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Preliminary survey of the brown planthopper, *Nilaparvata lugens* (Stål) (Hemiptera: Delphacidae) on different varieties of rice and its natural enemies in Central Thailand

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Abstract

The life history of *Nilaparvata lugens* was examined on five resistant rice varieties under laboratory conditions, whereas outbreaks of *N. lugens* and natural insect enemies were investigated in rice fields. In the laboratory, the samples of *N. lugens* treated on RD31, RD51 and PTT1 rice had short life cycles (mean ± SD) of 47.75 ± 2.06 d, 47.89 ± 3.14 d and 49.67 ± 1.80 d, respectively. In contrast, *N. lugens* reared on RD41 and RD47 rice had longer cycles of 54.28 ± 3.59 d and 56.78 ± 3.03 d, respectively (F = 15.621; p = 0.006). The highest prevalence of *N. lugens* was in PTT1, whereas the lowest populations were in RD51. However, there were no significant differences between mean rank numbers of *N. lugens* among the five rice varieties in both years (first year, p = 0.329; second year, p = 0.089). In addition to *N. lugens*, *Nephotettix* spp., *Recilia dorsalis*, *Sogatella furcifera* and *Tagosodes pusanus* were recorded as the four most abundant insect pests of rice. Significant correlations were found between the number of *N. lugens* and the high numbers of *Nephotettix* spp., *C. lividipennis* and *T. pusanus* during the second year. Of 18,999 natural enemies, *C. lividipennis* was the most abundant predator for *N. lugens* during the 2 yr period at 30.35% in the first year and 11.87% in the second year, respectively. Among 41 parasitic wasps, *Oligosita yasumatsui* was the dominant species collected in the first year (13.53%), followed by *Tetrastichus formusanus* (0.86%), *Anagrus optabilis* (0.62%), *Tetrastichus schoenobii* (0.50%) and *Temelucha* sp. (0.35%). The number of parasitic wasps during the second year decreased sharply in the rice plots.

Introduction

The brown planthopper, *Nilaparvata lugens* (Stål) (Hemiptera: Delphacidae), is among the most serious insect pests of rice in Asia (Heong et al., 1992). This insect contains two wing forms (barchypterous and macropterous). The brachypterous adults have reduced wings and cannot fly, while the macropterous adults have fully developed wings and can disperse over long distances (Kisimoto, 1976). Various factor cues such as population density, mate seeking, host and plant condition, temperature and photoperiod were reported as conditions influencing the wing form of *N. lugens* (Johno, 1963; Kisimoto, 1965; Saxena et al., 1981; Ichikawa, 1982; Cook and Perfect, 1985; Iwanaga and Tojo, 1986; Iwanaga et al., 1987). The preoviposition period of *N. lugens* averages 3–4 d

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for both brachypterous and macropterous females. The survival and development of the egg and nymphal stages depends on the temperature and cultivar. *Oryza sativa* (Poales: Poaceae) and ratoon paddy were recorded as true host plants for *N. lugens* (Chu and Hirashima, 1981). Thus, it is notable that *N. lugens* is a monophagous insect restricted to cultivated *O. sativa* rice and its many varieties of allied wild rice forms such as *Oryza perennis* (Poales: Poaceae), *Oryza spontanea* (Poales: Poaceae) and *Leersia hexandra* (Poales: Poaceae) (Den Hollander and Pathak, 1981; Sōgawa, 1982; Sezer and Butlin, 1998). *Nilaparvata lugens* is mainly abundant in irrigated rice in a lowland environment (Reissig et al., 1986). Both the nymphs and adults of *N. lugens* damage rice plants directly by sucking sap from the mesophyll and blocking the xylem. Adult females can damage the phloem by laying egg masses in the midribs of the leaf sheath and leaf blade, thus causing a reduction in crop vigor, plant height, productive tillers and filled grains. The feeding causes heavy infestation, which is referred to commonly as hopperburn due to the characteristic yellowing of tissue. Hopperburn begins in patches but can be spread rapidly by adult females moving from dying plants to adjacent ones. Moreover, *N. lugens* not only damages the rice crop directly, but it also is a potential agent for transmission of rice viruses, rice grassy stunt (RGSV) and rice ragged stunt (RRSV) (Hibino, 1979, 1996; Hibino et al., 1977; Saxena and Khan, 1985).

There have been recent occurrences of heavy pre-harvest losses caused by viral diseases and grassy and ragged stunt viruses, affecting rice production in several Asian countries including Thailand. The serious infestation of *N. lugens* was reported in portions of most provinces of the central plain, in 1976 (Pongprasert and Weerapat, 1979). The rice variety (RD1) was seriously attacked by this insect pest. To address this problem, resistant rice varieties such as RD9, RD21, RD23 and RD25 were distributed to Thai farmers as the main strategy to control *N. lugens* populations. The re-emergence of *N. lugens* was monitored later between 1989 and 1990 when it expanded to 18 provinces covering an area from the central region to the lower north of the country. In 1987, Suphan Buri 60 as a resistant rice variety was released due to its excellent grain quality and it has become the most popular rice variety in the central plain; however, 2 yr later, an outbreak of *N. luges* was found mostly on Suphan Buri 60 (den Braber and Meenakanit, 1992). Insecticide application was the predominant management option, while the Suphan Buri 90 and CNT1 resistant rice varieties were recommended in such areas.

In 1998 and 1999, heavy damage to CNT1 was also observed and new resistant rice varieties such as PTT1, PSL2, SPR1 and SPR2 were introduced to rice crops. Recommendations on insecticide use were reconsidered due to the resurgence in *N. lugens* populations (Heinrichs et al., 1982; Gao and Ma, 1998; Wu et al., 2001; Catindig et al., 2009; Sriratanasak et al., 2011). Moreover, *N. lugens* showed the apparent development of insecticide resistance with a remarkably increased lethal dosage to cause the death of 50% of the population (LD50) compared to data in the late 1970s (Nagata, 2002). Therefore, improving new resistant rice strains has been a continuous goal of Thai researchers (Pongprasert and Weerapat, 1979; Tinjuangjun et al., 2000; Renganayaki et al., 2002; Jairin et al., 2005; Jairin et al., 2007; Jairin et al., 2009; Jannoey et al., 2017).

Nilaparvata lugens feeds on not only rice that carries resistant genes (Bph1, Bph2, Bph3, Bph4), but also on certified varieties known as RD23, RD29, CNT1, PTT1, SPR1, SPR3, SPR60, SPR90 and PSL2 (Ketipearachchi et al., 1998; Thanysiriwat et al., 2009; Sriratanasak et al., 2011). Most rice fields on the central plain of Thailand were considered vulnerable to potential *N. lugens* outbreaks (Sriratanasak et al., 2011). In contrast, populations of rice pests have been controlled by their natural enemies in various rice growing areas. In addition to killing insect pests, misuse or overuse of pesticides can be unsafe to beneficial insects and create a loss of balance in the rice ecosystem. For example, from October 2010 to September 2012, the diversity of rice insects in paddy fields in Phitsanulok province, in lower northern Thailand was adversely affected (Soinark et al., 2015). Large-scale study has been quite limited in Thailand.

Therefore, the objectives of this study were to: 1) repeat the evaluation of the life history of *N. lugens* on resistant rice varieties under laboratory conditions; and 2) to determine outbreaks of *N. lugens* and investigate its natural enemies in the paddy fields of central Thailand, containing different rice varieties.

Materials and Methods

Duration of the different life stages of Nilaparvata lugens (Stål) and its effects on varieties of host rice

Five resistant rice varieties, namely RD31 (moderately resistant to *N. lugens* and resistant to white-backed planthopper; WBPH), RD41 (moderately resistant to *N. lugens*), RD47 (resistant to *N. lugens*), RD51 (resistant to *N. lugens*) and PTT1 (resistant to *N. lugens* and WBPH) were documented and selected as standardized rice plants. Ten-day-old rice seedlings were transplanted into plastic pots (20 cm in diameter and 5 cm tall) filled with garden soil with added nitrogen fertilizer and ammonium nitrate. The rice plants were cultivated, with four hills per pot and three plants per hill, inside a cylindrical plastic cage (14 cm in diameter and 55 cm tall) with a nylon mesh top and two nylon mesh side windows. Each treatment contained three pots of selected rice.

A laboratory colony of *N. lugens* was obtained from the Rice Department of Thailand. In order to obtain eggs, 30 gravid females (of about the same age) were released on 35-day-old rice cultivars and removed from the cage after 24 hr. Incubation periods for the eggs to hatch were determined by the first emergence day of newly hatched nymphs. The nymphal developmental time of each stage was determined every evening until completing their life cycle.

A complete blocks design (two blocks with each one consisting of five treatments) was used for this investigation. Each treatment consisted of three pots of rice plants. As a result, every treatment was replicated the same three times and this investigation was repeated twice.

All experiments were conducted under natural photoperiod conditions at 37°C in a temperature-controlled greenhouse at the Department of Entomology, Faculty of Agriculture, Kasetsart University, Bangkok, Thailand.

Field surveys of Nilaparvata lugens (Stål) populations in central Thailand

Field surveys of *N. lugens* populations were carried out in the paddy fields of central Thailand over a 2 yr period (first year, December 2012−July 2013; second year, November 2013−July 2014). The study area covered provinces with high potential for rice production, being Pathum Thani (Lam Luke Ka, Nhong Sue, Lad Lum Keaw districts), Phra Nakhon Si Ayutthaya (Ayutthaya) (Bang Pa In, Bang Pa Han, Nakorn Luang districts), Suphan Buri (Don Chedi, Sriprachan, Sam Chuke districts), Lop Buri (Mueang, Ban Mee, Tha Wung districts), Nakhon Nayok (Aongkarak, Banna, Pakplee districts) and Sing Buri (Mueang, In Buri, Bang Rachan districts), plus Prachin Buri (Nadee, Mueang, Bansarng districts) in the east. At least nine rice fields from three districts in each province were selected randomly for rice transplantation. The distance between paddy fields was at least approximately 1 km. Rice pests were based on the practices of pesticide use.

N. lugens collection was carried out once in each rice field. Old rice cultivars were collected 20–40 d prior to *N. lugens* collections, as the main criteria for rice field selection. Insect surveys were performed using the two techniques: 1) the push-aside-and-count method and 2) sweep net method, to determine the density of adult and nymph populations in and around the rice fields. When using the push-aside-and-count method, rice plants were pushed aside and the insects on the plants were counted. Whenever the sweeping net was used, the number of sweeps was 20 strokes per plot. Both techniques were carried out along 20 diagonal points from two sides of the paddy field. Insect collections from the sweep net were investigated for the natural enemies of *N. lugens*.

The coordinates in decimal degrees of the study location were recorded on each sampling day using a handheld GPS unit (Garmin eTrex® 10). The climatic factors in the survey areas consisting of temperature (°C), relative humidity (RH, %), light intensity (LI, lx) and wind velocity (WVEL, m/s), were recorded at the study locations using an ST−8820 Multi-Function Environment 4 in 1 and a thermo-anemometer.

Investigation of the natural enemies of Nilaparvata lugens (Stål)

The natural enemies of *N. lugens* and other rice pests were investigated from a total of 133 rice plots (first year consisted of 67 rice plots, second year consisted of 66 rice plots), containing various rice cultivars. The insect specimens collected were sacrificed at 4°C in a refrigerator for 20 min and preserved in 70% alcohol. Subsequently, all specimens were counted and classified into families under a light microscope using the taxonomic key of Training on Rice Arthropod Biodiversity and Taxonomy (International Rice Research Institute, 2011).

Statistical analysis

All data were analyzed for homogeneity of variance. One-way analysis of variance in the R version 3.2.4 Revised (2016-03-16 r70336) Platform was used to determine whether there were any statistically significant differences among the five treatments. The least significant difference (LSD) method was used in the post hoc analysis to test the means of significantly different groups between treatments. If data did not follow a normal distribution, a nonparametric or Kruskal-Wallis H test was applied.

Bivariate Pearson correlation was used initially to determine the relationship among *N. lugens* populations, rice insect pests and climatic data. The mean difference was considered significant at the 0.05 level.

Ethics statements

Animal care or biosafety and all experimental procedures were approved by the Human/Animal Experiment Committee, Biosafety Committee, Kasetsart University, Bangkok, Thailand (Approval no. ACKU60−AGR−004).

Results

Duration of the different life stages of Nilaparvata lugens (Stål) and their effect on host rice varieties

The period of egg incubation under greenhouse conditions was about 5–9 d for all five host rice varieties. Different life stage durations of *N. lugens* were computed by days from newly hatched nymphs to emergence of newly molted adults. The nymphal developmental time of *N. lugens* had a short life cycle after being treated of (mean ± SD) 47.75 ± 2.06 d, 47.89 ± 3.14 d and 49.67 ± 1.80 d on RD31, RD51 and PTT1, respectively, while *N. lugens* reared on RD41 and RD47 took longer to complete their life cycles of 54.28 ± 3.59 d and 56.78 ± 3.03 d, respectively ($F = 15.621$; $p = 0.006$) (Table 1).

Field surveys of Nilaparvata lugens (Stål) populations in central Thailand

N. lugens populations were investigated randomly from a total of 100 rice plots (50 rice plots in each year) in the seven provinces during the rice growing season. The rice strains in particular rice plots mainly comprised RD31, RD41, RD47, RD51 and PTT1 (see Appendix A and B).

From the total number of 12,860 and 346 *N. lugens* collected during the 2 yr of survey, respectively, the highest prevalence (mean ± SD) of *N. lugens* was in PTT1 at 538.78 ± 320.67 and 8.50 ± 4.02, respectively. In contrast, the lowest population of *N. lugens* was on RD51 (90.25 ± 32.63 /0.00 ± 0.00) then RD41 (129.71 ± 55.95 /1.00 ± 0.36), RD47 (210.50 ± 87.85/4.85 ± 1.08) and RD31 (236.88 ± 115.56/10.11 ± 4.09). However, there were no significant differences between the mean ranks for the numbers of *N. lugens* found among rice varieties throughout the first ($\chi 2 = 4.617$; $p = 0.329$) and second years of collection ($\chi 2 = 8.062$; $p = 0.089$) as shown in Table 2.

Table 1 Nymphal developmental time of *Nilaparvata lugens* (Stål) on different rice varieties under laboratory conditions

Rice	Life cycle	Nymphal developmental time (days)#				
	(d)	N1−N2	N2−N3	N3−N4	N4−N5	Adult
RD31	47.75±2.06[a]	9.83±2.71[a]	9.14±2.12[a]	8.71±1.80[a]	6.43±1.51[a]	5.00±0.00[a]
	(30–51)	(6–13)	(6–13)	(5–10)	(5–9)	(5)
RD41	54.28±3.59[b]	12.72±1.27[b]	6.33±2.35[b]	7.00±2.53[ab]	7.81±2.82[a]	5.00±0.82[a]
	(24–59)	(11–15)	(3–13)	(3–13)	(3–12)	(4–6)
RD47	56.78±3.03[b]	15.53±1.60[b]	8.00±3.16[ab]	8.07±1.58[a]	6.81±2.07[a]	6.50±0.93[b]
	(30–61)	(12–18)	(3–13)	(6–11)	(4–11)	(5–8)
RD51	47.89±3.14[a]	12.14±5.47[b]	6.46±1.33[b]	5.57±1.70[b]	6.67±1.84[a]	5.00±0.87[a]
	(18–50)	(4–17)	(4–9)	(3–8)	(3–9)	(3–9)
PTT1	49.67±1.80[a]	11.54±2.97[b]	6.18±0.98[b]	10.90±2.13[c]	8.50±1.69[a]	5.00±0.00[a]
	(30–54)	(6–15)	(5–8)	(8–14)	(7–11)	(4–6)
F	15.621	4.315	3.254	11.867	1.643	7.678
p	0.006	0.004	0.019	0.000	0.177	0.000

N1, N2, N3, N4, N5 = nymphal stages from one to five, respectively.
Data presented as mean ± SD and (minimum−maximum), in the same column and followed by a common superscript lowercase letter are not significant at the 0.05 level by Fisher's least significant difference.

Table 2 Mean rank of *Nilaparvata lugens* (Stål) populations sampled from rice varieties in central Thailand during the study periods of December 2012 to July 2013 (first year) and November 2013 to July 2014 (second year)

Rice variety	*Nilaparvata lugens* populations	
	First year	Second year
RD31	22.53 (6−1,835)[a]	28.84 (0−77)[a]
RD41	23.86 (11−432)[a]	14.67 (0−2)[a]
RD47	24.29 (6−1,210)[a]	27.81 (0−11)[a]
RD51	23.50 (37−173)[a]	7.00 (0−0)[a]
PTT1	34.83 (38−3,065)[a]	26.35 (0−38)[a]

Values of mean rank (minimum−maximum), in the same column followed by a common superscript lowercase letter are not significant at the 0.05 level using the Kruskal-Wallis H test.

Besides *N. lugens* being the most abundant, other rice insect pests were recorded, as shown in Table 3. In the family, Delphacidae, *Sogatella furcifera* (Horváth) was the most abundant (4.02%, first year; 13.19%, second year), followed by *Tagosodes pusanus* (Distant) (2.79%, first year; 1.96%, second year). In the family, Cicadellidae, the two most abundant insect species were *Nephotettix* spp. and *Recilia dorsalis* (Motschulsky), at 15.94% and 6.07%, respectively, in the first year, and 41.63% and 10.01%, respectively, in the second year.

Among the five most abundant insect pests, *N. lugens* was dominant during the first year. On the other hand, *Nephotettix* spp. (the second most abundant insect pest during the first year) had relatively large populations in the second year, followed by *N. lugens* (Fig. 1).

Correlation bivariate analysis was performed to determine the relationship between *N. lugens* populations, climatic factors and other rice insect pests such as *Nephotettix* spp., *S. furcifera*, *T. pusanus* and *R. dorsalis*, as well as an important natural enemy of *N. lugens*, namely *C. lividipennis*. The results from the first and second years revealed the same patterns, with no significant correlation between *N. lugens* populations and climatic data (Table 4). An increasing population of *N. lugens* during the second year of the survey correlated only weakly with a high number of *Nephotettix* spp., *C. lividipennis* and *T. pusanus*. This situation was not observed in the previous year (Table 5).

Investigation of natural enemies

Out of 18,999 insect specimens collected over the 2 yr period, 10 predator species belonging to the orders Coleoptera, Diptera, Dermaptera, Hemiptera and Odontata and 41 parasitoid insects classified into genus and species belonging to 19 families in the order Hymenoptera were identified as natural enemies of rice insect pests (Table 6). Among the predatory insects, *C. lividipennis* (Hemiptera: Miridae) was the most abundant for *N. lugens*, at 30.35% and 11.87% of 4,474 and 505 specimens for the first and second years, respectively. *Micraspis discolor* (Fabricius) (Coleoptera: Coccinellidae), *Ophionea ishii ishii* Habu (Coleoptera: Carabidae), *Paederus fuscipes* Curtis (Coleoptera: Staphylinidae), *Pipunculus* sp. (Diptera: Pipunculidae) and *Conocephalus* sp. (Orthoptera: Tettigoniidae) were other key predators of *N. lugens* (Table 6).

In the group of parasitoid wasps, *Tetrastichus formusanus* (Timberlake) (Eulophidae) and *Tetrastichus schoenobii* Ferriere (Eulophidae), *Temelucha* sp. (Ichneumonidae), *Anagrus optabilis* (Perkins) (Mymaridae) and *Oligosita yasumatsui* Viggiani et Subba Rao (Trichogrammatidae) were important parasitoids of *N. lugens* (Table 6).

Oligosita yasumatsui was the dominant species collected in the first the first year (13.53% of 1,995 specimens), followed by *T. formusanus* (0.86% of 127 specimens), *A. optabilis* (0.62% of 92 specimens), *T. schoenobii* (0.50% of 74 specimens) and *Temelucha* sp. (0.35% of 51 specimens). The proportion of *O. yasumatsui* decreased sharply to 0.02% in the second year, followed by *T. schoenobii* (0.23% of 10 specimens) and *Temelucha* sp. (0.12% of 5 specimens). It was not unexpected that *T. formusanus* and *A. optabilis* were not found in any rice fields throughout the second year (Table 6).

Table 3 Insect pests on rice collected from central Thailand during the study periods of December 2012−July 2013 (first year) and November 2013−July 2014 (second year)

Insect pests of rice	Species	Number of insects (%)	
		(First year)	(Second year)
Order Coleoptera			
Chrysomelidae	*Aulacophola frontalis* (Baly)	3 (0.01)	0 (0.00)
	Aulacopphola semilis Oliver	7 (0.03)	0 (0.00)
Curculionidae	*Sitophilus oryzae* (L.)	0 (0.00)	8 (0.75)
Hispidae	*Dicladispa armigera* (Olivier)	2 (0.01)	5 (0.47)
Order Hemiptera			
Aphididae	*Aphis craccivora* Koch	995 (4.32)	0 (0.00)
Cicadellidae	*Callitettix* sp.	1 (0.00)	0 (0.00)
	Cofana sp.	39 (0.17)	0 (0.00)
	Empoasca vitis Göthe	0 (0.00)	16 (1.50)
	Nephotettix spp.	3,674 (15.94)	445 (41.63)
	Recilia dorsalis (Motschulsky)	1,398 (6.07)	107 (10.01)
	Recilia distincta (Motschulsky)	0 (0.00)	4 (0.37)
	Tettigoniella spectra Distant	0 (0.00)	22 (2.06)
Delphacidae	*Nilaparvata lugens* (Stål)	12,763 (55.37)	205 (19.18)
	Perkinsiella saccharicida (Kirkaldy)	1 (0.00)	0 (0.00)
	Sogatella furcifera (Horváth)	926 (4.02)	141 (13.19)
	Sogatella kolophon (Kirkaldy)	11 (0.05)	0 (0.00)
	Sogatella vibix (Haupt)	142 (0.62)	0 (0.00)
	Tagosodes pusanus (Distant)	643 (2.79)	21 (1.96)
	unidentified	4 (0.02)	0 (0.00)
Membracidae	unidentified	1 (0.00)	0 (0.00)
Pentatomidae	*Scotinophara coarctata* (Fabricius)	0 (0.00)	16 (1.50)
Order Lepidoptera			
Ctenuchidae	*Euchromia polymena* Linnaeus	1 (0.00)	0 (0.00)
Gelechiidae	*Sitotroga cerealella* (Olivier)	1 (0.00)	0 (0.00)
Hesperiidae	unidentified	10 (0.04)	0 (0.00)
Noctuidae	*Mythimna* sp.	3 (0.01)	0 (0.00)
Pyralidae	*Cnaphalocrocis medinalis* Guenee	793 (3.44)	7 (0.65)
	Nymphula depunctalis Guenee	17 (0.07)	0 (0.00)
	Pyralidae sp.	10 (0.04)	0 (0.00)
Satyridae	*Melanitis leda* Linnaeus	1 (0.00)	0 (0.00)
Order Orthoptera			
Acrididae	unidentified	87 (0.38)	10 (0.94)
Gryllidae	*Anaxipha* sp.	7 (0.03)	0 (0.00)
	Euscyrtus sp.	4 (0.02)	0 (0.00)
	Metioche sp.	3 (0.01)	0 (0.00)
Pyrgomorphidae	unidentified	2 (0.01)	0 (0.00)
Tettigoniidae	unidentified	50 (0.22)	42 (3.93)
Order Thysanoptera			
Thripidae	*Stenchaetothrips biformis* (Bagnall)	1,450 (6.29)	20 (1.87)
Total		23,049 (100.00)	1,069 (100.00)

Values derived from a total of 133 rice plots (67 in the first year and 66 in the second year)

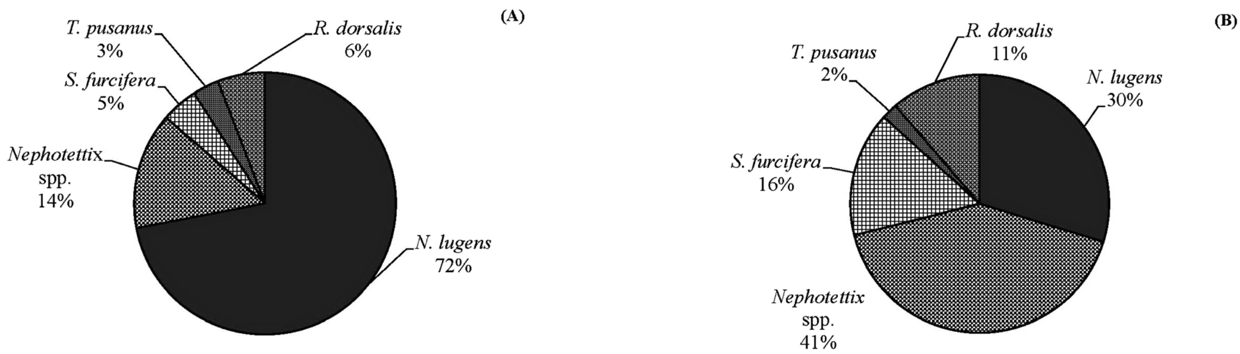

Fig. 1 Relative proportion (%) of five major insect pests of rice, based on sweep net collection and push-aside count sampling from paddy fields in central Thailand: (A) first year: December 2012−July 2013 (67 rice plots); (B) second year: November 2013−July 2014 (66 rice plots).

Table 4 Correlation between climatic variables and *Nilaparvata lugens* (Stål) populations collected from central Thailand during the study periods of December 2012−July 2013 (first year) and November 2013−July 2014 (second year)

Year	Temp (°C)	RH (%)	LI (lx)	WVEL (m/s)
First	-0.03 (0.80)	0.03 (0.80)	0.15 (0.37)	0.10 (0.51)
Second	0.05 (0.69)	0.01 (0.97)	0.13 (0.31)	-0.13 (0.30)

RH = relative humidity; LI = light intensity; WVEL = wind velocity.
Values represent Pearson's correlation coefficient (ρ) with the p value in brackets and all differences were not significant ($p > 0.05$).

Table 5 Correlation between *Nilaparvata lugens* (Stål) populations and other insects commonly found in rice fields in central Thailand during the study periods of December 2012−July 2013 (first year) and November 2013−July 2014 (second year)

Year	*Nephotettix* spp.	*S. furcifera*	*T. pusanus*	*R. dorsalis*	*C. lividipennis*
first	0.02 (0.86)	0.02 (0.85)	0.09 (0.45)	0.07 (0.95)	0.18 (0.15)
second	0.25 (0.04)*	0.14 (0.28)	0.34 (0.00)*	0.08 (0.49)	0.47 (0.00)*

Values = Pearson's correlation coefficient (ρ) with the p value in brackets.
* = significant ($p < 0.05$).

Table 6 List of natural enemy insects collected from central Thailand during the study periods of December 2012−July 2013 (first year) and November 2013−July 2014 (second year)

Insects	Species	Number of insects and (%)	
		(first year)	(second year)
Predator: Order Coleoptera			
Anthicidae	Unidentified	7 (0.05)	0 (0.00)
Carabidae	*Ophionea ishii ishii* Habu	0 (0.00)	80 (1.88)
	Ophionea nigrofasciata Schmidt-Gobel	80 (0.54)	8 (0.19)
Coccinellidae	*Micraspis discolor* (Fabricius)	738 (5.01)	127 (2.98)
	Menochilus sexmaculatus Fabricius	11 (0.07)	2 (0.05)
	Unidentified	0 (0.00)	343 (8.06)
Staphylinidae	*Paederus fuscipes* Curtis	126 (0.85)	100 (2.35)
Predator: Order Dermaptera			
Chelisochidae	*Proreus simulans* Stallen	2 (0.01)	0 (0.00)
Predator: Order Diptera			
Asilidae	Unidentified	1 (0.01)	0 (0.00)
Anthomyiidae	Unidentified	0 (0.00)	1 (0.02)
Chloropidae	*Anatrichus pygmaeus* Lamb	535 (3.63)	1,131 (26.57)
Ephydridae	*Ochthera brevitibialis* de Meijere	168 (1.14)	23 (0.54)
Empididae	*Drapetis* sp.	534 (3.62)	0 (0.00)
Pipunculidae	*Pipunculus* sp.	186 (1.26)	51 (1.20)
Sciomyzidae	*Sepedon* sp.	586 (3.97)	452 (10.62)

Table 6 (cont.)

Insects	Species	Number of insects and (%) (first year)	(second year)
Predator: Order Hemiptera			
Cixidae	Unidentified	0 (0.00)	1 (0.02)
Geocoridae	*Geocoris* spp.	1 (0.01)	0 (0.00)
Gerridae	*Gerris* sp.	3 (0.02)	0 (0.00)
Lygaeidae	Unidentified	3 (0.02)	0 (0.00)
Miridae	*Cyrtorhinus lividipennis* Reuter	4,474 (30.35)	505 (11.87)
Reduviidae	*Polytoxus* sp.	3 (0.02)	0 (0.00)
Saldidae	*Saldula* sp.	7 (0.05)	0 (0.00)
Veliidae	Unidentified	5 (0.03)	0 (0.00)
Predator: Order Odonata			
Coenagrionidae	Unidentified	1,847 (12.53)	1,038 (24.39)
Libellulidae	Unidentified	41 (0.28)	14 (0.33)
Parasitoid wasps: Order Hymenoptera			
Bethylidae	*Goniozus* sp.	5 (0.03)	0 (0.00)
Braconidae	*Aulacocentrum* sp.	19 (0.13)	1 (0.02)
	Cotesia sp.	442 (3.00)	98 (2.30)
	Macrocentrus sp.	0 (0.00)	2 (0.05)
	Opius sp.	174 (1.18)	36 (0.85)
	Tropobracon schoenobii (Viereck)	17 (0.12)	0 (0.00)
	Snellenius sp.	9 (0.06)	15 (0.35)
	Unidentified	0 (0.00)	24 (0.56)
Buiophidae	Unidentified	0 (0.00)	1 (0.02)
Chalcidoidea	*Anastatus* sp.	2 (0.01)	0 (0.00)
	Brachymeria sp.	10 (0.07)	0 (0.00)
	Litomastix sp.	0 (0.00)	1 (0.02)
	Mymar taprobanicum Ward	76 (0.52)	2 (0.05)
	Paracentrobia sp.	15 (0.10)	0 (0.00)
Diapriidae	Unidentified	55 (0.37)	1 (0.02)
Dryinidae	Unidentified	62 (0.42)	0 (0.00)
Elasmidae	*Elasmus* sp.	38 (0.26)	5 (0.12)
Encyrtidae	*Copidosomopsis* sp.	108 (0.3)	0 (0.00)
	Homalotylus sp.	1 (0.01)	0 (0.00)
Eucoilidae	Unidentified	300 (2.03)	0 (0.00)
Eulophidae	*Euplestrus* sp.	3 (0.02)	0 (0.00)
	Tetrastichus formusanus (Timberlake)	127 (0.86)	0 (0.00)
	Tetrastichus schoenobii Ferriere	74 (0.50)	10 (0.23)
	Stenomesius japonicus (Ashmead)	87 (0.59)	0 (0.00)
	Unidentified	0 (0.00)	28 (0.66)
Eupelmidae	*Neanastatus oryzae* Ferriere	1 (0.01)	0 (0.00)
Eurytomidae	*Eurytoma* sp.	95 (0.64)	3 (0.07)
Ichneumonidae	*Charops* sp.	16 (0.11)	2 (0.05)
	Itopletis sp.	0 (0.00)	1 (0.02)
	Paraphylax sp.	0 (0.00)	2 (0.05)
	Temelucha sp.	51 (0.35)	5 (0.12)
	Trichomma cnaphalocrosis Uchida	4 (0.03)	0 (0.00)
	Xanthopimpla flavolineata Cameron	35 (0.24)	12 (0.28)
Mymaridae	*Anagrus optabilis* (Perkins)	92 (0.62)	0 (0.00)
	Gonatocerus sp.	248 (1.68)	4 (0.09)
Panstenoninae	*Panstenon* sp.	20 (0.14)	1 (0.02)
Platygastridae	*Ceratobaeus* sp.	1 (0.01)	0 (0.00)
	Macroteleia sp.	6 (0.04)	1 (0.02)
	Platygaster sp.	435 (2.95)	3 (0.07)
Pteromalidae	*Trichomalopsis* sp.	371 (2.52)	33 (0.78)
Scelionidae	*Gryon* sp.	6 (0.04)	0 (0.00)
	Obtusiclava oryzae Subba Rao	66 (0.45)	84 (1.97)
	Psix sp.	100 (0.68)	0 (0.00)

Table 6 (cont.)

Insects	Species	Number of insects and (%) (first year)	(second year)
	Telenomus formosanus Triapitsyn	0 (0.00)	4 (0.09)
	Telenomus rowani (Gahan)	57 (0.39)	0 (0.00)
Trichogrammatidae	*Oligosita yasumatsui* Viggiani et Subba Rao	1,995 (13.53)	1 (0.02)
	Trichogramma sp.	162 (1.10)	0 (0.00)
Total		14,743 (100.00)	4,256 (100.00)

Data derived from a total of 133 rice plots (67 in first year; 66 in second year).

Discussion

Based on this investigation, the rice varieties RD31, RD41, RD47 and PTT1 were the most prevalent rice cultivars grown in the central region of Thailand. This finding was similar to that of reports that ranked RD31, RD41 and RD47 highest in terms of the irradiated Thai rice cultivars in central Thailand (Chanprasert et al., 2014; Promnart et al., 2017). Other rice varieties were observed consisting of Suphanburi1, Hom Phitsanulok (PL002), Khoa Chao Hom Phitsanulok (SPRLR 83228−PSL−32−1), Thai Hom Mali, Khoaw Lueang17, Lueang Thong, Hom Prachinburi (PCR89151−27−9−155), Khoaw Banna (PCRC92001−432), Phitsanulok 5 (OC−6), Homnil rice and Cittoo Chao Pad (WUS).

In general, insect bioassays, including reduction of nymphal survival and developmental time, fecundity, and hatching and feeding rates, have been used to verify the stability of resistant rice varieties to brown planthopper (BPH) infestation (Cohen et al., 1997; Tinjuangjun et al., 2000; Shori et al., 2016). In the current study, numbers of *N. lugens* were introduced to five resistant rice varieties. However, the susceptible standard TN1 and the resistant standard PTB33 were not used to compare the responses of different varieties to *N. lugens* in this experiment. Only the nymphal developmental time was used, with caution in this preliminary study, to check the response of BPH in resistant rice. The results of this study suggested that RD31, RD51 and PTT1 could produce a significantly shorter BPH life cycle than RD41 and RD47. This result was consistent with the damage score on rice, which ranged from 0 to 9 (International Rice Research Institute, 2002). BPH populations collected from Pathum Thani produced the highest virulence on PTT1 with damage scores ranging from 7 to 9, while RD31 showed moderate resistance compared to TN1, with a damage score of 5 (Sreewongchai et al., 2015).

In order to link the laboratory results to the *N. lugens* population in the rice field, it was assumed that most of the population would be observed on RD31, RD51 and PTT1 than on RD41 and RD47, which related to the duration of the life cycle after infestation. The collections over 2 yr indicated reliably that the highest prevalence of N. *lugens* was in PTT1, followed by RD31, RD47, RD41 and RD51, but without any significant differences. These findings corresponded with the past reports as during 2009 and 2010 the occurrences of massive *N. lugens* outbreaks were monitored in PTT1 rice production over Thailand's central region in Suphan Buri, Ang Thong and Chai Nat provinces (Luechaikham, 2010; Sriratanasak et al., 2011). The second most rice cultivar found in this study was RD31, which was reported to be resistant to the white-back planthopper and moderately resistant to the BPH (Promnart et al., 2017). However, it was noted as being susceptible to *N. lugens* in Chai Nat during the dry season (Abril et al., 2017). Since *N. lugens* took a long time to complete its life cycle on RD41 and RD47, small numbers were recorded remarkably from the rice fields. In comparison, RD41 and RD47 were reported as resistant to *N. lugens* populations from Chai Nat and Nakhon Nayok during the wet season (Abril et al., 2017). In spite of their short life cycle observed on RD51, the populations of *N. lugens* were hardly found in the rice fields, probably due to the small numbers of rice plots in both years of the survey (8% and 4%, respectively). In addition, RD51 was developed later for flash flooding tolerance and introduced to farmers after Thailand experienced its worst flooding in 2011 (Vanavichit et al., 2018).

Furthermore, the method of planting crops was not remarked upon in the data collected in the current study, which could have provided differences in numbers and types of insect pests and natural enemies in rice. This 2 yr survey of insect pests in Saraburi province proved that transplanted RD31 rice had *N. lugens* in low abundance, unlike directly seeded rice, in which *N. lugens* reached a level of economic injury (Anuson et al., 2015).

The status of rice pests from the findings in the current study (December 2012−July 2013 and November 2013−July 2014) was similar to that in a study by Ruay-aree (1998), where *N. lugens*, *Nephotettix* spp. *S. furcifera*, *T. pusanus* and *R. dorsalis* remained the dominant rice pests in central Thailand. The present situation was documented previously in Chai Nat and Phisanulok provinces from January to May 2009, when *N. lugens*, *S. furcifera* (white-backed planthopper), *Nephotettix* spp. (green leafhoppers) and *R. dorsalis* (zigzag leafhopper) had very high rice pest populations (Sirisantana et al., 2009). In addition, data from rice fields in the Pak Panang river basin and the Nakhon Si Thammarat Rice Research Center revealed that the pest species *S. biformis*, *Spodoptera litura*, *N. lugens*, *S. furcifera*, *Nephotettix*, *Nymphula depuntalis* Guenée, *Cnaphalocrocis medinalis* Guenée, *Scotinophara* sp. and *Leptocorisa oratorius* Fabricius were under surveillance from 2009 to 2013 (Jumruskarn et al., 2014). However, no *S. litura*, *N. depuntalis*, *C. medinalis* or *Stenchaetothrips* sp. specimens were established in this study. This could be explained by the methods used for insect collection. Adult lepidopteran rice pests were attracted more to the light traps used in the study by Jumruskarn et al., (2014). Increasing *N. lugens* populations correlated weakly with the high number of *Nephotettix* spp. and *T. pusanus* in the second year of the current survey.

The numbers of nymphs and adults in the current sampling were included in the total number of *N. lugens* in the rice field, based on visual counting and sweep netting from two diagonal transects of 10 rice hills per rice field. The wet or dry season was of no concern in this study. In consequence, a positive correlation between *N. lugens* and *C. lividipennis* populations was established clearly in only the second year. Correspondingly, a study in Nakhon Nayok stated that densities of BPH nymphs in resistant rice plots correlated positively with those of *C. lividipennis*, while those of long-winged adults did not correlate with the occurrence of *C. lividipennis* during the wet season. Densities of nymphs and short- and long-winged adults did not correlate in susceptible fields with those of *C. lividipennis* (Abril et al., 2017).

The sampling in the current study could be clarified by the proportion of *N. lugens* and its natural enemies (predators and parasitoids). Apart from the total number of 12,763 *N. lugens* during the first year (December 2012–July 2013), there was a high number of *C. lividipennis* (4,474 specimens) and other key parasitoid wasps (*O. yasumatsui*,1,995 specimens; *A. optabilis*, 92 specimens), resulting in the ratio between *N. lugens* and those three insect species, respectively, of 1:0.51. This occurrence was different from the outcome in the second year; when high numbers of *C. lividipennis* (505 specimens) played a key role in suppressing *N. lugens* populations (205 specimens) at a ratio of 1:3.98, while numbers of most key parasitoid wasps had reached zero. Nevertheless, a severe drought from October 2013 to April 2014 should be noted, as it might have suppressed the *N. lugens* population during the second year, as took place in similar patterns in China (Wu et al., 1997).

However, there was no evidence of the *N. lugens* population being related to microclimate. Likewise, a study in Nakhon Pathom province from January to May 2009 showed no correlation between species numbers of insect pests and abiotic factors, but it did relate to the species numbers of natural enemies (Sorapongpaisal et al., 2011). Another study on insect and spider diversity in irrigated paddy fields in Phitsanulok province from October 2010 to September 2012 also reported that rice insect pest numbers were compatible with only natural enemies, and not with any abiotic factor (Soinark et al., 2015).

A great abundance of predator insects was recorded in the current study, with *C. lividipennis* persisting as the primary predator of *N. lugens* over the 2 yr period, which was similar to surveys in Pathum Thani and Chachengsao provinces during 1989 and 1990 (Ruay-aree, 1991), in Phitsanulok province between 2010 and 2012 (Soinark et al., 2015) and in the Pak Panang river basin and Nakhon Si Thammarat province from 2009 to 2013 (Jumruskarn et al., 2014). *Oligosita yasumatsui* was the dominant species among parasitic wasps collected in the first year (13.53%), followed by *T. formusanus* (0.86%), *A. optabilis* (0.62%), *T. schoenobii* (0.50%) and *Temelucha* sp. (0.35%). Of interest, records from the second year showed that when the *O. yasumatsui* population declined, a rise in other parasitoids was monitored. These occurrences of egg parasites indicated that *O. yasumatsui* and *Tetrastichus* spp were the most abundant biological agents of *N. lugens*. Thus, the findings in this study suggested that the role of biological agents in rice field ecosystems was balanced.

In conclusion, this preliminary study showed that *N. lugens* individuals spent a significantly long period of time in completing their life cycle on treated RD41 and RD47 rice, compared to PTT1. This result was supported by the abundance of *N. lugens* on resistant rice cultivars in the rice fields of central Thailand. The highest prevalence of *N. lugens* was on PTT1 rice, whereas small populations were established on RD41 and RD47. The RD31 rice cultivar persisted with moderate resistance to *N. lugens*. Although the experiment was performed under laboratory conditions without resistance or susceptibility checks, RD41 and RD47 should be recommended to Thai farmers in the central region, as these types of rice related to the reduction of *N. lugens* outbreaks. Rice green leafhopper (*Nephotettix* spp.) was a critical species found to relate to the increase of *N. lugens*. Natural enemies clearly showed high diversity. *Cyrtorhinus lividipennis*, *O. yasumatsui*, *T. formusanus*, *A. optabilis*, *T. schoenobii* and *Temelucha* sp. still played a significant role in controlling *N. lugens* in the major rice production areas of Thailand sampled, while heavy use of pesticides can have negative impacts on insect species in the rice ecosystem.

Conflict of Interest

The authors declare no conflicts of interest. All authors contributed to data collection and analysis, and article preparation, and they all approved the final manuscript.

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Appendix A Field surveys of *Nilaparvata lugens* (Stål) populations on rice varieties (RD31, RD41, RD47, RD51, PTT1) in central Thailand from December 2012 to August 2013 (first year)

Period	Province	Rice variety	Degrees North	Degrees East	Temperature (°C)	RH (%)	LI (lx)	WVEL (m/s)	Number of *N. lugens*
Dec-12	Pathum Thani	RD31	13.93741	100.75505	39.30	45.90	–	0.74	46
Dec-12	Pathum Thani	RD31	14.19713	100.83081	39.00	35.70	–	0.70	60
Dec-12	Pathum Thani	RD31	14.19816	100.84251	37.40	37.00	–	0.74	10
Dec-12	Pathum Thani	RD31	14.04298	100.46445	31.00	64.10	–	0.70	6
Dec-12	Pathum Thani	RD31	14.05278	100.44368	34.10	59.50	–	0.76	50
Dec-12	Suphan Buri	RD31	14.59793	99.99308	30.00	69.60	–	1.30	134
Dec-12	Suphan Buri	RD31	14.78918	100.10201	32.80	58.50	–	1.71	55
Dec-12	Pathum Thani	RD41	13.97133	100.81973	35.50	44.30	–	1.33	80
Dec-12	Pathum Thani	RD41	14.15086	100.82111	34.80	47.50	–	0.71	432
Dec-12	Suphan Buri	PTT1	14.60686	100.11261	31.30	59.00	–	2.00	66
Jan-13	Ayutthaya	RD31	14.28487	100.58263	27.90	43.80	–	1.50	366
Jan-13	Ayutthaya	RD31	14.49368	100.56609	33.90	24.80	–	0.12	17
Jan-13	Ayutthaya	RD41	14.41883	100.62933	33.70	26.90	–	2.07	30
Jan-13	Ayutthaya	RD47	14.27933	100.58439	39.30	45.90	–	0.74	119
Jan-13	Ayutthaya	RD47	14.28514	100.58228	27.90	43.80	–	1.50	63
Jan-13	Ayutthaya	RD47	14.30398	100.56315	31.00	27.80	–	1.49	24
Jan-13	Ayutthaya	RD47	14.45131	100.63782	37.70	21.70	–	0.70	6
Jan-13	Ayutthaya	RD47	14.49685	100.57224	42.80	18.90	–	0.00	63
Jan-13	Ayutthaya	PTT1	14.42663	100.61873	27.10	61.70	–	0.71	221
Jan-13	Ayutthaya	PTT1	14.42634	100.61832	32.50	22.80	–	1.54	190
Feb-13	Suphan Buri	RD31	14.76571	100.09348	26.20	81.10	19200.00	1.25	102
Feb-13	Suphan Buri	RD41	14.63444	100.12767	30.80	72.50	48200.00	1.23	135
Feb-13	Suphan Buri	RD47	14.73288	100.09685	28.10	72.70	27900.00	2.23	216
Feb-13	Suphan Buri	RD51	14.60975	100.04742	33.70	53.90	47400.00	0.82	173
Feb-13	Suphan Buri	PTT1	14.63458	100.12784	33.30	52.30	72300.00	2.1	3,065
Mar-13	Lop Buri	RD31	15.00349	100.56917	35.40	50.00	77500.00	2.37	609
Mar-13	Lop Buri	RD41	–	–	31.20	63.20	74100.00	3.37	30
Mar-13	Lop Buri	RD47	14.84151	100.60258	34.80	63.10	85400.00	1.77	135
Mar-13	Lop Buri	RD47	14.73758	100.48271	31.50	75.70	59500.00	2.73	145
Mar-13	Lop Buri	RD47	14.73600	100.52019	31.00	58.60	75300.00	1.98	561
Mar-13	Lop Buri	PTT1	14.71006	100.49759	34.60	62.00	67400.00	2.10	355
Mar-13	Lop Buri	PTT1	14.71242	100.50626	36.60	58.30	70000.00	2.00	574
Jul-13	Nakhon Nayok	RD31	14.07925	101.02908	32.80	65.30	–	4.70	15
Jul-13	Nakhon Nayok	RD41	14.18277	101.06463	36.90	57.50	49400.00	3.80	190
Jul-13	Prachin Buri	RD47	14.10500	101.78361	33.60	68.00	36200.00	–	6
Jul-13	Nakhon Nayok	RD47	14.00547	101.06494	33.20	60.80	–	–	17
Jul-13	Nakhon Nayok	RD47	14.00350	101.02272	35.50	59.60	–	5.30	12
Jul-13	Prachin Buri	RD51	14.17100	101.81944	32.90	67.30	40400.00	–	39
Jul-13	Prachin Buri	RD51	14.01053	101.29194	29.00	75.90	21700.00	0.00	37
Jul-13	Prachin Buri	RD51	14.00355	101.17214	26.80	86.30	26400.00	–	112
Jul-13	Nakhon Nayok	PTT1	14.17344	101.02391	35.20	59.00	38700.00	–	75
Aug-13	Sing Buri	RD31	14.92713	100.36637	31.60	63.60	27100.00	–	435
Aug-13	Sing Buri	RD31	14.94685	100.36357	30.20	62.00	14100.00	–	30
Aug-13	Sing Buri	RD31	14.95733	100.34496	32.40	65.50	12900.00	–	1,835
Aug-13	Sing Buri	RD31	14.83579	100.29980	34.00	58.40	33200.00	–	20
Aug-13	Sing Buri	RD41	15.05134	100.30284	29.60	76.50	13400.00	–	11
Aug-13	Sing Buri	RD47	14.86010	100.38106	29.00	66.10	35500.00	–	1,210
Aug-13	Sing Buri	RD47	14.87069	100.39564	29.50	70.90	12100.00	–	370
Aug-13	Sing Buri	PTT1	14.86157	100.28995	32.40	62.80	32800.00	–	265
Aug-13	Sing Buri	PTT1	14.87780	100.32915	33.50	61.10	27300.00	–	38

RH = relative humidity; LI = light intensity; WVEL = wind velocity.

Appendix B Field surveys of *Nilaparvata lugens* (Stål) populations on rice varieties (RD31, RD41, RD47, RD51 and PTT1) in central Thailand from November 2013 to August 2014 (second year)

Time	Province	Rice variety	Degrees North	Degrees East	Temperature (°C)	RH (%)	LI (lx)	WVEL (m/s)	Number of *N. lugens*
Nov-13	Suphan Buri	RD31	14.59485	99.99269	27.30	63.30	45000.00	0.99	7
Nov-13	Suphan Buri	RD31	14.60778	99.99224	26.90	64.90	45800.00	1.38	77
Nov-13	Suphan Buri	RD31	14.61178	100.04164	28.80	58.00	12800.00	1.05	8
Nov-13	Suphan Buri	RD47	14.60790	100.08550	29.80	55.90	61000.00	2.00	4
Nov-13	Suphan Buri	PTT1	14.60798	100.11651	30.20	58.50	–	0.86	6
Nov-13	Suphan Buri	RD47	14.65822	100.11961	30.60	46.60	52200.00	0.96	11
Nov-13	Suphan Buri	RD31	14.78867	100.10183	27.70	49.60	43000.00	3.97	2
Nov-13	Suphan Buri	RD31	14.76871	100.09435	27.00	57.70	26500.00	2.74	7
Dec-13	Pathum Thani	RD47	13.95030	100.80611	29.60	55.20	39500.00	0.99	10
Dec-13	Pathum Thani	RD31	13.98340	100.82066	34.50	53.10	53300.00	1.09	25
Dec-13	Pathum Thani	RD31	14.23635	100.86969	35.50	49.10	59900.00	1.65	9
Dec-13	Pathum Thani	PTT1	14.23596	100.86946	35.80	25.00	63700.00	1.04	25
Dec-13	Pathum Thani	PTT1	14.16398	100.86952	38.80	24.50	59200.00	1.12	38
Dec-13	Pathum Thani	RD31	14.03101	100.37851	31.90	58.10	20400.00	0.72	2
Dec-13	Pathum Thani	RD31	14.03637	100.39911	33.50	51.60	35100.00	0.67	4
Dec-13	Pathum Thani	PTT1	14.04656	100.44228	33.30	50.60	24900.00	1.99	5
Dec-13	Ayutthaya	RD41	14.27934	100.58434	24.00	61.40	35200.00	2.28	0
Dec-13	Ayutthaya	RD51	14.27968	100.58486	23.50	64.50	27800.00	5.56	0
Dec-13	Ayutthaya	RD47	14.28440	100.58128	23.00	61.30	28700.00	2.40	0
Dec-13	Ayutthaya	RD31	14.28571	100.58366	24.50	57.50	41600.00	5.81	1
Dec-13	Ayutthaya	RD31	14.49229	100.56113	27.70	42.90	29000.00	2.66	0
Dec-13	Ayutthaya	RD31	14.49686	100.57234	35.10	22.70	43600.00	2.27	0
Dec-13	Ayutthaya	RD47	14.42078	100.60165	22.30	61.10	34100.00	1.78	0
Dec-13	Ayutthaya	PTT1	14.41725	100.61065	24.10	54.10	43100.00	2.45	6
Dec-13	Ayutthaya	RD41	14.42800	100.62391	27.00	38.10	45500.00	2.60	1
Dec-13	Ayutthaya	RD31	14.49206	100.58136	26.70	39.80	49400.00	1.66	7
Jan-14	Lop Buri	PTT1	14.85028	100.66139	24.20	42.90	10200.00	0.70	1
Jan-14	Lop Buri	PTT1	14.89611	100.72750	25.60	46.50	38200.00	0.70	0
Jan-14	Lop Buri	RD47	14.76917	100.70722	28.30	34.40	33000.00	0.70	3
Jan-14	Lop Buri	RD41	15.00806	100.65778	30.00	31.10	41100.00	1.34	0
Jan-14	Lop Buri	RD47	15.12722	100.61972	29.40	43.30	12500.00	1.20	0
Jan-14	Lop Buri	PTT1	14.96639	100.70556	29.70	34.10	39500.00	1.22	0
Jan-14	Lop Buri	RD41	14.88111	100.57556	24.40	–	33900.00	0.97	2
Jan-14	Lop Buri	RD31	14.78667	100.63083	29.30	–	16400.00	0.73	0
Jan-14	Lop Buri	RD47	14.85889	100.59500	29.10	–	42100.00	1.55	2
Feb-14	Sing Buri	RD31	14.99750	100.40611	30.80	65.60	40200.00	0.75	5
Feb-14	Sing Buri	PTT1	15.08556	100.36444	39.80	66.10	38000.00	1.04	3
Feb-14	Sing Buri	RD47	14.93415	100.34173	38.80	53.40	21000.00	0.76	8
Feb-14	Sing Buri	RD31	14.96492	100.30150	35.90	62.20	22600.00	0.74	3
Feb-14	Sing Buri	RD47	15.03777	100.29708	35.70	65.70	57500.00	0.84	9
Feb-14	Sing Buri	RD31	14.88162	100.34137	31.60	59.80	1909.00	0.91	26
Feb-14	Sing Buri	RD31	14.90775	100.19848	32.60	62.00	27400.00	1.42	9
Feb-14	Sing Buri	PTT1	14.91917	100.26320	33.80	49.20	31900.00	1.15	1
Jul-14	Prachin Buri	RD47	13.97011	101.34437	37.10	47.10	18230.00	0.70	7
Jul-14	Prachin Buri	RD51	13.97976	101.33613	37.50	57.20	13280.00	0.92	0
Jul-14	Prachin Buri	RD47	14.16436	101.80646	38.10	52.00	11130.00	1.51	6
Jul-14	Nakhon Nayok	RD47	14.08463	100.99955	32.00	51.40	56900.00	2.35	3
Jul-14	Nakhon Nayok	RD41	14.17026	101.05373	35.50	54.50	54200.00	1.55	2
Jul-14	Nakhon Nayok	RD31	14.21384	101.10069	35.20	59.00	38700.00	0.71	0
Jul-14	Nakhon Nayok	RD41	14.22914	101.12614	37.80	57.50	28800.00	0.77	1

RH = relative humidity; LI = light intensity; WVEL = wind velocity.