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Research Article/Araştırma Makalesi

Identification of genetic immunity to the warrior race and local population of stripe rust using conventional techniques in winter wheat genotypes

Kışlık buğday genotiplerinde konvansiyonel teknikler kullanılarak çizgili pas'ın warrior ırkı ve yerel popülasyonuna genetik bağışıklığın belirlenmesi

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ABSTRACT

Wheat stripe rust caused by the *Puccinia striiformis* f. sp. *tritici* (Pst) is a major and devastating biotic stress inducing notable product losses in wheat (*Triticum* spp.). Possibility of the breakdown of important genes conferring resistance against to stripe rust and the threat of emergence of new aggressive races remain a concern in all wheat growing areas around the world. Therefore, breeding programs must continue screening of wide genetic diversity to improve new varieties with different gene combinations against race changes. Within this scope, 140 wheat genotypes obtained from various countries and programs were evaluated in terms of their reactions to stripe rust at both seedling and adult-plant stages in 2020 and 2021 growing seasons. The adult-plant stage evaluations of these genotypes were conducted under artificial inoculation of PstS7 (*Warrior*) race at Haymana location of Field Crops Central Research Institute in Ankara and under naturally occurring local stripe rust population at Menemen location of Aegean Agricultural Research Institute in Izmir. Whereas the seedling stage tests were carried out using the PstS7 race under controlled conditions at Pest and Disease Resistance Unit of the Field Crops Central Research Institute. More than 80% of the genotypes tested at both locations exhibited immune, resistant, and moderately resistant reactions at the adult-plant stage, while only 36.4% of the genotypes exhibited resistance reactions at the seedling stage. The coefficients of infection (CI) of the genotypes were calculated by using the stripe rust reaction and disease severity of each genotype. Following scales were used for classification of the genotypes based on the CI: 0 = Immune; 0.1-5.0 = Resistant; 5.01-20.0 = Moderately Resistant; 20.1-40.0 = Moderately Susceptible; 40.1-100 = Susceptible. In conclusion, 101 genotypes (72.1%) evaluated at both locations were found to be immune, resistant, and moderately resistant to both the PstS7 race and local stripe rust population. These genotypes have been proposed as resistance gene sources for cultivars to be developed.

Key Words: Winter wheat; Stripe rust; Resistance; *Warrior* race; Local rust population

ÖZ

Puccinia striiformis f. sp. *tritici*'nin neden olduğu buğday çizgili pası, buğday'da (*Triticum* spp.) dikkate değer ürün kayıplarına neden olan önemli ve yıkıcı bir biyotik strestir. Çizgili pasa karşı dayanıklılık sağlayan önemli genlerin kırılma olasılığı ve yeni agresif ırkların ortaya çıkma tehdidi, dünyadaki tüm buğday yetiştirilen alanlarda endişe kaynağı olmaya devam etmektedir. Bu nedenle, ıslah programları ırk değişikliklerine karşı farklı gen kombinasyonlarına sahip yeni çeşitler geliştirmek için geniş genetik çeşitliliği taramaya devam etmelidir. Bu kapsamda, çeşitli ülke ve programlardan temin edilen 140 buğday genotipi, 2020 ve 2021 yetiştirme sezonlarında hem fide ve hem de ergin-bitki dönemlerinde çizgili pasa gösterdikleri reaksiyonlar bakımından değerlendirilmiştir. Bu genotiplerin ergin-bitki evresi değerlendirmeleri, Ankara'daki Tarla Bitkileri Merkez Araştırma Enstitüsü'nün Haymana lokasyonunda PstS7 (*Warrior*) ırkının suni inokülasyonu altında ve İzmir'deki Ege Tarımsal Araştırma Enstitüsü'nün Menemen lokasyonunda çizgili pasın doğal olarak ortaya çıkan yerel popülasyonu altında yürütülmüştür. Fide dönemi testleri ise Tarla Bitkileri Merkez Araştırma Enstitüsü, Hastalık ve Zararlılara Dayanıklılık Birimi'nde kontrollü koşullarda PstS7 ırkı kullanılarak gerçekleştirilmiştir. Her iki lokasyonda da test edilen genotiplerin %80'inden fazlası ergin-bitki evresinde immun, dayanıklı ve orta derecede dayanıklı reaksiyonlar sergilerken, genotiplerin sadece %36.4'ü fide döneminde dayanıklılık reaksiyonları sergilemiştir. Genotiplerin enfeksiyon katsayıları (CI), her bir genotipin çizgili pas reaksiyonu ve hastalık şiddeti kullanılarak hesaplanmıştır. Genotiplerin CI'na göre sınıflandırılmasında 0 = immun; 0.1-5.0 = dayanıklı; 5.01-20.0 = orta dereceli dayanıklı; 20.1-40.0 = orta dereceli hassas; 40.1-100 = hassas skalası kullanılmıştır. Sonuç olarak, her iki lokasyonda değerlendirilen 101 genotip (%72.1) hem PstS7 ırkına hem de yerel çizgili pas popülasyonuna karşı immun, dayanıklı ve orta dereceli dayanıklı bulunmuştur. Bu genotipler, geliştirilecek çeşitler için dayanıklılık gen kaynakları olarak önerilmiştir.

Anahtar Kelimeler: Kışlık buğday; Çizgili pas; Dayanıklılık; *Warrior* ırkı; Yerel çizgili pas popülasyonu

Introduction

The world population is anticipated to reach 9.7 billion by 2050 (Arora, 2019). Therefore, it is estimated that the demand for food will increase by up to 50%. The majority of this demand 70% is expected to be for wheat (Anonymous, 2021). However, wheat production is being significantly affected by abiotic and biotic stress factors. Among biotic stresses, fungal diseases constitute the most substantial threats to wheat production. Wheat stripe rust disease, caused by the obligate parasite *Puccinia striiformis* f. sp. *tritici* (Pst), is a major disease that occurs in many wheat-producing territories with moist and cool weather conditions during the growing season around the world. The pathogen can evolve rapidly and develop new virulent races. For this reason, stripe rust has caused a reduction in crop yields in wheat growing areas globally (Wellings, 2011). The annual loss in wheat production due to stripe rust is estimated to be equivalent to five million tons of wheat production that worths about one million dollars (Beddow et al., 2015). Even though the application of fungicides can be managed to control stripe rust development, but their usage increases production costs, and they are not environmentally friendly. Thus, breeding strategy for development of resistant cultivars to stripe rust remains the most effective and eco-friendly approach (Yang and Daqun, 2004).

A diverse of genes conferring resistance to stripe rust in wheat have been identified, previously (Wang and Chen, 2017; Feng et al., 2018; Nsabiyera et al., 2018). New resistance genes also have been detected in different germplasms/gene sources in the last 10 years such as *Yr83, Yr82, Yr81,* and *Yr84* (Gessese et al., 2019; Pakeerathan et al., 2019; Li et al., 2020; Klymiuk et al., 2022). In addition, various studies have been conducted on the presence of major resistance genes (*Yr5, Yr10*, and *Yr15*) in Turkish bread and durum wheat varieties as well as their wild relatives (Cat, 2021; Cat et al., 2022; Ipek et al., 2022; Tekin et al., 2022). The genes providing resilience to stripe rust have been designated as seedling resistance (R genes) and adult-plant resistance (APR). The R genes are race-specific and remain active throughout all growth stages of plants and are inherited monogenic. The R genes usually do not stay durable because of new races with a new virulence or combination of stripe rust (Line et al., 2002; Ellis et al., 2014). However, the APR genes function mainly at the adult-plant stage, and plants with adult-plant resistance are susceptible at the seedling stage but become resistant and durable in the late stages. Consequently, enhancing the improvement of new resistant varieties will reduce the frequency of stripe rust outbreaks and production costs, as well as contribute to minimizing environmental and human health risks and increasing the sustainability of production.

The objective of this study was to examine 140 wheat genetic materials in terms of stripe rust reactions at the seedling and adult-plant stages. In this way, genotypes resistant to stripe rust will be determined and recommended for use as genetic resources within the breeding community.

Material and Methods

Genetic materials

One-hundred-forty wheat genotypes (Table 1), including winter/facultative types, originating from different countries/programs, were used in this research. These genotypes were obtained from the International Winter Wheat Improvement Program (IWWIP). The primary purpose of this program is to develop winter/facultative wheat germplasms for the territory of Central and West Asia (CWA). All IWWIP germplasms are assessed in terms of stripe rust resistance under natural epidemic conditions or artificial inoculation before being distributed to wheat breeding communities.

To determine the efficiency of major resistance genes of stripe rust, two differential sets composed of genotypes (a combination of lines from the World and Europe differential sets) with different stripe rust resistance gene(s) were planted and assessed as per (Johnson et al., 1972; Wellings et al., 2004; De Vallavieille-Pope et al., 2012; Hovmøller et al., 2016). The differential set used in Izmir consists of *Yr1, Yr3, Yr5, Yr6, Yr7, Yr8, Yr9, Yr10, Yr15, Yr17, Yr18, Yr24, Yr26, Yr27, Spaldings Prolific, Avocet* 'S'. The differential set used in Ankara consists of *Yr1, Yr2, Yr3, Yr4, Yr5, Yr6, Yr7, Yr8, Yr9, Yr10, Yr17, Yr15, Yr24, Yr25, Yr26, Yr32,* and *Spaldings Prolific, Ambition* and *Avocet* 'S'. Rust spore samples of the PstS7 race were obtained from the Regional Cereal Rust Diseases Research Center located at the Aegean Agricultural Research Institute. The samples were reproduced and kept in an ultra-cold freezer (-80 °C) after drying in silica gel at +4 °C for 4 days in the Pathology Department of Field Crops Central Research Institute (Roelfs et al., 1992).

Table 1. Pedigree and origin of wheat genetic materials used in the research

Genotype	Pedigree	Origin
1	KATIA1	BULGARIA
2	GTP RADA	BULGARIA
3	GTP KALINA	BULGARIA
4	RF5	CHINA
5	RF6	CHINA
6	RF8	CHINA
7	RF36-2	CHINA
8	SALAZAR	GERMANY
9	THORUS	GERMANY
10	MV-BOJTAR	HUNGARY
11	AZAR2/87ZHONG291-58	IRAN
12	KAZAKHSTANSKAYA25/TR.TIMOPHEEVI-1	KAZAKHSTAN
13	DANPHE #1*2/SOLALA	MEXICO
14	VILLA JUAREZ F2009/SOLALA//WBLL1*2/BRAMBLING	MEXICO
15	SPARTANKA//PBW343*2/KUKUNA	MEXICO
16	KRASNOVODOPADSKAYA-25//PBW343*2/KUKUNA	MEXICO
17	GRK79/KKTS	MEXICO
18	ALMALY//PRL/2*PASTOR	MEXICO-TCI
19	NEMURA/CRDN//78014.40/3/ATTILA/BAV92//PASTOR/4/GONDVANA	MEXICO-TCI
20	DORADE-5/3/SUNCO.6/FRAME//PASTOR/4/DORADE-5	MEXICO-TCI
21	MERC/4/BJY/COC//PRL/BOW/3/FRTL/5/MRS/CI14482//YMH/HYS/3/H84160/4/RMN//F12.71/JUP	MEXICO-TCI
22	ALPU01/4/338-K1-1//ANB/BUC/3/KIRGIZ	MEXICO-TCI
23	FGMUT213	ROMANIA
24	ZINA	ROMANIA
25	BEZOSTAYA1	RUSSIA
26	KONKURENT	RUSSIA
27	AJVINA	RUSSIA
28	CH-111.15797	SWITZERLAND
29	ISFARA	TAJIKISTAN
30	NACIBEY	TCI
31	GANSU-1/MEZGIT-4	TCI
32	KS96WGRC39/JAGGER//BLOYKA	TCI

Genotype	Pedigree	Origin
33	YUBILEINAYA75/3/AGRI/BJY//VEE/4/SAULESKU #26/PARUS	TCI
34	8229/OK81306/8/AGRI/BJY//VEE/6/SN64//SKE/2*ANE/3/SX/4/BEZ/5/SERI/7/F10S-1	TCI
35	ESKINA-7/3/NEMURA/CRDN//78014-40	TCI
36	AGRI/NAC//KAUZ/3/1D13.1/MLT/4/ATAY/GALVEZ87//SHARK-1	TCI
37	F4141-W-1-1/PASTOR//PYN/BAU/4/VORONA//MILAN/SHA7/3/MV17/5/DORADE-5	TCI
38	DANPHE #1/6/CA8055/4/ROMTAST/BON/3/DIBO//SU92/CI13645/5/AGRI/BJY//VEES	TCI
39	JING411//PLK70/LIRA/3/GUN91/4/CANADIAN/2*PASTOR/5/CANADIAN/CUNNINGHAM//KENNEDY	TCI
40	F885K1.1/SXL/3/OMBUL/A1AMO//MV11/4/BONITO-36	TCI
41	PRL/2*PASTOR/3/KS82W409/SPN//TAM106/TX78V3630	TCI
42	UC1110(5+10;YR15;YR15;GPC)/8/AU/3/MINN//HK/38MA/4/YMH/34A/5/CT/GGT/6/PYN//TAM101/AMI/7/JUP/4/CLLF/3/II14-53/ODIN//CI134431/SEL6425/WA00477	TCI
43	SAVALAN//KRC66/SERI/3/TORIK/4/2*F10S-1//STOZHER/KARL	TCI
44	ESPADA/KARAHAN	TCI
45	OBRII/DNESTREANCA25//ILICIOVCA/OD.CRASNOCOLOS/3/UN-49	TCI
46	TX71A983.4/TX69D4812//PYN/3/VPM/MOS83.11.4.8//PEW/4/TAM200/KAUZ	TCI
47	MUFITBEY	TCI
48	PMF/MAYA//YACO/3/CO693591/CTK	TCI
49	RINA-6/4/BEZ/NAD//KZM (ES85.24)/3/F900K	TCI
50	TREGO/JGR 8W//DORADE-6	TCI
51	AGRI/BJY//VEE/6/SN64//SKE/2*ANE/3/SX/4/BEZ/5/SERI/7/F10S-1/8/AGRI/NAC//KAUZ/3/1D13.1/MLT	TCI
52	YUBILEINAYA75/3/AGRI/BJY//VEE/4/PYN/BAU	TCI
53	CA8055/4/ROMTAST/BON/3/DIBO//SU92/CI13645/5/AGRI/BJY//VEES/6/KS9468/NWT//ARKAN/3/PASTOR/7/YE2453//PPBB68/CHRC	TCI
54	ESPADA//KS82142/PASTOR	TCI
55	GALVEZ/WBLL1/6/CA8055/4/ROMTAST/BON/3/DIBO//SU92/CI13645/5/AGRI/BJY//VEES	TCI
56	AUS GS50AT34/SUNCO//CUNNINGHAM/3/ZARGANA-6/4/F10S-1//ATAY/GALVEZ87	TCI
57	AKULA/BONITO//F10S-1/7/AGRI/NAC//MLT/5/GOV/AZ//MUS/3/DODO/4/BOW/6/VORONA/TR810200/8/MAHON DEMIAS/3/HIM/CNDR//CA8055	TCI
58	TJB368.251/BUC//WEAVER/3/SIERRA/WI88-052/4/KUPAVA	TCI
59	AGRI/NAC//ATTILA/3/MV10-2000	TCI
60	SELYANKA/MERCAN-1	TCI
61	KROSHKA/GONDVANA	TCI
62	KINGBIRD/BILINMIYEN96.7	TCI
63	NIKIFOR/KROSHKA	TCI
64	NIKIFOR/KROSHKA	TCI
65	CBRD/TNMU//MILAN/SHA7/3/AGRI/NAC//ATTILA/4/IVETA NTA-92/89-6	TCI
66	VICTORYA/4/WBLL1/3/TSI/VEE#5//KAUZ/5/VORONA//MILAN/SHA7/3/MV17	TCI
67	PATWIN YR5/5/TAM 105/3/NE70654/BBY//BOW"S"/4/CENTURY*3/TA2450	TCI
68	PBW343/HUITES/4/YAR/AE.SQUARROSA (783)//MILAN/3/BAV92/5/AU/CO652337//2*CA8-155/3/F474S1-1.1	TCI
69	GONDVANA/5/ATTILA/3*BCN//BAV92/3/TILHI/4/SHA7/VEE#5//ARIV92/6/PATWIN YR5	TCI
70	GONDVANA/5/ATTILA/3*BCN//BAV92/3/TILHI/4/SHA7/VEE#5//ARIV92/6/PATWIN YR5	TCI
71	MILAN/S87230//BABAX/3/VORONA/KAUZ//1D13.1/MLT	TCI
72	TRCH/SRTU//KACHU/7/VEE#8//JUP/BJY/3/F3.71/TRM/4/BCN/5/KAUZ/6/163	TCI
73	MT0419/DESTIN//BONITO-36	TCI
74	SHARP/3/PRL/SARA//TSI/VEE#5/5/VEE/LIRA//BOW/3/BCN/4/KAUZ/6/DAPHAN	TCI
75	MAHON DEMIAS/3/HIM/CNDR//CA8055/4/INQALAB 91*2/TUKURU//PVN/3/INQALAB 91*2/KHVAKI	TCI
76	2180*K/2163//?/3/W1062A*HVA114/W34106/HP 1731	TCI
77	00*0100-51/3/T.DICOCCON PI94625/AE.SQUARROSA(372)//3*PASTOR	TCI
78	POSTROCK/4/AGRI/NAC//KAUZ/3/1D13.1/MLT	TCI
79	PANTHEON/BLUEGIL-2/6/SERI.1B*2/3/KAUZ*2/BOW//KAUZ/4/PBW343*2/KUKUNA/5/WHEAR	TCI
80	53/3/ABL/1113//K92/4/JAG/5/KS89180B/6/PBW343*2/KUKUNA*2//YANAC	TCI

Genotype	Pedigree	Origin
81	PANTHEON/BLUEGIL-2/3/INQALAB 91*2/TUKURU//WHEAR	TCI
82	LCR/SERI/3/MEX-DW/BACA//VONA/4/TAM200/JI5418/5/BABAX/LR42//BABAX*2/3/BRAMBLING	TCI
83	KS82142/PASTOR/3/ATTILA*2/PBW65*2//YANAC	TCI
84	QUAIU/3/MILAN CM75118/KA CM75118//TAJAN/4/MAHON DEMIAS/3/HIM/CNDR//CA8055	TCI
85	SAULESKU #44/TR810200//QUAIU/3/SAULESKU #44/TR810200	TCI
86	MERCATO/5/CHEN/AE.SQ//2*OPATA/3/BAV92/4/JARU/6/DEMIR2000/7/CUPRA-1/3/CROC1/AE.SQUARROSA (224)//2*OPATA/4/PANTHEON	TCI
87	BL2064//SW89-5124*2/FASAN/3/TILHI/4/2*BILLING(N566/OK94P597)	TCI
88	GONDVANA/6/53/3/ABL/1113//K92/4/JAG/5/KS89180B/7/AU//YT542/N10B/3/II8260 /4/JI/HYS/5/YUNNAT ODESSKIY/6/KS82W409/SPN	TCI
89	ZANDER-17//SAULESKU#26/PARUS	TCI
90	BLUEGIL-2/BUCUR//SIRENA	TCI
91	TREGO/JGR 8W//DORADE-6	TCI
92	ND643/2*WAXWING/4/TAM200/KAUZ/3/AGRI/BJY//VEE	TCI
93	PYN/BAU//ATTILA/4/ID800994.W/VEE//BAU/KAUZ/3/PYN/BAU	TCI
94	CRINA/BONITO-37	TCI
95	GONDVANA/6/53/3/ABL/1113//K92/4/JAG/5/KS89180B	TCI
96	YUKSEL	TCI
97	ALDANE	TURKEY
98	9852.1//ERYT1554.90/PEHLIVAN	TURKEY-EDIRNE-TCI
99	KARAHAN	TURKEY-KONYA
100	ESPERIA	TURKEY
101	NOGAL	TURKEY
102	BAYRAKTAR	TURKEY
103	PFAU/SERI.1B//AMAD/3/KRONSTAD F2004/4/SHARK-6/5/SHARK-6	TURKEY-EDIRNE
104	ZAPASHNA	UKRAINE-KHARKOV
105	LYMARIVNA	UKRAINE-KIEV
106	HATCHER/KS03HW12-1//NUDAKOTA	USA-COL-TCI
107	KS031009K-4/KS060142-K-4	USA-KSU
108	KS031009K-4/KS060285-M-1	USA-KSU
109	GREER/KANMARK	USA-KSU
110	KS050255K-6/KANMARK	USA-KSU
111	KS13DH002722	USA-KSU
112	KS13DH0030-20	USA-KSU
113	KS13DH0021-209	USA-KSU
114	KS14DH0012-12	USA-KSU
115	KS100298K-9	USA-KSU
116	KS100509K-2	USA-KSU
117	KS100610K-1	USA-KSU
118	OK01307/DUSTER//OK06822W	USA-OKSU
119	KS020638~5/GALLAGHER	USA-OKSU
120	(OPATA/RAYON//KAUZ)/BULK SELN 00F5-11-2//FARMEC	USA-OKSU
121	G991502/BULK SELN 00F5-11-2	USA-OKSU
122	BABAX/LR42//BABAX/3/MVC324-96/KS93U134//2137	USA-OK-TCI
123	OR2101043	USA-OSU
124	SY SUNRISE	USA-SYNGENTA
125	SY FLINT	USA-SYNGENTA
126	TAM305	USA-TX
127	KS020446TM~2/KS020469TM~1//KAJAGGER	USA-KS
128	KS940786-6-9FM/CO970547-7	USA-KS
129	ARS97135-9/O3A-B4//KS06O3A~49	USA-KS
130	KS090120C*-25	USA-KS
131	KS970187-1-10/KS031027-FHB~7	USA-KSU
132	PRL/2*PASTOR//N566/OK94P597(OK03522)	USA-OK-TCI
133	PGO/SERI//BAV92/3/O4VA7-25	USA-OK-TCI
134	WAXWING*2//PBW343*2/KUKUNA/3/ARMOUR/4/KS950412-F-4/TX96V2427	USA-OK-TCI
135	WEAVER/OCI//BORL95/4/CROC1/AE.SQ(224)//OPATA/3/U1254-1-5-1-1/TX89V4213(OCW00S160S-1B)/5/ART	USA-OK-TCI

Genotype	Pedigree	Origin
136	KINGBIRD'S'//KUKUNA/2*2174 (OCW03S649T-2)/3/KAUZ/STAR//U1254-1-5-1-1/TX89V4213 (OCW00S063S-2-4,12)	USA-OK-TCI
137	JAGGER/ALLIANCE	USA-UNL
138	PVN//CAR422/ANA/5/BOW/CROW//BUC/PVN/3/YR/4/TRAP#1/ /YILDIZ	USA-UNL-TCI
139	MERCATO//92.001E7.32.5/SLVS	USA-UNL-TCI
140	ARESO/ROELFS F2007	USA-UNL-TCI

Abbreviations stand for: TCI: TURKEY-CIMMYT-ICARDA; COL: Colorado; KSU: Kansas State University; OK: Oklahoma; OKSU: Oklahoma State University; TX: Texas; USA: United States of America; UNL: University of Nebraska Lincoln

Seedling stage tests

Seedling stage tests of genotypes were conducted during 2020 and 2021 by using the PstS7 (*Warrior*) race (virulence formulas; *1, 2, 3, 4, -, 6, 7, -, 9, -, -, 17, -, 25, -, 32, YrSP, AvS, Amb*) isolate of stripe rust. Wheat seeds samples were sown in three replications into plastic pots (7*7*9 cm) containing sterilized peat ready to use and were grown under greenhouse conditions at 18-20 °C. Urediniospores of the PstS7 race isolate multiplied by using the susceptible cultivars Morocco and Little Club were inoculated into seedling stage genotypes (Zadoks 11-12) as urediniospores suspended in mineral oil (Soltrol 170®). Following the inoculation process, all testing materials were placed in a dew chamber at 9±1 °C for 24 h for incubation and then transferred into a greenhouse with a 15±2 °C day/night temperature regime. After 15-17 days of the inoculation, seedlings were evaluated using a 0-9 scale described by McNeal et al. (1971). Genotypes with infection types (IT) between 0-6 were considered resistant, while those with 7-9 were considered susceptible (McNeal et al., 1971).

Adult plant stage tests

The field tests for the adult-plant stage of these genotypes were carried out at Ankara (39.62 N, 32.69 E, 1069 masl) and Izmir (38.61 N, 27.10 E, 31 masl) locations in the growing season of 2019-20 and 2020-21. Entire wheat genotypes were sown as head-row in 1 m long rows and 30 cm apart at both locations. The susceptible cultivars were planted between every ten genotypes to ensure the uniform spread of the inoculum and adequate disease development. The cultivars Little Club and Gönen were used as susceptible control at Ankara and Izmir locations, respectively. Fertilization, herbicide application for weed control, and routine irrigation procedures were followed to provide an appropriate environmental condition for rust development. Izmir location has favorable environmental conditions for stripe rust development when compared to Ankara, which is located in the Central Anatolia. For this reason, artificial disease inoculation was conducted using the PstS7 race in Ankara and the effect of the local stripe rust population was examined in Izmir. The artificial inoculum of the PstS7 race was sprayed with a water mist containing a mixture of urediniospores and talcum powder (1:20) in the early evening times, at the boot stage of wheat genotypes planted in Ankara (Khiavi et al., 2017). Two different differential sets were sown at both locations to control whether there is a different stripe rust race contamination from outside of Ankara and to learn about population structure in Izmir. Disease evaluations were performed two times at both locations. The genotypes were evaluated at the flag leaf stage when the disease was developed well on susceptible control based on the method presented by Khiavi et al. (2017). Infection type and disease severity of the genotypes were used to calculate the coefficient of infection (CI). The following coefficiency of infection types were used to calculate the CI: Immune (I) = 0, Resistant (R) = 0.2, Moderately Resistant (MR) = 0.4, Moderately Susceptible (MS) = 0.8 and Susceptible (S) = 1. For instance, the CI of disease score of 50MS is 40 (50x0.8=40) as reported by Roelfs et al. (1992). The CI values were classified as follows: 0 = I; 0.1-5.0 = R; 5.01-20.0 = MR; 20.1-40.0 = MS; 40.1-100 = S. In addition, the CI values from 0 to 20.0 were regarded as avirulent (resistance) while above 20.1 was grouped as virulent (susceptible) (Akan and Akcura, 2018). The average coefficient of infection (ACI) was derived from the average CI values of each genotype.

Results and Discussion

Two diverse differential sets were used to identify pathotypes of stripe rust and their reactions under the artificial inoculation in Ankara and the local rust population in Izmir. The success of the artificial inoculation applied using the PstS7 race was confirmed by field results of genotypes within the differential set planted in Ankara. The genotypes with *Yr5, Yr8, Yr10, Yr15, Yr24,* and *Yr26* genes were resistant to the PstS7 race (virulence formula; 1,2,3,4,-,6,7,-,9,-,-,17,-,25,-,32,Sp,AvS,Amb) while genotypes with *Yr1, Yr2, Yr3, Yr4, Yr6, Yr7, Yr9, Yr17, Yr25, Yr32* genes, and *Spaldings Prolific, Ambition*, and *Avocet* 'S' were susceptible. The local stripe rust population existing at the Izmir location was susceptible to *Yr3, Yr7, Yr8, Yr17, Yr18, Yr27, Spaldings Prolific,* and *Avocet* 'S' while resistance to *Yr1, Yr5, Yr6, Yr9, Yr10, Yr15, Yr24, Yr26* (virulence formula; -,3,-,-,7,8,-,-,-,17,18,-,27,Sp,AvS).

The seedling stage performance of genotypes was evaluated twice under greenhouse conditions. A total of 140 bread wheat lines were exposed to virulent stripe rust isolate PstS7 race. All genotypes were classified as R or S based on the average ITs obtained at the seedling stage (Table 2). Of these genotypes, 89 (63.6%) genotypes with the ITs between 7 and 9 were grouped as S while 51 (36.4%) genotypes with the ITs between 0 and 6 were grouped as R (Figure 1).

Table 2. The reaction of wheat genetic materials to stripe rust at the seedling and adult-plant stages

Genotype	Seedling Stage			Adult Plant Stage						
	ITs		Seedling	Ankara-CI			Ankara	Izmir-CI		Izmir
	2020	2021	Group	2020	2021	ACI	Group	2020	2021*	Group
1	8	7	S	60	60	60	S	70	0.8	S
2	7	7	S	18	24	21	MS	45	4	S
3	7	7	S	50	24	37	MS	24	4	MS
4	7	7	S	100	50	75	S	100	27	S
5	7	7	S	100	36	68	S	100	24	S
6	6	7	S	100	40	70	S	100	24	S
7	7	7	S	100	40	70	S	100	24	S
8	7	7	S	0	0	0	I	0	0	I
9	6	6	R	0.4	4	2.2	R	0.4	0	R
10	7	7	S	8	4	6	MR	9	0	MR
11	7	7	S	0	0	0	I	0.8	0	R
12	7	7	S	0	0	0	I	0.8	0	R
13	7	7	S	0.4	0.8	0.6	R	27	0	MS
14	7	7	S	4	0	2	R	18	0	MR
15	7	7	S	0	0	0	I	0	0	I
16	2	2	R	0	8	4	R	0.8	0	R
17	5	5	R	0	0	0	I	36	0	MS
18	7	7	S	24	16	20	MR	27	0	MS
19	5	4	R	0	0	0	I	0	0	I
20	5	5	R	0	0	0	I	4	0	R
21	7	7	S	0	8	4	R	3	0	R
22	7	7	S	16	16	16	MR	0.8	0	R
23	7	7	S	16	0	8	MR	4	0	R
24	7	7	S	0	9	4.5	R	0	0	I
25	8	7	S	70	40	55	S	30	4	MS
26	7	7	S	27	24	25.5	MS	16	0	MR
27	7	7	S	24	16	20	MR	18	0	MR
28	4	5	R	0	0	0	I	0	0	I
29	7	7	S	0	0	0	I	36	0	MS
30	3	2	R	0	0	0	I	0	0	I
31	7	7	S	0	0	0	I	0	0	I

Genotype	Seedling Stage			Adult Plant Stage						
	ITs		Seedling	Ankara-CI			Ankara	Izmir-CI		Izmir
	2020	2021	Group	2020	2021	ACI	Group	2020	2021*	Group
32	7	7	S	50	16	33	MS	16	0	MR
33	5	5	R	0	0	0	I	4	0	R
34	7	7	S	2	0.8	1.4	R	16	0	MR
35	5	5	R	0	0	0	I	0.4	0	R
36	7	7	S	24	4	14	MR	27	0	MS
37	5	5	R	0	0.8	0.4	R	4	0	R
38	7	7	S	0	0.8	0.4	R	4	0	R
39	7	7	S	40	24	32	MS	12	0	MR
40	7	7	S	50	24	37	MS	12	4	MR
41	7	7	S	32	16	24	MS	12	0	MR
42	7	7	S	0	0	0	I	4	0	R
43	7	7	S	2	0	1	R	8	0	MR
44	4	4	R	0	0	0	I	9	0	MR
45	5	7	S	8	0	4	R	0.8	0	R
46	7	7	S	4	4	4	R	12	0	MR
47	2	2	R	0	0	0	I	0	0	I
48	7	7	S	0	0	0	I	0	0	I
49	2	2	R	0	0	0	I	4	0	R
50	7	7	S	8	0	4	R	18	0	MR
51	3	4	R	0	0	0	I	18	0	MR
52	6	5	R	0	0	0	I	4	0	R
53	2	2	R	0	0	0	I	0.8	0	R
54	7	7	S	8	9	8.5	MR	8	0	MR
55	2	3	R	0	0	0	I	18	0	MR
56	7	7	S	0	0	0	I	0.8	0	R
57	3	2	R	0	0	0	I	0.4	0	R
58	7	7	S	50	16	33	MS	8	0	MR
59	2	2	R	0	0	0	I	8	0	MR
60	7	7	S	8	6	7	MR	24	0	MS
61	7	7	S	30	16	23	MS	12	0	MR
62	2	2	R	0	0	0	I	0	0	I
63	0	1	R	0	0	0	I	8	0	MR
64	0	0	R	0	0	0	I	0.8	0	R
65	7	7	S	8	27	17.5	MR	9	0	MR
66	3	3	R	0	0	0	I	8	0.8	MR
67	2	2	R	0	0	0	I	0	0	I
68	7	7	S	16	16	16	MR	4	0	R
69	1	1	R	0	0	0	I	0	0	I
70	2	2	R	8	0	4	R	6	0	MR
71	3	3	R	0	0	0	I	27	0	MS
72	2	2	R	0	0	0	I	24	0	MS
73	6	6	R	0	0	0	I	6	0	MR
74	2	2	R	0.4	3	1.7	R	8	0	MR
75	2	2	R	0	0	0	I	0	0	I
76	2	2	R	0	0	0	I	16	0	MR
77	6	6	R	8	60	34	MS	4	0	R
78	7	7	S	0	40	20	MR	0.8	0	R
79	6	7	S	0	0	0	I	0.4	0	R
80	7	7	S	16	40	28	MS	8	0	MR
81	2	2	R	8	9	8.5	MR	0.8	0	R
82	7	7	S	4	4	4	R	18	0	MR
83	2	2	R	16	24	20	MR	16	0	MR
84	5	5	R	0	0	0	I	0	0	I
85	6	6	R	0	0	0	I	8	0	MR
86	7	7	S	0	27	13.5	MR	8	0	MR
87	2	3	R	0.4	0	0.2	R	6	0	MR
88	7	7	S	4	27	15.5	MR	8	0.8	MR
89	7	7	S	0	8	4	R	27	4.5	MS
90	6	6	R	0	4	2	R	18	0	MR

Genotype	Seedling Stage			Adult Plant Stage						
	ITs		Seedling	Ankara-CI			Ankara	Izmir-CI		Izmir
	2020	2021	Group	2020	2021	ACI	Group	2020	2021*	Group
91	7	7	S	0	4	2	R	27	0	MS
92	6	6	R	0	0	0	I	18	0	MR
93	7	6	S	8	24	16	MR	18	0	MR
94	5	5	R	0.4	8	4.2	R	6	0	MR
95	7	7	S	0	40	20	MR	4	0	R
96	7	7	S	4	0	2	R	4	0	R
97	7	7	S	30	36	33	MS	36	0	MS
98	7	7	S	24	8	16	MR	4	0	R
99	7	7	S	4	4	4	R	24	0	MS
100	7	7	S	16	9	12.5	MR	6	0	MR
101	7	7	S	16	4	10	MR	0.4	0	R
102	7	7	S	16	8	12	MR	24	0	MS
103	7	7	S	0	0	0	I	4	0	R
104	6	7	S	50	40	45	S	18	4	MR
105	7	7	S	24	4	14	MR	12	0	MR
106	6	6	R	8	0	4	R	16	0	MR
107	7	7	S	32	8	20	MR	4	0	R
108	6	6	R	40	3	21.5	MS	8	0	MR
109	7	7	S	8	8	8	MR	8	0	MR
110	6	6	R	0	4	2	R	0	0	I
111	7	7	S	0	0	0	I	6	0	MR
112	7	7	S	24	24	24	MS	36	0	MS
113	7	7	S	0	0	0	I	8	0	MR
114	7	7	S	32	32	32	MS	27	0	MS
115	7	7	S	9	40	24.5	MS	16	0	MR
116	6	6	R	0	0	0	I	4	0	R
117	6	6	R	0	0	0	I	0	0	I
118	7	7	S	0	0.8	0.4	R	18	0	MR
119	7	7	S	0	0.8	0.4	R	4	0	R
120	7	7	S	8	16	12	MR	36	0.8	MS
121	7	7	S	0	8	4	R	4	0	R
122	7	7	S	0	0	0	I	0	0	I
123	7	7	S	0	0	0	I	0	0	I
124	5	7	S	8	0	4	R	8	0	MR
125	7	7	S	8	0	4	R	0	0	I
126	7	7	S	24	2	13	MR	12	0	MR
127	7	7	S	0	8	4	R	8	4	MR
128	7	7	S	8	8	8	MR	27	0.8	MS
129	2	2	R	0	0	0	I	0	0	I
130	7	7	S	24	40	32	MS	36	0	MS
131	7	7	S	0	32	16	MR	16	0	MR
132	7	7	S	16	0	8	MR	4	0	R
133	7	7	S	8	0	4	R	18	0	MR
134	7	7	S	0	0	0	I	18	0	MR
135	6	6	R	4	2	3	R	18	0.8	MR
136	7	7	S	0.4	0.4	0.4	R	27	16	MS
137	6	7	S	40	0	20	MR	0.8	0	R
138	3	3	R	0	0	0	I	0.4	0	R
139	3	3	R	0	4	2	R	0	0	I
140	2	2	R	0	0	0	I	0	0	I
Gönen				-	-	-	-	80	36	S
Little Club				80	90	85	S	-	-	-

Abbreviations stand for: ITs: Infection Types; CI: Coefficient of Infection; ACI: Average Coefficient of Infection; I: Immune; R: Resistant; MR: Moderately Resistant; MS: Moderately Susceptible; S: Susceptible. * The results were not included in the calculation of the ACI for Izmir.

The adult-plant stage reactions of the genotypes to stripe rust were grouped as I, R, MR, MS, and S based on the ACI calculated using two-year data of Ankara location. A total of 116 (83%)

genotypes were grouped as I, R, and MR, and 24 (17%) genotypes were grouped as MS and S at the adult-plant stage at the Ankara location where the PstS7 race was inoculated. In total, 51 genotypes were grouped as I, 35 genotypes as R, 30 genotypes as MR, 17 genotypes as MS, and 7 genotypes as S (Figure 1 and Table 2). For the Izmir location, only first-year data was used for the grouping of the genotypes due to the occurrence of unfavorable climatic conditions in the second year. A total of 113 (80.7%) genotypes exhibited I, R, and MR reactions while 27 (19.3%) genotypes exhibited MS and S reactions at the adult-plant stage tested under the local rust population in Izmir. In total, 22 genotypes were grouped as I, 37 genotypes as R, 54 genotypes as MR, 21 genotypes as MS, and 6 genotypes as S. Similar to our current study, several studies have been conducted over the last two decades to evaluate wheat germplasm for their resistance to stripe rust (Torabi et al., 1995; Foroutan et al., 2002; Malihipour et al., 2002; Nazari, 2006; Ali et al., 2008; Youssef et al., 2008; Shahin and Abu El-Naga, 2011). Although environmental conditions and race diversity at both locations can affect the reaction of examined genotypes, genotypes with an ACI value less than 20 will be introduced to breeding programs as appropriate genotypes resistant to stripe rust. Variable reactions of genotypes against stripe rust disease were also obtained in previous studies and are consistent with the results of our study (Malihipour et al., 2002; Foroutan and Ahmadian-Moghaddam, 2002; Afshari, 2004; Youssef et al., 2008; Wellings and Park, 2006; Herrera-Fossel et al., 2007; Bux et al., 2011; Shahin and Abu El-Naga, 2011). Genotypes 1, 4, 5, 6, and 7 showed susceptibility to stripe rust at both locations. These genotypes with an ACI value above 40.1 were grouped as susceptible to the PstS7 race and local rust population and were not recommended to be used as a source of resistance genes in the breeding programs.

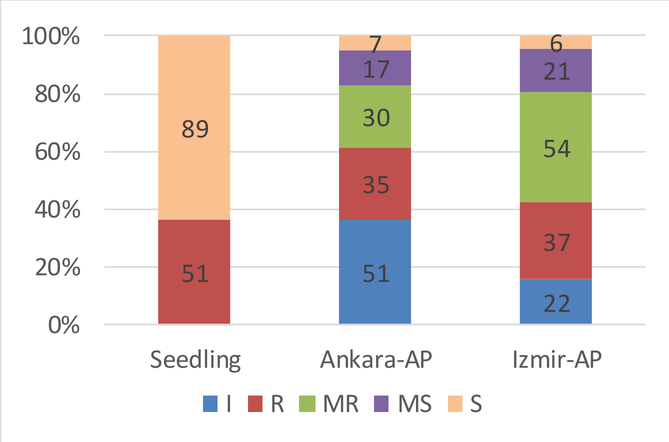

Figure 1. Distribution of the genotype reactions at the seedling and adult-plant stage

CIMMYT breeders have defended and successfully practiced breeding APR to rust for many years and have used “the single backcross approach” (Singh et al., 2014). It was determined that 49 of the genotypes, which were tested against the PstS7 race under Ankara conditions, may contain R genes as having both seedling and adult-plant stage resistance. However, it is stated that the rapid evolution ability of the Pst and the emergence of new virulent races always pose a risk for genotypes with race-specific resistance genes (Tekin et al., 2022). In addition, it was detected that 67 genotypes may contain APR genes since they are susceptible at the seedling stage and have resistance at the adult-plant stage.

Conclusion

This study was conducted to determine the stripe rust reactions of 140 wheat genetic materials at two distinct locations and to identify genetic resources to be used in resistance breeding programs. A total of 101 genotypes (72.1%) have been detected that have I, R, and MR reactions against the PstS7 race in Ankara and the local rust population in Izmir. In light of the promising results obtained from the study, genotypes were found to have diverse types of resistance can be considered as new genetic resources in breeding programs for the management of stripe rust disease. Stripe rust resistance breeding will continue to be based on the current awareness of stripe rust variability, a commitment to research and commercial development of new and effective resistance combinations, and their adoption as the best control method.

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