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Full Length Article

Identification of Seedling Resistance Genes to Stripe Rust and Analysis of Adult Plant Resistance in 82 Wheat Cultivars from Gansu Province in China

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Abstract

Wheat stripe rust, caused by *Puccinia striiformis* f. sp. *tritici* (*Pst*), is one of the most destructive foliar diseases affecting wheat in China. The use of resistant cultivars is the most economical, environment friendly, and effective means to control stripe rust. By means of gene postulation and pedigree analysis, the resistant genes to stripe rust in eighty-two wheat cultivars from the Gansu province in China were identified in 30 wheat genotypes with the known *Yr* gene and 26 *Pst* pathotypes at the seedling stage under controlled greenhouse conditions in the Institute of Plant Protection, Chinese Academy of Agricultural Sciences (IPP CAAS), based on the gene-for-gene concept. The adult plant resistance of the 82 cultivars were tested at two locations in Longnan region of Gansu province during the growing seasons of 2009–2010, 2010–2011 and 2014–2015. The results showed that four resistant genes, including *Yr9, Yr10, YrMor* and *Yr26,* were postulated. The wheat cultivar Longyuan 992 may possess *Yr9* and unknown gene(s). Five wheat cultivars, Longjian 385, Tianxuan 48, Tianxuan 51, Guinong 21 and Guinong 22, may possess *Yr10+YrMor*. Seven wheat cultivars, Lantian 24, Lantian 30, Lantian 091, Lantian 092, Zhongliang 29, 92R137, and 92R178 may possess *Yr26*. Other wheat cultivars may possess unknown gene(s). Eighteen cultivars were resistant in all stages. Fifty-six cultivars were resistant in the adult plant stage. Twenty-seven cultivars had slow-rusting characteristics. The cultivars that were resistant at all stages and the adult plant stage should be utilized widely.

Keywords: Wheat cultivars; Stripe rust; Resistance genes; Gene postulation; Adult plant resistance

Introduction

Wheat stripe rust, caused by *Puccinia striiformis* f. sp. *tritici* (*Pst*), is one of the most destructive foliar diseases affecting wheat in China and other regions around the world (Stubbs, 1985; Niu *et al.,* 2000; Li and Zeng, 2002; Line, 2002; Chen, 2005; Wan *et al.,* 2004, 2007; Chen *et al.*, 2007, 2014). China is the largest independent epidemic region in the world, with more than 20 million hectares of wheat affected by stripe rust (Stubbs, 1985,1988; Li *et al.,* 2011). Comprehensive research of the epidemiology of stripe rust, including over-summering and over-wintering areas, has been conducted since the 1950s (Wu *et al.,* 1993; Li and Zeng, 2002; Chen *et al.,* 2014). Epidemics of stripe rust have occurred periodically in the major wheat production regions, particularly in northwest and southwest China (Chen *et al.,* 2014; Li and Zeng, 2002; Wan *et al.,* 2004, 2007), and the disease has caused destructive yield losses, ranging from 10~70% in some years, and even reaching to 80~100% in some severely infected fields (Chen, 2005; Li and Zeng, 2002; Wan *et al.,* 2004).

Many control approaches have been applied to minimize the losses incurred by stripe rust, but growing resistant cultivars is the most economical, environmentally friendly, and effective method to control stripe rust in wheat (Li and Zeng, 2002; Wan *et al.,* 2004; Chen *et al.,* 2007). The widespread epidemics of stripe rust in China in 2002 and 2009 were caused by *Pst* races CYR (Chinese yellow rust) 32 and CYR33, which are virulent to all Chinese wheat cultivars/lines except those with the resistance genes *Yr5*, *Yr10*, *Yr15*, or *Yr24*/*Yr26* (Ma *et al.,* 2001; Li and Zeng, 2002; Yang *et al.,* 2003; Wan *et al.,* 2004). Studies on the

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genetic characteristics and genes in wheat cultivars provide basic information for wheat breeding and growing. At least 76 *Yr* genes that confer resistance to stripe rust have been identified, some of which have been incorporated into commercial wheat cultivars (Xiang *et al.*, 2016). Many of these genes are race-specific genes, showing hypersensitive reactions, and breeders are currently using several genes to develop new cultivars.

From the early 1970s, *Yr9* was included in Chinese wheat breeding programs through introductions in the wheat cultivars includes Lovrin 10, Lovrin 13, Predgornaia 2, Kavkaz and Neuzucht. The widespread growth of wheat cultivars with *Yr9* resulted in *Yr9*-virulent races, such as CYR29 and CYR28, which are predominant in the stripe rust population and have caused serious epidemics in major regions in China since 1990 (Li *et al.,* 2008). From the 1980s, an important wheat cultivar Fan 6, and its derivatives, such as Mianyang 11, Mianyang 19, and Mianyang 20, were widely grown in China. The resistance of Fan 6 was overcome by new Pst races CYR 31, CYR 32 and CYR33. The frequent and bust cycles have forced wheat breeders and growers to focus on the development of cultivars with durable resistance (Wan *et al.,* 2003; Chen *et al.,* 2007).

Following the gene-for-gene hypothesis proposed by Flor (Flor, 1956), Zadoks (Zadoks, 1961) identified a gene-for-gene interaction between wheat cultivars and the *Pst* pathotypes. Loegering and Burton reported that race-specific resistance genes in wheat cultivars could be identified by comparing their reactions to different *Pst* pathotypes with those of cultivars with known resistance genes (Loegering and Burton, 1974). Based on these concepts and methods, the most race-specific resistance genes, including *Yr*, *Lr*, *Sr* and *Pm* genes, which are present in host cultivars, have been postulated in the last 40 years (Flor, 1956; Wang *et al.*, 1963; Dyck and Johnson, 1983; Stubbs, 1985; Chen and Hu, 1993; Niu *et al.*, 2000; Li and Zeng, 2002; Yang *et al.*, 2003; Yuan *et al*., 2007; Liu *et al.*, 2010; Xu *et al.*, 2011). About five hundred wheat cultivars were tested, and some resistance genes have been postulated since the 1990s, but very little information is available on the sources and efficacy of resistance to wheat cultivars in the Longnan region of Gansu province in China. The objectives of this study were to evaluate stripe rust resistance in 82 commercial winter cultivars from the Longnan region at the seedling and the adult plant stages, and to postulate the resistance genes in the cultivars and to provide information for the preferred use of these genes in future.

Materials and Methods

Wheat Genotypes

Eighty-two wheat genotypes, consisting of major growing cultivars, advanced lines and resistant germplasms from the breeding programs in Gansu province in China, were used (Table 1). Thirty tester cultivars with known *Yr* genes were used for gene postulation, including the world differentials, European differentials, partly Chinese differentials and others. The world differentials are Chinese 166 (*Yr1*), Lee (*Yr7+Yr22+Yr23*), Heines Kolben (*Yr2+Yr6*), Vilmorin23 (*Yr3+YrV23*), Moro (*Yr10+YrMor*), Strubes Dickkopf (*Yr25+YrSD*), Suwon92/Omar (*YrSu*), and Clement (*Yr9+YrCle*). The European differentials includes Hybrid46 (*Yr4*,+), Reichersberg 42 (*Yr7*,+), Heines Peko (*Yr2+Yr6*,+), Nord Desprez (*Yr3*,+), Compaire (*Yr8+Yr19*), Carstens V (*Yr32*), Spaldings Prolific (*YrSpP*), and Heines Ⅶ (*Yr2+YrH7*). Partly Chinese differentials are Hybrid46 (*Yr4*,+), Lovrin 13 (*Yr9*,+) and *Triticum spelta* album (*Yr5*). Other testers includes Joss Cambier (*Yr2*), Cappelle Desprez (*Yr3a+Yr4a+Yr16*,+), Fielder (*Yr6+Yr20*), Mega (*Yr12*), Maris Huntsman (*Yr2+Yr3a+Yr4a+Yr13*), Dippes Triumph (*Yr15*), VPM1 (*Yr17*), K733 (*Yr24*), Tp981 (*Yr25*), Line R55 (*Yr26*), Selkirk (*Yr27*) and *T. tauschii*W-219 (*Yr28*). The wheat cultivar Mingxian 169, is a susceptible variety to all of the stripe rust pathotypes identified in China so far and was used as a susceptible control. All seeds were provided by the Institute of Plant Protection, Chinese Academy of Agricultural Sciences (IPP CAAS).

Pathogen Materials

The seedling resistance tests were performed using 26 *Pst* isolates with different virulence spectra, including 2E26 (P1), 3E10 (P2), 3E22 (P3), 7E158 (P4), 32E200 (P5), 34E30 (P6), 34E40 (P7), 36E8 (P8), 40E47 (P9), 41E233 (P10), 43E159 (P11), 44E169 (P12), 45E25 (P13), 45E169 (P14), 45E185 (P15), 45E191 (P16), 45E221 (P17), 64E12 (P18), 99E22 (P19), 107E58 (P20), 108E41 (P21), 109E125 (P22), 113E80 (P23), 167E62 (P24), 175E191 (P25) and 239E188 (P26). Its named with world differentials and European differentials. These isolates originated in China and other countries and were provided by the IPP CAAS. All of these Pst pathotypes increased on susceptible wheat cultivar Mingxian 169 in the greenhouse of IPP CAAS.

Seedling Testing

Identification was tested in controlled greenhouse conditions at the IPP CAAS in Beijing in 2011. Following a previously described method (Wang *et al.,* 1994; Niu and Wu, 1997; Niu *et al.*, 2000; Feng *et al.,* 2009), the tested cultivars seeds (6–8 per cultivar per hole) were grown in standard peat soil in a 40×20×10 cm square box with all forty cultivars in the same order. Each set of cultivars including Mingxian 169, known gene tester cultivars and tested cultivars, had four boxes, and there were 26 total sets. When the first leaves were fully expanded, the wheat plants were inoculated using a "sweep-dusting" method, sweeping the fully infected leaves of the check Mingxian 169 above the test wheat plants and dusting urediniospores on them with a very uniform deposit. The whole set of cultivars and the Yr gene carriers were inoculated with different *Pst* isolates. After inoculation, the seedlings were incubated for 24 h in the dark at 10°C with a relative humidity at saturation, which contributed to the fungal infection, and were then transferred to a growth chamber at 10–14/15–18°C (night/day) with 90–144 μmol.m^{-2}.s^{-1}of light intensity and a 10–12 h.d^{-1} photoperiod (Cao *et al.*, 2011). When the susceptible check Mingxian 169 was heavily infected, approximately 14–16 d after inoculation, the infection type (IT) on the seedlings was recorded using a 0–4 scale described by Li and Zeng (Li and Zeng, 2002). The scale for IT was 0= no symptom; 0;= produce dead spots or chlorosis reaction, does not produce uredinium; 1=Uredinium is very small, and few in number, often does not break down, have withered reaction around; 2=Uredinium were small to medium, and not broken, have withered and chlorosis reaction around; 3= Uredinium were medium size and Cultivars broken, and no dead reaction of surrounding tissue, but there is a slight chlorosis; 4=Uredinium were more and broken abundant, and no dead reaction of surrounding tissue, early chlorosis phenomenon is not obvious.Plants with IT of 0 to 2^{+} were considered resistant (R), and those with an IT of 3^{-} to 4 were considered susceptible (S).

Field Testing

The adult plant resistance levels of 82 cultivars were tested in nurseries at the Wangchuan Farm (altitude 1680 m) and the Gangu Farm (altitude 1270 m) in the Longnan region of the Gansu province during the 2009–2010, 2010–2011 and 2014–2015 cropping seasons. The two testing locations at Longan region, are the main areas where stripe rust survive the summer and variations of the pathogens occur frequently, respectively. The areas were the major source of inocula of stripe rust in China (Wang *et al.*, 1965; Li *et al.*, 1984; Li and Zeng, 2002; Wan *et al.*, 2004; Chen *et al.*, 2009), and were considered hot spots of stripe rust. One hundred twenty seeds of each cultivar were sown in a plot. Each plot was two m in length with 25 cm spacing, and there were three replicates per plot. Rows of the cultivar Mingxian 169 were planted perpendicularly and adjacent to the test rows. In the Wangchuan spot, the resistance was evaluated under a natural *Pst* infection. In the Gangu spot, an artificial inoculation on the spreader plants at the tiller stage was used to initiate the rust spread on March 30 in 2010, 2011 and April 1 in 2015. The inoculum mixture consisted of twelve pathotypes, including CYR29, CYR32, CYR33, HY4, HY7, HY8, Su11-4, Su11-5, Su11-7, Su11-11, G22-9 and G22-14. The IT, severity and percentage were recorded when the rust pustules were fully developed on the spreader plants. The IT was recorded using a 0–4 scale. Plants were considered resistant (R) and susceptible (S), with an IT of 0 to 2 and 3 to 4, respectively. The severity was recorded as 0, 5, 10, 20, 40, 60, 80 and 100%. The percentage was recorded as 0, 5, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100% (Li and Zeng, 2002).

Data Analyses

The data used to calculate the disease index (DI) were based on the method described by Li and Zeng, 2002. DI was calculated as DI = Final Severity × Final Percentage/100. The presence of *Yr* genes in the seedling stage was postulated by comparing the IT displayed by the cultivars with the IT of the known *Yr* gene testers. The pedigrees of the wheat cultivars were taken into consideration in the process of the gene postulation (Dubin *et al.*, 1989).

Results

Seedling/All-stage Resistance of the Wheat Genotypes from the Longnan Region

The ITs of the 26 *Pst* pathotypes with known *Yr*-genes and the wheat cultivars are presented in Tables 2 and 3, respectively. Wheat cultivar Mingxian 169 had a high IT (4) for all of the *Pst* isolates, indicating that all of the inoculations were successful. Genes were postulated by comparing the ITs displayed by the tested cultivars and known *Yr* genes carriers. High IT on a test cultivar indicated that it did not possess this resistance gene. Based on the IT patterns between the *Yr* genes and the *Pst* pathogens, four *Yr* genes were postulated in the cultivars/lines, including Yr9, Yr10, YrMor and Yr26. Due to inadequate patterns between the *Yr* genes and the *Pst* isolates, the resistance genes could not be postulated in most of the cultivars.

The tester Lovrin13 was susceptible to the tested *Pst* isolates P9, P10, P12, P23, P24, P25 and P26, and was resistant to the other *Pst* isolates. The wheat cultivar Longyuan 992 (No. 19) had wider resistant spectra than Lovrin13, and its parent was Predgornajia, with the *Yr9* gene. These data indicate that wheat cultivar Longyuan 992 (No. 19) may possess *Yr9* and unknown gene(s).

The tester Moro presented the genes *Yr10+YrMor*, which were effective in Longnan region (Southern Gansu) of the Gansu province before 2010. In this study, the resistance reactions of seven wheat cultivars, Longjian 385 (No. 26), Tianxuan 48 (No. 33), Tianxuan 51 (No. 36), Guinong 21 (No. 77) and Guinong 22 (No. 78), to 25 *Pst* isolates were the same as that of Moro, and P23 was virulent to them. In these five wheat cultivars, three were derivatives of Guinong 21 and Guinong 22. These data demonstrate that these cultivars had the resistance genes *Yr10+YrMor* (Table 2).

Five wheat cultivars, Lantian 24 (No. 1), Lantian 30 (No. 7), Lantian 091 (No. 9), Lantian 092 (No. 10) and Zhongliang 29 (No. 46), and two sources, 92R137 (No. 81) and 92R178 (No. 82), were resistant to the 25 *Pst* isolates except for P23. The resistance spectra were the same as that of the tester line R55.

Through a pedigree analysis, 92R137 and 92R178 were the parents from the Wheat-*Haynaldia villosa* 6AL/6VS chromosome translocation lines presented as *Yr26* (Ma *et al.*, 2001), the same was true for the tester line R55. These results indicated that these nine cultivars might carry *Yr26*.

Table 1: Name, pedigree and stripe rust resistance of 82 wheat cultivars were tested at Wangchuan spots and Gangu spots during 2009-2011, and 2014-2015

No.	Cultivars (lines)	Pedigree	Wangchuan spot						Gangu spot					
			2009-2010		2010-2011		2014-2015		2009-2010		2010-2011		2014-2015	
			Disease data	DI[a]	Disease data	DI	Disease data	DI	Disease data	DI	Disease data	DI	Disease data	DI
1	Lantian 24	92R137/87-121	0	0	2/10/50	5	3/10/100	10	0	0	2/10/50	5	3/10/80	8
2	Lantian 25	92-72/Mo(s)311	0	0	0	0	3/20/100	20	0	0	0	0	3/40/90	36
3	Lantian 26	Flanders/Lantian 10	0	0	0	0	2/10/30	3	0	0	0	0	3/10/100	10
4	Lantian 27	FR81/99-316	0	0	0	0	0	0	0	0	0	0	0	0
5	Lantian 28	Xifeng 20/Baofeng 20	0	0	0	0	0	0	0	0	0	0	0	0
6	Lantian 29	82F37/83-44-20//Tian 8380	0	0	0	0	0	0	0	0	0	0	0	0
7	Lantian 30	95-111-3/Shan 167	0	0	2/10/10	1	3/20/100	20	0	0	0	0	3/40/100	40
8	Lantian 31	Long Bow/Lantian 10	0	0	0	0	0	0	0	0	0	0	0	0
9	Lantian 091	Lantian 24/Shan 167	0	0	0	0	3/20/100	20	0	0	0	0	3/40/100	40
10	Lantian 092	Lantian 24/Shan 160	0	0	0	0	3/40/100	40	0	0	0	0	3/20/100	20
11	Lantian 093	Lantian 23/Zhou 92031	0	0	0	0	0	0	0	0	0	0	0	0
12	Lantian 094	Lantian 23/Zhou 92031	0	0	0	0	0	0	0	0	0	0	0	0
13	Lantian 095	-	0	0	0	0	0	0	0	0	0	0	0	0
14	Lantian 096	-	0	0	0	0	0	0	0	0	0	0	0	0
15	Lanhangxuan 1	-	0	0	0	0	2/10/10	1	0	0	0	0	2/10/30	3
16	Longyuan 961	-	3/40/90	36	3/10/40	4	3/20/100	20	3/20/50	10	3/40/80	32	3/20/100	20
17	Longyuan 937	-	0	0	0	0	0	0	0	0	0	0	0	0
18	Longyuan 082	-	0	0	0	0	0	0	0	0	0	0	0	0
19	Longyuan 992	Xifeng 16/Predgornajia/6828-6-0-1-1	0	0	0	0	3/10/20	2	0	0	0	0	2-3/10/20	2
20	Longyuan 014	-	0	0	0	0	3/10/20	2	0	0	0	0	3/10/40	4
21	Longjian 0071	EUREKA/9375-1-1	0	0	0	0	2/10/50	5	0	0	0	0	3/10/20	2
22	Longjian 102	95128 F_1/Longyuan 932	3/40/80	32	3/10/50	5	3/40/100	40	3/20/40	8	3/20/50	10	3/40/100	40
23	Longjian 103	Longjian 127/Mo(W)697	3/40/80	32	2/10/40	4	3/20/100	20	3/10/20	2	2/5/50	2.5	3/40/100	40
24	Longjian 301	DW803/7992	0	0	0	0	2/10/20	2	0	0	0	0	2-3/10/50	5
25	Longjian 9457	Q9086/Xifeng 1376	3/20/80	16	3/10/50	5	3/20/80	16	3/10/50	5	3/20/80	16	3/40/100	40
26	Longjian 385	Guinong 22/Longjian 29	0	0	2/10/50	5	3/20/100	20	3/10/40	4	3/20/50	10	3/40/80	32
27	Longjian 386	1321/Longjian 127	2/20/100	20	0	0	3/10/50	5	0	0	2/10/50	5	3/20/100	20
28	Longjian 387	7131/Longjian 196	2/10/40	4	2/10/40	4	3/10/20	2	2/10/40	4	3/10/10	1	3/10/80	8
29	Tianxuan 44	Tianxuan 41/Tianxuan 40	0	0	0	0	2/20/80	16	0	0	0	0	2/10/80	8
30	Tianxuan 45	15th12/8845-1-1	0	0	0	0	0	0	0	0	0	0	0	0
31	Tianxuan 46	Tian 882/Tianxuan 37	0	0	0	0	3/20/100	20	0	0	0	0	3/40/100	40
32	Tianxuan 47	Tian 94-3/Zhongliang 22	0	0	0	0	3/20/100	20	0	0	0	0	3/40/100	40
33	Tianxuan 48	9362-13-1-1/Tian 94-3	0	0	2/10/20	2	3/40/100	40	0	0	0	0	3/40/100	40
34	Tianxuan 49	Lantian 8/Zhongliang 22	0	0	2/10/50	5	3/40/100	40	2/10/10	1	1/10/20	2	3/20/100	20
35	Tianxuan 50	Tianxuan 41/Tianxuan 40	0	0	0	0	3/10/80	8	0	0	0	0	3/40/100	40
36	Tianxuan 51	9362-13-3-4/Lantian 1	0	0	2/10/50	5	3/40/100	40	1/10/50	5	3/10/10	1	3/20/100	20
37	Tian 9681	863-13//Tian 94-3/Baidatou	3/20/80	16	2/10/50	5	3/20/100	20	2/10/10	1	2/10/80	8	3/20/100	20
38	Tian 9727	Tian 94-3c3-1-1/Baofeng 6	0	0	3/10/10	1	3/10/80	8	2/10/50	5	3/10/10	1	3/10/100	10
39	Tian 9524	FUDNULEA900/Tian 94-3	0	0	0	0	2/10/50	5	0	0	0	0	2-3/10/70	7
40	Tian 00127	9591-3-2/Qing 85-173-4	0	0	0	0	0	0	0	0	0	0	0	0
41	Tian 9474	Tian 817/Tianxuan 40	3/10/40	4	2/10/50	5	3/20/100	20	2/10/10	1	3/10/50	5	3/20/100	20
42	Tian 9686	863-13/8560-2-2-1	0	0	0	0	2/10/80	8	0	0	0	0	2/10/40	4
43	Tian 9896	-	2/10/10	1	3/10/20	2	3/10/100	10	3/10/50	5	3/10/40	4	3/20/100	20
44	Tian 00104	Qing 85-173-4/CMS494-2	0	0	0	0	3/10/20	2	0	0	0	0	3/10/50	5
45	Zhongliang 28	Zhong 4, Qianbaode, Wan 8301, Han 7014-20, Zhongliang 23	2/10/20	2	2/10/10	1	3/40/100	40	2/10/50	5	3/10/40	4	3/20/100	20
46	Zhongliang 29	92R137/938-4	0	0	2/10/50	5	3/40/100	40	1/10/40	4	2/10/40	4	3/60/100	60
47	Zhongliang 30	Holdfast/Zhongliang 22	0	0	0	0	2-3/20/70	14	0	0	0	0	3/10/50	5
48	Zhongliang 31	Tao157/82（348）F_1//AT8118 /Tao 157 F_1	2/10/10	1	2/10/20	2	3/10/100	10	2/10/50	5	2/10/30	3	3/20/100	20
49	Zhongliang 32	Zhong 4, 90293, Zhongliang 12, Bulgaria10, Xiannong 4	2/10/30	3	3/10/50	5	3/20/100	20	0	0	3/10/40	4	3/10/100	10
50	Longyu 1	Qingnong 4/9016(16)	3/10/90	9	3/10/100	10	3/20/100	20	3/10/50	5	3/10/60	6	3/40/100	40
51	Longyu 2	Longdong 3//82（348）/9002-1-1F_3	3/10/80	8	3/10/100	10	3/40/100	40	3/10/50	5	3/10/60	6	3/40/100	40
52	Longyu 3	900518/Jinmai 30//Romania 3	3/10/100	10	3/10/50	5	3/20/100	20	3/10/50	5	3/10/60	6	3/20/100	20
53	Longyu 4	Xifeng 20/Zhong 210	3/10/50	5	3/10/20	2	3/40/100	40	3/10/20	2	3/10/50	5	3/40/100	40
54	Gandong 017	-	0	0	0	0	0	0	0	0	0	0	0	0
55	Zhong 4	-	0	0	0	0	0	0	0	0	0	0	0	0
56	Longyu 0027	94106-2-4/85-271-21C	0	0	0	0	0	0	0	0	0	0	0	0
57	Longyu 217	Xifeng 20/Qingnong 4	0	0	0	0	3/10/30	3	0	0	0	0	3/10/60	6
58	Xifeng 28	895021/Xifeng 16	3/40/100	40	3/20/100	20	3/40/100	40	3/40/100	40	3/20/100	20	3/40/100	40
59	Longyuan 034	-	2/10/50	5	2/10/50	5	3/20/100	20	2/10/10	10	3/10/10/	1	3/20/100	20
60	97t110	-	3/10/20	2	2/10/50	5	3/10/100	10	3/10/20	1	3/10/20	2	3/10/100	10
61	Tian 98294	-	2/10/40	4	2/10/10	1	3/10/20	2	2/10/50	5	3/10/50	5	3/10/40	4
62	Longyu 0456	-	3/10/30	3	3/20/100	20	3/40/100	40	3/20/40	8	3/10/100	10	3/40/100	40
63	Xifeng 26	-	3/10/20	2	3/10/50	5	3/20/100	20	3/10/20	2	3/40/80	32	3/40/100	40
64	Xifeng 27	83183-1-3-1/CA837	3/10/50	5	3/20/100	20	3/40/100	40	3/10/40	4	3/20/40	8	3/20/100	20
65	Pingliang 41	Qinmai 4/75108	3/40/100	40	3/60/100	60	3/60/100	60	4/40/100	40	4/40/100	40	3/60/100	60

Table 1: Continued

Table 1: Continued

66	Pingliang 42	Ta1Changwu131//Pingliang 38/82 (51)F3	3/40/100	40	3/60/100	60	3/60/100	60	3/60/100	60	3/60/100	60	3/60/100	60
67	Pingliang 43	Changwu 131/82（51）-9-5-3-2	3/40/90	36	3/60/100	60	3/40/100	40	3/80/100	80	3/60/100	60	3/60/100	60
68	Pingliang 44	85（Jia）1-3/Pingliang 41	3/40/80	32	3/80/100	80	3/60/100	60	3/80/100	80	3/80/100	80	3/40/100	40
69	Pingliang 45	82RB(62)/Qing82F1//84W(21)	3/40/60	24	4/40/100	40	3/60/100		3/60/100	60	3/60/100	60	3/40/100	40
70	Pingliang 46	Ta1Changwu131// Pingliang 38/82F_3	3/40/100	40	3/80/100	80	3/40/100		3/60/100	60	3/60/100	60	3/60/100	60
71	Pingliang 47	85（Jia）1-3/Pingliang 41	3/40/100	40	3/60/100	60	3/40/100	40	3/20/100	20	3/80/100	80	3/80/100	80
72	Wudu 16	7930-2/Xiaobaidongmai	3/10/20	2	3/10/20	2	3/60/100	60	3/10/50	5	3/10/40	4	3/60/100	60
73	Wudu 17	Mianyang 87-43/8358-14173	0	0	0	0	3/20/100	20	0	0	0	0	3/40/100	40
74	Linnong 7230	919-18-5/Mianyang 87-31	3/20/80	16	3/10/50	5	3/80/100	80	3/10/50	5	3/20/40	8	3/40/100	40
75	Linnong 9555	4814-2/86109-8-1	2/10/10	1	3/10/10	1	3/20/100	20	3/10/50	5	3/10/100	10	3/40/100	40
76	Linnong 826	919-18-5/Mianyang 87-31	3/20/100	20	3/20/100	20	3/80/100	80	3/10/50	5	3/20/80	16	3/40/100	40
77	Guinong 21	Haynaldia villosa/Suwon 20	0	0	2/10/10	1	3/20/100	20	0	0	2/10/10	1	3/40/100	40
78	Guinong 22	Haynaldia villosa/Suwon 20	0	0	2/10/5	0.5	3/40/100	40	1/10/20	2	3/5/10	0.5	3/40/100	40
79	Guinong 29	-	0	0	0	0	0	0	0	0	0	0	0	0
80	Guinong 775	-	0	0	0	0	0	0	0	0	0	0	0	0
81	92R137	Triticum aestivum L./Haynaldia villosa	0	0	1/10/30	3	3/40/100	40	1/10/20	2	2/10/10	1	3/40/100	40
82	92R178	Triticum aestivum L./Haynaldia villosa	0	0	2/10/10	1	3/40/100	40	2/10/20	2	3/10/20	2	3/40/100	40

a) Disease index
b) infection type/severity/percentage

Table 2: Resistance reactions of wheat cultivars with known genes tested with 26 *Pst* pathotypes in seedling stage

No.	Tester	*Yr* genes	*Pst*																									
			P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26
1	Chinese 166	1	R	S	S	S	R-S	R	R	R	R	S	S	R	R	S	S	S	S	R	S	S	R	R	S	S	S	S
2	Joss cambier	2	R	R	R	S	S	R	R	R	R	R	S	S	R	S	R-S	R	S	R	R	S	R	S	R	S	S	S
3	Heines Kolben	2,6	R	R	R	R	R	R	R	S	R	R	R-S	S	S	S	S	R-S	S	R	R	R	S	S	R	S	S	R
4	Heines Peko	2,6,+	R-S	R-S	S	S	R	S	R	R	R	R	S	R	R	R	R	S	S	R	S	R	R	S	R	S	S	S
5	Heines 7	2,H7	R-S	R-S	R	S	S	R	R	R-S	R	S	S	S	R	S	S	S	S	R	R-S	R	R	R	R	R	S	S
6	Vilmorin23	3,V23	R	R	R	R	R	R	R	R-S	S	S	S	S	S	S	S	S	S	R	R	S	S	S	R	R	S	R
7	Nord Desprez	3,+	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	R	R-S	S	S	S	R	S	S	S
8	Cappelle Desprez	3a,4a,16,+	R	R	S	R	S	R	R	S	S	S	S	S	S	S	S	S	S	R	R-S	S	S	S	R	S	S	S
9	Hybrid46	4,+	R	R	R	R	R	R	R	R	S	S	R	S	S	S	S	S	R	R	R	R-S	S	S	R	R	S	R
10	T.spelta album	5	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R-S	R	R	R
11	Fielder	6,20	R-S	S	R	R	R	S	R	R	R	R	S	R	R	R	R	R	S	R	S	R	R	S	R	S	S	S
12	Lee	7,22,23	S	S	S	S	R	S	S	R	R	R	S	R	R-S	R	R	R	R	R	S	S	R	R	R	S	S	S
13	Reichersberg 42	7,+	R	S	S	S	R	S	R	R	R	R	S	R	R	R	R	S	R-S	R	S	S	R	R	R	S	S	R
14	Compare	8,19	S	R-S	/	S	R	S	R	R	S	R	S	S	S	R	/	S	S	R	S	S	R	S	S	S	S	S
15	Clement	9,Cle	R	R	R	R	R	R	R	R	R	R	S	R	R	R	R	R	R	R	R	R	R	R	R	S	S	S
16	Lorvin 13	9,+	R-S	R-S	R	R	R-S	R-S	R	R-S	S	R-S	S	S	R-S	R	R-S	R	R	R	R-S	R-S	R	R	S	S	S	S
17	Moro	10,Mor	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R
18	Mega	12	R	R-S	R	R	R	R	R	R-S	S	S	S	S	S	S	S	S	R	R	R	S	R	S	R	S	S	S
21	VPM1	17	R	R	S	R	R	R	R	R	R	S	S	S	S	R-S	R	R-S	S	R	R	R	R	S	S	R	S	S
22	K733	24	R	R	R	R	R	R-S	R	R	R	R	R	R	R	R	R-S	R	R	R	R	R	S	R	R	R	R	R
23	Strubes Dickkopf	25,SD	R	R	R	R	S	S	S	S	S	S	R-S	S	S	S	S	S	S	R	S	S	S	S	S	S	S	R
24	Tp981	25	R	/	R	S	S	R-S	R	S	S	R	S	S	/	/	R	R	S	R	/	R	/	/	S	S	S	S
25	Line R55	26	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R
26	Selkirk	27	S	S	S	S	R	S	R	S	S	S	R	R	R-S	R	S	S	S	R	R	R	R	R	R	S	S	S
27	T.tauschiiW-219	28	R	R	R	R	R	S	R	R	R	R	R-S	R	R	R	R	R	R	R	R	R	R	R	R	S	S	R
28	Carstens V	32	R	R	R	R	R	R	S	R	S	S	S	S	R-S	S	S	S	R	R	R-S	S	S	S	R	S	S	S
29	Spaldings Prolific	SpP	R	R	R	R	S	R	R	R	R	S	R	R	R-S	R	R	R	S	R	R	R	R	S	S	R-S	R	S
30	Suwon92/ Omar	Su	R	R	R	R	R	R	R	R-S	R	R	R	R	R	R	R-S	R	R	R-S	S	S	S	S	S	R	R	S

Eleven wheat cultivars, Lantian 27 (No. 4), Lantian 31(No. 8), Lanhangxuan 1 (No. 15), Longyuan 937 (No. 17), Longyuan 082 (No. 18), Longjian 0071 (No. 21), Gandong 017 (No. 54), Zhong 4 (No. 55), Tian 98294 (No. 61), Guinong 29 (No. 79) and Guinong 775 (No. 80), were resistant to 26 *Pst* isolates and their resistance spectra were the same as that of the tester *T. spelta* album (*Yr5*). Their pedigree had no consanguinity with the *T. spelta* album. These results indicated that these cultivars might possess unknown resistance gene(s) (Table 3).

The resistance patterns of other wheat cultivars were different than those of the tests, indicating that these cultivars might carry unknown resistance gene(s).

Table 3: Resistance reactions of cultivars with 82 wheat cultivars (lines) inoculated with 26 *Pst* isolates in seedling stage

No.	Cultivars (lines)	*Yr* gene	*Pst*																									
			P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26
1	Lantian 24	26	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R
2	Lantian 25	+	R	R	R	R	R	R	R	R	R	S	R	R	R	S	R	S	R	R	R	R	S	R	R	R	R	R
3	Lantian 26	+	R	R	R	R	R	R	R	R	R	S	R	R	R	R	R	S	R	R	R	S	S	R	R	R	R	R
4	Lantian 27	+	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
5	Lantian 28	+	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	S	R	R	R	R	R	R	R	R
6	Lantian 29	+	R	R	R	R	R	S	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
7	Lantian 30	26	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R
8	Lantian 31	+	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
9	Lantian 091	26	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R
10	Lantian 092	26	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R
11	Lantian 093	+	S	R	R	R	S	S	R	S	S	R	R	R	S	R	R	R	R	S	R	R	R	R	S	R	R	R
12	Lantian 094	+	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	S	R	R	R	R
13	Lantian 095	+	S	R	R	R	R	S	R	R	S	R	R	S	R	R	R	S	R	R	R	R	R	R	R	R	R	R
14	Lantian 096		R	R	R	R	R	S	R	S	R	R	R	R	S	R	R	R	R	S	R	R	R	S	S	R	R	R
15	Lanhangxuan 1	+	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
16	Longyuan 961	+	R	R	R	R	R	R	S	R	R	R	R	R	R	R	S	R	R	R	R	R	R	R	R	R	R	S
17	Longyuan 937	+	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
18	Longyuan 082	+	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
19	Longyuan 992	9,+	R	R	R	R	R	R	R	R	R	R	R	S	R-S	R	R	R	R	R	R	R	R	R	S	S	S	S
20	Longyuan 014	+	R	R	R	R	S	R	R	R	R	R	R	S	R	R	S	S	R	R	R	S	R	S	R	R	R	R
21	Longjian 0071	+	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
22	Longjian 102	+	R	R	R	R	R	R	R	R	R	R	R-S	R	R	R	R	R	R-S	R-S	R	R	R	R	R	S	S	S
23	Longjian 103	+	R	S	R	R	R	R	S	R	R	S	R	S	S	R	R	S	R	R	R	S	R	R	R	R	R	S
24	Longjian 301	+	R	R	R	R	R	R	R	R-S	R	R	R	R	R	R-S	R	R	R	R-S	R	R	R	R-S	R	S	S	S
25	Longjian 9450	+	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R	R	R	R	S	S	S
26	Longjian 385	10+Mor	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R
27	Longjian 386	+	R	R	S	R	R	S	S	S	S	S	R	S	S	R	S	S	S	S	R-S	S	S	S	S	S	S	S
28	Longjian 387	+	R	S	R	R	R	R	S	R	R	S	R	S	S	R	S	R	R	R	R	S	R	R	S	R	R	R
29	Tianxuan 44	+	R	R	S	R	R	R	R	S	R	R	R	R	R	R	R	R	R	R	R	R	S	R	S	R	R	R
30	Tianxuan 45	+	R	R	S	R	R	R	R	S	R	R	R	R	R	R	S	R	R	R	R	R	S	R	S	R	R	R
31	Tianxuan 46	+	R	R	R	R	R	R	R	R	S	R	R	S	R	R	R	S	R	R	R	R	R	R	S	R	R	R
32	Tianxuan 47	+	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R
33	Tianxuan 48	10+Mor	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R
34	Tianxuan 49	+	S	R	R	R	R	R	R	R	R	R	R	S	R	R	R	R	R	R	R	S	R	S	S	R	R	R
35	Tianxuan 50	+	R	R	R	R	R	R	R	R	S	R	R	R	R	S	R	R	R	R	R	R	S	R	S	R	R	R
36	Tianxuan 51	10+Mor	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R
37	Tian 9681	+	R	R	R	R	R	R	R	S	R	R	R	R	R	S	S	R	R	R	R	R	S	R	S	R	R	S
38	Tian 9727	+	R	R	R	R	S	R	R	S	R	R	R	R	R	R	R	R	R	R	R	R	R	S	S	R	R	R
39	Tian 9524	+	R	R	R	R	R	R	S	R	S	R	R	R	S	S	R	S	R	S	R	R	R	R	R	R	R	S
40	Tian 00127	+	R	R	S	R	R	R	R	R	R	R	R	S	R	R	S	R	R	R	R	S	S	R	S	R	R	R
41	Tian 9474	+	R	R	S	S	S	R	R	R	R	R	R	R	S	R	R	S	S	R	R	R	R	S	S	R	R	R
42	Tian 9686	+	R	S	R	R	R	R	R	S	R	R	R	R	R	S	S	R	R	S	S	R	R	R	R	R	R	R
43	Tian 9896	+	S	R	R	R	R	R	R	S	R	S	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
44	Tian 00104	+	R	R	R	R	S	R	R	S	R	R	R	R	R	S	R	R	R	R	R	R	R	R	S	R	R	S
45	Zhongliang 28	+	R	R	R	R	R	R	S	R	R	S	R	R	R	R	S	S	R	S	S	R	R	S	R	R	S	S
46	Zhongliang 29	26	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R
47	Zhongliang 30	+	R	R	R	R	S	R	R	R	R	R	R	R	S	R	R	R	R	S	R	S	S	R	S	R	R	S
48	Zhongliang 31	+	S	R	R	R	R	R	R	S	R	R	R	S	R	R	R	R	R	R	R	S	R	R	S	R	R	S
49	Zhongliang 32	+	R	S	R	R	R	S	R	R	S	R	R	S	S	R	R	S	R	R	R	R	R	S	S	R	R	R
50	Longyu 1	+	R	R	S	R	R	R	S	R	R	R	R	R	R	S	R	R	R	S	S	R	R	R	S	S	S	S
51	Longyu 2	+	R	R	S	R	R	R	S	S	S	S	R	R	R	S	R	S	R	S	S	S	R	R	S	S	S	S
52	Longyu 3	+	S	R	S	R	S	R	S	R	R	R	R	R	S	R	R	S	R	S	S	S	R	S	S	S	S	S
53	Longyu 4	+	R	S	S	R		R	S	R	S	R	R	S	R	R	R	S	R	R	S	S	S	S	S	S	S	S
54	Gandong 017	+	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
55	Zhong 4	+	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
56	Longyu 0027	+	R	R	R	R	R	S	S	S	S	S	R	R	R	S	R	S	R	S	R	R	R	S	R	R	R	S
57	Longyu 217	+	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R	R	R	R	R	R	R	R	R	R	R	S
58	Xingfeng 28	+	R	R	R	R	S	R	S	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	S	R	S
59	Longyuan 034	+	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R	R	S	R	S	S
60	97t110	+	R	R	R	R	R	S	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R	R	R	S	R	R
61	Tian 98294	+	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
62	Longyu 0456	+	R	R	S	R	R	R	R	R	S	R	R	R	R	S	S	S	R	R	R	R	S	R	S	S	S	S
63	Xifeng 26	+	R	R	S	R	S	S	S	S	R	R	S	R	S	S	R	S	R	S	S	S	R	R	R	S	S	S
64	Xifeng 27	+	S	R	S	R	R	S	S	S	S	S	S	S	R	R	R	S	R	S	S	R	S	R	R	S	S	S
65	Pingliang 41	+	R	R	S	R	S	R	S	S	S	S	S	R	R	S	R	S	R	S	S	R	R	S	R	S	S	S
66	Pingliang 42	+	S	R	S	R	R	R	S	R	R	R	S	R	S	R	S	R	R	S	S	S	R	S	R	S	S	S
67	Pingliang 43	+	R	R	R	R	R	R	S	R	R	R	R	S	R	S	R	R	R	S	S	R	R	R	R	S	S	S
68	Pingliang 44	+	S	R	R	R	R	S	S	R	R	R	R	R	R	R	R	R	R	S	S	R	R	R	R	S	S	S
69	Pingliang 45	+	R	R	R	R	S	S	S	R	R	R	R	R	R	R	S	S	R	S	S	R	R	S	R	R	S	S
70	Pingliang 46	+	R	R	R	R	R	R	S	R	R	R	R	R	R	R	R	S	R	S	S	R	R	R	R	R	S	S

Table 3: Continued

Table 3: Continued

71	Pingliang 47	+	S	R	R	R	R	R	S	R	R	R	R	S	S	S	R	S	R	S	S	S	S	R	R	R	S	S
72	Wudu 16	+	R	R	S	R	S	R	R	R	R	S	S	R	S	S	R	S	R	R	S	S	R	R	R	S	S	R
73	Wudu 17	+	R	R	R	R	S	R	R	R	R	R	R	S	R	R	S	S	R	S	R	R	R	R	R	R	R	S
74	Linnong 7230	+	S	S	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R	S	S	R	R	S	R	R	R	S
75	Linnong 9555	+	R	R	R	R	R	S	S	S	S	S	R	R	R	R	S	R	R	R	R	R	R	R	R	R	S	S
76	Linnong 826	+	R	S	R	R	S	R	S	R	R	R	R	R	R	R	R	S	R	S	R	R	R	S	S	R	S	R
77	Guinong 21	10+Mor	R	R	R	R	R	R	R	R	R	R	R	R-S	R	R	R	R	R	R	R	R	R	R	S	R	R	R
78	Guinong 22	10+Mor	R	R	R	R	R	R	R	R	R	R	R	R-S	R	R	R	R	R	R	R	R	R	R	S	R	R	R
79	Guinong 29	+	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
80	Guinong 775	+	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
81	92R137	26	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R
82	92R178	26	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R

Adult Plant Resistance in Cultivars from the Longnan Region

Fifty-six and 57 wheat cultivars were resistant to artificially mixed *Pst* isolates at Gangu spots in 2009–2010 and 2010–2011 crop seasons, about 68.29 and 69.51%. Twenty-five wheat cultivars were resistant in 2014–2015, about 30.49%, respectively (Table 1). Fifty-six and Forty-seven wheat cultivars were resistant under natural infection at Wangchuan spots in the 2009–2010 and 2010–2011 crop seasons, about 68.29% and 57.32% respectively. Twenty-one wheat cultivars were resistant in 2014–2015, about 25.61%. Overall, twenty-one wheat cultivars were resistant at both sites during the crop seasons, about 25.61% (Table 1).

Eighteen wheat cultivars, including Lantian 24 (No. 1), Lantian 26 (No. 2), Longyuan 992 (No. 19), Longyuan 014 (No. 20), Longjian 0017 (No. 21), Longjian 386 (No. 26), Longjian 387 (No. 27), Tian 9681 (No. 37), Tian 9727 (No. 38), Tian 9474 (No. 41), Tian 0014 (No. 44), Zhongliang 30 (No. 47), Zhongliang 31 (No. 48), Zhongliang 32 (No. 49), Longyu 217 (No. 57), Longyuan 034 (No. 59), 97t110 (No. 60) and Tian 98294 (No. 61), were susceptible to stripe rust at the Gangu spots and Wangchuan spots during the 2009–2010, 2010–2011 and 2014–2015 crop seasons, which was approximately 21.95% of the cultivars tested. Their severities and percentages were lower than the susceptible cultivar Mingxian 169, and the disease index was less than 20, which might indicate slow rusting characteristics.

Twenty-two wheat cultivars, including Lantian 27 (No. 4), Lantian 28 (No. 5), Lantian 29 (No. 6), Lantian 31 (No. 8), Lantian 093 (No. 11), Lantian 094 (No. 12), Lantian 095 (No. 13), Lantian 096 (No. 14), Lanhangxuan 01 (No. 15), Longyuan 937 (No. 17), Longyuan 082 (No. 18), Longjian 301 (No. 24), Tianxuan 44 (No. 29), Tianxuan 45 (No. 30), Tian 9524 (No. 39), Tian 00127 (No. 40), Tian 9686 (No. 42), Gandong 017 (No. 54), Zhong 4 (No. 55), Longyu 0027 (No. 56), Guinong 29 (No. 79) and Guinong 775 (No. 80), were resistant to stripe rust at the Gangu spots and Wangchuan spots during the 2009–2010, 2010–2011 and 2014–2015 crop seasons, which was approximately 26.83% of the cultivars tested. Nine wheat cultivars, including Lantian 27 (No. 4), Lantian 31(No. 8), Lanhangxuan 1 (No. 15), Longyuan 937 (No. 17), Longyuan 082 (No. 18), Gandong 017 (No. 54), Zhong 4 (No. 55), Guinong 29 (No. 79) and Guinong 775 (No. 80) were resistant in all-stage, about 10.98%.These cultivars should be utilized widely and researched thoroughly in future.

Discussion

The postulation method of resistance genes was designed to study wheat genetics and is a fast, useful and simple method to identify genes in cultivars at the seedling stage in a greenhouse. It was developed in the 1970s, and much genetic information about both the wheat and the pathogen can be obtained in approximately 2–3 months. It has been used in studies of genetic resistance in hosts, especially in wheat, more broadly than traditional technologies, including Mendelian inheritance patterns and molecular technology, because it is less expensive and tested relatively more numbers of wheat cultivars. However, it should be kept in mind that gene postulation offers only approximate information on resistance genes and that the accuracy is restricted to cultivars with known genes and tested isolates.

There were four main factors affecting the ITs and accuracy of the results. The first factor affecting accuracy is the difference in the genetic backgrounds of the cultivars. Under normal conditions, one wheat cultivar was derived from one or more resistant sources as parents to obtain the target wheat cultivars, in such a case, the genetic background might be relatively complex. Second, the resistance might be affected by gene compatibility, gene additives, gene suppression and gene epistasis (Ittu, 2000). Thus, the same wheat cultivars might yield diverse results at different testing stations, including diverse repetition, staff and batch. Third, the *Pst* pathogen is sensitive to the environment and the host background, gene postulation might yield diverse results under different environmental conditions. Although the cultivars likely carried the same gene(s), the ITs could vary under different conditions or genetic backgrounds (Li *et al.*, 2008). The temperature sensitivities of the genes *Lr3*, *Lr17* and *Lr23* for resistance (i.e., IT) to *Puccinia recondita* in wheat were different at 10℃/15℃ and 15℃/20℃ (Dyck and Johnson, 1983). *Yr6*, which seemed to be less effective at higher greenhouse temperature, and Wellings reported that *Yr6* was less effective at lower in controlled environments (Wellings, 1986; Dubin *et al.*, 1989) The epidemic components included the latent period, the infection probability, the cumulative lesion sporulation, the lesion daily-expansion area and the parasitic fitness. In another study, twelve isolates of wheat powdery mildew with different sensitivities to temperature were tested using the detached leaf segment method at 18ºC and 22ºC, and there were significant differences among the epidemic components of the different isolates (Li *et al.*, 2008). Thus, if one or some environmental elements, such as water, fertilizer, flight and temperature, are changed during the testing process, the results for the disease index, the IT and the severity might be different for the same wheat variety or Pst isolate in the different replicates replicates or conditions. Fourth, because of the different classification standards of investigators and the recorded results for ITs 2, 2^+ and 3, some bias might be introduced, especially in a few of the sensitive wheat cultivars, which exhibit weak growth or are etiolated in the seedling stage. Finally, the specific *Pst* isolates used can influence the results. In addition, when more avirulent/virulent isolates are selected, better identification results can be obtained. It may be necessary to use more *Pst* isolates with different virulence formulae on these *Yr* genes and/or near-isogenic lines (NILs) with other resistance genes to obtain more accurate gene postulations. When comparing *T. spelta* album (*Yr5*) to the tested *Pst* isolates in this study, eighteen wheat cultivars had the same resistance spectra as *Yr*5, but their pedigrees did not have either *Yr5* consanguinity or postulated unknown gene(s). In addition, the tested *Pst* isolate P23, which had a better recognition reaction to the *Yr26*-virulent*,* might distinguish whether *Yr26* exists or not. The key point when employing postulation methods is in the selection of the *Pst* isolates, especially with local character isolates, predominant isolates, and new virulent isolates. In this study, we not only selected different isolates that possessed different spectra from those abroad but also selected strongly virulent and epidemic races from different times in China, such as CYR17 (P3), CYR26 (P4), CYR27 (P17), CYR29 (P11), CYR31 (P24), CYR32 (P25), CYR33 (P26) and CH42 (P23). Therefore, the results of the resistance evaluations and the gene postulations can guide the layout of cultivars.

The resistant gene *Yr9*, from *1B*/*1R* wheat-rye chromosome translocation lines, was used in wheat cultivars during the 1980s. Because its carriers, including Lovrin 10, Lovrin 13, Predgornaia 2, Kavkaz and Neuzucht, had excellent agronomic characters and better resistance to wheat striperust and powdery mildew than other wheat germplasms, they were widely used as a parent in wheat breeding in China since the 1970s. Its derivatives, Qingshan 843, Chengliang 6, Lantian 1 and Tao157, are important wheat cultivars and have played an important role in controlling stripe rust in Longnan region, Gansu province in China since 1980s. With the long-term and extensive use of *Yr9* in wheat breeding and planting, *Pst* isolates have accelerated their directional selection and newly virulent *Pst* isolates emerged, such as CYR28 and CYR29. Furthermore, the deduced cultivars and sources lost their resistance to stripe rust in field, causing serious outbreaks in many major wheat-growing regions since 1985. Previous studies determined that nine and nineteen Chinese wheat cultivars carried Yr9, approximately 19.39% and 21.43% of the totals, respectively (Wang *et al.*, 1994; Li *et al.*, 2006); thirteen commercial wheat cultivars of 52 varieties were from the Yunnan Province in China (Li *et al.*, 2011). In this study, only Longyuan 992 (No. 19) carried *Yr9*, about 1.22%. These data also indicate that the pedigree of *1B*/*1R* was not the major parent in wheat breeding in Longnan, Gansu province.

The climatic conditions, geographic characteristics, and cropping systems in southeastern Gansu are ideal for the year-round cycling of *Puccinia striiformis* f. sp. *tritici* (Li and Zeng, 2002; Chen, 2005; Chen *et al.*, 2007, 2014). Many wheat planting varieties (lines) and sources, including Fan 6 and its pedigree lines, have lost their resistance in the field since 1993 because of the new virulent *Pst* isolates, CYR30 and CYR31. Thus, approximately 13.3 million hectares of wheat are threatened by stripe rust every year in China (Niu and Wu, 1997). Eleven provinces (city, autonomous region), including Gansu, Sichuan, Chongqing, Ningxia, Qinghai, Shaanxi, Shandong, Hubei, Yunnan, Guizhou and Henan, suffered outbreaks of stripe rust in 2002, which caused over 1.3 million tons of yield loss (Wan *et al.*, 2003). A countrywide outbreak of wheat stripe rust occurred once more in 2009 (Kang *et al.*, 2010). Excavating and evaluating the wheat germplasm resistance to stripe rust is foundational work for wheat breeding. According to the 3822 identified wheat germplasms using artificial and natural inoculation *Pst* isolates in the Gangu field, some important wheat sources, such as Guinong 19, Guinong 21, Guinong 22, 92R137 and 92R178, were not only immune to CYR31, CYR32 and Su11-14 (CYR33) and mixed *Pst* isolates in all stages (Cao *et al.*, 2003), but also had good agronomic characters, such as similar growth periods, a plant height of approximately 70 cm, and greater combining capacity than other resistant cultivars, such as *T. spelta* album (*Yr5*). These sources have been widely used in breeding programs, especially in the Gansu and Sichuan provinces. From then on, an increasing number of wheat scientists and breeders have used these wheat materials as hot parents. In increasing number of resistant cultivars have been bred in since the 1990s, including Longjian9343, Longjian 385, 93Bao4-4, Tiaxuan 43, Tianxuan 48, Mianmai 39, Mianmai 40, Mianmai 41, Mianmai 42, Mianmai 43, Mianmai 44, Mianmai 45, Mianmai 46, Mianmai 47, Chuanmai 44, Chuanmai 49 and Chuanmai 50, whose parents were Guinong 19, Guinong 21 and Guinong 22. The wheat source 92R (*Yr26*) pedigree includes Lantian 17, Lantian 24, Lantian 091, Lantian 092, Zhongliang 29, Neimai 9, Neimai 10, and Neimai 11. The wheat variety Chuanmai 42 (*Yr24*) was immune to CYR32 and CYR33, which are the parents of Chuanmai 54 and Chuanmai 56.

All of these wheat cultivars were widely grown in wheat stripe rust hot spots and other regions, including the Sichuan and Gansu provinces. Similar to CYR28 and CYR29, new *Pst* virulent isolates emerged from 2010 in Sichuan, and the new *Pst* isolate CH42 was virulent to *Yr10* and *Yr24*/*Yr26* (Liu *et al.*, 2010). New virulent *Pst* isolates had an emergence prevalence of about 18% in the Gansu province in 2012 (Jia *et al.*, 2012; Liu *et al.*, 2012; Huang *et al.*, 2014). In the present study, twelve wheat cultivars might present *Yr10* and *Yr26*, about 14.63%. All of these wheat cultivars have become susceptible to stripe rust in the field, have gradually lost their value in the field since 2010 and have lost their value in wheat planting and breeding in the Longnan region, Gansu province. Currently, about 13.3 million hectares of wheat suffer from stripe rust (Niu and Wu, 1997; Kang *et al.,* 2010), which might cause further outbreaks as long as the environmental conditions are ideal for an epidemic in the future.

The Longnan region (southern Gansu), including Tianshui and Longnan, in Gansu Province is a special region where wheat grows from the lowland valleys at 550 m to highland terraces at 2,500 m. The *Pst* pathogen can easily survive over-summer and over-winter in these zones in normal years, and the virulence structure is very complex (Li and Zeng, 2002). The Longnan region is the probable original pathogen base in China because the stripe rust inoculum can over-summer on volunteer wheat seedlings that provide a "green bridge" and because the inoculum transfers from late mature wheat to early-sown seedlings. It has been deduced that these areas of wheat stripe rust in China constitute the largest and most important over-summering region, serve as the original pathogen base to eastern areas in China in the autumn every year, and are a key or hot area in China (Wang *et al.*, 1965; Li and Zeng, 2002; Wan *et al.*, 2004). Historically, almost all Chinese races were first detected in these regions and exhibited great diversity with a complex virulence structure; thus, the area was proposed as the origin of rust virulence in these regions (Wang *et al.*, 1963, 1986; Wu *et al.*, 1993; Chen *et al.*, 2007; Wan *et al.*, 1999, 2003, 2004, 2007; Li and Zeng 2002).

Gene postulation is based on Flor's gene-for-gene concept. It is necessary to develop a set of known gene cultivars as differential hosts suitable to China and to consider the pedigree of the test cultivars. In this study, gene information was postulated according to artificial inoculations in wheat cultivars in the seedling stage in the greenhouse. This information was only applied to the seedling stage. There were four reasons for restricting this work and not performing it at the adult stage. First, the working capacities of *Pst* isolates with different virulent spectra are heavy. Second, some *Yr* genes can only be identified with exotic *Pst* isolates if these exotic isolates inoculate in the field, which presents higher risks than testing in controlled greenhouse conditions. Third, artificial inoculation in the field cannot absolutely exclude natural *Pst* infections, thus affecting the accuracy of gene postulation. Finally, the virulence structure of the *Pst* isolates in the Longnan region Gansu province is very complex. Screening the resistance of cultivars and sources to stripe rust in these zones might provide more effective information in advance. Furthermore, evaluating the resistance of the main wheat cultivars genes in these hot spots for a long period time will provide a great deal of information.

Conclusion

Combined with the postulation results, this method will improve the efficiency and will reduce blindness in wheat resistance breeding to stripe rust by helping to deploy wheat resistance genes. All of these efforts will provide very important information for the integrated management of stripe rust in the Longnan region of the Gansu province.

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