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Determination of *Puccinia graminis* f. sp. *tritici* races of wheat in Turkey

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Abstract: Stem rust, caused by the fungus *Puccinia graminis* f. sp. *tritici* (*Pgt*), is one of the most important diseases limiting wheat production in Turkey. Surveys were conducted in 2007 and 2008 in order to determine the races of the pathogen present in Turkey. In 2007, it was found that 91 (43%) out of 207 inspected wheat fields were infected with stem rust, and in 2008, it was found that 61 (25%) out of 242 inspected fields were infected. From these samples, 40 single pustule isolates were obtained. The North American differential set, which includes 20 genotypes with different resistance genes, was employed to identify the races present. Seedling tests were used for race analysis under greenhouse conditions. A total of 21 different stem rust races were found. *Pgt* race TKTTC, which was found in 11 *Pgt* isolates, was the most common race. Genotypes possessing at least 1 of the Sr24, Sr31, Sr26, and Sr27 resistance genes showed low infection types for 40 *Pgt* isolates. The resistance genes determined in this study could be used in breeding programs for developing stem rust-resistant genotypes.

Key words: Pathogen races, *Puccinia graminis* f. sp. *tritici*, resistance genes, wheat stem rust, Turkey

Türkiye'de buğdayda hastalık oluşturan *Puccinia graminis* f. sp. *tritici* ırklarının belirlenmesi

Özet: Buğdayda *Puccinia graminis* f. sp. *tritici* (*Pgt*) fungusu tarafından meydana getirilen kara pas hastalığı üretimi sınırlayan en önemli faktörlerdendir. Bu hastalığa neden olan patojenin ırklarının tespiti için Türkiye'de 2007 ve 2008 yıllarında sörveyler yürütülmüştür. 2007 yılında incelenen 207 buğday tarlasının 91'inde (% 43), 2008 yılında ise 242 tanesinden 61'inde (% 25) karapas hastalığı görülmüştür. Toplanan örnekler içerisinde 40 farklı örnekten, tek püstül izolasyonu yöntemiyle izolatlar elde edilmiştir. Elde edilen buğday karapas izolatlarının ırklarının belirlenmesi için farklı dayanıklılık genleri içeren ve 20 genotipten oluşmuş Kuzey Amerika ırk ayırıcı seti kullanılarak sera koşullarında fide dönemi testleri yürütülmüştür. Bu testler sonucunda 40 buğday karapas izolatında 21 farklı karapas ırkı saptanmış olup, 11 izolatta belirlenen TKTTC karapas ırkı en fazla sayıda izolatta belirlenen ırk olmuştur. Sr24, Sr31, Sr26 ve Sr27 dayanıklılık genlerinden en az birini içeren genotipler 40 *Pgt* izolatına karşı dayanıklı reaksiyonlar vermiştir. Bu çalışmada belirlenen dayanıklılık genleri ıslah programlarında karapas'a karşı dayanıklı genotiplerin geliştirilmesinde kullanılabilir.

Anahtar sözcükler: Buğday karapası, dayanıklılık genleri, patojen ırkları, *Puccinia graminis* f. sp. *tritici*, Türkiye

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Introduction

Wheat (*Triticum* spp.) is the most important crop in Turkey. Turkey is also one of the gene centers of wheat (Gökgöl 1939; Vavilov 1950; Harlan 1971; Özkan et al. 2002). A total of 20.6 million tons of wheat was produced in 2009 (Turkish Statistical Institute 2009), and wheat plays a very important role in the economy and in rural life. As is known, rust diseases have been major and important diseases of small grains in Turkey and worldwide. Of the pathogenic agents causing significant losses to wheat production in Turkey, the rust pathogens (*Puccinia* spp.) are the most important. Of these pathogens, *Puccinia triticina* (casual agent of leaf rust) occurs in rather humid and warmer areas such as transitional zones, the Marmara region, and coastal areas. Yellow rust caused by *Puccinia striiformis* occurs in the cool season in all parts of the country. Stem rust caused by *Puccinia graminis* f. sp. *tritici* (*Pgt*) can occur in all parts of the country, but it occurs rather late in the season.

Stem rust is considered a serious threat to wheat production (Scheibe 1932; Kolmer et al. 2007; Pathan and Park 2007). Its occurrence and the magnitude of damage depend largely upon climatic conditions, virulence of the pathogen population, and host genotype. The first record of stem rust in Turkey was made by Scheibe in 1932 (Scheibe 1932). A number of epidemics occurred between 1936 and 1960. In 1938, a stem rust epidemic caused 75% yield losses in the Mediterranean region and 40% yield losses in the Aegean region in wheat (İyriboz and İleri 1941). In 1963, the disease caused yield losses of 15%-50% and 9% in southern Turkey (Antalya, Burdur) and the Black Sea region, respectively (Özbaş 1967). In 1967, yield losses of 15%-50% and 15%-30% were reported from southwest Anatolia and from Muş, Bingöl, and Elazığ provinces, respectively (Oran and Parlak 1969). The disease was observed in large areas between 1986 and 1991 in central Anatolia (Kınacı and Kınacı 1991). In 1993, it was found that 14.2% of the fields inspected in Konya, Karaman, Aksaray, and Niğde provinces were infected with stem rust (Yıldırım et al. 1999). In a survey carried out in central Anatolia, disease prevalence was reported as 12.4% and 8.8% in 1993 and 1994, respectively (Mamluk et al. 1997). In surveys conducted in central Anatolia, the prevalence of the disease was 4.9%, 28%, and 8.5% during 1996, 1997, and 1998, respectively (Düşünceli et al. 1999). No major losses from stem rust have occurred in Turkey in the wheat-producing areas during recent years.

İren (1955) used the Stakman differential set (Stakman et al. 1944) to undertake race analyses of stem rust isolates collected from Turkey. This set included the genotypes of Little Club, Marquis (Sr7b, Sr18, Sr19, Sr20), Reliance (Sr5, Sr16), Kota (Sr7b, Sr16, Sr28), Arnautka (Sr9d), Mindum (Sr9d), Spelmar (Sr9d), Kubanka (Sr9g), Acme (Sr9g), Einkorn (Sr21), Vernal emmer (Sr9e), and Khapli emmer (Sr7a, Sr13, Sr14). In this study, 5 different races were found in 17 isolates collected from central Anatolia. These races were 14, 17, 19, 21, and 24 according to Stakman's nomenclature (İren 1955). In another study, races 11, 14, 21, 24, 34, 53, and 122 were found using stem rust isolates obtained from İstanbul Province and the surrounding areas (İren 1956). In 1976, stem rust isolates were collected from 11 different locations in Turkey (Ankara, Adana, Diyarbakır, Mardin, Eskişehir, Korkuteli, Temelli, Yeşilköy, Menemen, Bergama, and Haymana). In these samples, 10 stem rust isolates were found to be race RKT (virulent on Sr5, Sr9d, Sr7b, Sr6, Sr8a, Sr9a, Sr14, Sr16, Sr13, and Sr10; avirulent on Sr9e and Sr11) and 1 stem rust isolate was determined to be race RLJ (virulent on Sr5, Sr9d, Sr7b, Sr11, Sr6, and Sr13; avirulent on Sr9e, Sr8a, Sr9a, Sr14, Sr16, and Sr10) (Çelik et al. 1976). Using race analyses on the reactions of 12 genotypes (Roelfs et al. 1993), RKQ, RKH, RKL, RKK, RTG, and MKG races were found by Bolat et al. (1993). These results show that race analyses were conducted in a limited area or region in Turkey. In this study, stem rust races were determined from isolates obtained from different regions of Turkey in the 2007 and 2008 growing seasons. The stem rust situation in the inspected fields was also reported.

Materials and methods

Surveys for this research were made along a route of 22,000 km, covering the Black Sea, Central Anatolia, East Anatolia, Southeast Anatolia, Mediterranean,

Marmara, and Aegean regions of Turkey during 2007 and 2008. The surveys followed a preselected route through important wheat-producing areas. In 2007 and 2008, surveys were made in the following important wheat producing areas: the Mediterranean (late May), East Anatolia (mid-late July), Aegean (mid-June), Southeast Anatolia (May-early June), Central Anatolia (late June), Black Sea (early June and late June), and Marmara (mid-June) regions. The presence of rust disease was inspected in the fields every 30 km and GPS coordinates were recorded for each field. Whenever rust was observed in a field, leaves or stems bearing uredinia were collected. Spores from each collection were used to inoculate seedlings of the susceptible common wheat cultivars Little Club or Michigan Amber at Zadoks growth stage 11 (Zadoks et al. 1974). Spores suspended in lightweight mineral oil (Soltrol 170, ChemPoint, Limburg, Netherlands) were sprayed onto plants. Inoculated seedlings were incubated for 48 h in a humidity chamber (95% relative humidity) within a greenhouse bench in which the temperature was maintained between 18 and 20 °C. Plants were then placed in a greenhouse, where each culture was maintained in separate greenhouse chambers. Greenhouse temperatures ranged between 20 and 25 °C. After 12 to 14 days, leaves, each bearing 1 uredinium or pruned to bear 1 uredinium, were saved in petri dishes. Cyclone collectors (G-R Manufacturing Co., Kansas, USA) and 00 gelatin capsules (Bayfar Medikal Ticaret-Danışmanlık Ltd. Şti., İstanbul, Turkey) were used to collect urediniospores from the uredinium. The urediniospores obtained from each uredinium suspended in mineral oil (Soltrol 170) were sprayed onto susceptible wheat cultivars Little Club or Michigan Amber, which were then placed in a dew chamber for 48 h at 18-20 °C. Plants were then placed in a greenhouse at 20 to 25 °C, where each culture was maintained in a separate clear plastic chamber (Pathan and Park 2007).

The North American stem rust differential series was used for race identification (Jin et al. 2008). The seeds of the differentials were obtained from Dr. Yue Jin (University of Minnesota, St. Paul, Minnesota, USA). The differential host series consisted of wheat lines with resistance genes Sr5 (ISr5-Ra), Sr21 (Cns_*Triticum monoc.* Deriv.), Sr9e (Vernstein), Sr7b (ISr7b-Ra), Sr11 (ISr11-Ra), Sr6 (ISr6a-Ra), Sr8a (ISr8a-Ra), Sr9g (CnSr9g), Sr36 (W2691SrTt-1), Sr9b (W2691Sr9b), Sr30 (BtSr30Wst), Sr17+13 (Combination VII), Sr9a (ISr9a-Ra), Sr9d (ISr9d-Ra), Sr10 (W2691Sr10), SrTmp (CnsSrTmp), Sr24 (LcSr24Ag), Sr31 (Benno Sr31/6*LMPG), Sr38 (Trident), and SrMcn (McNair 701).

Genotypes in the differential set were planted in pots with diameters of 12 cm containing sterile peat. Each pot contained 4 genotypes (5 seeds of each genotype) separated from each other. Plants were grown in a greenhouse with a 15-20 °C night/day temperature regime. No artificial light was employed. The urediniospores obtained from susceptible plants suspended in lightweight mineral oil (Soltrol 170) were sprayed on the differential host series at Zadoks growth stage 11 (Zadoks et al. 1974) using an inoculum concentration of 15 mg of urediniospores for each differential set. Care was taken to ensure uniform dispersal of the inoculum. Plants were placed in a dew chamber for 48 h at 18-20 °C after inoculation and then transferred to a greenhouse with a 20-25 °C night/day temperature regime. The plants were assessed 14-16 days after inoculation according to the infection types described by Stakman et al. (1962). Infection types 0, ;, 1, and 2 and combinations of these values were considered as low infection types. Infection types 3 and 4 and the combination of these values were considered as high infection types. In cases where similar but different infection types were observed on the same leaf, the values were used together. For example, if both ';' and '1' values were observed on the same leaf, the value ';1' was used. Races were assigned using the international *Puccinia graminis* f. sp. *tritici* code (Table 1) for the North American differential series (Jin et al. 2008).

In addition to this differential set, a supplemental set including Sr13 (W2691Sr13), Sr26+Sr9g (Eagle), Sr27 (Coorong Triticale), Sr29 (Pusa/Edch), Sr33+Sr5 (Tetra Canthatch/*Aegilops squarrosa* (RL5045)), Sr40 (RL6088), and Sr44 (Taf-2) resistance genes was also used to determine pathogenicity with respect to these resistance genes.

Table 1. A key for defining races of *Puccinia graminis* f. sp. *tritici* (*Pgt*) (Jin et al. 2008).

	Subset	**Infection type produced on host lines with stem rust**			
	1	Sr5	Sr21	Sr9e	Sr7b
Pgt-Code	2	Sr11	Sr6	Sr8a	Sr9g
	3	Sr36	Sr9b	Sr30	Sr17+13
	4	Sr9a	Sr9d	Sr10	SrTmp
	5	Sr24	Sr31	Sr38	SrMcn
B		Low*	Low	Low	Low
C		Low	Low	Low	High**
D		Low	Low	High	Low
F		Low	Low	High	High
G		Low	High	Low	Low
H		Low	High	Low	High
J		Low	High	High	Low
K		Low	High	High	High
L		High	Low	Low	Low
M		High	Low	Low	High
N		High	Low	High	Low
P		High	Low	High	High
Q		High	High	Low	Low
R		High	High	Low	High
S		High	High	High	Low
T		High	High	High	High

*Low: Infection types 0, ;, 1, and 2 and combinations of these values.
**High: Infection types 3 and 4 and a combination of these values.

Results

Surveys were conducted in 2007 and 2008 in order to determine the effectiveness of the stem rust. In 2007, of the total 207 wheat fields, 91 (43%) were found to be infected with stem rust. In 2008, of the total 242 inspected fields, 61 (25%) were infected (Table 2). Disease severity and percentage of infected plants were mostly very low in the infected fields, except for some fields in the Black Sea region (Table 2), especially in Kastamonu province.

In 2007 and 2008, stem rust races were identified from a total of 40 stem rust isolates (Table 3). In 2007, from 11 isolates, 6 races of *Pgt* were identified (Table 4), and in 2008, from 29 *Pgt* isolates, 18 races were identified (Table 5), giving a total of 21 different stem rust races. *Pgt* race TKTTC was the most common race, identified in 11 stem rust isolates.

Table 2. Survey regions, dates, numbers of fields inspected, and fields with wheat stem rust in 2007 and 2008.

Region	Survey Dates		Number of fields inspected		Number and percentage of infected fields	
	2007	2008	2007	2008	2007	2008
Mediterranean	28-30.05.2007	12-13.05.2008	26	23	11 (42%)	4 (17%)
East Anatolia	23-27.07.2007	20-24.07.2008	27	54	22 (81%)	7 (13%)
Aegean	21-23.06.2007	18-20.06.2008	22	22	6 (27%)	2 (9%)
Southeast Anatolia	01-02.06.2007	14-15.05.2008	27	27	8 (29%)	0 (0%)
Central Anatolia	24-25.06.2007	17-19.06.2008	37	70	10 (27%)	19 (27%)
Black Sea	28.06-02.07.2007	12-15.06.2008	40	46	33 (82%)	29 (63%)
Marmara	19-20.06.2007	-	28	-	1 (3%)	-
Total			**207**	**242**	**91 (43%)**	**61 (25%)**

In 2007, races TKTTC (5 isolates), PKSTC (2 isolates), TKTSC (1 isolate), TKSTC (1 isolate), PKNTC (1 isolate), and PKJSC (1 isolate) were found. Among these races, different reactions were observed only in genotypes possessing the Sr9b, Sr17+13, Sr21, Sr36, and SrTmp resistance genes. The resistance genes Sr11, Sr24, Sr31, and Sr38 were effective while genes Sr5, Sr9e, Sr7b, Sr6, Sr8a, Sr9g, Sr30, Sr9a, Sr9d, Sr10, and SrMcn were ineffective for all races identified in 2007.

In 2008, a total of 18 different races were identified from 29 stem rust isolates. The most common races were TKTTC (6 isolates), RTKTF (4 isolates), TKSTC (3 isolates), and TKKTC (2 isolates). The remaining 14 races were represented by single isolates only. Among these 18 races, different reactions were observed only in genotypes possessing the Sr8a, Sr9b, Sr9d, Sr9e, Sr9g, Sr11, Sr17+13, Sr21, Sr30, Sr36, Sr38, and SrTmp resistance genes. The resistance genes Sr24 and Sr31 showed low infection types against all isolates, while genes Sr5, Sr6, Sr9a, Sr10, and SrMcn showed high infection types against all isolates in 2007 and 2008 (Table 6).

The reactions of supplemental set genotypes W2691Sr13 (Sr13), Eagle (Sr26+Sr9g), Coorong (Triticale, Sr27), Tetra Canthatch/*Aegilops squarrosa* (RL5045, Sr33+Sr5), RL6088 (Sr40), and Taf-2 (Sr44) are shown in Table 7. Among these genes, Sr26 and Sr27 showed low infection types against all races.

However, some variation in the reactions of the genotypes in the supplemental set was observed among some of the same races that were determined from different isolates collected from different regions. According to race study results, *Pgt* isolates A7, A8, A9, A10, A11, B1, B7, B19, and B22 were found as *Pgt* race TKTTC. However, the response of supplemental set genotype RL6088 (Sr40) was susceptible to *Pgt* isolates A7 and A9, but resistant to *Pgt* isolates A8, A10, A11, B1, B7, B19, and B22 (Table 7). Furthermore, Taf-2 (Sr44) was susceptible to *Pgt* isolates A7, A8, A9, A10, A11, and B1, but resistant to *Pgt* isolates B7, B19, and B22 (Table 7).

Discussion

The amount of rainfall during the agricultural year (1 October to 30 September) was 16% lower in 2007 and 9% lower in 2008 compared to long-term average precipitation. Average precipitation in the Aegean, Marmara, and Central Anatolia regions in 2007 and in the Southeast Anatolia, Mediterranean, and Eastern Anatolia regions in 2008 were significantly

Table 3. Locations of 40 stem rust isolates collected in 2007 and 2008 and identified as *Puccinia graminis* f. sp. *tritici* races.

Year	Isolate Number	Location	Race
2007	A1	Adana-Çukurova Agr. Res. Inst.	TKSTC
2007	A2	Şanlıurfa-Ceylanpınar Agr. Enterprise	PKSTC
2007	A3	Diyarbakır- Çınar	TKTSC
2007	A4	Konya-Bahri Dağdaş Institute	PKNTC
2007	A5	Kayseri	PKJSC
2007	A6	Erzurum	PKSTC
2007	A7	Kastamonu entrance	TKTTC
2007	A8	Sivas-Acıpınar Village	TKTTC
2007	A9	Erzurum-Pırnakaban	TKTTC
2007	A10	Erzurum-Ilıca	TKTTC
2007	A11	Erzurum-Yukarısivri Village	TKTTC
2008	B1	Adana-Çukurova Agr. Res. Inst.	TKTTC
2008	B2	Osmaniye-Toprakkale	SJSTC
2008	B3	Çorum	RKGTC
2008	B4	Çorum	TKKTC
2008	B5	Çorum	TKCTC
2008	B6	Amasya-Merzifon	TKJTC
2008	B7	Samsun	TKTTC
2008	B8	Ankara	RKRTC
2008	B9	Samsun-Vezirköprü	TTJTC
2008	B10	Kayseri-Hisarcık	TKTTC
2008	B11	Kayseri-Mengücek	PKSTC
2008	B12	Kayseri-Kepez	RTKTF
2008	B13	Kayseri-Himmetdede	TKSTC
2008	B14	Eskişehir-Anatolian Agr. Res. Inst.	PKTTC
2008	B15	Yozgat-Çalatlı Village	TKTTF
2008	B16	Yozgat-Saraykent	TKSTC
2008	B17	Yozgat-Davutlu Village	RTKTF
2008	B18	Sivas-Çukursaray Village	LRHPF
2008	B19	Sivas-Çukursaray Village	TKTTC
2008	B20	Sivas-Kavak	RTKTF
2008	B21	Sivas-Hafik	TKSTC
2008	B22	Sivas-Hafik	TKTTC
2008	B23	Erzincan-Refahiye	RTKTF
2008	B24	Erzincan	MRKTF
2008	B25	Sivas-Yıldızeli	TKKTC
2008	B26	Kastamonu-Ağlı	RTKTC
2008	B27	Kastamonu-Ağlı	RTTTC
2008	B28	Kastamonu-Seydiler	RTTTF
2008	B29	Erzurum-Pasinler	TKTTC

Table 4. Races of *Puccinia graminis* f. sp. *tritici* identified in Turkey in 2007.

Genotypes	Resistance gene	Stem rust isolates collected in 2007*										
		A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11
ISr5-Ra	Sr5	3	3	3+	3+	3+	3+	3+	3+	33+	3+	3+
Cns_*Triticum monoc.* deriv.	Sr21	3	22+	3+	2+	2+	2+	2+3	3	3	3	3
Vernstein	Sr9e	3+	3	3+	3+	3	3+	3	3+	3+	3+	3
ISr7b-Ra	Sr7b	3+	3	3+	3	33+	3+	33+	3+	3	3	3
ISr11-Ra	Sr11	1-	1-	2-	1-	1-	1-	1-	2-	1-	1-	1-
ISr6a-Ra	Sr6	2+3	3+	3	3	3+	3+	3+	33+	33+	3+	3
ISr8a-Ra	Sr8a	3+	3	3+	3+	3+	3+	3+	3	33+	3+	3+
CnSr9g	Sr9g	3	3+	3+	3+	3+	3+	3+	3+	3+	3+	3+
W2691SrTt-1	Sr36	3+	3+	3+	3	x	3-	3+	3+	3+	3	3+
W2691Sr9b	Sr9b	3+	3	3+	2+	3	3-	3	3	3+	33+	3
BtSr30Wst	Sr30	3+	3	3+	3	3+	3+	3+	3	3+	33+	3
Combination VII	Sr17+13	2-	1-	3+	2-	1-	22+	3+	3	3+	3+	3
ISr9a-Ra	Sr9a	3+	3+	3	3	3+	3+	3	3+	3+	3+	3
ISr9d-Ra	Sr9d	3+	3+	3	3	3+	3+	3+	3+	2+3	3+	3
W2691Sr10	Sr10	3	33+	3	3+	3+	3+	3+	3	3	3+	3+
CnsSrTmp	SrTmp	3	3	2+	3+	22+	33+	3	33+	3	3	33+
LcSr24Ag	Sr24	1-	2-	2-	2-	1-	1-	22+	2-	22-	22+	22+
Benno Sr31/6*LMPG	Sr31	1-	1-	1-	2-	1-	1-	2-	1-	2-	2-	2-
Trident	Sr38	;	;	X	1-	1-	;	x	1-	;	:1-	1-
McNair 701	SrMcN	3+	3+	3+	3+	3+	3+	3	3+	3+	3+	3
Races		TKSTC	PKSTC	TKTSC	PKNTC	PKJSC	PKSTC	TKTTC	TKTTC	TKTTC	TKTTC	TKTTC

*0-4 scale was used for seedling assessment. 0, ;, 1, and 2 and combinations of these scores were low infection types; 3 and 4 and the combination of these scores were high infection types (Stakman et al. 1962).

Table 5. Races of *Puccinia graminis* f. sp. *tritici* identified in Turkey in 2008.

	Genotypes	Resistance gene	Stem rust isolates collected in 2008*														
			B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15
1	ISr5-Ra	Sr5	3+	3	3+	3+	3	3+	3+	3+	3+	3+	3+	3+	3+	3+	3+
2	Cns_*Triticum monoc*. deriv.	Sr21	3+	3	3	3+	3	3	3	3+	3+	3+	2+	3+	3-	2+	3+
3	Vernstein	Sr9e	3+	3+	;	3+	3	3+	3+	2-	3+	3+	3+	2-	3+	3+	3+
4	ISr7b-Ra	Sr7b	3	2+	3+	3+	3	3	3+	3+	3+	3+	3+	3+	3+	3+	3+
5	ISr11-Ra	Sr11	1-	1-	;	2+	2-	2+	;	1-	3+	2+	1-	3+	1+	2+	2+
6	ISr6a-Ra	Sr6	3+	3	3+	3+	3	3+	3+	3+	3+	3+	3+	3+	3+	3+	3+
7	ISr8a-Ra	Sr8a	3+	3	3+	3+	3	3-	3+	3+	3+	3+	3+	3+	3+	3	3+
8	CnSr9g	Sr9g	3+	2+	3+	3+	3	3+	3+	3+	3+	3+	3+	3+	3+	3+	3+
9	W2691SrTt-1	Sr36	3+	3+	;1-	;	1-	0	3	3+	0;	3+	3+	0;	3	3	3+
10	W2691Sr9b	Sr9b	3	3+	3c	3+	1-	3+	3	3+	3+	3+	3+	3+	3-	3+	3+
11	BtSr30Wst	Sr30	3+	3	22+	3+	2+	3	3+	2-	3+	3+	3+	3+	3+	3+	3+
12	Combination VII	Sr17+13	3+	2+	2	3	3	2+	3	3+	2-	3+	2-	3+	2+	3+	3+
13	ISr9a-Ra	Sr9a	33+	3	3+	3+	3	3+	3	33+	3+	3+	3+	3+	3+	3+	3+
14	ISr9d-Ra	Sr9d	3+	3	3+	3+	3	3+	3	3+	3+	3+	3+	3+	3+	3+	3+
15	W2691Sr10	Sr10	3+	3	3+	3+	3	3+	3+	3+	3+	3+	3+	3+	3+	3+	3+
16	CnsSrTmp	SrTmp	3	3+	3+	3+	3	3+	3+	3	3+	3+	3	3+	3+	3+	3+
17	LcSr24Ag	Sr24	2-	;1-	2-	2-	2-	2+	2+	2-	2-	2+	1-	2+	2-	2+	2+
18	Benno Sr31/6*LMPG	Sr31	1-	;1-	;1-	2-	1-	2+	;1-	1-	2-	2+	2-	1-	2+	2+	2+
19	Trident	Sr38	;cn	;	;	2-	;	1+	x	;	1-	2-	;cn	3+	1+	1-	3+
20	McNair 701	SrMcN	3+	3+	3+	3+	3+	3+	3+	3+	3+	3+	3+	3+	3+	3+	3+
	Races		TKTTC	SJSTC	RKGTC	TKKTC	TKCTC	TKJTC	TKTTC	RKRTC	TTJTC	TKTTC	PKSTC	RTKTF	TKSTC	PKTTC	TKTTF

Table 5. (Continued).

	Genotypes	Resistance gene	Stem rust isolates collected in 2008*													
			B16	B17	B18	B19	B20	B21	B22	B23	B24	B25	B26	B27	B28	B29
1	ISr5-Ra	Sr5	3+	3	3+	3	3+	3+	3	3+	3+	3	3+	3	3+	3+
2	Cns_*Triticum monoc.* deriv.	Sr21	3+	3	22+	3	3+	3+	3	3+	2-	3	33-	3	3+	3+
3	Vernstein	Sr9e	3+	1-	22-	3	2-	3	3	;1-	1-	3	1-	1-	2-	3+
4	ISr7b-Ra	Sr7b	3+	3	2+	3	3+	3	3	3+	3+	3	33+	3	3+	3+
5	ISr11-Ra	Sr11	1-	3	3+	1-	3+	1-	1-	3+	3+	1-	33+	3	3+	2-
6	ISr6a-Ra	Sr6	3+	3	3	3	3+	3+	3	3+	3	3	3+	3	3+	3+
7	ISr8a-Ra	Sr8a	3+	3	22+	3	3+	33+	3	3+	2+	3	3	3	3+	3+
8	CnSr9g	Sr9g	3+	3	3	3	3+	3+	3	3+	3+	3	3+	3	3+	3+
9	W2691SrTt-1	Sr36	3+	;1-	;	3	x	3+	3	;	;	;	;	3	3+	3+
10	W2691Sr9b	Sr9b	3	3	3	3	3+	2+3	3	3	3+	3	3-	3	3+	3+
11	BtSr30Wst	Sr30	3+	3	22-	3	3+	3+	3	3	3	3	3+	3	3+	3+
12	Combination VII	Sr17+13	2	3	33+	3	3+	2	3	3+	3	3	3+	3	3+	3+
13	ISr9a-Ra	Sr9a	3+	3+	3	3	3+	3+	3	3+	3	3	3+	3	3+	3+
14	ISr9d-Ra	Sr9d	3+	3+	2+	3	3+	3+	3	3+	3	3	3+	3	3+	3+
15	W2691Sr10	Sr10	3+	3+	3+	3	3+	3+	3	3+	3+	3	3	3	3+	3+
16	CnsSrTmp	SrTmp	2+3	3	3	3	3+	3+	3	3+	3	3	3+	3	3+	3+
17	LcSr24Ag	Sr24	2+	;	22-	1-	2+	1-	1-	2-	1-	1-	22+	1-	2+	2+
18	Benno Sr31/6*LMPG	Sr31	1-	;	1-	1-	2+	2-	1-	1-	1-	1-	1-	1-	2-	2+
19	Trident	Sr38	;	3	33+	;	3+	;	;	3	3+	;	1-	;	3	2-
20	McNair 701	SrMcN	3+	3	3+	3+	3+	3+	3	3+	3+	3	3+	3+	3+	3+
	Races		TKSTC	RTKTF	LRHPF	TKTTC	RTKTF	TKSTC	TKTTC	RTKTF	MRKTF	TKKTC	RTKTC	RTTTC	RTTTF	TKTTC

*0-4 scale was used for seedling assessment. In this scale, 0, ;, 1, and 2 and combinations of these scores were low infection types, while 3 and 4 and the combination of these scores were high infection types; cn: chlorosis and necrosis (Stakman et al. 1962).

Table 6. Number and percentage of virulent *Puccinia graminis* f. sp. *tritici* isolates on stem rust resistance genes in the differential set.

	Genotype	Resistance gene	Number of virulent isolates	Percentage of virulent isolates
1	ISr5-Ra	Sr5	40	100
2	Cns_*Triticum monoc*. deriv.	Sr21	32	80
3	Vernstein	Sr9e	29	72.5
4	ISr7b-Ra	Sr7b	38	95
5	ISr11-Ra	Sr11	10	25
6	ISr6a-Ra	Sr6	40	100
7	ISr8a-Ra	Sr8a	38	95
8	CnSr9g	Sr9g	39	97.5
9	W2691SrTt-1	Sr36	26	65
10	W2691Sr9b	Sr9b	38	95
11	BtSr30Wst	Sr30	36	90
12	Combination VII	Sr17+13	27	67.5
13	ISr9a-Ra	Sr9a	40	100
14	ISr9d-Ra	Sr9d	39	97.5
15	W2691Sr10	Sr10	40	100
16	CnsSrTmp	SrTmp	38	95
17	LcSr24Ag	Sr24	0	0
18	Benno Sr31/6*LMPG	Sr31	0	0
19	Trident	Sr38	8	20
20	McNair 701	SrMcN	40	100

lower than the long-term average (Turkish State Meteorological Service 2009).

Even though stem rust incidences were relatively high in both years, the percentage of plants infected with stem rust in diseased fields was low. The number of fields inspected during 2007 and 2008 was different (Table 2). Mean disease percentage showed differences in 2007 and 2008 in the inspected fields. The highest disease percentage (80%) was found in a field of Çorum Province in 2007 and in a field of Kastamonu Province in 2008. Although Adana and Osmaniye provinces have climates that favor rust development, the diseases were not apparent. The use of fungicides by farmers for rust control could explain why only a limited number of fields infected with stem rust were found in 2007 and 2008 in the Mediterranean region (Table 2). The surveys were undertaken between the milky dough and yellow head growth stages (Zadoks scale 70 to 80), from May to July depending on the actual region. This period

Table 7. Reactions of other resistance genes to *Puccinia graminis* f. sp. *tritici* isolates obtained in Turkey during 2007 and 2008.

	Genotypes	Resistance gene	Stem rust isolates collected in 2007, races identified, and reactions of other resistance genes*											Stem rust isolates collected in 2008, races identified, and reactions of other resistance genes*				
			A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	B1	B2	B3	B5	B6
			TKSTC	PKSTC	TKTSC	PKNTC	PKJSC	PKSTC	TKTTC	TKTTC	TKTTC	TKTTC	TKTTC	TKTTC	SJSTC	RKGTC	TKCTC	TKJTC
1	W2691Sr13	Sr13	2-	2-	3	2-	1-	22+	3+	3	3+	3+	3+	3+	2+	1-	3	2+
2	Eagle	Sr26+Sr9g	1-	1-	2-	;1-	1-	1-	22-	1-	2-	1-	;12-	;	1-	;1-	1-	1-
3	Coorong Triticale	Sr27	;	;	2-	;	;1-	;1-	;12-	;1-	;	;1-	;	;	1-	0	;	1-
4	Tetra Canthatch/ *Ae. squ.* (RL5045)	Sr33+Sr5	1-	;1-	22-	1-	1-	1-	2-	1-	2-	2-	;12-	;1-	1-	2	;	2-
5	RL6088	Sr40	1-	2	***	2-	1-	1-	33+	1-	3+	22+	2+	22+	2	;	;	22-
6	Taf-2	Sr44	3+	***	3+	3+	33+	3+	3+	3+	3+	3+	33+	3	2	2-	1-	1-

Table 7. (Continued).

	Genotypes	Resistance gene	Stem rust isolates collected in 2008, races identified, and reactions of other resistance genes*															
			B7	B8	B9	B11	B12	B16	B17	B18	B19	B21	B22	B23	B24	B25	B26	B27
			TKTTC	RKRTC	TTJTC	PKSTC	RTKTF	TKSTC	RTKTF	LRHPF	TKTTC	TKSTC	TKTTC	RTKTF	MRKTF	TKKTC	RTKTC	RTTTC
1	W2691Sr13	Sr13	3	3+	1-	2-	3+	2	3	3+	3	2	3	3	3	3	3+	3
2	Eagle	Sr26+Sr9g	;1-	;	1-	1-	;	;1-	;1-	1-	1-	;	;	1-	1-	;1-	22+	;1-
3	Coorong Triticale	Sr27	;	;	;1-	;	0;	;	;	1-	;	;	;	;	;1-	1-	0;	;1-
4	Tetra Canthatch/*Ae. squ.* (RL5045)	Sr33+Sr5	3	;1-	1-	;1-	;1-	;1-	1-	2	1-	;1-	1-	3+	2+	1-	;	;1-
5	RL6088	Sr40	2+	2-	3	2	1-	2-	3	2+	2-	22-	2-	2-	2-	3+	2	2
6	Taf-2	Sr44	;	***	***	3+	3+	22-	;	;	2+	;1	2+	3+	***	1-	3+	3+

*0-4 scale was used for seedling assessment. In this scale, 0, ;, 1, and 2 and combinations of these scores were low infection types, while 3 and 4 and the combination of these scores were high infection types (Stakman et al. 1962).

**There were no results for B4, B10, B13, B14, B15, B20, B28, or B29 stem rust isolates.

***There were no results for the genotype.

of about 3 months was due to differences in plant phenology and made the survey difficult in terms of time and labor. In addition, differences between the regions in terms of climate, sowing time, genotypes, and the effects of soil conditions on wheat growth affected the survey periods.

The isolation of 21 *Pgt* races among the 40 isolates collected in 2007 and 2008 showed that pathogenic variation was high. When present, the alternative hosts (*Berberis* spp.) of stem rust upon which sexual reproduction occurs can be an important source of pathogenic variation (Knott 1989; Roelfs et al. 1992). *Berberis* spp. is common in Turkey (Davis 1965). Some of the fields from which isolates were obtained are in areas in which *Berberis* bushes grows naturally (Davis 1965). It is therefore possible that many of the races identified in those areas originated from *Berberis* spp. Of the races identified, TKTTC was the most common. There was no correlation among the races and regions from which they were isolated. For example, race TKTTC was found in Erzurum (4 isolates), Sivas (3 isolates), Samsun, Kayseri, Adana, and Kastamonu provinces. There were also different races in provinces where more than 1 isolate was obtained (i.e. Kastamonu and Sivas provinces). In Kastamonu, in 2007, 1 isolate was identified as race TKTTC; however, in 2008, the isolates were identified as races RTKTC, RTTTF, and RTTTC. It appears that there were variations in the reactions of Sr9e, Sr11, Sr36, and Sr38 resistance genes in the region. Given that these isolates were obtained from an area rich in *Berberis* spp., it is possible that this could have enhanced the variation observed in this region.

Major epidemics of wheat stem rust, caused by *Puccinia graminis* f. sp. *tritici*, occurred in the US from 1900 through the 1950s. Since the late 1950s, destruction of *Berberis* bushes and registration of new cultivars containing more than one resistance gene reduced the number of epidemics and the virulence exchange in the pathogen significantly (Roelfs 1982). In recent surveys, 5 dominant stem rust races were found in the USA (Kolmer et al. 2007). In another study, stem rust samples were collected from 1 barley field, and from the 83 single pustule isolates obtained, 27 different *Pgt* races were found (Rouse et al. 2009). In this case, it is thought that the *Berberis* bushes common around the field were responsible for the high number of races identified. In recent years, barberry plants have been found in several of the original eradication sites in southeastern Minnesota in the USA (Peterson et al. 2005).

Studies on stem rust have been undertaken since the 1760s throughout the world, and there are records of stem rust in Turkey dating back to 1930. The stem rust fungus is an obligate pathogen and its main host is the wheat plant. Turkey is one of the gene centers of bread and durum wheat (Gökgöl 1939; Vavilov 1950; Harlan 1971; Özkan et al. 2002) and this obligate pathogen has probably coexisted with wheat for a long time. This could have affected the pathological variation observed in the fungus in Turkey.

Stem rust races are virulent on many genotypes possessing different resistance genes, including genotypes containing the resistance gene Sr31 throughout the world. The spread of an aggressive and new stem rust race, TTKS, was determined in the North American nomenclature system. This race, which is called Ug99, and subtypes such as TTKST, TTKSK, and TTKSK, are being carefully monitored by different countries such as Kenya, Uganda, Yemen, the USA, Canada, Australia, China, and India (Jin et al. 2008, 2009). Our results showed that Ug99 stem rust races were not determined in 40 isolates. The genotypes including Sr31 and Sr24 resistance genes affected by Ug99 and newly emerged subtypes were especially found to be resistant to all stem rust isolates in our study. Genotypes possessing Sr26 and Sr27, which were included in the supplemental set, were also resistant to Ug99 (Singh et al. 2006) as well as the stem rust races present in Turkey (Table 7). The stem rust races found in our study were virulent on many of the known stem rust resistance genes. Should environmental conditions favor the disease, and with the planting of susceptible wheat cultivars, an epidemic with the potential for large crop losses could develop.

There are some difficulties in comparing the race results of this study and previous studies conducted in Turkey. İren (1955) used a different differential set than that used in our study and identified 5 stem rust races from 17 isolates collected from the Central Anatolia region. In our study, more samples were collected from a wider area. This could be why more races were identified in our study. In another study,

Çelik et al. (1976) identified race RKT (virulent on Sr5, Sr9d, Sr7b, Sr6, Sr8a, Sr9a, Sr14, Sr16, Sr13, and Sr10, and avirulent on Sr9e and Sr11) and race RLJ (virulent on genotypes carrying Sr5, Sr9d, Sr7b, Sr11, Sr6, and Sr13 and avirulent on genotypes carrying Sr9e, Sr8a, Sr9a, Sr14, Sr16, and Sr10). Genotypes possessing Sr9e and Sr11 appear not to be affected by the race RKT. In our study, 25% of the isolates were virulent on Sr11 and 75% of the isolates were virulent on Sr9e (Table 6). Bolat et al. (1993) reported that race RKG was avirulent on Sr11. This race was also found in our study. In 2002, a total of 17 different stem rust races were determined from samples obtained from the North Transitional region and Central Anatolia region of Turkey by the Cereal Disease Laboratory, Minnesota, USA: QHCD, RKCJ, QHCN, QHJCS, QKCS, QJCD, QHCS, QHCD, RKCJ, QCHN, QKCS, QCCN, QHJCS, HFCS, RKCN, QKHJ, and RKHD (Düşünceli et al. 2005). In this study, large variation was observed in terms of the determined races. It appears that many resistance genes have different reactions to the races, and our results confirmed that there are many stem rust races in Turkey. Düşünceli et al. (2005) reported that Sr7b was effective against many races; however, in our study, this genotype was susceptible to all isolates tested. The genotypes possessing at least one of the resistance genes Sr24, Sr31, Sr26, or Sr27 were resistant to all isolates tested (Tables 4, 5, and 7). Each of these resistance genes or a combination of them could be used in developing stem rust resistant cultivars.

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