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Review

Sustainable Management Strategies for Rice Leaffolder, *Cnaphalocrocis medinalis* (Guenée): Progress and Prospects

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Abstract: The rice leaffolder, *Cnaphalocrocis medinalis* (Guenée), is a major migratory insect pest in paddy fields that damages rice by folding and feeding on leaves, causing chlorophyll loss and resulting in significant yield losses when its population density exceeds an economic threshold. Sustainable pest management requires 'green plant protection' solutions. Advances in science and technology have introduced numerous green methods for sustainable management of the rice leaffolder. This paper reviews recent research advancements in rice leaffolder management, such as ecological regulation, healthy cultivation, behavioral regulation, biological control, and rational insecticide application. Based on accurate monitoring and early warning systems, rice leaffolder management can incorporate comprehensive green control products, green control technologies, and control modes. This paper provides prospects for discussing the future of rice leaffolder management, achieving sustainable management of the rice leaffolder, and ensuring rice production safety.

Key words: *Cnaphalocrocis medinalis*; green control; rice; pest management

Rice (*Oryza sativa* L.) is a critical global grain crop and serves as a staple for nearly half of the world's population. In 2022, the rice planting area in China reached 29.45 million hectares (National Bureau of Statistics of China, 2023). However, rice production is challenged by diseases and insect pests throughout the entire growth cycle. The rice leaffolder, *Cnaphalocrocis medinalis* (Guenée), one of the important rice insect pests in China, Japan, Korea, Vietnam, Thailand, the Philippines, and other Asian countries, damages rice plants by folding and feeding on rice leaves, resulting in chlorophyll loss (Yang et al, 2015). It was listed in the List of Class I Crop Diseases and Insect Pests of China by the Ministry of Agriculture and Rural Affairs in 2023 due to its heavy damage in China (Ministry of Agriculture and Rural Affairs, PRC, 2023). From 2013 to 2022, the average annual occurrence area of rice leaffolders in China was 14 million hectares, leading to an annual loss of 350 700 t, and the mitigated annual loss reached 3 670 400 t (Zhuo et al, 2024).

For a long time, the control of *C. medinalis* relied on chemical insecticides. However, the abuse and misuse of chemicals can result in a variety of undesirable consequences, including environmental pollution and insect resistance. With the continual promotion of the concept of green development, the Chinese government explores and implements green control measures to avoid *C. medinalis* damage under the supervision of the plant protection policy of 'prevention first and comprehensive management'. Furthermore, the proposal of 'reductions in chemicals' in China encourages the use of non-chemical pest management approaches in paddy fields. In recent years, research and the application of sustainable or green management measures have

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increased in China. A schematic diagram of sustainable management strategies for *C. medinalis* is shown in Fig. 1. Sustainable management strategies for *C. medinalis* involve three levels: (i) fundamental measures, which include ecological regulation and healthy cultivation, ensuring ecosystem stability and increasing the control capacity of the ecosystem, and plant resistance or tolerance; (ii) conventional green control measures, including behavioral regulation and biological control, primarily reducing the population of adults or larvae; and (iii) emergent measures, which involve rational insecticide application to avoid significant damage to rice plants. The coordinated application of measures will create a sustainable rice leaffolder management system, effectively address the rice leaffolder damage, and keep the rice leaffolder population below the economic threshold. This review summarizes the latest research progress in sustainable management technologies for *C. medinalis* from the perspectives of ecological regulation, healthy cultivation, behavioral regulation, biological control, and rational insecticide application, and discusses the prospects to provide a theoretical basis and practical guidance for the effective control of the rice leaffolder.

Ecological regulation

Ecological regulation of pests, as an advanced strategy for pest management, aims to build an economic, handy, and effective ecological engineering technology system that controls pests below the ecological economic threshold level through control and regulation processes accomplished by incorporating ecological regulatory technologies and other means, such as modern biotechnology, agricultural control, biological control, physical and chemical attracting technology, and rational insecticide application, based on the principle of 'prevention first, making ecology a priority, using integrated management and precise implementation' (Ge, 2020). Ecological regulation is a strategy for ecosystems to achieve self-regulation through environmental improvement (Liu et al, 2024). A similar concept on the application of ecological regulation is ecological engineering. Odum (1962) coined the term 'ecological engineering' to refer to the artificial control of small ecosystem components in order to manage ecosystems driven by natural forces, and it later came to mean the systematic design of ecosystems to serve humans and nature. Ma (1983, 1985) proposed that ecological engineering simulates the principle of the ecosystem and adheres to the production process system. Ecological engineering is a human activity that alters the environment by employing ecological principles (Gurr et al, 2004). It is a useful conceptual framework for considering ways to manipulate ecosystems that are beneficial to natural enemies but detrimental to insect pests, using ecological methods focusing on habitat manipulation, biodiversity, multitrophic interactions, and so on (Gurr et al, 2003; Nicholls and Altieri, 2003; Selvam et al, 2020). Ecological engineering technology for insect pest management is a critical component of green management technology, which falls under the area of ecological regulation, and it also combines other

Fig. 1. Schematic diagram of sustainable management strategies for *Cnaphalocrocis medinalis*.

measures to manage species abundance such as trapping pests or releasing natural enemies. Rice insect pest control using ecological engineering technology mainly aims to design pest control measures, conduct artificial design at the ecological landscape level, balance biodiversity needs, and improve the service function of the ecosystem based on the relationship between pests and natural enemies (Lu et al, 2015; Zhu et al, 2022). A generalized sense of ecological engineering techniques for rice pest management includes a narrow sense of ecological engineering techniques and supporting techniques for increasing the efficiency of ecological engineering techniques. The former is to improve the ecosystem services of pest control by ecological approaches, while the latter includes means that operate by other mechanisms (such as releasing natural enemies and applying biopesticides) or that are implemented for wider, production-related issues (such as co-culture) (Zhu et al, 2022). This technique has been listed as the main technology by the Ministry of Agriculture and Rural Affairs of China for many years, and it has been widely promoted and applied in rice-planting regions across China. Here, we conclude ecological regulation strategies that would facilitate the ecosystem to self-regulate and sustain high species abundance of natural enemies and low insect pest populations, including rice leaffolders, in the paddy fields. Below are the two main strategies of ecological regulation for rice leaffolder management and the overall contribution to the restoration of rice ecosystem services (Fig. 2).

Maintaining or increasing biodiversity of natural enemies

Natural enemies are an important part of the rice field ecosystem, where their diversity serves as a key indicator of ecosystem stability and potential control ability against insect pests. The natural enemies of rice leaffolders are mainly parasitoids and predators. Parasitoids of rice leaffolder are distributed in various rice environments, including 9%–13% of dryland, 5%–61% of rain fed wetlands, and 7%–33% of irrigated wetlands (Litsinger et al, 1987). Gurr et al (2012) summarized the status of the parasitic natural enemies of rice leaffolders. Most of the parasitic natural enemies are Hymenoptera (91 species in 12 families) and Diptera (14 species in 3 families). The predatory natural enemies of rice leaffolders are frogs, dragonflies, spiders, rove beetles, carabid beetles, and others (Zhang and Huang, 2000). The increased biodiversity of natural enemies in paddy fields can benefit the control of rice leaffolders. Protecting or increasing the natural enemy biodiversity of insect pests is mainly achieved through the following aspects:

(i) Rational utilization of non-paddy field habitats to protect natural enemies. Non-paddy fields, such as ridges, ditches, and mechanized roadsides, can provide homes for natural enemies of pests in paddy fields. The rational utilization of non-paddy field habitats is critical to preserving the natural enemies of rice pests. Zhou et al (2011) reported that soybean (*Glycine max*) and sesame (*Sesamum indicum*) planting on ridges under conventional management have a beneficial effect on the protection of arthropod communities in rice fields. Predators frequently migrate between paddy and non-paddy field habitats, and the number of predators migrating from non-paddy habitats to paddy fields is 1.1–2.7 times greater than vice versa (Liu et al, 1999). Planting sesame along rice fields can boost the survival rate of parasitic natural enemies like *Trichogramma chilonis*, which contributes to the management of Lepidoptera pests in rice fields (Zhu et al, 2015). Gurr et al (2016) believed that growing nectar plants along the field would help reduce the rice leaffolder population by increasing the function of the natural enemies. The arthropod community over-wintering in the ridge and field weed habitats is relatively stable, with a higher diversity index and evenness index of the community (Zhang et al,

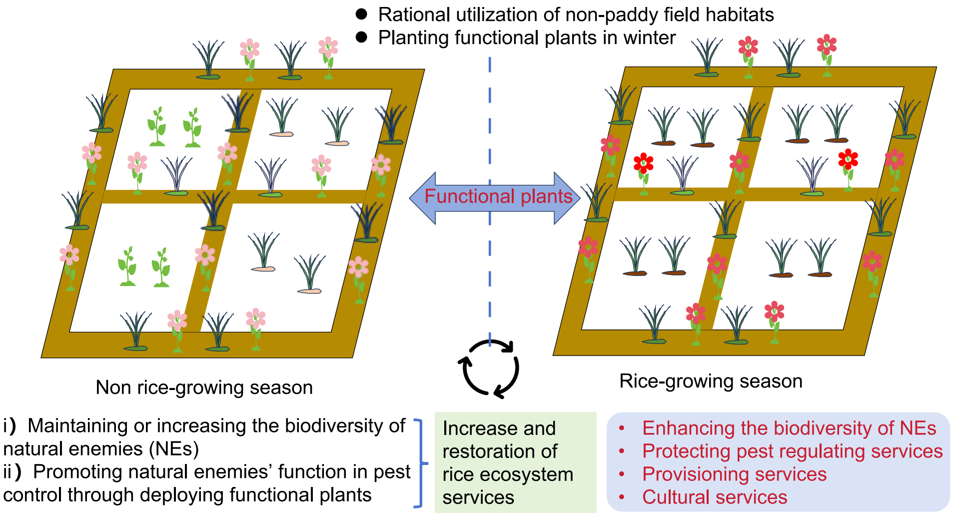

Fig. 2. Schematic diagram on ecological regulation strategies for *Cnaphalocrocis medinalis* management.

2010). Li et al (2004) surveyed 184 species of natural enemies in the weed environments around the paddy fields, including 71 predatory spiders, 31 predatory insects, and 82 parasitic natural enemies. More parasitic natural enemies spread from soybean to paddy field habitats than from maize (*Zea mays*), and the parasitism rates of rice pest eggs and larvae in paddy fields with soybean ridge are higher than in fields without soybean, with egg and larval parasitism rates of rice leaffolders increasing by 2.1% and 5.7%, respectively (Ge et al, 2013a). Annual wild rice (*Zizania aquatica*) fields adjacent to rice fields, as the principal wintering location and shelter for spiders such as *Pirata subpiraticus*, may increase the number of spiders in rice fields by approximately 30%, and spider density in *Z. aquatica* fields is 4–40 times that of other habitats (Zheng et al, 2002).

(ii) Planting functional plants in winter to protect natural enemies. Following the rice harvest, natural enemies will encounter challenges such as habitat destruction, and planting winter crops or plants will help them restore habitats. Planting Chinese milkvetch (*Astragalus sinicus*) and oilseed rape (*Brassica campestris*) boosts the abundance of natural enemies in winter and early-season rice fields while not promoting insect pest populations (Luo, 2016). Tan et al (2008) discovered that growing winter vegetables contribute significantly to the biodiversity of rice fields. Spider species diversity and richness index are considerably positively correlated with the proportion of fallow land and landscape and Shannon index at specific landscape scales, but are significantly negatively correlated with the proportion of construction land (Zhong, 2022). In the winter, fields with Italian ryegrass (*Lolium multiflorum*) and weeds have more insect resources than the winter fallow field, and the proportion of Hymenoptera insects (mainly parasitic wasps) is substantially greater than that during the rice-growing season (Jia et al, 2012). As the wintering grounds for Hymenoptera, Italian ryegrass and weeds in fields might assist in pest management in the following year (Jia et al, 2012).

Promoting natural enemies' functions in pest control through deploying functional plants

Functional plants primarily include nectar plants that aid in pest management or pollinating insects, habitat plants, and bank plants that benefit natural enemies, as well as plants that attract, kill, or repel pests (Ge, 2020). A reasonable allocation of functional plants can generate an environment that is beneficial to natural enemies but unfavorable to pests, achieving the goal of conserving natural enemies while suppressing pests (Ge, 2020; Yang et al, 2020). Nectar plants may help parasitic and predatory natural enemies improve their flying and host searching abilities, as well as boost their life span, fertility, and abilities to control pests (Wang G W et al, 2014). Sesame is a plant that can supply honey to natural enemies, extending their lives and improving their capacity to eliminate insect pests (Zhu et al, 2015, 2018). The creeping woodsorrel, *Oxalis corniculata*, may effectively boost the longevity and parasitic ability of *T. chilonis*, and the flowering time is staggered from the activity time of Lepidoptera pests such as rice leaffolders, with no ecological risk (Zhao et al, 2017). Two cutgrasses, *Leersia sayanuka* and *Leersia hexandra*, are able to conserve natural enemies by attracting rice leaffolders to lay eggs, which serve as hosts for natural enemies (Zheng et al, 2017). In *L. sayanuka* and *L. hexandra*, egg parasitic wasp densities can reach 1.47 and 1.42 individuals per tiller, respectively (Zheng et al, 2017).

Contributions on increase and restoration of rice ecosystem services

Strategies and measurements of ecological regulation are assembled and fused with ecological engineering technology to preserve or expand biodiversity, stimulate natural enemy reproduction, and improve control capability. A number of cases integrated technical measures including planting winter crops like Chinese milkvetch, reserving grasses in non-paddy fields, planting wild rice to regulate or protect biodiversity, planting floral plants like sesame in non-paddy fields to conserve natural enemies, and planting vetiver grass (*Chrysopogon zizanioides*) to attract and kill stem borers, supplemented by balanced fertilization technology and sex pheromone trapping technology (Chen et al, 2016; Zhu et al, 2017a, b). The implementation of ecological engineering technology can enhance the biodiversity of natural enemies in rice ecosystems. Dragonflies, long-jawed spiders (Tetragnathidae), and larval parasitic wasp populations in ecological engineering rice fields increases 1.63–8.94, 0–3.69, and 1.20–2.47 times compared with farmers' fields, respectively, and increases year by year or maintains a high level over time (Zhu et al, 2017a). Ma et al (2023) found that the spider number in ecological engineering rice fields is significantly higher than that in control fields. In another case by Zhu et al (2017b), the number of aquatic predators and neutral insects increases through ecological engineering, which is of great significance for playing the role of natural enemies at the later stages of rice growth. The practice of ecological engineering technology in Jinhua, Zhejiang Province, China, demonstrated that it increases rice ecosystem services for controlling insect pests, such as rice leaffolders and rice planthoppers (Chen et al, 2016). Experiments in many Asian countries showed that ecological engineering technology can promote the service function of farmland ecosystems, inhibit the occurrence of pests, reduce the use of chemical pesticides, and maintain yields (Gurr et al, 2016). Horgan et al (2022) indicated that ecological engineering for pest management in the Mekong Delta region of Vietnam not only supports natural enemies and restores pest-regulating services, but also increases provisioning services (production of supplementary foods) and cultural services (the aesthetic value of rice bunds) of the rice ecosystem. Many countries such as China, Vietnam, Thailand, the Philippines, and Cambodia, have implemented ecological engineering technology or ecological regulation, which reduces pesticides, strengthens agricultural growth, provides ecological and economic benefits to farmers, and supports sustainable and resilient global rice production (Gurr et al, 2016; Zhu et al, 2017a; Horgan et al, 2019; Wyckhuys et al, 2020; Sattler et al, 2021; Horgan et al, 2022, 2023; He et al, 2023).

Healthy cultivation

Application of tolerant/resistant rice varieties

Utilization of pest-resistant (tolerant) varieties is one of the most important pest management measures. At least more than 200 rice varieties or lines for tolerance/resistance against rice leaffolders have been evaluated by researchers (Li, 1995; Javvaji et al, 2021; Bairwa et al, 2023). Rice leaf morphological features (e.g., leaf type) and biochemical traits (e.g., nutritional or defensive composition) are associated with the rice tolerance against *C. medinalis* (Wang et al, 2008; Punithavalli et al, 2013a, b). Rice varieties with dark green, wide, and soft leaves are more severely damaged by *C. medinalis* than those with a light leaf color and a hard texture leaf, and rice varieties with many silicon layers in the leaf epidermis and a dense single or double row silicon chain are unsuitable for the rice leaffolder larvae feeding (Xu, 2008). The occurrence of rice leaffolders on rice cultivars with high free amino acid content is severe, while that on rice varieties with high soluble protein content is minor (Ge et al, 2013b).

Balanced fertilization

Fertilizers can provide essential nutrients for plant growth; however, excessive application of nitrogen fertilizer can boost nutrition in rice plants while also increasing pest populations such as rice leaffolders (Lu et al, 2006). Increasing nitrogen fertilizer application can improve the larval survival rate, food intake, pupal weight, adult longevity, and fecundity, as well as the rice leaffolder damage to rice (Liang et al, 1984; Dan and Chen, 1990; de Kraker et al, 2000). Balanced fertilization including reduced nitrogen, delayed nitrogen fertilization, increased potassium fertilizer, and optimized N-P-K ratio reduces rice leaffolder damage by 30.57% on average (Zheng et al, 2020a). The larval populations of rice leaffolders during the tillering and heading stages of rice in the balanced fertilization zone are lower than those in the control zone (Zheng et al, 2015). The balanced fertilization treatment on Zhongzao 39 and Yongyou 538 in Wenling, Zhejiang Province, China, significantly reduces major diseases and insect pests like rice leaffolder and rice sheath blight, with early rice and late rice having 22.28% and 73.17% lower rice leaffolder damage rates and 24.82% and 95.28% lower larval densities than the control (Huang et al, 2020). Continuous balanced fertilization maintains soil fertility and nutritional balance in rice fields and reduces rice diseases and insect pests. The three-year experiment in single-season rice in Linhai, Zhejiang Province, China shows a 16.0%–66.7% decrease in rice leaffolder damage rate (Zheng et al, 2020b). The application of silicon fertilizer can improve rice resistance to rice leaffolders by lowering food quality and conversion efficiency (Han et al, 2015), and affects the composition of rice volatiles induced by rice leaffolder feeding, attracting parasitic natural enemies (Liu et al, 2017).

Water management

Humidity has an important impact on insect growth and development. Water management can generate circumstances that prevent pest growth and minimize pest damage. Low humidity can reduce the weight of rice leaffolder eggs, cause them to shrivel, impede embryonic development, and finally result in egg death (Fang et al, 2013). High humidity in the field's microclimate promotes rice leaffolder occurrence (Rasul et al, 2019). Adjusting the field drying period, lowering the field humidity during the rice leaffolder incubation period, or filling deep water for 2–3 d during the pupation of rice leaffolders might aid in the rice leaffolder population reduction. Following early rice harvest, appropriate plowing and irrigation can reduce the density of rice leaffolder in the field, minimizing its damage to late rice (National Agricultural Technology Extension Service Center and Institute of Plant Protection, Sichuan Academy of Agricultural Sciences, 2012).

Non-spraying rice leaffolder at early stage of rice growth

Rice has a substantial natural compensatory effect following rice leaffolder feeding (Hu et al, 1993). Given the rice compensation, spraying for rice leaffolder should be avoided at the rice early growth stages. The rice variety Y Liangyou 1 demonstrates a yield improvement effect when rice leaffolder damage is less than 50% at the initial stage or less than 30% at the early stage of tillering (Shen et al, 2008). Zhang et al (2009) found yield increases in Y Liangyou 1 when there is 30% and 50% defoliation at the initial tillering stage or 30% at the tillering stage, and little yield loss when there is 15% to 30% defoliation at the jointing stage or less than 10% defoliation at the pre-rupturing stage. Similarly, 10%–70% defoliation of super hybrid rice Yongyou 8 and conventional *japonica* rice Ning 88 at the seedling and tillering stages has no effect on rice growth but improves yields, and less than 10% defoliation at the booting stage does not affect the yields (Wu J X et al, 2013). According to Tian (2013), 40% defoliation at the jointing stage can significantly boost the chlorophyll content of rice leaves. Zhang and Chen (1991) believed that the non-damaged second leaves would have a certain compensatory effect on the damaged functional leaves (flag leaves), with enhanced photosynthetic intensity, which is related to the flag leaf's damage degree and the time after the damage. Non-spraying rice leaffolders at the early stage of rice growth can also assist in protecting the natural enemies of insect pests like rice leaffolders and rice planthoppers, as well as boosting the natural control effect of natural enemies on insect pests.

Behavioral regulation

Sex pheromone trapping

Insect sex pheromones are chemical molecules released by insects to attract males for mating. Sex pheromone components of *C. medinalis* have been identified in many countries, including China (Kawazu et al, 2000, 2005; Wu J et al, 2013). Due to the attraction of sex pheromones to rice leaffolder males, sex pheromone trapping is widely utilized in rice leaffolder monitoring and control (Wu J et al, 2013). Different manufacturers' lures and traps, as well as the height and density of the trap settings, significantly influence the trap effect of rice leaffolders (Ye et al, 2017, Guo et al, 2019). The number of trapped rice leaffolders in the field with a trap bottom 20 cm below the rice canopy is 3.7–7.0 times higher than when the trap bottom is 20 cm above the rice canopy, and the recommended trap density is 15 traps per hectare considering the trapped number and the cost component (Ye et al, 2017). Wang et al (2017a) found that sex pheromone trapping reduces the rice leaffolder larvae population up to 51.4%, achieving an 80.07% leaf protection effect. The disadvantage of the sex pheromone trapping technique is that it is only effective for males and cannot trap females (Fig. 3-A). However, the implementation of sex pheromone trapping technology will also greatly minimize the usage of chemical pesticides, prevent pest resistance, and preserve natural enemies, fulfilling the purpose of sustainable pest management.

Food attractant trapping

Food attractants are volatile compounds derived from plants or fermentation of plant products that match the preferences of herbivorous pests (Cai et al, 2018; Gregg et al, 2018). They provide several benefits, including convenient use, high sensitivity, strong specificity, and attraction to both males and females (Fig. 3-B) (Gregg et al, 2018; Gao et al, 2023). Food attractants are more effective than sex pheromones, and the number of rice leaffolder females is 2.34 times that of males captured

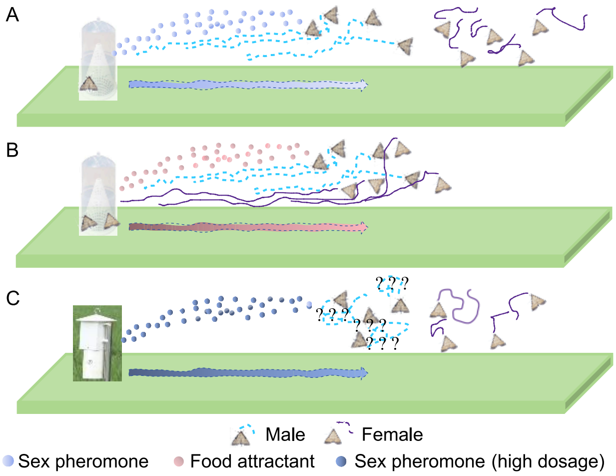

Fig. 3. Schematic diagram of behavioral regulation for *Cnaphalocrocis medinalis* management.

A, Sex pheromone trapping.
B, Food attractants.
C, Mating disruption.

by food attractant traps, with an unmated ratio of up to 96.15% (Lu et al, 2022). Zhu H et al (2021) found that food attractants can trap more rice leaffolder moths than sex pheromone traps, with similar moth peak periods as light traps and artificial sweeping. Population monitoring using food attractants can accurately represent the population dynamics of rice leaffolders in the field, with an accuracy rate of more than 85% (Zeng J et al, 2021). Yang Z X et al (2022) discovered that the rice leaffolder population decline rate is 84.21% and the leaf protection effect is 72.03% using food attractant traps, superior to that of sex pheromone traps. In recent years, food attractants have been employed to monitor and manage rice leaffolders in Hubei, Jiangsu, and Shanghai, China (Li et al, 2021; Cheng et al, 2022; Lu et al, 2022).

Mating disruption

Mating disruption, also known as mating interference, is a crucial component of behavioral regulation, resulting in a reduction in egg load or larval population through adult disorientation and mating disruption by inundating large amounts of pheromones in the field (Bakthavatsalam, 2016), plant volatiles (Wang et al, 2016), lights (van den Broeck et al, 2021), or vibrational signals (Mazzoni et al, 2019). Pheromone-mediated mating disruption is used in the rice leaffolder management (Fig. 3-C). There are two types of pheromone dispensers for pheromone-mediated mating disruption: passive dispensers and active dispensers. The release amount and time of the passive dispenser are affected by factors such as ambient temperature and wind, whereas the active dispenser can control the release time and amount of sex pheromones through the electronic mechanical dispenser system based on insect courtship and mating rhythms (Baker et al, 2016; Klassen et al, 2023). Mating disruption technology applied in paddy fields has been shown to disrupt the rice leaffolder mating with an average disrupted rate of 89.9%, resulting in a decline in the rice leaffolder population, and an increase in the parasitoid number in the treated fields due to the reduction of chemical insecticides compared with the control fields (Wang W Y et al, 2024). Wei (2021) found the control effect of the sex pheromone mating disruption technique on rice leaffolders is 72%. Xu S Z et al (2019) employed a 20% combination of rice leaffolder and rice stem borer sex pheromones to disturb rice leaffolder mating and found that it has a good effect on rice leaffolder, with a control effect of 53%–100%.

Biological control

Releasing natural enemies

Trichogramma, an important parasitic wasp of Lepidopteran eggs, has a wide range and a high parasitic rate. In recent years, *Trichogramma* has been used to control rice leaffolders on a significant scale, as large-scale breeding and release technology research into *Trichogramma* has progressed. *T. japonicum*, *T. chilonis*, *T. ostriniae*, and *T. dendrolimi* are common species of *Trichogramma* in paddy fields. The sex pheromone of rice leaffolder can attract these *Trichogramma* species within a certain concentration range (Bai et al, 2017). *T. japonicum* demonstrates superior performance on *C. medinalis* eggs compared with the other three *Trichogramma* species, with the greatest parasitic ability on different age *C. medinalis* eggs and more progeny between 20 ºC and 36 ºC, making it the most suitable *Trichogramma* candidate for controlling *C. medinalis* (Tian et al, 2017a). The southern *T. japonicum* populations prove more appropriate for the management of Lepidopteran pests such as rice leaffolders than the northern populations due to their greater performance on the parasitism rate, flight ability, and insecticide tolerance (Tian et al, 2017b). The release density of 150 000 *T. japonicum* per hectare showed a sufficient control effect on rice leaffolder (Xu et al, 2016). Wang et al (2017b) found that the release of *T. japonicum* in the field has an excellent control effect (67.09%) on rice leaffolder, with an egg parasitism rate of 69.20%. Shi et al (2023) employed *T. chilonis* to control the rice leaffolder, and the egg parasitism rate in the two experimental sites increased by 29.47% and 52.81% compared with the chemical control zone, while the rice leaffolder damage rates are 2.75% and 0.81%. Releasing *Trichogramma* is often applied to control rice leaffolder in combination with green control technologies like sex pheromone trapping and biological pesticides (Xie et al, 2019; Qiu et al, 2021). So far, China has initially established a standardized system of production and application of *Trichogramma* (Li et al, 2023). Chinese agricultural industry standard ‘Technical Regulations for Release of *Trichogramma* for Pest Control Part 1: Rice Fields’ (NY/T 3542.1–2020) and Zhejiang local standard ‘Rules for releasing *Trichogramma* for controlling the rice leaffolder, *Cnaphalocrocis medinalis* (Guenée)’ (DB33/T 2072–2017) regulate the technology of rice fields to control Lepidopteran pests such as rice leaffolder and promote the standardized application of this technology.

Biopesticides

Biopesticides refer to the types of pesticides derived from natural products, including animals, plants, microorganisms, and some minerals. Currently, the main biological insecticides used to control leaffolder are microbial pesticides, plant-derived pesticides, and agricultural antibiotics (Table 1). Examples of single-agent microbial pesticides include *Bacillus thuringiensis* (Bt), *Beauveria bassiana*, *Empedobacter brevis*, *Mamestra brassicae* nuclear polyhedrosis virus (NPV), and *Metarhizium anisopliae* CQMa421. One plant-derived pesticide is *Celastrus angulatus*. Agricultural antibiotics include abamectin, emamectin benzoate, spinosad, and spinetoram. The five mixture formulations that contain both biological pesticides, are Bt + *C. medinalis* granulovirus (CmGV), abamectin + spinosad, abamectin + Bt, spinosad + emamectin benzoate, and emamectin benzoate + Bt, and the mixture formulation of biological pesticides and chemical pesticides is mainly between agricultural antibiotics and chemicals (Bi et al, 2023).

Abamectin and emamectin benzoate are highly toxic to spiders and the green mirid bug (*Cyrtorhinus lividipennis*), and they should be used with caution in controlling rice leaffolders. The control effects on rice leaffolder after 7 and 14 d of treatment with 20% spinosad SC (300 mL/hm^2) are 72.72% and 76.99%, respectively (Guo et al, 2021). The 7-day control effects of 675 mL/hm^2 *Mamestra brassicae* NPV (2 billion PIB/mL) and 3 kg/hm^2 Bt powder (16 000 IU/mg) are both 100%, and the 15-day control efficiencies are 93.33% and 100%, respectively (Lu et al, 2020). The combination of CmGV and Bt have an obvious synergistic effect against rice leaffolders, shortening the initial infection death time by 3 d compared with CmGV alone, and increasing the infection mortality by 20.23%, with the effect period lasting over 30 d (Liu et al, 2013). The 7-day and 15-day control effects of Bt + CmGV on rice leaffolders are 83.33% and 97.85%, respectively (Lu et al, 2020). The effectiveness of biopesticides is often influenced by environmental factors such as humidity, and they should be employed at an appropriate time according to the instructions.

Symbiotic farming system

Symbiotic farming systems in paddy fields are a traditional mode of production in many Asian countries, including China. In recent years, supported by market demand and national policies, this system has developed rapidly in China. Symbiotic farming systems in paddy fields mainly include rice-duck, rice-fish, rice-turtle, and rice-frog. The symbiotic farming system in paddy fields plays an important role in pest control. Based on the system dynamics framework model analysis, if the initial egg number of the second generation of rice leaffolders and the spider density in paddy fields were 100 and 13 individuals per 100 hills, respectively, the adult rice leaffolder density could be reduced to 9 individuals per 100 hills, and the egg number of the third generation of rice leaffolders could be reduced by approximately 6.7% due to duck predatory behavior

Table 1. Biological agents registered for *Cnaphalocrocis medinalis* control in China.

Name	Source	Main group/Primary site of action	Type
Bt	*Bacillus thuringiensis*	Microbial disruptors of insect midgut membranes	Microbial single-agent
Beauveria bassiana	*B. bassiana*	Fungal agents	Microbial single-agent
Empedobacter brevis	*E. brevis*	Bacterial agents	Microbial single-agent
Mamestra brassicae nuclear polyhedrosis virus	*M. brassicae* nuclear polyhedrosis virus	Virus agents	Microbial single-agent
Metarhizium anisopliae CQMa421	*M. anisopliae*	Fungal agents	Microbial single-agent
Celastrus angulatus	*C. angulatus*	Plant-derived agents	Plant-derived pesticide
Abamectin	*Streptomyces avermitilis*	Glutamate-gated chloride channel (GluCl) allosteric modulators	Agricultural antibiotics
Emamectin benzoate	Derivant of abamectin	GluCl allosteric modulators	Agricultural antibiotics
Spinosad	*Saccharopolyspora spinosa*	Nicotinic acetyl-choline receptor (nAchR) allosteric modulators-site I	Agricultural antibiotics
Spinetoram	Modified metabolites (spinosyns) of *S. spinosa*	nAchR allosteric modulators-site I	Agricultural antibiotics
Abamectin + Bt	*S. avermitilis*, *B. thuringiensis*	Mixed action	Mixture
Abamectin + spinosad	*S. avermitilis*, *S. spinosa*	Mixed action	Mixture
Bt + *Cnaphalocrocis medinalis* granulovirus	*B. thuringiensis*, *C. medinalis* granulovirus	Mixed action	Mixture
Emamectin benzoate + Bt	Derivant of abamectin, *B. thuringiensis*	Mixed action	Mixture
Spinosad + emamectin benzoate	*S. spinosa*, derivant of abamectin	Mixed action	Mixture

Information is from Insecticide Resistance Action Committee (www.irac-online.org) and China Pesticide Information Network (www.chinapesticide.org.cn). The mixtures of biological agents and chemical agents are not listed here.

(Qin et al, 2010). Raising ducks in rice fields has good control over pests such as rice leaffolders and rice planthoppers (Huang et al, 2017; Xia, 2019; Chen S, 2021). Rice-fish can reduce the density of larvae and adults, reduce the folded leaf rate, and increase the number of tillers, the earbearing tiller percentage, the effective ear number, and the yields of rice (Ji and Chen, 2015; Wu et al, 2016). The 'fish-duck-rice' symbiotic farming system can effectively improve the predatory ability of fish, ducks, spiders, and other natural enemies in the ecosystem, thereby reducing rice pest damage (Wang et al, 2006). The rice-turtle symbiotic farming system can also effectively reduce the damage caused by migratory pests such as rice leaffolders (Cai et al, 2014). As generalist predators, frogs feed upon a variety of invertebrates and small vertebrates, many of which are considered notorious rice pests, including rice leaffolders (Khatiwada et al 2016; Propper et al, 2020). The integrated rice-frog ecosystem has a significant control effect on rice leaffolders, and achieved significant ecological and economic benefits (Yi, 2023). Rice-animal co-culture systems can reduce insect pest populations including rice leaffolders, improve soil health, and increase soil microbial community stability, maintaining high crop yields and benefiting global sustainable intensification (Cui et al, 2023).

Rational insecticide application

Principles of insecticide application

Based on monitoring the population dynamics of rice leaffolders and the damage characteristics of rice at the tillering and booting stages, rice leaffolder management should be concentrated at the booting stage, but not neglected at the tillering stage, where heavy damage may occur. If necessary, insecticides that are highly efficient, low in toxicity and low in residue should be selected to control rice leaffolders. Chemicals that are safe for natural enemies and biological pesticides should be prioritized in rice leaffolder management, whereas pyrethroids and insecticides that are banned in China should be avoided. Pesticide usage must follow all applicable national rules and regulations governing pesticide safety. Due to the increased resistance of rice leaffolders against insecticides such as chlorantraniliprole (Sun et al, 2023; Wang L et al, 2024), insecticides with different mechanisms of action and no cross-resistance should be used alternately between different locations or generations, and the use of chlorantraniliprole should be strictly controlled to delay resistance (National Agricultural Technology Extension Service Center, 2024).

Economic thresholds

Taking into account the compensation for rice leaffolder damage at the early stage of rice growth, especially the tillering stage, as well as the protection and utilization of natural enemy resources, the control threshold can be broadened at the early stage of rice growth, and the control can be abandoned at the rice early stage with only minor rice leaffolder damage (Yang et al, 2015). The control threshold is 150 larvae or new folds per 100 hills at the tillering stage and 60 larvae or new folds per 100 hills at the booting stage (NY/T 2737.1–2015). The optimal control time is from the egg's hatching peak to the early larval stage.

Chemical control coordinates with other insect pests

Chemical control measures for rice leaffolders should be coordinated with other rice pests, such as rice planthoppers and rice stem borers. Abamectin and emamectin benzoate are highly toxic against predatory natural enemies in paddy fields, such as spiders, *Cryptoptera*, and green mirid bugs, as well as parasitic natural enemies like *T. japonicum* (Li et al, 2009; Wang Y K et al, 2014; Khan, 2019; Yuan et al, 2019). Field applications of emamectin benzoate and abamectin significantly increase the brown planthopper population and reduce the field parasitism rate of *C. lividipennis* and *Anagrus nilaparvatae* (He et al, 2024). Abamectin and emamectin benzoate applications induce brown planthopper outbreaks for two reasons: they promote ovarian development and enhance brown planthopper fertility, and they reduce the natural control of brown planthoppers by natural enemies (He et al, 2024). Abamectin stress can stimulate F_1 generation proliferation of the whiteback planthopper (Cao et al, 2014). Emamectin benzoate and abamectin should be used cautiously or avoided during early rice growth stages to control rice leaffolder, thereby reducing harm to natural enemies and eventually decreasing the prevalence of rice planthoppers at the later stages. Coordinating the control of rice leaffolder and brown planthopper under certain conditions can reduce pesticide use with minimal rice yield loss (Yang, 2016). Because rice stem borers and rice leaffolders are both targets of many pesticides, coordinating their control can avoid repeated insecticide applications (National Agricultural Technology Extension Service Center, 2018).

Precise spraying technology

Spraying technology is crucial for pest control, and its effectiveness depends on the sprayer, application method, physicochemical properties of the agent, target site, and environmental conditions. Operators should choose appropriate spray techniques according to rice growth stage, weather conditions, and other criteria to achieve optimal control. Common sprayers include backpack manual sprayers, backpack motorized (electric) sprayers, stretcher motorized sprayers, self-propelled boom sprayers, and agricultural drones (unmanned aerial vehicles, UAVs) (National Agricultural Technology Extension Service Center, 2018). Research on spraying technology tailored to different sprayers and agents is helpful for the precise control of rice leaffolders. Xiao et al (2019) found that UAV-applied nanopesticides achieve a 93.35% control effect against rice leaffolders, significantly outperforming UAVs and backpack electric sprayers using conventional pesticides. UAVs with reduced dosages can effectively prevent rice leaffolder infestations (Zeng W et al, 2021). Chen et al (2021) reported that UAVs with medium spray droplets (22.5 or 30.0 L/hm^2) at 1.5 m height provide good control. Pesticide adjuvants are critical for improving spraying technology. Screening anti-drift, high-efficacy adjuvants for UAVs enhances control (Lu et al, 2019). Adjuvants synergize UAV-sprayed insecticides, and increased water volumes can reduce insecticide use by 15% (Sun et al, 2019). The National Agricultural Technology Extension Service Center (2023) issued UAV technical guidelines for rice migratory pests, including flight parameters and agent selection.

Integrated technologies for rice leaffolder management

The implementation of rice leaffolder green control technology requires an update of the control concept, that is, with the rice ecosystem and plant health as the center, to implement ecological regulation to build a stable rice paddy ecosystem and enhance its natural control ability, prioritize the use of physical/chemical trapping and biological control means, and reasonably use highly efficient, low-risk pesticides for emergency control. Variations in the ecological environment and pest occurrence across rice-producing locations necessitate the full implementation of different green control measures tailored to local requirements to form rice leaffolder green control technology (Shen et al, 2018; Xu et al, 2021; Zhang, 2021). The government promotes rice leaffolder green control technologies in conjunction with other pest green control techniques such as rice planthoppers and stemborers across diverse planting systems (Xu H X et al, 2019; Chen, 2021; Zhu F et al, 2021; Zhuo et al, 2024). The area under green management for rice pests in China expanded from 12.47 million hectares in 2019 to 15.83 million hectares in 2022, with coverage rising from 41.60% to 55.22% (Zhuo et al, 2024). Integrated green control reduces pesticide reliance (Chen et al, 2024), though some regions still exhibit fragmented implementation. Strengthening technology integration and standardization is needed.

Prospects

Green development is the most important direction for China's agricultural development, and green pest management technology plays a critical role. With the deepening of the concept of 'green plant protection', the green management technology for rice leaffolders has been continuously developed, and the application area in China has also increased, which is of great significance for the improvement of rice quality, environmental sustainability, and ecosystem stability. In recent years, research on rice leaffolders has made steady progress, which will help enhance the development and utilization of rice leaffolder green management technology.

Monitoring and early warning improvements

Accurate monitoring and early warning for rice leaffolders are crucial for their sustainable management. The precise monitoring and early warning encompass three aspects: monitoring and early warning of the quantity, characteristics, and damage caused by the *C. medinalis* population. Monitoring and early warning of population quantity and its damage reflect the occurrence and severity of rice leaffolders, which aids in determining the optimal control time for rice leaffolders (Huang et al, 2023). Bao et al (2023) established a physiological and ecological parameter estimation model for rice damaged by rice leaffolder based on hyperspectral parameters, and the SPAD estimate from the related factor estimation model has a high fit with the measured value, which provides a high and feasible estimation method for estimating the rice SPAD value under rice leaffolder damage. Using UAV multispectral images to monitor rice leaffolder damage, the distribution map of folded leaf rate derived from the construction model is generally consistent with the actual survey results (Tian et al, 2020; Guo et al, 2023). Adhikari et al (2023) employed hyperspectral remote sensing feature selection and calculated frequency band combinations using the RELIEFF algorithm and found that the selected bands 518, 661, and 731 nm achieve 81.67% accuracy in predicting rice leaffolder damage. Chen et al (2023) developed the rice leaffolder damage symptom detection system, which combines a horizontal-rotation area recommendation network and a rotation-rotating region curling neural network. This approach has an average detection rate of 73.7%, making it better suited for field surveys than the horizontal detection method. Intelligent monitoring networks improve efficiency (Zhang et al, 2023). Research on insecticidal resistance and mechanisms can help develop control tactics for rice leaffolders, leading to more precise control (Sun et al, 2023; Wang L et al, 2024). Developing and implementing new monitoring and early warning technology for rice leaffolders can enhance accuracy, clarify population characteristics, and support precise control.

New technologies and products

In recent years, the disciplines of molecular biology, omics, and materials science have rapidly developed, supporting relevant rice leaffolder research and contributing to the creation of innovative rice leaffolder management technologies and products. Advances in ecology-related research and theories have broadened the notion of ecological regulation in paddy fields, therefore stimulating the development of ecological regulation technology (Horgan et al, 2022, 2023; Zhu et al, 2022). The interaction between rice leaffolder and rice, along with rice genetic breeding, will also promote the breeding of insect-resistant rice varieties, benefiting rice leaffolder management (Zhuang et al, 2022; Li et al, 2024; Nayak et al, 2024; Zhao et al, 2024). A number of Bt insect-resistant rice varieties in China have been bred based on Bt proteins with high insecticidal activity against rice leaffolders (Chen et al, 2011; Zheng et al, 2011). However, the Bt insect-resistant rice has not been commercialized and can be used as a reserve variety against rice leaffolders. The omics study on rice leaffolders and their gut microbes has laid the foundation for the mining and application of functional genes and functional microbes of rice leaffolder in the future (Zhao et al, 2021; Yang Y J et al, 2022; Lin et al, 2024). Research on rice leaffolder selection, feeding, leaffolding, and mating behaviors, as well as the investigation of associated olfactory binding protein genes, will contribute to the creation and application of behavioral control products such as pheromones (Yang et al, 2018; Chen et al, 2022; Cheng et al, 2023a; Qian et al, 2024). The information and functions of a class of genes related to insecticidal resistance and specific physiological functions have been analyzed, which will promote the development of green control products based on specific targets (Cheng et al, 2023b; Han et al, 2023; Yang et al, 2023). Nucleic acid pesticides mainly use the dsRNA of target pests to silence the target genes by the RNAi system in the target body to achieve the purpose of plant protection (Wang et al, 2019; Niu et al, 2022). The study of the related genes of rice leaffolder will also promote the application of nucleic acid pesticides in the green management of rice leaffolders (Li et al, 2022). With the development of materials science, the research and application of nanopesticides have also increased, and many new nanopesticides with both slow release and adhesion can be transported to specific parts of plants to play an insecticidal role and improve the utilization efficiency of insecticides (Wang et al, 2019). Zhou et al (2023) found that the control effect and leaf protection effect of nanoaqueous solutions on rice leaffolders are significantly higher than those of traditional agents. Liu et al (2023) developed a high drug load of phosphate-modified cellulose/chitosan, carrying emamectin benzoate phosphate-modified cellulose microspheres and chitosan (EB-CMP @ CS) in rice growth soil, with retention capacity reaching 101.56 times that of commercial emamectin benzoate, effectively improving the development of rice pesticide absorption, and the control efficiency of the rice leaffolder is 14 times that of commercial emamectin benzoate. Ding et al (2024) developed a chlorantraniliprole nanosuspension, which has high insecticidal activity against rice leaffolder and reduces the dosage by 40% compared with the commercial suspension concentrate.

Conceptual principles for rice leaffolder sustainable management development

For a long time, rice diseases and insect pests were managed separately as single targets, and chemical control accounted for a significant portion of rice pest management. However, relatively monotonous chemical control and irrational insecticide application will lead to many negative effects, such as increased pest resistance, declined natural enemy populations, unstable ecosystem, and the loss of ecosystem service functions. Both pests and natural enemies are important parts of the ecosystem, and excessive pest elimination can lead to food web abnormalities and possibly ecosystem collapse. Moreover, the reduction of natural enemies caused by chemical control will indirectly contribute to pest resurgence. The obstinate reliance on chemical pesticides should be changed in rice leaffolder management, and overall and systematic thinking should be considered. That is, tactics should be evaluated from the perspective of the rice field ecosystem, rice plants, and crop safety. In the future practice of green management of rice pests, including rice leaffolders, the rice field ecosystem should be viewed as a whole, with plant health at the forefront. Green management technologies should be comprehensively applied to ensure rice production safety. It is fundamental to design and construct stable ecosystems to enhance biodiversity and maintain natural enemy populations. Pest control should coordinate several tactics to lower the insect population rather than completely eliminate it, with a focus on pest management measures that benefit natural enemies, ecosystems, and plants. The integration of overall and systematic thinking into rice leaffolder sustainable management will improve the level and quality of management.

Conclusions

Rice leaffolder green management should align with ecological security, plant health, and rice production safety. Rice leaffolder management should follow the 'green plant protection' concept, adhere to the 'prevention first, comprehensive management' plant protection policy, make comprehensive use of innovating green products, control technology, and equipment, as well as promote green control modes and standards for rice leaffolders on the basis of accurate monitoring, realizing sustainable management of rice leaffolders, reducing rice leaffolder damage, and ensuring the safety of food and the ecological environment.

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REFFERENCES

Adhikari B, Senapati R, Mohapatra M, et al. 2023. Detection of rice leaf folder, *Cnaphalocrocis medinalis* (Guenée) (Lepidoptera: Crambidae) infestation using ground-based hyperspectral radiometry. *Curr Sci*, **124**(8): 964-975.

Bai Q, Tian J C, Lu Y H, et al. 2017. Olfaction responses of three *Trichogramma* species to sex pheromone of *Chilo suppressalis* and *Cnaphalocrocis medinalis*. *Chin J Biol Control*, **33**(5): 584-589. (in Chinese with English abstract)

Bairwa K L, Ghoghari P D, Jena M K. 2023. Reaction of rice varieties to rice leaf folder, *Cnaphalocrocis medinalis* Guenee in South Gujarat. *Oryza*, **60**(4): 524-527.

Baker T C, Myrick A J, Park K C. 2016. Optimizing the point-source emission rates and geometries of pheromone mating disruption mega-dispensers. *J Chem Ecol*, **42**(9): 896-907.

Bakthavatsalam N. 2016. Chapter 19: Semiochemicals. *In*: Ecofriendly Pest Management for Food Security. Amsterdam, the Netherland: Elsevier: 563-611.

Bao Y X, Huang L, Guo M Q, et al. 2023. Estimation models of physiological and ecological parameters of rice damaged by *Cnaphalocrocis medinalis* under controlled field experiments and natural field experiments. *Acta Ecol Sin*, **43**(13): 5466-5479. (in Chinese with English abstract)

Bi F L, He D B, Zhu Y L, et al. 2023. Registered pesticides and application techniques for controlling rice leaf roller in China. *Agric Technol*, **43**(20): 86-91. (in Chinese with English abstract)

Cai B X, Yang F L, Xu G P, et al. 2014. Control of rice-turtle mode on the migratory insect pests in rice. *China Plant Prot*, **34**(9): 35-37. (in Chinese with English abstract)

Cai X M, Li Z Q, Pan H S, et al. 2018. Research and application of food-based attractants of herbivorous insect pests. *Chin J Biol Control*, **34**(1): 8-35. (in Chinese with English abstract)

Cao K R, Li J Q, Zhong X M, et al. 2014. Experiment on coordinated control of rice leaf roller and brown planthopper. *J Zhejiang Agric Sci*, **55**(11): 1730-1732. (in Chinese with English abstract)

Chen B C, Yang J, Zhao Q L, et al. 2021. Effects of spray factors on chlorantraniliprole sedimentation and its control effect on rice leaf roller. *China Plant Prot*, **41**(12): 57-60/72. (in Chinese with English abstract)

Chen B Y. 2021. Overview of integrated application of green control technology for rice 'two migratory pests' during the 13th Five-Year Plan period in Guilin. *China Plant Prot*, **41**(10): 91-95. (in Chinese with English abstract)

Chen G H, Zhu P Y, Zheng X S, et al. 2016. Application of ecological engineering to control rice pest technology in Jinhua. *China Plant Prot*, **36**(1): 31-36. (in Chinese with English abstract)

Chen M, Shelton A, Ye G Y. 2011. Insect-resistant genetically modified rice in China: From research to commercialization. *Annu Rev Entomol*, **56**: 81-101.

Chen P, Dai C G, Liu H, et al. 2022. Identification of key headspace volatile compounds signaling preference for rice over corn in adult females of the rice leaf folder *Cnaphalocrocis medinalis*. *J Agric Food Chem*, **70**(32): 9826-9833.

Chen S. 2021. Effect of rice-duck farming pattern on major diseases and pests occurred in rice. *South China Agric*, **15**(25): 38-40/51. (in Chinese with English abstract)

Chen T J, Wang R J, Du J M, et al. 2023. CMRD-Net: A deep learning-based *Cnaphalocrocis medinalis* damage symptom rotated detection framework for in-field survey. *Front Plant Sci*, **14**: 1180716.

Chen Y C, Zhao Y X, Tang Y T, et al. 2024. Progresses of pesticide reduction techniques and the synergistic effects on the control of rice leaffolders *Cnaphalocrocis medinalis*. *Sci Technol Rev*, **42**(6): 79-85.

Cheng J J, Chen Q H, Guo Q S, et al. 2023a. Moth sex pheromones affect interspecific competition among sympatric species and possibly population distribution by modulating pre-mating behavior. *Insect Sci*, **30**(2): 501-516.

Cheng J J, Gui J W, Yao X M, et al. 2023b. Functional identification of olfactory receptors of *Cnaphalocrocis medinalis* (Lepidoptera: Crambidae) for plant odor. *Insects*, **14**(12): 930.

Cheng J Y, Xia H X, Zhang C, et al. 2022. Preliminary study of the effect of population monitoring on *Cnaphalocrocis medinalis* using biological food attractant. *Hubei Plant Prot*, **3**: 31-33. (in Chinese with English abstract)

Cui J L, Liu H B, Wang H Y, et al. 2023. Rice-animal co-culture systems benefit global sustainable intensification. *Earth's Future*, **11**(2): e2022EF002984.

Dan J G, Chen C M. 1990. The effects of feeding condition on the growth, development, and reproduction of rice leaf roller. *J Plant Prot*, **17**: 193-199. (in Chinese with English abstract)

de Kraker J, Rabbinge R, van Huis A, et al. 2000. Impact of nitrogenous-fertilization on the population dynamics and natural control of rice leaffolders (Lep.: Pyralidae). *Int J Pest Manag*, **46**(3): 225-235.

Ding X Q, Guo L, Du Q, et al. 2024. Preparation and comprehensive evaluation of the efficacy and safety of chlorantraniliprole nanosuspension. *Toxics*, **12**(1): 78.

Fang Y S, Liao H J, Qian Q, et al. 2013. Combined effects of temperature and relative humidity on eggs of the rice leaf folder, *Cnaphalocrocis medinalis* (Lepidoptera: Pyralidae). *Acta Entomol Sin*, **56**(7): 786-791. (in Chinese with English abstract)

Gao L Y, Yan R, He W, et al. 2023. Use of food attractant to monitor and forecast population dynamics of *Cnaphalocrocis medinalis* (Lepidoptera: Pyralidae), a long-distance migratory pest. *Agronomy*, **13**(8): 2141.

Ge F. 2020. The ecological regulation and management of pests. *Chin J Appl Entomol*, **57**(1): 10-19. (in Chinese with English abstract)

Ge L Q, Hu Z W, Wu J C. 2013a. Effect of soybeans, corn and rice configurations on the biological control of pest insects. *Chin J Appl Entomol*, **50**(4): 921-927. (in Chinese with English abstract)

Ge L Q, Wang F, Wu J C. 2013b. Resistance of different rice varieties to *Cnaphalocrocis medinalis* Güenée (Lepidoptera: Pyralidae) larvae infestation. *J Yangzhou Univ: Agric Life Sci*, **34**(4): 84-88. (in Chinese with English abstract)

Gregg P C, Del Socorro A P, Landolt P J. 2018. Advances in attract-and-kill for agricultural pests: Beyond pheromones. *Annu Rev Entomol*, **63**: 453-470.

Guo C L, Gao F D, Huang X C, et al. 2019. Screening and effect evaluation of sex pheromones traps on rice leaffolder. *Shandong Agric Sci*, **51**(1): 124-127. (in Chinese with English abstract)

Guo M Q, Bao Y X, Huang L, et al. 2023. Application of multispectral image taken by unmanned aerial vehicle in monitoring *Cnaphalocrocis medinalis* Güenée damage on rice growth. *Jiangsu J Agric Sci*, **39**(7): 1530-1542. (in Chinese with English abstract)

Guo R G, Liu C M, Luo W H, et al. 2021. Control efficacy of different biological pesticides against *Cnaphalocrocis medinalis* larvae in field. *Hubei Plant Prot*, (6): 27-28. (in Chinese with English abstract)

Gurr G M, Scarratt S L, Wratten S D, et al. 2003. Ecological engineering, habitat manipulation and pest management. *In*: Gurr G M, Wratten S D, Altieri M A, Ecological Engineering for Pest Management: Advances in Habitat Manipulation for Arthropods. Wallingford, USA: CABI: 1-12.

Gurr G M, Wratten S D, Altieri M A. 2004. Ecological engineering: A new direction for agricultural pest management. *AFBM J*, **1**(1): 28-35.

Gurr G M, Read D M Y, Catindig J L A, et al. 2012. Parasitoids of the rice leaffolder *Cnaphalocrocis medinalis* and prospects for enhancing biological control with nectar plants. *Agric For Entomol*, **14**(1): 1-12.

Gurr G M, Lu Z X, Zheng X S, et al. 2016. Multi-country evidence that crop diversification promotes ecological intensification of agriculture. *Nat Plants*, **2**: 16014.

Han G J, Li C M, Zhang N, et al. 2023. *CmHem*, a *hemolin-like* gene identified from *Cnaphalocrocis medinalis*, involved in metamorphosis and baculovirus infection. *PeerJ*, **11**: e16225.

Han Y Q, Lei W B, Wen L Z, et al. 2015. Silicon-mediated resistance in a susceptible rice variety to the rice leaf folder, *Cnaphalocrocis medinalis* guenée (Lepidoptera: Pyralidae). *PLoS One*, **10**(3): e0120557.

He J C, Wang K Y, Hussain M, et al. 2024. Effect of emamectin benzoate and avermectin on the fecundity of *Nilaparvata lugens* (Hemiptera: Delphacidae) and the pest control capacity of parasitic wasp, *Anagrus nilaparvatae* (Hymenoptera: Mymaridae). *Acta Entomol Sin*, **67**(4): 538-548. (in Chinese with English abstract)

He X Q, Batáry P, Zou Y, et al. 2023. Agricultural diversification promotes sustainable and resilient global rice production. *Nat Food*, **4**(9): 788-796.

Horgan F G, Crisol Martínez E, Stuart A M, et al. 2019. Effects of vegetation strips, fertilizer levels and varietal resistance on the integrated management of arthropod biodiversity in a tropical rice ecosystem. *Insects*, **10**(10): 328.

Horgan F G, Vu Q, Mundaca E A, et al. 2022. Restoration of rice ecosystem services: 'Ecological engineering for pest management' incentives and practices in the Mekong Delta Region of Vietnam. *Agronomy*, **12**(5): 1042.

Horgan F G, Mundaca E A, Hadi B A R, et al. 2023. Diversified rice farms with vegetable plots and flower strips are associated with fewer pesticide applications in the Philippines. *Insects*, **14**(10): 778.

Hu G W, Chen Z X, Liu G J, et al. 1993. Dynamic modeling of compensation of late season hybrid to rice leaf-folder (*Cnaphalocrocis medinalis*) defoliation. *Sci Agric Sin*, **26**(2): 24-29. (in Chinese with English abstract)

Huang F D, Li B, Wang G R, et al. 2017. Control effect of ducks on rice diseases, pests and weeds. *J Zhejiang Agric Sci*, **58**(7): 1214-1216. (in Chinese with English abstract)

Huang L, Bao Y X, Guo M Q, et al. 2023. Hyperspectral characteristics of rice leaf and yield estimation under the infestation of *Cnaphalocrocis medinalis* güenée. *Chin J Agrometeorol*, **44**(2): 154-164. (in Chinese with English abstract)

Huang X F, Zheng X S, Chen H B, et al. 2020. Effects of fertilizer regulation on diseases, pests, yields and economic benefits of double cropping rice. *China Rice*, **26**(6): 91-95. (in Chinese with English abstract)

Javvaji S, Maheswari Telugu U, Damarla Bala Venkata R, et al. 2021. Characterization of resistance to rice leaf folder, *Cnaphalocrocis medinalis*, in mutant Samba Mahsuri rice lines. *Entomol Exp Appl*, **169**(9): 859-875.

Ji W L, Chen S. 2015. Preliminary report on the green control of insect pests and diseases in the single-season rice. *Inner Mongol Agric Sci Technol*, **43**(2): 59. (in Chinese with English abstract)

Jia F L, Zhou B Q, You Y L, et al. 2012. Relationship between planting Italian ryegrass during winter and hexapopod community in rice habitat. *Acta Sci Nat Univ Sunyatseni*, **51**(4): 87-91. (in Chinese with English abstract)

Kawazu K, Hasegawa J I, Honda H, et al. 2000. Geographical variation in female sex pheromones of the rice leaffolder moth, *Cnaphalocrocis medinalis*: Identification of pheromone components in Japan. *Entomol Exp Appl*, **96**(2): 103-109.

Kawazu K, Suzuki Y, Yosiyasu Y, et al. 2005. Sex pheromone of the rice leaffolder moth, *Cnaphalocrocis medinalis* (Lepidoptera: Crambidae): Comparison of attractiveness in the China, Vietnam and south Philippine of three synthetic pheromone blends. *Appl Entomol Zool*, **40**: 483-488.

Khan M M. 2019. Risk assessment of emamectin benzoate and chlorantraniliprole for the rove beetle *Paedervs fuscipes*, a general predator of the brown planthopper *Nilaparvata lugens*. Wuhan, China: Huazhong Agricultural University.

Khatiwada J R, Ghimire S, Paudel Khatiwada S, et al. 2016. Frogs as potential biological control agents in the rice fields of Chitwan, Nepal. *Agric Ecosyst Environ*, **230**: 307-314.

Klassen D, Lennox M D, Dumont M J, et al. 2023. Dispensers for pheromonal pest control. *J Environ Manage*, **325**(Pt A): 116590.

Li A G, Xu L, Liu X N. 2021. Effects of both sexes attractants on the adults of *Cnaphalocrocis medinalis*. *Mod Agric Sci Technol*, **23**: 84-85. (in Chinese with English abstract)

Li B T, Pei C M, Shi Q H, et al. 2009. Bioactivity of avermectins to *Chilo suppressalis* Walker and *Cnaphalocrocis medinalis* Guenée and the influence to natural enemies in the paddy fields. *J Plant Prot*, **36**(6): 550-554. (in Chinese with English abstract)

Li H, Deng L H, Weng L S, et al. 2024. Cell wall-localized Bt protein endows rice high resistance to Lepidoptera pests. *Pest Manag Sci*, **80**(4): 1728-1739.

Li J J, Du J, Li S W, et al. 2022. Identification and characterization of a double-stranded RNA degrading nuclease influencing RNAi efficiency in the rice leaf folder *Cnaphalocrocis medinalis*. *Int J Mol Sci*, **23**(7): 3961.

Li M L.1995. Advances of the researches on rice resistant against rice leaffolder. *Fujian Sci Technol Rice Wheat*, **13**(2): 56-58. (in Chinese with English abstract)

Li X F, Xiao S, Zhao L, et al. 2023. Construction of the standard system for industry of natural enemy *Trichogramma*. *Chin Agric Sci Bull*, **39**(35): 157-164. (in Chinese with English abstract)

Li Z S, Xu D M, Wei G R, et al. 2004. Composition of arthropod community in the weed habitat surrounding rice fields. *Entomol J East Chin*, **3**(1): 62-68. (in Chinese with English abstract)

Liang G W, Luo G H, Li C F. 1984. Effects of fertilization amount on adult and egg density of rice leaf roller. *Guangdong Agric Sci*, **11**(2): 34-35/14. (in Chinese with English abstract)

Lin S, Zhang B, Li Q, et al. 2024. Gut bacterial community of *Cnaphalocrocis medinalis* (Guenée) (Lepidoptera: Crambidae) is driven by rice varieties. *J Appl Entomol*, **148**(4): 434-446.

Litsinger J A, Barrion A T, Soekarna D. 1987. Upland Rice Insect Pests: Their Ecology, Importance and Control. Research Paper Series. Manila, the Philippines: International Rice Research Institute: 123.

Liu J, Zhu J W, Zhang P J, et al. 2017. Silicon supplementation alters the composition of herbivore induced plant volatiles and enhances attraction of parasitoids to infested rice plants. *Front Plant Sci*, **8**: 1265.

Liu Q, Xu J, Wang Y, et al. 2013. Synergism of CmGV and *Bacillus thuringiensis* against larvae of *Cnaphalocrocis medinalis* Güenée. *J Yangzhou Univ: Agric Life Sci*, **34**(4): 89-93. (in Chinese with English abstract)

Liu X T, Liu M X, Zhao D H, et al. 2024. Control of ecological networks: Abundance control or ecological regulation? *Chaos*, **34**(7): 073115.

Liu Y, Jiang F Q, Zhang Y W, et al. 2023. Phosphate-modified cellulose/chitosan with high drug loading for effective prevention of rice leaffolder (*Cnaphalocrocis medinalis*) outbreaks in fields. *Int J Biol Macromol*, **243**: 125145.

Liu Z L, Wang L S, Du Y X, et al. 1999. The dispersal patterns of predators between single-season rice fields and the neighboring non-rice habitats, and its application in conserving natural enemies of rice pests. *Acta Agric Zhejiang*, **11**(6): 344-348. (in Chinese with English abstract)

Lu F, Shen H M, Gu S G, et al. 2019. Preliminary report on screening test of additives for rice plant protection drone. *Shanghai Agric Sci Technol*, (4): 106-108. (in Chinese with English abstract)

Lu J H, Shen F Y, Zheng X S, et al. 2022. Preliminary report on the application of food attractant for *Cnaphalocrocis medinalis* in rice field. *China Rice*, **28**(6): 110-112. (in Chinese with English abstract)

Lu Q S, Chen G H, Gu S G, et al. 2020. Comparison of field efficacy of *Bacillus thuringiensis* and other pesticides against rice leaf roller. *Shanghai Agric Sci Technol*, (4): 123-124. (in Chinese with English abstract)

Lu Z X, Yu X P, Heong K L, et al. 2006. Nitrogen fertilizer affects herbivores and stimulates the populations of major insect pests of rice. *Chin J Rice Sci*, **20**(6): 649-656. (in Chinese with English abstract)

Lu Z X, Zhu P Y, Gurr G M, et al. 2015. Rice pest management by ecological engineering: A pioneering attempt in China. *In*: Heong K L, Cheng J A, Escalada M M. Rice Planthoppers. Dordrecht, the Netherlands: Springer Netherlands: 161-178.

Luo M. 2016. Influence of winter crops on arthropod community in winter and early rice fields. Nanchang, Jiangxi Province, China: Jiangxi Agricultural University. (in Chinese with English abstract)

Ma S J. 1983. Ecological engineering: The application of principle of eco-system. *Chin J Ecol*, **2**(3): 20-22. (in Chinese with English abstract)

Ma S J. 1985. Ecological engineering: Application of ecosystem principles. *Environ Conserv*, **12**(4): 331-335. (in Chinese with English abstract)

Ma X H, Guo L, Yu S Z, et al. 2023. Effect of ecological pest control and impact on spider community in rice paddy field. *North Rice*, **53**(2): 24-26. (in Chinese with English abstract)

Mazzoni V, Nieri R, Eriksson A, et al. 2019. Mating disruption by vibrational signals: State of the field and perspectives. Hill P S M, Lakes-Harlan R, Mazzoni V, et al. Animal Signals and Communication. Cham: Springer International Publishing: 331-354.

Ministry of Agriculture and Rural Affairs, PRC. 2023. Announcement No. 654 of the Ministry of Agriculture and Rural Affairs, PRC. [2024-9-10]. http://www.moa.gov.cn/govpublic/ZZYGLS/202303/t20230314_6422981.html. (in Chinese)

National Agricultural Technology Extension Service Center. 2018. Technical guidelines for the scientific use of pesticides in rice fields. Beijing, China: China Agricultural Press. (in Chinese)

National Agricultural Technology Extension Service Center. 2023. Technical guidance on insecticides application in the control of rice ‘two migratory’ pests using UAV. [2023-7-31]. http://www.

moa.gov.cn/gk/nszd_1/2023/202307/t20230731_6433191.htm. (in Chinese)

National Agricultural Technology Extension Service Center. 2024. Monitoring reports on the pesticidal resistance of the agricultural pests in China. [2024-2-27]. https://www.natesc.org.cn/News/des?kind=&id=bd03e7a6-cea5-4650-bdae-9a05473677ca&CategoryId=cb2a3d19-a7bd-4aa0-8f4e-4fdda4842057. (in Chinese)

National Agricultural Technology Extension Service Center, Institute of Plant Protection, Sichuan Academy of Agricultural Sciences. 2012. *In*: Brief Identification Manual of Major Rice Diseases and Insect Pests. Beijing, China: China Agricultural Press: 115-118. (in Chinese)

National Bureau of Statistics of China. 2023. The China Statistical Yearbook in 2023. Beijing, China: National Bureau of Statistics of China. (in Chinese)

Nayak A K, Golive P, Sasmal A, et al. 2024. Exploring genetic divergence and marker-trait associations for leaffolder *Cnaphalocrocis medinalis* (Guenee) resistance in rice landraces. *3 Biotech*, **14**(3): 90.

Nicholls C I, Altieri M A. 2003. Agroecological bases of ecological engineering for pest management. *In*: Gurr G M, Wratten S D, Altieri M A. Ecological Engineering for Pest Management: Advances in Habitat Manipulation for Arthropods. Wallingford, USA: CABI: 33-54.

Niu L, Yan H X, Sun Y J, et al. 2022. Nanoparticle facilitated stacked-dsRNA improves suppression of the Lepidoperan pest *Chilo suppresallis*. *Pest Biochem Physiol*, **187**: 105183.

Odum H T. 1962. Man and the ecosystem. *In*: Waggoner P E, Ovington J D. Proceedings of the Lockwood Conference on the Suburban Forest and Ecology. New Haven, USA: United Printing Services, Inc: 57-75.

Propper C R, Hardy L J, Howard B D, et al. 2020. Role of farmer knowledge in agro-ecosystem science: Rice farming and amphibians in the Philippines. *Hum-Wildl Interact*, **14**(2): 15.

Punithavalli M, Muthukrishnan N M, Rajkuma M B. 2013a. Defensive responses of rice genotypes for resistance against rice leaffolder *Cnaphalocrocis medinalis*. *Rice Sci*, **20**(5): 363-370.

Punithavalli M, Muthukrishnan N M, Rajkumar M B. 2013b. Influence of rice genotypes on folding and spinning behaviour of leaffolder (*Cnaphalocrocis medinalis*) and its interaction with leaf damage. *Rice Sci*, **20**(6): 442-450.

Qian Q, Guo X, Wu L J, et al. 2024. Molecular characterization of plant volatile compound interactions with *Cnaphalocrocis medinalis* odorant-binding proteins. *Plants*, **13**(4): 479.

Qin Z, Zhang J E, Luo S M, et al. 2010. Population control modelling of *Cnaphalocrocis medinalis* Guenee in rice-duck integrated farming system. *Trans Chin Soc Agric Eng*, **26**(11): 283-289. (in Chinese with English abstract)

Qiu X B, Wang L G, Xiao Y F, et al. 2021. Experiment of *Cnaphalocrocis medinalis* control using ‘sex pheromone attractant + insecticidal card with virus and *Trichogramma*’. *Hubei Plant Prot*, (3): 44-45/65. (in Chinese with English abstract)

Rasul A, Yasir M, Mansoor-ul-Hasan, et al. 2019. Population fluctuations of rice leaf folder, *Cnaphalocrocis medinalis* Guenée (Lepidoptera: Pyralidae) in relation to the meteorological factors. *Pak Entomol*, **41**(2):141-145.

Sattler C, Schrader J, Flor R J, et al. 2021. Reducing pesticides and increasing crop diversification offer ecological and economic benefits for farmers: A case study in Cambodian rice fields. *Insects*, **12**(3): 267.

Selvam K, Nagendran S, Manikandan P. 2020. Chapter 2: Ecological engineering: A sustainable tool for insect pest management. *In*: Raju S V S, Sharma K R. Recent Trends in Insect Pest Management. Volume 2. New Delhi, India: AkiNik Publications: 23-53.

Shen J X, Zhang X L, Wang N T, et al. 2008. Simulated trial on the damage of *Cnaphalocrocis medinalis* through cutting leaves. *Plant Prot*, **34**(4): 161-163. (in Chinese with English abstract)

Shen T H, Wang F L, Bian K Y, et al. 2018. Reason analysis of the heavy occurrence of rice leaffolder in 2017 and integration of its green control technologies in Dafeng, Yancheng. *Shanghai Agric Sci Technol*, (2): 106-108. (in Chinese with English abstract)

Shi J Q, Yang N, Shi Z C, et al. 2023. Application effect of *Trichogramma chilonis* against *Cnaphalocrocis medinalis* in planting area of midseason rice. *Guangxi Plant Prot*, **36**(1): 33-35. (in Chinese with English abstract)

Sun M M, Chen J H, Ren S P. 2019. Evaluation of control effect of UAV spray on rice pests by adding adjuvant. *Hunan Agric Sci*, **9**: 55-57. (in Chinese with English abstract)

Sun Y, Liu S T, Ling Y, et al. 2023. Insecticide resistance monitoring of *Cnaphalocrocis medinalis* (Lepidoptera: Pyralidae) and its mechanism to chlorantraniliprole. *Pest Manag Sci*, **79**(9): 3290-3299.

Tan Q K, Li H S, Luo S M, et al. 2008. Arthropod biodiversity and community structure as influenced by different winter-cropping systems in the paddy fields of Enping City, Guangdong Province. *Chin J Ecol-Agric*, **16**(4): 938-943. (in Chinese with English abstract)

Tian H. 2013. Research on evaluation of the resistance for mainly cultivated rice varieties to *Cnaphalocrocis medinalis* (Guenée) and the control action threshold in Chongqing. Chongqing, China: Southwest University. (in Chinese with English abstract)

Tian J C, Wang Z C, Wang G R, et al. 2017a. The effects of temperature and host age on the fecundity of four *Trichogramma* species, egg parasitoids of the *Cnaphalocrocis medinalis* (Lepidoptera: Pyralidae). *J Econ Entomol*, **110**(3): 949-953. (in Chinese with English abstract)

Tian J C, Wang Z C, Wang G R, et al. 2017b. Evaluation of fecundity, flight ability and insecticide tolerance of southern and northern *Trichogramma japonicum* populations. *Chin J Biol Control*, **33**(1): 32-38. (in Chinese with English abstract)

Tian M L, Ban S T, Yuan T, et al. 2020. Monitoring of rice damage by rice leaf roller using UAV-based remote sensing. *Acta Agric Shanghai*, **36**(6): 132-137. (in Chinese with English abstract)

Wang F M, Deng J Y, Schal C, et al. 2016. Non-host plant volatiles disrupt sex pheromone communication in a specialist herbivore. *Sci Rep*, **6**: 32666.

Wang G W, Tian J C, Zhu P Y, et al. 2014. Effects of sugar-rich foods on the longevity, fecundity and pest control capacity of arthropod natural enemies. *Acta Entomol Sin*, **57**(8): 979-990. (in Chinese with English abstract)

Wang L, Dong B B, Liu S T, et al. 2024. Monitoring of chlorantraniliprole resistance in rice leaffolder, *Cnaphalocrocis medinalis* (Lepidoptera: Pyralidae) and the cross-resistance of its chlorantraniliprole-resistant populations to other diamides. *Acta*

Entomol Sin, **67**(4): 498-506. (in Chinese with English abstract)

Wang L S, Liu Z L, Li X R, et al. 2006. Study on key technologies of controlling main pests and diseases in a fish-duck-single rice symbiotic ecosystem in the mountain area. *Acta Agric Zhejiang*, **18**(3): 183-187. (in Chinese with English abstract)

Wang Q X, Xu L, Wu J C. 2008. Physical and biochemical mechanisms of resistance of different rice varieties to the rice leaffolder, *Cnaphalocrocis medinalis* (Lepidoptera: Pyralidae). *Acta Entomol Sin*, **51**(12): 1265-1270. (in Chinese with English abstract)

Wang R, Xiao W P, Wei Q, et al. 2017a. Application effect of monitoring and controling of *Cnaphalocrocis medinalis* using sex pheromone in Duyun. *Chin Plant Prot*, **37**(2): 25-27/9. (in Chinese with English abstract)

Wang R, Xiao W P, Shao C Y, et al. 2017b. Application technology of *Cnaphalocrocis medinalis* control through *Trichogramma* releasing. *Chin Plant Prot*, **37**(11): 46-48. (in Chinese with English abstract)

Wang W Y, ChenY, Zhao H, et al. 2024. Evaluation of the control efficacy of mating disruption by active high dose aerosol pheromone dispensers on rice pests. *Chin J Biol Control*, **40**(6): 1293-1301. (in Chinese with English abstract)

Wang Y K, He J C, Li B, et al. 2014. Determination and safety evaluation of six insecticides to three species of spiders. *In*: 2014 Annual Academic Conference of China Society of Plant Protection. Beijing, China: China Agricultural Science and Technology Press: 224-228.

Wang Z W, Gao X, Ma D J, et al. 2019. Nucleic acid pesticides: The new plant protection products with great potential. *Chin J Pestic Sci*, **21**(5/6): 681-691. (in Chinese with English abstract)

Wei M. 2021. Study on the application effect of sex attractant disorientation technology for rice moth pests. *Mod Agric Sci Technol*, (22): 78-79/84. (in Chinese with English abstract)

Wu J, Wu X, Chen H, et al. 2013. Optimization of the sex pheromone of the rice leaffolder moth *Cnaphalocrocis medinalis* as a monitoring tool in China. *J Appl Entomol*, **137**(7): 509-518.

Wu J X, Zheng X S, Zhou G H, et al. 2013. Effect of leaf cutting at different growth stages on growth, yield and physiological traits of two rice cultivars. *Chin J Appl Entomol*, **50**(3): 651-658. (in Chinese with English abstract)

Wu M F, Guo L, Zhang J, et al. 2016. Effects of rice-fish interaction on rice leaf roller and rice growth. *J Zhejiang Agric Sci*, **57**(3): 446-449. (in Chinese with English abstract)

Wyckhuys K A G, Lu Y H, Zhou W W, et al. 2020. Ecological pest control fortifies agricultural growth in Asia-Pacific economies. *Nat Ecol Evol*, **4**(11): 1522-1530.

van den Broeck M, de Cock R, van Dongen S, et al. 2021. Blinded by the light: Artificial light lowers mate attraction success in female glow-worms (*Lampyris noctiluca* L.). *Insects*, **12**(8): 734.

Xia X Q. 2019. Effects of co-cultivation of rice and duck on diseases, insect pests and weeds of rice. *Mod Agric Sci Technol*, (21): 110-111. (in Chinese with English abstract)

Xiao H X, Zhou Z B, Lu S Z, et al. 2019. Demonstration test on spraying nanometer pesticide with plant protection UAV against rice planthopper and rice leaf roller. *Mod Agric Sci Technol*, (22): 58-59. (in Chinese with English abstract)

Xie Y L, Wan L, Ning Y H, et al. 2019. Preliminary report on the application of *Mamestra brassicae* multiple NPV SC + *Trichogramma japonicun* to control *Chilo suppressalis* and *Cnaphalocrocis medinalis*. *Hubei Plant Prot*, (6): 29-30/32. (in Chinese with English abstract)

Xu H X, Yang Y J, Zheng X S, et al. 2019. Research on the management of rice insect pests in China since the 21 century: Advances and future prospects. *Chin J Appl Entomol*, **56**(6): 1163-1177. (in Chinese with English abstract)

Xu L. 2008. Study on resistance and physiological and biochemical mechanism of different rice varieties to rice leaffolder *Cnaphalocrocis medinalis* (Guenee) infestation. Yangzhou, Jiangsu Province, China: Yangzhou University. (in Chinese with English abstract)

Xu L Y, Zhao L Y, Liu G L, et al. 2016. Effects of *Trichogramma* species and releasing amount on the control effects on *Cnaphalocrocis medinalis*. *Chin Plant Prot*, **36**(8): 37-40. (in Chinese with English abstract)

Xu Q, Deng Y S, Yan X X, et al. 2021. Occurrence characteristics and green control measures of rice leaffolder in Nanping. *Mod Agric Sci Technol*, (21): 114-115/120. (in Chinese with English abstract)

Xu S Z, Xiao M H, Wei Z H, et al. 2019. Application of sex pheromone mating interferentant on rice insect pest control. *Chin Plant Prot*, **39**(8): 48-51. (in Chinese with English abstract)

Yang H. 2016. Reproductive biology and the influence on the fecundity of *Sogatella furcifera* (Horváth) under the impact of insecticides. Guizhou, China: Guizhou University. (in Chinese with English abstract)

Yang Q F, Ouyang F, Men X Y, et al. 2020. Functional plants: Current uses and future research. *Chin J Appl Entomol*, **57**(1): 41-48. (in Chinese with English abstract)

Yang Y J, Xu H X, Zheng X S, et al. 2015. Progress in management technology of rice leaffolders in China. *J Plant Prot*, **42**(5): 691-701. (in Chinese with English abstract)

Yang Y J, Wang C Y, Xu H X, et al. 2018. Sublethal effects of four insecticides on folding and spinning behavior in the rice leaffolder, *Cnaphalocrocis medinalis* (Guenée) (Lepidoptera: Pyralidae). *Pest Manag Sci*, **74**(3): 658-664.

Yang Y J, Liu X G, Guo J W, et al. 2022. Gut bacterial communities and their assembly processing in *Cnaphalocrocis medinalis* from different geographic sources. *Front Microbiol*, **13**: 1035644.

Yang Y J, Lu K, Qian J N, et al. 2023. Identification and characterization of ABC proteins in an important rice insect pest, *Cnaphalocrocis medinalis* unveil their response to Cry1C toxin. *Int J Biol Macromol*, **237**: 123949.

Yang Z X, Zhu F, Wang J S, et al. 2022. Control effect of food attractant and sex pheromone attractant on *Cnaphalocrocis medinalis*. *Chin Plant Prot*, **42**(2): 38-40. (in Chinese with English abstract)

Ye C F, Lan J J, Li Y, et al. 2017. The effect of trap height and density on the trapping effect on rice leaffolder. *Zhejiang Agric Sci*, **58**(10): 1725-1726. (in Chinese with English abstract)

Yi S D. 2023. Effects of rice-duck-frog co-culture on rice diseases, insect pests and weeds control and rice grain quality. Wuhan, Hubei Province, China: Huazhong Agricultural University. (in Chinese with English abstract)

Yuan W N, Wei Y H, Niu L M, et al. 2019. Toxicity of emamectin benzoate to 3 kinds of pests (Lepidoptera) and *Trichogramma dendrolimi*. *Chin Agric Sci Bull*, **35**(26): 148-152. (in Chinese with English abstract)

Zeng J, Zhang T, Wang L Y, et al. 2021. Preliminary report of population dynamics of *Cnaphalocrocis medinalis* monitored through food attractant. *Plant Prot*, **47**(4): 203-214. (in Chinese with English abstract)

Zeng W, Deng J Z, Gao Q C, et al. 2021. P20 plant protection UAV to control *Cnaphalocrocis medinalis* by reduced pesticide application. *Trans Chin Soc Agric Engineer*, **37**(15): 53-59. (in Chinese with English abstract)

Zhang H B, Zhou C, Zhu X M, et al. 2023. Preliminary report of 'gathering points into network' of intelligent sex pheromone attracting monitoring equipment for major crop pests in Jiangsu Province. *Chin Plant Prot*, **43**(2): 91-94. (in Chinese with English abstract)

Zhang J, Hu L X, Liu J L, et al. 2010. Overwintering arthropod community in rice habitat and non-rice habitat. *Acta Sci Nat Univ Sunyatseni*, **49**(5): 118-121. (in Chinese with English abstract)

Zhang J P, Chen C M. 1991. The yield component and compensation relations of rice on the damage of rice leaf roller. *J Plant Prot*, **18**(1): 1-4. (in Chinese with English abstract)

Zhang X L, Ding T L, Zhu X S, et al. 2009. Simulated trial on the damage of *Cnaphalocrocis medinalis* through cutting leaves. *Mod Agric*, (3): 25-26. (in Chinese with English abstract)

Zhang Y P, Huang B Q. 2000. Discussion of the protection and utility of rice leaf folder's natural enemies. *Nat Enem Insects*, **22** (1): 38-44.

Zhang Y W. 2021. Damage of rice leaffolder and its green control technologies in Fanchang. *Anhui Agric Sci Bull*, **27**(14): 113-114. (in Chinese with English abstract)

Zhao X X, Xu H X, He K, et al. 2021. A chromosome-level genome assembly of rice leaffolder, *Cnaphalocrocis medinalis*. *Mol Ecol Resour*, **21**(2): 561-572.

Zhao X Y, Xu H X, Yang Y J, et al. 2024. Defense responses of different rice varieties affect growth performance and food utilization of *Cnaphalocrocis medinalis* larvae. *Rice*, **17**(1): 9.

Zhao Y Y, Tian J C, Zheng X S, et al. 2017. Feasibility of *Trifolium repens* and *Oxalis corniculata* as the nectar resource plant to *Trichogramma chilonis*. *Acta Agric Zhejiang*, **29**(1): 106-112. (in Chinese with English abstract)

Zheng X S, Yu X P, Lu Z X, et al. 2002. The diversity and the structure of spider community in *Zizania caduciflora* field. *Nat Enem*, (2): 53-59. (in Chinese with English abstract)

Zheng X S, Yang Y J, Xu H X, et al. 2011. Resistance performances of transgenic bt rice lines T2A-1 and T1c-19 against *Cnaphalocrocis medinalis* (Lepidoptera: Pyralidae). *J Econ Entomol*, **104**(5): 1730-1735.

Zheng X S, Cheng L P, Wang H F, et al. 2015. Effects of fertilizer regulation on occurrence of leaffolder, *Cnaphalocrocts medinalis* and rice production. *Acta Agric Zhejiang*, **27**(9): 1619-1624. (in Chinese with English abstract)

Zheng X S, Tian J C, Yang Y J, et al. 2017. The feasibility of using graminaceous weeds as a functional plant for controlling rice leaffolder (*Cnaphalocrocis medinalis*). *Sci Agric Sin*, **50**(21): 4129-4137. (in Chinese with English abstract)

Zheng X S, Zhong L Q, Wang H F, et al. 2020a. Demonstration on rice pests control by fertilizer regulation technique in different geographic rice growing areas of Zhejiang Province. *Acta Agric Zhejiang*, **32**(9): 1656-1664. (in Chinese with English abstract)

Zheng X S, Tian J C, Zhong L Q, et al. 2020b. Effect of continuous fertilizer control on rice yield, pest occurrence and soil fertility. *J Zhengjiang Agric Sci*, **61**(9): 1839-1842. (in Chinese with English abstract)

Zhong H N. 2022. The effect of farmland landscape pattern on diversity and density of over-wintering spiders and carabids. Nanchang, Jiangxi Province, China: Jiangxi Agricultural University. (in Chinese with English abstract)

Zhou G H, Zhou Y J, Zhao L W, et al. 2023. Preliminary study of the control effect of nano-pesticide on rice false smut and rice leaffolder. *Chin Plant Prot*, **43**(11): 80-82. (in Chinese with English abstract)

Zhou Z Y, Huang X C, Meng L, et al. 2011. Arthropod diversity on plants at field margins of organic farming paddy rice. *Chin J Ecol*, **30**(7): 1347-1353. (in Chinese with English abstract)

Zhu F, Cheng J J, Zhang G, et al. 2021. Research and application of simple and green pest control strategy in whole periods of rice production in Jiangsu Province. *Chin Plant Prot*, **41**(1): 94-101. (in Chinese with English abstract)

Zhu H, Fan M J, Wang K F, et al. 2021. Effect of *Cnaphalocrocis medinalis* monitoring through food attractant. *Chin Plant Prot*, **41**(8): 43-44/49. (in Chinese with English abstract)

Zhu P Y, Wang G W, Zheng X S, et al. 2015. Selective enhancement of parasitoids of rice Lepidoptera pests by sesame (*Sesamum indicum*) flowers. *BioControl*, **60**(2): 157-167.

Zhu P Y, Zheng X S, Zhang F C, et al. 2017a. Natural enemy functional guilds of rice leaf folder (*Cnaphalocrocis medinalis*) enhanced in paddy field with sustainable pest management by ecological engineering. *Chin J Biol Control*, **33**(3): 351-363. (in Chinese with English abstract)

Zhu P Y, Zheng X S, Zhang F C, et al. 2017b. Aquatic insect populations in paddy fields as affected by management of rice insect pests through ecological engineering technology. *Chin J Rice Sci*, **31**(2): 207-215. (in Chinese with English abstract)

Zhu P Y, Zheng X S, Zhang F C, et al. 2018. Quantifying the respective and additive effects of nectar plant crop borders and withholding insecticides on biological control of pests in subtropical rice. *J Pest Sci*, **91**(2): 575-584.

Zhu P Y, Zheng X S, Johnson A C, et al. 2022. Ecological engineering for rice pest suppression in China: A review. *Agron Sustain Dev*, **42**(4): 69.

Zhuang Y Q, Wang X J, Llorca L C, et al. 2022. Role of jasmonate signaling in rice resistance to the leaf folder *Cnaphalocrocis medinalis*. *Plant Mol Biol*, **109**(4/5): 627-637.

Zhuo F Y, Chen X X, Xia Y X, et al. 2024. The occurrence characteristics of rice diseases and insect pests and the integration of green control technology in China from 2013 to 2022. *Chin J Biol Control*, **40**(5): 1207-1213. (in Chinese with English abstract)

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