RELATIVE FITNESS AND FEEDING CAPACITY OF IMIDACLOPRID RESISTANT Nilaparvata lugens

KEBUGARAN RELATIIF DAN KEMAMPUAN MAKAN Nilaparvata lugens RESISTEN TERHADAP IMIDAKLOPRID

Jesayas A. Londingkene1), Y. Andi Trisyono2), Witjaksono2), & Edhi Martono2)

1)Agrotechnology Program, Faculty of Agriculture, Universitas Nusa Cendana
Jln. Adisucipto, Penfui-Kupang, NTT 85001
2)Department of Plant Pest and Disease, Faculty of Agriculture, Universitas Gadjah Mada
Jln. Flora 1, Bulaksumur, Sleman, Yogyakarta 55281
*Corresponding author. E-mail: sayaslondingkene@yahoo.com

ABSTRACT

Imidacloprid is a neonicotinoid insecticide that is recommended for controlling Nilaparvata lugens. In Asian countries, such as, China, Vietnam, India, and Thailand, imidacloprid has caused resistance to N. lugens. Imidacloprid has also caused resistance to N. lugens based on some previous studies in Indonesia. The aim of this study was to determine the fitness and feeding capacity of imidacloprid-resistant N. lugens. The population of N. lugens used in this study had a resistance level of 50.64 times compared to the susceptible population. When the resistant and susceptible population of N. lugens did not receive any exposure to imidacloprid, the susceptible population had better fitness than the resistance one. However, the fitness of the resistant population increased when this population was resistance which sublethal concentration (LC50 & LC20) of imidacloprid. The increase fitness of this resistant population most likely related to the increase in feeding capacity of the resistant population when they were treated which sublethal imidacloprid. These findings suggest that the field population of N. lugens that have developed resistance would increase the probability of outbreak if they were sprayed with imidacloprid.

Keywords: feeding capacity, imidacloprid, Nilaparvata lugens, relative fitness, resistance

INTRODUCTION

The brown planthopper, Nilaparvata lugens Stal (Hemiptera: Delphacidae), is a major pest of rice, which infests rice planted in many countries like Australia, Bangladesh, Bhutan, Myanmar, Cambodia, China, Fiji, India, Indonesia, Japan, North and South Korea, Laos, Malaysia, Nepal, Pakistan, Papua New Guinea, the Philippines, Sri Lanka, Taiwan, Thailand, and Vietnam (Chen et al., 2012; Liu et al., 2012). The loss caused by N. lugens infestation was around 2.7 million tons in China in 2005, 0.7 million tons in Vietnam in 2007, 1.1 million tons in Thailand between 2009 to 2011, and 0.8 million tons in Indonesia in 2011 (Botrell & Schoenly, 2012). The insect is a serious threat to worlds’ rice sustainability by affecting to the instability of rice production, monetary loss, and harvest failure (Catindig et al., 2009).

Insect pest resistance to insecticides is a major issue in many countries including Indonesia since it is directly related to the success in insect pest control. N. lugens resistance has been reported occurring in many rice producing countries like China, Thailand, India, and Vietnam (Catindig et al., 2009; Liu et al., 2012). In China, the resistance to buprofezin reached...
compared to the susceptible one. Chelliah and
organism (Leather, 1995). Ratna (2011) reported that
use, which are the main component in the life of an
resistant to insects’ feeding capacity and insects’ food
resistant fecundity and hatching rate, and relative fitness of
larval longevity, adult eclosion, the rate of copulation,
higher fitness cost covering the significant reduction
that unselected population developed faster to the
next generation, while selected population endured
development of this insecticide intensified its use which eventually
created the resistance in N. lugens. During 2005−2006
in China, the resistance of N. lugens to imidacloprid raised to 79.1−81.1 times compared to susceptible
N. lugens (Wang et al., 2008; Catindig et al., 2009).
Resistance to imidacloprid was found in N. lugens collected from some locations in Central and East Java (Y.A. Trisyono, 2012, personal communication).
The length of larval and adult stages could be
resistance. Sublethal dose affects pest biology (Wang
et al., 2008) such as the length of insects’ stadium.
The length of larval and adult stages could be longer, however the developmental and consumption rates decreased (Herbert & Harper, 1987). The reduction of eggs viability, oviposition period and prolonged larval stadium were related to the development of resistance in Leptinotarsa decemlineata selected with Bacillus thuringiensis CryIII A delta-endotoxin (Trisyono & Whalon, 1997). Liu et al. (2012) found that unselected population developed faster to the next generation, while selected population endured higher fitness cost covering the significant reduction of larval longevity, adult eclosion, the rate of copulation, fecundity and hatching rate, and relative fitness of resistant N. lugens on the next generation.
Insects’ fitness components like fecundity is related to insects’ feeding capacity and insects’ food use, which are the main component in the life of an organism (Leather, 1995). Ratna (2011) reported that resistant N. lugens showed different feeding capacity compared to the susceptible one. Chelliah and
Heinrichs (1984) found that reproduction rate of N. lugens increased when they were fed with rice sprayed with deltamethrin, methyl parathion, cypermethrin and fenvalerat. They suspect this condition was the consequence of insecticide residue or its metabolites, which induced chemical changes within the sprayed host plants. The rise of reproduction rates in N. lugens may be caused by the increase of consumption. This study was aimed to determine the fitness and feeding capacity of imidacloprid resistant N. lugens. The results of this study can be used as the bases to develop management tactics to delay or combat resistance to imidacloprid in N. lugens.

MATERIALS AND METHODS

Mass rearing of Nilaparvata lugens

N. lugens population used in this study was collected in 2010 from the District Klaten. The Laboratory susceptible population was used as a comparison. The laboratory population has been reared in Pesticide Toxicology Laboratory (PLT) of the Faculty of Agriculture, Universitas Gadjah Mada (FA-UGM) since 1986 without any exposure to insecticides and no additional field population. These population were reared using an establish laboratory rearing procedures. One hundred g of sorted Cisadane seeds were carefully cleaned and soaked for 24 h. The seeds were germinated in a plastic jar (diameter = 30 cm, height = 32 cm), and covered with gauze. Seven d-old seedlings were used as the oviposition media and the diet of N. lugens.

Resistant adults of N. lugens (75−100 pairs) were moved to rice seedlings for oviposition. After 10 d or after eggs hatching, N. lugens nymphs were moved to a new jar previously filled with fresh rice seedlings. Used seedlings were placed above these fresh ones in an upside down position, held by wires attached to the side of the jar to allow the newly hatched nymphs to move to the fresh seedlings. The replacement of the seedlings was conducted every 6−7 d until N. lugens reached adult stage. Newly formed adults were directly transferred into a new jar containing with fresh 7 d old seedlings to develop the next generation.

Insecticide

The insecticide used was imidacloprid (Confidor 5 WP; PT Bayer Indonesia). Imidacloprid is a wide spectrum neonicotinoid, systemic, worked by contact and stomach poisoning and this chemical is recommended to control plant pests including N. lugens (Elbert et al., 2008).
The Resistance of Nilaparvata lugens

The resistance of N. lugens to imidacloprid after the five generations of selection was 50.64 times compared to the susceptible population (Londingkene et al., 2016, in press). LC\textsubscript{50} and LC\textsubscript{20} of imidacloprid to resistant N. lugens was 33.93 and 1.18 ppm, respectively. These sublethal concentrations were used in the following studies.

Study 1. Relative Fitness (preoviposition, oviposition, fecundity, egg hatching percentage, adult longevity, and life cycle) of Nilaparvata lugens

The fitness of N. lugens was studied using CRD with four treatments and 20 replications. The treatments were resistant N. lugens without exposure to imidacloprid (unexposed), resistant N. lugens exposed to 33.93 ppm (LC\textsubscript{50}) and 1.18 ppm (LC\textsubscript{20}) of imidacloprid, and susceptible N. lugens without exposure to imidacloprid. There were three applications administered to three consecutive generations. The insects were fed with the 6 d old seedlings previously dipped thoroughly in insecticide solution or water.

Preoviposition and oviposition experiment was conducted by placing a pair of newly formed adults into a test tube filled with 5-d old rice seedling. The seedling was replaced and examined daily to ensure the oviposition. The examination of preoviposition period was stopped when the first egg was laid, and right after the observation of the oviposition period was started.

Fecundity was examined by placing a pair of newly molted adults (1-d old) into a plastic cup (d = 10 cm, h = 11 cm) filled with 10 rice seedlings of 5-d old. The seedlings were replaced every four days. The number of eggs laid was examined by dissecting the leaves sheath toward the stem to count eggs mass under the dissecting microscope. The egg hatching percentage or eggs’ viability was counted (Heinrichs et al., 1981).

The longevity of female adults was determined by placing a newly formed female adult into a test tube filled with a 5 d old seedling. The seedling was replaced every three days. The observation was ended when the insect died. Nymphal stages were determined by placing a newly hatched nymph into plastic cup having rice seedlings. Subsequently, the second instar that emerged from the first instar was placed into a new plastic cup. Procedure for observing the following stages were similar until the nymphs reached adults. If N. lugens dead during the test, they were substituted with N. lugens of the same age.

Study 2. Feeding capacity of Nilaparvata lugens

Feeding capacity of N. lugens was determined with ninhydrin method (Heinrichs et al., 1981) with modifications. The study was aimed to compare the feeding capacity of the imidacloprid exposed resistant N. lugens to the unexposed resistant ones. Three times exposure were made at 28, 53, and 78 days after planting (DAP), and each was replicated 10 times. Trays with the size of 50×50 cm were used for planting the seeds. The 14 DAP seedlings were removed from the trays and planted in the pots (d = 12 cm, h = 12 cm) and allowed to grow until 28, 53, and 78 DAP. The rice hill of 28 DAP were cut to leave only one stem in the pot. Every pot was enclosed with a plastic cup (d = 12 cm, h = 25 cm) equipped with a hole and cotton on its top to free the upper part of the stem, while keeping N. lugens inside the cup. The base of the cup was layered with plastic plate to allow the placement of filter paper and to prevent the moisture around the soil to enter the cup. A square opening of 4×4 cm was placed on the side of the cup and enclosed with gauze to allow air circulation. The surface of the stem was brushed with imidacloprid (33.93 and 1.18 ppm) or with water for the control (the unexposed resistant N. lugens and susceptible one). A Whatman filter paper (No 42, d = 12 cm) was placed around the lower stem. On every treatment five brachypteran female N. lugens adults (≤ 1 d old) were placed. These insects were previously starved for ± 3 h. After 24 h, the filter paper was retrieved, sorted according to the treatments and sprayed with 0.1% ninhydrin in aceton. The papers were then picked up with a pair of forceps and dried in oven for 5 min, at 100°C. Feeding capacity of N. lugens was observed by measuring the spots of amino acid (mm\textsuperscript{2}) left by the brachypteran females. The spots were the honey dew excretion of N. lugens containing amino acid which became purple after reacted with ninhydrin. The spots were measured with Leaf Area Meter (Heinrichs et al., 1981).

Calculation

The preoviposition period was calculated from the formation of female adult until its first oviposition. The oviposition period was determined from the first egg was laid until no more eggs were deposited. Fecundity was counted as the number of deposited eggs and unhatched ones by a female. Eggs viability represented the ratio between the number of new nymphs and deposited eggs. The life cycle of N. lugens counted since eggs were placed to the adults. The longevity of female adults was observed since the emergence of female adult to its death.
Increased the fecundity of its adult, due to the increase of juvenile III hormone on female adult. Both applied to first instar larvae of azadirachtin stimulated the reproduction of persicae the sublethal concentration of imidacloprid and capacity happens through the stimulation of fecundity not affect the fitness (preoviposition, oviposition, female age, fecundity, female age) of N. lugens. However, there was a significant difference between resistant N. lugens (control), exposed resistant N. lugens, and susceptible N. lugens (Table 1.).

The application of imidacloprid affected all fitness variables including preoviposition, oviposition, female age, fecundity, and eggs viability of N. lugens. Ecotoxicity of resistant N. lugens exposed to imidacloprid was significantly higher compared to the unexposed resistant one for all applications (Table 1.). This suggest that imidacloprid increase the fecundity of resistant females. Chelliah and Heinrichs (1984) explained that reproduction rate of N. lugens raised when they were fed with rice plants sprayed with deltamethrin, methyparathion, cypermethrin, and fenvalerate. Furthermore, the increase of N. lugens reproduction was also enhanced by the increase of nutrition consumption capacity due to the sublethal treatment of insecticide. Basit et al. (2012) said that insect resistant to insecticide influences other fitness component such as longevity, development, fecundity, and fertility. According to Moriarty (1969), the sublethal dose of insecticide affected insect population by altering their capacity to live, reproduce, and the genetic materials of the survival generation. The application of triazophos and fenvalerate on sublethal concentration increased the reproduction of female N. lugens (Bao et al., 2009). The increase of reproductive capacity happens through the stimulation of fecundity (Yin et al., 2008). Cutler et al. (2009) reported that the sublethal concentration of imidacloprid and azadirachtin stimulated the reproduction of Myzus persicae. Wang et al. (2005) informed that imidacloprid applied to first instar larvae of Tryporyza incertulas increased the fecundity of its adult, due to the increase of juvenile III hormone on female adult. Both studies showed a lesser fitness than the susceptible population of N. lugens.

In general, the application of imidacloprid to the resistant N. lugens prolonged the period of egg and nymph stages. Both resistant N. lugens (exposed and non exposed to imidacloprid) had longer egg and nymph period compared to the susceptible N. lugens (Table 2). This might be due to the lesser fitness level of resistant N. lugens compared to susceptible N. lugens which was better in fitness. Liu and Han (2006) found that the fitness of imidacloprid resistant N. lugens can drop to the initial state if the use of imidacloprid is stopped. Abbas et al. (2012) reported that the fitness of imidacloprid resistant Spodoptera litura was far below the susceptible one, in term of the length of larvae, pupae and adult stadia. Kliot and Ghanim (2012) mentioned that the population of unselected insects could develop very fast, while the fitness of selected population was very low in term of larval longevity, the number of molted adults, and the rate of copulation, fecundity, and hatching rate. All of these were significantly lower which caused a bigger fitness cost.

Feeding capacity of Nilaparvata lugens

The application frequency of imidacloprid did not affect the fitness (preoviposition, oviposition, fecundity, female age, eggs viability, and life cycle) of N. lugens. However, there was a significant difference among treatments. The statistical analysis was performed when anova showed significant difference among treatments. The statistical analysis was conducted using Statistix 8.0.

RESULTS AND DISCUSSION

The Fitness of Nilaparvata lugens

The application frequency of imidacloprid did not affect the fitness (preoviposition, oviposition, fecundity, female age, eggs viability, and life cycle) of N. lugens. However, there was a significant difference among treatments. The statistical analysis was conducted using Statistix 8.0.

The application frequency of imidacloprid did not affect the fitness (preoviposition, oviposition, fecundity, female age, eggs viability, and life cycle) of N. lugens. However, there was a significant difference among treatments. The statistical analysis was conducted using Statistix 8.0.

The application frequency of imidacloprid did not affect the fitness (preoviposition, oviposition, fecundity, female age, eggs viability, and life cycle) of N. lugens. However, there was a significant difference among treatments. The statistical analysis was conducted using Statistix 8.0.

The application frequency of imidacloprid did not affect the fitness (preoviposition, oviposition, fecundity, female age, eggs viability, and life cycle) of N. lugens. However, there was a significant difference among treatments. The statistical analysis was conducted using Statistix 8.0.

Data Analysis

LSD on 5% level was used to analyse every variable of fitness and feeding capacity. The significance test was performed when anova showed significant difference among treatments. The statistical analysis was conducted using Statistix 8.0.

The Fitness of Nilaparvata lugens

The application frequency of imidacloprid did not affect the fitness (preoviposition, oviposition, fecundity, female age, eggs viability, and life cycle) of N. lugens. However, there was a significant difference among treatments. The statistical analysis was conducted using Statistix 8.0.

The application frequency of imidacloprid did not affect the fitness (preoviposition, oviposition, fecundity, female age, eggs viability, and life cycle) of N. lugens. However, there was a significant difference among treatments. The statistical analysis was conducted using Statistix 8.0.

The application frequency of imidacloprid did not affect the fitness (preoviposition, oviposition, fecundity, female age, eggs viability, and life cycle) of N. lugens. However, there was a significant difference among treatments. The statistical analysis was conducted using Statistix 8.0.

The application frequency of imidacloprid did not affect the fitness (preoviposition, oviposition, fecundity, female age, eggs viability, and life cycle) of N. lugens. However, there was a significant difference among treatments. The statistical analysis was conducted using Statistix 8.0.

The application frequency of imidacloprid did not affect the fitness (preoviposition, oviposition, fecundity, female age, eggs viability, and life cycle) of N. lugens. However, there was a significant difference among treatments. The statistical analysis was conducted using Statistix 8.0.

The application frequency of imidacloprid did not affect the fitness (preoviposition, oviposition, fecundity, female age, eggs viability, and life cycle) of N. lugens. However, there was a significant difference among treatments. The statistical analysis was conducted using Statistix 8.0.

The application frequency of imidacloprid did not affect the fitness (preoviposition, oviposition, fecundity, female age, eggs viability, and life cycle) of N. lugens. However, there was a significant difference among treatments. The statistical analysis was conducted using Statistix 8.0.

The application frequency of imidacloprid did not affect the fitness (preoviposition, oviposition, fecundity, female age, eggs viability, and life cycle) of N. lugens. However, there was a significant difference among treatments. The statistical analysis was conducted using Statistix 8.0.

The application frequency of imidacloprid did not affect the fitness (preoviposition, oviposition, fecundity, female age, eggs viability, and life cycle) of N. lugens. However, there was a significant difference among treatments. The statistical analysis was conducted using Statistix 8.0.
Table 1. The effect of imidacloprid to the fitness of *Nilaparvata lugens*

| Application | *Nilaparvata lugens* population | Imidacloprid (ppm) | Preoviposition (d) | Oviposition (d) | Female age (d) | Fecundity (eggs/female) | Eggs viability (%) |
|-------------|--------------------------------|--------------------|--------------------|-----------------|----------------|------------------------|--------------------|
| 1           | Resistant                       | -                  | 2.17 c             | 7.15 c          | 7.05 c         | 105.00 c              | 86.3 c             |
| 1           | Resistant                       | LC50 (33.93)       | 1.88 c             | 7.50 b          | 8.90 b         | 127.75 b              | 95.7 b             |
| 1           | Resistant                       | LC20 (1.18)        | 2.29 b             | 7.05 c          | 8.80 b         | 131.40 b              | 94.3 b             |
| 1           | Susceptible                     | -                  | 2.93 a             | 8.70 a          | 11.65 a        | 159.75 a              | 98.3 a             |
| 2           | Resistant                       | -                  | 2.11 b             | 7.10 b          | 7.50 c         | 109.20 c              | 85.7 c             |
| 2           | Resistant                       | LC50 (33.93)       | 1.97 c             | 7.00 b          | 8.85 b         | 149.40 b              | 92.3 b             |
| 2           | Resistant                       | LC20 (1.18)        | 2.18 b             | 7.25 b          | 8.65 b         | 144.15 b              | 94.6 b             |
| 2           | Susceptible                     | -                  | 3.04 a             | 9.15 a          | 11.10 a        | 167.05 a              | 98.4 a             |
| 3           | Resistant                       | -                  | 2.37 b             | 7.85 c          | 7.70 c         | 108.40 c              | 83.3 c             |
| 3           | Resistant                       | LC50 (33.93)       | 2.22 b             | 8.05 b          | 8.80 b         | 141.05 b              | 91.7 b             |
| 3           | Resistant                       | LC20 (1.18)        | 2.09 c             | 8.14 b          | 8.65 b         | 138.40 b              | 92.3 b             |
| 3           | Susceptible                     | -                  | 3.42 a             | 9.80 a          | 11.35 a        | 147.20 a              | 98.7 a             |

Note: A pair of brachypteric *Nilaparvata lugens* was released two days after imidacloprid application. Means in each column for each application followed by similar letter is not significantly different (LSD; α = 0.05). d = day
Although the fitness and feeding capacity of imidacloprid-resistant *N. lugens* were less than the susceptible population, application of imidacloprid at sublethal concentration to the resistant population increased their fitness and feeding capacity. These effects could contribute to the outbreak of *N. lugens*. In other words, the probability of outbreak is higher when imidacloprid is applied to field population of *N. lugens*.

### ACKNOWLEDGEMENT

We are thank to the Nuffic project-PT MDF. Pacific-Indonesia for providing the scholarship for pursuing doctoral program. Thanks also to Mr. Sriyanto and Mr. Tugimin for technical assistance.

### LITERATURE CITED

Abbas, N., S.A. Shad, & M. Razaq. 2012. Fitness Cost, Cross Resistance and Realized Heritability of Resistance to Imidacloprid in *Spodoptera litura* (Lepidoptera: Noctuidae). *Pesticide Biochemistry and Physiology* 103: 181–188.

Bao, H., S. Liu, J. Gu, X. Wang, X. Liang, & Z. Liu. 2009. Sublethal Effects of Four Insecticides on the Reproduction and Wing Formation of Brown Planthopper, *Nilaparvata lugens*. *Pest Management Science* 65: 170–174.

Basit, M., A.H. Sayyed, S. Saeed, & M.A. Saleem. 2012. Lack of Fitness Costs Associated with Acetamiprid Resistance in *Bemisia tabaci* (Hemiptera: Aleyrodidae). *Journal of Economic Entomology* 105: 1401–1406.

Bass, C., I. Denholm, M.S. Williamson, & R. Nauen. 2015. The Global Status of Insect Resistance to Neonicotinoid Insecticides. *Pesticide Biochemistry and Physiology* 121: 78–87.

### Table 2. The effect of imidacloprid to eggs and nymphs of *Nilaparvata lugens*

| *Nilaparvata lugens* population | Imidacloprid (ppm) | Eggs (d) | 1st instar (d) | 2nd instar (d) | 3rd instar (d) | 4th instar (d) | 5th instar (d) |
|--------------------------------|---------------------|----------|----------------|----------------|----------------|----------------|----------------|
| 1st application                |                     |          |                |                |                |                |                |
| Resistant                      | -                   | 12.15 b  | 2.80 bc        | 2.65 b         | 2.85 a         | 2.65 b         | 2.95 a         |
| Resistant LC50 (33.93)         | 13.50 a             | 3.40 a   | 3.45 a         | 3.10 a         | 3.20 a         | 3.20 a         | 3.30 a         |
| Resistant LC20 (1.18)          | 12.95 b             | 3.22 a   | 2.90 b         | 3.00 a         | 3.00 a         | 3.15 a         |                |
| Susceptible                    | -                   | 11.20 c  | 2.40 c         | 2.15 c         | 2.30 b         | 2.45 b         | 2.35 b         |
| 2nd application                |                     |          |                |                |                |                |                |
| Resistant                      | -                   | 12.10 b  | 2.80 b         | 2.65 c         | 2.85 b         | 2.70 b         | 2.95 b         |
| Resistant LC50 (33.93)         | 13.65 a             | 3.55 a   | 3.50 a         | 3.40 a         | 3.45 a         | 3.45 a         | 3.45 a         |
| Resistant LC20 (1.18)          | 13.10 a             | 3.25 a   | 3.05 b         | 3.25 a         | 3.25 a         | 3.25 a         | 3.30 ab        |
| Susceptible                    | -                   | 9.80 c   | 2.30 c         | 2.40 c         | 2.25 c         | 2.30 c         | 2.25 c         |
| 3rd application                |                     |          |                |                |                |                |                |
| Resistant                      | -                   | 12.15 b  | 2.80 b         | 2.90 b         | 3.05 b         | 2.75 b         | 3.05 b         |
| Resistant LC50 (33.93)         | 13.70 a             | 3.40 a   | 3.45 a         | 3.45 a         | 3.55 a         | 3.55 a         | 3.50 a         |
| Resistant LC20 (1.18)          | 13.15 a             | 3.00 b   | 3.00 b         | 3.30 ab        | 3.20 a         | 3.25 ab        |                |
| Susceptible                    | -                   | 9.90 c   | 2.25 c         | 2.25 c         | 2.20 c         | 2.35 c         | 2.25 c         |

Note: The average on the column with similar letter is not significantly different on 5% LSD for its application.

### Table 3. The effect of imidacloprid on feeding capacity of female brachypteran of *Nilaparvata lugens*

| *Nilaparvata lugens* population | Imidacloprid (ppm) | Amino acid area (mm²)/5females | 28 DAP  | 53 DAP  | 78 DAP |
|--------------------------------|---------------------|--------------------------------|--------|--------|--------|
| Resistant                      | -                   | 7.0 c                          | 7.5 c  | 7.2 c  |        |
| Resistant LC50 (33.93)         | 9.0 b               | 11.5 b                         | 10.0 b |        |        |
| Resistant LC20 (1.18)          | 9.0 b               | 9.5 b                          | 10.5 b |        |        |
| Susceptible                    | -                   | 14.0 a                         | 17.0 a | 16.0 a |        |

Note: Means in each column followed by similar letter is not significantly different at 5% level (LSD).
Botrell, D.G. & K.G. Schoenly. 2012. Resurrecting the Ghost of Green Revolutions Past: the Brown Planthopper as a Recurring Threat to High Yielding Rice Production in Tropical Asia. *Journal of Asia-Pacific Entomology* 15: 122–140.

Catindig, J.L.A., G.S. Arida, S.E. Bachaki, J.S. Bentur, L.Q. Cuong, M. Norowi, W. Rattanakarn, W. Sriratanaak, J. Xia, & Z. Lu. 2009. Situation of Planthoppers in Asia, p. 191–220. In K.L. Heong & B. Hardy (eds), *Planthoppers: New Threats to the Sustainability of Intensive Rice Production Systems in Asia*. IRRI, Philippines.

Chelliah, S. & E.A. Heinrichs. 1984. Factor Contributing to Brown Planthopper Resurgence, p. 107–115. In M.S. Swaminathan (ed.), *Judicious and Efficient Use of Insecticides on Rice*. IRRI, Philippines.

Chen, Z., S. Bai, Z. Wang, S. Zeng, F. Zhu, J. Zhuang, R. Guo, & D. Hu. 2012. Study on Twenty-Five Percent Pymetrozine-Thiamethoxam Suspension Concentrate as an Insecticide against Rice Planthopper. *African Journal of Agricultural Research* 7: 4627–4633.

Cutler, G.C., K. Ramanaidu, T. Astatkie, & M.B. Isman. 2009. Green Peach Aphid, *Myzus persicae* (Hemiptera: Aphididae), Reproduction during Exposure to Sublethal Concentrations of Imidacloprid and Azadirachtin. *Pest Management Science* 65: 205–209.

Elbert, A., M. Haas, B. Springer, W. Thielert, & R. Nauen. 2008. Applied Aspects of Neonicotinoid uses in Crop Protection. *Pest Management Science* 64: 1099–1105.

Elsa, R., Y. Suzuki, K. Arimura, K. Miyanoto, M. Matsumura, & T. Watanabe. 2003. Comparing *Nilaparvata lugens* Stal. and *Sogatella furcifera* (Horvath) (Homoptera: Delphacidae) Feeding Effects on Rice plant Growth Processes at the Vegetative Stage. *Crop Protection* 22: 967–974.

Heinrichs, E.A., S. Chelliah, S.L. Valencia, M.B. Arceo, L.T. Fabellar, G.B. Aquino, & S. Pickin. 1981. *Manual for Testing Insecticides on Rice*. IRRI, Philippines. 134 p.

Herbert, D.A., & J.D. Harper. 1987. Food Consumption by *Helothis zea* (Lepidoptera: Noctuidae) Larvae Intoxicated with a B–edotoxin of *Bacillus thuringiensis*. *Journal of Economic Entomology* 96: 1083–1090.

Jeschke, P. & R. Nauen. 2005. Neonicotinoid Insecticides, p. 53–105. In L.I. Gilbert, K. Iatrou, & S.S. Gill (eds.), *Comprehensive Molecular Insect Science*, Elsevier, Oxford, UK.

Kliot, A. & M. Ghanim. 2012. Fitness Costs Associated with Insecticide Resistance. *Pest Management Science* 68: 1431–1437.

Kumar, K. & R.B. Chapman. 1984. Sublethal Effects of Insecticides on the Diamondback Moth *Plutella xylostella* (L.). *Pesticide Science* 15: 344–352.

Leather, S.R. 1995. Factors Affecting Fecundity, Fertility, Oviposition, and Larviposition in Insects, p. 143–174. In S.R. Leather & J. Hardie (eds), *Insect Reproduction*. CRC Press, Boca Raton.

LeOra Software. 1997. POLO-PC: Probit and Logit Analysis.LeOra Software, Berkeley, CA.

Liu, Z. & Z. Han. 2006. Fitness Costs of Laboratory-Selected Imidacloprid Resistance in the Brown Planthopper, *Nilaparvata lugens* Stal. *Pest Management Science* 62: 279–282.

Liu, S.H, B.J. Yang, S. Liu, Z.P. Ding, Z.W. Liu, & J. Tang. 2012. Effects of Sublethal Dose of Imidacloprid and Pymetrozine on Relative Biological Fitness of Brown Planthopper, *Nilaparvata lugens*. *Chinese Journal of Rice Science* 26: 361–364.

Melnahah, Witjaksono, & Y.A. Trisyono, 2002. Selection of Resistance to Brown Planthopper of Fipronil Insecticide. *Indonesian Journal of Plant Protection* 8: 107–113.

Moriarty, F. 1969. Sublethal Effects of Sicytic Insecticides on Insects. *Biological Reviews* 44: 321–357.

Ratna, Y. 2011. Mechanism of Resurgence on Rice Brown Planthopper after Deltamethrin Application Sublethal Concentrations. Dissertation. Faculty of Agriculture, Gadjah Mada University, Yogyakarta. 112 p.

Sutrisno. 1989. Study of Resistance to Brown Planthopper, *Nilaparvata lugens* Stal of Organophosphate and Carbamate Insecticides. Dissertation. Gadjah Mada University, Yogyakarta. 210 p.

Trisyono, Y.A. & Whalon. 1997. Fitness Cost of Resistance to *Bacillus thuringiensis* in Corolado Potato Beetle (Coleoptera: Crysomelidae).*Journal of Economic Entomology* 90: 267–271.

Wang, A.H., J.C. Wu, Y.S. Yu, J.L. Liu, J.F. Yue, & M.Y. Wang. 2005. Selective Insecticide-Induced Stimulation on Fecundity and Biochemical Changes in *Tryporyza incertulas* (Lepidoptera: Pyralidae). *Journal of Economic Entomology* 98: 1144–1149.

Wang, Y., J. Chen, Y.C. Zhu, C. Ma, Y. Huang, & J. Shen. 2008. Susceptibility to Neonicotinoids and Risk of Resistance Development in the Brown Planthopper, *Nilaparvata lugens* (Stål) (Homoptera: Delphacidae). *Pest Management Science* 64: 1278–1284.

Yin, J.L., H.W. Xu, J.C. Wu, F. Wang, & G.Q. Yang. 2008. Cultivar and Insecticide Applications Affect the Physiological Development of the Brown Planthopper, *Nilaparvata lugens* (Stål) (Homoptera: Delphacidae). *Environmental Entomology* 37: 206–212.