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ORIGINAL ARTICLE

Imidacloprid-induced transference effect on some elements in rice plants and the brown planthopper *Nilaparvata lugens* (Hemiptera: Delphacidae)

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Abstract The widespread use of imidacloprid against insect pests has not only increased the rate of the development of target pest resistance but has also resulted in various negative effects on rice plants and *Nilaparvata lugens* resurgence. However, the effect of imidacloprid on elements in rice plants and the transference of these element changes between rice and *N. lugens* are currently poorly understood. The present study investigated changes of Cu, Fe, Mn, Zn, Ca, K, Mg and Na contents in rice plants following imidacloprid foliar sprays in the adult female of *N. lugens* that develops from nymphs that feed on treated plants and honeydew produced by females. The results indicated that imidacloprid foliar spray significantly increased Fe and K contents in leaf sheaths. Generally, Fe, Mn, K and Na contents in leaf blades were noticeably decreased, but Ca contents in leaf blades for 10 and 30 mg/kg imidacloprid treatments were significantly increased. The contents of most elements except K and Mg in the adult females and honeydew were significantly elevated. Multivariate statistical analysis showed that Fe, Mn and Na in leaf blades and Fe and Mn in leaf sheaths could be proportionally transferred to *N. lugens*. The relationship between most elements in adult female bodies and in the honeydew showed a positive correlation coefficient. There were significant differences in the contents of some elements in rice plants and *N. lugens* from different regions.

Key words elements, imidacloprid, *Nilaparvata lugens*, rice plant, transference effect

Introduction

Imidacloprid is a neonicotinoid insecticide and is used as the active component in many commercial pest control products (Kagabu, 1997). It possesses a relatively low toxicity to mammals (Yamamoto *et al.*, 1998) and a high and long-lasting efficacy against homopterans. Imidacloprid has been commonly used to control *Sogatella furcifera* (Horvath) and *Nilaparvata lugens* (Stål) in China for over a decade (Su *et al.*, 1997; Feng & Pu, 2005; Liu & Han, 2006).

However, the wide application of imidacloprid against pests has not only increased the risk of resistance development in target insects (Grafius & Bishop, 1996; Prabhaker *et al.*, 1997; Wen & Scott, 1997; Liu *et al.*, 2003, 2005), but also resulted in various negative effects on crop plants and non-target insects. The foliar spraying of imidacloprid causes a significant reduction in the amount of chlorophyll and the rate of photosynthesis in leaf blades of rice plants (*Oryza sativa* L.) (Wu *et al.*, 2003). When applied at the heading stage of rice plants, both low and high doses of imidacloprid could significantly retard the active growth of proximal grains. Moreover, the high dose of imidacloprid reduced the growth rate of distal grains (Qiu *et al.*, 2004). However, the low dose of imidacloprid significantly increased the uptake of phosphorus (P) and potassium (K) (Qiu *et al.*, 2004). In addition to imidacloprid, other pesticides also affect the physiology

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and biochemistry of plants (Wood & Payne, 1986; Huckaba *et al.*, 1988; Youngman *et al.*, 1990; Sayed *et al.*, 1991; Wu *et al.*, 2001a, 2001b; Luo *et al.*, 2002). Some studies report that pesticide sprays influence changes in the nutrient levels of plants. For example, spraying of selected pesticides significantly decreased the amount of phosphorus and zinc in cabbage while iron, calcium and potassium were significantly increased (Reddy *et al.*, 1997). Furthermore, a variety of studies have found that pesticide spraying can cause marked changes in the nutrients of plant foods (Dedatta *et al.*, 1972; Roochaad *et al.*, 1982; Srimathi *et al.*, 1983). Insecticide-induced changes in plant quality have even been linked to the resurgence of *N. lugens* in rice (Chelliah & Heinrichs, 1980; Heinrichs & Mochida, 1984).

N. lugens is a serious insect pest that affects rice throughout Asia (Dyck & Thomas, 1979). Outbreaks of *N. lugens* have occurred in China and other Asian countries in recent years (Gao *et al.*, 2006; Liu & Liao, 2006). Outbreaks have mainly been associated with pesticide overuse and the resistance of the insect to imidacloprid (Gao *et al.*, 2006). Numerous studies have demonstrated that *N. lugens* is a classic resurgent insect pest (Chelliah & Heinrichs, 1980; Chelliah *et al.*, 1980; Gao *et al.*, 1988). Ecological mechanisms for pesticide-induced *N. lugens* resurgence include the reduction in natural enemies (Fabellar & Heinrichs, 1986; Gao *et al.*, 1988) and the stimulation of fecundity (Gu *et al.*, 1984; Wang *et al.*, 1994). In addition, *N. lugens* is also a migratory pest of rice in Asia (Cheng *et al.*, 1979; Riley *et al.*, 1994). Measurements of element levels in both rice plants and the insect body can be used to identify the migration areas of the insects. Therefore, we hypothesis that pesticides affect the element contents in crop plants, and these elements may be transferred through the food chain. However, the conductance effect of this transference following pesticide application has not been understood until recently. The objectives of the present investigation were to examine the transference effects of imidacloprid-induced element changes in rice plants on *N. lugens* and to identify populations originating from different regions based on element levels in *N. lugens*.

Materials and methods

Insecticide, rice variety and insect

Formulated 10% imidacloprid WP (Yangnon Group Co., Yangzhou, China) was used in the foliar spray experiment. Wandao 69 (japonica rice) was used as the rice variety. Rice seeds were sown in content tanks (60 × 100 × 200 cm). Five-leaf seedlings were transplanted into plastic pots with two seedlings as a hill and with four hills per pot. Rice plants were covered with a nylon cage to protect the plants from other pest infestations. Experimental insects were taken from a population of *Nilaparvata lugens* in the greenhouse of the Insect Department, Yangzhou University. Before the experiment started, the *N. lugens* colony was maintained for 10 generations in an insectary at 28 ± 4 °C and 14 : 10 (L : D) h.

Effect of different rates of imidacloprid on elements of rice plants, N. lugens *and honeydew excretion*

Potted rice plants at the tillering stage were sprayed with the recommended label rates applied in rice fields of 10, 30 and 60 mg/kg of imidacloprid (0.5, 1.5 and 3.0 g active ingredient [ai]/ha) using a Jacto sprayer (Maquinas Agricolas Jacto, Pompeia, S.A., Brazil) equipped with a cone nozzle (1-mm diameter orifice; pressure 45 psi; and flow rate, 300 mL/min). Control plants were sprayed with tap water. A parafilm sachet was attached to the rice stem approximately 10 cm above the soil surface, and an adult female insect was confined in a sachet at 24 h after the treatments were performed (Pathak *et al.*, 1982); an empty sachet was used as a control. Prior to the inoculation, the planthoppers were starved for 2 h. After a 24-h feeding period, the sachets were removed from the plants. Honeydew in the sachets was collected using a medical injector (Honqiao Medical Apparatus and Instruments Ltd. Co., Yangzhou, Jiangsu Province, China) and weighed using a Mettler Toledo electronic balance (EC 100 mode; 1/10 000 g sensitivity; Mettler Toledo Instrument (Shanghai) Ltd. Co., Shanghai, China). Sixteen adult females were confined per pot (4 females per hill). All treatments and controls were replicated five times. To measure elements in rice plants, planthoppers and their honeydew, 2 g of fresh stems and leaves were sampled 48 h after the treatment period, respectively, and dried in an electric oven at 105°C for 30 min and thereafter at 80°C for 24 h. All adult females and their honeydew were dried at 80°C for 24 h.

Quantifications of chemical elements of rice plants, N. lugens *and honeydew*

Contents of chemical elements in rice sheaths, leaves, *N. lugens* bodies and honeydew were quantified using inductively coupled plasma-atomic emission spectrometry (ICP-AES, IRIS Intrepid II XSPDuo, American Thermo. Electron. Ltd. Co., Boston, MA, US) after microwave digestion (microwave digestion system [MARS]) (CEM, Matthews, NC, USA), as described by Huang *et al.* (2003). For ICP-AES, each of eight spectrum reagents with 0.1 mg/mL was used to establish a standard solution. Two grams of the dried samples of rice sheaths or leaves were weighed and ground. Ground dried samples of rice sheaths or leaves were weighed to 0.4 g and put into the inner tin of the system with 5 mL of ultrapure water, 3 mL of HNO_3 and 0.1 mL of H_2O_2 and digested for 2 h. The digested solution was filtered with a filter paper and adjusted to 50 mL.

Sixteen dried adult females per replication were weighed, placed in the inner tin with 6 mL ultrapure water, 2 mL of HNO_3 and 0.05 mL of H_2O_2 and digested for 2 h. The digested solution was filtered with a filter paper and adjusted to 50 mL.

Honeydew from the replicated samples of 16 adult females was weighed and placed in the inner tin with 6 mL ultrapure water, 2 mL of HNO_3 and 0.05 mL of H_2O_2 and digested for 2 h. The digested solution was filtered with a filter paper and adjusted to a volume of 25 mL.

Standard solution

Each of eight spectrum regents at a 0.1 mg/mL concentration was used to establish a standard solution. The compound standard solution was made according to each element in sample solution as follows. Ten millilitres of spectrum regent of Cu, Fe, Mn and Zn was absorbed after adding 1 mL of HNO_3 to a 100-mL flask, mixed, and adjusted with tap water to 100 mL, which resulted in a 10 mg/L standard solution for each element. Spectrum regents of 50 mL K, 10 mL Ca, 10 mL Mg and 10 mL Na were absorbed after the addition of 1 mL HNO_3 to a 100-mL flask, mixed, fixed with tap water to 100 mL, which resulted in 50 and 10 mg/L standard solutions each of K, Ca, Mg and Na.

Measurement of several elements in plants and N. lugens *from rice fields in two regions*

Rice plants and *N. lugens* mature adults from rice fields in two regions, Dianbu (rice variety Wandao 69; application of imidacloprid against planthoppers), Feidon, Anhui Province (117.47°E, 31.89°N) and Hangzhou (rice variety Xinliangyou 6; application of imidacloprid against planthoppers), Zhejiang Province (120.2°E, 30.3°N), were sampled, using three fields per region. These samples were dried as described previously, and the element concentrations were measured.

Statistical analyses

Two two-way analysis of variance (ANOVA) tests (rice organs × insecticide concentrations and adult female × honeydew and insecticide concentrations) were performed to analyze the content of each element in rice leaves, leaf sheaths, adult female bodies and honeydew, following the imidacloprid foliar spray. Multiple comparisons of means were conducted based on Fisher's Protected Least Significant Difference (PLSD). All analyses were conducted using the GLM procedures of SPSS II program (SPSS, 2002). Multivariate correlations were conducted to analyze the transference of elements between rice organs and insect bodies or honeydew (Draper & Smith, 1998). In addition, the correlations between element contents in rice leaves, leaf sheaths and in *N. lugens* and between *N. lugens* and honeydew were analyzed using this data processing system (DPS) for practical statistics (Tang & Feng, 2002). The differences of each element level in rice field plants from regions were tested using the *t*-test.

Results

Effects of imidacloprid foliar sprays on elements of rice leaf sheaths and leaf blades

The content of each element varied with the rice organ (leaf or leaf sheath) and imidacloprid concentration (Table 1). A two-way ANOVA showed that the rice organ, imidacloprid concentration and their interactions (except the interaction with Mg) had significant effects on eight chemical elements in rice leaf sheaths and leaf blades ($P < 0.01$ for all elements except Na, where $P = 0.45$). *The* P-values for the imidacloprid concentration were < 0.01 for all elements. In the interaction between the rice organ and imidacloprid concentration, P-values were < 0.05 for all elements except Mg ($P = 0.24$). For two rice organs, the contents of Cu, Fe, Zn, Ca and Mg in the leaf sheath were significantly lower than those in the leaf blades, decreasing by 56.6%, 48.5%, 39.6%, 55.7% and 27.8%, respectively. In contrast, Mn and K contents in leaf sheath were significantly higher than those in the leaf blades, increasing by 26.9% and 88.7%, respectively. Changes in the amount of the eight elements in rice plants were also related to imidacloprid rates and element types (Table 1). Multiple comparisons indicated that some elements were not affected by imidacloprid. Fe content in leaf blades and Mn contents in both leaf blades and leaf sheaths were significantly decreased when compared to the control. In contrast, Fe in the leaf sheaths and K content in the leaf

Table 1 Contents of elements in the rice leaf sheath and leaf following imidacloprid foliar spray.

Rice organ	I.C. (mg/kg)	Cu (μg/g)	Fe (μg/g)	Mn (μg/g)	Zn (μg/g)	Ca (mg/g)	K (mg/g)	Mg (mg/g)	Na (mg/g)
Leaf blade	0 (CK)	7.9 ± 0.9 a	214.0 ± 4.6 a	276.1 ± 8.7 b	36.7 ± 4.4 b	4.0 ± 0.4 b	23.0 ± 1.3 a	2.2 ± 0.3 ab	1.4 ± 0.3 a
	10	8.0 ± 0.8 a	135.4 ± 4.4 c	174.2 ± 6.9 d	36.4 ± 5.9 b	6.4 ± 1.3 a	19.2 ± 1.4 ab	2.7 ± 0.4 a	1.1 ± 0.2 a
	30	8.1 ± 1.6 a	166.9 ± 4.9 b	296.9 ± 7.4 a	50.9 ± 6.6 a	6.3 ± 0.9 a	16.6 ± 1.6 b	2.3 ± 0.3 ab	0.5 ± 0.3 b
	60	6.0 ± 1.2 b	109.3 ± 9.1 d	227.3 ± 5.8 c	43.8 ± 9.4 ab	4.0 ± 0.7 b	23.2 ± 3.8 a	2.0 ± 0.1 b	0.3 ± 0.1 b
Leaf sheath	0 (CK)	2.9 ± 0.4 a	63.4 ± 6.7 b	352.2 ± 9.1 a	23.6 ± 2.2 a	2.0 ± 0.3 a	27.7 ± 9.7 b	1.5 ± 0.3 b	0.7 ± 0.2 a
	10	3.3 ± 0.2 a	90.7 ± 5.8 a	251.9 ± 8.5 d	26.5 ± 4.8 a	3.0 ± 1.0 a	47.9 ± 4.7 a	2.1 ± 0.2 a	0.9 ± 0.1 a
	30	3.6 ± 0.4 a	94.4 ± 8.3 a	327.4 ± 9.1 b	25.1 ± 2.0 a	2.3 ± 0.2 a	40.4 ± 2.4 a	1.8 ± 0.1 ab	0.8 ± 0.2 a
	60	3.1 ± 0.4 a	73.5 ± 7.3 b	305.1 ± 7.9 c	26.0 ± 4.5 a	2.0 ± 0.3 a	38.7 ± 1.5 a	1.8 ± 0.2 ab	0.7 ± 0.4 a

I.C. is the imdacloprid concentration. Means are followed by different letters for the same rice organ within a column showing a significant difference at 0.05 level.

sheaths were significantly increased, whereas Zn, K and Mg contents in the leaf blades hardly changed. Ca contents in the leaf blades following 10 and 30 mg/kg imidacloprid treatments were noticeably increased, but the Na content in the leaf blades following 30 and 60 mg/kg imidacloprid treatments significantly decreased.

Effects of imidacloprid foliar sprays on elements in adult females and their honeydew

The imidacloprid foliar spray had significant effects on eight chemical elements in adult females that developed from feeding on treated plants and in honeydew ($P < 0.01$ for all elements; $P < 0.01$ imidacloprid concentration for all elements; $P < 0.01$ interaction effect between *N. lugens* and honeydew for all elements). Contents of Cu, Fe, Mn, Ca, K and Mg in honeydew were significantly greater than those in adult female bodies, increasing by 21.9%, 238.3%, 21.7%, 92.7%, 210.4% and 30.4%, respectively. The contents of all elements increased with the increase of imidacloprid concentrations, except for K. Multiple comparisons indicated that almost all elements in female bodies corresponded with increases of imidacloprid doses when compared to the control (Table 2). Percent increases of Cu, Fe, Mn, Zn and Ca in adult female bodies became greater with increased imidacloprid doses. Ca experienced the greatest increase among the eight elements, increasing by 80%, 230% and 240% for 10, 30 and 60 mg/kg imidacloprid treatments, respectively. Percent increases of elements in honeydew were significantly greater than those in female bodies, except for K and Mg.

Transference of imidacloprid-induced element changes between rice plants and N. lugens

The transference of changes of imidacloprid-induced elements was related to element types and rice organs (Table 3). The relationships between most elements in leaf sheaths and elements in *N. lugens* were negatively correlated (Table 3). Positive correlations were observed

Table 2 Contents of the elements in *Nilaparvata lugens* and its honeydew following imidacloprid foliar spray.

N. lugens	I.C. (mg/kg)	Cu (μg/g)	Fe (μg/g)	Mn (μg/g)	Zn (μg/g)	Ca (mg/g)	K (mg/g)	Mg (mg/g)	Na (mg/g)
Body	0 (CK)	27.1 ± 6.0 c	552.5 ± 31.9 d	22.3 ± 3.4 c	235.7 ± 8.2 d	2.3 ± 0.8 c	9.5 ± 0.9 a	1.5 ± 0.2 a	2.9 ± 0.1 c
	10	41.9 ± 5.4 b	877.8 ± 41.8 c	41.2 ± 3.8 a	464.9 ± 5.3 c	4.2 ± 0.4 b	11.8 ± 1.9 a	2.4 ± 0.4 a	3.9 ± 0.7 c
	30	48.9 ± 10.7 ab	1085.2 ± 47.8 a	32.2 ± 4.3 b	496.8 ± 4.8 b	7.7 ± 1.0 a	19.8 ± 12.6 a	3.7 ± 2.3 a	6.4 ± 0.8 a
	60	57.7 ± 3.9 a	988.5 ± 49.3 b	47.8 ± 4.8 a	575.0 ± 5.2 a	7.8 ± 0.9 a	12.8 ± 2.4 a	2.7 ± 0.6 a	4.9 ± 0.4 b
Honeydew	0 (CK)	21.8 ± 8.5 c	579.8 ± 74.6 d	11.6 ± 2.9 c	195.4 ± 39.8 c	6.7 ± 1.0 b	43.9 ± 1.6 a	2.3 ± 0.3 b	1.7 ± 0.4 c
	10	35.7 ± 9.8 c	2381.5 ± 170.9 c	39.2 ± 10.7 b	335.3 ± 57.8 b	9.2 ± 2.4 b	50.9 ± 7.5 a	2.7 ± 0.7 b	3.0 ± 0.9 c
	30	44.3 ± 5.7 b	2849.1 ± 146.7 b	46.4 ± 14.5 b	381.4 ± 82.4 b	8.4 ± 1.5 b	40.6 ± 6.0 ab	2.3 ± 0.4 b	3.0 ± 0.6 b
	60	112.1 ± 13.1 a	6046.3 ± 233.0 a	77.6 ± 16.6 a	679.1 ± 79.8 a	18.0 ± 2.1 a	31.1 ± 5.8 b	6.1 ± 0.5 a	5.5 ± 0.7 a

I.C. is the imdacloprid concentration. Means are followed by different letters for the same body or honeydew within a column showing a significant difference at 0.05 level.

Table 3 Correlation coefficients with a significant level† between the element contents in leaves or leaf sheaths and the element contents in female *Nilaparvata lugens*.

Rice organ	Element	Female body							
		Cu	Fe	Mn	Zn	Ca	K	Mg	Na
Leaf	Cu								
	Fe	−0.76	−0.67	−0.91	−0.90	−0.60			
	Mn			−0.61					
	Zn		0.57						0.57
	Ca								
	K		−0.48						−0.47
	Mg								
	Na	−0.81	−0.78	−0.56	−0.80	−0.83			−0.67
Leaf sheath	Cu		0.49						
	Fe		0.64		0.51				0.59
	Mn			−0.66	−0.51				
	Zn								
	Ca								
	K		0.55	0.55	0.57				
	Mg		0.48	0.46	0.49				
	Na								

†$R_{0.05} = 0.444$, $R_{0.01} = 0.561$.

between Zn content in leaves and Fe content in *N. lugens* and between Na, Ca and Fe contents in *N. lugens*. In contrast, the relationships between most of the elements in leaf sheaths and the elements in *N. lugens* were positively correlated (Table 3). Most correlation coefficients between elements in female bodies and elements in honeydew were significantly positive (Table 4), suggesting that most elements in *N. lugens* were transferred to honeydew, excluding K, Mg and Na.

Differences in the element contents of rice plants and N. lugens *in the rice field*

The *t*-test showed that the content of K in rice plants from Hangzhou was significantly greater than in those from Dianbu (Table 5). In contrast, the content of Mg in rice plants from Hangzhou was significantly lower than those from Dianbu (Table 5). The other element levels in plants did not show a significant difference between the

Table 4 Correlation coefficients with a statistically significant level† between the element contents in the female *N. lugens* body and the element contents in honeydew.

Female body	Honeydew							
	Cu	Fe	Mn	Zn	Ca	K	Mg	Na
Cu	0.71	0.83	0.81	0.83	0.72	−0.46	0.63	0.79
Fe	0.49	0.68	0.69	0.62				0.55
Mn	0.73	0.82	0.74	0.76	0.71		0.70	0.78
Zn	0.74	0.88	0.85	0.82	0.68		0.62	0.76
Ca	0.68	0.79	0.80	0.73	0.58	−0.55	0.52	0.70
K								
Mg						0.58	−0.48	
Na		0.48	0.56	0.48				

†$R_{0.05} = 0.444$, $R_{0.01} = 0.5$.

Table 5 Content of elements in the plants and *Nilaparvata lugens* in rice fields from two regions.

	Element content (mg/g)	Location of sample	
		Dianbu (Anhui Province)	Hangzhou (Zhejiang Province)
Rice plant	Mn	0.327 ± 0.057 a	0.254 ± 0.034 a
	Zn	0.434 ± 0.070 a	0.303 ± 0.059 a
	Cu	0.031 ± 0.040 a	0.032 ± 0.005 a
	Fe	0.558 ± 0.125 a	0.494 ± 0.119 a
	Mg	1.654 ± 0.496 aA	0.747 ± 0.071 bB
	K	9.139 ± 2.330 bB	23.23 ± 3.30 aA
	Ca	10.683 ± 2.940 a	7.677 ± 1.045 a
Nilaparvata lugens	Mn	0.104 ± 0.022	0.025
	Zn	2.263 ± 0.677	1.958
	Cu	0.168 ± 0.112	0.088
	Fe	2.684 ± 1.983	1.098
	Mg	1.763 ± 1.485	0.721
	K	4.071 ± 1.121	3.063
	Ca	19.493 ± 9.061	22.020

Means ± SD. Means are followed by different small and capital letters for the same elements within a line showing a significant difference at 0.05 (lower case) and the 0.01 level (upper case), respectively. Statistical analysis of the elements in *N. lugens* from two regions was not conducted because there was only a single sample from the Hangzhou population.

two regions. Statistical analysis of elements in *N. lugens* from the two regions was not conducted, because there was only a single sample from the Hangzhou population.

Discussion

The effects of pesticides on the physiology and biochemistry of crops greatly vary, and these effects can be either harmful or beneficial (Johnson *et al.*, 1983; Rao & Rao, 1983; Youngman *et al.*, 1990). Our investigation demonstrates that most pesticides commonly used in rice fields have a negative effect on the physiology and biochemistry of rice (Luo *et al.*, 2002; Wu *et al.*, 2003). For example, foliar sprays of imidacloprid, buprofezin, triazophos and jinggangmycin resulted in declines of oxalic acid and glutathione-S-transferase (GST) contents in rice plants and decreased photosynthesis rates in rice leaf blades (Wu *et al.*, 2003). High doses of imidacloprid reduced the length of the active growth stage and the grain weight. However, a low dose of imidacloprid can promote the uptake of phosphorus and potassium (Qiu *et al.*, 2004; Gu *et al.*, 2008). In addition, some pesticides induce the susceptibility of rice to *N. lugens* (Wu *et al.*, 2001a, 2001b, 2004). Imidacloprid foliar spray reduces levels of plant hormone zeatin riboside (Qiu *et al.*, 2004). However, the effect of pesticides on elements in rice plants and the conductance of pesticide-induced element changes in the rice–*N. lugens* system have rarely been investigated. This relationship may be of importance in understanding the mechanisms of pest population resurgences and their resistance to insecticides, because some elements are essential to many biochemical substances.

The present findings demonstrated that imidacloprid application significantly affects the contents of some elements in rice plants, and this effect can be transferred to adult females and their honeydew, indicating a transference effect. Fe, Mg, Cu, Zn and Mn are not only components of chlorophyll and activators of some enzymes but also are involved in various physiological processes of plants (Wang, 2000). In addition, changes in some element contents in rice plants are associated with the resistance of rice to pests and the population growth of planthoppers. For example, high K levels in plants are unsuitable for the population growth of *Sogatella furcifera* (Horvath), but a high Fe level promotes the growth of the insect population (Salim & Saxena, 1991).

Our investigation confirmed that changes of eight element levels in rice plants, adult female bodies and honeydew following imidacloprid application were related to the element type. This finding may be associated with physiological and biochemical processes and element interactions. This investigation indicated that phosphorus (P) can result in declines of Zn, Cu, Fe and Mn. Similarly, Zn can cause declines of P, Cu and Fe but also can increase levels of Mn (Haldar & Mandal, 1981). The present findings demonstrated that the relationships between Fe and Na in leaf blades, Mn in leaf sheaths and Zn in adult female bodies were negatively correlated (Table 3). After imidacloprid application, Fe and Mn in rice plants can be transferred to adult females during their nymph stage where they feed on treated plants and honeydew. This occurrence may aid in the understanding of the origin of immigration populations, because this insect is a long-distance migratory and resurgent insect pest in temperate eastern Asia (Cheng *et al.*, 1979; Riley *et al.*, 1994). Rapid population growth cycles and northern and north-eastern migration has spread *N. lugens* to northern China, Korea and Japan (Cheng *et al.*, 1979; Riley *et al.*, 1994). In China, this insect migrates from the south to rice-producing regions in the mid and lower reaches of the Yangtse River during the summer, where it produces three to four generations per year (Cheng *et al.*, 1979). In general, *N. lugens* will emigrate after the population outbreak in south China. Insects must be controlled with insecticides when *N. lugens* outbreaks occur, and this treatment results in high Fe levels in rice plants and adults (based on the findings of this study), because pesticide application can cause changes in some element levels in rice plants and *N. lugens* bodies via the transference effect of food chains. In addition, the start date of chemical control periods for *N. lugens* in the southern rice region is commonly earlier than that in the northern rice region in the summer; in contrast, the chemical control period begins earlier in the northern region during the fall compared to the southern region control scheme. These modifications in application may result in concentration gradients of some elements in different regions if pesticides affect element levels in rice plants and *N. lugens* bodies. Element levels in rice plants and insect bodies in a given region may also be associated with fertilization methods, rice varieties and soil types in the area, in addition to pesticide application. Therefore, source regions of migratory populations of *N. lugens* can be identified by the element level present in insect bodies. The evidence of source regions of natural migratory populations will be further examined by element levels within *N. lugens* bodies.

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