Bitki Koruma Bülteni / Plant Protection Bulletin

http://dergipark.gov.tr/bitkorb

Original article

Assessment of Pm41 gene frequency in Turkish bread wheat germplasm

Türk ekmeklik buğday germplazmında Pm41 gen frekansının değerlendirilmesi

Zemran MUSTAFA[a]

https://orcid.org/0000-0002-1754-6320

[a]*Faculty of Agricultural Sciences and Technology, Sivas University of Science and Technology, Gültepe Mahallesi, Mecnun Otyakmaz Caddesi, No:1 Merkez/Sivas, Türkiye 58000*

ARTICLE INFO

Article history:

DOI: 10.16955/bitkorb.1555981
Received : 25-09-2024
Accepted : 19-12-2024

Keywords:

powdery mildew, resistance gene, wheat breeding, haplotype diversity

* Corresponding author: Zemran MUSTAFA
zemranm@gmail.com

ABSTRACT

Powdery mildew, caused by *Blumeria graminis* f. sp. *tritici*, poses a high risk to worldwide wheat production, resulting in severe yield reductions. Resistance breeding provides a sustainable approach to managing this disease, with the *Pm41* gene being pivotal in providing all-stage resistance. This research examined 96 cultivars of Turkish bread wheat (*Triticum aestivum*) from several Turkish research institutions for the *Pm41* gene. PCR analysis indicated that 57% of the studied cultivars possessed the Pm41 gene. The highest detection rate of 89% was recorded in cultivars from Bahri Dağdaş International Agricultural Research Institute Directorate/Konya, whereas Field Crops Research Institute Directorate/Ankara exhibited a lesser frequency of 29%. The data demonstrate regional disparities in *Pm41* presence. The observed *Pm41* gene in over half of the cultivars suggests that Turkish wheat cultivars possess gene variants that might be important for resistance. This work underscores the significance of preserving genetic materials for finding novel variants of the resistance genes, which are essential for sustainable wheat cultivation and food security.

INTRODUCTION

Bread wheat (*Triticum aestivum*) is one of the most significant crops globally, serving as a primary source of calories and proteins in human diets. Its importance is underscored by its role in food security, as it constitutes a staple food for billions of people worldwide. The cultivation of bread wheat has evolved significantly, with modern varieties developed through selective breeding and genetic improvements aimed at enhancing yield, disease resistance, and adaptability to various environmental conditions (Cavalet-Giorsa et al. 2024, Merchuk-Ovnat et al. 2016). However, the genetic diversity of contemporary bread wheat has been compromised due to the processes of domestication and polyploidization, which have led to a reduction in the genetic variability that is crucial for resistance against biotic and abiotic stresses (Cavalet-Giorsa et al. 2024, Zhou et al. 2020).

Local cultivars possess unique genetic traits that have evolved in specific environmental conditions, making them well-suited to local climates and agricultural practices. These cultivars are vital reservoirs of genetic diversity, harboring

alleles that may confer advantages such as biotic and abiotic stress resistance and nutritional quality (Morgounov et al. 2016, Cheng et al. 2019, Yang et al. 2022).

Wheat production is significantly threatened by various fungal diseases, with powdery mildew (caused by *Blumeria graminis* f. sp. *tritici*) being one of the most destructive. This biotrophic pathogen can lead to substantial yield losses of up to 40% depending on environmental conditions and crop management practices (Morgounov et al. 2012). The prevalence of powdery mildew is particularly concerning in regions with high humidity and mild temperatures, which facilitate rapid disease spread and infection. The global incidence of wheat diseases, including powdery mildew, underscores the urgent need for effective management strategies to mitigate their impact on wheat production (Chai et al. 2022).

Türkiye, one of the world's largest wheat producers, is particularly vulnerable to diseases like powdery mildew. It is manifested as one of the most destructive diseases of wheat, appearing in different regions (Arslan et al. 2024, Özdemir et al. 2017, Sönmezoğlu et al. 2019). Mostly it is observed in the Thrace, Eastern Marmara, and Black Sea Regions and occasionally in the Aegean Region (Aydin et al. 2021, Tosun et al. 2011).

Protection against powdery mildew primarily involves the use of resistant wheat cultivars and the application of fungicides. Breeding programs have focused on identifying and incorporating resistance genes into wheat varieties, which has proven effective and environmentally sustainable (Wu et al. 2021, Zhang et al. 2017). Addressing the challenge of powdery mildew in wheat requires a multifaceted approach that leverages genetic resistance, advanced breeding techniques, and environmentally sound management practices. As the global demand for grain rises, developing resistant varieties and effective control measures against powdery mildew will be critical to ensuring food security and sustainable agricultural practices.

The study of Cheng et al. (2022) aimed to assess powdery mildew resistance at both the seedling and adult stages, and to identify the presence of *Pm* genes in 332 germplasms from an international wheat collection utilizing molecular markers. It was determined that only a few accessions were resistant to *Blumeria graminis* f. sp. *tritici* (Bgt) races E09, E15, and A13, while all evaluated accessions were fully susceptible to Bgt race A44 in the seedling stage. The gene *Pm41* was identified in wild emmer wheat (*Triticum turgidum* var. *dicoccoides*), specifically from accession IW2, collected from Mount Hermon, Israel, which represents a significant advancement in the fight against powdery mildew (Li et al. 2009). This gene is part of a broader family of over 130 known powdery mildew resistance genes, with 69 officially designated (*Pm1-Pm69*) across various wheat species and related genera (Chen et al. 2024).

The discovery of *Pm41* is particularly noteworthy as it confers all-stage resistance to powdery mildew, making it a valuable asset for wheat breeding programs to enhance disease resistance. The resistance gene was successfully introduced into common wheat through backcrossing and marker-assisted selection (Li et al. 2009). Research indicates that *Pm41* was mapped to a genetic interval on chromosome arm 3BL, utilizing bulked segregate analysis and simple sequence repeat (SSR) markers (Li et al. 2020).

The *Pm41* resistance gene stands out as a critical component in the ongoing efforts to control powdery mildew in wheat. Its identification and characterization pave the way for innovative breeding approaches that leverage genetic diversity to enhance disease resistance in agricultural systems. With the integration of *Pm41* into breeding programs, wheat varieties that resist powdery mildew could be developed in an environmentally friendly manner.

In the present study, a total of 96 Turkish bread wheat cultivars sourced from various agricultural research institutes of Türkiye were screened for the presence of the *Pm41* gene. The objective was to identify this gene as a long-term solution to powdery mildew disease.

MATERIALS AND METHODS

Plant material

Ninety-six bread wheat cultivars of Turkish origin were used in the present study (Table 1).

DNA isolation

Every one of the 96 bread wheat samples was cultivated in a growth room, and approximately 100 milligrams of freshly harvested leaves were obtained for extraction of DNA. Following the freezing of the leaves in liquid nitrogen, they were pulverized into fine powder using a porcelain mortar. Genomic DNA was isolated using the cetyltrimethylammonium bromide (CTAB) technique, as described by Doyle (1991), with minor modifications. The powder was introduced into a heat-treated CTAB buffer (2% CTAB, 1.4 M NaCl, 0.2% 2-mercaptoethanol, 20 mM EDTA, and 100 mM Tris at a temperature of 65 °C, with a pH of 8.0). After incubating the samples at 65 °C for 30 minutes, chloroform–isoamyl alcohol was added and thoroughly mixed. Next, the top phase (600 µl) was transferred to

a fresh tube after being centrifuged at 6000 g at room temperature (RT) for 20 minutes. Cold isopropanol (1200 µl) at a temperature of -20 °C was added to the 2 ml tubes. Following centrifugation at 6000 g at RT for 5 minutes, the supernatant was removed and 600 µl of the washer buffer (70% EtOH, 10 mM NaAc) was added. Following a 20-minute incubation period at RT, the mixture was subjected to centrifugation at 6000 g at RT for 10 minutes, and the supernatant was removed. The pellet was rinsed with cold ethanol and then subjected to centrifugation at 6000 g at RT for 10 minutes. The supernatant was discarded, and the pellet was then dissolved in 50 µl of molecular grade water. Quantification of DNA concentration was conducted using Nanodrop (DS11 FX, manufactured by DeNovix Inc. in Wilmington, DE, USA) and adjusted to 100 nanograms per microliter.

PCR assay

PCR assay for detection of *Pm41* gene was performed using Pm41-645F/Pm41-645R forward and reverse using 2 primers (Li et al. 2022, Table 2). PCR mixture was adjusted according to the manufacturer's protocol; 5 µl of 10X Taq Buffer, 2.5 µl of 25 mM MgCl2, 0.5 µl of 10 mM dNTP, 0.5 µl of 10 µM forward and reverse primer each, 0.3 µl of DNA polymerase (5U/µl), 1 µl of DNA template (100 ng/µl) was mixed and the volume was filled with ddH_2O to 25 µl (Thermo Fisher EP0402). Thermocycler conditions were adjusted as follows: initial denaturation at 95 °C for 5 min, 35 cycles of denaturation at 95 °C for 30 s, annealing at 59 °C for 30 s, extension at 72 °C for 45 s, and final extension at 72°C for 10 min (Baloch et al. 2024).

PCR amplification results were subjected to a 1% (w/v) agarose gel using TBE buffer (0.54% Tris base, 0.027% boric acid, 0.0037% EDTA) at a voltage of 120 V for 60 minutes. An ethidium bromide stain was applied to the gel and then visualized using a UV Imager (Bio-Rad Laboratories, Inc., located in Hercules, CA, USA). For band length comparison, GeneRuler 100bp Plus DNA ladder was used.

Table 1. Catalogue of historical Turkish bread wheat cultivars: origins, historical records, and information about other valuable characteristics (1963-2014)

Serial No.	Genotypes	Collection locations	Wheat type	Date of registration	Grain color	Presence of awn
1	Ankara 093/44	TARM/ANK	*T. aestivum*	7.10.1963	White	Yes
2	Köse 220/39	TARM/ANK	*T. aestivum*	7.10.1963	White	No
3	Sivas 111/33	TARM/ANK	*T. aestivum*	7.10.1963	-	Yes
4	Sürak M. 1593/51	TARM/ANK	*T. aestivum*	7.10.1963	-	Yes
5	Haymana 79	TARM/ANK	*T. aestivum*	15.05.1979	Red	Yes
6	Gün-91	TARM/ANK	*T. aestivum*	26.04.1991	Red	Yes
7	İkizce 96	TARM/ANK	*T. aestivum*	16.04.1996	Red	Yes
8	Mızrak	TARM/ANK	*T. aestivum*	12.05.1998	White	Yes
9	Türkmen	TARM/ANK	*T. aestivum*	12.05.1998	White	Yes
10	Uzunyayla	TARM/ANK	*T. aestivum*	12.05.1998	White	yes
11	Yakar-99	TARM/ANK	*T. aestivum*	26.04.1999	White	Yes
12	Aksel 2000	TARM/ANK	*T. aestivum*	28.04.2000	Red	Yes
13	Bayraktar 2000	TARM/ANK	*T. aestivum*	28.04.2000	White	Yes
14	Demir 2000	TARM/ANK	*T. aestivum*	28.04.2000	Red	Yes
15	Atlı-2002	TARM/ANK	*T. aestivum*	2.05.2002	Red	Yes
16	Zencirci-2002	TARM/ANK	*T. aestivum*	2.05.2002	White	Yes
17	Eser	TARM/ANK	*T. aestivum*	2.05.2003	White	Yes
18	Seval	TARM/ANK	*T. aestivum*	1.04.2004	Red	Yes
19	Tosunbey	TARM/ANK	*T. aestivum*	1.04.2004	White	Yes
20	Kenanbey	TARM/ANK	*T. aestivum*	6.04.2009	White	Yes

21	Lütfibey	TARM/ANK	*T. aestivum*	30.03.2010	Red	Yes
22	4-11	ATAEM/ESK	*T. aestivum*	7.10.1963	-	No
23	4-22	ATAEM/ESK	*T. aestivum*	7.10.1963	-	No
24	P 8-6	ATAEM/ESK	*T. aestivum*	7.10.1963	-	Yes
25	P 8-8	ATAEM/ESK	*T. aestivum*	7.10.1963	-	No
26	Melez	ATAEM/ESK	*T. aestivum*	11.04.2014	-	No
27	Ak 702	ATAEM/ESK	*T. aestivum*	12.04.2014	-	Yes
28	Sertak	ATAEM/ESK	*T. aestivum*	13.04.2014	-	Yes
29	Yayla 305	ATAEM/ESK	*T. aestivum*	9.04.1966	-	Yes
30	Yektay 406	ATAEM/ESK	*T. aestivum*	18.03.1968	Red	Yes
31	Bolal 2973	ATAEM/ESK	*T. aestivum*	27.04.1970	Red	Yes
32	Kıraç 66	ATAEM/ESK	*T. aestivum*	27.04.1970	White	Yes
33	Porsuk-2800	ATAEM/ESK	*T. aestivum*	13.05.1976	White	Yes
34	Gerek 79	ATAEM/ESK	*T. aestivum*	15.05.1979	White	Yes
35	Atay-85	ATAEM/ESK	*T. aestivum*	25.04.1985	White	Yes
36	Kutluk 94	ATAEM/ESK	*T. aestivum*	17.05.1994	White	Yes
37	Kırgız 95	ATAEM/ESK	*T. aestivum*	20.04.1995	White	Yes
38	Sultan 95	ATAEM/ESK	*T. aestivum*	20.04.1995	White	Yes
39	Süzen 97	ATAEM/ESK	*T. aestivum*	6.05.1997	White	Yes
40	Aytın 98	ATAEM/ESK	*T. aestivum*	12.05.1998	White	Yes
41	Yıldız 98	ATAEM/ESK	*T. aestivum*	12.05.1998	White	Yes
42	Harmankaya-99	ATAEM/ESK	*T. aestivum*	26.04.1999	Red	Yes
43	Altay 2000	ATAEM/ESK	*T. aestivum*	28.04.2000	White	Yes
44	Çetinel 2000	ATAEM/ESK	*T. aestivum*	28.04.2000	White	Yes
45	Alpu 2001	ATAEM/ESK	*T. aestivum*	24.04.2001	White	Yes
46	İzgi 2001	ATAEM/ESK	*T. aestivum*	24.04.2001	White	Yes
47	Sönmez 2001	ATAEM/ESK	*T. aestivum*	24.04.2001	Red	No
48	Soyer02	ATAEM/ESK	*T. aestivum*	2.05.2002	White	Yes
49	Müfitbey	ATAEM/ESK	*T. aestivum*	14.04.2006	White	Yes
50	Nacibey	ATAEM/ESK	*T. aestivum*	2.04.2008	Red	Yes
51	ES 26	ATAEM/ESK	*T. aestivum*	30.03.2010	White	Yes
52	Yunus	ATAEM/ESK	*T. aestivum*	17.04.2012	Red	No
53	Mesut	ATAEM/ESK	*T. aestivum*	12.04.2013	-	Yes
54	Dağdaş 94	BDUAAEM/KNY	*T. aestivum*	17.05.1994	White	Yes
55	Kınacı-97	BDUAAEM/KNY	*T. aestivum*	6.05.1997	Red	Yes
56	Göksu-99	BDUAAEM/KNY	*T. aestivum*	26.04.1999	White	Yes
57	Karahan-99	BDUAAEM/KNY	*T. aestivum*	26.04.1999	White	Yes
58	Bağcı-2002	BDUAAEM/KNY	*T. aestivum*	2.05.2002	Red	Yes
59	Konya-2002	BDUAAEM/KNY	*T. aestivum*	2.05.2002	Red	Yes
60	Ahmetağa	BDUAAEM/KNY	*T. aestivum*	1.04.2004	Red	Yes

61	Ekiz	BDUAAEM/KNY	*T. aestivum*	1.04.2004	Red	Yes
62	Eraybey	BDUAAEM/KNY	*T. aestivum*	17.04.2012	Red	Yes
63	Kırkpınar 79	TTAEM/EDN	*T. aestivum*	15.05.1979	White	Yes
64	Murat-1	TTAEM/EDN	*T. aestivum*	26.04.1991	-	Yes
65	Kate A-1	TTAEM/EDN	*T. aestivum*	26.04.1988	Red	No
66	Pehlivan	TTAEM/EDN	*T. aestivum*	12.05.1998	Red	No
67	Prostor	TTAEM/EDN	*T. aestivum*	26.04.1999	Red	Yes
68	Saroz 95	TTAEM/EDN	*T. aestivum*	26.04.1999	White	Yes
69	Atilla-12	TTAEM/EDN	*T. aestivum*	24.04.2001	Red	No
70	Saraybosna	TTAEM/EDN	*T. aestivum*	24.04.2001	Red	No
71	Gelibolu	TTAEM/EDN	*T. aestivum*	30.03.2005	Red	Yes
72	Tekirdağ	TTAEM/EDN	*T. aestivum*	30.03.2005	Red	Yes
73	Aldane	TTAEM/EDN	*T. aestivum*	6.04.2009	Red	No
74	Selimiye	TTAEM/EDN	*T. aestivum*	6.04.2009	Red	No
75	Bereket	TTAEM/EDN	*T. aestivum*	30.03.2010	Red	No
76	Saban	TTAEM/EDN	*T. aestivum*	11.04.2014	Red	Yes
77	Lancer	DATAE/ERZ	*T. aestivum*	12.05.1977	Red	Yes
78	Doğu 88	DATAE/ERZ	*T. aestivum*	16.04.1990	Red	Yes
79	Karasu 90	DATAE/ERZ	*T. aestivum*	16.04.1990	Red	No
80	Palandöken 97	DATAE/ERZ	*T. aestivum*	6.05.1997	White	Yes
81	Alparslan	DATAE/ERZ	*T. aestivum*	24.04.2001	Red	Yes
82	Nenehatun	DATAE/ERZ	*T. aestivum*	24.04.2001	White	Yes
83	Daphan	DATAE/ERZ	*T. aestivum*	2.05.2002	White	Yes
84	Yıldırım	DATAE/ERZ	*T. aestivum*	2.05.2002	White	Yes
85	Ayyıldız	DATAE/ERZ	*T. aestivum*	8.04.2011	Red	Yes
86	Kırik	DATAE/ERZ	*T. aestivum*	30.03.2010	-	Yes
87	Karacadağ 98	GATAEM/DYB	*T. aestivum*	12.05.1998	Red	Yes
88	Nurkent	GATAEM/DYB	*T. aestivum*	24.04.2001	White	Yes
89	Cemre	GATAEM/DYB	*T. aestivum*	2.04.2008	White	Yes
90	Dinç	GATAEM/DYB	*T. aestivum*	12.04.2013	White	Yes
91	Tekin	GATAEM/DYB	*T. aestivum*	11.04.2014	White	Yes
92	Inia 66	STAEM/SKY	*T. aestivum*	11.04.2014	-	Yes
93	Bezostaja-1	STAEM/SKY	*T. aestivum*	19.03.1968	Red	No
94	Bandırma 97	STAEM/SKY	*T. aestivum*	6.05.1997	White	Yes
95	Karacabey 97	STAEM/SKY	*T. aestivum*	6.05.1997	Red	Yes
96	Pamukova 97	STAEM/SKY	*T. aestivum*	6.05.1997	Red	Yes

* Abbreviations: ATAEM/ESK: Transition Zone Agricultural Research Institute Directorate/Eskişehir, BDUAAEM/KNY: Bahri Dağdaş International Agricultural Research Institute Directorate/Konya, DATAE/ERZ: Eastern Anatolia Agricultural Research Institute Directorate/Erzurum, GATAEM/DYB: GAP Agricultural Research Institute Directorate/Diyarbakır, STAEM/SKY: Sakarya Agricultural Research Institute Directorate/Sakarya, TARM/ANK: Field Crops Research Institute Directorate/Ankara, TTAEM/EDN: Thrace Agricultural Research Institute Directorate/Edirne.

Table 2. *Pm41* gene specific primers (Li et al. 2022)

Primer name	5' – 3' sequence	Expected band length
Pm41-645F	TCGGGTACATCTGACTGTTCA	1690 bp
Pm41-645R	TGGCCAGAGTAATTATCGCCA	

RESULTS

The Turkish bread wheat cultivars used in this study were registered between 1963 and 2014. This historical range illustrates ongoing wheat breeding efforts across several decades to improve and diversify wheat varieties. The majority of the cultivars were registered in the 1990s and 2000s, highlighting intensified wheat research during these decades. There is a mix of red and white grain varieties. White grains were more prevalent (42 genotypes), though red varieties were also widely represented (40 genotypes), especially in the later registrations. In 14 cultivars the color of grain was not specified. Grain color can affect market preferences and processing qualities. Most cultivars have awns, but some are awnless, particularly the older ones. The presence or absence of awns can influence threshing and feeding qualities. Several wheat varieties were collected from various research institutions in Türkiye, allowing for a wide geographical spread in the selection and testing process.

The electrophoresis results are shown in Figure 1. The scoring methodology employed a system, with a value of "+" denoting the presence of the band and a value of "–" signifying its absence at 1690 bp.

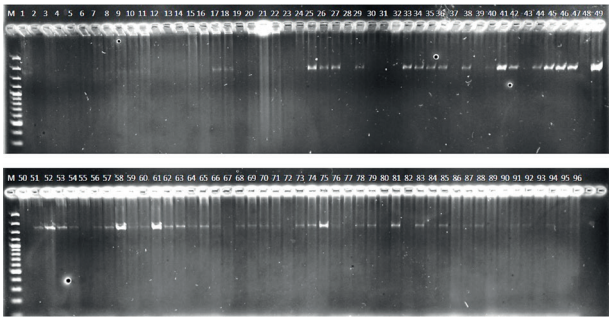

Figure 1. Electrophoresis results of *Pm41* gene in 96 Turkish bread wheat cultivars with an expected band at 1690 bp

The results of *Pm41* specific PCR are given in Table 3. Out of 96 samples, 55 were positive for the *Pm41* gene, indicating roughly 57% of the tested genotypes carried the gene. Samples from Field Crops Research Institute Directorate/Ankara displayed mixed results, with 6 out of 21 (29%) genotypes testing positive for *Pm41*. For Transition Zone Agricultural Research Institute Directorate/Eskişehir, 20 out of 32 (62%) genotypes were positive, suggesting a slightly higher detection rate in this location. In Bahri Dağdaş International Agricultural Research Institute Directorate/Konya, 8 out of 9 (89%) genotypes showed the presence of the gene, the highest proportion compared to other locations. Other locations, like Thrace Agricultural Research Institute Directorate/Edirne and Eastern Anatolia Agricultural Research Institute Directorate/Erzurum, also had a substantial number of positive results, with 11 out of 14 (79%) and 5 out of 10 (50%), respectively. GAP Agricultural Research Institute Directorate/Diyarbakır and STAEM/SKY: Sakarya Agricultural Research Institute Directorate/Sakarya comprised a low number of cultivars, five samples each, with 3 (60%) and 2 (40%) positives for *Pm41* respectively.

DISCUSSION

The existence of the *Pm41* gene alleles in Turkish wheat germplasm favours the global trends of searching for new forms of the gene for wheat breeding, where disease resistance is a primary focus due to the significant impact of fungal pathogens such as powdery mildew. The disease, whose causal agent is *Blumeria graminis* f. sp. *tritici*, remains a persistent threat in regions where climatic conditions, particularly high humidity, favour the rapid spread of the disease (Morgounov et al. 2012, Tosun et al. 2011).

The presence of the *Pm41* haplotypes in Turkish bread wheat cultivars is a significant resource in the country's efforts to control powdery mildew. The study's detection of the *Pm41* gene in 57% of the 96 tested cultivars indicates that Turkish wheat cultivars possess the gene, although the haplotype is currently unknown. Research by Li et al. (2020) demonstrated that *Pm41* confers broad-spectrum resistance and has been successfully mapped to chromosome arm 3BL, offering an effective genetic defence against powdery mildew. Despite these successes, there remain challenges in ensuring the long-term sustainability of powdery mildew resistance. Pathogens are highly adaptable and can overcome resistance genes through mutation and genetic variation (Cavalet-Giorsa et al. 2024). According to Li et al. (2020), among 31 common wheat accessions from China, only 3% have the *Pm41* gene absent from the genome (haplotype 3) whereas

Table 3. PCR screening results of *Pm41* gene

Serial No.	Genotypes	Detection of *Pm41* gene	Serial No.	Genotypes	Detection of *Pm41* gene
1	Ankara 093/44	+	49	Müfitbey	+
2	Köse 220/39	-	50	Nacibey	-
3	Sivas 111/33	-	51	ES 26	+
4	Sürak M. 1593/51	-	52	Yunus	+
5	Haymana 79	-	53	Mesut	+
6	Gün-91	-	54	Dağdaş 94	+
7	İkizce 96	-	55	Kınacı-97	-
8	Mızrak	-	56	Göksu-99	+
9	Türkmen	+	57	Karahan-99	+
10	Uzunyayla	+	58	Bağcı-2002	+
11	Yakar-99	+	59	Konya-2002	+
12	Aksel 2000	-	60	Ahmetağa	+
13	Bayraktar 2000	-	61	Ekiz	+
14	Demir 2000	-	62	Eraybey	+
15	Atlı-2002	-	63	Kırkpınar 79	+
16	Zencirci-2002	-	64	Murat-1	+
17	Eser	+	65	Kate A-1	+
18	Seval	+	66	Pehlivan	+
19	Tosunbey	-	67	Prostor	-
20	Kenanbey	-	68	Saroz 95	+
21	Lütfibey	-	69	Atilla-12	+
22	4-11	-	70	Saraybosna	+
23	4-22	-	71	Gelibolu	+
24	P 8-6	-	72	Tekirdağ	-
25	P 8-8	+	73	Aldane	+
26	Melez	+	74	Selimiye	+
27	Ak 702	+	75	Bereket	+
28	Sertak	-	76	Saban	-
29	Yayla 305	+	77	Lancer	-
30	Yektay 406	-	78	Doğu 88	+
31	Bolal 2973	-	79	Karasu 90	+
32	Kıraç 66	-	80	Palandöken 97	-
33	Porsuk-2800	+	81	Alparslan	+
34	Gerek 79	+	82	Nenehatun	-
35	Atay-85	+	83	Daphan	+
36	Kutluk 94	+	84	Yıldırım	-
37	Kırgız 95	-	85	Ayyıldız	+
38	Sultan 95	+	86	Kırik	-
39	Süzen 97	-	87	Karacadağ 98	+
40	Aytın 98	+	88	Nurkent	+

41	Yıldız 98	+	89	Cemre	-
42	Harmankaya-99	+	90	Dinç	-
43	Altay 2000	-	91	Tekin	+
44	Çetinel 2000	+	92	İnia 66	+
45	Alpu 2001	+	93	Bezostaja-1	-
46	İzgi 2001	+	94	Bandırma 97	+
47	Sönmez 2001	+	95	Karacabey 97	-
48	Soyer02	-	96	Pamukova 97	-

97% of them had *Pm41* gene (haplotype 2 and haplotype 7), which have some SNP and in/del mutations compared to the active form of haplotype 1. Seven haplotypes were observed in Durum wheat (*T. turgidum* subsp. *durum*) and wild emmer wheat (*T. turgidum* ssp. *dicoccoides*).

Previous studies have emphasized the need for incorporating multiple resistance genes to control evolving pathogens (Laroche et al. 2019). The results of this study have significant implications for wheat breeding and sustainable agricultural practices in the country.

In Türkiye, there have been studies conducted regarding the resistance of powdery mildew. Research by Aydın et al. (2021) shows that more than one gene controls the Tahirova-2000 variety's resistance to powdery mildew. In another study, two genotypes from CIMMYT were bred with susceptible varieties, including one of Turkish origin to find resistance through monogenic and digenic modes of inheritance (Ilker et al. 2009, Tosun et al. 2011).

As the increasing global demand for wheat, it is imperative to develop wheat varieties that are not only high yielding but also resistant to diseases like powdery mildew. Enhancing powdery mildew resistance in wheat can be effectively achieved by the identification and application of specific resistance genes. For instance, the gene *Pm21*, derived from the wild relative *Haynaldia villosa*, has been demonstrated to offer broad-spectrum resistance against several strains of the pathogen. This gene has been effectively introduced into common wheat, indicating its potential for lasting resistance (Cao et al. 2011, Wu et al. 2019). Similarly, the *Pm3* gene, one of the earliest found resistance loci, contains many alleles that have been extensively used in breeding programs, displaying its efficiency in different environments (Wu et al. 2021).

The use of wild relatives of wheat as sources of resistance genes has been a longstanding strategy in wheat breeding. Genetic studies have revealed that several wild species harbor valuable resistance genes that can be introduced into cultivated wheat. For example, the gene *Pm60*, derived from *Triticum urartu*, has been successfully transferred to common wheat, demonstrating its potential to enhance resistance (Zhang et al. 2021). The exploration of genetic diversity in wheat germplasm collections has also revealed novel resistance sources, which can be utilized to develop new resistant cultivars (Cheng et al. 2020, Li et al. 2016).

This study suggests that Turkish cultivars may possess novel *Pm41* genes, with silenced variants which can be utilized against emerging strains of powdery mildew.

One of the most noteworthy findings of this study is the significant regional variation in the detection of the *Pm41* gene. In the Bahri Dağdaş International Agricultural Research Institute Directorate/Konya, 89% of the tested cultivars were positive for *Pm41*, the highest detection rate observed in the study. In contrast, the Field Crops Research Institute Directorate/Ankara exhibited a much lower detection rate, with only 29% of cultivars testing positive for *Pm41*.

The findings from this study contribute to the broader global discourse on wheat disease resistance. The identification of *Pm41* in 55 Turkish cultivars is consistent with efforts in other wheat-producing regions to find novel genetic resistance genes against powdery mildew. The discovery and utilization of genes like *Pm41*, which originated from wild emmer wheat, demonstrate the importance of different alleles of the gene as a genetic diversity resource for wheat improvement.

ACKNOWLEDGEMENTS

The author thanks Dr. Emine Burcu TURGAY for providing a bread wheat germplasm collection.

Author's Contributions

Authors declare that each author's contribution is equal.

Statement of Conflict of Interest

The authors have declared no conflict of interest.

ÖZET

Blumeria graminis f. sp. *tritici*'nin neden olduğu külleme hastalığı, dünya çapında buğday üretimi için yüksek risk taşır ve ciddi verim düşüşlerine neden olmaktadır. Direnç ıslahı, *Pm41* geninin tüm aşamalarda direnç sağlamada önemli rol oynamasıyla bu hastalığın yönetimi için sürdürülebilir bir yaklaşım sağlamaktadır. Bu araştırmada, *Pm41* geni için çeşitli Türk araştırma kurumlarından 96 Türk ekmeklik buğday (*Triticum aestivum*) çeşidi incelenmiştir. PCR analizi, incelenen çeşitlerin %57'sinin *Pm41* genine sahip olduğunu göstermiştir. En yüksek tespit oranı %89 ile Bahri Dağdaş Uluslararası Tarımsal Araştırma Enstitüsü Müdürlüğü/Konya'dan alınan çeşitlerde kaydedilirken, Tarla Bitkileri Araştırma Enstitüsü Müdürlüğü/Ankara'da %29 ile daha düşük bir frekans görülmüstür. Veriler, *Pm41* varlığında bölgesel farklılıklar olduğunu göstermektedir. Çeşitlerin yarısından fazlasında gözlemlenen *Pm41* geni, Türk buğday çeşitlerinin direnç için önemli olabilecek gen varyantlarına sahip olduğunu düşündürmektedir. Bu çalışma, sürdürülebilir buğday yetiştiriciliği ve gıda güvenliği için olmazsa olmaz olan direnç genlerinin yeni varyantlarını bulmak için genetik materyallerin korunmasının önemini vurgulamaktadır.

Anahtar kelimeler: külleme, direnç geni, buğday ıslahı, haplotip çeşitliliği

REFERENCES

Arslan M.S., Oğuz A.Ç., Karakaya A., 2024. Edirne ilinde buğday ve arpa bitkilerinde görülen yaprak hastalıkları. Journal of Agricultural Faculty of Bursa Uludag University, 38 (1), 13-26.

Aydın N., Demir B., Güleç T., Şermet C., Bayramoğlu H.O., Sayaslan A., Mut Z., 2021. Ekmeklik buğdayda geliştirilen rekombinant kendilenmiş hat populasyonunda kalite özellikleri için fenotipik ve genotipik değişim. Anadolu Tarım Bilimleri Dergisi, 36 (3), 418-432.

Baloch F.S., Ali A., Tajibayev D., Nadeem M.A., Ölmez F., Aktaş H., Alsaleh A., Cömertpay G., Imren M., Mustafa Z., Dababat A.A., Yang, S.H., 2024. Stripe rust resistance gene Yr15 in Turkish and Kazakhstan wheat germplasms and the potential of Turkish wild emmer for stripe rust breeding. Genetic Resources and Crop Evolution, 71 (6), 2699-2719.

Cao A., Xing L., Wang X., Yang X., Wang W., Sun Y., Qian C., Ni J., Chen Y., Liu D., Wang X., Chen, P., 2011. Serine/threonine kinase gene Stpk-V, a key member of powdery mildew resistance gene Pm21, confers powdery mildew resistance in wheat. Proceedings of the National Academy of Sciences, 108 (19), 7727-7732.

Cavalet-Giorsa E., González-Muñoz A., Athiyannan N., Holden S., Salhi A., Gardener C., Quiroz-Chávez J., Rustamova S.M., Elkot A.F., Patpour M., Rasheed A., Mao L., Lagudah E.S., Sambasivam K., Periyannan S.K., Sharon A., Himmelbach A., Reif J.C., Knauft M., Mascher M., Stein N., Chayut N., Ghosh S., Perovic D., Putra A., Perera A.B., Hu C., Yu G., Ahmed H.I., Laquai K.D., Rivera L.F., Chen R., Wang Y., Gao X., Liu S., Raupp W.J., Olson E.L., Lee J., Chhuneja P., Kaur S., Zhang P., Park R.F., Ding Y., Liu D., Li W., Nasyrova F.Y., Dvorak J., Abbasi M., Li M., Kumar N., Wilku B., Meyer W.B., Boshoff W.H.P., Steffenson B.J., Matny O., Sharma P.K., Tiwari V.K., Grewal S., Pozniak C.J., Chawla H.S., Ens J., Dunning L.T., Kolmer J.A., Lazo G.R., Xu S.S., Gu Y.Q, Xu X., Uauy C., Abrouk M., Bougouffa S., Brar G.S., Brande B.H., Wulff B.B.H., Krattinger S.G., 2024. Origin and evolution of the bread wheat D genome. Nature, 633 (8031), 848-855.

Chai Y., Senay S., Horvath D., Pardey P., 2022. Multi-peril pathogen risks to global wheat production: A probabilistic loss and investment assessment. Frontiers in Plant Science, 13, 1034600.

Chen X., Wang Y., Han G., Fan J., Tan Q., Liu G., Zhang H., Wang Y., 2024. Identification and transfer of a new powdery mildew resistance gene pmcahm from landrace changanhongmai into common wheat. Agronomy, 14 (4), 667.

Cheng H., Liu J., Wen J., Nie X., Xu L., Chen N., Li Z., Wang Q., Zheng Z., Li M., Cui L., Liu Z., Bian J., Wang Z., Xu S., Yang Q., Appels R., Han D., Song W., Sun Q., Jiang Y., 2019. Frequent intra-and inter-species introgression shapes the landscape of genetic variation in bread wheat. Genome biology, 20, 1-16.

Cheng B., Ding Y.Q., Gao X., Cao N., Xin Z.H., Zhang L.Y., 2020. The diversity of powdery mildew resistance gene loci among wheat germplasm in Southwest China. Cereal Research Communications, 48 (1), 65-70.

Cheng P., Guo M., Hao X., Guo X., Yao Q., Guo Q., Li Q., Wang B., 2022. Evaluation of powdery mildew resistance and molecular detection of resistance genes in an international wheat collection. Crop Protection, 160, 106033.

Doyle J., 1991. DNA protocols for plants. In 'Molecular techniques in taxonomy. Vol. 57. NATO ASI Series H: cell biology. Hewitt G.M., Johnston A.W., Young J.P.W., ((Eds. pp. 283–293.

Ilker E., Tonk F.A., Tosun M., Altinbas M., Kuçukakça M., 2009. Inheritance and combining ability in some powdery

mildew resistant wheat lines. Crop Breeding and Applied Biotechnology, 9, 124-131.

Laroche A., Frick M., Graf R.J., Larsen J., Laurie J.D., 2019. Pyramiding disease resistance genes in elite winter wheat germplasm for Western Canada. The Crop Journal, 7 (6), 739-749.

Li G., Fang T., Zhan H., Xie C., Li H., Yang T., Nevo E., Fashima., Sun Q., Liu Z., 2009. Molecular identification of a new powdery mildew resistance gene Pm41 on chromosome 3BL derived from wild emmer (*Triticum turgidum* var. *dicoccoides*). Theoretical and Applied Genetics, 119, 531-539.

Li G., Xu X., Bai G., Carver B.F., Hunger R., Bonman J.M., 2016. Identification of novel powdery mildew resistance sources in wheat. Crop Science, 56 (4), 1817-1830.

Li M., Dong L., Li B., Wang Z., Xie J., Qiu D., Li Y., Shi W., Yang L., Wu Q., Chen Y., Lu P., Guo G., Zhang H., Zhang P., Zhu K, Li Y., Zhang Y., Wang R., Yuan C., Liu W., Yu D., Luo M., Fahima T., Nevo E., Li H., Liu Z., 2020. A CNL protein in wild emmer wheat confers powdery mildew resistance. New Phytologist, 228 (3), 1027-1037.

Li M., Dong L., Zhu K., Wu Q., Chen Y., Lu P., Guo G., Zhang H., Zhang P., Li B., Li W., Yang Y., Hou Y., Cui X., Li H., Dong L., Zhao Y., Liu Z., 2022. Provoking a silent R gene in wheat genome confers resistance to powdery mildew. Plant Biotechnology Journal, 20 (11), 2039-2041.

Merchuk-Ovnat L., Barak V., Fahima T., Ordon F., Lidzbarsky G.A., Krugman T., Saranga Y., 2016. Ancestral QTL alleles from wild emmer wheat improve drought resistance and productivity in modern wheat cultivars. Frontiers in Plant Science, 7, 452.

Morgounov A., Tufan H.A., Sharma R., Akin B., Bagci A., Braun H.J., Kaya Y., Keser M., Payne T.S., Sonder K., McIntosh R., 2012. Global incidence of wheat rusts and powdery mildew during 1969–2010 and durability of resistance of winter wheat variety Bezostaya 1. European Journal of Plant Pathology, 132, 323-340.

Morgounov A., Keser M., Kan M., Küçükçongar M., Özdemir F., Gummadov N., Muminjanov H., Zuev E., Qualset C.O., 2016. Wheat landraces currently grown in Turkey: distribution, diversity, and use. Crop Science, 56 (6), 3112-3124.

Özdemir H.Y., Karakaya A., Çelik Oğuz A., 2017. Kırıkkale ilinde buğday ve arpa ekim alanlarında görülen fungal yaprak hastalıklarının belirlenmesi. Bitki Koruma Bülteni, 57 (2), 89-112.

Sönmezoğlu Ö.A., Yıldırım A., Türk Ü., Yanar Y., 2019. Bazı yerel makarnalık buğday çeşitlerinde küllemeye (*Blumeria graminis* f. sp. *tritici*) karşı dayanıklılığın belirlenmesi. Avrupa Bilim ve Teknoloji Dergisi, (17), 944-950.

Tosun M., Altınbaş M., İlker E., Tonk F.A., Küçükakça M., 2011. Buğdayda külleme (*Erysiphe graminis*) hastalığına dayanıklılığın kalıtımı. Bitkisel Araştırma Dergisi, 1, 6–10

Wu X.X., Xu X.F., Ma D.X., Chen R.Z., Li T.Y., Cao Y.Y., 2019. Virulence structure and its genetic diversity analyses of *Blumeria graminis* f. sp. *tritici* isolates in China. BMC Evolutionary Biology, 19, 1-11.

Wu X., Bian Q., Gao Y., Ni X., Sun Y., Xuan Y., Cao Y., Li T., 2021. Evaluation of resistance to powdery mildew and identification of resistance genes in wheat cultivars. PeerJ, 9, e10425.

Yang F., Wan H., Li J., Wang Q., Yang N., Zhu X., Liu Z., Yang Y., Ma W., Fan., Yang W., Zhou Y., 2022. Pentaploidization enriches the genetic diversity of wheat by enhancing the recombination of AB Genomes. Frontiers in Plant Science, 13, 883868.

Zhang Y., Bai Y., Wu G., Zou S., Chen Y., Gao C., Tang D., 2017. Simultaneous modification of three homoeologs of Ta EDR 1 by genome editing enhances powdery mildew resistance in wheat. The Plant Journal, 91 (4), 714-724.

Zhang Q., Li Y., Li Y., Fahima T., Shen Q., Xie C., 2021. Introgression of the powdery mildew resistance genes Pm60 and Pm60b from *Triticum urartu* to common wheat using durum as a 'bridge'. Pathogens, 11 (1), 25.

Zhou Y., Zhao X., Li Y., Xu J., Bi A., Kang L., Xu D., Chen H., Wang Y., Wang Y., Liu S., Jiao C., Lu H., Wang J., Yin C., Jiao Y., Lu F., 2020. Triticum population sequencing provides insights into wheat adaptation. Nature Genetics, 52 (12), 1412-1422.

Cite this article: Mustafa, Z. (2024). Assessment of Pm41 gene frequency in Turkish bread wheat germplasm. Plant Protection Bulletin, 64-4. DOI: 10.16955/bitkorb.1555981

Atıf için: Mustafa, Z. (2024). Türk ekmeklik buğday germplazmında Pm41 gen frekansının değerlendirilmesi. Bitki Koruma Bülteni, 64-4. DOI: 10.16955/bitkorb.1555981