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ORIGINAL ARTICLE

Determining the geographic origin of the brown planthopper, *Nilaparvata lugens*, using trace element content

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Abstract A chemometric study using pattern recognition technology was carried out to characterize the geographic origins of the brown planthopper, *Nilaparvata lugens*. The concentrations of 23 trace elements (Mn, Mo, Cd, Ce, V, Th, Cs, Be, Tl, Fe, Nd, Pr, Se, Tm, Lu, Eu, Ho, Br, Dy, Gd, U, Sm and Er) in 53 samples from seven regions in southern China were determined using inductively coupled plasma mass spectrometry. The data obtained were successively evaluated using a multivariate statistical approach, namely, linear discriminant analysis, which allowed classification and discrimination of the *N. lugens* samples from Fuqing, Shaoguan, Hepu, Yongfu, Hengnan, Wan-an and Yongkang with high accuracy and a clear separation among the seven regions. The results show that pattern identification on the basis of trace elements in the bodies of *N. lugens* is feasible for determining the geographic origins of individuals.

Key words brown planthopper, discriminant analysis, forecasting, geographic origin, trace element

Introduction

The brown planthopper *Nilaparvata lugens* (Stål) is a long-distance migratory insect that is considered a rice pest. Because of lower temperatures and the absence of rice plants during winter, *N. lugens* cannot overwinter in temperate and subtropical regions (Chen *et al.*, 1979; Kisimoto & Sogawa, 1995) and thus must overwinter in permanent breeding areas. Each year in spring, *N. lugens* migrating populations move northward from permanent breeding areas to southern China to breed for one or two generations. In early June, *N. lugens* populations begin to migrate into the Yangtze-Huaihe River Basin in China, as well as into Korea and Japan (Sogawa, 1995).

Since the migration of *N. lugens* was identified in 1967 (Asahina *et al.*, 1968), the methods and techniques for monitoring *N. lugens* migration have constantly been improved. The radar remote sensing technique, for example, has been applied to investigate the migration of *N. lugens* and confirmed that a long-distance return migration of *N. lugens* occurs in China (Riley *et al.*, 1990, 1991, 1994, 2003). On the other hand, the migration of *N. lugens* has been closely related to synoptic weather conditions (Kisimoto, 1971, 1976, 1979). *N. lugens* migration has been examined using atmospheric models to analyze the immigrant trajectory route, possible pest source areas, and regions of immigration (Rosenberg *et al.*, 1983; Watanabe *et al.*, 1990, 1991; Turner *et al.*, 1999). These studies have contributed substantially to migration forecasting and control of *N. lugens*.

However, without the aid of other methods to distinguish insect species, radar remote sensing cannot directly differentiate *N. lugens*. Further, the atmospheric model based on meteorological parameters (e.g., atmospheric pressure level and the weather during the migration) did not identify a true migration route of *N. lugens* but was a simulation. Therefore, these methods have limitations for monitoring *N. lugens* migration routes.

Tracking the source area of a migratory pest is important for forecasting and management of the species and its

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movements. Therefore, developing a technology to determine the geographic origins of *N. lugens* is of great significance. A variety of pattern recognition techniques have been employed to estimate food quality and determine the geographic origins of food based on its chemical composition (Szefer, 2007). Measurement of chemical parameters such as fatty acids or triglycerides may not provide a reliable classification of geographical origin but measurement of stable isotope ratios and multi-element data has been proposed as the best analytical approach for accurate verification of geographical origin (Aparicio, 1999).

In recent years, determination of multi-elements has been widely used in various research fields, and has proven to be the most effective methodology for identifying geographic origins. A number of studies on the geographical origins of agricultural products, such as honey (Devillers *et al.*, 2002; Hernandez *et al.*, 2005; Nalda, *et al.*, 2005; Torres *et al.*, 2005; Tuzen *et al.*, 2007; Pisani *et al.*, 2008), potato (Anderson *et al.*, 1999; Rivero *et al.*, 2003; Giacomo *et al.*, 2007), rice (Yasui *et al.*, 2000; Kelly *et al.*, 2002), tea (Lamble *et al.*, 1995; Marcos *et al.*, 1998; Fernández-Cáceres *et al.*, 2001; Pineiro *et al.*, 2003) and meat (Franke *et al.*, 2005; Sacco *et al.*, 2005; Heaton *et al.*, 2008) have been carried out to identify origins based on mineral and trace element content. Most of these studies have related to protecting consumers and maintaining the prestige and credibility of the foodstuff.

Local soil composition and local environmental conditions influence the concentration and distribution of mineral and trace elements in *N. lugens* and the chemical element composition acquired during the growth stage does not undergo alterations. Thus, it is reasonable to infer that chemical elements in *N. lugens* could be used as markers of geographical classification. The aim of this study was to determine trace element contents in *N. lugens* individuals from the Fuqing, Shaoguan, Hepu, Yongfu, Hengnan, Wan-an and Yongkang regions of China and to use the data to classify *N. lugens* from these regions according to a multivariate statistical procedure, linear discriminant analysis (LDA). A set of indicator elements proved suitable for discriminant analysis and was specific for determining the geographic origin of *N. lugens*.

Materials and methods

N. lugens *samples*

A total of 53 *N. lugens* samples were collected during the period from June to September in 2008 from 15 villages in the seven target regions. These regions were located at seven different geographical environments in southern China. Table 1 and Figure 1 show the *N. lugens* sampling points in the seven regions. All of the collected *N. lugens* samples were frozen immediately before being transferred to the laboratory, where all samples were stored at –20°C and dried in a 50°C oven for 24 h before analysis.

Table 1 Studied *Nilaparvata lugens* sampling points in seven regions of southern China.

Region	Point (Village)	Latitude	Longitude
Fuqing, Fujian	Moshi	25°78′07″ N	119′30′61″ E
	Mianting	25°53′34″ N	119′27′35″ E
	Hongshan	25°55′35″ N	119′27′71″ E
Shaoguan, Guangdong	Xilian	24°45′32″ N	113′32′02″ E
Hepu, Guangxi	Lianbei	21°40′27″ N	109′11′40″ E
	Xiayang	24°41′21″ N	109’08′01″ E
Yongfu, Guangxi	Gancun	25°58′42″ N	110′00′16″ E
	Shihuadong	25°00′39″ N	109′59′45″ E
	Tangbao	25°02′36″ N	110′00′55″ E
Hengnan, Hunan	Baishui	24°44′37″ N	112′35′36″ E
	Zhutang	26°49′04″ N	112′29′43″ E
Wan-an, Jiangxi	Guangming	26°29′34″ N	114′46′09″ E
Yongkang, Zhejiang	Huajie	28°55′24″ N	119′57′52″ E
	Jingtou	28°54′17″ N	120′11′23″ E
	Tianfanlin	28°53′49″ N	120′06′30″ E

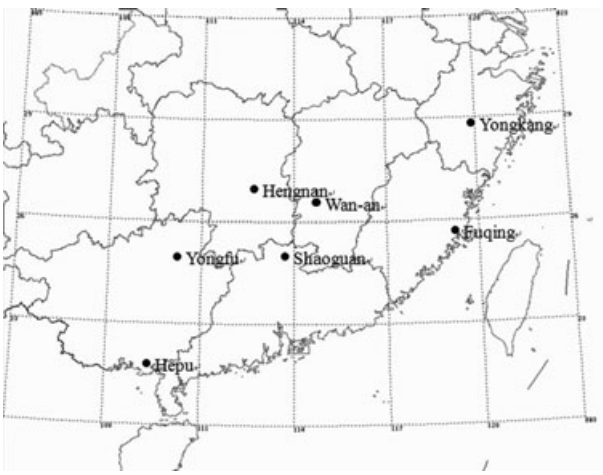

Fig. 1 Map of distribution of *Nilaparvata lugens* samples in southern China [ZS(2010)605].

According to the sampling plan, each sample for chemical analysis needs 0.2 g insect material, approximately 350 adults. Accordingly, we collected more than 1200 *N. lugens* adults in each of the paddy fields across the regions for sampling. *N. lugens* adult samples were collected from indica hybrid rice in the milk-ripe stage. In the Shaoguan region, because the population of *N. lugens* was low in 2008, we were unable to collect the number of insects as planned and thus analyzed the *N. lugens* samples that were available.

Apparatus

Determination of mineral elements was performed using an inductively coupled plasma mass spectrometer (ICP-MS) (Agilent 7500A, Yokogawa Analytical Systems Inc., Tokyo, Japan) with an Octopole Reaction System. The samples were digested in a blast air oven (model DGX-9143B, Fuma Inc., Shanghai, China).

Reagents

Standard solutions were prepared by dilution of a stock solution of 1 000 mg/L Mn, Mo, Cd, Ce, V, Th, Cs, Be, Tl, Fe, Nd, Pr, Se, Tm, Lu, Eu, Ho, Br, Dy, Gd, U, Sm and Er (Agilent, Palo Alto, CA, USA). An internal standard stock solution (^{6}Li, ^{45}Sc, ^{72}Ge, ^{115}In, ^{209}Bi, HNO_3 10%) was obtained from Agilent. A multi-element solution with nitric acid (2%) was obtained from 65% nitric acid and 18 megohm (MΩ) high-purity deionized water (Milli-Q system, Strasbourg, Cedex, France) for external calibration. HNO_3 65% Suprapur and H_2O_2 30% Suprapur were from Merck (Darmstadt, Germany).

Analytical procedure

Twenty-three elements (Mn, Mo, Cd, Ce, V, Th, Cs, Be, Tl, Fe, Nd, Pr, Se, Tm, Lu, Eu, Ho, Br, Dy, Gd, U, Sm and Er) were determined in each *N. lugens* sample. Exactly 0.2 g of each dry *N. lugens* sample was weighed in polytetrafluoroethylene (PTFE) vessels and subjected to sufficient digestion using 4 mL of nitric acid 65% and 0.5 mL of hydrogen peroxide (H_2O_2) 30% for 2 h. The sample was then subjected to mineralization using a dry oven as follows: 120 min for 600 W at 120°C, 480 min for 600 W at 160°C. Digestion was confirmed as complete when no nitrous oxide gases were present. This step was followed immediately by ventilation at room temperature, and the solution was transferred through a medium-speed filter. After mineralization, the sample was diluted with deionized water and transferred to a 50-mL volumetric flask. Blank solutions were prepared from nitric acid (65% HNO_3) using the same procedure. The limit of detection (LD) for each of the 23 elements was estimated as three times the standard deviation (SD) of the average of blank solutions. The sample was analyzed with an ICP-MS, using the following operating conditions: Radio frequency (Rf) power, 1 250 W; plasma gas flow rate, 15.0 L/min; carrier gas, 1.06 L/min; and sample uptake rate by peristaltic pump, 0.1 revolutions per second (r/s).

Statistical analyses

Statistical analyses were carried out using the DPS data processing system software 11.50 for Windows (Tang *et al.*, 2007). The concentration of each element was expressed as the mean ± SD. The experiments were designed as a two-stage nested design with the seven regions as the primary factors. For each region, 2–3 rice fields were sampled. An analysis of variance (ANOVA) with a two-stage nested design was used to evaluate the geographic effects of trace elements among the seven regions. Linear discriminant analysis (LDA) was applied to the separation of the analyzed *N. lugens* samples according to their geographic origin. LDA can obtain a reasonable representation of populations that involve only a few linear combinations of the observations (Timm, 2002; Rencher, 2003). In our study, the best differentiation among the seven regions (Fuqing, Shaoguan, Hepu, Yongfu, Hengnan, Wan-an and Yongkang) was defined as the dependent categorical variable, and the concentrations of eight elements (V, Mn, Fe, Mo, Se, Cd, Ce and Nd) were used as the independent variables. As the group membership of each sample was already known, the sample differentiation and classification of data were expressed as discriminant functions. Finally, these functions enabled *N. lugens* samples to be correctly classified.

Results

Trace element content

The *N. lugens* samples from the seven different regions were detected in 2008 by using ICP-MS quantitative analysis, and the values regarding the concentrations of the 23 trace elements are shown in Table 2. On the basis of these concentrations, the results could be differentiated into three trace element groups, described below.

The first element group consisted of Fe and Mn, with average concentrations exceeding 100 μg/L. Iron was quantitatively the most abundant element in the *N. lugens* samples, ranging from 361.99 to 4 704.85 μg/L with an

Table 2 Element content data matrix of *Nilaparvata lugens* samples in southern China (μg/L).

Element	LD	Mean† ± SD						
		Fuqing ($n = 7$)	Shaoguan ($n = 4$)	Hepu ($n = 14$)	Hengnan ($n = 7$)	Wan-an ($n = 7$)	Yongkang ($n = 7$)	Yongfu ($n = 7$)
Be	0.02	0.09 ± 0.07	0.51 ± 0.13	0.05 ± 0.04	0.04 ± 0.02	0.03 ± 0.02	0.03 ± 0.02	0.06 ± 0.04
V	0.05	2.61 ± 1.67	8.72 ± 1.86	2.10 ± 1.62	2.54 ± 1.72	0.93 ± 0.33	0.67 ± 0.40	1.48 ± 0.99
Mn	0.06	233.41 ± 90.21	365.99 ± 44.28	224.52 ± 71.17	202.60 ± 64.29	106.96 ± 10.82	156.14 ± 42.86	108.49 ± 27.31
Fe	2.62	1552.41 ± 815.04	3867.32 ± 782.75	1337.8 ± 1019.32	1090.56 ± 539.61	1032.81 ± 230.21	621.71 ± 171.55	1038.16 ± 543.24
Br	0.50	20.2 ± 24.29	7.41 ± 4.30	10.31 ± 8.05	14.92 ± 10.31	10.21 ± 9.17	16.22 ± 15.65	19.98 ± 25.79
Se	0.21	2.22 ± 0.51	1.97 ± 0.31	1.94 ± 0.28	2.03 ± 0.27	1.54 ± 0.28	1.09 ± 0.40	2.84 ± 1.14
Mo	0.02	9.98 ± 3.09	8.54 ± 1.92	4.66 ± 1.97	3.53 ± 1.46	4.22 ± 1.75	6.59 ± 1.08	9.60 ± 2.64
Cd	0.01	1.64 ± 1.27	14.83 ± 3.65	3.24 ± 1.97	6.57 ± 1.69	0.74 ± 0.58	0.44 ± 0.33	0.67 ± 0.47
Cs	0.02	0.20 ± 0.12	2.20 ± 0.44	0.29 ± 0.19	0.29 ± 0.23	0.10 ± 0.02	0.04 ± 0.02	0.10 ± 0.07
Ce	0.01	3.32 ± 2.37	10.46 ± 2.67	2.26 ± 1.82	1.75 ± 1.61	0.78 ± 0.17	0.32 ± 0.13	0.89 ± 0.69
Pr	0.01	0.39 ± 0.32	1.15 ± 0.26	0.24 ± 0.16	0.20 ± 0.19	0.13 ± 0.04	0.06 ± 0.03	0.09 ± 0.07
Nd	0.01	1.45 ± 1.31	4.40 ± 1.07	0.87 ± 0.62	0.65 ± 0.58	0.38 ± 0.08	0.15 ± 0.07	0.35 ± 0.27
Sm	0.01	0.26 ± 0.21	0.78 ± 0.19	0.18 ± 0.11	0.14 ± 0.15	0.07 ± 0.03	0.05 ± 0.03	0.06 ± 0.05
Eu	0.01	0.06 ± 0.04	0.13 ± 0.01	0.05 ± 0.04	0.07 ± 0.12	0.03 ± 0.04	0.04 ± 0.03	0.02 ± 0.01
Gd	0.01	0.24 ± 0.18	0.71 ± 0.14	0.17 ± 0.11	0.14 ± 0.14	0.07 ± 0.04	0.05 ± 0.03	0.06 ± 0.05
Dy	0.01	0.17 ± 0.12	0.52 ± 0.10	0.12 ± 0.08	0.11 ± 0.12	0.06 ± 0.03	0.05 ± 0.03	0.04 ± 0.03
Ho	0.01	0.04 ± 0.02	0.11 ± 0.01	0.04 ± 0.03	0.05 ± 0.09	0.03 ± 0.04	0.03 ± 0.03	0.01 ± 0.01
Er	0.01	0.10 ± 0.05	0.27 ± 0.05	0.08 ± 0.05	0.08 ± 0.10	0.04 ± 0.03	0.05 ± 0.03	0.03 ± 0.03
Tm	0.01	0.03 ± 0.02	0.04 ± 0.01	0.03 ± 0.03	0.05 ± 0.08	0.02 ± 0.03	0.03 ± 0.02	< LD
Lu	0.01	0.03 ± 0.03	0.03 ± 0.02	0.03 ± 0.03	0.06 ± 0.10	0.02 ± 0.03	0.03 ± 0.03	0.01 ± 0.01
Tl	0.01	0.04 ± 0.01	0.17 ± 0.02	0.04 ± 0.01	0.04 ± 0.02	0.02 ± 0.01	0.01 ± 0.01	0.02 ± 0.01
Th	0.01	0.33 ± 0.29	1.67 ± 0.40	0.25 ± 0.24	0.22 ± 0.21	0.06 ± 0.05	0.04 ± 0.04	0.17 ± 0.21
U	0.08	0.21 ± 0.07	0.53 ± 0.10	0.19 ± 0.10	0.18 ± 0.07	0.14 ± 0.01	0.12 ± 0.03	0.16 ± 0.06

†Average of the replicates.

LD, limit of detection.

average concentration of 1 398.88 μg/L. Iron in *N. lugens* samples from Shaoguan (3 867.32 μg/L) had higher mean concentrations than the other samples.

The second element group consisted of Br, V, Se, Mo, Cd, Ce and Nd, which had concentrations in the range of 1–100 μg/L. The samples from Wan-an, Yongfu and Yongkang had lower values of Cd and Ce (concentrations < 1 μg/L).

The third group consisted of Be, Cs, Pr, Sm, Dy, U, Gd, Er, Eu, Tl, Ho, Lu, Tm and Th, all with concentrations $<$ 1 μg/L. Sm, Eu, Gd, Dy, Ho, Er and Tm are rare earth elements and generally were present in *N. lugens* samples at low concentrations. In comparison to the concentrations of V, Mn, Fe, Ce, Th and U in Brazilian Cerrado soil (Marques *et al.*, 2004), these elements were present in lower concentrations in the *N. lugens* samples.

The LD for each of the elements is listed in Table 2. Elements (Be, Cs, Pr, Sm, Dy, U, Gd, Er, Eu, Tl, Ho, Lu, Tm and Th) in the third group were removed in cases where analytical uncertainty is too large because concentration levels were close to the LD. The first two groups were retained and considered as chemical descriptors for identifying *N. lugens* samples from different origins.

Analysis of variance

As a first step in the chemometric analysis, the data were analyzed using an ANOVA with a two-stage nested design. Table 3 lists the main results, *F*-statistics, df and *P*-value for each element. The results showed significant differences among the primary factors of the different places of origin for the nine trace elements, except Br. Therefore, eight elements could be used for the discriminant analysis.

Table 3 ANOVA of nine elements in *Nilaparvata lugens* samples.

Element	Regions		Rice fields	
	$F_{(6,16)}$	P	$F_{(16,30)}$	P
V	7.51	0.000 6	9.16	$<$0.000 1
Mn	4.48	0.007 5	32.85	$<$0.000 1
Fe	4.37	0.008 5	8.34	$<$0.000 1
Br	0.53	0.779 5	1.65	0.114 3
Se	5.46	0.003 0	1.77	0.086 3
Mo	4.99	0.004 7	10.07	$<$0.000 1
Cd	26.74	$<$0.000 1	3.33	0.002 2
Ce	9.51	0.000 2	7.53	$<$0.000 1
Nd	9.36	0.000 2	7.48	$<$0.000 1

Linear discriminant analysis

All data obtained were analyzed statistically using multivariate statistical method LDA. This methodology was applied to separate the 53 *N. lugens* samples based on the presence of eight trace elements. The 53 *N. lugens* samples were randomly divided into two parts: half of the samples were used for establishing the model, and the other half were used for testing the model. The aim of this procedure was to evaluate sample differentiation and classification of data expressed as discriminant scores. Therefore, depending on the number of groups, six discriminant functions were extracted. To determine the number of linear discriminant functions to retain, Bartlett's χ^2 test was applied, as follows:

$$\chi^2 = -[N - 1 - (p + g)/2] \quad \text{In } \lambda, \qquad (1)$$

where N stands for the number of *N. lugens* samples, p for the number of trace elements, g for the number of regions and λ for the ratio of the within-group sum of squares to the total sum of squares. The lambda λ value provides information about how much of the total variability results from differences between the group means or from within-group variability. The value of λ can range between 0 and 1: the value λ is close to 1 when the G group means are equal, whereas λ is close to 0 if they differ.

A significant lambda λ ($\lambda = 0.000\,9$, Bartlett $\chi^2 = 126.75$, df $= 54$, $P < 0.000\,1$) was obtained when the *N. lugens* samples were classified as a function of the place of origin. The number of groups in our samples was 7, and 7–1 is the maximum allowable number of eigenvalues for the matrix $W^{-1}B$. The first four eigenvalues were significant at the 0.05 level using the χ^2 test (Table 4).

The discriminant functions were estimated and could be used to plot the group subjects in the orthogonal space of the functions. The first two eigenvalues accounted for 72.4% and 16.0% of the total variability, respectively, and the sum of these accounted for 88.4% of the total variability. Therefore, the distribution of data was expressed as discriminant scores along the first two eigenvectors (Fig. 2). *N. lugens* samples from Fuqing were characterized by high values in Function 2 and negative values in Function 1. *N. lugens* samples from Shaoguan and Hengnan were both characterized by positive values in Function 1. The seven sample classes corresponding to different provinces of China were distinct, as is shown by the centroid coordinates. The second sample class, corresponding to *N. lugens* samples from Shaoguan, seemed to be well separated from the others, as were Yongfu, Hengnan, Fuqing and Hepu. Several chemical elements in *N. lugens* samples from Shaoguan region, including

Table 4 The results of χ^2 tests of six canonical correlations of *Nilaparvata lugens* samples.[†]

No.	Eigenvalue root	Proportion	Canonical R	Chi-square	df	Probability
1	22.391 4	0.724 5	0.978 4	123.225 9	54	<0.000 1
2	4.935 0	0.159 7	0.911 9	68.059 5	40	0.003 7
3	2.512 9	0.081 3	0.845 8	36.894 4	28	0.121 2
4	0.727 0	0.023 5	0.648 8	14.906 8	18	0.668 4
5	0.287 9	0.009 3	0.472 8	5.345 1	10	0.867 0
6	0.053 8	0.001 7	0.226 0	0.917 4	4	0.922 1

[†]Test of Ho: The canonical correlations in the current row and all that follow are zero.

V, Mn, Fe, Cd, Ce and Nd, had possible higher mean concentrations than those in other samples (Table 2). However, the samples from Wan-an and Yongkang appeared to slightly overlap. Thus, *N. lugens* samples from these seven regions of China could be differentiated according to their concentrations of trace elements.

On the basis of the values for the seven linear discriminant functions for each sample, the group membership could be predicted using a classification rule. Table 5 summarizes the results of the classification for the *N. lugens* samples. The chemical data (eight element concentrations) of 27 *N. lugens* samples were used for the table, and 27 *N. lugens* samples were randomly taken from different regions, including Fuqing ($n = 3$), Hepu ($n = 7$), Shaoguan ($n = 2$), Hengnan ($n = 4$), Wan-an ($n = 4$), Yongfu ($n = 4$) and Yongkang ($n = 3$), respectively. The *N. lugens* samples from Shaoguan, Hepu, Yongfu, Yongkang and Hengnan were correctly assigned to the group to which they belong. Only two samples from Fuqing and Wan-an were misclassified as Hepu and Yongkang, respectively. The overall classification success was 92.6%.

To test the validity of the linear discriminant model, a blind trial was conducted using the remaining 26 *N. lugens* samples. The samples were correctly assigned to the group to which they belong. Only two unknown samples were misclassified as Fuqing and Hepu respectively, and the classification success was 92.3% (Table 6).

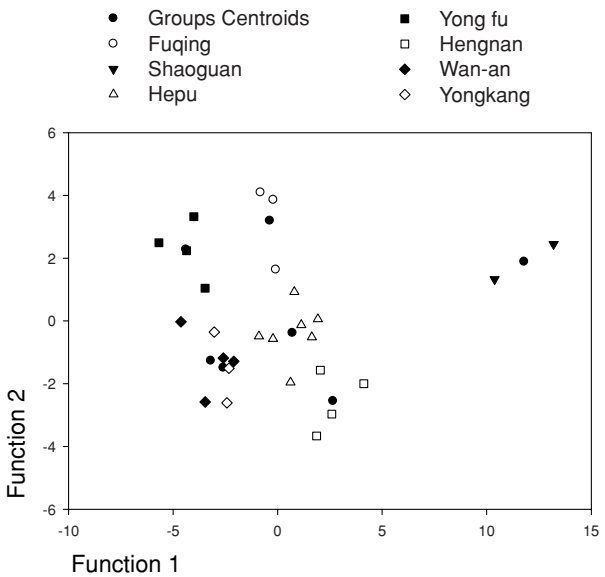

Fig. 2 Distribution of data, related to *Nilaparvata lugens* samples from the seven regions (Fuqing, Shaoguan, Hepu, Yongfu, Hengnan, Wan-an and Yongkang), expressed as discriminant scores along the two eigenvectors, as a function of place of origin.

Discussion

The geographic origin of *N. lugens* was studied by means of ANOVA and LDA on the basis of eight trace elements. The results showed that it is possible to identify the different geographic origins of *N. lugens* using differences in trace element concentrations in the bodies of *N. lugens*.

Using the LDA method, the discriminant functions for identifying geographic origin of *N. lugens* were built up. The discriminant functions classified the data sets with higher accuracy, and the first two presented a clear separation of the seven regions. The results indicated that the trace element data can be used to determine the geographic origin of *N. lugens*. This result is in accordance with findings reported in previous work in which discriminant analysis was also applied to distinguish among the five sites under investigation, on the basis of the concentrations of five chemical elements in mayfly larvae (Fialkowski & Rainbow, 2006).

A pattern of chemical elements that has built up in an insect during its growth stage may represent the characteristics of the geographic region where the insect has

Table 5 Classification table for seven groups of *Nilaparvata lugens* samples.

Actual group	Predicted group							
	Fuqing	Shaoguan	Hepu	Yongfu	Hengnan	Wan-an	Yongkang	Total
Fuqing	2	0	1	0	0	0	0	3
Shaoguan	0	2	0	0	0	0	0	2
Hepu	0	0	7	0	0	0	0	7
Yongfu	0	0	0	4	0	0	0	4
Hengnan	0	0	0	0	4	0	0	4
Wan-an	0	0	0	0	0	3	1	4
Yongkang	0	0	0	0	0	0	3	3
Accuracy of prediction, %	66.7	100	100	100	100	75	100	27

been living (Dempster *et al.*, 1986). It is possible that trace element composition reflects the geographic conditions of the growing insect. In particular, the pattern should be closely related to the soil background. Because of different soil parent materials, the abundance of trace elements in soil varies, and the concentrations of trace elements in host plants differ (Alloway, 1995; Pendias, 2000). Therefore, the trace elements in the bodies of *N. lugens* individuals could be used as a factor for identifying their geographic origin. However, much work remains to be done, including a further study to analyze the conductance of chemical elements in the soil–rice plant–*N. lugens* system. In addition, the variation in chemical element content in the bodies of *N. lugens* across different years and different developmental stages of rice requires investigation.

Table 6 Summary of established origin for unknown *Nilaparvata lugens* samples compared with the actual group.

Unknown samples	Established origin	Actual group
1	Fuqing	Yongkang
2	Yongkang	Yongkang
3	Yongkang	Yongkang
4	Yongkang	Yongkang
5	Hepu	Hepu
6	Hepu	Hepu
7	Hepu	Hepu
8	Hepu	Hepu
9	Hepu	Hepu
10	Hepu	Hepu
11	Hepu	Hepu
12	Fuqing	Fuqing
13	Fuqing	Fuqing
14	Fuqing	Fuqing
15	Hepu	Fuqing
16	Shaoguan	Shaoguan
17	Shaoguan	Shaoguan
18	Yongfu	Yongfu
19	Yongfu	Yongfu
20	Yongfu	Yongfu
21	Hengnan	Hengnan
22	Hengnan	Hengnan
23	Hengnan	Hengnan
24	Wan-an	Wan-an
25	Wan-an	Wan-an
26	Wan-an	Wan-an

In conclusion, in light of the significant differences in trace element concentrations in respect to geographic origins of *N. lugens*, "point to point" pattern recognition analyses on the different geographic origins of *N. lugens* populations were conducted using a multivariate statistical method. The "point" represents the region of growth or origin of *N. lugens* and the "point to point" represents the different regions along the migration route of *N. lugens*. In comparison with studies on existing approaches to exploring the migration route of *N. lugens*, this pattern recognition technique would be more efficient for tracking the source area of *N. lugens*, because it does not involve including complicated meteorological factors related to atmospheric circulation, such as wind and temperature fields. Once a database of the chemical elements of different regions of *N. lugens* is established, sampling of *N. lugens* could be conducted to analyze the "point to point" pattern recognition, and the possible source area of *N. lugens* migration could be tracked. Use of this method in combination with radar observation and meteorological models of numerical simulation analysis, and so on, could allow more accurate identification of the source area of *N. lugens* immigration.

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