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Morphometric Variations of a Populations of the Whitebacked Planthopper, *Sogatella furcifera* Horváth (Homoptera: Delphacidae), from Korea, China, and the Philippines

한국, 중국, 필리핀산 흰등멸구의 계량형태적 변이

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ABSTRACT Morphometrics of the sensory appendages for host plant discrimination such as antenna, leg, rostrum of *S. furcifera* sampled from Korea, China, and Philippines were determined and compared. Computed discriminant scores of 89 characters produced scatter diagrams and group centroids revealing discrete segregations of the three populations.

KEY WORDS *Sogatella farcifera*, morphometric variation

초 록 한국, 중국, 필리핀산 흰등멸구의 계량형태학적 차이를 분석하기를 위하여 총 89개 부분의 형태적 특징(촉각 34, 다리45, 주둥이10)을 조사하고 계량형태적 분석을 위하여 정준 판별 분석법을 이용하였다. Scatter plot diagram 상에서 3개 집단의 중심점은 분리 현상이 뚜렷하였고 그 정도는 단시형 암컷에서 크게 나타났다. Mahalanobis distance(MD)는 단시형 암컷의 경우 3개 집단 모두 5%에서 유의성이 있었고, 장시형 암컷의 경우 MD는 중국산 대 필리핀산, 한국산 대 필리핀산이 각각 0.1%, 1%에서 유의성이 있었으나, 중국산 대 한국산은 유의성이 없었다.

검 색 어 흰등멸구, 형태

The whitebacked planthopper (WBPH), *Sogatella furcifera* (Horvath : Delphacidae) is an economically important pest of rice. The increased incidence of thes insect is generally attributed to the reduced genetic variability of short-statured high yielding varieties, use of high levels of nitrogenous fertilizers, and continuous croppings of rice (Saini et al. 1982). Severe outbreaks causing hopperburn have been reported from Bangladesh, China, Japan, Korea, Nepla, and Vietnam (Alam & Alam 1977,Hirao 1981, Lee et al. 1981, Mochida et al. 1982, Gyawali 1983, Lee 1987).

Varietal resistance proved effective in regulating the pest infestation. From 47,089 world collections of rice at the International Rice Research Institute (IRRI), 391 rice varieties (accessions) with resistance to WBPH have been selected. Six of these resistant varieties at IRRI originated from China (Khan & Saxena 1986). Four varieties having moderate

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resistance to *S. furcifera* have been released for commercial cultivation (Heinrichs 1985). In Korea, the variety Cheongcheongbyeo incorporated from IR2035 has been released as a recommended rice variety (Kim et al. 1985).

Genetic analyses of resistant varieties have identified five genes for resistance to *S. furcifera*, namely : *Wbph1* in N22 (Sidhuet al. 1979), *Wbph2* in ARC 10239 (Angeles et al. 1981), *Wbph3* in ADR 52 (Hernandez & Khush, 1981), *Wbph4* in Podiwi A8 (Hernandez Khush 1981), *Wbph5* in N'Diang Marie (IRRI 1984). Also, Angeles et al. (1981) identified the digenic cultivars IR2035-117-3 (*Wbph1*+ *Wvph2*), WC1240 (*Wbph1*+unidentified recessive gene), and Colombo (*Wbph2* + unidentified recessive gene). At IRRI, the identified digenic cultivars were Chaia Anaser *Wbph1* + *Wbph3* and Cl-6010-I (*Wbph1* + unidentified dominant gene) (IRRI 1984).

A limiting factor to varietal resistance to insect pests is the occurrence of biotypes. So far, no reported case of biotype formation is available yet regarding WBPH. However, the possibility of the development of biotype cannot be excluded if WBPH-resistant varieties will be planted intensively (Khan & Saxena 1985).

Upon exposure to varying host cultivars, the salient responses usually exhibited by the phytophagous insects are recognition and discrimination. In such host selection behavior, the sensory appendages such as antennae, legs, and rostrum, are mainly involved. The study herein reported investigated the morphometrica of some of these characters in populations of *S. furcifera* from Korea, China, and the Philippines.

MATERIALS AND METHODS

Collection of WBPH

In China (c) two to three hundred WBPH were collected in May, 1986 from the field (30 days after transplanting) in Hangzhou, Zhejiang province. They were reared in the greenhouse on native susceptible rice variety Guangluai 4. In August, 1987, macropterous males and brachypterous and macropterous females were randomly sampled.

In Korea (k), twenty to thirty macropterous males and femalea WBPH were collected from the rice field in Suweon in September, 1987. The brachypterous females were sampled from the insectary.

In the Philippines (p), fifty females of WBPH were collected from the field in Los Banos, Laguna in August, 1987. They were mass-reared in the Insectary on Taichoug Native 1 (TN1). First generation macropterous males and females and brachypterous females were sampled randomly in alcohol vials for morphological investigation.

Mounting of specimens

The sampled WBPH from China, Korea, and the Philippines were mounted for morphological examinations as follows ; (1) boiled in 95% ethyl alcohol for 10 minutes in a water bath; (2) macerated in 10% lukewarm NaOH for 10-15 minutes ; (3) washed in 95% ethyl alcohol and boiled for 15-20 minutes in chloral-phenol (1:1 parts chloral hydrate and phenol crystals) ; (4) body parts such as rostrum and legs were properly oriented and mounted on a glass microslides using Hoyer's medium (30 g gum arabic, 50 ml water, 200 g chloral hydrate, 20 ml glycerine). Antennae were mounted in glycerol medium on slides so that they could be moved freely during microscopic examinations.

Table 1. Charactera used in the morphometric evaluation of antennae, legs, and rostrum of *S. furcifera*

Abbreviation	Structures and their morphometric parameters
	Antenna
	Pegs of sensoria of second antennal segment (n)
AAD1 L and R	First anterodorsal sensorium of left and right antennae
AAD2 L and R	Second anterodorsal sensorium of left and right antennae
AAD3 L and R	Third anterodorsal sensorium of left and right antennae
ADS1 L and R	First dorsocentral sensorium of left and right antennae
ADS2 L and R	Second dorsocentral sensorium of left and right antennae
ADS3 L and R	Third dorsocentral sensorium of left and right antennae
ADS4 L and R	Fourth dorsocentral sensorium of left and right antennae
ADS5 L and R	Fifth dorsocentral sensorium of left and right antennae
APD1 L and R	First posterodorsal sensorium of left and right antennae
APD2 L and R	Second Posterodorsal sensorium of left and right antennae
APD3 L and R	Third posterodorsal sensorium of left and right antennae
APD4 L and R	Fourth posterodorsal sensorium of left and right antennae
APV1 L and R	First posterventral sensorium of left and right antennae
APV2 L and R	Second posteroventral sensorium of left and right antennae
AAV L and R	Anteroventral sensorium of left and right antennae
AVS L and R	Ventrocentral sensorium of left and right antennae
TNS L and R	Sensoria of second antennal segment of left and right antennae (total n)
	Leg-foretarsus
	Setae of third subsegmeut of taraus (n)
F-DS1 L and R	First dorsocentral setae of left and right tarsi
F-DS2 L and R	Second dorsecentral setae of left and right tarsi
F-AD L and R	Anterodorsal setae of left and right tarsi
F-PD L and R	Posterodorsal setae of left and right tarsi
F-AV L and R	Anteroventral setae of left and right tarai
F-PV L and R	Posteroveutral setae of left and right tarsi
F-CL and R	Claw [maximum length and maximum width (μ)]
F-CL/CW	Claw [length (μ)/claw [width (μ)]
LFL	Third subsegment of foretarsus [length (μ)]
	Leg-midtarsus
	Setae of third subsegment of taraus (n)
M-DS1L and R	First dorsocentral setae of left and right tarsi
M-DS2L and R	Second dorsecentral setae of left and right tarsi
M-AD L and R	Anterodorsal setae of left and right tarsi
M-PD L and R	Posterodorsal setae of left and right tarsi
M-AV L and R	Anteroventral setae of left and right tarai
M-PV L and R	Posteroveutral setae of left and right tarsi
M-CL and CW	Claw [maximum length and maximum width (μ)]
M-CL/CW	Claw [length (μ)/claw [width (μ)]
LML	Third subsegment of foretarsus [length (μ)]

Table 1. Continued

Abbreviation	Structures and their morphometric parameters
	Leg-hindtarsus
	Setae of third subsegment of taraus (n)
H-DS1 L and R	First dorsocentral setae of left and right tarsi
H-DS2 L and R	Second dorsocentral setae of left and right tarsi
H-AD L and R	Anterodorsal setae of left and right tarsi
H-PD L and R	Posterodorsal setae of left and right tarsi
H-AV L and R	Anteroventral setae of left and right tarai
H-PV L and R	Posteroveutral setae of left and right tarsi
LHL	Third subsegmeut of hindtarsus [leugth (μ)]
	Rostrum
URL	Ultimate rostral segment (UR) [length (μ)]
PRL	Penultimate rostral segment (PR) [length (μ)]
URAC 1 AND 2	First and second anterocentral setae of Ur (n)
URAL 1 AND 2	First and second anterolateral setae of UR (n)
PRAC 1 AND 2	Anterocentral setae of left and right sides of PR (n)
PR/UR	PR [length (μ)/UR [length (μ)]
PL	UR [length (μ)]/third subsegment of hindtarsus [length (μ)]

Morphometric investigation and statistical analysis

A total of 89 morphometric characters (antenna (34), leg (45), and rostrum (10) were determined (Table 1) in brachypterpus females and both sexes of macropterous WBPH from Korea, China, and the Philippines. Morphometric data were analyzed using canonical discriminant analysis (SAS, institute 1985).

RESULTS

Standardized cononical coefficients

The standardized canonical coefficients indicate the relative importance of the variable in determining scores on the two functions (F1 and F2). The variable with the highest coefficient contributed most to the determination of scores.

In brachypterous females, the variable with the highest contribution to the first function was PRL, while F-CW contributed most to the second function. In the case of macropterous males, the highest coefficients for F1 and F2 were M-CW and F-CL/CW, respectively. For macropterous females, LHL and RL contributed msot to the two functions. These variables contributed significantly to the segregations among the three populations of *S. furcifera* (Table 2).

The Eigen value is directly related to the discriminating power of the function such that the higher the value, the stronger the discriminating power and vice versa. The first function (F1) is the initial discriminator, the second function (F2) provides more powerful discrimination after the first has done its best; and so on.

Canonical correlation is a measure of association which summarizes the degree of relationship between the group and the discrimination function.

Table 2. Standardized canonical coefficients of *S. furcifera* among the three populations based on 20 selected characters[a]

Characters selected	BRAC female		Characters selected	MAC male		Characters selected	MAC female	
	F1	F2		F1	F2		F1	F2
AADIR	-0.17	-2.15	AADIR	-0.71	-0.49	AAD1L	1.23	-1.71
AAD1R	-1.14	0.58	ADSIL	0.75	1.24	AAD2R	1.57	-0.79
AAD2L	-0.89	0.40	AKS4R	-0.33	0.63	AAD3L	0.48	1.09
AAD2L	-0.19	0.38	ADS5L	-0.13	0.63	ADS2L	-1.96	1.24
APV2R	1.39	0.89	APDIR	-0.64	0.34	APV2R	-0.59	0.34
APV2R	1.66	-1.35	APD4L	1.14	-0.07	AAVR	0.97	0.10
F-CL	-3.77	18.56	AVSR	0.69	-0.55	F-DS2R	-0.59	0.06
F-CW	5.56	-24.74	F-CL	4.28	1.78	F-CL	-1.87	0.98
F-CL/CW	4.71	-22.77	F-CW	-3.93	-2.32	F-CW	-0.23	2.35
M-CW	-1.17	5.42	F-CL/CW	-4.98	-3.25	F-CL/CW	0.37	1.05
M-CL/CW	-0.46	5.67	F-DS2R	0.92	-0.56	LFL	0.99	-2.59
H-DS2L	-0.03	2.88	M-ADR	-0.28	0.28	M-CW	-0.38	0.59
H-ADR	0.45	0.52	M-ADL	0.17	0.56	LML	-0.05	0.99
H-PDL	-0.63	0.91	M-CL	-5.81	0.40	H-DS2L	-0.05	-0.45
H-AVL	-0.30	2.17	M-CW	8.54	-1.27	LHL	7.40	1.93
H-PVR	0.55	0.40	M-CL/CW	6.45	-0.96	URL	-4.68	-1.55
H-PVL	0.06	1.42	H-DS2L	-0.05	1.03	URAC2	1.06	0.63
URL	-4.26	-15.30	H-PDR	0.05	-0.95	PRAC1	1.11	-0.27
PRL	8.17	14.00	H-PVR	1.08	-1.04	PRAC2	-1.42	0.01
PR/UR	-3.24	-4.78	PRL	0.16	-0.24	RL	5.80	4.18

[a]BRAC; brachypterous *S. furcifera*, MAC; macropterous F1; Function 1, F2; Function 2.

A value of zero denotes no relationship at all, while an increasing value with 1.0 being the maximum indicates otherwise.

When all the selected characters from antenna, leg and rostrum were combined on the higher standardezed canonical coefficients and computed together, two discriminating functions provided maximum segregations among the three populations as indicated by the higher eigen value and its canonical correiations. The eigen values of the Fl's were higher than those of F2. The highest eigen value was observed in Function l of macropterous female (Table 3).

Two-function plots

The scatter plot diagrams based on computed discriminant scores of 20 selected and combined characters of sensory appendages such as antenna, leg, and rostrum approximated the amount of variations and segregations between and among the three populations of *S. furcifera* from China, Korea, and the Philippines (Fig. 1).

In the brachypterous females (Fig. la), the scatter plot diagram distinctly segregated the three populations. Their group centroids were evidently separated. The clusters of each population in the canonical variate plane were amply tight implying low variability within each population.

In the macropterous males (Fig. 1b) the clusters of each population in the canonical variate plane were less tight due to certain amount of variation within each population. However, their group centroids were far from one another and still the three populations were grouped separately.

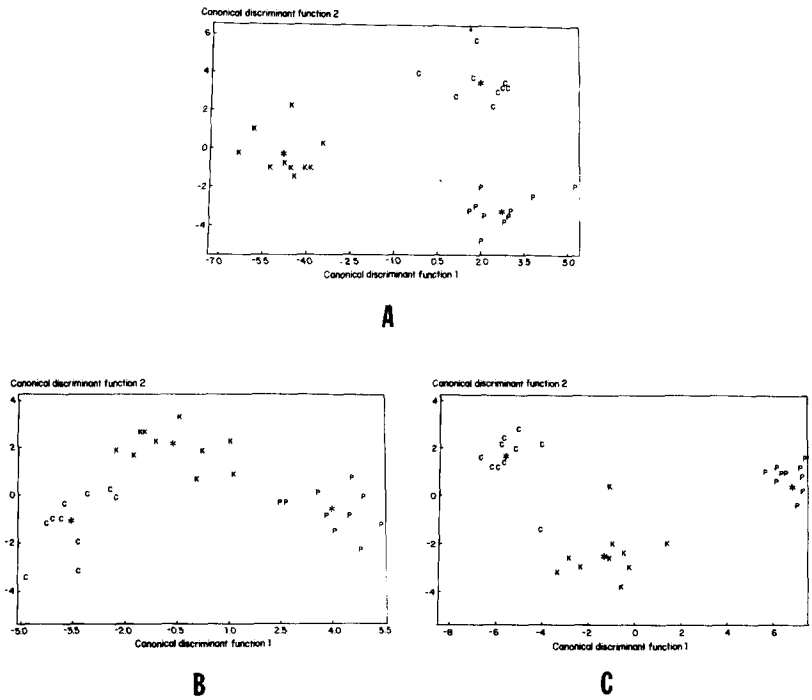

Fig. 1. Scatter plot diagrams based on computed discriminate scores of 20 selected characters of antennae, leg, and rostrum of brachypterous female (A) and macropterous males (B) and females (C) of *S. furcifera* from China (c), Korea (k) and the Phillippines (p).

In the macropterous females (Fig 1c), the population of WBPH from the philippines exhibited tighter cluster in the canonical variate plane than those from China and Korea. Their group centroids were distinctly far from one another.

Thus, the three populations of WBPH from China, Korea, and the Philippines can be distinctly differentiated from one another based on the morphometrics of their antennal, leg, and rostral characters.

Mahalanobis distance between classes

The values of mahalanobis distances between population pairs were obtained from the 20 characters of antenna, leg, and rostrum with higher standardized canonical coefficients. The higher the value of distance, the higher the degree of differentiation between populations (Table 4).

In the brachypterous females, the values between classes were significantly different in all the population pairs at 5% level. The highest distance was between Korea and the Philippines.

In the macropterous males, the highest distance was between China and the Philippines. Korean populations of WBPH closely resembled China's and Philippine's populations.

In the macropterous females, the highest significant distance at 0.1% level was between China and the Philippines, followed by Korea

Table 3. Canonical correlations an eigen value of the three populations of *S. furcifera* based on 20 selected characters

	Function 1	Function 2
	BRAC Females	
Canonical correlation	0.963	0.943
Eigen value	12.71	8.06
Proportain (%)	61.2	38.8
	MAC Males	
Canonical correlation	0.957	0.827
Eigen value	10.91	2.16
Proportion(%)	83.5	16.5
	MAC Females	
Canonical correlation	0.983	0.877
Eigen value	28.18	3.34
Proportiaon(%)	81.4	10.6

Table 4. Relationships between populations of *S. furcifera* from China, Korea, and the Philippines based on the combinations of the 20 selected character

Population pairs	Mahalanobis distance[a]		
	BRAC females	MAC males	MAC females
China vs. Korea	7.78*	4.31	5.87
China vs. Philippines	6.61*	7.62*	12.18***
Korea vs. Philippines	8.00*	5.40	8.51**

[a]BRAC=brachypterous; MAC=macropterous.
*,**,***-singnificant at 5%, 1% and 0.1%, respectively.

Table 5. Predicted group membership of the three populations of *S. furcifera* based on 20 selected characters[a]

Actual group	Wing forms and sexes	Group(%) cases correctly identified		
		China	Korea	Philippines
China	BRAC female	100.0	0.0	0.0
	MAC female	100.0	0.0	0.0
	MAC female	90.0	10.0	0.0
Korea	BRAC female	0.0	100.0	0.0
	MAC male	0.0	100.0	0.0
	MAC female	0.0	100.0	0.0
Philippines	BRAC female	0.0	0.0	100.0
	MAC male	0.0	0.0	100.0
	MAC female	0.0	0.0	100.0

[a]BRAC-brachypterous; MAC-macropterous.
Ten individuals of each wing forms and sexes was used.

and the Philippines at 1% level. China's and Korea's populations had insignificant distance.

Thus, in terms of the degree of differentiation based on Mahalanobis distance values, the three populations of WBPH can be ranked and compared as follows; China vs. Philippines Korea vs. the Philippines China vs. Korea. These relationship were almost correlated with their geographical distances.

Group classifications of *S. furcifera* populations

When all the selected characters were combined (based on the higher standardized canonical coefficients) and computed together,89 individuals out of 90 were classified into their proper populations. The combinations of selected characters among the three populations from brachypterous females and macropterous males exhibited perfect group classification. However, 10% of macropterous females in China populations were misclassified as Korea population (Table 5).

DISCUSSION

The establishment of a given species in different habitats or geographical areas results in populations with different ecological, physiological, and even morphological traits. The change in ecological and physiological traits of the species in many organisms is frequently followed by the beginning of change in its morphological characteristics (Bey-Bianko 1958). For instance, the populations of *S. furcifera* from China, Korea, and the Philippines differed in the morphometrics of their sensory characters. These variations suggested gradual divergence in the micro geographically isolated popu-

lations of *S. furcifera*. If these populations will be prevented from exchanging genes for a long time, the normal processes of mutation, recombination, and selection will cause the differentiation of the isolated populations. The gene pools of the isolated populations will become more and more different from that of the rest of the species, finally reaching a level of distinctness that normally characterize different species. The taxonomic status of the three allopatric populations of *S. furcifera* can be definitely known after determining the amount of interbreeding between and among them. Thus, the next phase of the study should be geared toward the analysis of the genitic systems of *S. furcifera* populations.

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