Assessment of pests, natural enemies and soil microorganisms in lowland rice field under organic and inorganic production systems

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Abstract. Dela Peña WB, Ratilla BC. 2022. Assessment of pests, natural enemies and soil microorganisms in lowland rice field under organic and inorganic production systems. Asian J Agric 6: 40-46. Farmers readily use synthetic pesticides over organic and natural pest management strategies in controlling pests that may disrupt the ecological balance. This study was conducted to assess the population of insect pests, natural enemies, and soil microorganisms associated with lowland rice PSB Rc18 grown under different production systems. A lowland area at the Department of Agronomy, Visayas State University, Visca, Baybay City, Leyte, Philippines, devoted to organic rice production for four consecutive cappings, was used. Results revealed that organic farmers’ practice in Leyte (T2) showed a higher population of natural enemies, especially mirid bugs, and fewer brown planthoppers, green leafhoppers at 14-44 DAT and the number of folded leaves observed. However, conventional farmers’ practice in Leyte (T3) had the highest incidence and severity of bacterial blight and rice blast. On the other hand, bacterial and fungal microorganisms were found associated with the soil samples. The fungal population increased in both organic production systems compared to the conventional production system. Hence, organic production systems increased the number of beneficial insects and soil microbes’ populations that may, directly and indirectly, affect pests and diseases in lowland rice.

Keywords: Lowland rice, microbial population, natural enemies, organic production system

INTRODUCTION

Lowland rice fields are considered a unique and varied ecosystem. It is characterized by rapid physical, chemical, and biological changes and has a large diversity of floral, faunal, and microbial species where most of these species are beneficial, such as predators, parasitoids, and soil microorganisms (MEA 2005; Acosta et al. 2016). On the other hand, it is also home to several insect pests and diseases. Accordingly, about 44 diseases causing microorganisms (Hollier 1994) and about 187 species of insect pests (Yunus and Ho 1980) in rice are known to cause greater economic losses. It is estimated that the global losses in rice due to weeds, animal pests, and diseases reach 10.2%, 15.1%, and 12.2%, respectively, of the total rice production per year (Oerke 2006).

Studies have shown that organic crops are more resistant to pest attacks due to their thicker cell wall and lower levels of free amino acid than the conventional rice (Ramesh et al. 2005), and the presence of natural enemies is enhanced under organic systems, thus reduced the pest population (Hesler at al. 1993; Drinkwater et al. 1995). In addition, some insect species (lady beetles, ground beetle, crickets, long-horned grasshopper, water bugs, and damselfly) and spiders often control insect pests and maintain a balance insect population (Shepard et al. 1987). For instance, the hymenopteran parasitoids, Telenomus dignus, Tetrastichus schoenobii, and Trichogramma japonicum were found parasitizing 75.29 to 97.56% of stem borer egg (Rama et al. 2013). Jayakumar and Sankari (2010) also reported five spiders, namely: Lycosa pseudoannulata, Callitrichia formosana, Tetragnatha javanensis, Argoiope catenulata, and unidentified Plexippus species that successfully reduced six different insect pests such as Nephrotettix virescens, Scirpophaga incertulnas, Cofana spectra, Cnaphalocrosis medinalis, Nilaparvata lugens, and Leptocorisa acuta.

However, the production practices employed to affect the ecological balance of different organisms within the rice ecosystem. With the extent to achieve the targeted potential yield of modern varieties nowadays, intensive crop management practices were introduced (Byerlee 1994). The higher application of synthetic fertilizers and periodic pesticide spraying resulted in environmental toxicity, pollution, eutrophication, soil acidity, and ecological imbalance (Vimpany and Kelly 2004). Continuous application of synthetic insecticide also caused a resurgence of pests (Wu et al. 2001; Dutcher 2007; Matsumura and Morimura 2010) due to resistance build-up against insecticides and reduction in natural enemy populations, disrupting the natural balance of insect pests and their natural enemies (Hardin et al. 1995). Furthermore, applying a large amount of chemical fertilizer and pesticide in the agricultural soil reportedly resulted in increased heavy metals like Cadmium (Cd), Lead (Pb), and Arsenic (As) that pose negative effects to the soil fauna (Atafar et al. 2010). Liu et al. (2011) reported the significant reduction of microbial diversity and population in paddy soil due to the intensive application of inorganic inputs.

Organic farming is one of the possible solutions that could address the problems mentioned above while also
addressing food and resource sustainability, health, and environmental issues. It reduces the use of agrochemicals, thereby enhancing productivity without destroying the ecosystem balance, harming farmers, consumers, and the environment, hence this study.

**MATERIALS AND METHODS**

This study focused only on evaluating the effects of different production systems on pests, natural enemies, and soil microorganisms in the lowland rice field. A total area of 782 m² lowland experimental area at the Department of Agronomy devoted to various production systems for 4 consecutive cropping with similar treatment applications was used. A Randomized Complete Block Design (RCBD) with 3 treatments and 4 replications separated by 2 m alleyway used by the previous crops were retained. Each treatment plot measured 5 m × 6 m with 750 hills of lowland rice spaced at 20 cm × 20 cm.

The following treatments were as follows: (i) T1= Best bet organic production system (green manuring + green leaf manuring + vermicast + vermitea + fermented plant juice (FPJ) + fermented fruit juice + organic insecticide (rumphii “panyawan” based extract). (ii) T2= Organic farmers’ practice in Leyte (vermicast + FPJ + vermitea + fermented fruit juice + organic insecticides (rumphii “panyawan” based extract). (iii) T3= Conventional farmers’ practice in Leyte (urea + complete + Karate a.i. lambda-cyhalothrin + Lannate a.i. methyhnol)

**Field management and treatment application**

A month after harvesting the previous cropping, mungbean (*Vigna radiata* L.) seeds were broadcasted at the rate of 30 kg/ha to the best bet organic production system (T1) plots without tilling the soil. When the mungbean reaches the flowering stage, it is plowed and mixed in the soil together with the kakawate (*Gliricidia sepium* (Jacq.) Kunth) leaves at a rate of 2 kg m⁻² and allowed to decompose for 3 weeks before transplanting. Plowing was done twice at weekly intervals without disturbing the previous croppings' layout. In addition, dikes and canals around the experimental plot were cleaned, fixed, and repaired.

Three sets of PSB Rc 18 seeds were soaked and incubated separately, the seeds for T1 were coated with microbial slurry (20% solution of MykoPlus). Pre-germinated seeds for T1 and T2 were sown evenly in a prepared wet bed applied with vermicompost at a rate of 0.5 kg m⁻², while T3 seeds were sown in a seedbed applied with complete fertilizer at a rate of 30 g m⁻². After sowing, these seedlings were reared and transplanted at 21 days after sowing to their respective treatment plots. Seedlings were transplanted at 20 x 20 cm planting distance. Seedlings planted in T1 were dipped in the microbial slurry before planting. Replanting was done on the missing hills 5 days after transplanting to maintain the plant population.

FPJ, fruit juice, and vermitea were applied as foliar sprays for T1 and T2. For T1, vermitea and 10% solution of FPJ were sprayed alternately at weekly intervals 2 weeks after transplanting up to the flowering stage. T2 was applied with a mixture of FPJ and vermitea spray at weekly intervals starting 2 weeks after transplanting up to the flowering stage at a rate of 30 mL of each foliar supplement per liter of water. At the panicle initiation stage, fermented fruit juice was sprayed at weekly intervals for T1 and T2 at the rate of 30 mL per liter of water up to two weeks before the harvesting date. Spraying of foliar fertilizers was done at 4 o’clock in the afternoon when sunlight was not so intense. For T3, synthetic fertilizer at a rate of 109.04 -17.5-17.5 kg N, P2O5, K2O ha⁻¹.

Weeds were controlled manually throughout the experiment, and proper water management was employed. For the pests and diseases, T1 and T2 were sprayed with organic-based insecticides (*Tinospora rumphii* based extract) while T3 was applied with chemical insecticide lambda-cyhalothrin during the vegetative and methomyl insecticide during the heading stage. To prevent contamination of spray mists of chemical pesticides to organic treatments, a plastic enclosure was provided during spraying around the conventional treatment plots.

**Statistical analysis**

Analysis of variance on data gathered was done using the Statistical Analysis Software (SAS) Version 9.2 developed by SAS Institute. In addition, a comparison of means was done using Tukey's Honestly Significant Difference (HSD) test.

**Data gathered**

**Disease incidence of major rice diseases**

This was determined at 30, 60, and 90 days after transplanting by counting the number of infected hills within the harvestable area. This was calculated using the formula:

\[
\text{Disease incidence (\%) = } \frac{\text{no of infected hills}}{\text{total no of hills}} \times 100
\]

**Disease severity of the observed diseases**

**Rice blast.** The severity of blast infection was determined by visual observation of the ten sample plants randomly selected within the harvestable area in each treatment plot using the following rating scale (IRRI 1996).

**Bacterial leaf blight.** This was obtained by measuring the length of the lesion from the 3th fully expanded leaf of the infected plants.

**Table 1. Rice blast scale rating by IRRI (1996)**

| Rating | Description                      |
|--------|----------------------------------|
| 0      | no infection                     |
| 1      | less than 1% area affected       |
| 2      | 1-5% area affected               |
| 3      | 6-15% area affected              |
| 4      | 16-25% area affected             |
| 5      | 26-50% area affected             |
| 6      | 51-100% area affected            |
Population of insect pests and beneficial insects

This was determined by sweeping each treatment plot using a swept net. Swept insects were identified and counted with the aid of a hand lens. Sampling was done at 14, 44, and 74 DAT.

Insect damage

This was assessed by counting the number of folded/rolled leaves, dead hearts, whiteheads, and other forms of insect damage observed within the harvestable area of each treatment plot throughout the production period.

Grain yield

This was determined by weighing the grains from the harvestable area (12 m²) of each treatment plot after cleaning. Moisture content (MC) was determined before weighing using a grain moisture tester. Grain yield was adjusted to 14% MC using the formula:

\[
\text{Adjusted Grain Yield at 14\%MC} = \frac{100\% - \text{MC}\%}{100\% - \text{Desired MC (14\%)} \times \frac{\text{Grain yield at harvest (kg)}}{\text{Grain yield at harvest (kg)}}
\]

The weight per plot will be converted to tons per hectare using the formula:

\[
\text{Grain yield (t ha}^{-1}) = \frac{\text{Plot yield (kg)}}{\text{Harvestable area (20 m}^2\text{)}} \times \frac{10,000 \text{ m}^2 \text{ ha}^{-1}}{1000 \text{ kg t}^{-1}}
\]

Soil microbial analysis

Soil samples from each treatment plot at a depth of 20 cm were collected using a soil auger. Freshly collected samples were submitted to Plant Disease Diagnostic Laboratory, Visayas State University, Visca, Baybay, Leyte for microbial identification, and colony count mL⁻¹.

RESULTS AND DISCUSSION

Incidence and severity of rice diseases

The incidence and severity of the major rice diseases throughout the production period are presented in Table 2. Analysis of variance showed that the occurrence of tungro disease was significantly higher in T2 while T1 and T3 are comparable. The higher incidence of tungro in T2 could be due to the lower amount of nutrient applied as compared to the other treatments involved in the study. According to Rillon et al. (1998), rice plants treated with additional N fertilizer during the production period showed significantly lower symptoms and concluded that application of N enabled the plants to recover from RTSV and RTBV disease, thereby reducing the disease infection.

Lower incidence and severity of bacterial blight and rice blast diseases were observed in T1 and T2 compared to T3. These results could be due to the higher nitrogen applied in the conventional production system which favored the disease infection spread. Long et al. (2000) reported that applying nitrogen at a higher rate significantly increases blast incidence and total lesion regardless of cultivar. Kurschner (1992) also mentioned that increasing nitrogen application increases leaf blast due to increases in tissue susceptibility and canopy density. Moreover, Chaudhary et al. (2009) reported that nitrogen application also affects bacterial leaf blast incidence and severity. They found out that different N doses caused 6.67 to 55.11% bacterial leaf blast incidence under research filed condition and 7.12 to 62.00% at farmers’ field condition.

Table 2. Incidence and severity of rice diseases of lowland rice PSB Rc18 as affected by different production systems

| Treatments  | Tungro incidence | Rice blast | Bacterial blight |
|-------------|------------------|------------|-----------------|
|             | Incidence        | Severity   | Incidence       | Severity   |
| T1          | 4.17b            | 2.58b      | 0.27b           | 2.50b      | 18.67b |
| T2          | 7.83a            | 2.42b      | 0.15b           | 3.67b      | 11.60b |
| T3          | 5.42b            | 9.17a      | 1.08a           | 18.25b     | 26.17b |
| Mean        | 5.80             | 4.72       | 0.50            | 8.14       | 18.81  |
| CV %        | 11.61            | 27.85      | 22.85           | 21.25      | 21.50  |

Note: Means within each column followed by a common letter and those without designation are not significantly different from each other based on HSD and ANOVA, respectively. Legend: T1: Best bet organic production system, T2: Organic farmers’ practice in Leyte, T3: Conventional farmers’ practice in Leyte
Moreover, the population of five dominant beneficial insects, namely: damselfly, long-horned grasshopper, lynx spider, mirid bug, and wasp at 14, 44, 74 DAT is presented in Figure 2. Results showed that more long-horned grasshoppers and damselfly were noted in T3 at 14 DAT of rice, which subsequently reduced as the crop matures at the succeeding sampling periods. On the other hand, the mirid bug was higher in T2 at 14 and 44 DAT, eventually reducing at 74 DAT.

Lynx spider population was also higher in both organic production systems (T1 and T2) than in T3 in all sampling periods. On the other hand, higher wasps were observed in T2 at 44 DAT compared to the other production systems. However, no wasp was observed at 14 DAT and fewer at 74 DAT. The reduction of beneficial insects at a later stage (74 DAT) was due to the spraying of organic insecticides (rumphii “panyawan” based extract) in T1 and T2, and chemical insecticide in T3 which either deter or kill the beneficial insects.

The total population of insect pests and beneficial insects at 14, 44, and 74 DAT is presented in Figure 3. The graph shows that the mean number of beneficial insects was higher at 14 and 44 DAT and eventually reduced at 74 DAT. However, the mean number of insect pests increased at 74 DAT while the mean number of beneficial insects reduced.

The fewer number of insect pests at an earlier sampling period was possibly due to the reasonable number of beneficial insects and lesser infestation during earlier days of crop establishment. On the other hand, the reduction of beneficial insects in the later sampling period was perhaps due to the spraying of organic insecticide in organic treatments T1 and T2, and chemical insecticide in T3. The later increase in the population of insect pests was mainly attributed to the increased number of rice bugs during the milking stage and the reduction of beneficial insects due to spraying.

**Yield and insect damage**

Table 3 shows the yield and insect damage of rice as affected by the different organic production systems throughout the production period. Analysis of variance revealed that there was no significant difference in the number of dead hearts and whiteheads. However, a higher number of folded leaves were observed in T3 which was 93.30% higher than in T2 followed by T1 with 37.50 folded leaves. This result may be attributed to the higher N concentration in conventional farmers’ practice in Leyte, which conforms to the findings of Singh and Shahi (1984). They noted an increasing damage rate at increasing N application. At 30 kg nitrogen/ha, leaf folder damage rate reached 11.03% while at 60 and 150 kg N/ha, leaf damage increases to 15.33% and 15.06-16%, respectively.

A significantly higher percentage of unfilled spikelets was observed in T1 and T3 while lowest in T2. On the other hand, no significant difference was observed in grain yield indicating a comparable grain yield of rice between organic and inorganic production systems. The higher number of unfilled spikelets is mainly due to the higher number of black bugs and rice bugs in T1 and T3.
Soil microbial analysis

Table 4 presents the microbial counts (cfu mL\(^{-1}\)) while Figures 4 and 5 show the bacterial cells and fungi associated with the sample. Initial and final microbial analysis indicated that bacterial and fungal microorganisms were found associated with the soil samples. Regardless of the treatment applied, bacterial and fungal colony count mL\(^{-1}\) increased at the final analysis relative to the initial count. However, colony-forming unit mL\(^{-1}\) of fungi in T1 and T2 showed a reasonably higher increase in count than in T3. The microorganism species found associated in T1 were Bacillus, Chromobacterium, Coccobacillus and Aspergillus. In T2, Chromobacterium, Bacillus, Coccobacillus, Aspergillus, and Trichoderma were observed while T3 observed Chromobacterium, Bacillus, Coccobacillus, Aspergillus, and Fusarium. These are saprophytic soil-inhabiting microorganisms which are the major decomposers of organic matter (Gomes et al. 2014; Sudrajat et al. 2019). The higher increase of microorganisms in both organic production systems compared to conventional farmers’ practice in Leyte could be attributed to the application of organic fertilizer. Bot and Benites (2005) reported that most fungi, bacteria, and actinomycetes rely on organic materials for their carbon and energy needs.

Table 3. Insect damage of lowland rice PSB Rc18 as affected by different production systems

| Treatments | Insect damage | Percentage unfilled spikelet panicle\(^{-1}\) | Grain yield (t ha\(^{-1}\)) |
|------------|--------------|---------------------------------|--------------------------|
|            | Folded leaves | Dead hearts and whiteheads      |                          |
| T1         | 37.50\(^b\)  | 44.00                           | 45.04\(^a\)              | 3.03                      |
| T2         | 4.50\(^c\)   | 69.25                           | 30.43\(^b\)              | 3.26                      |
| T3         | 67.25\(^a\)  | 42.75                           | 50.15\(^a\)              | 3.08                      |
| Mean       | 46.33         | 52.01                           | 41.87                    | 3.12                      |
| CV %       | 29.75         | 28.19                           | 13.45                    | 12.75                     |

Note: Means within each column followed by a common letter and those without designation are not significantly different from each other based on HSD and ANOVA, respectively

Table 4. Microbial counts (cfu mL\(^{-1}\)) of microorganism associated with soil samples from different production systems using potato dextrose agar (PDA) and nutrient agar (NA)

| Treatment | Bacteria | Molds/fungi |
|-----------|----------|-------------|
|           | Initial  | Final       | Initial  | Final |
| T1        | 1.17x105 | 2.33x105    | 3.00x102 | 4.03x103 |
| T2        | 2.60x105 | 4.63x105    | 1.33x102 | 3.00x103 |
| T3        | 2.47x105 | 4.66x105    | 2.00x102 | 1.47x103 |

Figure 4. Molds/fungal isolates found associated with soil samples. A. Trichoderma sp.; B. Aspergillus niger; C. Aspergillus sp.; D. Fusarium sp.
In conclusion, lower incidence and severity of rice blast and bacterial blight but higher tungro virus incidence was observed in rice grown in organic farmer’s practice in Leyte compared to the conventional practice. Conventional farmers’ practice in Leyte had a slightly higher number of harmful insects such as brown planthopper, green leafhopper, and rice bug. In contrast, organic farming practices in Leyte had the highest number of beneficial insects, like the mirid bug as a predatory insect. The number of folded leaves observed was lowest in organic farmers’ practice in Leyte while highest in conventional farmers’ practice. The different production systems did not significantly affect the number of deadhearts, whiteheads, and grain yield, but lower unfilled grains were observed in organic farmers’ practices in Leyte. The population and diversity of microorganisms are higher in organic farmers’ practice in Leyte.

REFERENCES

Acosta LG, Jahnke SM, Redaelli LR, Pires PRS. 2016. Insect diversity in organic rice fields under two management systems of levees vegetation. Braz J Biol 77 (4): 731-744. DOI: 10.1590/1519-6984.19615.

Atafar Z, Mesdaghinia A, Nouri J, Homaei M, Yanesian M, Ahmadmoghaddam M, Mahvi AH. 2010. Effect of fertilizer application on soil heavy metal concentration. Environ Monit Assess 160 (1-4): 83-89. DOI: 10.1007/s10661-008-0659-x.

Balasubramanian P, Palaniappan S P, Gopalan M. 1983. The effect of carbfuran and nitrogen on leaf folder incidence. Intl Rice Res Note 8 (5): 13-14.

Bot A, Benites J. 2005. The importance of soil organic matter: Key to drought-resistant soil and sustained food production. FAO Soils Bulletin. http://www.fao.org/3/a0100e/a0100e.pdf

Byerlee D. 1994. Technology transfer systems for improved crop management: Lessons for the future. In: Anderson J (eds). Agricultural Technology: Policy Issues for the International Community. CAB International, UK.

Chaudhary SU, Husain M, Iqbal J, Ali MA. 2009. Effect of nitrogen doses on incidence of bacterial leaf blight in rice. J Agric Res 47 (3): 253-258.

Drinkwater LE, Letourneau DK, Workneh F, Van Bruggen AHC, Shenman C. 1995. Fundamental differences between conventional and organic tomato agroecosystems in California. Ecol Appl 5 (10): 98-112. DOI: 10.2307/2269357.

Dutcher JD. 2007. A Review of resurgence and replacement causing pest outbreaks in IPM. In: Ciancio A, Mukerji KG (eds). General Concepts in Integrated Pest and Disease Management. Integrated Management of Plants Pests and Diseases, vol 1. Springer, Dordrecht. DOI: 10.1007/978-1-4020-6061-8_2.

Gomes FS, Pontual EV, Coelho LB, Paiva P. 2014. Saprophytic, symbiotic and parasitic bacteria: Importance to environment, biotechnological applications and biocontrol. Adv Res 2 (5): 250-265. DOI: 10.9734/AJR/2014/9161.

Hardin MR, Benrey B, Colt M, Lamp WO, Roderick GK, Barbosa P. 1995. Arthropod pest resurgence: An overview of potential mechanisms. Crop Prod 2 (1): 3-18. DOI: 10.1016/0261-2194/0591106-P.

Hesler LS, Grigarick AA, Oraze MJ, Palrang AT. 1993 Arthropod fauna of conventional and organic rice fields in California. J Econ Entomol 86 (1): 49-58. DOI: 10.1093/jee/86.1.149.

Hollier CA, Groth DE, Leyj RV, Courville BA, McCorry JC. 1994. Rice yield differences: A comparison of fungicide application methods. Proc Rice Tech Wkrg Grp 25:88-89.

International Rice Research Institute (IRRI). 1996. Standard Evaluation System for Rice. (4th ed). IRRI, Manila, Philippine.

Jayakumar S, Sankari A. 2010. Spider population and their predatory efficiency in different rice establishment techniques in Aduthurai, Tamil Nadu. J Biopestic 3 (1): 20-27.

Karnataka J. 2011. Influence of fertilizer on the incidence of insect pests in paddy. Agric Sci 24 (2): 241-243.

Kurschner E, Bonman JM, Garrity DP, Taminis MM, Pabale D, Estrada BA. 1992. Effect of nitrogen timing and split application on blast disease in upland rice. Plant Dis 76: 384-389. DOI: 10.1094/PD-76-0384.

Liu M, Klemens E, Zhang B, Holzhauer SI, Li Z, Zhang T, Rauch S. 2011. Effect of intensive inorganic fertilizer application on microbial properties in a paddy soil of subtropical China. Agric Sci China 10 (11): 1758-1764. DOI: 10.1016/S1671-2929(11)60175-2.

Long DH, Lee FN, Tebeest DO. 2000. Effect of nitrogen fertilization on disease progress of rice blast on susceptible and resistant cultivars.
Am Phytopathol Soc 84 (4): 403-409. DOI: 10.1094/PDIS.2000.84.4.403.

Manti I. 1990. Predation of brown planthopper (BPH) eggs by *Cyrtorhinus lividipennis* Reuter. Int Rice Res Notes 15 (6): 25.

Matsumura M, Morimura SS. 2010. Recent status of insecticide resistance in Asian rice planthoppers. Jpn Agric Res Quart 44 (3): 225-230. DOI: 10.6090/jarq.44.225.

Millennium Ecosystem Assessment (MEA). 2005. Ecosystems and Human Well-Being: Synthesis. Island Press, Washington DC, USA.

Shepard BM, Barrion AT, Litsinger JA. 1987. Helpful Insects, Spiders, and Pathogens. International Rice Research Institute Los Baños, Laguna, Philippines.

Singh J, Shahi HN. 1984. Effect of nitrogen on leaf folder, *Cnaphalocrocis medinalis* (Guen.), incidence in rice. J Res Punjab Agric Univ 21 (4): 629-630.

Sudrajat, Widhayasa B, Rusdiansyah, Susanto D. 2019. *Rhizosphere* fungal community, soil physicochemical properties, understorey vegetation and their relationship during post-coal mining reclamation in East Kalimantan, Indonesia. Biodiversitas 20: 1953-1962. DOI: 10.13057/biodiv/d200723.

Vimpany I, Kelly R. 2004 Fertilizers and the Environment. NSW Department of Primary Industries, New South Wales. http://www.dpi.nsw.gov.au/content/agriculture/resources/soils/improvement/environment. Accessed April 15, 2016.

Wang MQ, Wu RZ. 1991. Effects of nitrogen fertilizer on the resistance of rice varieties to brown planthopper. Guangdong Agric Sci 1: 25-27.

Wu JC, Xu JX, Yuan SZ, Liu JL, Jiang YH, Xu JF. 2001. Pesticide-induced susceptibility of rice to brown planthopper *Nilaparvata lugens*. Entomologia Experimentalis et Applicata 100 (1): 119-126. DOI: 10.1046/j.1570-7458.2001.00854.x.

Yunus A, Ho TH. 1980. List of economic pests, host plants, parasites and predators in West Malaysia (1920-1978). Ministry of Agriculture, Malaysia.