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# Oviposition Behaviour Preference of Yellow Stem Borer (*Scripophaga incertulas*) on Vetiver Grass (*Vetiveria zizanoides*) and Local Rice Varieties

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**ABSTRACT**

Stem borers pose a significant threat to paddy production, accounting for substantial yield losses. To mitigate this challenge, sustainable pest management strategies integrating ecological engineering principles have been proposed. This study investigates the efficacy of vetiver grass (*Vetiveria zizanioides*) as a trap crop for controlling stem borer populations. Unlike invasive weeds, vetiver grass offers a low-risk and effective solution. The oviposition preferences of yellow stem borers (*Scirpophaga incertulas*) between vetiver grass and three local paddy varieties (MR297, MR269, and PadiU Putra 1) were examined. Using a randomized complete block design (RCBD) with four replications, 240 female *S. incertulas* were released into net cages containing different treatment combinations. Evaluation of total egg masses laid on different host plants revealed no significant differences in attractiveness for oviposition, although *S. incertulas* displayed a preference for the adaxial surface of *V. zizaniodes*. Additionally, larvae fed on vetiver grass did not survive, while those on paddy plants exhibited similar growth rates and sizes. Overall, while no statistically significant oviposition preference was observed among host plants, vetiver grass demonstrated a pronounced lethal effect on *S. incertulas* larvae. This study contributes valuable insights into integrated pest management strategies in paddy cultivation systems, emphasizing the potential of vetiver grass as an environmentally sustainable solution.

## 1. Introduction

Rice, scientifically known as *Oryza sativa* or referred to as "padi" in Malay, serves as a vital staple in global food production, primarily centered in Asia. Acknowledging its significance, Malaysia has set ambitious targets for rice self-sufficiency levels (SSL) through the National Agrofood Policy (NAP) 2.0 [1]. However, the pursuit of intensified rice production for higher yields has inadvertently brought forth environmental challenges, jeopardizing food safety and exacerbating pest outbreaks.

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Among these pests, the yellow stem borer (YSB) presents a formidable threat to Malaysian rice yields [2-4]. The escalating resistance of YSB to conventional insecticides underscores the urgency to explore sustainable alternatives, such as ecological engineering (EE) or agroecology. This study aims to assess the efficacy of vetiver grass (*Vetiveria zizanoides*) as a potential agroecological tool in managing YSB infestations, aiming to reduce reliance on chemical pesticides while enhancing integrated pest management practices in paddy cultivation.

Since its inception, rice cultivation has grappled with pest challenges, intensifying over time due to evolving pest dynamics. Arthropods and stem-boring insects like *Chilo* spp., *Scirpophaga* spp., and *Sesamia* spp. infest rice crops, posing threats throughout various growth stages (Edde, 2022). The abundance and diversity of these pests fluctuate across planting seasons, geographical regions, and paddy growth stages [5].

The widespread adoption of monoculture in paddy cultivation, both globally and in Malaysia, has exacerbated pest issues by diminishing the density of natural enemies and limiting ecological diversity [6]. Moreover, modern agricultural practices favoring monoculture have suppressed predatory insects' activities, fostering an environment conducive to insect pest proliferation. Malaysia's warm and humid climate exacerbates the situation, providing ideal conditions for rapid insect pest and disease proliferation [7].

The significance of insect abundance in cultivation systems cannot be overstated, as it shapes interspecific competition and predator-prey dynamics. Many rice pests engage in interspecific competition for resources, resulting in diminished paddy yields. Fostering ecosystem health and diversity in insect abundance is pivotal for averting future pest outbreaks and sustaining rice cultivation.

Although Malaysia hosts over 150 insect species, only a few have emerged as significant rice pests [8]. Natural enemies like predators and parasites possess the potential to effectively regulate rice insect pest populations [9]. However, their efficacy is hindered by indiscriminate chemical pesticide applications, leading to uncontrolled pest populations and substantial yield losses [10].

In response to these challenges, adopting sustainable integrated pest management strategies, such as agroecological approaches, becomes imperative to mitigate pest pressures while safeguarding crop yields and environmental health.

## 2. Paddy Cultivation in Malaysia

According to Shaw (2007), food security is orientated around 4 dimensions: Food Availability, Access, Utilization, and Stability. According to the Department of Statistics Malaysia (DOSM, 2022), Malaysia is still a net importer of rice from Vietnam, India, and other neighboring countries with the importation of more than 30% of rice to meet the local rice demand for more than 20 years and contributing to food security susceptibility. Associated with this realization, the government of Malaysia (GoM) had focused on the paddy production industry with an aim to secure food availability, agriculture modernization is always one of the focuses in the yearly budget. As reported in Agrofood Statistics (2016), public resources with a range of 30% to 50% of the national budget had been allocated directly to paddy and rice-related subsidies, assistance, and incentives. Associated with that, approximately RM 1.7 billion had been utilized to achieve the aim, and rice self-sufficiency level 100% (DOSM, 2022).

DOSM (2022) reported an increment of about 20% in rice production and the main contributor to this growth is a state in northern Malaysia, Kedah. Based on Malaysia Trade Statistic Review Volume 1 (2021), the major paddy cultivation areas fall in Peninsular Malaysia which contributed to more than 70% of paddy cultivation areas, whereas only approximately 25% is in East Malaysia: Sabah and Sarawak.

In Peninsular Malaysia, 12 main areas had been categorized by DOA in 2019 as granary areas. These granary areas are referring as the main rice production area with more than 4000ha of irrigate scheme in Malaysia（Rahmat et al., 2019. They are Muda Agricultural Development Authority (MADA), Kemubu Agricultural Development Authority (KADA), and Integrated Agricultural Development Area (IADA) in Kerian – Sungai Manik (IADA Kerian), Barat Laut Selangor (IADA BLS), Pulau Pinang (IADA Pulau Pinang), Seberang Perak (IADA Seberang Perak), Northern Terengganu (IADA KETARA), Kemasin Semerak (IADA Kemasin Semerak), Pekan (IADA Pekan), Rompin (IADA Rompin), Kota Belud (IADA Kota Belud), and lastly, Batang Lupar (IADA Batang Lupar).

## 3. Paddy Production Challenges

Yield whether it pertains to quantity or quality, is the only priority of farmers, and it is always a crucial aspect to be considered for any professionals that venture into paddy production. Associated with that, paddy production is susceptible to both abiotic and biotic stress. The challenges are as follows: -

a. **Climate Change**
Many studies revealed that paddy production is highly vulnerable to environmental changes (FAO, 2008; Deressa & Hassan, 2009; Vaghefi et. al., 2011). Likewise, the reduction of water availability and salinization, increment in temperature, and alteration of weather events arose as signs of climate changes, and these events may be contributing to the yield reduction and increment in the occurrence of pests and diseases (Siwar et al., 2019; Chamhuri et al., 2009; Alam et al., 2009). Aside from that, Roslin & Abu K. (2009) revealed that global warming will lead to a decrease in agricultural production by 1.2% to 5.5% in Malaysia.

b. **Soil Quality Degradation**
Various studies revealed that intensive and continuous paddy cultivation promotes the deterioration of topsoil quality via promoting soil compaction and reducing soil microbial biomass, soil nutrient availability, and soil physiochemical quality (Wei et al., 2022; Pulleman et al., 2000; Hamza & Anderson, 2005; Scott et al., 1994; Ozgoz et al., 2013). The heavy machinery used during cultivation practices such as soil preparation, the long-term anaerobic condition of the field, and intensive chemical fertilizer application are parts of the factors that contribute to soil quality degradation. It is important to note that rice yield is closely dependent on soil performance.

c. **Insect Pest Problem**
The insect rice pests are reported causing serious infestation in Malaysia, and some caused outbreaks in Malaysia, but all started as minor pests and then evolved into major pests (Nik Mohd Noor, 2012; Dale, 1994; Barrion, 2009). Several studies reported the damage of the infestation is caused during their feeding activities and some are the vectors for rice viruses while holding great potential to destroy the whole field (Chen & Chiu, 1981; Bhatti, 1995; Ooi & Yazid, 1982; Hafeez et al., 2010).

Noor Ainon (2019) reported that rice stem borer is now a serious insect pest in Peninsular Malaysia, and there are several outbreaks had been recorded since 2017, and published in several local papers such as Berita Harian, Harian Metro, and Sinar Harian (Anirul, 2021; Hidayah, 2021; Izzatul, 2021). Additionally, the infestation of rice stem borer had affected 70% and above of the farmers' income and production, while accounting for more than one-fourth of the yield loss and a record of more than 1000 hectares of infestation area in Seberang Perak, Malaysia.(Noor Anion, 2019; Noorazura, 2019; Krishnaiah & Varma, 2015).

## 4. Major Rice Pests in Malaysia

The rice pests exist as old as the paddy started to be cultivated, but managing these rice pests seems to be increasingly challenging over decades with more frequent and complex changes among the pests. These pests included insect pests such as the arthropod pest and stem-boring insects including Chilo spp., Scirpophaga Spp., and Sesamia spp. which attack rice plants at every stage of the growing process (Edde, 2022). Associated with that, the abundance and richness of these important rice pests differ from planting seasons, location, and paddy growth stage (Yaakop et al., 2020).

Monoculture in paddy is a cropping strategy that had been adopted around the world including Malaysia, in which the rice pests' natural enemies are low density, and the system lacks ecological variety and diversity, which is contributing to the pest issues (Wei et al., 2022; Hagen & Hale, 1974). Additionally, the modernization of the agricultural practices that promote monoculture is limiting the predatory insects' activities in the field, while the prolonged and continuous rice cultivation has created a conducive environment for the insect pest. Furthermore, Khan (2013) reported that the climate in Malaysia, which is warm and humid is favorable for insect pests and diseases to multiply rapidly, meanwhile, many studies revealed that increments in temperature, and alterations of weather events arose as signs of climate changes, and these events may be contributing to the yield reduction and increment in the occurrence of pests and diseases (Chamhuri et al., 2009; Chamhuri & Abdul Quasem, 2009).

Additionally, it is worth mentioning the importance of insects' abundance in the cultivation system. Svanback (2019) emphasized the increment in the abundance of insects is promoting competition interspecifically, interspecifically, and prey predatory. For instance, most rice pests are engaging in interspecific competition, in which competition across species over the same resources, likewise, most of the lepidopteran rice pests share the same food source and attach the paddy stem while causing declining paddy yield. Thus, promoting ecosystem health and creating a healthy and diverse abundance of insects in the system is vital, and this may prevent the outbreak or emergence of epidemic species in the future.

There are more than 150 insect species are found and revealed in Malaysia, but only a few have become significant rice pests (Yunus & Ho, 1980; Yunus & Balasubramanian, 1981). According to Yasumatsu and Tan (1981), there are sufficient populations of predatory and parasitic natural enemies to suppress the rice insect pest population. However, the exploitation of natural biocontrol agents had been limited due to the indiscriminate chemical pesticide applications Thus, the rice insect pest's population become uncontrollable, and major pest outbreaks occurred while causing massive yield loss (Badrulhadza et al., 2006).

### a. Hoppers

Rice plant hoppers (Order: Hemiptera) are the most important rice insect pests across South and Southeast Asia countries such as Malaysia, China, Japan, and the Republic of Korea, in the areas that practiced intensive rice cultivation (Pathak & Khan, 1994; Konda & Chandar, 2022; Atiqah, 2021). As disclosed in various studies, there are a few species of rice hoppers that are serious pests, and they are as followed: -

- Brown Plant Hopper (*Nilaparvata lugens*)
- Green LeafHopper (*Nephotettix* spp.)
- Whitebacked Plant Hopper (*Sogotella furcifera*)

The abundance of rice planthoppers is reported to be imputed to environmental temperature, humidity, availability of foods, and the balance of the rice ecosystems. Associated with that, these species mentioned are more preferability found in lowland, highly nitrogenous-fertilized, and highly chemical-pesticide-depended rice fields. The presence of these rice planthoppers mentioned had been reported to cause complete loss of yield via direct feeding damage or act as the rice viral disease's vectors such as Rice Grassy Stunt Virus (RGSV), Rice Tungro Spherical Virus (RTSV) and Rice Ragged Stunt Virus (RRSV) (while feeding on the rice plants' fluid (Nik, Mohd Noor, 2012; Chen & Chiu, 1981; Pathak & Khan, 1994).

The symptom of rice planthopper infestation is known as hopper burn which showed circular patches in the field, which started with the outer layer of the leaves drying up and then followed by the whole plant. the plants turn yellowish and eventually lead to death. The damage of the planthoppers is applied during oviposition and their exploratory feeding while they pluck in their feeding sheaths into the xylem, meanwhile, the open wounds and sticky fluid excreted encourage fungal and bacterial infection (Pathak & Khan, 1994; Bisen et al., 2019).

**b) Rice Stem Borers**

Rice stem borers (Order: Lepidoptera) is the most important pests among all, in which they infest paddy in every growing stage with annual damage up to 10% and more than 60% during occasional outbreaks (Noor Ainon, 2019; Suharto & Usyati, 2005; Yaakop et al., 2020). In Asia including Malaysia, the most serious and destructive rice stem borers are from the family of Pyralidae and Noctuidae, and 4 main species are as below:

- Yellow Stem Borer (*Scirphophaga incertulas*)
- Striped Stem Borer (*Chilo suppressalis*)
- Pink Borer (*Sesamia inferens*)
- Dark Headed Stem Borer (*Chilo polychrysus*)

The pyralidae borers (*S. incertulas, C. polychrysus* and *C. supperesssalis*) are documented as highly host specific, while the noctuidae borers (*S. inferens*) and are mostly polyphagous and the degree of damage is ruinous and occasionally resulted in economic loss respectively (Ooi, 2015; Soundararajan & Katti, 2018; Pathak & Khan, 1994). The destructive stage of these stem borers is the larvae stage, while the larvae bore and feed in the paddy stems and cause the symptoms of deadhead (DH) and whitehead (WH) depending on the paddy growth stage when the infestation happens (Shamik, 2020; Casida & Quistad, 1998).

**b. Rice Leaf Folder**

Rice leaf folder is also known as *Cnaphalocrosis medinalis* (Order: Lepidoptera; Family: Pyralidae) is widely distributed in Asia countries including Malaysia, and *C. medinalis* is a common sole leaf folder pest found in the lowland paddy field (Pathak & Khan, 1994). *C. medinalis* population shares similar preferences in the growth environment, and the population is attributed to the high humidity, rainfall, and highly indiscriminate use of nitrogen fertilizer (Rupashree, 2020).

The crucial phase of *C. medinalis* infestation is during the larvae phase. The symptom of rice leaf folders infestation is at the leaf, where many folded leaves with white stripes can be found in scorched fields, and it is observable that the leaf margins will be stitched together, and form longitudinally leaves, followed by the feeding activities of the larvae on the green mesophyll tissues. Additionally, the fecal matter or eggs in ovoid shape is observable when the infestation happens during the vegetative stage and flowering stage respectively (Bhatti, 1995; Bisen et al., 2019). Moreover, *C. medinalis* had once reported to cause an outbreak in Sekinchan, Malaysia 20 years ago, and to date, the potential of an outbreak should not be underestimated (Ooi & Yazid, 1982; Ooi, 2015).

**c. Rice Ear Bug**

Rice ear bug or known as *Leptocorisa oratorius* (Order: Hemiptera; Family: Alydidae) is one of the serious rice pests and dominant *Leptocorisa* species found in Asia countries, especially rainfed lowland paddy fields (Rzali et al, 2015; Litsiger, 2015; NorJasmin & Izzati, 2022). Aside from that, the abundance of *L. oratorius* fluctuates along the temperature and humidity of the field. Likewise, the conducive environment to population growth is around 27 – 28 °C with frequent drizzling during the end of the rainy season and starting to decline drastically at the start of dry months (Pathak & Khan, 1994).

The crucial stage of *L. oratorius* is adults and nymphs, which both feed on grain sap by piercing through the rice spikelet and feeding on the ovary. The feeding activity results in symptoms of brown spots on the pierced sites, seed discoloration due to the promotion of common fungi and bacteria infection, and whitehead (WH) when *L. oratorius* feeds on pre-flowering spikelet (Singh et al., 2017; Van der Goot, 1949; Van Den Berg & Seohardi, 2000). Besides attacking the grains, *L. oratorius* also feeds on leaves and the panicle and leads to deflorations (Usmani et al., 2012). In literature prior to 2014, the damage of *L. oratorius* has been recorded to contribute yield reduction of up to 30%, and there is no outbreak history yet to report in Malaysia (Tiwari et al., 2014).

**5. Taxonomy and Morphology of S. Incertulas**

Yellow stem borer (YSB) is also known as *Scirpophaga incertulas* (Sym: *Chilo incertulas* Walker) from the Lepidoptera order and Pyralidae family. *S. incertulas* is a monophagous pest that only feeds on paddy, and it is found in deepwater rice fields where the environment is continuously flooding (Shweta & Chandra, 2017).

Each egg mass of *S. incertulas* contains more than 80 eggs while having the capability to oviposit 3 times when they are mature. The eggs are covered with pale orange-brown velvety hairs from the anal tufts of the female moths, and they are mostly found at the leaf blade tips (Panigrahi & Rajamani, 2008; Pathak & Khan, 1994). Interestingly, Yhone et al. (2019) and Yunus et al. (2011) reported that the fine orange-brown hairs were from the female *S. incertulas* abdomen, and these fine hairs loosed when ovipositing and do not grow back on post-oviposition, while serving a protection purpose on the eggs.

Further, according to Krishi et al. (2010), Kharif (2005), and Kharif (2006), there are generally 5 larvae instar in *S. incertulas*, where the early-stage larvae will bore into the leaf sheath and result in longitudinal yellowish-white blotches, and infiltrates the stems, and feed on the inner cell wall from the pith. During the pupa stage, *S. incertulas* forms a white silk cocoon that contains up to 3 water-tight membranes near the water surface on the tiller (Puttarudriah, 1946; Satya, 2018).
The female and male adult moth of *S.incertulas* has a wingspan of 34 mm and 18-22mm respectively. The female *S. incertulas* has a distinct color that ranges from pale to yellowish with a pair of forewings associated with a pair of distinct black dots at the center of the forewings, whereas the male has a drab appearance with the presence of black specks on the forewings (Panigrahi & Rajamani, 2008).

The complete life cycle of *S. incertulas* is within 35 to 70 days depending on the climatic factors, which the hatching of eggs will take from 5 to 10 days, followed by 20 to 40 days of fully grown larva formation and turning into pupa for 6 to 12 days before metamorphosis into the adult (Samiksha, n.d.)

## 6. Damage of *S. incertulas*

*Sicrpophaga. Incertulas* had been recorded with an increasing trend in richness across the vegetative until the maturation of the paddy growth stage, while the flooding area with less moisture stress, stem elongation, and lower temperatures contributed to higher borer pest activity in paddy fields (Catling et al., 1984; Yaakop et al., 2020). Besides that, damage to yellow stem borers had been found in various growth phases of paddy cultivation from seedlings to mature rice (Hamsien et al., 2020).

Various studies revealed that the rice stem borers infestation shared similar symptoms on the paddy plants by showing the white head (WH) symptom [Figure 2.3], which caused the central tiller to dry off, and deadheart (DH) [Figure 2.2], in which the grain became empty, unfilled, chaffy, and whitish in color (Muralidharan & Pasalu, 2006; Shamil, 2020). These two symptoms happened differently depending on the growth stage of the paddy when the infestation happened. During the vegetative phase of the paddy, the DH symptom is formed when the larvae feed upon the tillers and resulting in the drying of the central tillers or also known as dead hearts. On the other hand, if the infestation happens during the reproductive stage, the feeding activities of the larvae will damage the stem and prevent the transportation of nutrients from root to leaf and resulting in deformation or unfilled panicle or grain, and causing whitehead symptoms (Bandong & Litsinger, 2005; Maralidharan & Pasalu, 2006; Letsinger, 2009).

There are relatively few studies that reported that the infestation severity is related to the growth stage of the paddy plants in terms of yield. The severity and impact of rice stem borer infestation at the vegetative stage is lower than at the reproductive stage and will not directly affect the yield as paddy plants are still able to recover after the injury. However, the impact of infestation at the reproductive phase is causing yield loss proportionally to the WH incidence with the yield loss rate at the range of 1% to 3% (Pallavi et al., 2017; Rubia et al., 1990; Suharto & Usyati, 2005).

In 2021, Izzatul reported that approximately 6000 hectares of paddy in IADA BLS, and more than 1500 locations in Sungai Pangan and Bagan Terap area had been infested severely by the rice stem borer. and infestation had reached a high peak of 70% coverage around Simpang Lima, Kuala Selangor. Thus, to manage the rice stem borer before infestation, GoM allocated RM 1 million to tackle this issue.

## 7. *S. Incertulas* Pest Control Management

The symptoms of infestation of rice stem borers are shown during the late infestation stage. It is hard to detect at the early stage of infestation, thus, the stem borers must be controlled prior the infestation happening to secure the yield and prevent uncontrollable circumstances [4].

Aside from that, several studies revealed the cultural methods that adopt field draining, regular weed control, delayed flooding in the field, and early planting to avoid the life cycle of stem borers are also common to apply in the field to control the population of rice stem borers (Stout et al., 2009; Tindal et al., 2005; Hesler et al., 1992). Meanwhile, clipping the leaf tips is also one of the cultural methods to minimize the transfer of *S. incertulas* eggs to the field, as *S. incertulas* has an oviposition behavior of laying the egg sat the leaf blade’s tip (Pathak & Khan, 1994).

Additionally, the adoption of mechanical control in managing the *S. incertulas* population is performed via any hands-on technique, devices, and natural ingredients to promote the protective barrier between pests and host plants (David & Pat, 2017). For instance, the application of pheromone or synthetic pheromone trap is reported to contribute towards the population reduction of stem borers by attracting the male adult stem borers and disturbing reproductive activities (Weinzierl et al., 2012; Chen & Klien, 2012). Aside from that, the light trap is also one of the mechanical control methods that is used to lure stem borers and monitor them by counting the number of adult moths, and if the number exceeds the economical threshold level, further action should be carried out (Baehaki, 2017). However, the mechanical control methods mentioned are not commonly practiced in Malaysia paddy field.

The front-line weapon to control the stem borer infestation is still chemical insecticides (Bhagat et al., 2021). However, Chelliah & Bharathi (1994) raised the negative impacts of insecticide application such as environmental contamination, the hazard to farmers' and consumers' health, pest resurgence, and other. Cheng et al. (2010) reported that the prolonged and high application of insecticides in the paddy field had promoted the development of high resistance of the stem borers towards the insecticides and resulted in lower insecticide efficacy in controlling the population. Also, several studies have highlighted that the exploitation of insecticide applications killed the natural enemies and predators in the paddy field contributing to the outbreaks and infestation (Mohd Khari & Ab Hamid, 2022; Bhagat et al., 2021).

Aside from the chemical management approach, biological control can also be applied to regulate the population of *S. incertulas* via natural enemies' preservation and conservation (Ardestani, 2020). There are various of parasitoids that are present in the paddy fields such as *Tetrastichus shcoenobii, Trichogramma japanicum and Telenomous rowani*. These parasitoids are known as egg parasitoids that can attack *S. incertulas* eggs and regulate the population (Kyaw, 2020). Additionally, creating a conducive environment and breeding ground for insect predators to create a healthy ecosystem is also one of the biological methods. Many studies have discovered that growing flowering plants (e.g., *Lantana camara*), and minimizing the chemical pesticide application can promote the paddy field biodiversity balance while reducing the population of rice stem borers (Kyaw, 2020; Jamian, 2017)

James (2017) emphasized the need for and importance of integrating the control strategies that complement each other to develop a more sustainable crop production. Additionally, Hamsien et al. (2020) stated that integrated pest management (IPM) programs are introduced to reduce the dependency on chemical usage. The combination of cultural, mechanical biological, and chemical control approaches is the combination found in IPM and it served the goals of being cost-effective and environmentally friendly (Heinrichs, 1994; Zalon, 2010; Horgan, 2017).

## 8. Vetiver Grass as an Agroecological Tools

Vetiver grass, scientifically known as *Vetiveria zizanioides* (Syn: *Chrysopogon zizanioides*; Family: Poaceae), originated from India and is widely distributed in Southeast Asia, Africa, and other subtropical regions. Since its introduction to the southern provinces of China in 1988, *V. zizanioides* has become extensively prevalent [10].

The utilization of *V. zizanioides* has been studied and commonly adopted to improve soil fertility, prevent soil erosion, engage in phytoremediation, and rehabilitate contaminated water [11]. This is attributed to the abundant, strong tensile strength, and vertical growing pattern of *V. zizanioides* roots, which can extend up to 7m in length after three years of planting without interfering with other crops due to very few lateral surface roots [12,13].

Vetiver grass is employed as a tool in ecological engineering, sustainability, and integrated pest management (IPM) strategies by maintaining graminaceous plants around the rice field ecosystem [14,15]. It serves as a trap plant in cultivation systems, as defined by Hokkanen [16], attracting insects or other organisms to protect target plants from pest infestation or concentrate pests to certain parts of the field where they can be easily controlled and destroyed.

There are generally three types of trap plants and vetiver grass is categorized as a lethal trap plant or a dead-end trap plant, possessing a strong attraction for pest species to oviposit but causing lethal effects once adults or juveniles feed on the plants [17]. Various literature documents that Lepidopteran pests exhibit relatively high oviposition preferences on lethal trap plants but are unable to survive [18].

The working principles of vetiver grass as a lethal trap crop are oriented around two mechanisms: the attractive mechanism and the lethal mechanism. Phytochemicals extracted from *V. zizanioides* leaves and stems contain terpenoids, which act as strong attractants and oviposition stimulants for stem borers [19]. Additionally, volatiles emitted by *V. zizanioides* are found to be similar in level to those emitted by rice. However, the nutrient content in *V. zizanioides*, such as cellulose, total sugar, amino acids, and others, is significantly lower than in rice, leading to nutritional imbalance and digestive disorders. Moreover, *V. zizanioides* contains toxic-active substances that inhibit the detoxification enzyme CarE and P450 activities, ultimately resulting in death when stem borer larvae feed on *V. zizanioides* [15,20]. Additionally, larvae fail to burrow into, fall off, and die when egg masses oviposited on *V. zizanioides* hatch due to the presence of hairs on the underside of the leaves [21].

In short, the multifaceted utility of *V. zizanoides* extends far beyond its origins in India. Its widespread adoption across Southeast Asia, Africa, and other subtropical regions underscores its efficacy in addressing various agricultural challenges. From enhancing soil fertility and preventing erosion to serving as a crucial component in integrated pest management strategies, vetiver grass stands as a testament to the principles of ecological engineering and sustainability. Its role as a lethal trap plant highlights its potential to mitigate pest infestations while minimizing reliance on chemical pesticides. Through its intricate mechanisms, including both attractive and lethal properties, vetiver grass offers a promising avenue for sustainable pest management in agricultural systems.

## 9. Oviposition Preference on Plant Choice

In total, our study identified 27 egg masses deposited on both vetiver grass and paddy plants. Analysis of the data presented in Table 1 revealed no statistically significant difference in the total number of egg masses laid and the oviposition preference across all treatment combinations between vetiver grass and the three rice varieties: MR 297, MR 269, and UPutra 1. This suggests that *S. incertulas* exhibits a uniform degree of oviposition preference across both host plants. However, it is noteworthy that the selection ratio of paddy over vetiver grass in treatment 2 (MR269) was the highest, with a ratio of 5 to 1, indicating that for every five instances of *S. incertulas* depositing eggs on paddy, one instance occurred on vetiver grass.

Previous research, as exemplified by Lu *et al.* (2015) in their study on *Chilo suppressalis*, suggested that the volatiles emitted by *V. zizanioides* influence the oviposition behavior of stem borers, potentially making it a preferred host. However, our findings did not observe a stronger attraction of *S. incertulas* to vetiver grass. This discrepancy may be attributed to differences in the feeding habits between *Chilo suppressalis*, a polyphagous stem borer, and *S. incertulas*, a monophagous stem borer, despite both belonging to the Pyralidae family (Jiang et al., 2015; Senapato & Panda, 1999; Deka & Barthakus, 2010).

Moreover, several factors may have influenced the observed oviposition patterns in our study. Lu *et al.* (2017) demonstrated that the responses of vetiver grass varied among female and male stem borers, different ages of adults, and the concentration of specific volatile chemicals. These volatile chemicals are synthesized in response to various environmental conditions, establishing ecological relationships between plants and other organisms and serving as signals for host-location and oviposition site selection (Musilova *et al.,* 2016). In line with the findings of Lu *et al.* (2015), it is plausible that the concentration of volatile compounds presents in the vetiver grass used in this study may differ from those in studies conducted in other countries, potentially contributing to the observed results.

Additionally, the presence of predatory ants, likely attracted by the scent of the eggs, may have deterred *S. incertulas* from depositing eggs directly onto the host plants. Additionally, some eggs were laid on the plastic mesh of the cage wall, potentially indicating a lack of suitable oviposition sites or environmental cues for the insects. Furthermore, a notable mortality rate ranging from 10% to 35% was observed among released *S. incertulas*, attributed to difficulties in acclimatizing to the greenhouse environment upon their arrival.

Considering these complexities and nuances, further investigation is warranted to elucidate the intricacies of *S. incertulas* oviposition behavior and its interactions with host plants and environmental factors. This understanding will be instrumental in refining pest management strategies and promoting sustainable agricultural practices in paddy cultivation systems.

**Table 1**
Number of *S. incertulas* egg oviposited on different plant

| Treatment | Number of Egg Masses on Different Host Plants | |
|---|---|---|
| | Paddy | Vetiver Grass |
| MR 297 + Vetiver Grass | 1.5 (±0.534) a | 0.5(±0.378) a |
| MR 269 + Vetiver Grass | 1.25 (±0.313) a | 0.25(±0.164) a |
| PadiU Putra 1 + Vetiver Grass | 0.75 (±0.313) a | 0.375(±0.263) a |

The mean with a similar letter between treatments is not significantly different at P≤0.05 using LSD.

## 10. Oviposition Preference on Leaf Surfaces

On the paddy plant, the result revealed an equal likelihood of the *S. incertulas* oviposit on both the abaxial and abaxial of the paddy leaves as no significant differences in the mean of the egg masses were observed (Table 2).

This result is consistent with Cheok *et al.* (2019), in the literature reviewed that *S. incertulas* acquired the same level of preference, while inconsistent with the studies documented by Shahjahan and Thornton *et al.* (2002) that report obtaining a high preference for oviposition on the abaxial surface as a better footing stage for adult moth and provided better protection against predation (Renwick & Chew, 1994; Rojas *et al.,* 2018). However, the adaxial leaf surface has significantly higher numbers of oviposited egg masses than the abaxial leaf surface on vetiver grass. Meanwhile, the number of eggs attaching on the plant surface after watering, vetiver grass has significantly lower in numbers compared to paddy, while all eggs remain attached on the oviposited site.

**Table 2**
Main effect of different on leaf surfaces of different plant host on the number of egg masses oviposited by *S. incertulas.*

| Host Plants | **Number of Egg Masses on Different Leaf Surfaces** | |
|---|---|---|
| | Adaxial | Abaxial |
| Paddy | 1.0 (±0.275) a | 1.333(±0.376) a |
| Vetiver Grass | 0.75 (±0.278) a | 0(±0) b |

Mean with a similar letter between treatment are not significantly difference at P≤0.05 using LSD.

**11. Larval Length and Head Capsule Width**

On the paddy plant, the result revealed an equal likelihood of the *S. incertulas* larvae growth feeding on the 3 rice varieties as the food source, which has no significant differences in the body length and head width measured at each time points except the larvae body length measured after 21 days of feeding was showing a significant different that are denoted by different letters a and b (Table 4.3).

Based on the resulted shown in Table 3 and the LSD calculated with the value of 0.593, there is no significant difference of larvae development between MR 269 and PadiU Putra 1. While larvae at vetiver grass does not survive from day 3 after feeding. As stated by Valentine & Suleman (2013), different rice varieties have different nutritional quality and digestibility. Associated with that theory, the result revealed MR 269 and PadiU Putra 1 shared the same beneficial nutritional quality for the development of *S. incertulas* larvae at each time point, while MR 297 has higher nutritional quality among the food sources used in this study, that promote faster and larger growth in terms of body length which had been expressed in the late instar of *S. incertulas* larvae.

Besides that, among the food sources tested, namely MR 297, MR 269, PadiU Putra 1, and vetiver grass in this study, it is observed that larvae fed with MR 297, MR 269, and PadiU Putra 1 were able to survive and showed growth throughout the experimental period. However, Vetiver Grass did not support larval survival, as indicated by the absence of measurements for body length and head width.

The factors contributed to the failure of *S. incertulas* larvae survival feeding on vetiver grass may be due to vetiver grass toxic-active substance that can caused lethal effect on the larvae that react consistence to the larvae of *Chilo supressalis,* which had been reported in Lu *et al.* (2017). Secondly, the nutritional content in vetiver grass is insufficient for the growth of the larvae and lead nutritional imbalance and death.

In short, based on Table 3, the result suggested that the rice varieties: MR 297, MR 269 and PadiU Putra are suitable food sources to support the development of *S. incertulas* larvae, while the vetiver grass performed its lethal mechanism that killed the larvae when feeding on it.

**Table 3**
Main effect of different food sources on the larval length and head capsule width of S. incertulas after 7 days, 14 days and 21 days of feeding

| Plant | *S. incertulas* Larvae Size (mean ± stdv, mm) | | | | | |
|---|---|---|---|---|---|---|
| | 7 Days after Feeding | | 14 Days After Feeding | | 21 Days After Feeding | |
| | Body Length | Head Width | Body Length | Head Width | Body Length | Head Width |
| MR 297 | 3.48±0.29 a | 0.38±0.02a | 9.42±0.50a | 0.70±0.02a | 18.05±0.26a | 0.81 ±0.04a |
| MR 269 | 3.52±0.12 a | 0.36±0.04a | 9.42±0.36a | 0.68±0.04a | 17.18±0.64b | 0.79 ±0.02a |
| PadiU Putra 1 | 3.73±0.15 a | 0.41±0.01a | 9.57±0.26a | 0.72±0.02a | 17.40±0.37b | 0.79 ±0.02a |
| Vetiver Grass | - | - | - | - | - | - |

Mean with a similar letter between food sources is not significantly different at P≤0.05 using LSD.

## 6. Conclusion

In our investigation, we observed no significant disparity in the oviposition preference of *S. incertulas* between vetiver grass and three paddy varieties (MR 297, MR 269, and PadiU Putra 1), indicating an equivalent attractiveness of both substrates. Furthermore, this preference was consistent across the leaf surfaces of these plants. Despite the similar attraction exerted by vetiver grass and paddy on *S. incertulas*, no viable populations of the pest were found on vetiver grass after feeding.

Notably, however, other rice stem borer species, such as *Chilo suppressalis* and *Sesamia inferens*, displayed a notable preference for oviposition on vetiver grass (Zhang et al., 2009). Given the lethal and attractive mechanisms of vetiver grass compared to paddy for *S. incertulas* as an oviposition site, it remains a promising tool in managing *S. incertulas* and other stem borer species in paddy cultivation systems. Therefore, further investigation is warranted to assess the efficacy and potential adoption of vetiver plants in cultivation systems, with a particular focus on elucidating their insecticidal properties for potential integration into biopesticides.

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