Whitebacked Planthopper Resistance in Chinese Rice Varieties

SOGAWA Kazushige[1], ZHANG Hong[2], YANG Xiao-jun[3], LIU Guang-jie[4]

([1]Japan International Research Center for Agricultural Sciences, Tsukuba 305-8686, Japan; E-mail: ksogawa@jircas.affrc.go.jp; [2]College of Agriculture, Yangzhou University, Yangzhou 225009, China; [3]College of Agriculture and Biotechnology, Zhejiang University, Hangzhou 310029, China; [4]Chinese National Center for Rice Improvement, China National Rice Research Institute, Hangzhou 310006, China)

中国水稻品种对白背飞虱的抗性

寒川一成[1]　张　红[2]　杨晓君[3]　刘光杰[4]

([1] 日本国际农林水产业研究中心, 日本 筑波 305-8686; E-mail:ksogawa@jircas.affrc.go.jp; [2]扬州大学 农学院, 江苏 扬州 225009; [3]浙江大学 农业与生物技术学院, 浙江 杭州 310029; [4]中国水稻研究所 国家水稻改良中心, 浙江 杭州 310006)

摘　要:评价了来自中国的13个粳稻品种、11个籼稻品种、13个杂交稻组合,以及11个热带粳稻品种的杀卵作用和拒食抗性。具有杀卵作用的品种仅见于粳稻品种。测试的13个粳稻品种中,4个表现出明显的杀卵作用。重新评价了来自中国不同省份的42份粳稻和43份籼稻对白背飞虱的抗性。10个粳稻(约占24%)具有杀卵抗性,卵死亡率为53%～100%;95%以上的籼稻品种中,白背飞虱的卵死亡率低于30%;来自浙江的4个粳稻品种明显地抑制白背飞虱的取食。浙江的21个粳稻地方品种对白背飞虱拒取食和杀卵作用表现出独立性和连续变化。三千黄、长红稻和矮秆稻具有杀卵抗性,鸡脚黄和麻雀青具有拒取食抗性。这些发现表明抗白背飞虱基因在中国存在于同一生态区的粳稻地方品种中。

关键词: 白背飞虱; 品种抗性; 水稻; 杀卵抗性; 拒取食抗性; 地方品种

中图分类号: S433.1; S435.112+.3; S511.034　　**文献标识码**:A　　**文章编号**:1001-7216(2003)增刊-0047-06

Abstract: Ovicidal- and sucking-inhibitory resistance to the whitebacked planthopper (WBPH) in 13 japonica, 11 indica, 13 hybrid rice from China, and 11 tropical japonica from other countries were evaluated. Ovicidal varieties were found only in japonica rice, four of 13 japonica varieties showed significant ovicidal response. No ovicidal varieties were involved in indica, hybrid and tropical japonica varieties tested. In addition, 42 japonica and 43 indica varieties from different provinces in China were re-evaluated for WBPH resistance. Ten japonica varieties (about 24%) had ovicidal resistance, causing 53%－100% egg mortality. In more than 95% of indica varieties, WBPH egg mortality was below 30%. Only four japonica varieties from Zhejiang Province significantly suppressed honeydew excretion by WBPH. Among 21 japonica landraces in Zhejiang Province, ovicidal and sucking response of WBPH showed independent and continuous variations. Sanqianhuang, Changhongdao and Aigandao had ovicidal resistance. Jijiaohuang and Maqueqing inhibited WBPH sucking. This finding indicated that WBPH resistance genes were retained in sympatric japonica landraces in China.

Key words: whitebacked planthopper; varietal resistance; rice; ovicidal resistance; sucking inhibition; landrace

1 Introduction

The whitebacked planthopper (WBPH), *Sogatella furcifera*, is a rice monophagous herbivore in the paddy fields. Previously, WBPH was a secondary insect pest of rice, which seldom caused economic injuries to the paddy crop. However, since around the 1980s, WBPH populations have significantly increased following a nation-wide adoption of hybrid rice in China[6,17]. Chemical control of WBPH became inevitable for high yielding cultivation of hybrid rice. Besides, WBPH that propagates in hybrid rice areas makes massive migrations to the inbred rice areas, where the planthopper has also become an important economic insect pest at early growth stage of rice. Intensification of early insecticide applications for controlling WBPH will deteriorate IPM approaches in the paddy ecosystems because of ecological toxicity. Rice varieties with WBPH-resistance are fully compatible with natural enemies, and enable to reduce pesticide applications to the rice plants at early vegetative growth stages, when the natural enemies are actively recruited to the paddy ecosystem. Therefore, utilization of WBPH-resistant varieties is an effective approach to the sustainable IPM in rice.

We have found that a Chinese japonica rice Chunjiang 06 (CJ-06) not only has a unique ovicidal resistance as that seen commonly in Japanese japonica rice, but also has a sucking inhibitory resistance to WBPH. Antixenosis of CJ-06 due to sucking inhibitory nature plays a decisive role in reducing WBPH density on the variety[16]. In addition, reproduction of WBPH on CJ-06 is markedly reduced by inhibition of sucking as well as by the ovicidal activities. As a consequence, CJ-06 expresses highly stable field resistance to WBPH.

收稿日期: 2002-12-03。

基金项目: JIRCAS国际合作研究项目(B3333101)。

注:本文是中日合作研究项目"中国重要食物资源的可持续生产和高度利用技术的开发"在中国水稻研究所实施的"中国迁飞性稻飞虱综合防治技术的开发"研究内容的一部分。

第一作者简介: 寒川一成(1941－),男,博士,主任研究官。

The present experiments were conducted to clarify the genetic background for WBPH resistance in Chinese rice varieties.

2 Materials and Methods

2.1 Rice varieties tested

All the rice varieties except for tropical japonica (javanica) were provided by China National Rice Research Institute (CNRRI). In particular, Prof. Ying Cunshan, former Director General of CNRRI, supplied Chinese japonica and indica breeding materials, and japonica landraces from Zhejiang Province from the rice germplasm bank of CNRRI with his kind arrangements. Two varieties of japonica landrace, Laolaiqing and Xintaihuqing, were supplied by Jiaxing Academy of Agricultural Sciences. The japonica landraces used in the present experiments were listed in Table 1. The tropical japonica varieties from the Philippines and Indonesia were obtained from National Institute of Agro-Biological Sciences in Japan.

2.2 Evaluation of WBPH resistance

All the varieties tested were individually planted in disposable plastic cups (7 cm in diameter, 9 cm in height) until early tillering stage under open conditions. Gravid females were individually confined onto the upper portion of leaf sheaths with parafilm sachets (2 cm×2 cm), and allowed to suck and lay eggs for a day at room temperature (26—30℃).

Sucking inhibitory resistance was evaluated by honeydew excretion. The varieties on which WBPH excreted little honeydew were classified as the varieties with sucking suppressive resistance. In the experiments with 21 Chinese japonica landraces, amount of honeydew excreted was quantified by weighing.

Ovicidal resistance was confirmed by egg mortality, which was calculated by counting live and dead eggs at 5—6 days after oviposition by dissecting the leaf sheath tissues at oviposition sites. The eggs with reddish eye-spots were recorded as developing live eggs, and white opaque eggs as dead ones.

Table 1. Japonica landraces used in the experiments.

Variety	Abbreviation	Accession no. [1)]
Aigandao 矮秆稻	AGD	1216
Baijing 白粳	BJ	1391
Baikechangdaotou 白壳长稻头	BKCTD	20224
Changdaotou 长稻头	CDT	1437
Changhongdao 长红稻	CHD	993
Hongke 红壳	HK	774
Huangzhong 黄种	HZ	1169
Jijiaohuang 鸡脚黄	JJH	664
Luganqing 芦秆青	LGQ	831
Laohudao 老虎稻	LHD	1053
Linhaiwandao 临海晚稻	LHWD	878
Laolaiqing 老来青	LLQ	JAAS
Laowusi 老勿死	LWS	399
Manluoqing 慢落青	MLQ	699
Maqueqing 麻雀青	MQQ	690
Sanqianhuang 三千黄	SQH	951
Shuangjiangwu 霜降乌	SJW	20112
Taihuqing 太湖青	THQ	20119
Tieganwudao 铁秆乌稻	TGWD	20126
Xintaihuqing 新太湖青	XTHQ	JAAS
Yisuizhong 一穗种	YSZ	694

[1)] Accession no. of CNRRI Germplasm Bank. JAAS, Jiaxing Academy of Agricultural Sciences.

3 Results

3.1 Distribution of ovicidal resistance to WBPH among different variety groups

Ovicidal varieties were restrictedly found in japonica rice. Of 13 varieties tested, four varieties, CJ-06, Chunjiang 15, Bin-97-405 and Bin-97-408-1, showed significant ovicidal reactions. No ovicidal varieties were detected among 11 indica, and 13 hybrid rice combinations in China (Table 2). As a comparison with temperate japonica varieties in China, 11 tropical japonica varieties were tested. However, no tropical japonica varieties showed ovicidal response. WBPH excreted considerable amounts of honeydew on all the varieties tested except for CJ-06.

3.2 Occurrence of WBPH resistant varieties in Chinese japonica and indica rice

Totally 42 japonica varieties from 11 provinces were subjected to the evaluation of the WBPH resistance. Egg mortality varied continuously from 2% to 100% among them. Ten varieties (about 24%) showed an egg mortality (53%—100%) as high as that of CJ-06 (79%) (Table 3). On the other hand, no significant ovicidal variety was detected in the 43 indica varieties tested. Egg mortality in the indica rice ranged from 1.5% to 51%, and was below 30% in 95% or more varieties (Table 4).

WBPH discharged significantly less honeydew on 4 japonica varieties from Zhejiang Province, namely Xianghu 84, Xiaohuangchong, Xiushui 04 and Yuanjing 2, which indicated sucking suppressive resistance to WBPH in these varieties. No indica varieties suppressed honeydew excretion by the planthopper.

3.3 Sucking inhibitory and ovicidal resistance to WBPH in japonica landraces in Zhejiang Province

WBPH excreted varying amounts of honeydew in different landraces tested, which showed continuous variations among them. Honeydew excretion in Jijiaohuang and Maqueqing was as little as that in CJ-06, indicating their sucking inhibitory resistance (Fig. 1). On the contrary, WBPHs excreted as much honeydew in Shuangjiangwu, Hongke, Manluoqing, Changdaotou, Taihuqing, and Yisuizhong as they did in TN1. The other landraces were between CJ-06 and TN1.

More than 80% of WBPH eggs died on Sanqianhuang, Changhongdao and Aigandao (Fig. 2). Their egg mortality was as high as that in the ovicidal CJ-06. Egg mortality in

Table 2 . Occurrence of ovicidal varieties in different variety types of rice.

Variety type and Variety	No. of plants examined	Average no. of eggs laid per plant	Average mortality of eggs[1)] /%	Variety type and Variety	No. of plants examined	Average no. of eggs laid per plant	Average mortality of eggs[1)] /%
Japonica rice				Hybrid rice			
Bin 97-408-1	6	28.0	80.0 a	Teyou 500	6	18.2	25.1
Chunjiang 06 (CJ-06)	6	28.0	79.0 a	Ⅱ You 500	5	35.8	17.6
Chunjiang 15	6	24.5	73.9 a	Xieyou 10	6	23.3	17.5
Bin 97-405	6	24.2	64.9 a	Ⅱ You 63	5	32.0	16.7
Chunjiang 11	6	26.2	61.7	Ⅱ You 2070	6	26.8	15.5
UCD106-17	6	51.7	48.0	Xieyou 300	6	35.3	15.4
Bin 97-412	6	16.7	39.2	Teyou 63	6	27.3	11.6
Bin 97-264	6	27.7	11.7	Xieyou 100	5	23.8	11.5
Bin 94-54	6	20.6	7.8	Shanyou 63	6	26.3	8.9
Chunjiangzao 1	5	28.0	6.0	Xieyou 63	5	36.6	7.9
Xiushui 11	5	24.5	4.9	Xieyou D2	6	44.7	5.9
Xiushui 47	6	26.2	4.9	Teyou D2	6	20.8	4.0
Chunjiang 100	5	33.0	3.0	Xieyou 9308	6	25.2	3.5
Indica rice				Tropical japonica rice			
Nanji 3	6	27.2	45.2	Ketan Eson	6	40.7	35.2
You 71	5	33.6	26.1	Ingsa Putih	5	49.0	33.6
Qixiangzhan	5	39.4	13.6	Unoy	6	19.6	20.8
TN1	6	26.5	8.1	Binato	6	42.2	15.6
Shenggui	6	32.2	7.8	Simedan	6	42.4	12.0
Chaohongzao 1	5	35.4	6.4	Palawan	5	33.6	11.6
Saituofu	6	33.3	3.9	Putih	6	44.4	10.8
Zhongyin 85	6	22.7	3.7	Siboru Toba	6	42.0	5.0
Jingxian 89	5	24.4	2.7	Simedan 2	6	27.3	4.9
Wangdao	6	29.0	2.7	Sigadogabo	6	36.0	4.0
Zhongyu 93-1	5	28.8	2.1	Sihompa	6	26.8	1.6

1) a: There is a significant difference from TN1, but not from CJ-06 ($P < 0.05$, t-test).

Jijiaohuang, Manluoqing, Laohudao, Laolaiqing, Baijing, Baikechangdaotou, Taihuqing, and Huangzhong was below 30%, and had no ovicidal resistance to WBPH eggs like TN1. The egg mortality of other landraces showed continuous variations between those of CJ-06 and TN1.

None of the 21 landraces tested in the present experiment had both the sucking inhibitory- and ovicidal resistance. Only Maqueqing showed high sucking inhibitory and moderate ovicidal resistance, and Changhongdao had moderate sucking inhibitory- and high ovicidal resistance.

4 Discussion

Since 1971, mass screening of resistant varieties to WBPH has been undertaken at International Rice Research Institute (IRRI) by using the standardized seedbox test. Most of the WBPH resistant varieties were detected among indica local rice from Pakistan, Nepal and India[10]. From them, five major genes for WBPH resistance have been identified, and designated as *Wbph 1*, *Wbph 2*, *Wbph 3*, *wbph 4* and *Wbph 5*[1,4,9,11,13,20]. These WBPH resistant indica

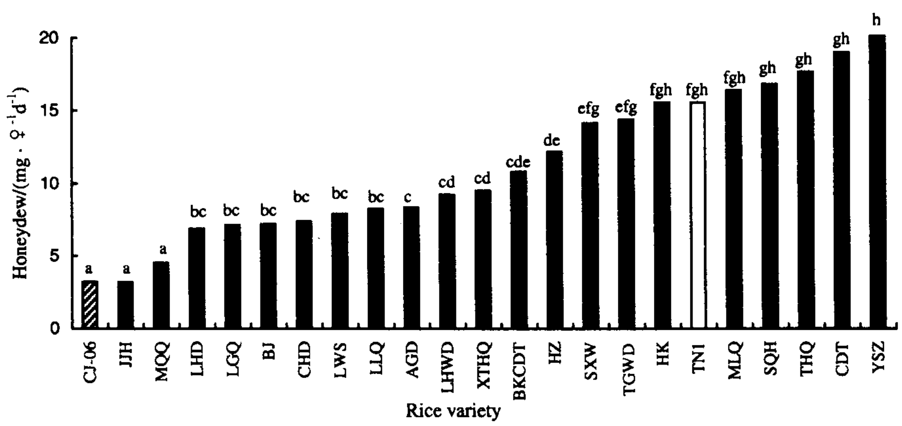

Fig. 1. Honeydew excretion by WBPH females in japonica landraces in Zhejiang Province.
Varieties followed by the same letters are not significantly different ($P < 0.05$, LSD).
CJ-06 (Chunjiang 06), Resistant check; TN1, Susceptible check.

Table 3. Ovicidal response in Chinese japonica rice varieties.

Variety	Origin	No. of plants examined	Average no. of eggs laid per plant	Average mortality of eggs[1] /%
Longjing 3	Heilongjiang	6	43.0	53.2 a
Hejiang 19	Heilongjiang	6	27.3	42.3
Tongxi 112	Heilongjiang	5	40.6	25.4
Ji 90-105	Jilin	5	20.0	12.8
Zhuganqing	Shandong	5	35.0	72.2 a
Yanjing 2	Jiangsu	4	20.5	82.5 a
Nanjing 11	Jiangsu	5	23.6	78.8 a
Xianyu 1	Jiangsu	4	34.3	62.4 a
Nanjing 7	Jiangsu	5	27.0	55.8 a
Ninghui 18	Jiangsu	5	28.6	36.8
Suyunuo	Jiangsu	5	57.6	31.4
Wuyujing 2	Jiangsu	5	33.6	22.8
Wuyujing 3	Jiangsu	5	26.0	6.0
2428	Jiangsu	4	30.5	5.5
Gaogansuyunuo	Jiangsu	4	29.3	4.5
Xiushui 115	Zhejiang	4	19.8	86.0 a
T42	Zhejiang	5	41.6	53.2 a
Xianghu 25	Zhejiang	5	33.6	46.8
Xianghu 84	Zhejiang	5	34.6	46.4
Yongjing 194	Zhejiang	5	26.0	46.0
Xiushui 11	Zhejiang	5	24.4	45.8
Chengte 232	Zhejiang	4	26.3	41.7
Aicheng 804	Zhejiang	5	32.4	29.4
Xiushui 48	Zhejiang	5	22.4	28.6
Xiushui 46	Zhejiang	4	22.3	28.5
Xiaohuangzhong	Zhejiang	5	24.6	18.2
Xiushui 04	Zhejiang	5	25.4	17.8
Laohudao	Zhejiang	5	30.6	16.6
Jing 15	Guangxi	6	34.7	20.0
Baizhujing	Guizhou	6	27.0	39.2
Anjing 314	Guizhou	6	33.5	31.3
Zizaojing	Guizhou	5	24.2	22.2
Huangjinjing	Guizhou	6	32.2	13.2
Fu 53	Guizhou	4	41.0	11.7
Cungunuo	Guizhou	6	32.7	5.7
Xinjing 6	Henan	6	32.5	8.3
Xinjing 5	Henan	5	32.8	2.0
Jing 185-7	Hubei	5	20.0	100.0 a
Xiangjing 1	Hunan	5	12.0	100.0 a
Tainan 17	Taiwan	6	27.5	20.8
Gaohsiung 13	Taiwan	6	24.0	10.2
CJ-06 (ovicidal control)	Zhejiang	6	21.0	79.0
TN1 (non-ovicidal control)	Taiwan	5	26.5	8.8

[1] a: There is a significant difference from TN1, but not from CJ-06 ($P < 0.05$, t-test).

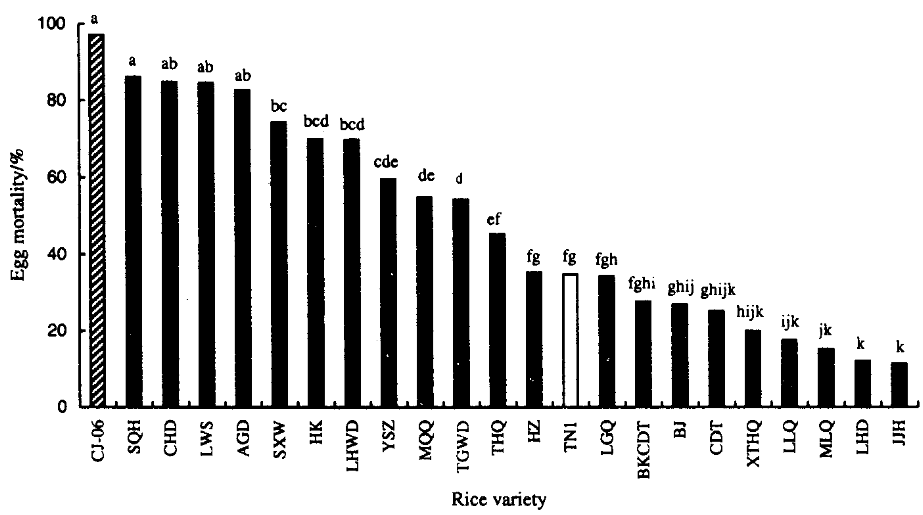

Fig. 2. WBPH egg mortality in japonica landraces in Zhejiang Province.

Varieties followed by the same letters are not significantly different ($P < 0.05$, LSD).

CJ-06 (Chunjiang 06), Resistant check; TN1, Susceptible check.

Table 4. Ovicidal response in Chinese indica rice varieties.

Variety	Origin	No. of plants examined	Average no. of eggs laid per plant	Average mortality of eggs/%
Yunanheixiannuo	Henan	6	33.5	12.3
Xindao 26	Henan	6	45.7	10.8
91499	Anhui	5	44.6	51.4
Zhongxian 58	Anhui	4	33.5	44.2
Wandao 27	Anhui	5	29.0	17.2
Wuxiangxian	Jiangsu	5	38.6	21.6
Lianjian 33	Jiangsu	5	29.2	8.0
Xiangnuo 4	CNRRI	5	18.8	13.4
Zhongyouwan 1	CNRRI	6	45.5	5.2
Zhong 86-44	CNRRI	6	30.2	3.5
Zhongzao 18	CNRRI	6	40.5	0.7
Guihuanuolian	Hubei	5	41.2	6.0
Yushuinuo	Hunan	6	34.0	13.5
Zaoyou 1	Hunan	6	36.2	12.2
Zaoyou 3	Hunan	5	36.4	4.4
Yuexinzhan 3	Guangdong	5	46.2	61.4
Xinfengzhan 2	Guangdong	4	13.3	25.7
Yezhenai	Guangdong	5	40.8	22.4
Yuexinzhan	Guangdong	5	34.2	14.6
Yueyezhan 2	Guangdong	5	33.8	14.0
9567	Guangdong	5	27.0	12.6
Pin 278	Guangdong	5	32.6	11.2
Lijinghongmi	Guangdong	5	22.6	11.0
Qingjing 21	Guangdong	5	31.6	10.0
Lujingzhan 1	Guangdong	5	25.0	9.6
Yumei 153	Guangdong	5	38.4	9.2
Zhensizhan	Guangdong	6	24.5	9.2
Qingjingzhan 11	Guangdong	5	15.8	7.2
Aojingzhan 1	Guangdong	5	22.6	5.8
Xianhuangzhan	Guangdong	4	13.3	1.7
Xiansizhan	Guangdong	5	19.6	1.5
Yueyezhan 1	Guangdong	4	37.3	1.5
Jiangxixiangsimiao	Jiangxi	5	25.2	75.4
Fengxinhongmi	Jiangxi	4	29.8	41.7
Xiangsimiao	Jiangxi	5	37.2	20.4
Ganyouwan 9	Jiangxi	4	34.8	11.5
Xuxunian	Guizhou	6	31.3	15.8
Guiyu 100	Guizhou	6	32.2	3.3
Tonglianghuozhong	Sichuan	6	45.0	11.0
Pengshantieganzhan	Sichuan	6	42.3	7.7
Nanjianxiangdao	Sichuan	6	46.0	3.2
Longqingzixiangnuo	Yunnan	5	36.8	15.4
CJ-06 (ovicidal control)	Zhejiang	6	21.0	79.0
TN1 (non-ovicidal control)	Taiwan	5	26.5	8.8

varieties expressed various antixenotic and antibiotic phenomena during the processes of host plant selection and reproduction by the planthoppers[2,3,7]. The antixenotic and antibiotic phenomena commonly resulted from sucking inhibition of WBPH on the resistant indica varieties.

In the period from 1986 to 1990, 28527 Chinese rice germplasm accession lines were screened for WBPH resistance by the seedling box tests in China. Of them, 2743 varieties and lines were moderately to highly resistant to WBPH[5]. About 0.4% local rice varieties from Guangdong Province were all non-glutinous indica rice[19]. Allelic analysis revealed that four local indica varieties from Yunnan Province, Guiyigu, Biangu, Daqigu and Dahuagu, have a new dominant gene for WBPH resistance, which was tentatively designated as *Wbph 6(t)*[8].

Compared with indica rice, only a few japonica varieties have been reported to be resistant to WBPH[21,22]. Xiushui 620 is a parental line of CJ-06, which is highly resistant to WBPH. Yanjing 2 was also derived from a common intermediate variety, from which Xiushui 620 and CJ-06 were bred. All the japonica rice in Japan had been believed to be susceptible to WBPH. However, it was recently disclosed that Japanese japonica had a unique ovicidal resistance[12,15,18]. The WBPH eggs deposited on japonica rice suffered high mortality by an ovicidal substance induced at the oviposition sites. Because it is so common among Japanese japonica rice, high egg mortality had not been recognized as an induced resistance. Subsequent low reproduction on japonica rice had long been misunderstood as a biological character of WBPH. Such ovicidal resistance can not be detected by the seedbox screening test during infections with WBPH nymphs. Thus, it was obscure whether or not other types of rice varieties have the same mechanism of WBPH resistance.

In the present experiments, we first employed selected rice varieties belonging to the different types of Chinese rice for evaluation of their ovicidal resistance. Ovicidal varieties were restrictedly found in japonica rice. Tropical japonica, indica and hybrid rice did not show ovicidal resistance at all.

Such discriminative distribution of ovicidal resistance between japonica and indica rice was further confirmed by testing 88 rice varieties from different provinces in China. Ovicidal varieties existed only in japonica rice, but not in indica rice. Similar ovicidal resistance was also found in landraces of native japonica in Zhejiang Province. The landraces showed varying levels of ovicidal activities. These findings indicated that the ovicidal resistance to WBPH was a physiological trait that was specifically associated with japonica rice.

On the other hand, sucking inhibitory resistance to WBPH has been little known in japonica rice varieties. Only four japonica varieties, namely Xianghu 84, Xiaohuangzhong, Xiushui 04 and Yuanjing 2 were found to cause excretion of very little honeydew, indicating that they have a sucking inhibitory resistance. Of them, Xianghu 84, Xiushui 04 and Yuanjing 2 are derived from common germplasm resources. Xiaohuangzhong is a japonica landrace in Zhejiang Province. In addition to Xiaohuangzhong, two more japonica landraces, Jijiaohuang and Maqueqing, were found to have sucking inhibitory as well as ovicidal resistance. Of 21 japonica landraces tested here, 15 races have been described to be resistant to WBPH based on the seedbox screening test[23]. Particularly, it was mentioned that Sanqianhuang showed definite resistance to WBPH in the repeated seedbox screening tests. However, the present experiments clarified that at least eight of the reportedly resistant landraces, including Sanqianhuang, did not have any sucking inhibitory resistance to WBPH. The nature of resistance evaluated by the seedbox screening test remains unclear.

The present finding that japonica landraces retain not only ovicidal but also sucking inhibitory resistance in their germplasm may indicate a possible co-evolution with WBPH in the places where japonica rice was domesticated.

Literature cited:

1 Angeles E R, Khush G S, Heinrichs E A. New genes for resistance to whitebacked planthopper in rice. *Crop Sci*, 1981, 21:47−50.

2 Gunathilagaraj K, Chelliah S. Feeding behavior of whitebacked planthopper, *Sogatella furcifera* (Horváth), on resistant and susceptible rice varieties. *Crop Prot*, 1985, 4:255−262.

3 Heinrichs E A, Rapusas H R. Levels of resistance to the whitebacked planthopper, *Sogatella furcifera* (Homoptera: Delphacidae), in rice varieties with different resistance genes. *Environ Entomol*, 1983, 12:1793−1797.

4 Hernandez J E, Khush G S. Genetics of resistance of whitebacked planthopper in some rice (*Oryza sativa* L.) varieties. *Oryza*, 1981, 18:44−50.

5 Hu G W, Liu G J. Recent development of varietal resistance to insect pests of rice in China. *In*: Wan F H, Kang L. Transaction of the Ecological Society of Chinese Youth. Beijing: Chinese Scientific and Technical Publishing House, 1992. 22−31.[胡国文，刘光杰.我国水稻抗虫性研究进展.见:万方浩，康 乐.昆虫生态学研究.北京:中国科学技术出版社，1992.22−31.] (in Chinese with English abstract)

6 Hu G W, Tang J, Tang J Y. Recent prevalence of the whitebacked planthopper *Sogatella furcifera* Horváth in China. *Shokubutu-Boeki* (*Plant Prot*), 1992, 46: 219−222. (in Japanese)

7 Khan Z R, Saxena R C. Electronically recorded waveforms associated with the feeding behavior of *Sogatella furcifera* (Homoptera: Delphacidae) on susceptible and resistant rice varieties. *J Econ Entomol*, 1984, 77:1479−1482.

8 Li X M, Xiong Z M, Min S K, Hu G W. Genetical analysis of resistance to whitebacked planthopper *Sogatella furcifera* (Horváth) in four rice varieties (*Oryza sativa*) of Yunnan Province. *Chinese J Rice Sci*, 1990, 4:113−116.[李西明，熊振民，闵绍楷，胡国文.四个云南水稻品种对白背飞虱的抗性遗传分析.中国水稻科学，1990，4:113−116.] (in Chinese with English abstract)

9 Nair R K, Masajo T M, Khush G S. Genetic analysis of resistance to whitebacked planthopper in twenty-one varieties of rice, *Oryza sativa* L. *Theor Appl Genet*, 1982, 61:19−22.

10 Romena A M, Rapusas H R, Heinrichs E A. Evaluation of rice accessions for resistance to the whitebacked planthopper *Sogatella furcifera* (Horváth) (Homoptera: Delphacidae). *Crop Prot*, 1986, 5:334−340.

11 Saini R S, Khush G S, Heinrichs E A. Genetics analysis of resistance to whitebacked planthopper, *Sogatella furcifera* (Horváth) in some rice varieties. *Crop Prot*, 1982, 1:289−297.

12 Seino Y, Suzuki Y, Sogawa K. An ovicidal substance produced by rice plants in response to oviposition by the whitebacked planthopper, *Sogatella furcifera* (Horváth) (Homoptera: Delphacidae). *Appl Entomol Zool*, 1996, 31:467−473.

13 Sidhu G S, Khush G S, Medrano F G. A dominant gene in rice for resistance to white-backed planthopper and its relationship to other plant characteristics. *Euphytica*, 1979, 28:227−232.

14 Singh P K, Pathak P K. Genetics of resistance in some rice cultivars to whitebacked planthopper, *Sogatella furcifera* (Horváth). *J Insect Sci*, 1994, 7:140−142.

15 Sogawa K. Resistance of Chinese japonica rice to the whitebacked planthopper. *Shokubutu-Boeki* (*Plant Prot*), 2000, 54: 238−241. (in Japanese)

16 Sogawa K. Super-susceptibility to the white-backed planthopper in japonica-indica hybrid rice. *Kyushu Agric Res*, 1991, 53:92. (in Japanese)

17 Sogawa K. Vulnerability to insect pests in Chinese hybrid rice. *Nogyou Gijutsu* (*Agric Tech*), 2001, 56:398−402. (in Japanese)

18 Suzuki Y, Sogawa K, Seino Y. Ovicidal reaction of rice plants against the whitebacked planthopper, *Sogatella furcifera* Horváth (Homoptera: Delphacidae). *Appl Entomol Zool*, 1996, 31:111−118.

19 Tan Y J, Zhang Y, Pan Y, Liu G Z, Xu C. Evaluation of resistance to the brown planthopper and whitebacked planthopper in the local rice varieties in Guangdong Province. *Guangdong Agric Sci*, 1990, (6):35−38.[谭玉娟，张 扬，潘 英，刘钩赞，许聪.广东地区稻种资源对褐飞虱、白背飞虱的抗性鉴定.广东农业科学，1990，(6):35−38.] (in Chinese)

20 Wu C F, Khush G S. A new dominant gene for resistance to whitebacked planthopper in rice. *Crop Sci*, 1985, 25:505−509.

21 Xiao Y F, Du Z W. Studies on the resistance of japonica rice varieties to white-backed planthopper *Sogatella furcifera* (Horváth). *Acta Entomol Sin*, 1989, 32(3):286−292.[肖英方，杜正文.几个粳稻品种抗白背飞虱的研究.昆虫学报，1989，32(3):286−292.] (in Chinese with English abstract)

22 Yu X P, Wu G R, Tao L Y. The infestation of the brown planthopper and the whitebacked planthopper on rice varieties. *Chinese J Rice Sci*, 1991, 5(2):91−93.[俞晓平，巫国瑞，陶林勇.褐飞虱和白背飞虱在水稻品种上的为害特征.中国水稻科学，1991，5(2):91−93.] (in Chinese)

23 Zhang L H, Ying C S. Atlas of Rice Germplasm Resources in Zhejiang. Hangzhou: Zhejiang Scientific and Technnical Publishing House, 1993.[张丽华，应存山.浙江水稻品种资源图志.杭州:浙江科学技术出版社，1993.](in Chinese with English abstract)