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Eco-Engineering for Managing Insect Pests in Rice Fields

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ABSTRACT

This study was consisted of eight experiments across Boro and Transplanted Aman seasons in various locations in Bangladesh to explore eco-friendly insect pest control methods in rice fields. The primary objectives were to safeguard natural-enemies through ecological engineering techniques and minimize the use of insecticides in rice farming. Ecological engineering aimed to boost biodiversity in the rice environment, fostering both plant and animal diversity to offer extra support for natural enemies in terms of sustenance and shelter. To fulfill these objectives, nectar-rich flowering plants such as marigold, cosmos, sesame and sunflower were planted strategically in rice bunds ensuring habitats by establishing crucial sources of food and protection for beneficial insects. These beneficial insects, in turn, contribute to biological pest control by establishing an equilibrium between harmful and beneficial insects within the rice ecosystem and consequently reducing the dependency on insecticides. The study consisted of two treatments, T_1: Rice fields with flowering plants on bunds; and T_2: Farmer's practice of prophylactic insecticide use. The study observed a significant increase in the predators and parasitoids abundance in eco-engineering field (T_1) compared to insecticide-treated fields (T_2). Across seasons and locations, T_1 consistently showed higher populations of various beneficial insects such as spiders, damsel flies, dragon flies, ladybird beetles, carabid beetles, staphylinid beetles, green mirid bugs, and parasitic wasps compared to T_2. Notably, despite maintaining insect infestation below the economic threshold level in both T_1 and T_2, T_1 exhibited significantly higher egg parasitism rates of rice hispa, brown planthopper, yellow stem borer, and rice leafroller compared to T_2. Remarkably, on average while achieved statistically similar yields between T_1 and T_2 (5.99 t/ha and 5.93 t/ha, respectively), the study highlights the efficacy of manipulating habitats to enhance biocontrol services in rice fields. By providing nectar sources, alternative prey, and refuges for natural enemies, this approach offers promising prospects for reducing insecticide usage in rice fields by maintaining or potentially increasing rice yield equivalents.

Key words: Eco-engineering, natural enemies, flowering plants, predator and parasitoid.

INTRODUCTION

The global imperative for increased rice production, driven by burgeoning populations worldwide, poses a pressing challenge, particularly in countries like Bangladesh (Kennedy, 2002; Miao *et al*., 2011). Central to this challenge is the prevalence of diverse arthropod pests that ravage rice fields. Bangladesh's rice ecosystems have seen a recorded count of 266 arthropod species and 375 natural enemies (comprising predators and parasitoids) that play crucial roles in these ecosystems (Islam *et al.,* 2003; 2012; Roy *et al.,* 2024). These myriad arthropods perform diverse ecological roles, ranging from herbivory on rice plants to activities such as parasitization, predation, pollination, decomposition, and nutrient cycling. The complex interactions among rice plants, pests, and a wide variety of natural enemy species aim to establish balances that deter

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abnormal pest outbreaks.

However, the pervasive use of synthetic pesticides poses a significant challenge, proving hazardous not only to target pests but also to non-target organisms (Ahmed *et al.,* 2002; 2011). Farmers in Bangladesh resort to chemical pesticides, particularly during the early stages of crop growth when pest populations might not inflict substantial damage (Bari *et al*., 2015). Evidence suggests that refraining from harmful pesticide use during this critical period, approximately 30 to 40 days after rice transplanting allows natural enemy populations to curb abnormal pest outbreaks and prevent significant harm to crops (BRRI, 2016).

Varied management practices prevail among farmers across Bangladesh, and some alternative technologies aim to reduce chemical pesticide reliance in rice production (Bari *et al*., 2015). One such strategy is ecological engineering, which aims to rejuvenate or augment biodiversity in the rice ecosystem, catering to both flora and fauna species. This approach improves vital resources for natural-enemies, such as shelter and food. The application of ecological engineering entails cultural practices, primarily centered around vegetation management, with the objective of reinforcing biological control or the direct impacts on pests known as 'bottom-up' effects (Gurr *et al.,* 2004).

The provision of resources like sap and pollen to the predators fosters bio-control, whereas pesticides diminish natural enemy populations, impairing this biological control (Heong, 2009). Manipulation in insect's habitat to bolster biological control has been explored keenly across various crops (Landis *et al*., 2000). This strategy intends to enhance the activity of natural-enemy by providing enough resources that augment their performance, including alternative foods specially, when the prey or the hosts are intermittently unavailable (Gurr, 2009).

Several studies underscore the efficacy of ecological engineering. As an example, a field investigation carried out in Vietnam showed that cultivating flowering plants with abundant nectar on the embankments of rice fields substantially elevated the abundance of natural-enemies and had an effect on the incidence of rice planthopper infestation (Lan *et al.,* 2010). This approach encompasses three key ecological policies to heighten suppression of insect pest (Gurr *et al.,* 2012). Firstly, reducing the application of insecticide application at the early cropping stages decreases mortality among beneficial arthropods. Secondly, offering alternative food sources to predators during these stages, coupled with refraining from early-season insecticide use, enhances their efficacy. Finally, habitat manipulation, such as planting flowering plants on the embankment of rice field which contain nectar, bolsters hymenopteran parasitoids.

This ecological engineering approach holds immense promise in cultivating ecosystem services to bolster pest suppression sustainably (Gurr *et al*., 2011). The existence of nectar-rich flowering plants on levees not only aids pest parasitoids by providing nourishment but also serves as a potential communication tool to encourage farmers to reduce insecticide usage, countering the influence of pervasive insecticide commercialization like marketing and advertising to increase public awareness (Escalada and Heong, 2012).

Based on these foundations, this research aimed to preserve natural-enemies through ecological engineering methods, specifically by growing flowering plants rich in nectar on embankments, with the goal of reducing the reliance on insecticides in rice cultivation.

MATERIALS AND METHODS

During the Boro seasons of 2018-19 and 2019-20, a series of experiments were conducted involving different rice varieties. In the Boro 2018-19 season, experiments were carried out at BRRI Gazipur and a farmer's field in Rajshahi, where test varieties were BRRI dhan28 and BRRI dhan63 respectively. Additionally, experiments with BRRI dhan88 were conducted at both BRRI HQ Gazipur (Photo-1) and Charbadna farm at BRRI Regional Station (RS), Barishal, during the Boro 2019-20 season. The experiment was carried out by Complete Randomized Design (CRD) with three replications. The size of each treatments was 400 m^2 and the plot size of each replicated treatment was 133 m^2.

The treatments employed were as follows: T_1 involved cultivating flowering-plants (Marigold, cosmos, and sunflower) at bunds within the rice fields to provide essential food and shelter for various parasitoids. The width of the flowering bunds was 50 cm. T_2 represented the standard farmer's practice, encompassing prophylactic insecticide use. In T_2, different insecticides, viz., carbofuran 5G, chlorpyrifos 20EC, and (chlorantraniliprole + thiamethoxam) 40WG-were applied four times at 10.0kg ha^{-1}, 1.0 L ha^{-1} and 75 g ha^{-1} doses respectively, following a 15-day interval after the first urea fertilizer top dressing (after 20 DAT). Among the three insecticide carbofuran 5G was used first two times followed by other two insecticides one time.

BRRI dhan87 were used in T. Aman 2019 season, at BRRI HQ farm, Gazipur, BRRI RS Rajshahi, and a farmers' field in Alimganj, Paba, Rajshahi. In T. Aman 2020, an experiment was done solely at BRRI, Gazipur (Photo-2). Similar treatments (T_1 and T_2) were implemented across all locations: T_1 involved cultivating sesame and cosmos on rice bunds, while T_2 replicated the farmers' standard practice of prophylactic insecticide use. The same three insecticides utilized during the Boro season were applied three times in T_2. At first granular insecticide (carbofuran 5G) was applied during the first urea fertilizer top dressing (after 20 DAT) following a 15-day interval of other two insecticides. In T. Aman season, 20 days old seedling and in case of Boro season 35-day old seedling were transplanted in both the treatments at a time.

Uniformly across seasons and locations, twenty complete sweeps were conducted from both the treatments at 15-day intervals until the flowering stage. Insect pests and their predators and parasitoids were counted from all the sweeps, meticulously recorded and tallied separately. Additionally, the egg parasitism rates of rice hispa (RH), brown planthopper (BPH), and yellow stem borer (YSB) were determined using the retrieval method. Moreover, larval parasitism of rice leafroller (RLR) from natural infestation was exclusively evaluated at BRRI HQ, Gazipur across various seasons.

Statistical analysis: All data were subjected to statistical analysis separately by using the analysis of variance technique by R software (versions-2024.04.0) using 'doebioresearch' package.

Photo-1. Scenario of eco-engineering maintained plot at BRRI HQ, Gazipur, during Boro 2019-20.

Photo-2. Scenario of eco-engineering maintained plot at BRRI HQ, Gazipur, during T. Aman 2020.

RESULTS

Across seasons and locations, the incidence of insect infestation consistently persisted beneath the economic threshold level (ETL). Notably, insect pest prevalence was comparatively lower during the Boro season than in the T. Aman season.

During Boro 2018-19 season, the highest numbers of grasshoppers (GH) were observed in T_1 (5.50/20 sweep) at BRRI

Gazipur, followed by green leafhoppers (GLH), long-horned grasshoppers (LHG), and rice bugs (RB) at 1.0, 0.75, and 0.75/20 sweep respectively (Fig. 1). Similarly, in the farmer's field at Alimganj, Paba, Rajshahi, the highest GH count was 6.0/20 sweep in T_1, followed by brown planthoppers (BPH) at 3.0/20 sweep (Fig.1). Natural enemies, notably spiders (SPD), showed higher numbers in T_1 compared to T_2 at both BRRI Gazipur and farmer's field, Alimganj, Paba, Rajshahi (Fig. 2).

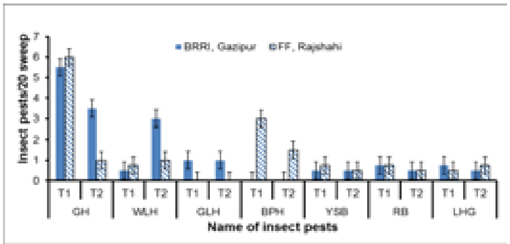

Fig.1. Insect pest population/ 20 sweep in different treatments at BRRI, Gazipur and farmers field, Rajshahi during Boro 2018-19 (T_1=Flowering plants on levee, T_2= Farmers practice/insecticide application)

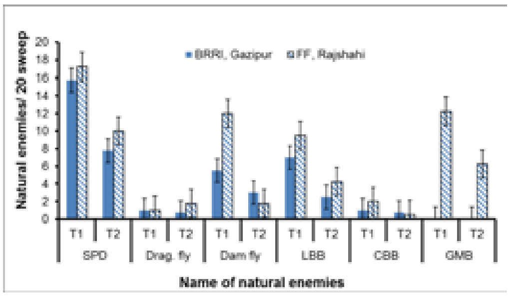

Fig.2. Predator (natural enemies) population/20 sweep in different treatments at BRRI, Gazipur and farmers field, Rajshahi during Boro 2018-19, (T_1=Rice field with flowering plants on bunds, T_2= Farmers practice / insecticide application)

Remarkably, in Boro 2018-19 at BRRI Gazipur, despite three applications of insecticides in T_2, comparable yields were observed between T_1 (7.06 t/ha) and T_2 (7.01 t/ha). Additionally, egg parasitism rates for RH, BPH, and YSB were notably higher in T_1 (59.2%, 13.5%, and 24.0% respectively) compared to T_2 (Table 1). In Rajshahi, similar yields were also observed in T_1 (4.55 t/ha) and T_2 (4.57 t/ha).

During Boro 2019-20, the incidence of GH and GLH was the lowest in both T_1 and T_2 at BRRI Gazipur (Fig.3). However, the population of the insect pests was more at Charbadna farm, BRRI RS, Barishal, with the highest GLH and GH counts in T_2 (Fig. 3). Natural enemies showed higher numbers in T_1 at both BRRI, Gazipur and Barishal, with notable exceptions such as staphylinid beetles and parasitic wasps that were absent in T_2 at BRRI, Gazipur (Fig. 4).

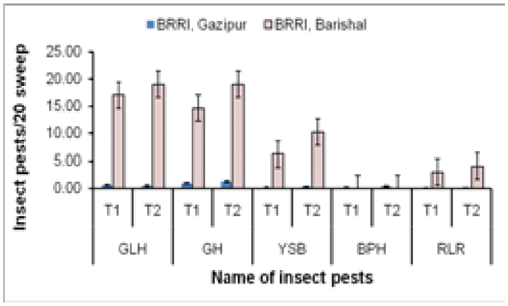

Fig.3. Insect pest population/20 sweep in different treatments at Gazipur and BRRI Barishal farm during Boro 2019-20, BRRI, (T_1=Rice field with flowering plants on bunds, T_2= Farmers practice /insecticide application)

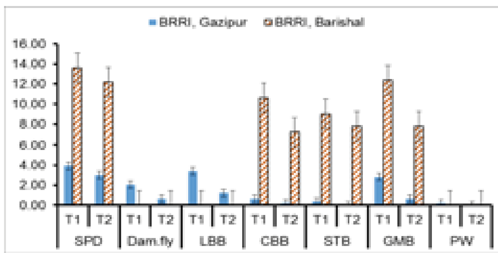

Fig.4. Predator (natural enemies) population/20 sweep in different treatments at Gazipur and BRRI Barishal during Boro 2019-20, BRRI, (T_1=Rice field with flowering plants on bunds, T_2= Farmers practice i.e., insecticide application)

In T_2 insecticide used three times both in BRRI Gazipur and BRRI RS Barishal. But similar yield was obtained both in T_1 and T_2 (7.82 and 7.85 t/ha respectively at BRRI, Gazipur and 6.71 and 6.72 t/ha respectively at BRRI RS Barishal) (Table 1).

During the T. Aman 2019 season, comparable levels of harmful and beneficial insects were observed across all locations, albeit with a higher incidence in T. Aman season compared to the Boro season. At BRRI Gazipur, T_1 exhibited the highest count of grasshoppers (GH) followed by white leafhoppers (WLH), green leafhoppers (GLH), and rice leaf folders (RLF). Lower pest incidence was noted at BRRI RS Rajshahi and in the farmers' fields of Rajshahi (Fig. 5). Moreover, T_1 consistently showed a higher population of predator, including damsel flies, spiders, ladybird beetles, carabid beetles, and dragon flies compared to T_2 at BRRI farm, Gazipur (Fig. 6). The locations BRRI RS Rajshahi and farmer's fields of Rajshahi displayed the highest count of beneficials and the lowest insect incidence. Across seasons and locations, T_1, consistently harbored more natural enemies. Additionally, T_1 displayed significantly higher egg parasitism rates for brown planthopper (BPH), yellow stem borer (YSB), and larval parasitism for rice leaf rollers (RLR) compared to T_2 at BRRI, Gazipur. Grain yield was similar between T_1 and T_2; however, T_1 additional sesame production substantially increased the rice equivalent yield (REY) to 7.0 t/ha (Table 2). This trend was also observed at BRRI RS Rajshahi and farmer's fields of Rajshahi, where REY was higher in T_1 compared to T_2 (Table 2). Although insecticides were used three- and four-times during T. Aman and Boro seasons in T_2, respectively, the yield remained comparable to that of T_1. However, T_1 generated extra profit due to additional production of crops in bunds without the use of insecticide.

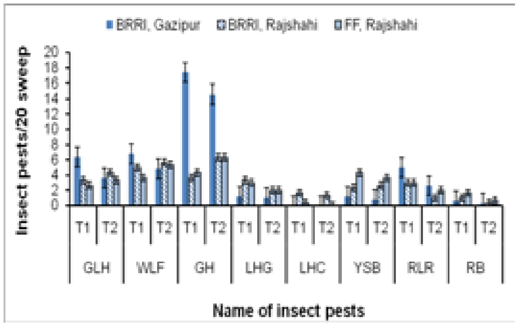

Fig.5. Insect pest population/ 20 sweep in different treatments at BRRI, Gazipur, BRRI Rajshahi and Farmers field, Rajshahi during T. Aman 2019, (T_1=Rice field with flowering plants on bunds, T_2= Farmers practice / insecticide application)

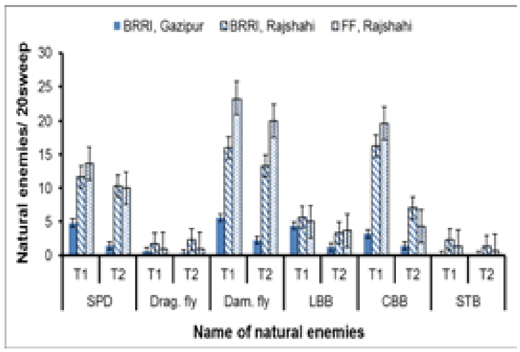

Fig.6. Predator (natural enemies) population/20 sweep in different treatments at BRRI,Gazipur, BRRI, Rajshahi and Farmers field, Rajshahi during T. Aman 2019, (T_1=Rice field with flowering plants on bunds, T_2= Farmers practice/insecticide application)

In the T. Aman 2020 season, T_1 at BRRI, Gazipur exhibited the highest count of grasshoppers, followed by rice leaf folders, green leafhoppers, and white leafhoppers (Fig. 7). Conversely, T_2 showed a lower incidence of insect pests. Similarly, T_1 displayed a higher count of predators like spiders, damsel flies, ladybird beetles, carabid beetles, and dragon flies compared to T_2 at BRRI farm, Gazipur (Fig. 7). T_1 also demonstrated higher egg parasitism rates for

YSB and larval parasitism for RLR compared to T_2 at BRRI, Gazipur (Table 2). Grain yield was similar between T_1 and T_2; however, the additional sesame production in T_1 significantly raised the REY to 5.12 t/ha (Table 2). Challenges faced by BRRI dhan87 due to lodging during the soft dough stage of the crop resulting lower yield in both the treatments. Treatment T_2, where insecticides were used four times, yielded similarly to T_1. Yet, T_1 yielded additional profit due to increased sesame production without the use of insecticide.

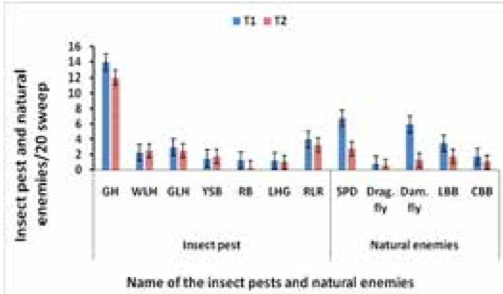

Fig.7. Insect pest and beneficial insects (natural enemies)/20 sweep in different treatments at BRRI, Gazipur during T. Aman 2020, (T_1=Rice field with flowering plants on bunds, T_2= Farmers practice/insecticide application)

Table 1. Parasitism (%) and yield of different treatments in different locations during boro season.

Treatment	Boro 2018-19					Boro 2019-20	
	BRRI Gazipur				FF Rajshahi	BRRI Gazipur	BRRI Barishal
	RH PP	BPH PP	YSB PP	GY ($t\ ha^{-1}$)	GY ($t\ ha^{-1}$)	GY ($t\ ha^{-1}$)	GY ($t\ ha^{-1}$)
T_1	59.20 a	13.5 a	24 a	7.06	4.55	7.82	6.71
T_2	17.83 b	0.0 b	0.00 b	7.01	4.57	7.85	6.70
Levels of significance	***	***	***	ns	ns	ns	ns
LSD (5%)	2.05	1.60	3.21	-	-	-	-
CV	2.35	10.48	11.79	1.35	7.98	2.91	7.58

(Where, T_1=Rice field with flowering plants on bunds, T_2= Farmer'ss practice/insecticide application, RH=Rice Hispa, BPH=Brown Planthopper, YSB=Yellow Stem Borer, GY=Grain Yield, PP=Parasitism Percentage, GY= Grain yield)

Table 2. Percent parasitism and yield of different treatments in different locations during T. Aman season.

Treatment	T. Aman 2019 BRRI Gazipur					T. Aman 2020 BRRI, Gazipur				T. Aman 2019			
										BRRI Rajshahi		FF Rajshahi	
	BPH PP	RLR PP	YSB PP	GY ($t\ ha^{-1}$)	REY ($t\ ha^{-1}$)	RLR PP	YSB PP	GY ($t\ ha^{-1}$)	REY ($t\ ha^{-1}$)	GY ($t\ ha^{-1}$)	REY ($t\ ha^{-1}$)	GY ($t\ ha^{-1}$)	REY ($t\ ha^{-1}$)
T_1	23.67 a	29.23 a	34.35a	5.60	7.0a	19.22a	25.39a	5.60	7.10 a	6.00	7.49a	4.53	6.03 a
T_2	3.67 b	4.40 b	0.0 b	5.65	5.65b	1.25 b	0.0 b	5.65	5.65b	5.70	5.70 b	4.41	4.41 b
Levels of significance	***	***	***	***	ns	***	***	ns	**	Ns	**	ns	***
LSD (5%)	1.60	1.61	1.60	3.21	-	0.42	1.60	-	0.49	-	0.26	-	0.09
CV	5.13	4.23	4.13	11.79	5.15	1.80	5.57	5.06	3.39	4.98	1.13	3.54	0.54

(Where, RLR=Rice Leaf Roller, BPH=Brown Planthopper, YSB=Yellow Stem Borer, GY=Grain Yield, REY= Rice Equivalent Yield, PP=Parasitism Percentage, T_1=Rice field with flowering plants on bunds, T_2= Farmers practice/insecticide application, FF= Farmers field)

DISCUSSION

In rice production, insecticides are frequently employed to manage insect pests and ensure optimal yields. Bangladesh's rice ecosystem harbors 232 detrimental insect species, 183 parasitoids, and 192 predators, among which only 20-33 species pose significant threats, capable of inducing yield losses when present in substantial numbers (Islam *et al*., 2003; 2012). Predators and parasitoids naturally regulate these pests in the field. However, the initiation of the modern rice varieties in the last three decades, driven by the need to feed growing populations in countries like Bangladesh, has led to extensive chemical insecticide use. These pesticides diminish natural enemy populations, impeding biological control and fostering pest outbreaks (Heong, 2015).

Habitat manipulation, aimed at augmenting biological control, has been explored across various crops (Landis *et al*., 2000). Thus, this strategy strives to augment the effectiveness of natural enemies by supplying resources that bolster their performance when prey or hosts are scarce (Gurr, 2009). Materials like nectar have been demonstrated to extend the lifespan, improve foraging efficiency, and increase the actual parasitism of various parasitoid species. (Mitsunaga *et al*., 2006; Shearer and Atanassov, 2004; Zhu *et al*., 2013; Lou *et al*., 2014).

The eco-engineering technique for rice insect control, pioneered by the International Rice Research Institute (IRRI) and was started in countries like China, Vietnam, and Thailand in 2008, has shown promising results. Vietnamese studies demonstrated that cultivating nectar plants alongside rice crops on bunds significantly bolstered the population and effect of beneficials on rice planthopper species (Lan *et al*., 2010).

Our study modified the existing rice ecosystem by implementing ecological engineering techniques, planting flowering—plants carrying nectar such as sunflower, sesame, marigold, and cosmos on bunds around rice fields. These plants provided crucial resources like food, shelter, and nutrients, facilitating the growth and development of biocontrol agents within the rice ecosystem (Photos 1 and 2). Parasitoids frequently consumed nectar from these flowers, improving their fitness (Zhang *et al*., 2017). Our results demonstrated a substantial increase in parasitoids and predators' abundance (Figs 2, 4 and 6), leading to enhanced parasitism rates of rice planthopper, yellow stem borer eggs and rice hispa in rice fields (Table 1).

During the T. Aman season, sesame flowers on bunds served as essential resources for natural enemies, particularly hymenopteran parasitoids. These flowers significantly improved the efficacy of the genus *Anagrus*- an egg parasitoid of planthopper (Gurr *et al.,* 2011). Zhang *et al.* (2017) announced that incorporating nectar containing plants and discontinuing insecticide use increased egg parasitism rates of planthopper significantly and enhanced egg parasitism of lepidopteran insects in rice ecosystem.

The integration of flowering-plants in our study, which contain nectar and stand on rice bunds are primarily beneficial for parasitoids and act as crucial global pest control agents (Macfadyen *et al*., 2015). Numerous parasitoids, effective against pests like *Scirpophaga incertulas*, *Dicladispa armigera*, *Cnaphalocrosis suppressalis*, *C. medinalis* and planthoppers, were identified (Lu *et al*., 2014). The *Anagrus* spp., commonly prevailed in our experiment, have shown effectiveness opposed to planthoppers in various Asian countries which are rice growing (Gurr *et al*., 2011; Lu *et al*., 2014).

Additionally, rice plots with plants on levees having nectar gave shelter more predators compared to those treated with insecticides. Spiders are highly effective predators globally and in rice fields (Lu *et al*., 2014; Bamberadeniya and Edirisinghe, 2009; Wang *et al*., 2017). Global spider communities have the capacity to eliminate approximately 800 million tons of insect pest species, estimated by Nyffeler and Birkhofer (2017) and (Lu *et al*., 2005) stated that *Tetragnathidae* being the predominant spider taxon in rice ecosystems.

Conversely, the T_2 treatment, which involved the application of broad-spectrum insecticides 3 to 4 times without the presence of flowering plants, exhibited lower parasitism rate and captures of parasitoids for planthopper, coleopteran, lepidopteran eggs and larvae. Insecticide application decreased parasitoid abundance, resulting in reduced parasitism rates various insects like yellow stem borer, planthopper and rice hispa eggs, as well as rice leafroller larvae. Insecticide use is known to negatively impact planthopper natural enemies (Chien and Cuong, 2009; Teo, 2011; Zhang *et al*., 2017), potentially inducing planthopper outbreaks by diminishing parasitoids and predators (Sogawa, 2019).

Evidently, the rice field in close proximity to flowering plants abundant in nectar, without any insecticide treatment, harbored the greatest abundance of beneficials and the least incidence of harmful insects. In contrast, the use of insecticides (T_2 treatment) resulted in the lowest count of beneficials and parasitism rates. This highlights the influence of insecticide application in diminishing parasitoids and the rates of parasitism for the examined eggs of insect pests (Gurr *et al*., 2016).

Insect infestation was beneath the ETL in the T_1 plots. Notably, regular insecticide application in rice fields (T_2) did not boost yields, aligning with findings by (Ali *et al*., 2017), who demonstrated comparable rice yields without insecticide application, emphasizing the reduction in insecticide use and farmers cultivation cost in rice production. Our experiment outcomes emphasize that altering the current rice ecosystem using eco-engineering effectively managed pests without compromising crop yield. The T_1 treatment, in particular, enhances sound environment and faunal biodiversity, simultaneously improving the visual appeal of the rice ecosystem. Introducing nectar rich flowering plants on levee could also serve as supplementary income sources for economically disadvantaged rice farmers. Although sunflower, cosmos, sesame and marigold were utilized in this study- other appropriate crops such as okra and common bean, featuring nectar-rich flowers, could yield more advantages.

CONCLUSION

Sap-rich flowering plants presence on levee resulted in the highest count of beneficials and the greatest percentage of parasitism observed in rice fields, targeting insect pest eggs and larvae. Conversely, rice fields surrounded by flowering plants exhibited no observable decrease in yield in comparison with insecticides. This discovery suggests that farmers have the potential to reduce or eliminate the application of hazardous and toxic insecticides for pest management by incorporating flowering plants along rice bunds which are rich of nectar. This approach holds potential for ecosystem revitalization, contributing to the preservation of natural-enemies. Ultimately, it aids in reducing production expenses and environment pollution mitigating insect outbreak and decreasing the labourer involved for application of pesticide, thereby increasing overall income.

The utilization of ecological engineering can complement existing Integrated Pest Management (IPM) strategies employed in various agricultural systems, including tropical rice farming. By bolstering the effectiveness of natural enemies and diminishing reliance on pesticides, this technique opens up new avenues for application within the rice landscape. The challenge ahead lies in disseminating this technology among Bangladeshi farmers, necessitating a shift away from indiscriminate insecticide use. Efforts toward widespread adoption of ecological engineering practices hold the key to sustainable pest management in the region.

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