Ecological engineering in low land rice for brown plant hopper, *Nilaparvata lugens*(Stål) management

YogeshYele[1]* and Subhash Chander[2], Sachin S. Suroshe[3]*, Suresh M. Nebapure[3], Prabhulinga T.[4] Arya P.S.[3]

[1]ICAR-National Institute of Biotic Stress Management, Raipur-493 225, India.
[2]ICAR-National Centre for Integrated Pest Management, New Delhi- 110 012, India
[3]ICAR-Indian Agricultural Research Institute, Pusa, New Delhi- 110 012, India.
[4]ICAR-Central Institute of Cotton Research, Nagpur- 440 010, India.
Corresponding Authors:
Sachin S. Suroshe[3]* and YogeshYele[1]*
Email address: sachinsuroshe@gmail.com, yogeshyele13@gmail.com

Abstract

Rice field bunds and edges can play like near crop habitats, available for planting flowering plants to attract and conserve the natural enemies. We evaluated the effect of ecological engineering on the incidence of Brown Planthopper (BPH), *Nilaparvata lugens* (Stål) (Hemiptera; Delphacidae) and the abundance of its predators in the rice variety Pusa Basmati-1121. Plots included the oilseed crops *viz*. sesamum, sunflower and soybean, with plantings of flowering crops marigold, balsam and gaillardia as bund flora around the edges of rice plots. Ecologically engineered plots contained both crops+flowers and resulted in a significantly reduced BPH population per hill in rice plots for 2019 (6.3) and 2020 (9.4) compared to the control plots (9.8 and 14.4). Ecologically engineered plots also witnessed the delayed appearance of BPH during each growing season. Peak BPH populations are lower in the ecologically engineered plots than in the control grounds.

Furthermore, the activity of natural enemies, *viz.,* spiders, mirid bugs and rove beetles was the highest in rice fields planted with oilseed crops like sesamum, sunflower and soybean. Olfactory response studies showed that the attraction response of spiders toward sesamum and balsam leaves was more significant than in other crop plants. Rice yield enhanced in plots planted with crops+flowers during both seasons compared to control plots. Planting of oilseed crops plants such as sesamum, sunflower and soybean with flowering crops such as marigold, balsam and gaillardia as bund flora on the bunds around the main rice field enhanced the natural enemy activity, suppressed the planthopper population, and increased yields. Based on the

results, we recommend including ecological engineering techniques as one of the management components in the Integrated Pest Management program for rice crops.

Keywords: Biological control, Ecological engineering, Floral resources, Integrated pest management, Natural enemies, Rice pests.

Introduction

Rice, *Oryza sativa* L. is the world's most important staple food that provides nutrition to more than half of the world's population. Many biotic and abiotic stresses face various bottlenecks that challenge rice production. Extensive rice cultivation systems, especially monoculture, have increased rice cultivation problems, including insect pests, diseases and weeds (Behura *et al*., 2011). Several decades of agricultural intensification and overuse of agrochemicals resulted in a depletion of natural enemy populations (Matsumura *et al*., 2008). Without enough natural enemies, the pesticide-survived pests maintain that inoculum population during the off-season that will outbreak during the subsequent season infestation (Yele *et al.,* 2020). Survivors sustain insecticide resistance and invasive pest population infestations over rice varieties (Horgan *et al*., 2015). Indiscriminate use of insecticide by rice farmers causes, reasonably, the repeated occurrence of pest outbreaks, including planthoppers outbreaks in several regions throughout Asia (Catindig *et al*., 2009; Cheng, 2009). Ecological pest outbreaks connect with the reduced diversity and efficiency of the natural enemies in the rice crop ecosystem.

Ecological engineering is an approach of deliberate manipulation of habitat for the benefit of society and the natural environment (Horgan et al., 2016). Ecological engineering for pest management mainly focuses on increasing the abundance, diversity and function of natural enemies in agricultural habitats by providing them with refuges and supplementary food resources (Gurr, 2009; Lv *et al*., 2015). There are successful cases in crop production systems for the method application, solving pest management issues. Planting buckwheat, *Fagopyrum esculentum* Moench as a cover crop in vineyards and Alyssum, *Lobularia maritima* (L.) Desv. between rows of vegetables provide flower and nectar resources for predators and parasitoids, resulting in enhanced biological control (Berndt *et al*.,2006; Gillespie *et al*., 2011). Flowering plants and weeds offer many resources for the survival of natural enemies like alternative prey/hosts, pollen, nectar, and microhabitats. The concept of pest management through ecological engineering is still in its infancy in the rice ecosystem in India. Previous studies on ecological engineering for rice pest management primarily focused on integrating flower and/or vegetable strips into rice landscapes.

Planting rice bunds with okra, mungo beans and string beans increased the structural diversity of predators in the rice fields. Results indicated that spider abundance increased, and the ratio of plant hoppers to spiders was lower among rice plants in fields close to planted bunds (Horgan *et al*., 2016). Zhu *et al.* (2014) studied the influence of various plant species on the performance of the predatory mirid bug, *Cyrtorhinus lividipennis* Reuter, a key natural enemy of rice planthopper. The presence of flowering plants like *Tagetes erecta* L., *Tridax procumbens* L., *Emilia sonchifolia* (L.) and *Sesamum indicum* L. around the rice plots increased the abundance and survival of *C. lividipennis*. Predation efficiency and consumption of *Nilaparvata lugens* by *C. lividipennis* increased in flower treatment plots. Among flowering plants, *S. indicum* was favourable and strongly promoted host predation by *C. lividipennis.* These studies suggest *S. indicum* is the best suited floral component for ecological engineering in rice. Chandrasekar *et al*. (2017) recommended using weed strips of *Echinochloa colonum* (L.) and *E. crusgalli* in the rice ecosystem to enhance the availability of mirid bugs. Zheng *et al.* (2017) studied using the banker plant system in rice for biological control of BPH, *N. lugens* and plant hoppers *N. muiri.* The banker plant system consisted of planting a grass species, *Leersia sayanuka* Ohwi, adjacent to rice fields. *Leersia sayanuka* is a host plant for *N. muiri,* but it could not complete the life cycle on rice.

Similarly, BPH could not complete the life cycle on grass, *L. sayanuka*. The egg parasitoid *Anagrus nilaparvatae* (Pang et Wang) actively parasitizes eggs of both BPH and *N. muiri.* Plantings of *L. sayanuka* improve the establishment and persistence of the egg parasitoid, *A. nilaparvatae*. The study showed that BPH densities were significantly lower in rice fields with a banker plant system compared to control rice fields. In a recent study, Jado *et al.* (2019) demonstrated the enhancement of the biological control potential of parasitoids on aphids by exposure to flowering plants. Long-term exposure to buckwheat (*F. esculentum*), alyssum (*L. maritima*) and white rocket (*Diplotaxis erucoides* L.) flowers greatly enhanced the longevity, the potential fecundity, and the parasitism rate of *Aphidius colemani* Vieron on aphid *Myzus persicae* (Sulzer).

Conservation of biodiversity and optimization of ecosystem functions is the need of the hour for sustainable agriculture. Ecological management methods are one way to achieve these goals while at the same time restoring the ecology of rice landscapes is also necessary (Horgan *et al*., 2016). There is considerable potential for ecological engineering techniques in rice pest management, including BPH, to reduce pesticide dependence and slow the breakdown of varietal resistance. Identification of flowering plants that selectively favors natural enemies over insect pests is a crucial consideration for ecological engineering. However, there is very little information available on the optimal fauna and flora species to be employed for this cause. The selection of appropriate flowering plants for the attraction, enhanced biological activity and conservation of natural enemies is essential for the success of ecological engineering. Studies shall start evaluating the effect of ecological engineering in rice on the incidence of BPH and the abundance of its natural enemies.

Materials and Methods:

Field preparation and transplanting

Experiments on ecological engineering studies on BPH and their natural enemy population were conducted in the rice fields using rice cultivar *Pusa Basmati 1121* during *kharif* (rainy season) in 2019 and 2020. A tractor equipped with a drawn cultivator and rotavator ploughed twice the main field to get fine tilth. All weeds and previous crop stubbles were removed from the field, submerged with water for two to three days and puddled 2-3 times, followed by leveling. Plots were 5×4m with ridges on all sides, spaced 1 meter apart. Transplanting was done on 22nd July 2019 and on 30th July 2020. Seedlings were two per hill; spaced at 15 × 20 cm. Ridges surrounded all the plots, filling the gaps after a week to ensure a uniform plant population in each plot.

Experimental treatments and layout

This experiment aimed to study the effect of field crops and flowering crops surrounding the rice fields on the abundance of BPH and their natural enemies. Three oilseed crops *viz*., sesamum (*Sesamum indicum* L.), sunflower (*Helianthus annuus* L.) and soybean (*Glycine max* L.); and three flowering crops *viz*., marigold (*Tagetes erecta* L.), balsam (*Impatiens balsamina* L.) and gaillardia (*Gaillardia pulchella* Foug.) were selected for the study. The study focuses on the interaction of oilseed and flowering crops and evaluating the effect of natural weeds on the abundance of pests and their natural enemy populations in rice crops. To undertake these studies, we designed the treatments as T1= Oilseed crops; T2= Flowering crops; T3= Natural weeds (No weeding); T4= Oilseed crops + Flower Crops; T5= Control rice plots with all recommended agronomic practices.

Sesamum, sunflower and soybean seeds were directly sown by dibbling on the bunds adjacent to respective treatments. Marigold, balsam and gaillardia plants were first raised in the nursery and, at the appropriate time, transplanted to rice bunds adjacent to the proper treatments.

Oilseed crops and flowering plants were also grown in plastic plots for placing around rice plots in respective treatments at the appropriate time. Placing oilseed and flowerings in bund and staggered maintain a more extended flowering in the plot. A one-meter channel between replications allows the experiment management in the proper Completely Randomized Block Design (CRBD) with five treatments and four replications.

Observations and statistical analysis

Ten random hills in each plot gave the incidence of BPH and its natural enemies, spider [*Lycosa pseudoannulata* (Bosenberg and Strand)], mirid bug (*Cyrtorhinus lividipennis* Reuter) and rove beetles (*Paederus fuscipes* Curtis). The observation interval was ten days till the crop harvesting. Records per hill include the BPH total hoppers and the natural enemies for the spider, mirid bug and rove beetle. Yield data was recorded after harvesting and expressed as tons per hectare. Thus, data obtained for BPH and natural enemies underwent a two-way analysis of variance (Two-way ANOVA) and the significance of differences between the treatments and weeks tested by F-tests. In contrast, the treatment means compared least significant differences (LSD) at $P = 0.05$. Rice yield data passed ANOVA and means comparison by least significant differences (LSD) at $P = 0.05$.

Olfactory response studies

A y-tube olfactometer (Fand et al., 2020) allows the evaluation of spiders' olfactory attraction responses towards flowering plants' odors. The experimental arena consisted of a y-tube having two arms 7.5 cm long, one 7.5 cm base long, 15 cm total length and 1 cm internal diameter. One arm of the y-tube was attached to a plant odor source, and another arm to the source of clean air. A vacuum pump and a flow meter at the base end maintained a constant air inflow from both arms. Teflon tubing sections of an intermediate diameter were employed as tight-fitting unions to plant source and vacuum lines. A nylon mesh barrier between the Teflon union and the glass y-tube prevented spiders from crawling to the tube ends. The complete y-tube assembly was stationed on a foam platform to minimize the ambient vibrations caused by the vacuum pump.

Deleted: odour

Fresh plant leaves arrived from the field in an airtight zipper plastic bag. Spiders collected from rice fields and individually stored in glass vials starved for 2 hours before participating in the attraction response experiments. One arm of the y- tube connected by Teflon tubes to the plastic bags enclosing plant leaves. Other arm was a source of charcoal-passed clean air. A single starved spider was released at the base of the y-tube and observed for 20 minutes, making its choices between the two arms. Most spiders began moving towards arms within a few minutes of release. A new spider replaced a non-active individual. The active spiders moving towards the arms and touching the mesh barrier were respondents, while the others non-respondents. The bioassay used 20 spiders per treatment. Finally, the per cent attraction and a two-tailed paired t-test (0.01 and 0.05) tested the significant difference between the mean of the per cent spiders attracted towards the plant source.

Results

Effect of ecological engineering on the incidence of BPH

BPH population (nymph, female, and male) significantly differed across the treatments ($F=4.32$, $P=0.002$ and $F=11.5$, $P<0.001$) and weeks ($F=81.2$, $P<0.001$) during *kharif* 2019 and 2020. BPH population first appeared at 36 SMW (Standard Meteorological Week) during *kharif* 2019 and 2020 (Table 1 & 2). BPH per hill population did not differ significantly till 64 DAT (Days After Transplanting) across the treatments in the *kharif* seasons. During *kharif* 2019, all the treatments experienced the peak BPH population at 94 DAT (43 SMW). Mean BPH population density was the highest in control plots (9.8±3.9 BPH/hill), and it did not differ significantly from the population density in natural weeds treatment (11.5±4.2 BPH/hill) (Table 1).

The BPH population density was significantly lower in treatments with crops (5.2±1.8 BPH/hill) as compared to other treatments and control (Fig.1). The highest BPH population was recorded in control (27.8±9.5 BPH/hill) at 94 DAT while the lowest BPH peak population existed in crop plants treatment (15.1±3.9 BPH/hill) at 94 DAT (Fig. 2). In the treatments with flowers and crops+flowers, peak population was significantly lower as compared to natural weeds treatment and control, the mean population density was also lower in treatment than in control. During *kharif* 2020, the peak population appeared at 82 DAT (42 SMW) in all the treatments except for crop treatment, where it appeared at 71 DAT (41 SMW) (Table 2). The lowest BPH mean population density was in crops + flowers treatment (9.4±3.6 BPH/hill). In contrast, the highest population was recorded in control (14.4±5.1 BPH/hill) (Fig. 1). At crops + flowers treatment, the BPH population ranged from 0.1±0.1 BPH/hill at 41 DAT to 23.6±0.4 BPH/hill at 71 DAT, which was the lowest population among all the treatments (Table 2). During *kharif* 2020, the highest peak population appeared in control (33.7±2.1 BPH/hill). The lowest peak for crops + flowers (23.6±0.4 BPH/hill) occurred at 71 DAT (41 SMW) (Fig. 2). Rice plots surrounded with crops and flowers harbored significantly less BPH population as compared to natural weeds treatment and control. Overall, the BPH population was higher during *kharif* 2020 than during *kharif* 2019, irrespective of the treatments. Control plots harboured a significantly higher BPH population than any other treatments. Contrary to this, rice plots with oilseed crop plants, flowering plants, and plots with a combination of crops + flowers have lower BPH populations than weedy plots and control plots.

Effect of ecological engineering on the abundance of natural enemies

The spider *L. pseudoannulata* population was monitored after 40 DAT in rice plots for successive *kharif* seasons in 2019 and 2020. The populations differed significantly between the treatments (F=14.7, P<0.001 and F=47.9, P<0.001) and weeks (F=29.6, P<0.001and F=13.8, P<0.001) in both *kharif* seasons (Table 3 & 4). In general, there was no difference in the abundance of spider populations during *kharif* 2019 and 2020. During *kharif* 2019, rice plots surrounded with crops + flowers witnessed the highest abundance of spider population (2.5±0.3 spider/hill), which ranged from 1.3±0.2 spider/hill at 44 DAT to 3.9±0.3 spider/hill at 104 DAT (Table 3). On the other hand, the lowest spider population thrive in natural weed rice plots (1.7±0.2 spider/hill). Peak spider population during *kharif* 2019 was observed during 104 DAT in all the treatments, while the peak occurred in crops + flowers treatment (3.9±0.3 spider/hill) (Table 3). Treatments with crops and flowers alone also had a significantly higher spider population than the control treatment. During *kharif* 2020 also, the spider population was found to be higher in crops (2.4±0.2 spider/hill) and crops + flowers (2.3±0.2 spider/hill) treatments as compared to other treatments and control plots (Table 4). The peak spider population significantly differed between the treatments, and the highest peak population was in crop treatments (3.1±0.3 spider/hill) at 82 DAT. The lowest spider population was in the control treatment (1.1±0.1 spider/hill), which was at par with the natural weed treatment (1.3±0.1 spider/hill). In general, spider abundance was higher in rice plots planted with crops + flowers, crops alone and flowers alone, compared to control plots. Crops and flower diversity along the rice plots enhanced the spider abundance in the rice plots (Table 4).

In the present study, the mirid bug (*C. lividipennis*) population significantly differed across the treatments and weeks in both seasons (Tables 5 & 6). The mirid bug population abundance was higher in *kharif* 2019 compared to *kharif* 2020. During *kharif* 2019 mirid bug population was present during all the observation weeks, while during *kharif* 2020, it first appeared in the field at 82 DAT. A significantly higher mirid bug population was in the treatments of crops (3.3±1.9 mirid/hill), flowers (3.3±2.0 mirid/hill) and crops+flowers (2.8±1.7 mirid/hill) as compared to control treatment (1.8±1.1 mirid/hill) during *kharif* 2019 (Table 5). In natural weeds treatment, the mirid bug population was found to be the lowest (1.5±0.8 mirid/hill) but was at par with the control treatment. The highest peak mirid bug population existed in crops treatment (12.5±1.0 mirid/hill) at 104 DAT, followed by flowers

Deleted: s

treatment (12.4±0.6 mirid/hill) at 114 DAT and crops + flowers (10.9±0.6 mirid/hill) at 104 DAT (Table 5). Till 94 DAT, the mirid population was lesser but stable. However, it significantly increased after 100 DAT irrespective of the treatment, which coincided with the higher BPH population on rice. Like *kharif* 2019, the mirid bug population was higher in crops (1.0±0.3 mirid/hill), flowers (1.1±0.2 mirid/hill) and crops + flowers (1.4±0.4 mirid/hill) treatments as compared to control treatment (0.5±0.1 mirid/hill) in *kharif* 2020 (Table 6). The highest mirid bug population was in the crops + flowers treatment (1.4±0.4 mirid/hill), which was at par with the crops and flowers treatment (Table 6). Overall, in both the *kharif* seasons, mirid bug population abundance was found to be on the higher side in rice plots surrounded with crops, flowers and crops + flowers. During the current study, we found that the rice fields' rove beetle population was less abundant in both seasons. Its population did not differ significantly across the treatments and weeks in the kharif seasons. However, in *kharif* 2019, it appeared early in the season, i.e., at44 DAT, while in *kharif* 2020, i.e., at 61 DAT (Table 7 & 8). In general, natural enemy populations were more abundant in rice plots planted with crops, flowers and crops + flowers than control plots in both the *kharif* seasons. Among the natural enemies, the spider population was more abundant in rice crops than the mirid bug and rove beetle populations.

Attraction response of spider in Y-tube olfactometer

The olfactory response of spiders towards leaves of plant species *viz.,* sesamum, balsam, sunflower, marigold and soybean were studied using a Y-tube olfactometer. Sesamum (P< 0.01) and balsam (p<0.05) attracted spiders much more than the other plant species. We observed the highest spider attraction towards sesamum leaves, i.e. 83.3±1.67 %, followed by balsam, 73.33±3.33 % (Fig. 3). We also kept spider attraction towards sunflower and marigold leaves but not statistically significant. The present study showed that spider attraction was higher towards sesamum and balsam leaves than other plants.

Rice grain yield in ecologically engineered rice fields

The rice yield significantly differed between the treatments in 2020 (F=25.2, P<0.001) but less significantly during 2019 (F=3.7, P=0.033) (Table 8). However, substantially higher rice yield was in rice plots planted with oilseed crops + flowers during 2019 (5.60±0.24 tons/ha) and 2020 (5.27±0.06 tons/ha) as compared to control rice plots. Treatments with oilseed crops alone (4.52±0.24 and 4.71±0.07 tons/ha) and flowers alone (4.80±0.55 and 4.97±0.05 tons/ha) also recorded significantly higher yields than control treatment in both seasons (Fig. 4).

Discussion

Over the past few decades, Integrated Pest Management (IPM) has become a way of life and showing great potential for reducing the dependence on chemical control methods (Pretty,1998, Atanassov *et al*., 2002). We propose treating Ecological engineering as a refined and precise version of IPM in agricultural ecosystems. IPM requires coordinated efforts, integrating diverse tactics, including cultural, biological, and chemical control (Dent, 1991). Ecological engineering strategies for pest management include using cultural practices based on vegetation management to enhance biological control or the bottom-up effect that acts directly on pests (Horgan et al., 2016). It involves identifying optimal forms of botanical diversity to incorporate into a farming system to suppress pests by promoting their natural enemies. We attempted to diverse plant species, including flowering annuals around the rice crop, to study the effect of these plants on the occurrence of different rice pests and the abundance of the natural enemies for two successive *kharif* seasons.

Our study reports that rice plots planted with oilseed crop plants, flowering plants and combinations of crops and flowering plants had less abundance of BPH population than general rice fields in both seasons. Also, the peak BPH population appears higher and earlier in the season in the conventional rice plots than in the ecologically engineered rice plots. Furthermore, the pest population build-up is slower in rice plots planted with oilseed crops and flowering annuals than in conventional rice plots. 2019 recorded the lowest BPH population in rice plots planted with crops like sesamum, sunflower and soybean. However, in 2020, the BPH population was the lowest in rice plots planted with oilseed crops and flowering plots. It suggests that rice crops grown with diverse crops and flowering plants had low BPH population than conventional rice plots.

Natural enemies like spiders, mirid bugs and rove beetles are not strictly specialized predators who prey on leafhoppers, planthoppers, and soft-bodied caterpillar pests. The abundance of these natural enemies in rice fields helps suppress many crop pests, especially the Hemipteran pests like planthoppers and leafhoppers, in a natural way. Spider population in all the ecologically engineered plots was abundant throughout the rice growing season in both *kharif* seasons. Rice plots planted with oilseed crops and flowers or joined doubled the antagonist's population in control plots during the *kharif* seasons. Notably, the rice fields surrounded by oilseed and flower crops had greater spider abundance than other treatments and control plots.

In the present study, we found greater mirid bug abundance during *kharif* 2019, also reported early in the season. On the other hand, during *kharif* 2020, mirid bugs were lesser and later in the season, which may be due to the late appearance of BPH. During both seasons, the mirid bug population was much more abundant in the ecologically engineered plots than in natural weeds and control plots. The mean population of mirid was twice as abundant as in the ecologically engineered plots or the control rice plots. Similarly, the rove beetle population was also higher in rice plots planted with oilseed crops and flowering plants. The natural enemies' population (spiders, mirid bugs and rove beetles) was more abundant in rice plots planted with produce, flowers and crops + flowers. The spider population was more abundant in rice than the mirid bug and rove beetle populations.

Furthermore, olfactory response studies with Y-tube suggest that sesamum and balsam plant leaves are more attractive to spiders. Sesamum and balsam leaves were the better spider attractant. The rice yield was higher in the ecologically engineered treatments than in weedy and control plots. The highest yield originates from plots planted with a mixture of crop and flowering plants during both seasons. Thus, it appears that rice fields planted with flowering and other crop plants had lower pest activity; consequently, it reduced the damage caused by insect pests and enhanced the rice crop yield.

Reduced pest activity and delayed appearance of BPH in rice growing season in ecologically engineered rice fields may relate to the higher natural enemy activity in the diverse crop and flowering plant system around the rice crop. The presence of an array of vegetation around the main crop has provided shelter and floral resources in the form of nectar food for the natural enemies. Staggered planting of flowering plants ensured the availability of flowers for a longer duration in the rice growing season. It has also given the broader window for the availability of floral resources and food for the natural enemies. We can suggest that increased flowering plant diversity around the rice crop field positively increases the natural enemy activity and helps suppress the pest population. Higher activity of natural enemies like spiders and mirid bugs in the ecologically engineered plots may manage the BPH population and slow the population build-up throughout the rice season. Similar results were in some initial ecological engineering studies (Yu *et al*., 2001; Gurr *et al*., 2011; Liu *et al*., 2014). Inundation of flowering plants around main crops reduces the pest population by enhancing the natural enemy activity (Zhu *et al*., 2015; Chen *et al*., 2016; Kong *et al*., 2016; Keerthi *et al.,* 2016;). The presence of grasses and weed flora around rice fields (Chen *et al*., 2016) and the planting of sesamum crops on bunds as a source of nectar (Zhu *et al*., 2015; Yele *et al*., 2022) reduce pest abundance in rice fields.

Similarly, intercropping zizania, planting vetiver grass along irrigation canals and releasing *Trichogramma* lowered the pest activity in the rice fields (Zhu *et al*., 2017). Implementation of ecological engineering techniques has increased the activity of egg parasitoids of planthoppers like *Oligosita* and *Anagrus,* leading to a significant reduction in the planthopper's population in rice (Zhu *et al*., 2015).

Planting sesame around the rice crops is a known measure to improve the natural enemy activity in the rice plots, which helps suppress pest populations. Planting flowering plants like marigolds, balsam and gaillardia around the rice plots helps attract natural enemies by providing them with nectar and a harboring/resting place around the rice fields. Zhu (*et al.,* 2014) proposed that flowering plants like *T. erecta, T. procumbens, E. sonchifolia* and *S. indicum* around the rice reduced the planthopper pest population and increased the abundance of natural enemies like mirid bugs. Predation efficiency and consumption of BPH by *C. lividipennis* increased in flower treatment plots. Among all flower plants, *S. indicum* was the most favorable and strongly promoted predation of *C. lividipennis.* These results align with our present study and suggest that *S. indicum* is well suited for ecological engineering on bunds of rice crops. *Anagrus* spp. and *A. nilaparvatae* are egg parasitoids that play a relevant role in the management of leaf and plant hoppers (Yu *et al*., 2001; Gurr *et al*., 2011).

Deleted: favourable

Our findings complement previous studies showing that ecological engineering technology can keep rice pest populations lower than conventional cultivation throughout the rice growing season without hampering the yield component.

Olfactometers studies revealed that the volatile compounds emitted by plant species like *S. indicum*, *I. balsamina, E. sonchifolia, T. procumbens and H. esculentus* attract the *Anagrus* spp. Parasitoids also enhance their biological performance (Zhu *et al*., 2013). Notably, ample access to the sesame flowers enhances the life span of *A. nilaparvatae* and *A. optabilis*. In line with this, our olfactometer study also revealed the highest attraction of spiders towards sesamum and balsam leaves. The volatile released by these plants may have the potential to attract spiders towards the plants. Ample availability of nectar food for bioagents not only improves the reproductive abilities of natural enemies but also improves survival and host searching ability, thus playing a pivotal role in enhancing the biological control ability of natural enemies (Wackers *et al.,* 2005: Poddar *et al*., 2019). Planting nectar and floral resources like sesame, marigold, sunflower etc., in the near vicinity of the crop is effective in improving biological control and conservation of biocontrol agents (Lu and Guo, 2015).

Access to the sesamum flowers significantly enhances the adult parasitoid longevity and parasitization rate on BPH eggs (Zhu *et al*., 2012). Likewise, the fecundity of egg parasitoid *T.*

chilonis on lepidopterous pests significantly increases by sesamum flower access. Sesamum flowers also enhance the longevity of egg parasitoids of lepidopterous pests like pink stem borers, spotted stem borers and leaf folders without hosting these pests (Zhu *et al.*, 2012; Zhu *et al.*, 2015).

Conclusion

Vegetation around the field has a significant effect on enhancing the structural and functional diversity of arthropods. The availability of structural habitats in the form of vegetative growth of crops, floral resources, longer flowering duration, and nectar provided by diverse vegetation greatly enhances natural enemies' activity. Higher natural enemy activities in the ecologically engineered fields directly affect the incidence and population build-up of *N. lugens*. An ecological engineering technique aims to reduce pest damage by maximizing natural mortality through the strategic introduction of plant diversity. Ecological engineering has great potential and will develop rapidly as a fully available and effective biological pest control action within the IPM strategy. We consider planting oilseed crop plants such as sesamum, sunflower and soybean and flowering crops such as marigold, balsam and gaillardia on the bunds around the main rice field alone or in combination enhances the natural enemy activity allowing the management of the *N. lugens* population infesting rice. With growing awareness about the effects of insecticides among farmers, an ecological engineering technique paves the way for sustainable pest management in rice. Ecological engineering technique has great potential in reducing the pesticide use for plant protection. In today's changing climate scenario, ecological engineering techniques are an ecologically sustainable option for biotic stress mitigations in climate resilient agriculture. Also, there is need to promote it as pest smart strategy for climate smart agriculture. Here we recommend adopting and developing this ecological engineering technique in the IPM module for sustainable *N. lugens* management in rice. Further large-scale studies and farmers field trials are needed to evaluate diverse flowering plants to embed into this ecological engineering approach.

Acknowledgement

Authors thank Director, ICAR-Indian Agriculture Research Institute, New Delhi for providing necessary facilities for the research.

Additional Information and Declarations

Funding

No funding required.

Grant Disclosures

NA

Competing Interests

Authors declare no competing interest.

Author Contributions

- YY, SC and SSS conceived and designed the experiments, performed the experiments, analyzed the data, prepared figures and tables, prepared drafts of the article, and approved the final draft.
- SMN, PT and APS analyzed the data and approved the final draft.

References

Atanassov A, Shearer PW, Hamilton G, Polk D. 2002. Development and implementation of a reduced risk peach arthropod management program in New Jersey. *Journal of Economic Entomology* **95**:803-812.

Behura N, Sen P, Kar MK. 2011. Introgression of yellow stem borer (*Scirphophaga incertulas*) resistance gene, into cultivated rice (*Oryza* spp.) from wild spp. *Indian Journal of Agricultural Sciences* **81**:359-362.

Berndt LA, Wratten SD, Scarratt SL. 2006. The influence of floral resource subsidies on parasitism rates of leafrollers (Lepidoptera: Tortricidae) in New Zealand vineyards. *Biological Control* **37**:50-55.

Catindig JLA, Arida GS, Baehaki, SE, Bentur JS, Cuong LQ, Norowi M, Rattanakarn W, Sriratanasak W, Xia J, Lu Z, Heong, KL. 2009. Situation of planthoppers in Asia. In: Heong KL, Hardy B, eds. *Planthoppers: New Threats to the Sustainability of Intensive Rice Production Systems*. Los Baños: International Rice Research Institute, 191-220.

Chandrasekar K, Muthukrishnan N, Soundararajan RP. 2017. Ecological engineering cropping methods for enhancing predator, *Cyrtorhinus lividipennis* (Reuter) and suppression of planthopper, *Nilaparvata lugens* (Stal) in rice-weeds as border cropping system.*Journal of Pharmacognosy and Phytochemistry* **6**:2387-2391.

Chen GH, Zhu PY, Zheng XS, Yao XM, Zhang FC, Sheng XQ, Xu HX, Lu ZX. 2016. The practice of ecological engineering on the control of rice insect pests in Jinhua. *China Plant Protection* **36**:31-36.

Cheng JA. 2009. Rice planthopper problems and relevant causes in China. In: Heong KL, Hardy B, eds. *Planthoppers: New Threats to the Sustainability of Intensive Rice Production Systems in Asia*. Los Baños: International Rice Research Institute, 157-178.

Dent D. 1991. Insect pest management. Wallingford (UK): CAB International 604 pp.

Fand BB, Amala U, Yadav DS, Rathi G, Mhaske SH, Upadhyay A, Ahammed Shabeer TP, Kumbhar DR.2020. Bacterial volatiles from mealybug honeydew exhibit kairomonal activity toward solitary endoparasitoid *Anagyrus dactylopii*. *Journal of Pest Science* **93**(1):195-206.

Gillespie KM, Rogers A, Ainsworth EA. 2011. Growth at elevated ozone or elevated carbon dioxide concentration alters antioxidant capacity and response to acute oxidative stress in soybean (*Glycine max*). *Journal of Experimental Botany* **62**:2667-2678.

Gurr GM, Liu J, Read DM,Catindig JLA, Cheng JA, Lan LP, Heong KL. 2011. Parasitoids of Asian rice planthopper (Hemiptera: Delphacidae) pests and prospects for enhancing biological control by ecological engineering. *Annals of Applied Biology* **158**:149-176.

Gurr GM. 2009. Prospects for ecological engineering for planthoppers and other arthropod pests in rice. *Planthoppers: New threats to the sustainability of intensive rice production systems in Asia*, 371-388.

Horgan FG, Ramal AF, Bentur JS, Kumar R, Bhanu KV, Sarao PS, Iswanto EH, Van Chien, H, Phyu MH, Bernal CC, Almazan MLP. 2015. Virulence of brown planthopper (*Nilaparvata lugens*) populations from South and South East Asia against resistant rice varieties. *Crop Protection* **78**:222-231.

Horgan FG, Ramal AF, Bernal CC, Villegas JM, Stuart AM, Almazan ML. 2016. Applying ecological engineering for sustainable and resilient rice production systems. *Procedia food science* **6**:7-15.

Jado RH, Araj SE, Abu-Irmaileh B, Shields MW, Wratten SD. 2019. Floral resources to enhance the potential of the parasitoid *Aphidius colemani* for biological control of the aphid *Myzus persicae*. *Journal of Applied Entomology* **143**:34-42.

Keerthi MC, Sharma RK, Suroshe SS, Sinha SR. 2016. Ecological engineering in cauliflower for aphid management. *Indian Journal of Agricultural Sciences* **90**(7): 1356-1358.

Kong SS, Zheng SJ, Zhu PY, Zheng XS, Zheng RQ, Lu ZX. 2016. Survey of amphibian diversity in the paddy field on controlling rice pests by ecological engineering. *China Plant Protection* **36**:10-14.

Liu GL, Zhang XM, Zhao LW, Zhang JL, Wang XT, Chen YB, Zheng XS. 2014. Application of ecological engineering technology for managing rice pests and the benefit analysis. *Journal of Zhejiang Agricultural Sciences* **55**:1809-1811.

Lu ZX, Guo R. 2015. Ecological engineering methods to manage rice insect pests. In: Ministry of Agriculture. Agricultural Leading Varieties and Mainstay Technologies in 2015. Beijing: China Agricultural Press: 274 pp.

Lv Z, Zhu P, Gurr GM, Zheng X, Chen G, Heong KL. 2015. Rice pest management by ecological engineering: a pioneering attempt in China. In: Heong KL, Cheng J, Escalada MM. eds. *Rice planthoppers: Ecology, management, socio economics and policy*. Beijing: Springer science and Business Media, 161-178.

Matsumura M, Takeuchi H, Satoh M, Sanada-Morimura S, Otuka A, Watanabe T, Van Thanh D. 2008. Species-specific insecticide resistance to imidacloprid and fipronil in the rice planthoppers *Nilaparvata lugens* and *Sogetella furcifera* in East and South-East Asia. *Pest Management Science* **64**:115-1121.

Poddar N, Yele Y, Kumari A. 2019. Cropping System Approach in IPM. In:Prasad D, Gopal L, Imtiyaz A, eds. *Adaptive Crop Protection Management Strategies.* Write and Print Publications, New Delhi, 358-371.

Pretty JN. 1998. Supportive policies and practice for scaling up sustainable agriculture. *Facilitating sustainable agriculture: participatory learning and adaptive management in times of environmental uncertainty*, 23-45.

Wackers FL, van Rijn PCJ, Bruin, J. eds., 2005.*Plant-provided food for carnivorous insects: a protective mutualism and its applications*. Cambridge University Press 356 pp.

YeleY, Chander S, Suroshe SS, Nebapure SM, Arya PS, Prabhulinga T. 2022. Effect of ecological engineering on incidence of key rice pests. *Indian Journal of Entomology* **84**(3):503-508.

Yele Y, Singh SK, Tanwar A, Poddar N. 2020. Off-season and carry over hosts of Bemisia tabaci in north India. *Indian Journal of Entomology* **82**(2): 397-399.

Yu XP, Barrion AT, Lu ZX. 2001. A taxonomic investigation on egg parasitoid, *Anagrus* of rice planthopper in Zhejiang Province. *Chinese Rice Research Newsletter* **9**:8-9.

Zheng X, Lu Y, Zhu P, Zhang F, Tian J, Xu H, Chen G, Nansen C, Lu Z. 2017. Use of banker plant system for sustainable management of the most important insect pest in rice fields in China. *Scientific Reports* **7**:1-8.

Zhu P, Gurr GM, Lu Z, Heong KL, Chen G, Zheng X, Yang Y. 2013. Laboratory screening supports the selection of sesame (*Sesamum indicum*) to enhance *Anagrus* spp. parasitoids (Hymenoptera: Mymaridae) of rice planthoppers. *Biological Control* **64**:83-89.

Zhu P, Zheng X, Zhang F, Xu H, Yao X, Yang Y, Chen G. 2017. Aquatic insect populations in paddy fields as affected by management of rice insect pests through ecological engineering technology. *Chinese Journal of Rice Science* **31**:207-215.

Zhu PY, Lu ZX, Gurr G, Zheng XS, Read D, Yang YJ, Xu HX. 2012. Ecological functions of flowering plants on conservation of the arthropod natural enemies of insect pests in agroecosystem. *Chinese Journal of Biological Control* **28**:583-588.

Zhu PY, Lu ZX, Heong KL, Chen GH, Zheng XS, Xu HX, Yang YJ, Nicol HI &Gurr GM. 2014. Selection of nectar plants for use in ecological engineering to promote biological control of rice pests by the predatory bug, *Cyrtorhinus lividipennis* (Heteroptera: Miridae). *PLoS One* **9**:108669.

Zhu PY, Zheng XS, Yao XM, Xu HX, Zhang FC, Chen GH, Lu ZX. 2015. Ecological engineering technology for enhancement of biological control capacity of egg parasitoids against rice planthoppers in paddy fields. *China Plant Protection* **35**:27-32.