	Arthropoda	Insecta	Hemiptera	Delphacidae	Sogatella	Incomplete	Rice, maize, and many grass weeds	Nymphal and adult	Stunted growth
White leafhopper	*Cofana spectra* (Distant)	Animalia	Arthropoda	Insecta	Hemiptera	Cicadellidae	*Cofana*	Incomplete	Rice, apple, grapes, strawberry, and potato	Nymphal and adult	Discoloration and dwarfing or stunting of leaves
							Grasshoppers				
Rice grasshopper	*Hieroglyphus banian* (F.)	Animalia	Arthropoda	Insecta	Orthoptera	Acrididae	Hieroglyphus	Incomplete	Rice, maize, millet, sugarcane, and other grasses.	Nymphal and adult	Defoliation of the plants, leaving only the mid ribs and the plant growth
Small grasshopper	*Oxya multidentata* (Will.)	Animalia	Arthropoda	Insecta	Orthoptera	Acrididae	*Oxya*	Incomplete	Rice, sugarcane, wheat, maize, and fodder crops	Nymphal and adult	Yellow-green oblong to linear spots on the base of the youngest leaves
Rice hispa	*Dicladispa armigera* (Oliver)	Animalia	Arthropoda	Insecta	Coleoptera	Chrysomelidae	Dicladispa	Incomplete	Rice	Nymphal and adult	Tunneling through leaf tissue, causing irregular translucent white patches

2.1. Stem Borers

Rice stem pyralidae and Noctuidae families of Lepidopteran can infect seedlings to maturity with rice plants. It is a well-known fact that pyralid borer species, which are widely distributed throughout the world, are among the most powerful and destructive stern borer species. However, there are many varieties of nocturnal borers, and they rarely cause economic damage to the economy. The yellow stem borer (Walker), white stem borer (Walker), pink stem borer (Walker), *sesamia inferens* (Walker), and striped stem borer, chilogruler (Walker) are the most common and widely dispersed species. The larvae of the borer start to bore into the inside of the sheaths. At this stage, the longitudinal yellowish-white spots at feeders on the sheet are a sign of damage. As part of the excavation of the stem, the apical components of the plant are often separated from the base. This means the center leaf blade does not open, and it turns brown and dry. On the other hand, the lower leaves may appear healthy and green. The tillers damaged do not panic, and the distress is called "dead heart". If the growing parts of plants are separated after initiation of the panicle, they may not form or produce cereals. These panics stand out on the ground as they have empty grains and are upright and white. They are known as "white heads" [19,20].

2.2. *Scirpohaga incertulas* (Walker), Yellow Stem Borer

Distribution: South and Southeast Asian countries (Figure 1).

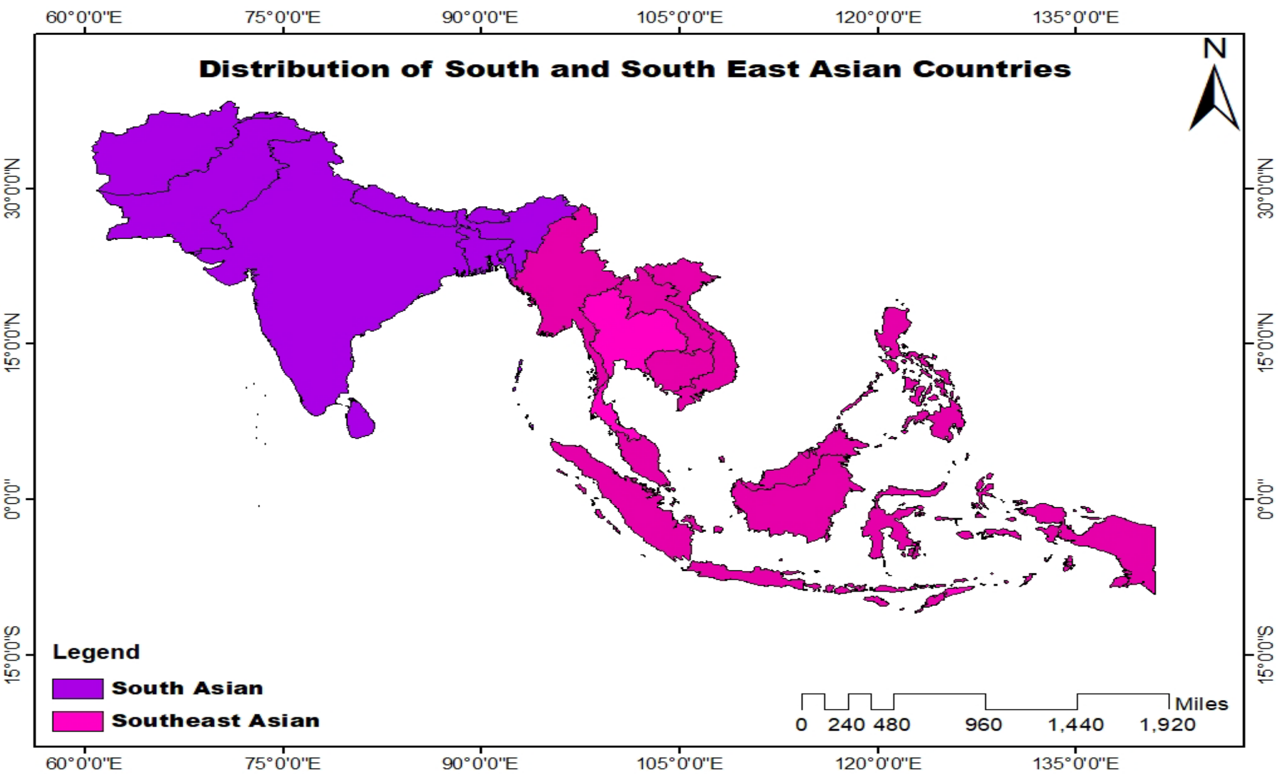

Figure 1. Worldwide distribution of *Scirpohaga incertulas* (Walker), yellow stem borer.

Life history: When not actively flying, the yellow stem borer adults are diurnal and repose in the shade. They are active fliers who are nocturnal and phototropic. Early in the morning is when moths are most busy. Female moths have beautiful golden-brown forewings containing a distinct black spot in the center, and they are larger in size than the male moths. They have a large abdomen adorned with yellowish tufts of hair that adorn the tip of the abdomen. They are pale yellow in color, with a slender abdomen and a thin hairy coating on the posterior end of the female moth. In male moths, there are hardly any visible spots on the wings. Mating occurs between the hours of 7 and 9 p.m. It has been observed that YSB females are more numerous than males based on light trap catches. Female moths lay their eggs towards the apex of the leaf blade in tiny groups early in the night. A total of 100–150 eggs can be laid by a female moth. The eggs are creamy white, flattened, oblong, and scale-like, and they are coated in female moth anal hairs. The eggs turn dark brown before they hatch. The hatching larvae are geotropically negatively, raising up to the top of the plant, where they remain only for a short time. There are also plants that spin, suspend, and swing silky threads through the air and rest on other plants. Many larvae die during this roaming period because of the conditions in which they live. In the next two to three days, the survivors feed on the green fabric of the leaf sheath that surrounds them. Afterwards, the larvae burrow into the trunk of the plant and feed on the tissues of the inner part of the plant, usually around the nodes of the plant. Approximately 25 mm long, the sixth larvae have a well-divided prothoracic shield, and their color is white or yellow. Soon after the prepupal molds are formed, they form a thin silk enclosure inside the stem. It usually takes 30 days for the larvae to emerge from the egg. During larval development, an exit hole is constructed before the adult moth is wet. In most cases, pupation development occurs in the stem at or slightly above the plant's lowest node. Pupae at first are light in color, but they become a darker brown after a while. The pupal phase takes six to ten days, but it may be longer in cold months. Rice stubble causes diapause in winter when the rice crop is not grown in the field and temperatures are not favorable to the development of the larval plants [21,22].

Damage: The size of the losses changes depending on the time of year and location. From early elongation through ripening and booting-heading of the crops, to late elongation and booting-heading of the crops, the average incidence increased. The yellow stem borer has been predicted to cause a 20–30% reduction in Basmati variety yields, with infestations reaching 90 percent on rare occasions [23,24].

2.3. Scirpophaga innotata (Walker), White Stem Borer

Distribution: All rice-growing areas in Pakistan and other, different regions of world, i.e., Australia, South and Southeast Asian countries (Figure 2).

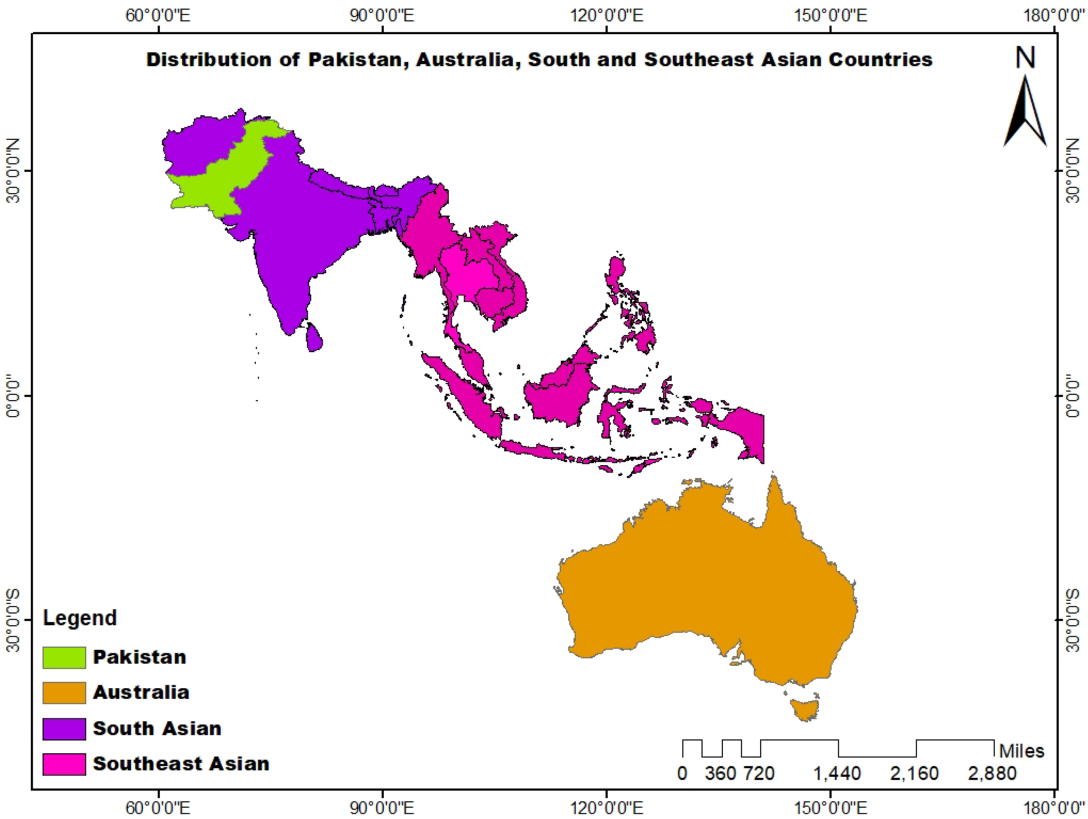

Figure 2. Worldwide distribution of *Scirpophaga innotata* (Walker), white stem borer.

Life history: Rice fields in Pakistan are heavily damaged by the white stem borer. The adult WSB looks like the YSB. In the adult stage, every WSB moth looks the same. A white moth in the field shows an orange tuft on its anus, particularly in the early stages of the crop. There is a range of 26 to 30 mm for a female adult, while there is a range of 18 to 24 mm for a male adult. There are usually 70–260 eggs laid by the female moth on the underside of young leaves in clusters. Similarly to the yellow bored stem, the egg mass is wrapped in an area at the front of the female moth's silky hair, much like the egg mass in the silky hair of the female moth. When the eggs hatch into larvae, it takes between 4 and 9 days for them to hatch into adulthood. The larvae penetrate the sheaths of the leaves during the initial stages of development and dig their way into the trunks of the trees. Larvae reach a width of 25 mm and are milky white. It can take between 19 and 31 days to complete the larval stage. The fully grown larvae pupate in the stem, as in *S. incertulas*, after developing the exit hole through which the moth may emerge. Pupae have a length of 12–15 mm and a delicate body. They are pale in color, and pupation lasts 7–11 days. Both *S. innotata* and *S. incertula* larvae diapause over the winter season. White stem borers can produce three to five generations of rice plants, depending on the variety, the seed and transplant times and the harvesting time [25].

Damage: Similar to the yellow stem borer in terms of damage and natural history. Dead hearts in nurseries and young crops are caused by the first three generations, while white heads are caused by the second and third generations.

2.4. *Chilo suppressalis* (Walker), Striped Stem Borer

Distribution: Europe, South and Southeast Asian countries (Figure 3).

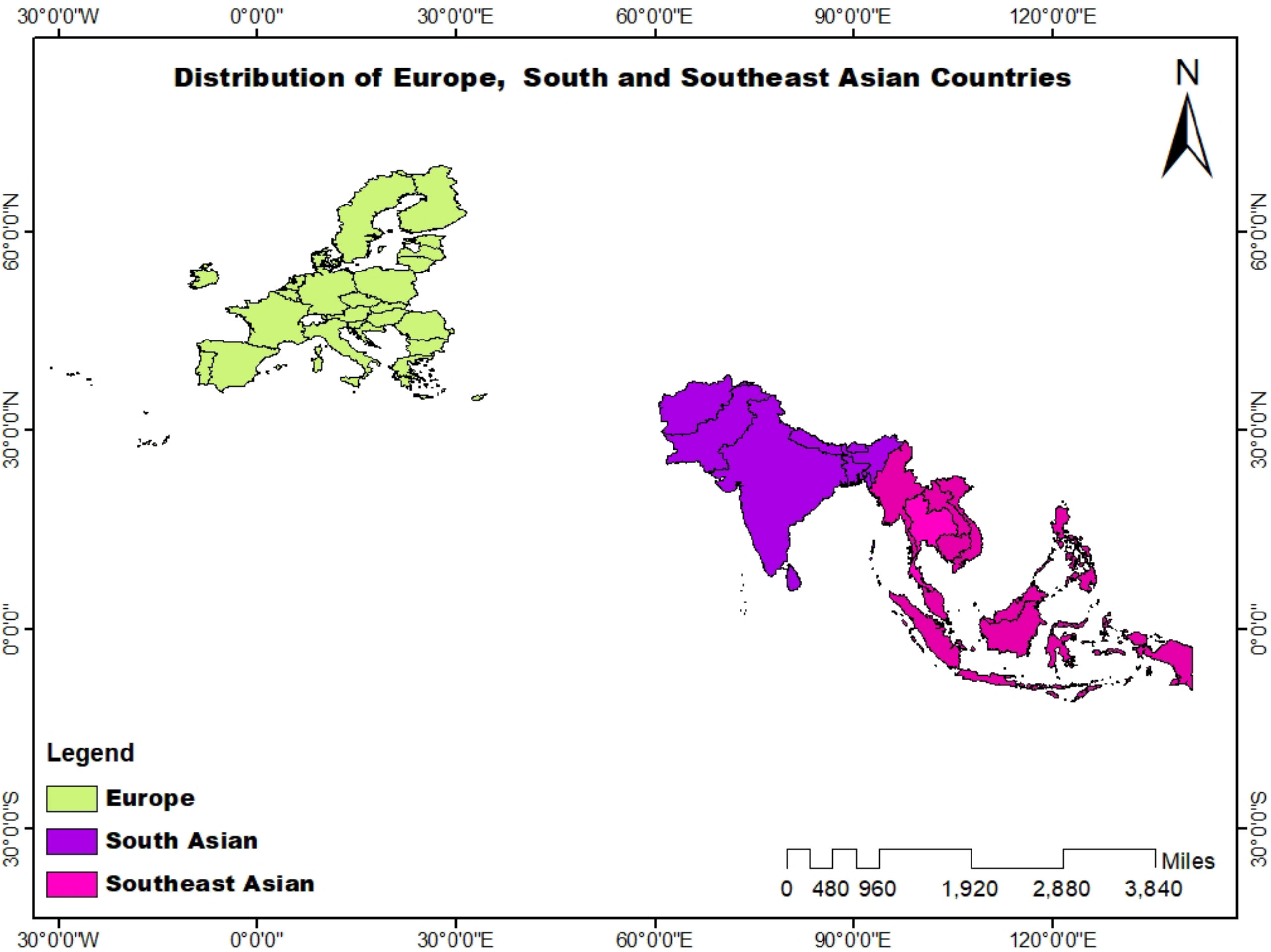

Figure 3. Worldwide distribution of *Chilo suppressalis* (Walker), striped stem borer.

Life history: In adults, the forewings of the moth are inflexible and light brown, and they are 13–16 mm long. The anterior wings of the borer moths are striped and usually have five black spots on the top, while they are yellowish white. The hindwings are white. The males are louder than the females. Moths emerge in the early hours of the night and are active in the early hours of the morning. Moths can be seen amid dense foliage during the day. Despite mating occurring on the night of emergence, egg laying begins the following night. During the lifetime of a moth, both males and females can only mate a total of eight times. Within 3–5 days, a female moth can lay between 100 and 550 eggs, which are laid in batches of 50 to 80 eggs each. The eggs are scale-like and naked, arranged in masses in overlapping rows, and they range in color from pale to dark yellow. The egg masses that have accumulated on some of the lower portions of the leaves can be observed. To hatch eggs, it takes between 3 and 5 days. A gregariously living larvae population characterizes these three instars. The newly hatched larvae move up the rice plant before congregating behind the leaf sheath, where they will remain until they hatch. The larvae enter the stalk through an opening they share. When the larva is fully developed, it measures 26 mm long and 2.5 mm wide. There are three brown abdomen streaks on the dorsal side and two on the latter side, with a golden-brown head. It has a golden-brown body on the back with three brownish stripes on the abdomen and two on the side. The larval stage in most cases lasts from 20 to 48 days. Waxing is done within the stem, as with other borers of the stem. The pupa is reddish-brown in color and has no silky cocoon. In ideal environmental conditions, 5–6 larval settings exist, but reports are made of up to nine larval settings in stressful situations. Depending on host plant availability and optimal temperature conditions, 1–4 generations of the host plant are available each year [26].

Damage: Rice is usually attacked by the pest in the middle or late stages of the plant's life cycle, depending on the species. Lice feeding can cause a variety of problems, including plant vigor reduction, less tiller production, unfilled grain production, and plant lodging.

2.5. *Sesamia inferens (Walker), Pink Stem Borer*

Distribution: South Asian countries (Figure 4).

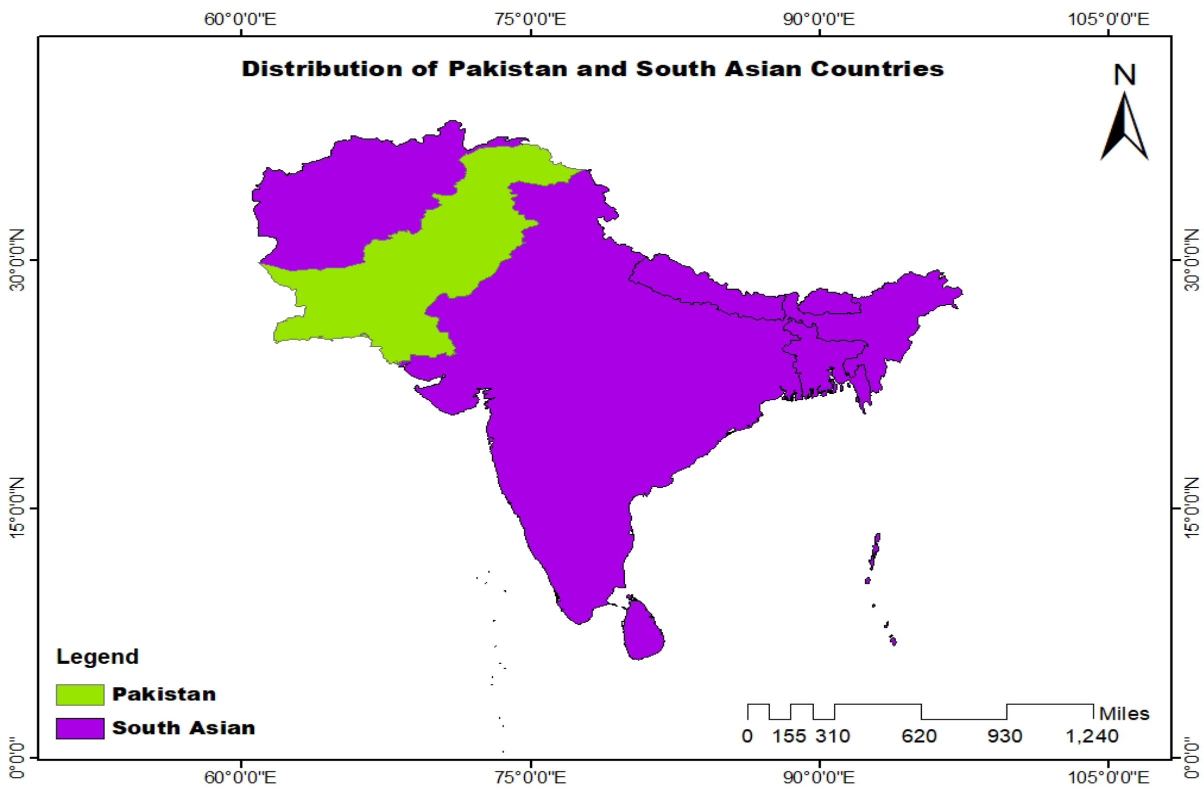

Figure 4. Worldwide distribution of *Sesamia inferens* (Walker), pink stem borer.

Life history: Pink stem borers are the least harmful of stem borer species. As an adult, the moth is fawn in color, with tan forewings and dark brown patterns surrounding a central point on the forewings. The wing tips are surrounded by gray-black lines and a thin line of dark dots. On the pronotum, there are hair tufts. The hindwings are white in color. The female has a 30–35 mm wingspan, while that of the male is 20–30 mm. Around 400 eggs are laid by the female moth. The naked eggs range in color from creamy white to black and hatch in about a week. The larva's head capsule is orange-red, and its body is purplish pink on the dorsal side and white on the ventral side. Compared to the rest of the body, the head is large. Larvae frequently emerge from a single stem and penetrate into other stems, killing multiple plants. After experiencing 5–7 molts, the larva reaches full size in 4–5 weeks. The length at this point is between 20 and 26 mm. As well as inside the larval tube of the stem, pupation can also occur between the leaf sheath and the stem. In the cephalic region of the pupa, there is a hint of purple. It has a length of 18 mm and a width of 4 mm. Pupation usually lasts around a week. In a single year, there can be as many as six generations [26].

Damage: Like other borers of stem but less destructive. This can be because of its polyphagous nature. Outbreaks in rice are usually caused by population from adjacent sugarcane or other alternative hosting sites.

2.6. *Leaf Folders*

Rice leaf folders, which were previously thought to be a tiny and intermittent rice pest, seems to be on the rise. Any changes in cultural practices that occur as a result of the dissemination of high-producing cultivars are important [25]. High leaf folder populations have been attributed to the misuse and overuse of nitrogenous fertilizers.

2.7. *Cnaphalocrocis medinalis (Guenee), Rice Leaf Folder*

Distribution: Australia, South and Southeast Asia (Figure 5).

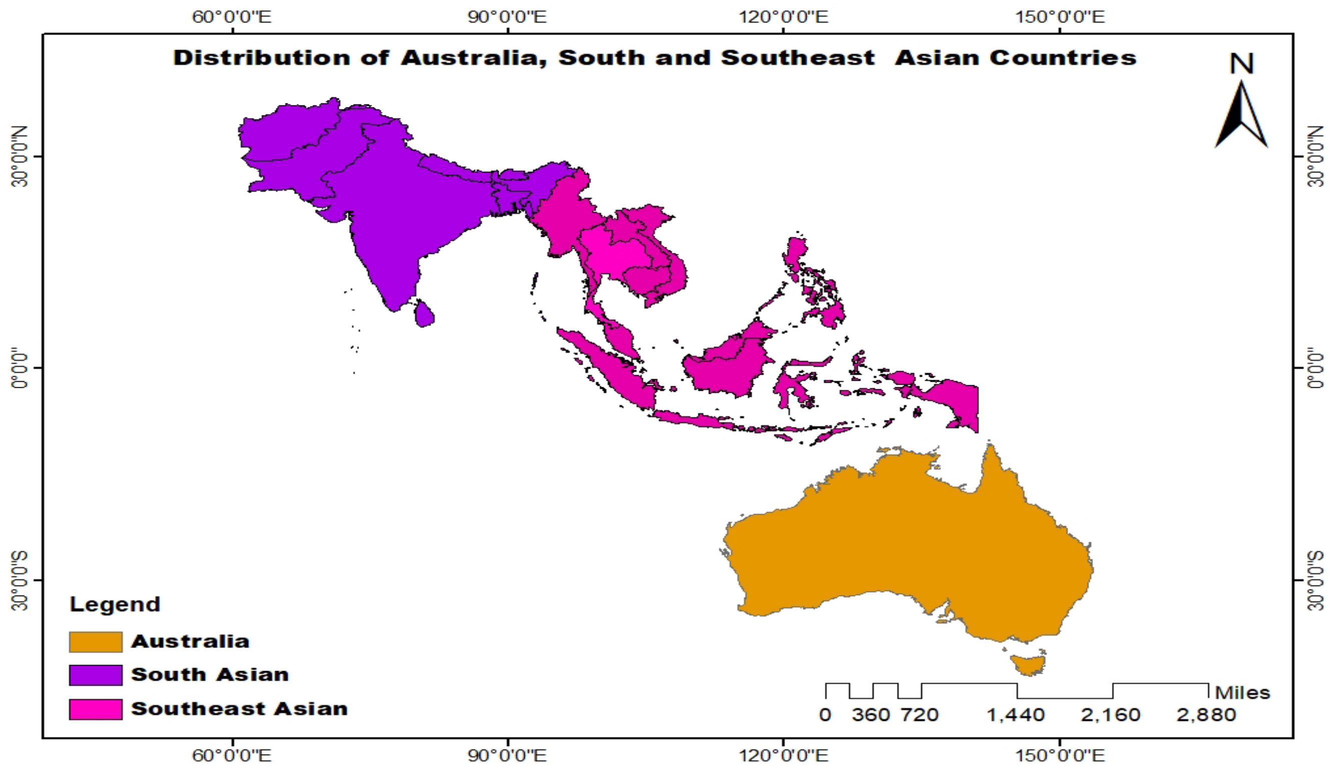

Figure 5. Worldwide distribution of *Cnaphalocrocis medinalis* (Guenee), rice leaf folder.

Life history: In broad daylight, moths hide under leaves and on stems as they are nocturnal. During the early hours of the morning, moth activity is at its peak, but as the day continues, the moth activity lessens. Moths are attracted to light. As adults, the moths are very small, and they have a yellowish-brown appearance. They are 10–12 mm in length with wingspans of around 13–15 mm. When the wings are not moving, they form an equal-sided triangle. Three oblique lines of different lengths run across the forewings. The area of the hind wings is large. The male moth's tibiae are tufted with black hairs, whereas the female's are not. Males have a broad abdomen tip, while females have a pointy tip. The female uses a pheromone to attract its mate, and they usually mate between the hours of dusk and midnight. Adults have a life expectancy of one week. After one or two days of mating, the eggs begin to be laid. On both surfaces of young leaves, females lay flat, oval, creamy golden eggs, either singly or in rows parallel to the midrib of the leaf, and either in one or two layers. Eggs are laid in batches of ten to twelve. Female moths have the ability to deposit up to 300 eggs during the course of their lives. The duration of incubation can range anywhere between 3 and 6 days. Upon hatching, the newly hatched larva has a light brown head and a white, transparent body. Nevertheless, the larva's body turns green once it starts feeding. It starts feeding on the youngest leaf that is yet to open immediately after hatching by climbing to the bottom of the leaf that has just emerged. The second instar moves to a more mature leaf and wraps it together. Some of the freshly born larvae hang from the leaf tip on silken threads and are dispersed by the wind to adjacent plants. A total of five larval instars are present. Upon reaching full size, the larva measures roughly 16 mm in length and 1.7 mm across the thorax. In appearance, it has a yellowish-green head and a dark brown prothoracic shield. When touched, larvae quickly jump or squirm. The larval stage takes 15 to 25 days to complete. Pupation occurs in looser woven silk strands inside the leaf roll. The pupa is slender and greenish-brown when it is first created, but it eventually turns brown. After 6–8 days, the molt develops.

Damage: They scorch the leaves by folding them inward and scraping away at their green tissues from within, causing them to dry and scorch. To survive, each larva must consume several leaves. Each attacked rice crop may have several rolling leaves during a serious infestation that reduces its capability to manufacture food. Filling grain may be partly completed when flag leaf stage plants are attacked [24,26,27].

2.8. Marasmia patnalis, Bradley, Rice Leaf Folder

Distribution: Australia and some countries of South and Southeast Asia (Figure 6).

Life history: The biology and behavior of *Marasmia patnalis* are very similar to those of *C. medinalis*. The two species are closely related. The forewings have three long dark bands for the adult moth, while the forewings of *C. medinalis* have two long bands and one short band. The adult moth has a length of about 7 mm and a wing width of 13 mm. Its forewings are furnished with light yellow and brown patterns. The grave female moths, rather than on the plants' leaves, place their eggs on the green sections of high rice plants. The eggs are laid on the top side of the leaves, either individually or in groups of two to nine, but they can also be found on the leaf sheaths, which are covered in eggshells. Approximately 4–5 days are required for the virus to incubate. As the newly hatched larvae begin to develop, they scrape the surface of the leaf with their claws in order to gain access to nutrients. The larvae of the second instar fold the leaves to the inside and start feeding on the leaves from within. Because the larva's pronotum apex is convex, as opposed to the straight pronotum apex of *C. medinalis*, it differentiates the adult form of the species. The larval phase usually lasts about 23 days. The pupal stage can last for up to 9 days and is characterized by the development of a silky cocoon, usually made of stitched leaves. In the middle of the night, the adult appears [28].

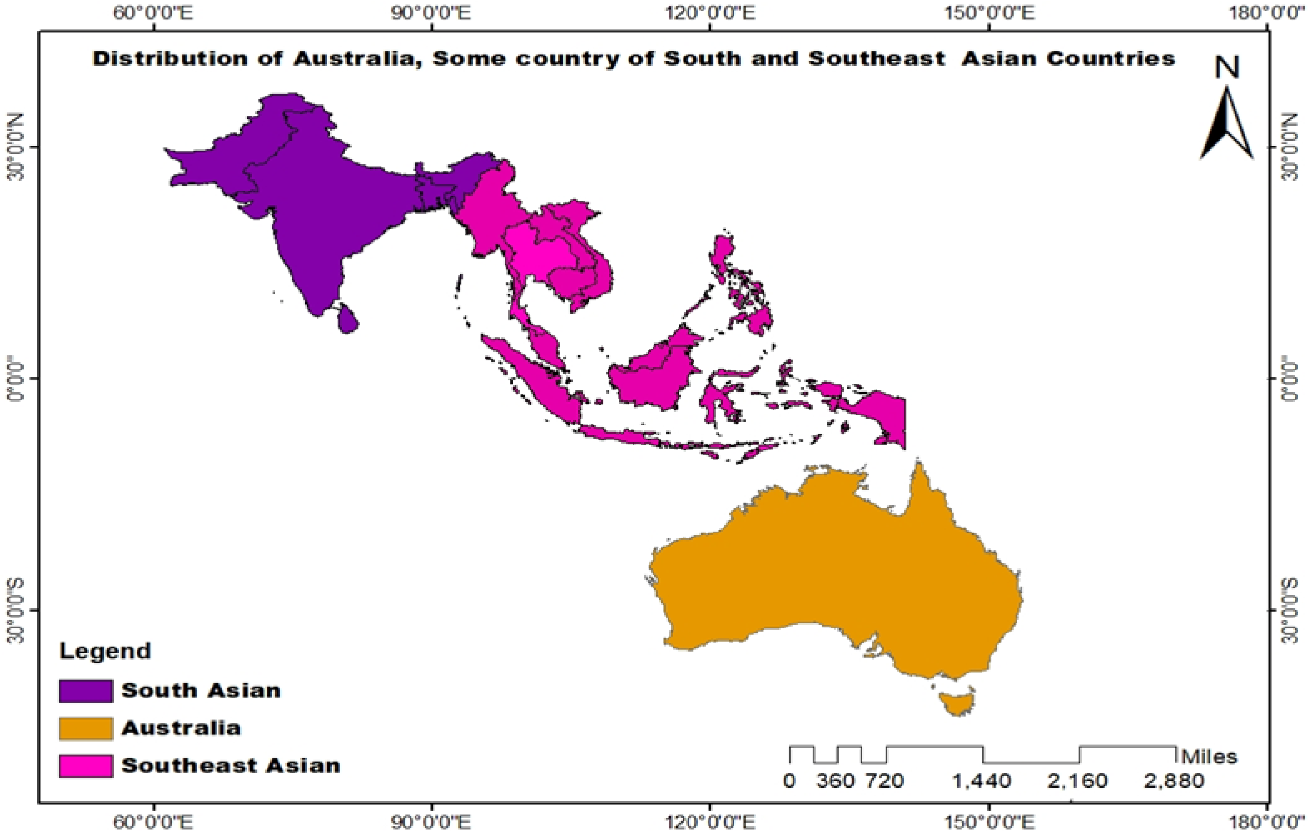

Figure 6. Worldwide distribution of *Marasmia patnalis*, Bradley, rice leaf folder.

Damage: same as *C. medinalis*.

2.9. Leafhoppers and Planthoppers

As of recent years, plant breeders and rice leaf breeders have become very important in terms of economic production in rice fields. Interestingly, the introduction of high-yielding, short-duration varieties of crops in recent years has resulted in leaf- and planthoppers acquiring a pest level status in Pakistan. Rice pest (*Sogatella furcifera*) is the second-most commonly found and most destructive pest in Pakistan after stem borers. In 1952, iii Sind province first appeared on 1000 hectares with an estimated loss of 60 percent of grain [4,27]. However, the first Sind outbreak in semi dwarf varieties was reported by Mahar et al. [24]. These pest population densities are higher in the past years for high-production varieties than those in local Basmati [29].

2.10. *Sogatella furcifera* (Horvarth), White Backed Planthopper

Distribution: Australia, Southeast Asia, and Far Eastern countries (Figure 7).

Life history: In the first month of sowing, long-winged insects invade the paddy field. During the flowering phase of rice, they migrate, and they prefer young plants. Approximately 3.5–4.0 mm is the length of the adult hopper insect. Forewings with dark veins are almost evenly sub-hylined. The wings of the wings have a prominent white band. It has a creamy white mesonotum, black abdomen, and ochraceous brown legs. Brachypterous females and macropterous males, commonly found in rice crops, are extremely rare in contrast to brachypterous males. The adults prefer to stay in the upper part of the rice. Phototropic adults are very strong and are attracted to light traps. In the midribs, eggs are placed; on average, a female can lay 150–300 eggs. In six days, the egg hatches. Nymphs are white in color or black and white to a strongly roll-out dark grey. Nymphs reach adulthood in 12–17 days after five instars. The grassy adult starts laying diaphragm eggs during the winter season, spreading through the middle of the spring.

Weeds for feedings are preferable to nymphs. Infesting rice fields are the adult trinkets from those snacks [29].

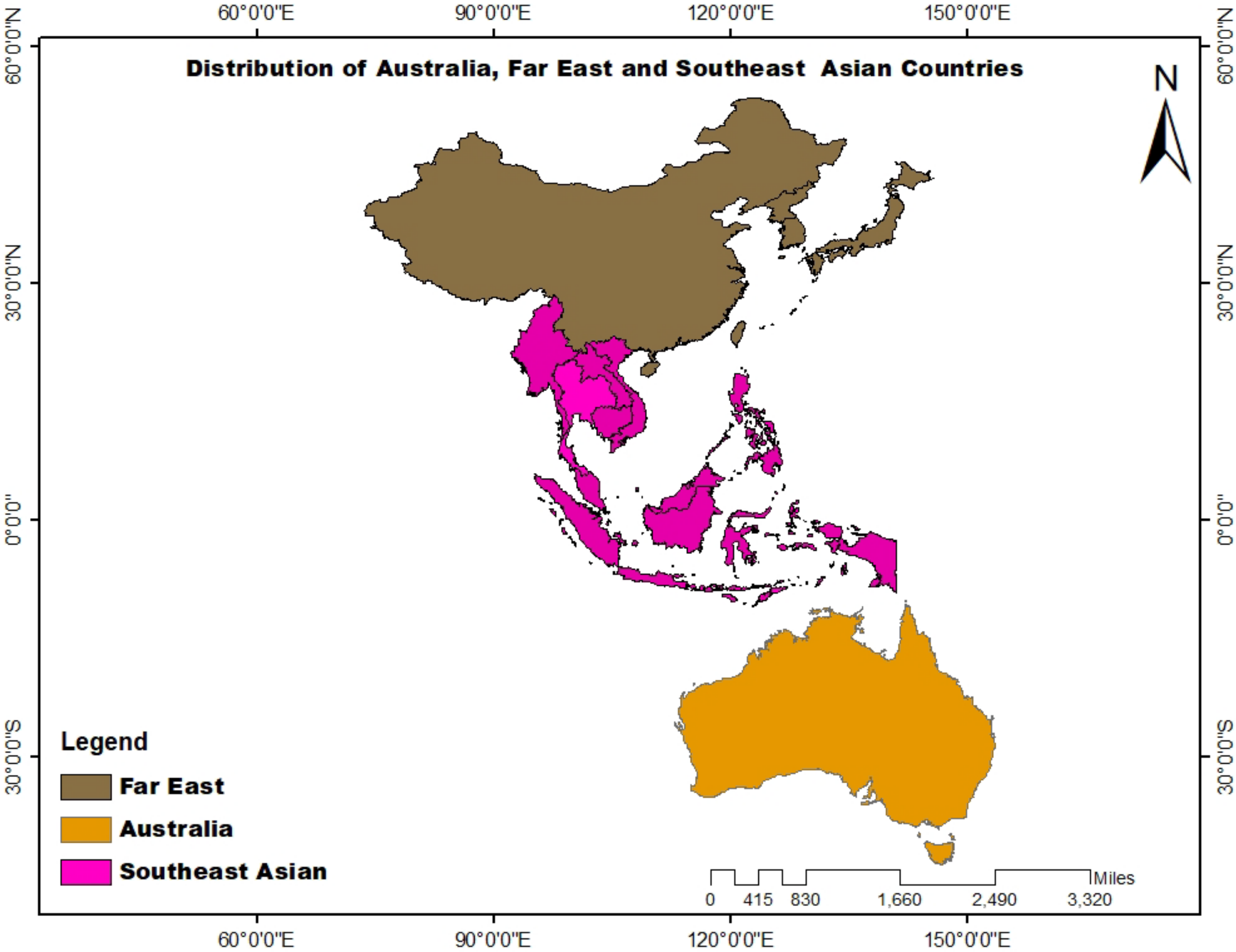

Figure 7. Worldwide distribution of *Sogatella furcifera* (Horvarth), white backed planthopper.

Damage: It appears that the rice plants affected by white hopper plants are uniformly distributed throughout large areas of the field. Bathing plants are sucked in both nymphs and adults. Sap is sucked primarily at the rice plants' base both for adults and nymphs, reducing plants' strength and causing stumping in the lower leaves. Many brownish spots appear at feeding sites. The leaves of the attack quickly turn yellow, and the tips dry. The harm caused to these pale-yellow plants results in them turning brownish, diminishing in strength, disintegrating, and eventually dying without giving rise to any ear buds. This is called "burning hopper". Grave females cause further damage through the creation of oviposit punching in sheaths. Feeding locations created by egg laying could eventually become infested with bacterial and fungal diseases. The springtime's sweet wine serves as a breeding ground for mold. The white-hackled hopper is not a viral disease vector in Pakistan and elsewhere. Environmental conditions and components are favorable for a pest population expansion in various areas [30]. A lengthy monsoon with sporadic rain or a big dose of nitrogen fertilizer were the causes of an outbreak in Pakistan.

2.11. *Cofana spectra (Distant), White Leafhopper*

Distribution: Africa, South and Southeast Asian countries such as India, the Philippines, Sri Lanka, and Taiwan (Republic of China) (Figure 8).

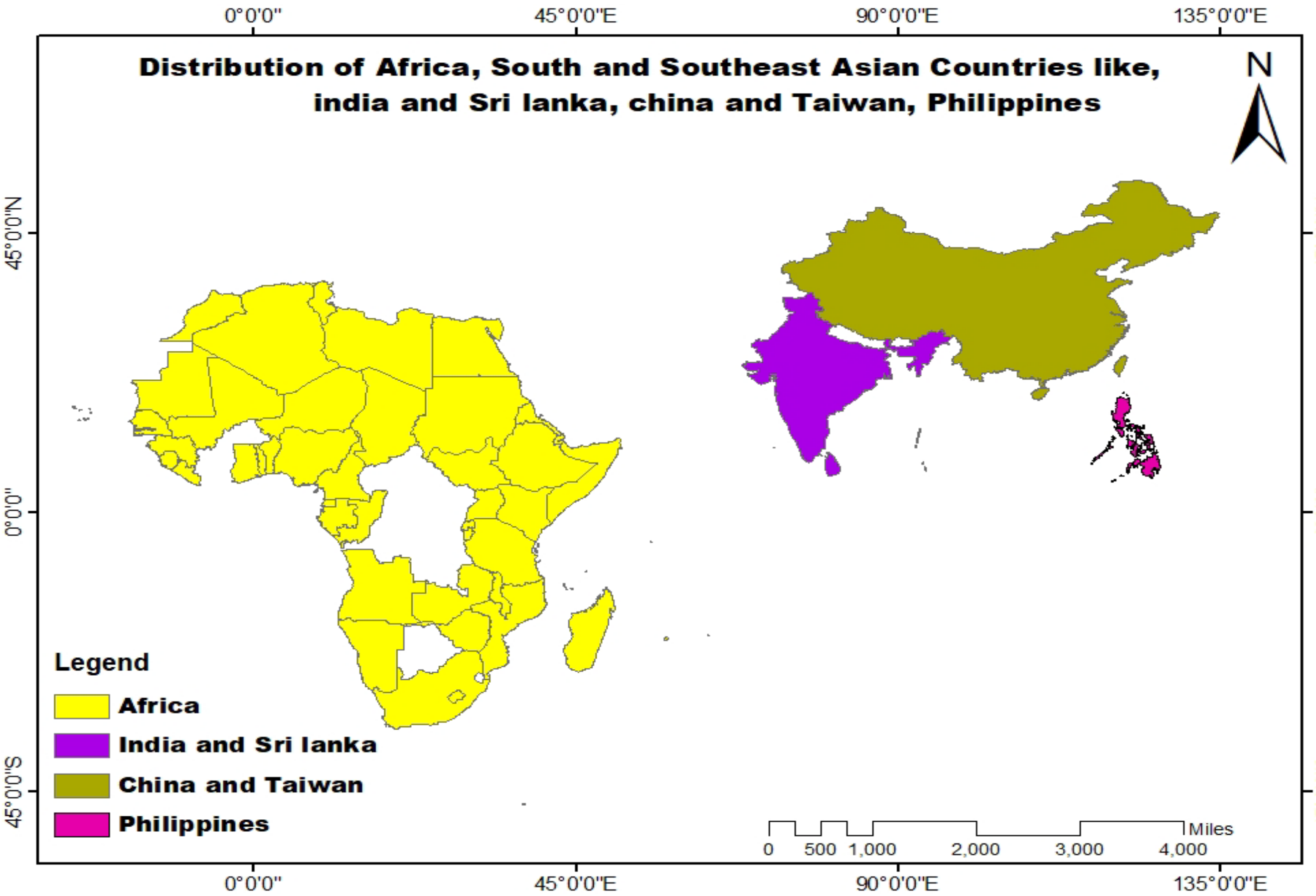

Figure 8. Worldwide distribution of *Cofana spectra* (Distant), white leafhopper.

Life history: A yellowish body, with four black spots on the head, and grey-white forewings with pronounced veins are all that distinguishes *C. Spectra*. The female is around 9.5 mm long, including the tegmina, whereas the male is about 7.5 mm long, including the tegmina [31]. Adult life expectancy is between 7 and 10 days. Adults have a strong phototropic tendency and rest on the lowest section of the plant. Females lay their eggs in rows of 10–15 in each row, parallel to the long axis of the leaf, after cutting the sheath of the leaf parallel to the axis with their saw-like ovipositors. Typically, females lay 50 eggs, which hatch within 5 to 12 days [28].

Damage: *C. spectra* was once considered a minor nuisance. It results in the usual sap loss. The leaf tips dry out first, then the entire leaf becomes orange and coils. Plants are stunted and yellowed by the pest, and severe infestations result in plant death.

2.12. *Grasshoppers*

Shaded fields may contain a variety of grasshopper species. However, they rarely cause harm unless the grasshoppers are near the edge [31,32]. They eat angular holes in leaves, injuring them like leaf folders and armyworms do. Grasshoppers are insect pests that can eat a variety of different foods.

2.12.1. *Hieroglyphus banian* (F.), Rice Grasshopper

Distribution: Southeast Asian countries (Figure 9).

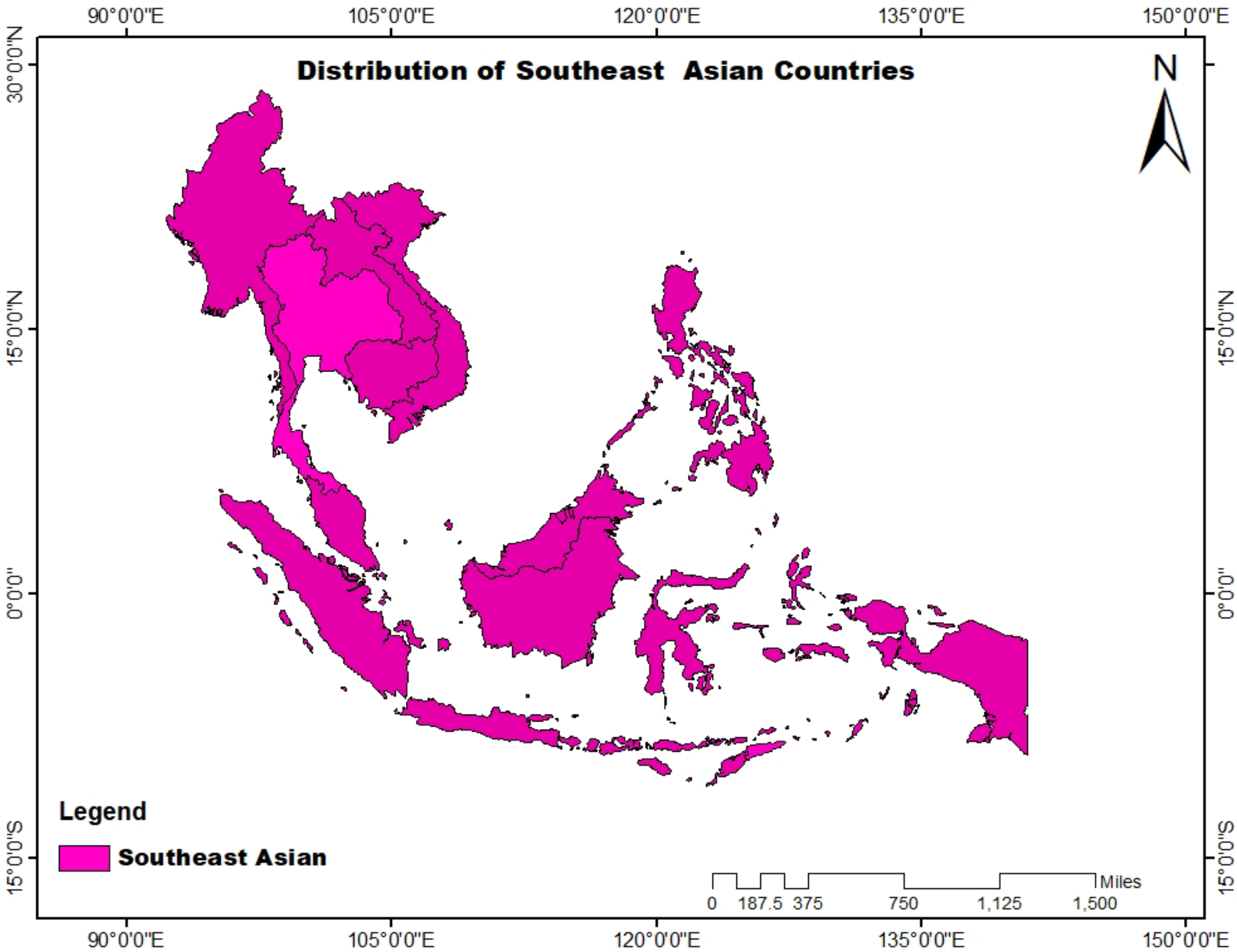

Figure 9. Worldwide distribution of *Hieroglyphus banian* (F.), rice grasshopper.

Life history: The female grasshopper measures 34–54 mm in length, while the male measures 28–40 mm. It has a drab green or yellow-brown upper body with a brownish-black bottom body surface. After a brief pre-copulation stage of one to three days, the adults mate. A lifespan of between 1 and 8 months is possible. In the soil, egg pods are placed, each containing about 30–35 eggs. A female lays 100 to 150 eggs during her life cycle. There is a sticky covering on each egg that hardens into a waterproof layer. Individual eggs are yellowish in color. After the first rainfall, the eggs hatch and the baby hoppers emerge, initially a brownish-yellow color, but they eventually change to a dull green. Normally, the males have 5–6 instars, whereas the females have seven instars, and there is only one generation of the species per year [29].

Damage: During the early stages of rice seedling development, nymphs feed on newly germinated seedlings, causing them to shrink. The adult sautons feed on the leaves and shoots of the plants as well as cutting off parts of the ear heads of the plants. The resulting grains become stunted when the emerging inflorescence is attacked. Their attacks may cause heavy defoliation during August and September.

2.12.2. *Oxya multidentata* (Will.), Small Grasshopper

Distribution: Africa, South and Southeast Asia (Figure 10).

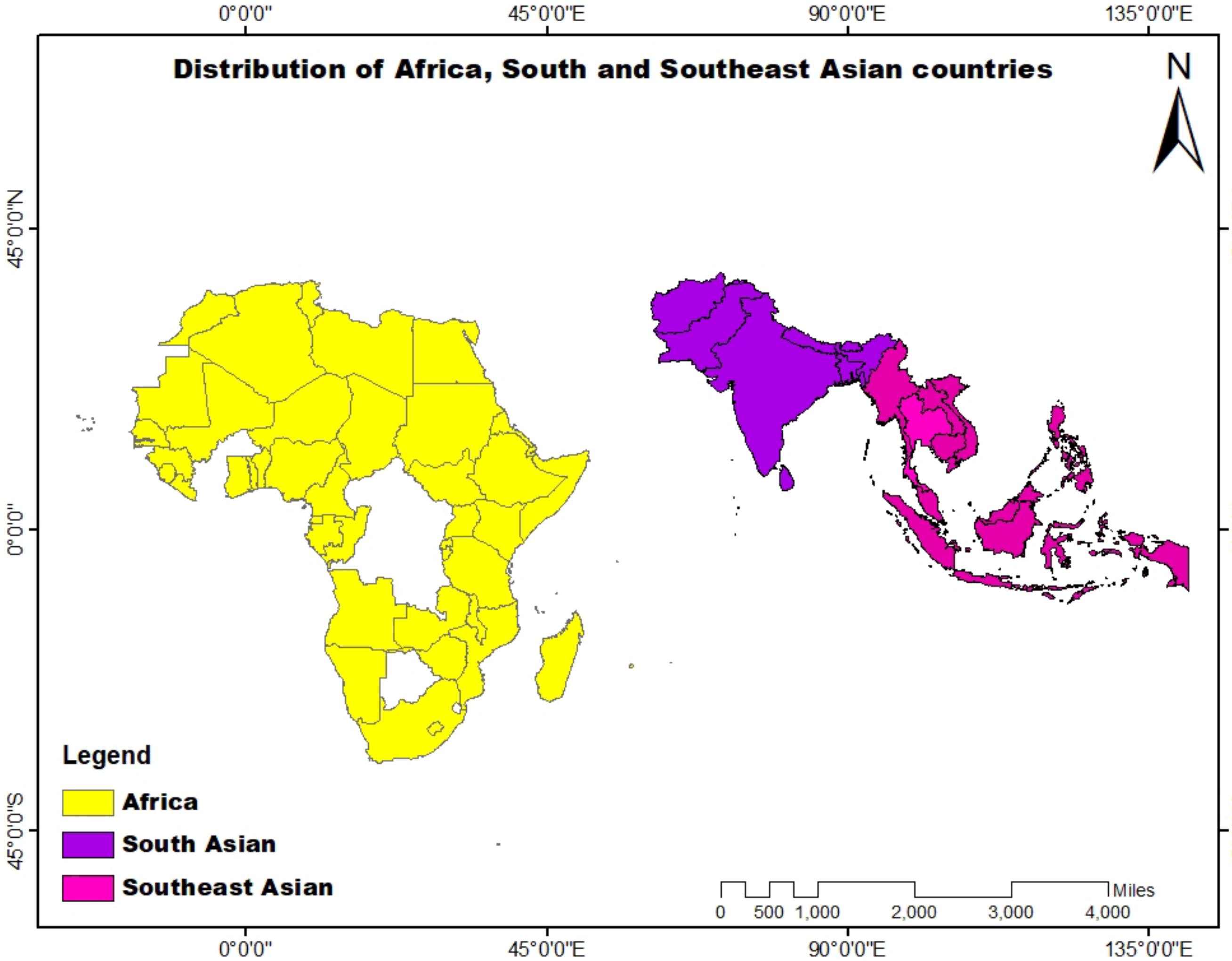

Figure 10. Worldwide distribution of *Oxya multidentata* (Will.), small grasshopper.

Life history: Adults have 30 mm of flowing green or light brown from each eye to their thorax. Eggs are placed on stems in weights of 10–30 above water. Females bury eggs beneath the ground under dry conditions. Eggs are enclosed in a theca-forming rubber bubble. In 2–3 weeks, the eggs hatch. Six larval instars and the female pass through an additional molt. It generally takes three months for nymphal development to develop. There is only one generation a year [31,32].

Damage: This pest is a small rice pest but has become more important in economic terms. Rice and nurseries are the feeding ground for nymphs and adults. The adult feeds at the foundations of mature ear heads, which causes them to dry up.

2.13. *Dicladispa armigera (Oliver), Rice Hispa*

Distribution: South and Southeast Asian countries.

Life history: Adult beetles emerge from the plant early in the morning, and through the day, they lay their eggs on the lowest parts of the plants. Beetles have spines on their wing covering and are little, shiny black insects that are around 5.5 mm long. Female beetles have a lifespan of 20 days, while male beetles live for barely two weeks. The beetles mate 3–4 days after emerging. Single eggs are deposited, and a female can lay a total of 50–55 eggs on average. It takes 4–5 days for the eggs to hatch. The newly hatched larvae are pale yellow in color, with a flattened dorsoventral surface and a length of 2.4 mm. They begin mining from the tip of the leaf and work their way down to the base of the blade. It takes 7–12 days for a larva to develop. The pupa is flat, brown, and exarate. Within the leaf mines, the pupal stage takes 4–5 days to complete. A rice leaf is cut open by an adult beetle, and that beetle begins to feed on its outside surface [31].

Damage: This pest causes significant crop losses in Pakistan. The introduction and improved agronomic practices of high-yield varieties in more areas seem partly responsible for increased infestations. Both grubs and adult beetles feed on the rice plants. A grub mines leaves by feeding on the mesophyll between the veins and tunneling through the tissues towards the axis of the leaf sheath. The leaves are brown in severe cases, and the field looks dry. Even replanting cannot be carried out as the pests persist and infest the newly planted rice plants [31].

3. A New Era in Integrated Pest Management

Insect pests and diseases are the major problem for crops, fruits, and vegetables globally. Worldwide, different techniques have been adopted to control these insect pests and prevent yield losses. In the beginning, most people depended upon pesticides and insecticides, but later, due to their hazardous effect on health and the environment, alternative methods were adopted. These methods include biocontrol [32,33], resistance varieties [34], botanical extract [35–39], essential oils [40,41], volatile organic compounds that change preference and host selection behavior of insect pests [42–44],

The techniques used in insect pest control are described in Figure 11.

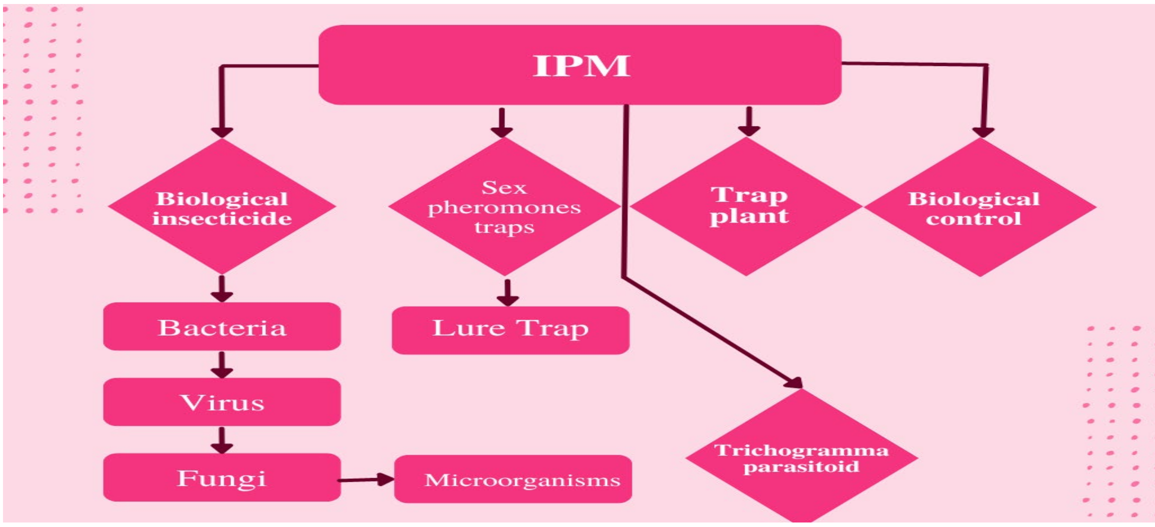

Figure 11. Integrated pest management techniques for rice.

3.1. Biological Insecticides

In China, as popular and governmental concern for the environment and food safety has increased, environmentally friendly biological pesticides have been more broadly approved and widely employed. Bt is China's most popular biological insecticide for rice stem borers and RLFs and is officially recommended for use against rice stem borers. SSB and RLF effects are 65.31%, −96.69%, and 88.00–97.17%, respectively. After spraying the control effect of nuclear polyhedrose virus *Mamestra brassicae* on RLF, 14 d is more than 83%. More insecticidal rice pests, including RLF and SSB Lepidoptera, are controlled by Spinosad, *Spinétoram*, *Bassian Beauvera*, and BREVERS of Empedobacter. *Cnaphalocrocis Medine Granulovirus* (Cnme GV), which possesses an RLF synergy of Bt compounds, is another possible biological insecticide in the management of RLF. CnmeGV and Bt were the initial dead time for RLF treatment, 3 d short of the one treated only with CnmeGV, 20.23 percent mortality and more than 30% duration. Nine percent 12 THR biological insecticide is highly controllable in RLF, BPH, and WBPH [45–49].

3.2. Release Trichogramma Parasitoids

In China, many *Trichogramma* release studies were carried out in the 1950s to control Lepidoptera pesticides in rice paddy fields. *Trichogramma* parasitoids control SSB and RLF. However, *Trichogramma* parasitoids cannot be used in rice fields at large due to the problems of selection, cultivation, and application of field techniques, including *Trichogramma*. *Trichogramma* has just been recognized as meeting food, ecological, and environmental safety requirements for insect pest management in rice fields. *T. japonicum*, *T. chilonis*, *T. dendrolimi*, and *T. ostriniae* are the four most prevalent *Trichogramma* species discovered in rice fields [50]. *T. dendrolimi* thrives in temperatures between 18 and 26 degrees Celsius, while *T. japonicum* thrives in temperatures between 30 and 34 degrees Celsius. Meanwhile, after 4 days, *Trichogramma* is unable to parasitize any SSB egg successfully [51,52]. In the parasitization of RLF eggs in regions with any of the above two temperatures, particularly in regions with high temperatures, *T. japonicum* works best. There is no difference in parasitizing 1–3 d RLF eggs among all four *Trichogramma* species, but parasitism of the four-day-old eggs has declined significantly. In recent years, *Trichogramma* release technologies have also been developed, including the appropriate rice field release devices for *Trichogramma*, nectar-food supplement release instruments for *Trichogramma*, and unmanaged aircraft release techniques for *Trichogramma* [52–54]. A series of *Trichogramma* release technology demonstration tests were carried out by the China National Chinese Service for Extension of Agricultural Technology to improve *Trichogramma's* application in rice insect pest control. These tests included species selection, time release intervals, times of application, height, and density. These experiments can potentially improve technological standardization while laying the groundwork for the widespread use of *Trichogramma* in paddy fields (unpublished data).

3.3. Sex Pheromones Cause Mate Conflict

SSB and RLF pheromones have been successfully developed and are easy to use. Only one sex pheromone should be utilized in each trap for maximum effectiveness, as the appealing capacity of two or more sex pheromones may be reduced. The ideal trap height is 10–20 cm beneath the rice canopy. The pest control effect of sex pheromone traps was shown to be greater than 50% in demonstration trials on a wide scale, and it may be further increased by combining it with other pest management tactics. When used to control SSB and RLF, sex pheromone traps can save up to two sprays of insecticide. In some cases, the pest control results of sex pheromone traps are comparable to those of insecticides, while the input costs are slightly cheaper [48,53–56].

Overwintering SSB has a 40–60-day emergence phase, and its oviposition phase is equally protracted. SSB sex pheromones, on the other hand, have an effective work time of more than 50 days, and a large number of male SSB adults can be trapped and killed (the maximum number of single traps is more than 130 individuals). The populations of the first-generation SSB in the field can be dramatically reduced by catching a significant number of males from the overwintered generation and significantly reducing the death rates induced by the first generation of SSB. For example, if more than 300 pheromone traps per hectare are placed in isolation and large regions, the number of SSB eggs is decreased by more than 70%. When there are 60 sex pheromone traps set up in large demonstration sites every hectare, the mass of eggs is reduced by over 70% both on rice seedlings and on rice grounds. The larger the area of sexual pheromone traps, the more effective the control of pests [57].

3.4. Application of Trap Plants

An effective conservation biological control method, trap cropping involves growing another non-crop in a designated area in order to attract pests from a target crop, prevent them from reaching the crop, and then control those pests in order to reduce damage to the crop. Trap cropping has been successfully used for managing various insect pests since the 1930s, resulting in a substantial reduction in the use of pesticides in developing countries.

Due to the high population of pests on these new trap plants placed in agricultural fields, trap cropping must prevent insect dispersal back onto the focal crop to be effective. Borers of rice stems, such as SSBs and PSBs, lay their eggs on the vetiver grass *Vetiveria zizanioides*, but their life cycle is not complete. In rice fields, vetiver grass may effectively "drag" borers into mature rice stems for eggs, reducing pest levels. The vegetable plantation is determined to represent about 6–10% of the rice cultivation area between late March and early April. To further diminish the populations of stem borers, eggs and early larvae can be ripped down with certain treatments [57–59].

3.5. Animal Husbandry Model Farm

Since it has evolved through self-regulation, the combination of the ecological planting and breeding system, which includes a combination of rice ducks, rice fish, rice soft-shelled turtles, and rice crabs, is a perfect system in comparison to the traditional rice cultivation system.

Ducks are introduced into the rice–duck system to reduce inefficient tillers, encourage the exchange of gas, improve the decomposition of effective soil components, increase rice pest resistance, and reduce rice pests. For example, the fourth and fifth generations of rice cultivations fell by 70.2% and 70.4% in the mid-rice seasons, and by 56.2% and 64.6%, respectively, in the late rice seasons. Furthermore, SSB can effectively be controlled by mutual rice–duck behavior in paddy fields. The number of SSB larvae of the second and third generations has decreased by 53.2% to 76.8% and 61.8%, respectively. In mid-season rice and late-season rice, the SSB damage has been reduced by 13.4–47.1% [60–62].

Additionally, rice ducks can increase the number of natural enemies significantly and reduce pest populations. Compared to conventional paddy fields, rice cuckoo fields held 63.6 percent more spiders, and conventional paddy fields held 1.65–2.61 times more spiders [60]. In early and late season, ratios of spider hoppers to rice plants have been increased by 2.3 and 2.1 times, respectively, with ducks. RLF larvae are at a parasitic rate of 53.0–61.3% for duck-filled rice in the early season and the rate of rice with duck in the late season ranges from 29.4% to 38.3%. Compared to conventional rice farms, they are 1.05–3.21 times larger [63,64].

4. Integrated Pest Management

As efforts have been made to reduce the use of chemical controls in an attempt to reduce their impact on the environment and on human health, there has been an increase in the number of environmental and human health outcomes associated with the use of pesticides in recent decades. The development of alternative pesticides is undoubtedly needed, but how will they be developed? Insecticide treatments can be greatly reduced by eliminating rice core pests more effectively through non-insecticide control. Historically, by using chemical pesticides widely in the fight against major pests in field crops, new secondary pesticides (rice leaflets in Pakistan) have emerged by suppressing the activity of natural arthropods, these enemies normally disregard these secondary pests.

- ❖ Several individuals or combined tactic products are expected to reduce the use of insecticides in various agricultural products, not only for rice but across the board in the IPM. Improved scouting and monitoring and sophisticated, accurate crop simulations can easily lead to a 50 percent reduction in the accurate estimate of injury levels.
- ❖ Improved crop rotations, including amended laying methods and effective management of crop residues; lower and more efficient use of insecticides.
- ❖ Improved crop rotations, with modified techniques for tillage and effective management of crop residues.
- ❖ Improved crop types that are more resistant to pest attacks.
- ❖ Transgenic plants are included.
- ❖ Biological control is a term used to describe how something is controlled biologically.

- ❖ Natural enemies have a long history of reducing the impact of pests. Integrated pest management (IPM) can be achieved through inoculative increases, introduction and setup approaches, as well as introducing new pathogenic strains into existing species. Insect biological control is based on three basic approaches, increasing and conserving natural enemies, and insect pathogens. These approaches were effective, but they only received a fraction of the research on parasitoid and similar predatory approaches. These approaches minimize entomopathological weaknesses, including slow weakening of pests and populations, and take advantage of the recycling, persistence, and quick generation environmental forces. It is important to further refine and adapt the biological control approaches and application to realize the complete potential of this biologically based pest management strategy.
- ❖ The individuals responsible for implementing the IPM are the most important audience for the assessment results. These include farmers, agents of extension, and phytosanitary control. All efforts will be academic exercises without the members of this public recognizing and building upon the central and immune economic influence of biological control in their decision making.

5. Biological Conservation Control

5.1. Conservation Biological Control

There is an ecological complexity associated with the rice crop, which is characterized by a high diversity of cultivated plants and a redundant food web among them. Predators and parasitoids from a variety of classes and orders prey on and parasitize herbivorous insects in rice ecosystems, including araneae, orthopterans, coleopterans, aquatic and terrestrial heteropter, hymenopterans, strepsiptera, and dipterans [65–68].

At a very early stage of the crop season, Settle et al. [69] showed that generalist predators (e.g., spiders and mirid bugs) were abundant through the irrigated rice production sites in Java at an early stage of the crop season. An increase in the organic matter prior to the season led to an increased abundance of decomposers and a further increase in populations of predators. These correlations show that rice predators use decomposer communities as alternative prey before phytophagic insects arrive. Widespread staggered planting in the intensive cultivation areas of rice could further ensure continued availability and abundance of prey and hosts in rice fields [70].

In rice environments, biological conservation management capitalizes on and increases the natural pest controls provided by these prevalent natural enemy populations. Annual monoculture cropping practices are frequently linked to high disturbance regimes in natural enemies' habitats. Pesticide use is high, and there may be a dearth of adult food and shelter in certain agricultural systems [71]. Conservation biological control tries to address this problem by reducing insecticide use, promoting selective insecticides, and changing crop habitats to improve natural enemy populations' support.

5.2. Augmentative Biological Control

Whilst the irrigated rice ecosystem is a redundant food network, it is plausible that the populations of insect pests sometimes have economic damage. Cure measures are necessary, and the first curative option, wherever available, should be increased biological control. While conservation biological controls aim to improve the effects of indigenous enemy communities, increased biological control usually aims to increase the number of specific natural enemies for a short period of time, to temporarily suppress pesticide populations and activities, and to prevent economic damage to the yield, as opposed to conservation biological controls, which aim to improve the effects of indigenous enemy communities. A good way to achieve enhanced controls is usually by releasing predators, parasitoids, or pathogens into the field that are predicted to produce the desired effects for a long or short period of time [33]. Inoculate biological control, with the expectation of rapid increase of the small number of natural enemies released during that short period of time (inundative biological control [mass releases], where a natural enemy is unlikely to reproduce quickly enough), is one way to achieve this.

As a biological control agent, Rombach et al. [72] provided a bibliography of all major fungal groups, bacteria, viruses, and nematodes that have been identified as rice insect pests between 1960 and 1985. Since then, there have been a number of studies that have demonstrated the effectiveness of rice pests of two entomopathogens, *Metarhizium* and *Beauveria*. Furthermore, toxins from *Bacillus thuringiensis* (Bt) were found to inhibit feeding larvae from rice-stray borer (*Chilo Suppressalis* (Walker)) during a laboratory experiment using an artificial diet [73–75].

As an alternative to using invertebrate pathogens in rice production as a biocontrol agent, a common argument is that invertebrate pathogens take a long time to control and have only limited effect at the field level [76]. Among a number of entomopathogenic species that were applied to the field (including *Beauveria bassiana* and *Metarhizium anisopliae*), Rombach et al. [72] found a very low frequency of mortality (0–4% death rate) after 7 days following their application. Nonetheless, at 21 days after therapy, the mortality rate had risen to 70–100%. Identifying extremely aggressive fungal strains, improving formulation, and addressing these critiques, the future development of biological control agents may combine augmentative biocontrol with other control methods.

5.3. Bacteria

Microbial pesticides, also known as biopesticides, have gained popularity as an alternative to chemical pesticides in the pesticide market. In the years 1988–1995 in the United States, 90% of the bio pesticide market was dominated by *Bacillus thuringiensis* (80). Even though BT insecticides still make up only around 1% of the global market for insecticides, they have been used for decades as a means of controlling larvae of lepidopterous insects, and they have recently been combined with strains capable of controlling other insects. It produces crystalline insecticide protein (1CP) or 6-endotoxins in protein crystalline parasphorus inclusions that are released into the soil by Gram-positive, aerobic soil bacteria. It is known that Bt 6-endotoxins are oral toxins that do not demonstrate any contact activity. The processes that explained the modes of operation of *-endotoxins are ingestions, solutionization, proteolytic activation, transit via peritrophe, binding of the receptor, insertion of the membrane, creation of the ion channel, and lysis of a cell. The downside of Bt as a bio pesticide is that UV sunlight can make the toxin ineffective against insect pests quickly. Because of high transgenic crop selection pressure, Bt endotoxin resistance is of great concern to the population of pests, and this may also apply to other insecticide proteins. It is recommended that the use of Bt endotoxins (natural or biotechnology-based) and synthetic chemical pesticides should be combined with a pest complex with little selection of resistance to ensure efficient control of the pests. The other potentially useful toxic proteins made in crop plants (protease inhibitors, lectins, etc.) are of less field use [77,78].

5.4. Fungi

Metarhizium, *Beauveria*, *Hirsutella*, *Nomuraea*, and *Paecilomyces* are among the most regularly collected entomopathogenic fungi in agricultural crops. As biological pesticides, they offer a great deal of promise. Because of the harmful consequences of chemical pesticides, there has been a renewed interest in exploring their possibilities in recent years. Entomophogenic fungi probably do not acquire a large portion of the pesticide sector but have a specialist place in the field of insect pest control systems and integral applications. The rice ecosystem in Pakistan should be the focus of future growth rather than a single pest or pathogen. Unless genetic alterations increase the number of fast-damaging pathogens, in the future, the number of successful inundative augmentations will probably be restricted. Natural L, a recognized product based on Beauveria species, is the only one available in Pakistan.

5.5. Viruses

Insects can be infected by viruses in many different ways. Among all lepidopterous pests, only a small number of them have baculoviruses, which have not been shown to have negative health effects or be harmful to the environment. As control agents, they have been used in a variety of ways; however, issues such as sluggish action and photosensitivity restrict their usefulness and economic value. Several attempts have been made to improve the potency and speed with which baculoviruses kill by incorporating other genes to express them, such as chitinase, poisons, insect hormones, and juvenile hormone esterase; however, none have been successful [79]. So far, there has not been a single report of baculoviruses being used to control insects in Pakistan.

6. Economic Injury Thresholds

The concept of economic injury in IPM is defined as the population density with the lowest economic damage, which is one of the most essential elements in the theory of IPM. In Asia and North America, several levels of economic injury and economic action thresholds were developed and tested against a variety of rice pests [80]. Despite extensive testing in the Philippines against rice bugs and leafhoppers, Litsinger et al. [81] concluded that action thresholds were generally significantly higher than untreated checks (approximately 0.3 to 0.5 tons/ha) but were not always profitable for farmers.

This may involve several factors: (1) In economic damage development, the value of the commodity market and the cost of management actions are normally considered; rice has not adjusted its level of economic harm to reflect temporary fluctuations and spatial variation. (2) The majority of rice pests have not taken into account their natural pest control potential in the natural environment [81].

Due to the restrictions mentioned above, the value of setting action thresholds in the rice ecosystem has been questioned, particularly among small-scale farmers [82]. Without considering geographical and temporal variables, the consequences of using economic thresholds can be serious (such as price variability, natural enemy populations, and planted types).

7. Economic Threshold IPM

A second model of IPM, economic threshold IPM, uses pesticides instead of beneficial insects/spiders to control pests. It is considered that the economic threshold of control is reached when the cost of control is greater than the benefit of pest control in such a way that no economic loss occurs. In comparison to FFS, the economic threshold model teaches farmers in the classroom with some field time to identify some major pests, while FFS teaches them in the field. The economic threshold model proposes that crop protection decisions will be made based on the "scouting" of pests at the four most critical stages of the pest's life cycle, and pesticides are to be applied when the pest reaches its economic threshold level. In terms of economic thresholds in IPM, the effect of pests on plants is not considered as part of the agroecosystem as a whole, but only takes into account the interaction between the pest and the plant. The objective of this method is to identify and control three or four pests with the use of the right chemicals. Experts teach farmers how to control pests using the correct formulas and chemicals. When the economic threshold is reached, the control strategies are based on rules that are applied when the treatment decision is based on the economically derived decision rules [83].

8. Economic Threshold Levels (ETLs)

An overview of the major insect pests of rice and their economic thresholds (ETLs).

(1) Insect pests.
(2) Stem borer: As a nursery plant, this can range from moderate to severe, 5% dead hearts or one egg mass per m^2 during the planting tillering and flowering stages, or one moth per m^2 during panicle initiation, booting and flowering.

(3) Gall midge: The proportion of affected tillers is one gall per m^2 in endemic areas and 5% per m^2 in non-endemic areas. At the mid-tillering stage, 5% of the tillers are affected by the ETL.
(4) Whorl maggot: Approximately 20% of hills damaged within 30 days of planting.
(5) Case worm: one to two cases per hill.
(6) Leaf folder: At planting, one damaged leaf or one larva per hill is planted and at mid-tillering or panicle initiation to booting 1–2 newly damaged leaves planted per hill.
(7) Hispa: During planting and pre-tillering, one adult or one grub per hill is required or one or two damaged leaves per hill is required at mid-tillering.
(8) Green leafhopper: At the tillering stage, there are two insects per hill in tungro-endemic areas, ten insects per hill in other areas, and twenty insects per hill from the mid-tillering stage through panicle initiation and booting in other areas.
(9) Brown planthopper: At the tillering stage, five to ten insects are present per hill. It is estimated that 20 insects per hill are present during panicle initiation to booting stage, and 5–10 insects are present during flowering and after flowering.
(10) White-backed planthopper: At the tillering stage, there are 10 insects per hill, and at the flowering stage and after flowering, there are 5–10 insects per hill.
(11) Gundhi bug: One or two bugs per hill.

9. IPM Strategies

9.1. Cultural Practices

A key component of IPM is cultural practices. The following practices are used for pest management in rice paddies: removing weeds from fields, raising healthy nurseries, planting at the right time, selection of healthy seeds, summer plowing, and applying fertilizers as recommended.

9.2. Mechanical Practices

Biocontrol agents are conserved in bamboo cages by removing and destroying pest-infested plant parts, clipping the tips of rice seedlings, and collecting egg masses and larvae of pests.

9.3. Biological Control Practices

It is important to conserve biocontrol agents such as coccinellids, spiders, damsel flies, and dragonflies. Rice seedlings are treated with chlorpyriphos as part of a root dip treatment. The eggs and masses of borers are collected and placed in bamboo cages until they flower. By allowing the parasites to escape, it also traps and kills the hatching larvae.

9.4. Behavioral Control

During the first 10 days after transplanting, pheromone traps are installed at a rate of 20 traps per hectare in order to capture yellow stem borers.

9.5. Chemical Control Measures

The use of chemical control measures is considered a last resort under IPM. There must be a careful planning and application of pesticides so they can be applied appropriately, and the crops must be monitored regularly as well as crop health observed, so that ETL can be observed, and that natural biocontrol agents can be conserved before applying chemical pesticides.

10. Conclusions

It is clear from this study that indiscriminate use of pesticides harms human health and the environment. Insects that are beneficial to the environment are destroyed by excessive pesticide use, resulting in pest outbreaks. Hence, to manage rice insect pests in fields, integrated pest management is the best alternative to pesticides. Therefore, it is necessary to understand the problems of farmers better so that the key constraints can be reduced and control strategies developed more adequately. Considering the fact that foreign exchange is spent on importing chemical pesticides, it is evident that Pakistan has a good potential for developing organic pest control technology and incentive programs. Work is available, and incentives to internalize pest control economies are strong, considering that foreign exchange is spent on importing chemical pesticides. As far as differences between IPM's different approaches are concerned, the participatory approach often proves to be more effective in solving the complex problems that small-scale, risk-prone rice farmers face on a local level. Integrated biological control approaches and the useful development of the IPM for farmers' resistance to host plants (traditional and transgenetic) should be made use of. To discover the various eco-friendly integrated pest control methods, different studies must be conducted in different parts of the world. Farmers should be involved in pest control activities through the implementation of integrated pest control methods.

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References

1. Bai, X.; Wang, S.; Xiong, K. Assessing Spatial-temporal Evolution Processes of Karst Rocky Desertification Land: Indications for Restoration Strategies. *Land Degrad. Dev.* **2013**, *24*, 47–56. [CrossRef]
2. Liu, J.; Shen, J.; Li, Y.; Su, Y.; Ge, T.; Jones, D.L.; Wu, J. Effects of Biochar Amendment on the Net Greenhouse Gas Emission and Greenhouse Gas Intensity in a Chinese Double Rice Cropping System. *Eur. J. Soil Biol.* **2014**, *65*, 30–39. [CrossRef]
3. Parras-Alcántara, L.; Martín-Carrillo, M.; Lozano-García, B. Impacts of Land Use Change in Soil Carbon and Nitrogen in a Mediterranean Agricultural Area (Southern Spain). *Solid Earth* **2013**, *4*, 167–177. [CrossRef]
4. Brevik, E.C.; Sauer, T.J. The Past, Present, and Future of Soils and Human Health Studies. *Soil* **2015**, *1*, 35–46. [CrossRef]
5. Mekonnen, M.; Keesstra, S.D.; Stroosnijder, L.; Baartman, J.E.M.; Maroulis, J. Soil Conservation through Sediment Trapping: A Review. *Land Degrad. Dev.* **2015**, *26*, 544–556. [CrossRef]
6. Rao, A.N.; Johnson, D.E.; Sivaprasad, B.; Ladha, J.K.; Mortimer, A.M. Weed Management in Direct-seeded Rice. *Adv. Agron.* **2007**, *93*, 153–255.
7. Bajwa, A.A.; Mahajan, G.; Chauhan, B.S. Nonconventional Weed Management Strategies for Modern Agriculture. *Weed Sci.* **2015**, *63*, 723–747. [CrossRef]
8. Sorby, K.; Fleischer, G.; Pehu, E. *Integrated Pest Management in Development: Review of Trends and Implementation Strategies*; World Bank: New Delhi, India, 2003.
9. Chauhan, B.S. Weed Ecology and Weed Management Strategies for Dry-Seeded Rice in Asia. *Weed Technol.* **2012**, *26*, 1–13. [CrossRef]
10. Chauhan, B.S.; Johnson, D.E. The Role of Seed Ecology in Improving Weed Management Strategies in the Tropics. *Adv. Agron.* **2010**, *105*, 221–262.
11. Wright, M.G.; Hoffmann, M.P.; Kuhar, T.P.; Gardner, J.; Pitcher, S.A. Evaluating Risks of Biological Control Introductions: A Probabilistic Risk-Assessment Approach. *Biol. Control* **2005**, *35*, 338–347. [CrossRef]
12. Wu, K.M.; Guo, Y.Y. The Evolution of Cotton Pest Management Practices in China. *Annu. Rev. Entomol.* **2005**, *50*, 31–52. [CrossRef]
13. De-Clercq, P.; Mason, P.G.; Babendreier, D. Benefits and Risks of Exotic Biological Control Agents. *BioControl* **2011**, *56*, 681–698. [CrossRef]
14. Pretty, J.; Pervez Bharucha, Z. Integrated Pest Management for Sustainable Intensification of Agriculture in Asia and Africa. *Insects* **2015**, *6*, 152–182. [CrossRef]

15. Jules, P.; Camilla, T.; Stella, W. Sustainable Intensification in African Agriculture. *Int. J. Agric. Sustain.* **2011**, *9*, 5–24.
16. Niaz, N.S. Rice Production Falls. Press Conference, Secretary Agriculture Punjab. *The Pakistan Times*, 2 April 1971.
17. Pathak, M.D. Ecology of Common Insect Pests of Rice. *Annu. Rev. Entomol.* **1968**, *13*, 257–294. [CrossRef]
18. Mayatullah, C.; Tanweer, N.; Manhood, N. Incidence of Rice Stem Borer (SB) in the Punjab. *Int. Rice Res. Newsl.* **1989**, *14*, 38.
19. Ahmed, I.; Afzal, M.; Khan, M.A.M. 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. Sci. Ind. Res.* **1979**, *22*, 40–45.
20. Ahmad, I.; Afzal, M. 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* **1982**, *11*, 521–524. [CrossRef]
21. Joshi, R.C.; Venugopal, M.S.; Chelliah, S. *A Bibliography of the Rice Leaf Folder, Cnaphalocrocis medinalis Guenee*; No. 131; Asia and Pacific Plant Protection Commission: Bangkok, Thailand, 1982.
22. Khan, Z.R.; Ramachandran, R. Studies on the behavior of rice leaf folders *Cnapffalocrocis medinalis* and *Marasmia patnalis*. In *Seventeenth Annual Reports, International Centre of Insect Physiology and Ecology*; ICIPE Science Press: Nairobi, Kenya, 1989; pp. 19–24.
23. Mochida, O.; Perfect, T.J.; Dyck, V.A.; Mahar, M.M. The White Backed Plant Hopper *Sogatella furcifera* (Horvath) (Horn., Delphacidae), Its Pest Status and Ecology. 1982. Available online: https://agris.fao.org/agris-search/search.do?recordID=XB8210585 (accessed on 28 January 2023).
24. Mahar, M.M.; Bhatti, I.M.; Hakro, M.R. White backed plant hopper appears on Rice in Sind, Pakistan. *Int. Rice Res. Newsl.* **1980**, *3*, 11.
25. Inayatullah, C.; Astraf, M.; Khan, L. White backed plant hopper (WBPH) damage in Pakistan. *Int. Rice Res. Newsl.* **1987**, *12*, 18.
26. Haq, E.; Mohsin, A.; Hashmi, A.A. Efficacy of botanical and organophosphate pesticides against white backed plant hopper *Sogatella furcifera* (Horv.). *Proc. Elev. Pak. Congr. Zool.* **1991**, *11*, 149–152.
27. Sam, M.D.; Chelliah, S. Biology of the white leafhopper on Rice. *Int. Rice Res. Newslett.* **1984**, *9*, 22.
28. Barrion, A.T.; Litsinger, J.A. Identification of rice leaf folders (LF) by wing markings. *Int. Rice Res. Newsl.* **1985**, *10*, 24.
29. Irshad, M. Grasshoppers on Rice in Pakistan. *Int. Rice Res. Newslett.* **1977**, *2*, 8–9.
30. Zafar, M.A. Chemical control of rice hispa. *Int. Rice Res. Newsl.* **1984**, *9*, 18–19.
31. Vadadia, L.D.; Shah, A.H.; Pandya, H.V. Biology of rice *hispa*. *Oryza* **1989**, *26*, 206–208.
32. Fu, W.; Yu, X.; Ahmed, N.; Zhang, S.; Liu, T. Intraguild predation on the aphid parasitoid *Aphelinus asychis* by the ladybird Harmonia axyridis. *BioControl* **2017**, *62*, 61–70. [CrossRef]
33. Khan, J.; Khan, A.; Ahmed, N.; Alhag, S.K.; Almadiy, A.A.; Sayed, S.; Alam, P.; Ullah, F. Age and stage-specific life table parameters of *Harmonia dimidiata* (Coleoptera: Coccinellidae) fed on *Rhopalosiphum padi* (Hemiptera: Aphididae) at different temperatures. *Egypt. J. Biol. Pest Control* **2022**, *32*, 113. [CrossRef]
34. Ahmed, N.; Chamila-Darshanee, H.L.; Fu, W.Y.; Hu, X.S.; Fan, Y.; Liu, T.X. Resistance of seven cabbage cultivars to green peach aphid (Hemiptera: Aphididae). *J. Econ. Entomol.* **2018**, *111*, 909–916. [CrossRef]
35. Khater, H.F. Prospects of botanical biopesticides in insect pest management. *Pharmacologia* **2012**, *3*, 641–656.
36. Ullah, M.; Ullah, F.; Khan, M.A.; Ahmad, S.; Jamil, M.; Sardar, S.; Tariq, K.; Ahmed, N. Efficacy of various natural plant extracts and the synthetic insecticide cypermethrin 25EC against *Leucinodes orbonalis* and their impact on natural enemies in brinjal crop. *Int. J. Trop. Insect Sci.* **2022**, *42*, 173–182. [CrossRef]
37. Iqbal, T.; Ahmed, N.; Shahjeer, K.; Ahmed, S.; Al-Mutairi, K.A.; Khater, H.F.; Ali, R.F. Botanical Insecticides and their Potential as Anti-Insect/Pests: Are they Successful against Insects and Pests? In *Global Decline of Insects*; IntechOpen: London, UK, 2021.
38. Ahmed, N.; Alam, M.; Saeed, M.; Ullah, H.; Iqbal, T.; Al-Mutairi, K.A.; Shahjeer, K.; Ullah, R.; Ahmed, S.; Ahmed, N.A.H.; et al. *Botanical Insecticides Are a Non-Toxic Alternative to Conventional Pesticides in the Control of Insects and Pests, In Global Decline of Insects*; El-Shafie, H., Ed.; IntechOpen: London, UK, 2021.
39. Jan, Q.; Khan, I.A.; Al-Shuraym, L.A.; Alshehri, M.A.; Ahmed, N.; Saeed, M.; El-Sharnouby, M.; Sayed, S. Comparative conventional preventive strategies for insect pest of okra. *Saudi J. Biol. Sci.* **2022**, *29*, 3114–3121. [CrossRef]
40. Khater, H.F. Ecosmart Biorational Insecticides: Alternative Insect Control Strategies. In *Insecticides-Advances in Integrated Pest Management*; Preveen, F., Ed.; InTech: Rijeka, Croatia, 2012; pp. 17–60, ISBN 978-953-307-780. [CrossRef]
41. Khater, H.F. Bioactivity of Essential Oils as Green Biopesticides: Recent Global Scenario. *Recent Prog. Med. Plants* **2013**, *37*, 151–218.
42. Darshanee, H.L.; Ren, H.; Ahmed, N.; Zhang, Z.F.; Liu, Y.H.; Liu, T.X. Volatile-mediated attraction of greenhouse whitefly *Trialeurodes vaporariorum* to tomato and eggplant. *Front. Plant Sci.* **2017**, *8*, 1285. [CrossRef] [PubMed]
43. Ahmed, N.; Darshanee, H.L.; Khan, I.A.; Zhang, Z.F.; Liu, T.X. Host selection behavior of the green peach aphid, *Myzus persicae*, in response to volatile organic compounds and nitrogen contents of cabbage cultivars. *Front. Plant Sci.* **2019**, *10*, 79. [CrossRef]
44. Saeed, M.; Ahmad, T.; Alam, M.; Al-Shuraym, L.A.; Ahmed, N.; Alshehri, M.A.; Ullah, H.; Sayed, S.M. Preference and performance of peach fruit fly (*Bactrocera Zonata*) and Melon fruit fly (*Bactrocera Cucurbitae*) under laboratory conditions. *Saudi J. Biol. Sci.* **2022**, *29*, 2402–2408. [CrossRef]
45. Gao, X.W.; Wu, M.X.; Sun, J.H.; Wang, Y.C. Empedobacter brevis on insecticidal effect and technology for *Cnaphalocrocis medinalis* Guenee. *Pest Sci. Admin.* **2012**, *33*, 43–50.

46. Zhai, H.W.; Zhao, Y.F.; Gao, X.W.; Wu, M.X. Efficacy of *Empedobacter brevis* in controlling rice stem borer. *Biol. Disast. Sci.* **2013**, *36*, 291–294.
47. Liu, Q.; Xu, J.; Wang, Y.; Li, C.; Han, G.; Qi, J.; Sun, J.; Ma, T. Synergism of CmGV and *Bacillus thuringiensis* against larvae of *Cnaphalocrocis medinalis* Güenée. *J. Yangzhou Univ. Agric. Life Sci. Ed.* **2013**, *34*, 89–93.
48. Zhai, H.; Chai, Y. Effect of *Mamestra brassicae* nuclear polyhedrosis virus suspending agent on *Chilo suppressalis* in Rice. *North Rice* **2013**, *43*, 64–65.
49. Mo, J.; Ding, W.B.; Li, Y.Z.; Li, G.H. Control effect of 9% 12 α-hydroxy-rotenone EW against three pests of Rice. *Hunan Agric Sci.* **2014**, *10*, 40–42.
50. Wang, G.R.; Han, R.P.; Shen, Q.; Yang, W.T.; Wang, G.D.; Lu, Z.X.; Zheng, X.S. Effects of modified fertilizer application on rice pests, diseases and yields. *China Rice* **2015**, *21*, 94–97.
51. Yuan, X.H.; Song, L.W.; Zhang, J.J.; Zang, L.S.; Zhu, L.; Ruan, C.C.; Sun, G.Z. Performance of four Chinese Trichogramma species as biocontrol agents of the rice striped stem borer, *Chilo suppressalis*, under various temperature and humidity regimes. *J. Pest Sci.* **2012**, *85*, 497–504. [CrossRef]
52. Zhang, S.; Jia, X.W.; Sun, S.F.; Pang, Y.; Chen, Q.J.; Yang, K. Phylogenetic analysis and epidemiologic investigation of a *Cnaphalocrocis medinalis* granulovirus strain. *J. Environ. Entomol.* **2014**, *36*, 756–762.
53. Li, D.S.; Yuan, X.; Zhang, B.X.; Zhao, Y.; Song, Z.W.; Zuo, C. Report of using unmanned aerial vehicle to release Trichogramma. *Chin. J. Biol. Control* **2013**, *29*, 455–458.
54. Tian, J.C.; Wang, G.R.; Zheng, X.S.; Wang, G.W.; Lu, Z.X.; Xu, H.X.; Yang, Y.J.; Lu, Y.H. A Trichogramma Release Device with a Sugar Feeding Device. Chinese Patent ZL201420667926.1, 2015.
55. Du, Y.J.; Guo, R.; Han, Q.R. The application techniques of insect sex pheromone control of rice stem borer and rice leaf folder. *China Plant Prot.* **2013**, *33*, 39–42.
56. Zhu, P.Y.; Sheng, X.Q.; Feng, F.; Li, Y.H.; Chen, G.H. Trapping technique of insect sex pheromone on striped stem borer and rice leaf folder. *J. Zhejiang Agric. Sci.* **2013**, *54*, 825–826.
57. Yang, F.A.; Sheng, C.F.; Wei, Y.B. Study on mating disruption with synthetic sex pheromone for controling rice stem borer. *Plant Prot.* **2001**, *27*, 4–6.
58. Xia, Y.Z.; Sun, W.Y. Trapping and killing effects of *Vetiveria zizanioides* on rice stem borers. *Zhejiang Agric. Sci.* **2012**, *1*, 1693–1695.
59. Liang, Q.; Lu, Y.H.; He, X.C.; Zheng, X.S.; Xu, H.X.; Yang, Y.J.; Tian, J.C.; Lu, Z.X. Mini review of the significance of trap crop in insect pest management. *J. Biosaf.* **2015**, *24*, 184–193.
60. Yang, Z.P.; Liu, X.Y.; Huang, H.; Liu, D.Z.; Hu, L.D.; Su, W.; Tan, S.Q. A study on the influence of rice-duck intergrowth on spider, rice diseases, insect and weeds in rice-duck complex ecosystems. *ACTA Ecol. Sin.* **2004**, *24*, 2756–2760.
61. Long, P.; Huang, H.; Liao, X.; Fu, Z.; Zheng, H.; Chen, A.; Chen, C. Mechanism and capacities of reducing ecological cost through Rice–duck cultivation. *J. Sci. Food Agric.* **2013**, *93*, 2881–2891. [CrossRef] [PubMed]
62. Zhu, P.; Zheng, X.; Yao, X.; Xu, H.; Zhang, F.; Chen, G.; Lü, Z. Ecological engineering technology for enhancement of biological control capacity of egg parasitoids against rice plant hoppers in paddy fields. *China Plant Prot.* **2015**, *7*, 27–32.
63. Tao, L.Y.; Yu, X.P.; Wu, G.R. Preliminary monitoring the biotypes of the brown planthopper *Nilaparvata lugens* Stål in China. *Sci. Agric. Sin.* **1992**, *25*, 9–13.
64. Liu, X.Y.; Liu, D.Z.; Chen, Y.F.; Huang, H.; Zhong, L.; Yu, J.B. The character of rice roots in rice-duck-fish commensalisms ecosystem and its economic benefit. *J. Hunan Agric. Univ. Nat. Sci.* **2005**, *31*, 314–316.
65. Sigsgaard, L.E. Early season natural biological control of insect pests in Rice by spiders-and some factors in the management of the cropping system that may affect this control. *Eur. Arachnol.* **2000**, *17*, 57–64.
66. De-Kraker, J.; Rabbinge, R.; Van-Huis, A.; Van-Lenteren, J.C.; Heong, K.L. Impact of nitrogenous-fertilization on the population dynamics and natural control of rice leaffolders (Lep.: Pyralidae). *Int. J. Pest Manag.* **2000**, *1*, 225–235. [CrossRef]
67. Preap, V.; Zalucki, M.P.; Jahn, G.C.; Nesbitt, H.J. Effectiveness of brown planthopper predators: Population suppression by two species of spider, *Pardosa pseudoannulata* (Araneae, Lycosidae) and *Araneus inustus* (Araneae, Araneidae). *J. Asia-Pac. Entomol.* **2001**, *4*, 187–193. [CrossRef]
68. Wilby, A.; Heong, K.L.; Huyen, N.P.; Quang, N.H.; Minh, N.V.; Thomas, M.B. Arthropod diversity and community structure in relation to land use in the Mekong Delta, Vietnam. *Ecosystems* **2006**, *9*, 538–549. [CrossRef]
69. Settle, W.H.; Ariawan, H.; Astuti, E.T.; Cahyana, W.; Hakim, A.L.; Hindayana, D.; Lestari, A.S. Managing tropical rice pests through conservation of generalist natural enemies and alternative prey. *Ecology* **1996**, *77*, 1975–1988. [CrossRef]
70. Gurr, G.M.; Liu, J.; Read, D.M.; Catindig, J.L.; Cheng, J.A.; Lan, L.P.; Heong, K.L. Parasitoids of Asian rice plant hopper (Hemiptera: Delphacidae) pests and prospects for enhancing biological control by ecological engineering. *Ann. Appl. Biol.* **2011**, *158*, 149–176. [CrossRef]
71. Heinrichs, E.A.; Muniappan, R. IPM for tropical crops: Rice. *CAB Rev.* **2017**, *12*, 1–30. [CrossRef]
72. Rombach, M.C.; Rombach, G.M.; Roberts, D.W. Pathogens of insect pests of Rice: A bibliography. *Insect Sci. Its Appl.* **1987**, *8*, 197–210. [CrossRef]
73. Jin, S.F.; Feng, M.G.; Chen, J.Q. Selection of global Metarhizium isolates for the control of the rice pest *Nilaparvata lugens* (Homoptera: Delphacidae). *Pest Manag. Sci.* **2008**, *64*, 1008–1014. [CrossRef]
74. Jin, S.F.; Feng, M.G.; Ying, S.H.; Mu, W.J.; Chen, J.Q. Evaluation of alternative rice plant hopper control by the combined action of oil-formulated *Metarhizium anisopliae* and low-rate buprofezin. *Pest. Manag. Sci.* **2010**, *67*, 36–43. [CrossRef]

75. Li, M.Y.; Lin, H.F.; Li, S.G.; Chen, P.R.; Jin, L.; Yang, J. Virulence of entomopathogenic fungi to adults and eggs of *Nilaparvata lugens* Stål (Homoptera: Delphacidae). *Afr. J. Agric. Res.* **2012**, *7*, 2183–2190.
76. Way, M.O. Rice arthropod pests and their management in the United States. In *Rice: Origin, History, Technology, and Production*; Smith, C.W., Dilday, R.H., Eds.; John Wiley & Sons: Hoboken, NJ, USA, 2003; pp. 437–456.
77. Karim, S.; Riazuddin, S. Rice insect pests of Pakistan and their control: A lesson from past for sustainable future integrated pest management. *Pak. J. Biol. Sci.* **1999**. [CrossRef]
78. Fenggu, Z.; Qingsheng, F. Control impact of rice-duck ecological structure on harmful biotic community of rice fields. *Acta Agric. Zhejiangensis* **2004**, *16*, 37–41.
79. Koudamiloro, A.; Nwilene, F.E.; Togola, A.; Akogbeto, M. Insect vectors of rice yellow mottle virus. *J. Insects* **2015**, *2015*, 721751. [CrossRef]
80. Litsinger, J.A.; Bandong, J.P.; Canapi, B.L.; Dela-Cruz, C.G.; Pantua, P.C.; Alviola, A.L.; Batay-An, E.H., III. Evaluation of action thresholds for chronic rice insect pests in the Philippines: I. Less frequently occurring pests and overall assessment. *Int. J. Pest Manag.* **2005**, *51*, 45–61. [CrossRef]
81. Litsinger, J.A.; Bandong, J.P.; Canapi, B.L.; Dela-Cruz, C.G.; Pantua, P.C.; Alviola, A.L.; Batay-An, E.H., III. Evaluation of action thresholds for chronic rice insect pests in the Philippines: III. Leaffolders. *Int. J. Pest Manag.* **2006**, *52*, 181–194. [CrossRef]
82. Matteson, P.C. Insect pest management in tropical irrigated Rice. *Annu. Rev. Entomol.* **2000**, *45*, 549–574. [CrossRef] [PubMed]
83. Dhakal, A.; Poudel, S. Integrated pest management (IPM) and its application in rice—A review. *Rev. Food Agric.* **2020**, *1*, 54–58. [CrossRef]