Related to Earthquake Prediction (eds Hayakawa, M. and Fujinawa, Y.), Terra Sci. Pub Co, Tokyo, 1994, pp. 131–148.
15. Yoshino, T., *J. Sci. Explor.*, 1991, **5**, 121–144.
16. Hata, M. and Yabashi, S., in *Electromagnetic Phenomena Related to Earthquake Prediction* (eds Hayakawa, M. and Fujinawa, Y.), Terra Sci. Pub Co, Tokyo, 1994, pp. 159–174.
17. Quin, S., Yian, J., Cao, H., Shi, S., Lu, Z., Li, J. and Ren, K., in *Electromagnetic Phenomena Related to Earthquake Prediction* (eds Hayakawa, M. and Fujinawa, Y.), Terra Sci. Pub Co, Tokyo, 1994, pp. 205–211.
18. Fujinawa, Y. and Takahashi, K., Paper presented at IUGG Meeting Boulder, Colorado, 2–4 July 1995.
19. Ohta, K., Paper presented at the International Workshop on Seismo-Electromagnetic and Space Science held at Agra during 19–21 December 2000.
20. Hayakawa, M. and Fujinawa, Y., *Electromagnetic Phenomena Related to Earthquake Prediction*, Terra Sci. Pub Co, Tokyo, 1994.
21. Hayakawa, M., *Atmospheric and Ionospheric Electromagnetic Phenomenon Associated with Earthquakes*, Terra Sci. Pub Co, Tokyo, 1999.
22. Singh, B., Singh, R. P., Bansal, V., Kumar, M. and Hayakawa, M., *J. Atmos. Electr.*, 1999, **19**, 119–134.
23. Singh, R. P., Singh, B., Bansal, V. and Hayakawa, M., *J. Atmos. Electr.*, 2000, **20**, 7–20.
24. Singh, R. P. and Singh, B., *Curr. Sci.*, 2000, **78**, 492–498.
25. Okada, Y. and Yamamoto, E., *J. Phys. Earth*, 1991, **39**, 177–195.
26. Oike, K. and Ogawa, T., *J. Geomagn. Geoelectr.*, 1986, **38**, 1031–1040.
27. Yoshino, T. and Tomizawa, I., *Res. Lett. Atmos. Electr.*, 1992, **12**, 203–210.
28. Rikitake, T. and Yamazaki, Y., *Proc. Jpn. Acad.*, 1967, **44**, 447–482.
29. Arora, B. R. and Reddy, C. D., in *Uttarkashi Earthquake* (eds Gupta, H. K. and Gupta, G. D.), Geol. Soc. India, 1995, Memoir No. 30, pp. 109–124.
30. Kayal, J. R., Ghosh, B., Chakrborty, P. and De, R., in *Uttarkashi Earthquake* (eds Gupta, H. K. and Gupta, G. D.), Geol. Soc. India, 1995, Memoir No. 30, pp. 25–41.
31. Enomoto, Y. and Hashimoto, H., in *Electromagnetic Phenomena Related to Earthquake Prediction* (eds Hayakawa, M. and Fujinawa, Y.), Terra Sci. Pub Co, Tokyo, 1994, pp. 261–270.
32. Matsumoto, Y., Fujinawa, Y. and Takahashi, K., *J. Atmos. Electr.*, 1996, **16**, 175–191.

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Inheritance of resistance to brown planthopper in an *Oryza rufipogon* (Griff.)-derived line in rice

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Screening of 94-42-5-1, a derivative of wild *Oryza rufipogon* (Griff.) accession revealed its high resistance against three brown planthopper (BPH) biotypes from the predominantly rice-growing regions of Asia, viz. biotype 2, Cuulong (Vietnam) and Pantnagar (India), the latter two being the most virulent. Inheritance studies indicated the nature of its resistance to be monogenic recessive against the Pantnagar biotype and digenic recessive against Cuulong biotype. One of the two recessive resistance genes was allelic to *bph4*, while the other was non-allelic with all other known BPH resistance genes of cultivated species *O. sativa* L. The new source with the AA genome identical to the cultivated rice, would have great potential in combating the problem for BPH resistance in cultivated rice.

BROWN planthopper (BPH) is considered as the most serious pest throughout the rice-growing areas of the world. Variations in BPH biotypes are known to occur. Of these, Cuulong (southern Vietnam) and Pantnagar (northern India) biotypes are highly virulent as none of the nine resistance genes reported[1–5] in the cultivated species, *Oryza sativa* L., confer high degree of resistance against these biotypes[6,7]. The biotype 2 is predominant in most rice-growing areas of China[7]. Since the resistance gene(s) from the related wild species with AA genome are easy to transfer into elite cultivars, a study was undertaken to search for new gene(s) for resistance in the wild species, *Oryza rufipogon* Griff.

The materials comprised 94-42-5-1 and 11 tester varieties. The former is a doubled haploid homozygous BPH resistance line derived from anther culture of a wild *O. rufipogon* accession 94-42, highly resistant to BPH[8]. The materials were screened against biotype 2 and Cuulong biotype in China at Guangxi Academy of Agricultural Sciences, Nanning and Pantnagar biotype in India at G.B. Pant University of Agriculture and Technology, Pantnagar. The three biotypes – biotype 2, Cuulong and Pantnagar, collected from Nanning, Omon and Pantnagar, represented the most virulent biotypes in southern China, southern Vietnam and northern India, respectively. For genetic analysis of resistance, F_1, F_2, BC_1P_1 and BC_1P_2 progenies from the cross of 94-42-5-1 with susceptible variety, TN 1 were screened with BPH population of Pantnagar and Cuulong biotypes. The F_3 progenies of the cross were screened against Pantnagar biotype only. The allelic relationship of resistance genes of 94-42-5-1 was also investigated. For this purpose, 94-42-5-1 was crossed with five testers having known recessive genes, viz. *bph2*, *bph4*, *bph5*, *bph7* and *bph8* (Table 1). The parental, F_1

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Table 1. Allelic test of the resistance gene(s) in 94-42-5-1 (P_2) with known recessive resistance genes against Culong biotype of BPH

		BPH reaction*							
					F_2 segregation				
					No. of plants				
Cross (P_1/P_2)	Resistance gene in tester	P_1	P_2	F_1	R	S	Ratio	X^2	*P*-value
TN 1/P_2	None	S	R	S	7	147	1 : 15	0.76	0.25–0.50
ASD 7/P_2	*bph2*	S	R	S	45	269	10 : 54	0.40	0.50–0.75
Babawee/P_2	*bph4*	MR	R	MR	64	171(MR)	1 : 3	0.63	0.25–0.50
ARC 10550/P_2	*bph5*	S	R	S	11	245	1 : 15	1.36	0.25–0.50
T 12/P_2	*bph7*	S	R	S	9	240	1 : 15	2.96	0.05–0.10
Chin-saba/P_2	*bph8*	S	R	S	14	258	1 : 15	021	0.50–0.75

*R, resistant; MR, moderately resistant; and S, susceptible.

Table 2. Reaction of wild derivative 94-42-5-1 and tester varieties against three BPH biotypes

		Reaction to BPH biotype*		
Test entry	Resistance gene	Pantnagar	Cuulong	Biotype 2
94-42-5-1	Unknown	HR	HR	HR
TN 1	None	S	S	S
Mudgo	*Bph1*	S	S	S
ASD 7	*bph2*	S	S	R
Rathu Heenati	*Bph3*	MR	MS	R
Ptb 33	*bph2 Bph3*	R	MR	R
Babawee	*bph4*	S	MR	R
ARC 10550	*bph5*	S	S	S
Swarnalata	*Bph6*	MS	S	S
T 12	*bph7*	S	S	S
Chin-saba	*bph8*	S	S	S
Pokkali	*Bph9*	S	–	–

*HR, highly resistant; R, resistant; MR, moderately resistant; MS, moderately susceptible; and S, susceptible.

Figure 1. Reaction of the parental (P_1 and P_2), F_1 and segregating (F_2 and BC_1) populations of cross TN 1/94-42-5-1 against BPH Pantnagar biotype at 7th day after the death of TN 1, the susceptible check: P_1–TN 1, female parent and highly susceptible; P_2–94-42-5-1, male parent and highly resistant; F_1, highly susceptible; F_2, segregating in the ratio of 1 resistant: 3 susceptible; BC_1–TN 1/94-42-5-1/94-42-5-1, segregating in the ratio of 1R : 1S.

and F_2 progenies of the crosses were evaluated against Cuulong biotype. Reaction against BPH was recorded following the standard method of evaluation[7] on 1–9 scale, where 1 is highly resistant (HR), 3 is resistant (R), 5 is moderately resistant (MR), 7 is moderately susceptible (MS) and 9 is susceptible (S). For the study of genetic segregation, the plants with scores 1–5 were grouped into resistant class and those with score 7–9 into susceptible class.

The data of Table 2 indicated highly resistant reaction of 94-42-5-1 against all the three BPH biotypes compared to Rathu Heenati (*Bph3*) and Ptb 33 (*bph2 Bph3)* which displayed MR reaction against Cuulong and Pantnagar biotypes. Tester varieties with resgenes *bph2*, *Bph3* and *bph4* conferred resistance only to biotype 2. Reaction of Babawee with *bph4* gene against Cuulong biotype varied between MS and MR category (scores 4.8 in 1999 and 5.2 in 1995). In our earlier screening (unpublished data), 94-42-5-1 had shown high level of resistance against biotype 1, Mekong (Vietnam) and Bangladesh biotypes also.

TN 1, the female parent was highly susceptible, male parent 94-42-5-1 was highly resistant and all the F_1 plants were susceptible to Pantnagar biotype, indicating recessive nature of resistance (Figure 1). Genetic segregation of progenies in F_2, BC_1P_2 and F_3 generations was in the ratio 1R : 3S, 1R : 1S and 1R : 2 segregating: 1S, respectively, where R stands for resistance and S for susceptibility. All the plants in BC_1P_1 generation were susceptible, while F_3 progenies derived from resistant plants in F_2 were all true breeding for resistance. This suggested monogenic recessive nature of resistance in 94-42-5-1 against the Pantnagar biotype (Table 3). Screening against Cuulong biotype also indicated the F_1 and BC_1P_1 plants to be uniformly susceptible, but the F_2 and BC_1P_2 generations segregated in the ratio of 1R : 15S and 1R : 3S, respectively, indicating digenic control of resistance in 94-42-5-1 (Table 3).

The allelic test of the resistance gene(s) of 94-42-5-1 with known recessive resistance genes against Cuulong biotype of BPH showed susceptibility in F_1 and digenic

Table 3. Segregation of plants for brown planthopper resistance in cross TN 1 (P_1)/94-42-5-1 (P_2) against Pantnagar and Cuulong biotypes

	Segregation of plants/progenies*					
Biotype/generation	R	Seg.	S	Ratio	X^2	*P*-value
Pantnagar biotype						
TN 1 (P_1)	0	–	40			
94-42-5-1 (P_2)	40	–	0			
(P_1/P_2) F_1	0	–	40			
F_2	73	–	195	1 : 3	0.72	0.25–0.50
BC_1P_1	0	–	60			
BC_1P_2	65	–	58	1 : 1	0.40	0.50–0.75
F_3 (random sample)	15	31	11	1 : 2 : 1	0.80	0.50–0.75
F_3(from F_2 R plants)	45	–	0			
Cuulong biotype						
P_1	0	–	20			
P_2	20	–	0			
(P_1/P_2) F_1	0	–	20			
F_2	19	–	203	1 : 15	2.02	0.10–0.25
BC_1P_1	0	–	160			
BC_1P_2	94	–	321	1 : 3	1.28	0.25–0.50

*R, resistant; Seg., segregating; and S, susceptible.

segregation (1R : 15S) in the F_2 of its crosses of TN 1 with ARC 10550 (*bph5*), T 12 (BPH7) and Chin-saba (*bph8*) and trigenic segregation (10R : 54S) in F_2 of ASD 7/94-42-5-1. However, the F_1 of cross Babawee/94-42-5-1 gave MR reaction with lower score (4.8) and the F_2 segregation in the ratio of 1R : 3MR (Table 1). These results indicated that one of the two recessive resistance genes in 94-42-5-1 was allelic to *bph4*, but neither was allelic to *bph2*, *bph5*, *bph7* and *bph8*.

In rice, wider spectrum of BPH resistance in Ptb 33 is known to be due to combination of two different resistance genes, viz. *bph2* and *Bph3* (ref. 7). Similarly, high level of resistance in 94-42-5-1 could be explained due to presence of two resistance genes. This suggests a breeding strategy of pyramiding suitable resistance genes for enhancing BPH resistance in rice cultivars. Recently, BPH biotype 2 has become the most dominant biotype in major rice-growing areas in China[7]. The biotypes Cuulong and Pantnagar have already been reported highly virulent[6,7] and predominant in rice-growing areas of Cuulong Delta in Vietnam and north India, respectively. Resistance genes of wild rice with AA genome are easily transferred into cultivated rice as shown in the transfer of the broad spectrum resistance gene, *Xa21*, from *O. longistaminata* which conveys resistance to six races of bacterial leaf blight[9–10] and a gene from *O. nivara* against tungro virus[11]. The high level of resistance of the new line 94-42-5-1 has, therefore, very significant implications in the rice improvement programmes aimed at developing BPH-resistant cultivars.

1. Sidhu, G. S. and Khush, G. S., *Theor. Appl. Genet.*, 1978, **53**, 199–203.
2. Khush, G. S., Rezaul, K. A. N. M. and Angeles, E. R., *J. Genet.*, 1985, **64**, 121–125.
3. Kabir, M. A. and Khush, G. S., *Plant Breed.*, 1988, **100**, 54–58.
4. Nomoto, H., Ikeda, R. and Kaneda, C., *Jpn. J. Breed.*, 1989, **39**, 23–28.
5. Kinoshita, T., *Rice Genet. Newsl.*, 1995, **12**, 9–153.
6. Pathak, P. K. and Lal, M. N., *Int. Rice Res. Newsl.*, 1976, **1**, 8.
7. Li, Q., Luo, S. Y., Shi, A. X., Wei, S. M. and Huang, F. K., *Acta Entomol. Sin.*, Suppl. 1997, **40**, 139–146.
8. Li, R. B. and Qin, X. Y., *Southwest China J. Agric.*, 1999, **12**, 18–23.
9. Ronald, P. C., Albono, B., Tabien, R., Abenes, L., Wu, K., McCouch, S. and Tanksley, S. D., *Mol. Gen. Genet.*, 1992, **236**, 113–120.
10. Khush, G. S., Bacalangco, E. and Ogama, T., *Rice Genet. Newsl.*, 1990, **7**, 121–122.
11. Toriyama, K., in *The Virus Diseases of the Rice Plant*, International Rice Research Institute, John Hopkins, Baltimore, 1967, pp. 313–334.

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