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*Review Article*

# Life Cycle and Feeding Behaviour of Rice Stem Borer Species in Southeast Asian Regions' Paddy Fields

**Aisyah Pratiwi Suryanto Sugian[1], Patricia King Jie Hung[2]*, Muhamad Azmi Mohammed[2], Tunung Robin[3], Leong Sui Sien[4], Freddy Yeo Kuok San[5], Zakry Fitri Ab. Aziz[2], Noorasmah Saupi[2], Shiamala Devi Ramaiya[2], Ribka Alan[3], Adrian Daud[3], Anita Rosli[3], Philip Lepun[6], Zahora Ismail[1], Sivasangar Seenivasagam[7], and Suziana Hassan[8]**

*[1]Institute of Ecosystem Science Borneo (IEB), Universiti Putra Malaysia Sarawak, 97000 Bintulu, Sarawak, Malaysia*
*[2]Department of Crop Science, Faculty of Agricultural and Forestry Sciences, Universiti Putra Malaysia Sarawak, 97000 Bintulu, Sarawak, Malaysia*
*[3]Department of Social Science and Management, Faculty of Humanities, Management and Science, Universiti Putra Malaysia Sarawak, 97000 Bintulu, Sarawak, Malaysia*
*[4]Department of Animal Science and Fisheries, Faculty of Agricultural and Forestry Sciences, Universiti Putra Malaysia Sarawak, 97000 Bintulu, Sarawak, Malaysia*
*[5]Faculty of Resource Science and Technology, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia*
*[6]Department of Forestry Science, Faculty of Agricultural and Forestry Sciences, Universiti Putra Malaysia Sarawak, 97000 Bintulu, Sarawak, Malaysia*
*[7]Department of Science and Technology, Faculty of Humanities, Management, and Science, Universiti Putra Malaysia Sarawak, 97000 Bintulu, Sarawak, Malaysia*
*[8]Center for Sustainable and Inclusive Development, Faculty of Economics and Management, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia*

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*E-mail addresses*:
gs66768@student.upm.edu.my (Aisyah Pratiwi Suryanto Sugian)
patricia@upm.edu.my (Patricia King Jie Hung)
tunungrobin@upm.edu.my (Tunung Robin)
mm_azmi@upm.edu.my (Muhamad Azmi Mohammed)
leongsuisien@upm.edu.my (Leong Sui Sien)
zakryfitri@upm.edu.my (Zakry Fitri Ab. Aziz)
yksfreddy@unimas.my (Freddy Yeo Kuok San)
philip@upm.edu.my (Philip Lepun)
noorasmah@upm.edu.my (Noorasmah Saupi)
shiamala@upm.edu.my (Shiamala Devi Ramaiya)
ribka@upm.edu.my (Ribka Alan)
adrian@upm.edu.my (Adrian Daud)
anitarosli@upm.edu.my (Anita Rosli)
zahora_i@upm.edu.my (Zahora Ismail)
sivasangar@upm.edu.my (Sivasangar Seenivasagam)
suzi_h@ukm.edu.my (Suziana Hassan)
* Corresponding author

## ABSTRACT

Rice stem borers are among the most damaging pests in paddy fields and are a growing concern for farmers. This is concerning due to the decline in rice production they may cause, especially in areas with high infestation, where infestation coincides with critical stages of paddy growth. This review discusses existing knowledge on the life cycle, feeding behaviour, and oviposition patterns of six main recognised species in Southeast Asian regions, particularly *Scirpophaga incertulas*, *Scirpophaga innotat*a, *Chilo suppressalis*, *Chilo polychrysus*, *Chilo auricilius*, and *Sesamia inferens*. Their distinct characteristics in egg-laying behaviour, feeding sites, and the infestation timing were then further

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discussed and correlated with rice phenology to observe the variation of damage expression and how it affects yield, ultimately. Though common symptoms such as deadheart and whitehead are expected after infestation, the occurrence and severity of damage, as well as the chances of plant recovery, may differ. The differences between the infestation events are crucial, especially when considering management controls in the field to produce better alignment with paddy growth stages, together with suitable ecological factors. However, there is still limited information on specific economic thresholds in many parts of Southeast Asia. This research gap provides the need for future research, as it may support more targeted IPM control strategies and reduce dependence of farmers on broad-spectrum insecticides.

*Keywords:* Feeding behaviour, life cycle, oviposition, phenology, rice stem borer, Southeast Asia

## INTRODUCTION

These days, rice cultivation around the world faces many challenges, including harmful pests that lead to significant yield losses. 120-200 million tons of annual loss in rice production is attributed to insect pests, approximately 37% of the average global yield (Song et al., 2025). Among these factors, one of the most damaging insect pests in rice cultivation is the rice stem borer, which is considered one of the most economically important insect pests. This particular pest is a concerning issue due to its damaging feeding patterns, distribution, and continuous infestation across multiple growth stages, which makes it difficult to control among rice farmers.

The focus of this review is on existing stem borer species in the Southeast Asia region, where rice production is one of the backbones of agricultural economies, as well as serving as a staple food for the people. Most of them are rice-producing countries and consumers, making rice an important food source for their people. Any yield losses in this sector, particularly from stem borer, may lead to detrimental impacts on food availability and production stability, especially for those countries that rely on imports as their agricultural economies.

Rice stem borers around the world have been identified as approximately 70 species, including pyralid, noctuid, and diopsid taxa. This pest remains a persistent challenge in Southeast Asia, especially for the local or rural farmers. This is due to the damage done by the pest, which may lead to a reduction in tiller survival, development of paddy panicle, and eventually disruption in grain yield production. Over generations, they are renowned as a significant pest, yet most studies have examined individual species in isolation or have emphasised population density and yield loss relationships, often treating the pest as internal feeders that infest in the same way.

In this review, the emphasis is put on particular rice stem borer species in Southeast Asia based on their ecological relevance, impact on the economy, and functional significance.

In many literature reviews, *Scirpophaga incertulas*, *Scirpophaga innotata*, *Chilo suppressalis*, *Chilo polychrysus*, and *Sesamia inferens* were found to be important stem borer species around Southeast Asia regions. The focus of this review is on the respective species.

The species selection was done according to their feeding behaviour, the time when they penetrate the paddy stem, and their interaction with rice phenology. These factors may indicate the rate of damage irreversibility and provide a management regime for the farmers. With this approach, this review can remain aligned with relevant management processes instead of geographically biased reporting intensity. Across the literature review, there are many findings on stem borer species having distinct feeding behaviour, as well as their preferred location within the rice stem, and their own synchronisation with rice growth stages. These suggest a crucial effect of how damage can be different according to their species under field conditions, especially for places that possess multiple prevalent stem borer species. Understanding their distinctive infestation patterns helps us to interpret how different the damage done by each species could be, and the corresponding interaction and effect on rice phenology.

Despite extensive review on this pest, much of the literature often discusses the abundance of the pest, direct yield loss and management, often treating this pest as a similar internal feeder. There is less on species-specific feeding behaviour, oviposition, life cycle, and their corresponding relation to rice phenology. This review aims to fill in the gap by correlating the relationship of the stem borer life cycle, feeding, and oviposition behaviour with rice phenology to produce a better stage-specific management in Southeast Asian regions' rice systems.

## REVIEW METHODOLOGY

In this narrative review, existing literature on rice stem borers was synthesised, with a focus only on Southeast Asian countries. Google Scholar, Scopus, and Web of Science were used as scientific databases to perform a thorough literature search. A combination of keywords such as "*rice stem borer*", "*paddy pests*", "*stem borer feeding behaviour*", "*life cycle*", "*oviposition of stem borer*", "*Southeast Asia*", and "*rice insect pests*" was used to identify relevant publications, and the selected publications were chosen from the years between 2000 and 2025. To refine the search results in current databases, Boolean operators such as AND and OR were also used. In this review, a few selected grey literature sources were cross-checked and used to provide regional production. The sources were not used to support a mechanistic interpretation of stem borer biology or any management regime.

Studies on major rice stem borer species affecting paddy fields, their life cycle, feeding pattern, and oviposition behaviour, their corresponding damage characteristics, and relevant relationships to rice production systems in Southeast Asia were included.

This is also put as inclusion and exclusion criteria set for studies in tables. Studies that are not at the species-level resolution or phenology-linked to paddy may be discussed narratively in this review. Distinctions are also made between controlled experimental studies and farmer field observations, where possible, especially when interpreting yield loss, compensation capacity, and effectiveness of management systems in real field conditions.

## Rice Cultivation and Production

To provide a regional context for these dynamics, Table 1 summarises rice production, consumption, and trade characteristics of Southeast Asian countries. This contextualization highlights the economic and food security relevance of stem borer damage, particularly in countries with high reliance on domestic rice production or limited capacity to compensate for yield losses through imports.

Table 1
*Countries in Southeast Asian regions, highlighting rice-producing and planting countries*

| Countries | Rice Production | Domestic Consumption | Rice Imports | Rice Exports |
|---|---|---|---|---|
| Malaysia | Approximately 1.44 million tons (Siddharta, 2024), average yield of around 3.0 tons per hectare. | Approximately 2.7 million metric tonnes in 2023, where national production meets 67% of national demand (Dorairaj & Govender, 2023). | Relies on rice imports, 30 - 40% from neighbouring countries, Vietnam, Thailand, Pakistan, and India. | Primarily a net importer but still exports $48 million in 2023 to several countries (Mat, 2023; World Bank, 2024) |
| Brunei Darussalam | 4,200 tons of rice in 2022 (Statista, 2024), average yield of around 1.7 tons per hectare (Galawat & Yabe, 2012). | Information not found in the current literature. | Imports approximately 28.324 million BND (Brunei Dollars) worth of rice from outer countries. | Relies heavily on imports but exports an amount of 0.002% of total merchandise exports. |
| Cambodia | Produced approximately 11.62 million tons of rice, with 3.29 tons per hectare. (Khmer Times, 2023; USDA Foreign Agricultural Service, 2024). | 142 kilograms per year for per capita consumption (USDA Foreign Agricultural Service, 2024). | Imports are relatively low considering its total production per year. | Export approximately 656,323 tonnes of milled rice in the marketing year of 2022/2023 (USDA Foreign Agricultural Service, 2024). |

Table 1 (*continued*)

| Countries | Rice Production | Domestic Consumption | Rice Imports | Rice Exports |
|---|---|---|---|---|
| Indonesia | Rice production is projected to be 30.34 million in 2024. | Domestic rice consumption is projected to be approximately 31 million tonnes. | Indonesia's rice imports have significantly increased, often exceeding 3 million tonnes annually. | Relatively low, it focuses more on ensuring a sufficient domestic supply. |
| Laos (Lao People's Democratic Republic) | Projected to produce approximately 1.7 million metric tons of rice. | Estimated to be around 1.8 million metric tons. | Imports about 100,000 metric tons of rice, primarily glutinous rice from Vietnam and Thailand. | Forecasted at approximately 80,000 metric tons. |
| Philippines | Expected to produce around 12.5 million metric tons of rice in 2024. | Projected at about 13.5 million metric tons. | Importing around 1.5 million metric tons annually. | Exports minimal amounts of rice, generally less than 100,000 metric tons. |
| Myanmar | Estimated at around 13.5 million metric tons for 2024. | Projected to be approximately 12 million metric tons. | Imports about 100,000 metric tons of rice, mainly due to quality preferences and specific market demands. | Exports around 2 million metric tons, primarily to neighbouring countries like China and Bangladesh. |
| Thailand | Expected to be about 20 million metric tons in 2024. | Projected at approximately 10 million metric tons. | Imports very little rice, typically less than 50,000 metric tons, as it is a major exporter. | One of the largest exporters globally, with expected exports of around 7 million metric tons. |
| Vietnam | Approximately 43 million metric tons. | Projected at around 30 million metric tons. | Imports a small amount of rice (around 50,000 metric tons). | Exports approximately 6 million metric tons, making it one of the top rice exporters globally. |
| Singapore | Has negligible rice production due to limited agricultural land; local production is below 10,000 metric tons. | Estimated at about 600,000 metric tons. | Imports virtually all its rice needs, sourcing from countries like Thailand and Vietnam, with imports around 600,000 metric tons annually. | Does not export significant amounts of rice due to its reliance on imports. |

*Note.* Country-level production data are presented for contextual purposes and do not influence the biological interpretations or conclusions drawn in this review

## Yield Loss and Economic Impacts of Rice Stem Borers

Rice stem borers, as described, are among the most destructive rice pests around the world, causing significant economic loss. According to Subedi et al. (2024), they described the borer as one of the most critical insect pest groups, highlighting the need to be prioritised in management control due to the severity and consistency of damage they cause to rice crops. The expected damage is caused by the destructive larval stage, where the larvae bore and feed inside the stem, which later produces two common symptoms: deadheart (during the vegetative stage) and whitehead (during the reproductive stage), as shown in Figure 1. Both symptoms affect the production of grain yield, leading to a critical decline in production when at high infestation levels.

The impact on yield production can be different due to distinct infestation timing related to rice growing stages. Deadheart symptoms that occur during the vegetative phase may be partially compensated through the production of new paddy tillers. Meanwhile, the later stage of deadheart, which is whitehead, occurs after panicle initiation, where the larva keeps boring throughout the stem, eventually disrupting the translocation of nutrients to vascular tissue supplying the developing panicle. At a later stage, the respective plant has limited capacity for compensatory growth as compared to during the vegetative stage, which translates directly into irreversible yield loss. This may explain why relatively low levels of whitehead incidence often result in higher large reductions in grain yield compared with deadheart damage.

*Figure 1.* Observed damage symptoms caused by rice stem borers at different stages: (a) Deadheart at the paddy vegetative stage, showing gradual death of the central tiller due to larval feeding (surrounding tillers remain green); (b) Whitehead at the paddy reproductive stage, shown by creamy white, empty panicles

These differences are clearly reflected in long-term yield-damage relationships. Based on an analysis of 770 experimental units conducted over 28 years (1965-1992), Muralidharan and Pasalu (2006) estimated the effects of rice stem borer injury on grain yield across major rice ecosystems in Asia. In irrigated systems, a 1% increase in deadheart incidence resulted in only a 0.3% reduction in yield (approximately 12 kg $ha^{-1}$), whereas a 1% increase in whitehead damage caused a substantially higher yield loss of 4.2% (approximately 183 kg $ha^{-1}$). In rainfed lowland systems, where plants exhibit greater capacity for compensatory tillering, both 1% deadheart and whitehead damage were associated with an approximate yield reduction of 2.3% (about 76 kg $ha^{-1}$). The much greater impact of whitehead damage reflects its direct association with the loss of productive panicles, in contrast to the partially recoverable effects of deadheart damage. Recent studies also supported the idea, showing that the relationship between stem borer injury and yield loss is not fixed but depends on several factors. For instance, rice variety, growth stage, and environmental conditions may influence how much damage translates into yield losses (Horgan et al., 2021).

Between irrigated and rainfed systems, recent reviews emphasise there is no fixed threshold between both systems, but they do depend strongly on the system itself, varietal tolerance, and environmental conditions (Khan et al., 2020; Sapkota et al., 2019). Zhao et al. (2018) and Nguyen et al. (2022) mentioned in a physiological context that irrigated rice exhibits stronger compensatory growth due to wider availability of nutrients and water, as compared to the rainfed system, where the compensatory growth may be limited due to a smaller source of water and nutrients.

Reported yield losses caused by rice stem borers vary widely across studies (Savary et al., 2000; Litsinger et al., 2011). Severe, localised outbreaks can result in losses as high as 70% (Rahim et al., 1992). There is no direct relationship between larval density and reduction in yield. Yield reduction may be heavily influenced by different factors such as crop growth stage, compensation ability, and planting density (Villegas et al., 2021). Previous literature studies commonly described the association of yield loss with damage symptoms (deadheart and whitehead incidence) as compared to larval counts. In Southeast Asia, yield losses attributed to rice insect pests, stem borers, gall midges, and planthoppers range from 21% to 50% (Pasalu et al., 2004).

Also, most published literature on the relationship between stem borer damage and yield loss often describes using older rice varieties and management practices. Hence, the described loss estimate is more recommendably viewed as a general risk indicator than a precise estimate for modern high-yielding cultivars grown under intensified systems nowadays. The overall damage estimate patterns can still be used by researchers and farmers to understand the occurrence of damage, and so the stages of paddy are the most vulnerable.

Since the infestation of stem borers is unpredictable, many farmers continue to manage the issue using chemical pesticides. Insecticide sales have increased to USD 674 million (2012) from USD 409 million (2009) in South and Southeast Asia. Cabasan et al. (2019) described 62% of the farmers utilise pesticides to control stem borers and leaf folders.

This is supported by Mondal et al. (2017), where pesticide use represents the second-highest in production cost after plant nutrition. This highlights the concern caused by stem borers and calls the need for more sustainable and stage-specific management control.

## Ecology and Distribution of Rice Stem Borers in Southeast Asia

Rice stem borers are described as a type of lepidopteran pest, with the most identified species being *S. incertulas*, *S. innotata*, *C. suppressalis*, *C. auricilius*, and *S. inferens* in Southeast Asian regions. In these regions, the climate is often characterised by high temperatures and humidity. Continuous or staggered planting cycles promote ideal conditions for the survival of stem borers and also produce multiple generations throughout the year. Despite this, differences in crop intensity, irrigation regimes, landscape structure, and planting synchrony may influence the prevalence of species and abundance in the area.

The diversity and species distribution prevalent in an area are crucial to be determined due to their difference in biological traits and preferences, as this will in the future be considered in management strategies, from monitoring, determination of threshold level, to deciding which control measures are the most appropriate. In Table 2, the major rice stem borer species reported across Southeast Asian countries are highlighted.

Table 2
*Major stem borer species in Southeast Asian countries*

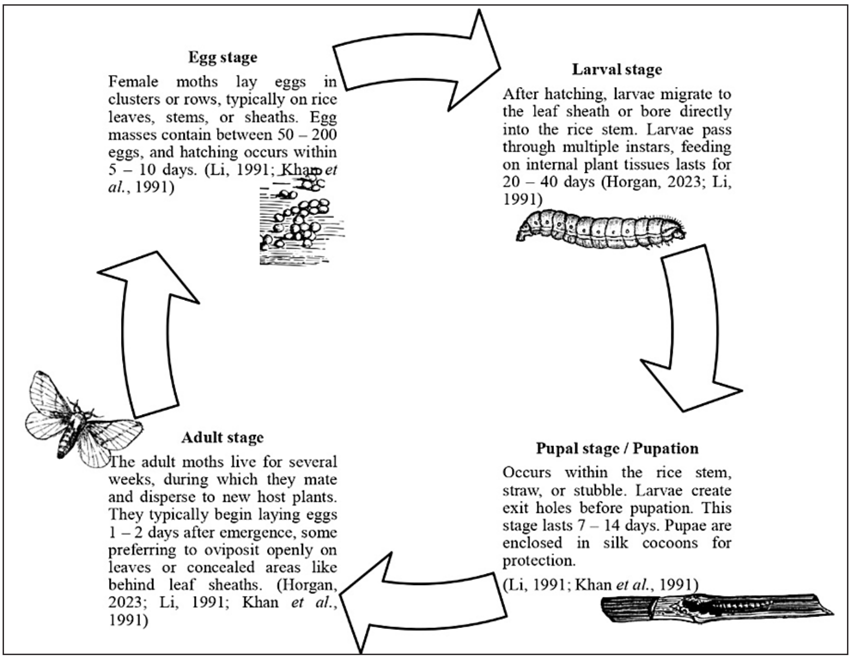
| Countries | Rice Stem Borer | References |
|---|---|---|
| Cambodia | *C. suppressalis, S. incertulas* | Dunn et al. (2023); Castilla et al.(2020) |
| Indonesia | *C. suppressalis, S. innotata* | Agustina & Herlina (2025); Wijarya et al., (2024); Subba et al. (1969) |
| Laos (Lao People's Democratic Republic) | *C. suppressalis, S. incertulas* | Coulibaly et al. (2021); Douangboupha et al. (2006) |
| Malaysia | *C. polychrysus, S. incertulas, S. innotata, C. auricilius, C. suppressalis, S. inferens* | Mohd Khari & Ab Hamid (2022); Ling et al. (2020); Yeo et al. (2025); Gumbek & Hamsein (2011) |
| Philippines | *S. incertulas, C. suppressalis, S. innotata, S. inferens, C. auricilius* | Viz & Pacada (2024); Horgan et al. (2021); Litsinger et al. (2011) |
| Myanmar | *S. incertulas* | Maung et al. (2020); Pham & Kwon (2024) |
| Thailand | S. incertulas | Arunmit et al. (2024); Catling et al.(1984) |
| Vietnam | *S. incertulas, C. suppressalis* | Quang et al. (2025); Pham & Kwon (2024); Thuy et al. (2022) |
| Brunei Darussalam | Published documentation on rice stem borer incidence in Brunei Darussalam remains limited, with few peer-reviewed studies specifically addressing species distribution or damage severity. | |
| Singapore | Limited rice cultivation, hence fewer literature sources regarding borer species. | |

*Note. S. incertulas* (Yellow stem borer); *S. innotata* (Rice white stem borer); *C. auricilius* (White-backed rice borer); *C. polychrysus* (Dark-headed rice borer); *C. suppressalis* (Striped rice stem borer); *S. inferens* (Pink stalk borer)

### *Life Cycle, Developmental Stage and Feeding Behaviour*

Rice stem borer is a lepidopteran and holometabolous insect which complete their life cycle through four different developmental stages. It starts from adult moths laying eggs on rice plants. The eggs will hatch into larvae that will undergo several larval instars, which vary among species. The larval stage, known as the most damaging stage to rice crops, is where they bore and feed within rice stems before entering the pupal stage (Figure 2). Pupation occurs where they embed themselves within protective cocoons, formed inside the stem or plant debris, after which they will emerge into adult moths in a few weeks to complete the life cycle.

Looking closer at how different species feed, *Scirpophaga* species usually feed inside the central pith of a single tiller and are less mobile, creating more localised damage and a quicker appearance of damage symptoms. *Chilo* species are more mobile, where their larvae move between tillers, making the damage more spread out and develop more gradually, making early symptoms more difficult to notice in the field. Compared to both *Scirpophaga* and *Chilo*, *Sesamia* species show more flexible feeding behaviour. For instance, *S. inferens* larvae often start by feeding on leaf sheaths before boring into the stem. Their ability to develop on rice as well as other grasses suggests they may infest different plant tissues at various growth stages (Li et al., 2023; Sau et al., 2022).



**Egg stage**

Female moths lay eggs in clusters or rows, typically on rice leaves, stems, or sheaths. Egg masses contain between 50 – 200 eggs, and hatching occurs within 5 – 10 days. (Li, 1991; Khan *et al.*, 1991)

**Larval stage**

After hatching, larvae migrate to the leaf sheath or bore directly into the rice stem. Larvae pass through multiple instars, feeding on internal plant tissues lasts for 20 – 40 days (Horgan, 2023; Li, 1991)

**Pupal stage / Pupation**

Occurs within the rice stem, straw, or stubble. Larvae create exit holes before pupation. This stage lasts 7 – 14 days. Pupae are enclosed in silk cocoons for protection.

(Li, 1991; Khan *et al.*, 1991)

**Adult stage**

The adult moths live for several weeks, during which they mate and disperse to new host plants. They typically begin laying eggs 1 – 2 days after emergence, some preferring to oviposit openly on leaves or concealed areas like behind leaf sheaths. (Horgan, 2023; Li, 1991; Khan *et al.*, 1991)

*Figure 2.* The general life cycle of the rice stem borer consists of four distinct stages: egg, larva, pupa, and adult. The estimated total life cycle is approximately 34 to 55 days

*Source: Adapted from Horgan (2023) and Li (1991)

Evidence for direct interactions among rice stem borer species remains limited. Most studies suggest that different species can coexist because they exploit the rice plant in different ways, rather than through strong competition. Variations in oviposition timing, larval feeding position within the stem, and preference for rice growth stages help reduce overlap within the same tillers.

When multiple stem borer species occur together, damage severity is more likely determined by combined feeding pressure and synchronisation with susceptible rice growth stages than by direct interactions among species (Table 3 and Table 4). Understanding these indirect relationships helps explain variable damage outcomes in multi-species infestations. Under field conditions where multiple species coexist, yield loss is therefore more strongly influenced by cumulative internal feeding across growth stages than by direct competition.

## Linking Species-specific Behaviour to Rice Phenology

Linking species-specific behaviour to rice growth stages helps the researchers explain how damage develops in the field. Damage caused by stem borer depends not only on when the pest is present, but also on how each species feeds and where it attacks the plant. Differences in egg-laying behaviour and larval feeding patterns determine when, where, and how severe the damage becomes (Table 5).

Damage expression in rice stem borers is closely linked to the synchronisation between pest development and crop phenology. However, interspecific variation in oviposition behaviour and larval feeding mechanisms (Tables 3 and 4) governs the timing, location, and severity of injury across growth stages.

### *Early Vegetative Stage: Different Establishment Success*

During the early vegetative state, there are differences in how larvae establish themselves within the young rice plant. For *Scirpophaga* species, their neonates quickly move

Table 3
*General comparison of feeding patterns between* Chilo spp., Scirpophaga spp., *and* Sesamia spp.

| Feature | *Chilo* spp. | *Scirpophaga* spp. | *Sesamia* spp. |
|---|---|---|---|
| Early Feeding | Leaf sheath/whorl | Minimal external feeding | Briefly on the leaf sheath |
| Entry into Stem | Early-mid larval stage | Very early | Early after short sheath feeding |
| Feeding Depth | Stem internodes | Central stem or growing point | Deep stem tunnelling |
| Host Range | Moderate | Mostly the rice plant host | Broad (rice, maize, sorghum) |
| Damage Pattern | Deadheart, Whitehead | Severe deadheart, whitehead | Deadheart, hollow stem, whitehead |

Table 4

*Detailed comparison of life cycle, oviposition behaviour, and feeding mechanism of major rice stem borers in Southeast Asia*

| Life cycle | | | |
|---|---|---|---|
| **Features** | ***Chilo* spp.** | ***Scirpophaga* spp.** | ***Sesamia* spp.** |
| | • Larval development comprises up to 7 instars and typically lasts approximately 20-30 days, depending on temperature and host condition.<br>• Pupation occurs within the rice stem or between the leaf sheath and stem tissues.<br>• Adult emergence is temperature-dependent, generally occurring above 15-16ºC.<br>• In tropical regions, multiple generations may occur annually, whereas two generations are typical in temperate zones. | • Eggs hatch within five to eight days under favourable conditions.<br>• Larvae feed internally for approximately 20-35 days.<br>• Pupation occurs inside the stem, usually near the plant base.<br>• Adult lives for approximately three to five days.<br>• Three to five generations per year may occur, depending on climatic conditions. | • Larvae undergo six to eight instars, with development lasting approximately 30-70 days depending on host plant and season.<br>• Pupation occurs inside the stem or near the plant base and lasts 9-11 days.<br>• Adult longevity ranges from five to seven days.<br>• Four to five overlapping generations may occur annually in tropical environments. |
| **Oviposition Behaviour** | | | |
| Location of Egg-laying | Eggs are laid in flattened, fish-scale-like masses on the underside of leaves, typically near the leaf sheath and plant base. | Eggs are deposited in compact masses covered with yellowish-brown hairs or scales from the female abdomen, usually on the upper leaf surface near the midrib. | Eggs are laid inside or near leaf sheaths and are rarely deposited on exposed leaf surfaces. |
| Number of Eggs | Approximately 200 - 700 eggs per female over its lifetime. | Several hundred eggs per female. | Approximately 150-400 eggs per female. |
| Timing of Oviposition/ Hatching | Mostly at night, with a peak shortly after mating. | Often in a short time window and hatch synchronously within five to eight days. | Duration of seven days, with a peak on the second day after adult emergence. |
| **Feeding Mechanism** | | | |
| *Chilo* spp. | Newly hatched larvae remain clustered within the leaf sheath before stem penetration.<br>Early feeding causes sheath withering and superficial lesions.<br>Larvae bore into the stem typically by the third instar (approximately 10-12 days after hatching) and remain concealed thereafter.<br>Feeding primarily occurs within stem internodes rather than exclusively at the central growing point. | | |

Table 4 (*continued*)

| **Feeding Mechanism** | |
|---|---|
| *Scirpophaga* spp. | Neonate larvae rapidly migrate downward after hatching.<br>They penetrate the stem directly through the leaf sheath and bore toward the central growing point.<br>Early feeding is concentrated at the apical meristem, leading to rapid expression of deadheart symptoms. |
| *Sesamia* spp. | Neonate larvae initially remain within or behind the leaf sheath.<br>Early feeding produces water-soaked or gummy lesions.<br>Larvae subsequently bore into the central stem and may tunnel across multiple internodes (first to fifth internodes).<br>Later instars may exit and re-enter adjacent tillers, increasing cumulative plant damage. |

Table 5
*The synchronisation of stem borer activity with critical phases of rice growth*

| Species | Feeding Focus | Dominant Symptom Stage | Compensation Potential | Risk Window |
|---|---|---|---|---|
| *Scirpophaga* spp. | Apical meristem | Early deadheart | Lower recovery | Early vegetative |
| *Chilo* spp. | Internodes | Progressive vascular damage | Moderate recovery | Vegetative to booting stage |
| *Sesamia* spp. | Multi-internode + movement between tiller | Cumulative late damage | Low recovery | Booting to the grain filling stage |

downward after hatching and feed directly at the growing point, leading to the swift appearance of deadheart formation. In comparison, *Chilo* larvae initially remain within the leaf sheath and only later bore into the stem, usually around the third instar. Their feeding often occurs within the stem internodes rather than directly at the meristem. *Sesamia* larvae may remain within or behind the sheath initially, and later instars can exit and re-enter adjacent tillers, increasing overall plant damage.

These differences affect how damage appears in the field. Because *Scirpophaga* targets the growing point early, deadheart symptoms tend to appear earlier and more suddenly compared to other species. *Chilo*, with a slight delay in stem penetration, usually causes more gradual symptom development. Meanwhile, *Sesamia* can create more scattered damage due to its movement between tillers. As a result, even when infestation levels are similar, the severity and pattern of damage at early stages can vary between species.

Differences between early- and late-planted rice can modify larval establishment and feeding intensity; field studies consistently report lower stem borer incidence in early-planted crops and elevated infestation in late-sown crops (Patil & Rao, 2020). Although direct movement tracking is limited, repeated field observations indicate that staggered planting creates continuous host availability that facilitates inter-field movement and increased pest pressure in later plantings (Heong et al., 2010).

### *Tillering Stage: Interaction with Compensatory Capacity*

During the active tillering stage, larval tunnelling disrupts the vascular system of the plant and interferes with nutrient movement. However, the level of damage and the ability of the plant to recover depend on where different species feed. Since *Scirpophaga* usually feed at the growing point, it may lead to a direct impact on the central tiller and limit further tiller development. *Chilo* species tend to feed within the internodes, which may initially spare the growing point, unlike *Scirpophaga*, gradually weakening the plant's structure and function eventually. While for *Sesamia* species, more widespread disruption may occur due to its mobility tunnelling through several internodes and between nearby tillers.

These differences in feeding behaviour suggest that the mix of prevalent species present in a field may influence both the severity of damage and the plant's ability to recover. Compensatory tillering is most effective when infestation occurs early, and damage is limited to a small proportion of tillers. However, species that concentrate feeding at the meristem may reduce recovery potential compared to species that initially feed within internodes. This suggests that species composition within a field may influence the effectiveness of compensation during vegetative stages.

### *Reproductive Stage: Whitehead Formation and Yield Impact*

At panicle initiation and heading stages, stem borer infestation results in more severe consequences, as all species ultimately disrupt the vascular system of the plant that is necessary for nutrient translocation for panicle development and grain filling. However, differences in tunnelling behaviour may influence the timing and expression of symptoms. From the initial tillering stage, *Scirpophaga* neonate's early infestation on the apical meristem may induce whitehead formation shortly after the paddy booting stage. *Chilo* neonates that feed across stem internodes may cause whitehead symptoms when vascular tissues supplying the developing panicle are sufficient. *Sesamia* neonates are capable of tunnelling across multiple internodes and occasionally moving between adjacent tillers, which may generate more extensive cumulative disruption during late reproductive stages. Unlike vegetative-stage damage, injury during panicle initiation and heading may be irreversible, as the plant's capacity for compensatory tillering is minimal at this stage. Consequently, species that sustain feeding during reproductive development may contribute disproportionately to final yield loss.

## Control Management of Rice Stem Borer

In history, recent syntheses highlight the role of insectivorous birds and bats in suppressing arthropod pests in rice landscapes, supporting conservation of bird habitat as a complementary pest-suppression strategy (Gogoi, 2023; Sottomayor, 2024).

The pests are also primarily controlled through cultural practices, including altering transplanting dates, flooding fallow fields, manually removing egg masses, and digging or burning stubble, in addition to using light traps (Luo et al., 2021). Over the years, the management has been improved to manage these pests based on several methods, including biological method, biochemical method, microbial method, chemical method and varietal resistance.

### *Biological Control Method*

In Southeast Asian countries, biological methods are getting more attention as their various approaches within biological means to manage pests (Babendreier et al., 2022). One of the most common biological control methods is using natural enemies. Natural enemies, including egg parasitoids, are extensively utilised and studied. For instance, *Trichogramma japonicum* is highly deployed as a biological control agent in many regions. They are highly utilised for their high feasibility to mass rear and target major rice stem borer species, especially *S. incertulas* and several *Chilo* species. There are many field releases of *T. japonicum* in the Southeast Asian regions, including Indonesia, Philippines, Vietnam, Malaysia, and Thailand, commonly reporting moderate to high with a satisfactory rate of egg parasitism under optimal conditions (Horgan 2023; Subedi et al., 2024). *T. japonicum*, in the form of small parasitic wasps, commonly oviposit within host eggs that will prevent larval emergence and thus suppress crop damage at an early stage. This is highly favoured in IPM programmes due to their high specificity, environmental friendliness, and good compatibility with ecological pest regulation (Pasalu et al., 2004).

Apart from T. japonicum, there are more parasitoids used as biological control of stem borers in Southeast Asia, as presented in Table 6. Other egg parasitoids such as *Telenomus rowani*, *Telenomus dignus*, and *Trichogrammatoidea nana* have been found to be useful as biological control, with reported field parasitism of 10 - 60% (depending on habitat conditions and management regimes). *T. rowani* is reported to exhibit more stable parasitism under less to non-disturbed field conditions (low-input or unsprayed systems), whereas *Trichogramma* performance is more habitat-dependent and sensitive to insecticide exposure.

In contrast, pupal parasitoids such as *Tetrastichus schoenobii* are also reported to achieve localised parasitism levels of up to approximately 40%, yet their effectiveness is strongly affected by insecticide regimes and seasonal host availability. Generally, parasitoids, including *Cotesia flavipes* and related braconids, are present but generally play a secondary role in rice ecosystems because stem borer larvae remain concealed within plant tissues, limiting parasitoid access and reducing consistent field impact.

Despite reports of moderate to high parasitism, these effects are frequently inconsistent across seasons and locations. High parasitism does not necessarily mean stable stem borer suppression or yield protection, largely due to poor synchrony between persistent parasitoid activity and stem borer oviposition, intensive insecticide use, and simplified rice landscapes that limit parasitoidal interactions.

Recent evidence further suggests that habitat complexity, crop mosaics, and planting synchrony help to increase parasitoid effectiveness by influencing both pest movement and the availability of host stages (Dominik et al., 2018; Saksongmuang et al., 2024). Diversified and ecologically managed rice systems may enhance parasitism; these benefits are often context-dependent, which may be affected by many external factors rather than consistent across all environments. Overall, evidence from egg, larval, and pupal parasitoids suggests that the success of biological control in Southeast Asian rice systems depends more on factors such as crop phenology, landscape structure, and management practices. This may suggest the need for biological control strategies that are aligned with crop growth stages and supported by favourable habitat conditions (Catalayud et al., 2006).

Collectively, the synthesis of field parasitism patterns across egg, larval, and pupal parasitoids indicates that parasitoid efficacy in Southeast Asian rice systems is governed less by intrinsic biological potential and more by crop phenology, landscape structure, and management intensity, underscoring the need for phenology-aligned and habitat-supported biological control strategies (Calatayud et al., 2006).

Table 6
*Major parasitoids targeted at the stem borer*

| Parasitoid | Target stage | Countries | Analysis |
|---|---|---|---|
| *Trichogramma japonicum* | Egg | Indonesia, Philippines, Vietnam, Malaysia, Thailand | Most widely released, however, performance is strongly habitat-dependent |
| *Trichogrammatoidea nana* | Egg | Indonesia, Malaysia, Thailand, Vietnam | Effective egg parasitoid under augmentative release |
| *Telenomus rowani* | Egg | Indonesia, Malaysia, Philippines | Often more stable than Trichogramma under farmer fields |
| *Telenomus dignus* | Egg | Philippines, Indonesia, Malaysia | Native egg parasitoid contributing to natural biological control in unsprayed fields |
| *Eriborus sinicus* | Larva | Philippines, Vietnam | Important larval parasitoid of *Chilo* spp., the effectiveness varies with host density and insecticide exposure |
| *Cotesia flavipes* | Larva | Indonesia, Philippines, Vietnam, Thailand | Key larval parasitoid of stem borers; widely used in classical biological control and IPM programmes |
| *Elasmus albopictus* | Larva | Philippines, Indonesia | Secondary parasitoid, population strongly influenced by cropping system and pesticide use |
| *Tetrastichus schoenobii* | Pupa | Indonesia, Philippines | Sensitive to insecticide regimes |

### *Biochemical Control Method*

The use of semiochemicals is another biological method for controlling stem borers, as these compounds are naturally released by plants and animals. This category includes sex pheromones, which are widely utilised to attract and trap insect pests (mass trapping), implement 'lure and kill' strategies, and disrupt mating processes. According to Regnault-Roger (2012) and El-Sayed et al. (2006), the diffusion of artificial pheromones can effectively interfere with the natural pheromone communication between male and female pests, reducing their ability to mate.

In Southeast Asian rice systems, pheromone-based control (Z)-11-hexadecenal (± Z9-16:Ald, Z13-18:Ald) is mainly used to manage lepidopteran stem borers. These species rely on sex pheromones to find their mates, which makes them a suitable target for this method. In general, three main deployment strategies are commonly used. First, low trap densities (about 1-2 traps per hectare) are applied to monitor pest flight activity and seasonal patterns. Second, moderate to higher trap densities are used for mass trapping to reduce the male populations, and lastly, by conducting area-wide mating disruption strategies that aim to saturate the field with pheromones so the males cannot locate the females. The third approach is becoming more important in rice systems because stem borer larvae remain hidden inside plant tissues and are difficult to control directly (Vacas et al., 2016).

The recommendations of using around 20 traps per hectare, with each containing about 5 mg of synthetic pheromone, have been supported by field studies, but still depend on the local conditions. Research shows that the trap densities below about 10 traps per hectare are usually not effective in reducing mating, especially in rice landscapes where pests continuously move between fields. In contrast, about 20 traps per hectare is considered a practical minimum level to ensure enough overlap of pheromone signals to interfere with the male orientation. This setup requires roughly 100 mg pheromone per hectare and matches regional IPM guidelines, which emphasise that the total pheromone amount per area is more important than trap number alone.

However, pheromone-based control does not always work the same way under different pest densities. When pest populations are low to moderate, mass trapping can delay mating and reduce egg laying. But under higher pest density, which is common in Southeast Asian rice fields, mass trapping alone is often less effective. This is mainly due to trap saturation, strong competition from naturally calling females, continuous pest movement from neighbouring fields, and the short mating period of stem borers. Consequently, pheromone-based suppression under high pest pressure is more reliably achieved through mating disruption integrated within additional and broader IPM strategies rather than through mass trapping alone (Balingbing et al., 2025; Hajjar et al., 2023).

The use of botanical extracts has also become a common and practical biological approach to managing rice stem borers. These methods are considered safer alternatives compared to conventional pesticides, especially when applied in specific target areas.

Studies across Southeast Asia show that semiochemicals and plant-based extracts mainly work due to their influence on insect behaviour and support for ecological balance instead of killing the pests directly. For example, volatiles released from host and non-host plants can attract or repel insects and are often used in push-pull strategies to manage the movement of stem borers in rice fields. Plant defence activators such as jasmonic acid, salicylic acid, and methyl salicylate can further support pest management by stimulating the release of herbivore-induced plant volatiles. These signals will attract natural enemies, particularly *Trichogramma* spp., which play an important role in controlling the populations of stem borer. Among the botanical products tested, citrus-derived orange oil and neem-based formulations have shown the most consistent performance under field conditions, helping to reduce the damage from stem borer while still conserving the beneficial insects.

Overall, these approaches highlight the gradual shift in the IPM of Southeast Asian rice from relying heavily on single chemical inputs toward more integrated strategies. Farmers are increasingly combining pheromone-based techniques, plant-derived repellents, and natural biological control to achieve more stable and sustainable stem borer management (Table 7).

Table 7
*Semiochemicals and plant-derived extracts used for rice stem borer management in Southeast Asia*

| Category | Compound/Extract | Target Stem Borer | Mode of Action | Sources |
|---|---|---|---|---|
| Host Plant Volatiles | Hexanal, nonanal, benzaldehyde, decanal | *S. incertulas* | Host attraction, oviposition stimulation | Adak et al., (2024) |
| Non-host/ Repellent Volatiles | 2-octenal, 2-pentylfuran, menthol | *S. incertulas* | Repellence, oviposition deterrence | Adak et al., (2024) |
| Plant Defence Elicitors (HIPVs) | Jasmonic acid (JA), salicylic acid (SA), methyl salicylate (MeSA) | Rice stem borers | Induces plant volatiles; indirect control | Rani & Murali-Baskaran (2026) |
| **Botanical Extract** | | | | |
| Citrus | Orange oil (Citrus spp.) | Rice stem borers | Repellent + neurodisruptive | Chou et al., (2022) |
| Neem | Neem oil/azadirachtin (*Azadirachta indica*) | Rice stem borers | Antifeedant, growth regulator | Majlish et al., (2015) |
| Legumes | Karanja (*Pongamia pinnata*), mahogany oils | Rice stem borers | Repellent, feeding inhibition | Majlish et al., (2015) |
| Roots/Leaves | *Derris elliptica*, *Neorautanenia mitis*, tobacco, *Adhatoda* | *Chilo* spp., *Scirpophaga* spp. | Toxicity and repellence | Dutta et al., (2024) |
| Trap Plant/ Plant-derived Semiochemicals | Vetiver (*Vetiveria zizanioides*) terpenes | *C. suppressalis* | Attraction (trap plant) | Li et al., (2025) |

### *Microbial Control Method*

Microbial control method is also one of the control methods that is gaining attention among farmers and researchers. Widely used microbial control agents such as *Bacillus thuringiensis*, *Beauveria bassiana*, and *Metarhizium anisopliae* are used for managing rice stem borer. As well as a biological control method, this method is also considered safe as it specifically targets insect pests without disrupting the populations of natural enemies.

Conducted screening studies on entomopathogenic fungi by Shahriari et al. (2021) reported that there are indigenous or locally isolated strains of *Beauveria* and *Metarhizium* that possess high virulence and better environmental endurance compared to some commercial strains, highlighting the importance of local adaptation in microbial control regimes. Mechanistic studies, as described by Wang et al. (2021) and Sutarman et al. (2023), found that *B. bassiana* produces beneficial secondary metabolites (beauvericin and bassianolide) that possess the ability to suppress host immune responses and accelerate mortality. These findings support the use of entomopathogenic fungi as slow-acting but persistent agents, particularly suitable for integration into IPM rather than as stand-alone replacements for chemical insecticides.

Apart from entomopathogenic fungi, beneficial bacteria such as *B. thuringiensis* are also widely used against rice stem borer. Recent reviews and genomic studies (2023-2025) demonstrate the continued effectiveness of Cry1Ab/Cry1Ac toxins against rice stem borers, especially when expressed in transgenic rice lines. However, resistance monitoring studies published up to 2025 provide evidence that low-frequency Cry resistance alleles are present in some *C. suppressalis* populations (Hu et al., 2024; Li et al., 2023). For example, in Cambodia, *B. bassiana* and 6% cold-pressed orange oil have been successfully used to manage insect pests in rice fields. In Malaysia, *B. thuringiensis*, as well as *Skermanella* sp. and *Serratia* sp., are also widely used as microbial control at concentrations of $3.80 \times 10^4$ CFU ml$^{-1}$ and $2.29 \times 10^5$ CFU ml$^{-1}$, respectively, to mitigate *C. medinalis* and *S. inferens* (Abdullah & Mokhtar, 2024; Panneerselvam et al., 2018)

Importantly, recent field-oriented syntheses indicate that microbial agents perform best when deployed as part of integrated pest management systems, combined with cultural practices, biological agents, and proper chemical inputs. Studies from tropical and subtropical rice systems report that environmental factors, especially humidity, temperature, and canopy structure, strongly influence the persistence and efficacy of entomopathogenic fungi, explaining variability in field outcomes across locations (Jaronski, 2010; Mascarin & Jaronski, 2016). These studies provide insights into the potential of microbial agents for rice stem borer management; however, the transferability of findings beyond the studied regions remains uncertain. While the pest shares broadly similar feeding behaviour and physiological traits across geographic regions, the field-level efficacy of microbial control agents is strongly influenced by environmental conditions, host population dynamics, formulation characteristics, and application practices.

Overall, reported findings from Southeast Asian rice systems on microbial control methods should also be conveyed as indicative rather than predictive for other regions. As well as other natural methods, microbial control also relies heavily on external factors, hence requiring additional region-specific validation trials. Local strain screening and resistance monitoring are recommended to promote local adaptation and to confirm validity before being used in broader applicability.

### *Chemical Control Method*

Chemical pesticides remain an important tool for managing pest and disease challenges in agriculture. The use of synthetic organic, inorganic, and natural chemicals, such as pyrethroids, insect growth regulators, and fumigants, is considered a chemical control method. Their use is guided by Good Agricultural Practices (GAP) to ensure safe, effective, and responsible pesticide selection and application  (Table 8). This approach minimises the risks associated with excessive or improper pesticide use, safeguarding the health of farmers, consumers, and the environment.

There are reported findings of high-yielding production under intensive management through extensive use of chemical insecticides. It has been reported by Peng et al. (2000) that rice yield potential in Asia can reach approximately 10 t $ha^{-1}$ when high-input pest control strategies are employed. For instance, long-term evaluations conducted by the International Rice Research Institute, encompassing 117 experiments over fifteen years, demonstrated that the production of insecticide-treated plots produced up to 87% higher yields than untreated plots, with benefit-cost ratios ranging from 3 to 10 (Pathak & Khan, 1994). These findings highlight the substantial contribution of chemical insecticides to yield protection, particularly under high pest pressure.

Several control strategies have been recommended to achieve effective suppression of rice stem borers during vulnerable crop stages. These include prophylactic or early-stage interventions such as seedling root soaking with systemic insecticides, as well as targeted applications of granular formulations during key developmental phases. Such approaches reflect the importance of aligning insecticide use with periods of heightened pest susceptibility.

Table 8
*Comparison of the efficacy of chemical pesticides against the stem borer*

| Effective | Moderately Effective | Highly Effective | Source |
|---|---|---|---|
| Carbaryl | Phosphamidon, quinalphos | Monocrotophos, fipronil, chlorpyrifos, phosalone, isazophos, carbofuran, and fenthion | El-Wakeil et al., (2013); (Seni & Naik, 2017) |
| Safer from natural enemies | Carbofuran, phorate, cartap, isazophos, triazophos, acephate. | | |

*Source: Modified from Yadav et al. (2021) and Pasalu et al. (2004)

Despite these demonstrated benefits, prolonged and intensive reliance on chemical insecticides has raised significant ecological and management concerns. Repeated application of broad-spectrum insecticides can disrupt populations of natural enemies, weakening biological regulation within rice ecosystems and increasing the risk of pest resurgence once insecticide residues decline (Ali et al., 2019). Repeated use of similar insecticides may place strong selection pressure on stem borer populations, increasing the risk of pest resistance, especially when applications are not well timed with the pest's life cycle.

The development of rice stem borer has a strong dependent relationship with the effectiveness of chemical control. Application of chemical pesticides when larvae have already hatched from the eggs may not be as effective as they become physically protected by the paddy's external structure. This may result declination in control efficacy and may further accelerate resistance development by exposing the pest to sub-lethal doses. Thus, correct time applications targeting early infestations can help to achieve effective control at a lower input level and simultaneously reduce the frequency of insecticide use.

Thus, judicious use of chemical insecticide is only recommended when infestation has exceeded the established economic threshold, as suggested by Saad Abdullah et al. (2012) that application should be made when approximately 10% of hills are infested or when four egg masses per hill are detected. 10% deadheart incidence is widely cited as a threshold; the application of chemical control should be adjusted to local or regional pest pressure, crop stage, and production system. Generally, applications made after the appearance of whitehead symptoms are ineffective, as the damage to reproductive tissues is irreversible. These highlight the importance of correct timing and threshold-based decision-making in creating control strategies and highlight the need for judicious use of chemical control with IPM approaches to ensure long-term sustainability.

## Varietal Resistance

Host plant resistance to rice stem borers has mainly been approached by developing rice varieties with moderate resistance or field tolerance immunity (Chaudhary et al., 1984; Horgan et al., 2021). Early breeding programmes at IRRI reported several varieties that showed lower levels of deadheart and whitehead damage when exposed to stem borer species. Widely cultivated varieties such as IR20, IR36, and IR50 were reported with moderate resistance and shorter crop duration, making them more practical to be cultivated under field conditions in Southeast Asia rice fields. Other varieties, including Ratna, Chandina, and Taitung 16 (T16), have also been identified as relatively resistant in both experimental and field settings (Table 9).

In the Philippines, recent varietal releases, including NSIC Rc 480 and NSIC Rc 27, highlight the importance of early-maturing rice (107 days) with moderate resistance to

Table 9

*Rice varieties in Southeast Asia regions with resistance to stem borers*

| Variety | Key Regions of Use | Crop Duration | Reaction to Stem Borers |
|---|---|---|---|
| IR20 | Widespread Asia (Philippines, Vietnam) | Medium | Moderate resistance |
| IR36 | Indonesia, Thailand | Short | Moderate resistance / tolerant |
| IR50 | Philippines, Vietnam | Medium-short | Moderate resistance |
| Ratna | Regional (e.g., Indonesia) | Medium | Moderate resistance |
| Chandina | Southeast Asia | Medium | Moderate resistance |
| Taitung 16 (T16) | IRRI trials (Philippines) | Medium | High resistance in screening |
| NSIC Rc 480 | Philippines | Short (~107 days) | Intermediate reaction |
| NSIC Rc 27 | Philippines (upland) | Short (~107 days) | Moderate resistance (white stem borer) |

stem borers (Philippine Rice Research Institute, 2023). Shorter growth duration limits the available time for stem borers to create infestation, especially during the reproductive stage of the paddy crop. Similarly, in Malaysia, no rice variety has been classified as resistant to stem borers, although some local varieties show an association with lower damage to stem borers (Abdullah et al. 2025).

However, resistance in these varieties is still partial and is heavily influenced by environmental conditions, and up to this moment, no widely grown variety provides complete protection against stem borers. This suggests the stem borer damage and yield loss are more strongly influenced by crop duration and timing of exposure; even when larval infestation occurs, tolerant rice varieties may experience less yield loss. This approach should be considered a risk-reduction strategy that helps the farmers stabilise yield, rather than a complete control solution, while ensuring good agronomic performance.

## Integrating Stem Borer Ecology with Management Strategies

Given the wide range of stem borer management strategies used across Southeast Asia, a comparative synthesis is needed to better understand how these approaches can work together in a compatible way. Table 10 presents different control measures to vulnerable stages in the pest life cycle, together with corrective actions across the crop growth stages.

Because yield loss becomes irreversible once larvae penetrate stems during reproductive stages, IPM prioritises early-stage suppression. At the adult stage, habitat and synchrony manipulation, including modified planting geometry and landscape-level synchronous planting, reduce oviposition preference and host continuity. Pheromone monitoring supports threshold-based timing, strengthening decision precision.

Interventions may be intensified at the egg stage, where *Trichogramma* and other parasitoids are released, and conservation of the natural enemies increases pre-entry mortality.

Table 10
*Ecology-aligned integrated management framework for rice stem borers in Southeast Asia*

| Stem Borer Stage | Crop Stage Vulnerability | Management Strategy | Functional Role in IPM | Type of Control |
|---|---|---|---|---|
| Adult (oviposition stage) | Early vegetative | Jajar Legowo planting geometry (Indonesia) | Reduces oviposition preference via canopy modification | Cultural |
| | Pre-season | Synchronous planting (Malaysia, Laos) | Reduces asynchronous host availability | Cultural |
| | Pre-season/all stages | Pheromone monitoring and ETL-based targeted trapping (Vietnam) | Early detection and improved spray timing | Semiochemical/ Monitoring |
| Egg stage | Early vegetative | Trichogramma release (Malaysia, Vietnam) | Egg parasitism before larval emergence | Biological |
| | Early vegetative | Conservation of natural enemies, community-based mass release of Trichogramma (Philippines) | Maintains ecological mortality factors | Biological |
| Early larval stage (before deep stem entry) | Vegetative (tillering) | Alternate wetting and drying (AWD) (Thailand, Vietnam, Philippines) | Disrupts larval establishment | Cultural |
| | Vegetative | Split nitrogen application (Malaysia) | Reduces excessive vegetative attractiveness | Cultural (Nutrient management) |
| | Early infestation | Chlorantraniliprole, fipronil (ETL-based use) (Myanmar, Malaysia) | Rapid suppression before irreversible stem damage | Chemical |
| Late larval stage (internal feeding) | Tillering-booting | Incorporate *B. bassiana*, *M. anisopliae*, and *B. thuringiensis* (Thailand, Cambodia) | Biological mortality of concealed feeders | Biological (Microbial) |
| | Booting-heading | Targeted insecticide application (ETL-guided) | Prevents whitehead formation during the reproductive stage | Chemical |
| Overwintering/ stubble survival | Post-harvest | Stubble destruction/crop sanitation | Reduces carry-over population | Mechanical/ Cultural |
| | | Flooding fallow fields | Suppresses diapausing larvae/ pupae | Cultural |

During early larval establishment, cultural practices such as alternate wetting and drying and split nitrogen management reduce habitat suitability and plant susceptibility. These measures collectively lower larval survival before structural damage occurs.

Selective insecticides are reserved for threshold-exceeding infestations and function as a corrective safeguard rather than a routine measure. By concentrating chemical inputs at critical risk points, the framework reconciles yield protection with environmental risk reduction, demonstrating that ecological alignment enhances both sustainability and strategic efficiency.

## FUTURE TREND AND RESEARCH GAP

In this review, the control management regime could be properly strategised by understanding how the stem borer damage and rice phenology are correlated. However, there are several research gaps that remain unfilled. One of the main research gaps is an experimental study that shows a clear quantification of yield loss by different stem borer species at different paddy growth stages. Since a multi-species complex is quite common in rice fields, to determine yield loss under such condition is necessary to observe the interaction or even dominance of species towards affecting the production of grain yield.

At the current time, a lot of management and control recommendations often treat stem borers as if they behave similarly, though they behave differently in terms of feeding pattern, oviposition behaviour, and life cycle. All these characteristics have effects on the ability of the rice crop to recover from the damage after infestation. While the improvement in management controls by integrating biological, microbial, chemical, and biochemical in a system is applauded, they are still mostly discussed conceptually rather than field-based experimental evidence. Hence, another research gap that may be considered in the future is to produce a management control regime that is species-specific towards rice stem borers at targeted rice growth stages.

Thus, the discussed concepts should therefore be studied in a controlled experiment involving both single and mixed species across targeted rice growth stages. This will help to quantify and provide knowledge for the researchers and farmers to determine the extent of irreversible yield loss, plant compensation, as well as the effectiveness and specificity of each management control towards rice stem borer. By filling in these gaps, the researchers can help to develop more precise, species-specific, and aligned phenology solutions that may improve yield protection while reducing judicious use of chemicals and their detrimental impacts.

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## REFERENCES

Abdullah, S. W. R., & Mokhtar, A. S. (2024). Overview of yellow rice stem borer, *Scirpophaga incertulas* in Malaysia. *Outlooks on Pest Management*, *35*(3), 126-131. https://doi.org/10.1564/v35_jun_08

Abdullah, S. W. R., Adam, N. A., Tajidin, N. E., & Mokhtar, A. S. (2025). Review of key rice stem borer species threatening Malaysia's paddy industry. *Serangga*, *30*(3), 353-371. https://doi.org/10.17576/serangga-2025-3003-24

Adak, T., Mahanty, A., Jena, S., Gowda Gadratagi, B., Patil, N., Guru-Pirasanna-Pandi, G., Annamalai, M., Golive, P., & Rath, P. C. (2024). Volatolomics to decrypt the monophagous nature of a rice pest, *Scirpophaga incertulas* (Walker). *Journal of Chemical Ecology*, *50*, 373-384. https://doi.org/10.1007/s10886-024-01498-7

Agustina, R. Y., & Herlina, M. (2025). Types of rice pests (*Oryza sativa* L.) in rice fields in Tebat Karai District, Kepahiang Regency. *Journal of Multidisciplinary Research*, *1*(3), 137-144. https://doi.org/10.70963/jmr.v1i3.202

Ali, M. P., Bari, M. N., Haque, S. S., Kabir, M. M. M., Afrin, S., Nowrin, F., Islam, M. S., & Landis, D. A. (2019). Establishing next-generation pest control services in rice fields: Eco-agriculture. *Scientific Reports*, *9*, Article 10180. https://doi.org/10.1038/s41598-019-46688-6

Arunmit, S., Channoo, C., Boonsa-nga, K., Thammasamisorm, B. O., & Intalae, K. (2024). Impact of insecticides on natural enemy diversity in Chainat Province's paddy fields. In *Proceedings of the 16th NPRU National Academic Conference*. Nakhon Pathom Rajabhat University.

Babendreier, D., Tang, R., & Horgan, F. G. (2022). Prospects for integrating augmentative and conservation biological control of leaffolders and stemborers in rice. *Agronomy*, *12*(12), Article 2958. https://doi.org/10.3390/agronomy12122958

Balingbing, C., Gummert, M., Pangesti, N., Van Hung, N., & Hensel, O. (2025). Insect attractants for enhanced monitoring and control of pests in rice storage. *Journal of Stored Products Research*, *113*, Article 102697. https://doi.org/10.1016/j.jspr.2025.102697

Cabasan, M. T. N., Tabora, J. A. G., Cabatac, N., Jumao-As, C. M., Soberano, J. O., Turba, J. V., Dagamac, N. H. A., & Barlaan, E. (2019). Economic and ecological perspectives of farmers on rice insect pest management. *Global Journal of Environmental Science and Management*, *5*(1), 31-42.

Calatayud, P.-A., Le Ru, B. P., Schulthess, F., & Silvain, J.-F. (2006). Les recherches sur les lépidoptères foreurs des graminées et leurs antagonistes : Bilan et perspectives [Research on lepidopteran cereal borers and their antagonists: Review and perspectives]. *Annales de la Société Entomologique de France (N.S.)*, *42*(3-4), 259-262. https://doi.org/10.1080/00379271.2006.10697458

Castilla, N. P., Stuart, A. M., Makara, O., Sathya, K., Somany, S., Kumar, V., & Hadi, B. A. R. (2020). Characterisation of cropping practices, pest constraints, and yield variation in irrigated lowland rice of Cambodia. *Crop Protection*, *135*, Article 104906. https://doi.org/10.1016/j.cropro.2019.104906

Catling, H. D., Islam, Z., & Pattrasudhi, R. (1984). Seasonal occurrence of the yellow stem borer, *Scirpophaga incertulas* (Walker), on deepwater rice in Bangladesh and Thailand. *Agriculture, Ecosystems & Environment*, *12*(1), 47-71. https://doi.org/10.1016/0167-8809(84)90060-4

Chaudhary, R. C., Khush, G. S., & Heinrichs, E. A. (1984). Varietal resistance to rice stem borers in Asia. *Insect Science and Its Application*, *5*(6), 447-463. https://doi.org/10.1017/S1742758400004872

Chou, C., Hadi, B. A., Chiba, S., Sato, I., Choi, I. R., & Tanaka, T. (2022). An entomopathogenic fungus and a natural extract benefit rice (*Oryza sativa*) by suppressing populations of insect pests while keeping high populations of their natural enemies. *Biological Control*, *165*, Article 104793. https://doi.org/10.1016/j.biocontrol.2021.104793

Coulibaly, T. P., Du, J., & Diakité, D. (2021). Sustainable agricultural practices adoption. *Agriculture*, *67*(4), 166-176. https://doi.org/10.2478/agri-2021-0015

Dominik, C., Seppelt, R., Horgan, F. G., Settele, J., & Václavík, T. (2018). Landscape composition, configuration, and trophic interactions shape arthropod communities in rice agroecosystems. *Journal of Applied Ecology*, *55*(5), 2462-2474. https://doi.org/10.1111/1365-2664.13226

Dorairaj, D., & Govender, N. T. (2023). Rice and paddy industry in Malaysia: Governance and policies, research trends, technology adoption and resilience. *Frontiers in Sustainable Food Systems*, *7*, Article 1093605. https://doi.org/10.3389/fsufs.2023.1093605

Douangboupha, B., Khamphoukeo, K., Inthavong, S., Schiller, J., & Jahn, G. (2006). Pests and diseases of the rice production systems of Laos. In J. M. Schiller, M. B. Chanphengxay, B. Linquist, & S. Appa Rao (Eds.), *Rice in Laos*. International Rice Research Institute.

Dunn, L., Latty, T., Van Ogtrop, F. F., & Tan, D. K. (2023). Cambodian rice farmers' knowledge, attitudes, and practices (KAPs) regarding insect pest management and pesticide use. *International Journal of Agricultural Sustainability*, *21*(1), Article 2178804. https://doi.org/10.1080/14735903.2023.2178804

Dutta, S., Hossain, A., & Roy, N. (2024). Bioecology and management of major insect pests of rice in West Bengal. *Indian Journal of Entomology*, *86*, 300-318. https://doi.org/10.55446/IJE.2023.1349

El-Sayed, A. M., Suckling, D. M., Wearing, C. H., & Byers, J. A. (2006). Potential of mass trapping for long-term pest management and eradication of invasive species. *Journal of Economic Entomology*, *99*(5), 1550-1564. https://doi.org/10.1093/jee/99.5.1550

El-Wakeil, N., Gaafar, N., & Sallam, A. (2013). Side effects of insecticides on natural enemies and possibility of their integration in plant protection strategies. In M. Stoytcheva (Ed.), *Pesticides - Advances in chemical and botanical pesticides* (pp. 1-56). InTech. https://doi.org/10.5772/54199

Galawat, F., & Yabe, M. (2012). Profit efficiency in rice production in Brunei Darussalam: A stochastic frontier approach. *Journal of the International Society for Southeast Asian Agricultural Sciences*, *18*(1), 100-112.

Gogoi, H. (2023). Avian diversity in the paddy field ecosystem and its ecological significance. *Journal of Entomology and Zoology Studies*, *11*(3), 45-52.

Gumbek, M., & Hamsein, N. N. (2011). Status of paddy pests in Sarawak. In *Proceedings of the Research Officers Progress Meeting* (p. 13).

Hajjar, M. J., Ahmed, N., Alhudaib, K. A., & Ullah, H. (2023). Integrated insect pest management techniques for rice. *Sustainability*, *15*(5), Article 4499. https://doi.org/10.3390/su15054499

Heong, K. L., Hardy, B., & Cruz, F. (2010). Ecology and management of rice insects. In R. S. Zeigler & A. B. Bennett (Eds.), *Rice: Origin, history, technology, and production* (2nd ed., pp. 429-460). Cambridge University Press.

Horgan, F. G. (2023). The structure of rice stemborer assemblages: A review of species' distributions, host ranges, and interspecific interactions. *Insects*, *14*(12), Article 921. https://doi.org/10.3390/insects14120921

Horgan, F. G., Villegas, J. M., Bernal, C. C., Almazan, M. L. P., & Ramirez, D. A. (2021). Host resistance, tolerance, and vulnerability determine levels of field damage from Asian rice stem borers. *Crop Protection*, *142*, Article 105513. https://doi.org/10.1016/j.cropro.2020.105513

Hu, L., Zhang, Q., Chen, M., & Ye, G. (2024). Progress and challenges in developing Bt rice for lepidopteran pest management. *Environmental and Experimental Botany*, *221*, Article 105634. https://doi.org/10.1016/j.envexpbot.2023.105634

Jaronski, S. T. (2010). Ecological factors in the inundative use of fungal entomopathogens. *BioControl*, *55*(1), 159-185. https://doi.org/10.1007/s10526-009-9248-3

Khan, Z. R., Midega, C. A. O., Pittchar, J. O., Murage, A. W., & Pickett, J. A. (2020). Field evaluation of stem borer damage and yield loss responses under varied nutrient regimes. *Field Crops Research*, *250*, Article 107753. https://doi.org/10.1016/j.fcr.2020.107753

Khmer Times. (2023). Cambodia produced more than 11 million tonnes of rice last year. https://www.khmertimeskh.com/501241911/cambodia-produced-more-than-11-million-tonnes-of-rice-last-year/

Li, C., Shen, Z., Tang, L.-D., Wang, X.-Y., Huang, Y.-Q., Zhang, Y.-F., Mu, M.-Y., Smagghe, G., & Zang, L.-S. (2023). Demography and fitness of *Sesamia inferens* Walker (Lepidoptera: Noctuidae) on three important gramineous crops. *CABI Agriculture and Bioscience*, *4*, 1-10. https://doi.org/10.1186/s43170-023-00191-1

Li, Q., He, K., Lu, Y., He, B., Zheng, X., Lu, Z., Li, F., & Xu, H. (2025). A vetiver-specific terpene synthase VzTPS9 contributes to the high attractiveness of vetiver to rice stem borer. *Proceedings of the National Academy of Sciences of the United States of America*, *122*(20), Article e2424863122. https://doi.org/10.1073/pnas.2424863122

Li, Z. (1991). *World bibliography of rice stem borers (1794-1990)*. International Rice Research Institute.

Ling, A. X. R., Yeo, F. K. S., Hamsein, N. N., Ting, H.-M., Sidi, M., Wan Ismail, W. N. N., Taji, A. S., & Cheok, Y. H. (2020). Screening for Sarawak paddy landraces with resistance to yellow rice stem borer, *Scirpophaga incertulas* (Walker) (Lepidoptera: Crambidae). *Pertanika Journal of Tropical Agricultural Science*, *43*(4), 491-501. https://doi.org/10.47836/pjtas.43.4.06

Litsinger, J. A., Barrion, A. T., Canapi, B. L., Lumaban, M. D., Dela Cruz, C. G., & Pantua, P. C. (2011). Philippine rice stemborers: A review. *Philippine Entomologist*, *25*, 1-47. https://doi.org/10.59852/TPE-A587V25I1

Luo, G.-H., Lu, M.-H., Wu, K.-M., & Li, Y.-H. (2021). The response to flooding of two overwintering rice stem borers likely accounts for their changing impacts. *Journal of Pest Science*, *94*, 1341-1352. https://doi.org/10.1007/s10340-020-01282-y

Majlish, A. K., Uddin, M. M., Jahan, M., & Rahman, M. M. (2015). Comparative efficacy of different botanicals and chemical insecticides for controlling rice stem borer. *Journal of the Bangladesh Agricultural University*, *13*(2), 183-189. https://doi.org/10.3329/jbau.v13i2.28778

Mascarin, G. M., & Jaronski, S. T. (2016). The production and uses of *Beauveria bassiana* as a microbial insecticide. *World Journal of Microbiology and Biotechnology*, *32*, Article 177. https://doi.org/10.1007/s11274-016-2131-3

Mat, K. W. (2023). *The rice landscape in Malaysia: Sustainable rice production and trade*. Food and Fertiliser Technology Centre. https://ap.fftc.org.tw/article/3869

Maung, K. L., Latt, Z. K., Htun, P. W., Myint, M., & Khai, A. A. (2020). Rice stem borer distributions and their native parasitoids rearing on the host eggs, *Corcyra cephalonica*, in Mandalay Region, Myanmar. *Asian Journal of Research*, *4*(6).

Mohd Khari, N. A., & Ab Hamid, S. (2022). Abundance and infestation of rice stem borer in North Malaysia. *Malaysian Applied Biology*, *51*(5), 165-177. https://doi.org/10.55230/mabjournal.v51i5.2423

Mondal, D., Ghosh, A., Roy, D., Kumar, A., Shamurailatpam, D., Bera, S., Ghosh, R., Bandopadhyay, P., & Majumder, A. (2017). Yield loss assessment of rice (*Oryza sativa* L.) due to different biotic stresses under system of rice intensification (SRI). *Journal of Entomology and Zoology Studies*, *5*, 1974-1980.

Muralidharan, K., & Pasalu, I. C. (2006). Assessments of crop losses in rice ecosystems due to stem borer damage (Lepidoptera: Pyralidae). *Crop Protection*, *25*(5), 409-417. https://doi.org/10.1016/j.cropro.2005.06.007

Nguyen, T. P., Bernal, C. C., Almazan, M. L. P., Villegas, J. M., & Horgan, F. G. (2022). Water limitation reduces compensatory tillering after stem borer injury in upland vs. irrigated systems. *Agronomy Journal*, *114*(4), 2456-2467. https://doi.org/10.1002/agj2.21045

Panneerselvam, P., Kumar, U., Sahu, S., Mohapatra, S. D., Dangar, T. K., Parameswaran, C., Jahan, A., Senapati, A., & Govindharaj, G. P. P. (2018). Larvicidal potential of *Skermanella* sp. against rice leaf folder (*Cnaphalocrosis medinalis* Guenée) and pink stem borer (*Sesamia inferens* Walker). *Journal of Invertebrate Pathology*, *157*, 74-79. https://doi.org/10.1016/j.jip.2018.08.003

Pasalu, I. C., Mishra, B., Krishnaiah, N. V., & Katti, G. (2004). Integrated pest management in rice in India: Status and prospects. *Indian Agriculture*, *48*(1-2), 125-140.

Pathak, M. D., & Khan, Z. R. (1994). *Insect pests of rice*. International Rice Research Institute.

Patil, B. L., & Rao, B. R. (2020). Effect of sowing dates on stem borer incidence and yield parameters in rice (*Oryza sativa* L.). *Entomological Journal*, *8*(5), 245-252.

Peng, S., Cassman, K. G., Virmani, S. S., Sheehy, J., & Khush, G. S. (2000). Grain yield of rice cultivars and lines developed in the Philippines since 1966. *Crop Science*, *40*(2), 307-314. https://doi.org/10.2135/cropsci2000.402307x

Pham, T. L., & Kwon, O. (2024). Study of major insect pests on rice and corn in four provinces in Red River Delta of Vietnam during 2018-2022. *Proceedings of the National Institute of Ecology of the Republic of Korea*, *5*(1), 21-27.

Philippine Rice Research Institute. (2023). *RCEF delivers El Niño-ready rice varieties*. https://www.philrice.gov.ph/rcef-delivers-el-nino-ready-rice-varieties/

Quang, T. V., Huyen, T. T., Do, D. V., Lan, T. H., Ha, C. D., & Loc, N. V. (2025). Optimisation of fertiliser application and transplanting density across agro-ecological zones and cropping seasons for black glutinous rice cultivation. *Australian Journal of Crop Science*, *19*(7), 729-736. https://doi.org/10.21475/ajcs.25.19.07.p11

Rahim, A., Memon, A. J., Soomro, A. R., & Leghari, A. H. (1992). Chemical control of yellow stem borer in Sindh. *Pakistan Journal of Agricultural Research*, *13*(4), 380-383.

Rani, M., & Murali-Baskaran, R. K. (2026). Semiochemical potential of elicitor-induced plant volatiles strengthens cereal defense. *Journal of Natural Pesticide Research*, *15*, Article 100182. https://doi.org/10.1016/j.napere.2026.100182

Regnault-Roger, C. (2012). Trends for commercialisation of biocontrol agent (biopesticide) products. In J. M. Mérillon & K. G. Ramawat (Eds.), *Plant defence: Biological control* (pp. 139-160). Springer Netherlands. https://doi.org/10.1007/978-94-007-1933-0_6

Saad Abdullah, B., Amzah, B., Othman, S., Man, A., Hussein, Y., Misman, S. N., & Mohamad Saad, M. (Eds.). (2012). *Pengurusan perosak bersepadu tanaman padi ke arah pengeluaran berlestari* [Integrated pest management for paddy towards sustainable production]. Penerbit MARDI.

Saksongmuang, V., Michalko, R., Petchard, B., & Brumngsrsi, S. (2024). Changes in vegetation complexity during the development of rice ecosystems affect orb-weaving spider-prey trophic networks. *Agricultural and Forest Entomology*, *26*(2). https://doi.org/10.1111/afe.12618

Sapkota, S., Dara, S. K., & Horgan, F. G. (2019). Review of rice stem borer damage relationships and economic thresholds in Asia. *Journal of Integrated Pest Management*, *10*(1), 1-12. https://doi.org/10.1093/jipm/pmz007

Sau, A. K., & Rajesh, D. M. (2022). Aspects of host plant resistance with reference to *Sesamia inferens* (Walker): A review. *Pharma Innovation Journal*, *11*(2), 1006-1010.

Savary, S., Willocquet, L., Elazegui, F. A., Castilla, N. P., & Teng, P. S. (2000). Rice pest constraints in tropical Asia: Quantification of yield losses due to rice pests in a range of production situations. *Plant Disease*, *84*(3), 357-369. https://doi.org/10.1094/PDIS.2000.84.3.357

Seni, A., & Naik, B. (2017). Ecological IPM strategies for management of pests of rice. *The Pharma Innovation Journal*, *6*(12), 365-466.

Shahriari, M., Mehrabadi, M., Zibaee, A., & Bandani, A. R. (2021). Screening and virulence of entomopathogenic fungi associated with *Chilo suppressalis* (Walker) (Lepidoptera: Crambidae) larvae. *Journal of Fungi*, *7*(1), Article 34. https://doi.org/10.3390/jof7010034

Siddharta. (2024). *Rice production volume in Malaysia from 2013 to 2022 (in 1,000 metric tons)*. Statista. https://www.statista.com/statistics/794700/rice-production-volume-malaysia/

Song, T., Zhang, C., Dong, Y., Xu, Z., Li, C., Makowski, D., & Zhang, F. (2025). Control of rice blast drives yield benefits from variety mixture in rice: A meta-analysis. *Field Crops Research*, *350*, Article 110054. https://doi.org/10.1016/j.fcr.2025.110054

Sottomayor, M. (2024). Nature-based solutions to increase rice yield. *Agriculture, Ecosystems & Environment*, *365*, Article 108929. https://doi.org/10.1016/j.agee.2024.108929

Subedi, S., Bohara, A. K., Thapa, S., & Timilsena, K. (2024). Safeguarding rice crops in Nepal: Unveiling strategies against the yellow stem borer (*Scirpophaga incertulas*). *Discover Agriculture*, *2*(1), Article 64. https://doi.org/10.1007/s44279-024-00065-8

Sutarman, S., Anggreini, A. D., Prihatiningrum, A. E., & Miftahurrohmat, A. (2023). Application of biofertilizing agents and entomopathogenic fungi in lowland rice. In *E3S Web of Conferences* (Vol. 444, Article 04009). EDP Sciences. https://doi.org/10.1051/e3sconf/202344404009

Thuy, N. P., Loc, H. T., & Chakravarthy, A. K. (2022). Application of genetic engineering technologies to manage crop pests and diseases in Vietnam. In A. K. Chakravarthy (Ed.), *Genetic methods and tools for managing crop pests* (pp. 253-284). Springer Nature Singapore. https://doi.org/10.1007/978-981-19-0264-2_8

USDA Foreign Agricultural Service. (2024). *Grain and feed annual: Phnom Penh, Cambodia* (Report No. CB2024-0001). U.S. Department of Agriculture. https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Grain+and+Feed+Annual_Phnom+Penh_Cambodia_CB2024-0001

Vacas, S., Navarro, I., Primo, J., & Navarro-Llopis, V. (2016). Mating disruption to control the striped rice stem borer: Pheromone blend, dispensing technology and number of releasing points. *Journal of Asia-Pacific Entomology*, *19*(2), 253-259. https://doi.org/10.1016/j.aspen.2016.02.001

Villegas, J. M., Wilson, B. E., & Way, M. O. (2021). Management of stemborers (Lepidoptera: Crambidae) using foliar-applied chlorantraniliprole in rice. *Florida Entomologist*, *104*(3), 210-215. https://doi.org/10.1653/024.104.0404

Viz, J. A., & Pacada, I. G. (2022). Density, orientation, and distribution of foliar trichomes in selected Philippine traditional rice varieties with resistance to *Scirpophaga* spp. *Philippine Journal of Science*, *151*(5), 1737-1745. https://doi.org/10.56899/151.05.16

Wang, P., Li, M. J., Bai, Q. R., Ali, A., Desneux, N., Dai, H. J., & Zang, L. S. (2021). Performance of *Trichogramma japonicum* as a vector of *Beauveria bassiana* for parasitising eggs of rice striped stem borer, *Chilo suppressalis*. *Entomologia Generalis*, *41*(2), 213-223. https://doi.org/10.1127/entomologia/2021/1068

World Bank. (2024). *Malaysia rice imports and exports, 2023* [Data set]. World Integrated Trade Solution (WITS). https://wits.worldbank.org/trade/comtrade/en/country/MYS/year/2023/tradeflow/Imports/partner/ALL/product/1006

Yadav, P. K., Sharma, S., & Sharma, A. (2021). Management trends of rice insect pests in South Asia: A review. *Research in Food and Nutrition Agriculture*, *2*, 46-53. https://doi.org/10.26480/rfna.02.2021.46.53

Yeo, F. K. S., Cheok, Y. H., Lam, T.-Y., & Chong, Y. L. (2025). Metagenomic characterisation of bacterial communities associated with rice yellow stemborer, *Scirpophaga incertulas*. *Vegetos*. Advance online publication. https://doi.org/10.1007/s42535-025-01483-9

Zhao, L., Horgan, F. G., Bernal, C. C., & Almazan, M. L. P. (2018). Growth compensation in rice following stem borer damage under irrigation vs. rainfed conditions. *Plant Ecology*, *219*(8), 973-982.