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DKP: collecting plant material for research, writing the manuscript, statistical analysis; JN: research designing; TK: inoculate preparation; ZS: evaluation of plants infestation; AT, DW, SM: conducting experiment

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ORIGINAL RESEARCH PAPER

Characteristics of spring wheat genotypes exhibiting high resistance to FHB in terms of their resistance to other fungal diseases

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Abstract

The field experiment was carried out in 2010–2012 at the Dłń Agricultural Research Station, the Poznań University of Life Sciences, Poland. The study was designed to evaluate the degree of infection by powdery mildew, brown rust, and septoria leaf blotch in 61 spring wheat genotypes differing in their resistance to *Fusarium* spp.

The vast majority of spring wheat genotypes in the collection of gene resources in the USA defined as resistant to *Fusarium* spp. confirmed their resistance under Polish climatic conditions. The *B. graminis* infection rate of genotypes that are considered to be resistant to Fusarium head blight was high. The resistance ranged from 7 for Sumai 3 (PL2) up to 8.8 for Ning 8331 (in a 9-point scale). Most of the genotypes (56.5%) were infected by *Puccinia recondita* at a level of 1–3 (in a 9-point scale). The genotypes of Sumai 3 exhibited high resistance to septoria leaf blotch, amounting to 1–2 in a 9-point scale; the resistance of Frontana ranged from 1 to 3.5, while the genotypes of Ning were infected by *Mycosphaerella graminicola* at 5–6.

Keywords

spring wheat; *Fusarium* spp.; powdery mildew; brown rust; septoria leaf blotch

Introduction

Fusarium species infect all cereal crops, however wheat exhibits the greatest susceptibility to Fusarium head blight (FHB) and accumulates the greatest amounts of mycotoxins in the grain, including deoxynivalenol (DON) [1,2]. In Poland, Fusarium head blight is not considered to be a disease of economic importance in terms of grain yield reduction. However, grain contamination with *Fusarium* spp. mycotoxins is a serious problem and has been repeatedly reported in recent decades [3–5], which indicates the need to improve the resistance of wheat cultivars to FHB [6]. Breeding for resistance to FHB has received increasing attention in Europe and North America since the 1990s [7–9].

The resistance of plants to *Fusarium* spp. is horizontal, polygenic, and complex in character. For this reason, there are no completely resistant genotypes. Most cultivars grown in Europe exhibit high or very high susceptibility to FHB [10]. The lack of potentially good genotypes for initial material in resistance breeding is a great problem for Polish breeding programs. Genotypes with resistance originated from the spring cultivars (Sumai 3, Frontana) exhibit disadvantageous yield performance (crop yield

and yield stability) and insufficient resistance to other fungal diseases. For these reasons, finding genotypes resistant to *Fusarium* ssp. and exhibiting enhanced resistance to other fungal diseases would facilitate more effective resistance breeding of wheat in Poland.

The aim of the study was to assess infection rates by powdery mildew (*Blumeria graminis*), brown rust (*Puccinia recondita*), and septoria leaf blotch (*Mycosphaerella graminicola*) in genotypes of spring wheat characterized by high resistance to *Fusarium* spp.

Material and methods

The study was conducted on 61 genotypes of spring wheat, i.e., 13 from Brazil (e.g., Frontana), 13 from China (e.g., Sumai 3 and Ning), 10 from Japan, four from Argentina, three from Peru, three from Italy, two from Hungary, and one from Sweden, Switzerland, Uruguay, Venezuela, Russia, Mexico, Norway, and Greece. The experiment comprised all major genotypes of spring wheat used in breeding programs as sources of resistance to *Fusarium* ssp. The genotypes were obtained from the wheat National Small Grain Collection at the Agriculture Research Station in Aberdeen, belonging to the National Plant Germplasm System (NPGS) Germplasm Collection Genebanks in USA. These genotypes were preliminarily evaluated as resistant to *Fusarium* ssp. Five varieties were of Polish origin – Nawra, Zadra, Łagwa, Waluta, and Katoda.

The field experiment was conducted between 2010 and 2012, at the Dłóń Agricultural Research Station, the Poznań University of Life Sciences, Poland. The 61 genotypes selected were sown in plots of 1 m² (1 × 1 m) in a randomized block design in three replications. Two combinations were applied in this experiment:

- no chemical plant protection, natural fungal infection
- no chemical plant protection, artificial inoculation with fungi from the genus *Fusarium* ssp.

Inoculum was produced using several isolates of fungi from the genus *Fusarium* ssp. infesting wheat, representing different species and exhibiting high pathogenicity: *F. graminearum* and *F. culmorum* – with three isolates from each species (each isolate in an equal amount). The isolates came from the wheat grains harvested in the previous year: *F. graminearum* (191/3, 18/4, 17.5) and *F. culmorum* (25/1, 29/2, 24/3). Spore concentration was established at approximately 106 mL. Next, suspensions of all isolates were mixed. Wheat heads were sprayed with the spore suspension at anthesis at a rate of 100 mL/m². Spraying operations were performed twice at 1-week intervals during the flowering phase of wheat plants.

The infection rate with *Fusarium* head blight was assessed 3 weeks after the second inoculation. This evaluation was conducted based on a graphic disease identification key developed by the European and Mediterranean Plant Protection Organization (EPPO) [11]. Plot disease severity for a population of approximately 200 spikes per plot was estimated for both incidence (percentage of infected spikes) and severity (percentage of infected spikelets of the diseased spikes). *Fusarium* head blight was scored based on the mean percentage of blighted spikelets per infected spike (disease severity) and the percentage of infected spikes per plot (disease incidence). *Fusarium* head blight index was calculated as the combination of disease severity and disease incidence.

The infection rates of the genotypes by fungal pathogens such as *B. graminis*, *P. recondita*, and *M. graminicola* were assessed in the plots in combinations with natural infection conditions by diseases on a scale from 1 (slightly infested) to 9 (completely infested). Field evaluations of whole plots on 0–9 scale was due to Bennett and Westcott [12]. The assessments were conducted in phases from the onset of flowering to full anthesis of spring wheat (BBCH 61–65).

The results were analyzed statistically by applying one-way ANOVA. The least significant difference (LSD) was calculated using Tukey's test at $p \leq 0.05$. The normality of distributions for the studied traits as well as multivariate normality were tested. Multivariate analysis of variance (MANOVA) was performed on the basis of

the following model using a MANOVA procedure in GenStat 17th edition: $Y = XT + E$, where: Y is $(n \times p)$ -dimensional matrix of observation, n is a number of all observations, p is a number of traits; X is $(n \times k)$ -dimensional matrix of design, k is number of genotypes; T is $(k \times p)$ -dimensional matrix of unknown effects; E is $(n \times p)$ -dimensional matrix of residuals. All the parameters are unknown and have to be estimated under the usual assumptions concerning random errors, such as that of the same covariance matrix for each experimental unit and of no correlations between different experimental units [13].

The Pearson's correlation coefficients were used to assess the interdependence between the observed traits [14]. The means for genotypes were calculated using the FCORRELATION procedure in GenStat 16th edition. Euclidean distance was used as the resemblance coefficient for cluster analysis with the unweighted pair group arithmetic means method (UPGMA) [15].

Results

Weather conditions impacted on the incidence of fungal diseases (Tab. 1). The main factor promoting the occurrence and development of fungal diseases in wheat was frequent rainfall, resulting in high humidity. In comparison to the multi-year period, more than twofold greater total precipitation was recorded in May 2010 and in June 2012. In turn, both in May and June 2011 the total precipitation was markedly lower than the long-term mean, while the temperatures were higher than the long-term means.

The cultivars analyzed included both genotypes considered to be sources of resistance to *Fusarium* ssp. and currently grown Polish spring wheat cultivars. The mean FHB index for the period of 3 years is presented in Tab. 2. The vast majority of genotypes defined in the gene resource collection in the USA as resistant to *Fusarium* ssp. confirmed their resistance under Polish conditions. A low FHB index was also recorded for Waluta and Katoda. Following inoculation, a FHB index of over 10% was observed in 11 genotypes, including Łagwa, Zadra, and Nawra. The same group of the most infected genotypes comprised wheat coming from other European countries (Greece, Hungary), South America (Brazil, Venezuela, and Uruguay), and Asia (Japan and China; Tab. 2).

The mean level of plant infection by *B. graminis* for the 3 years was 7.56 in a 9-point scale, while in the dry year (2011) it was significantly lower than in the other years of the study (Tab. 2, Tab. 3). The range of genotype responses was from 2 for the Polish cultivar Łagwa up to 9 for MULT 760 (PI 271129) from Peru. The differences in *B. graminis* infection between genotypes were statistically significant. On average, the lowest infection by *B. graminis*, below 5 on the 9-point scale, was observed in all the Polish cultivars tested and in genotype B 576 (PI 352040) from Switzerland. The genotypes (56) from other countries exhibited a mean infection by *B. graminis* of over 6.3, thus comprising a homogeneous group. The *B. graminis* infection of genotypes

Tab. 1 Average monthly temperatures and monthly precipitation totals during the vegetation period of spring wheat (2010–2012, Dłóń).

Month	Average air temperature (°C)				Precipitation total (mm)			
	2010	2011	2012	1956–2009	2010	2011	2012	1956–2009
March	3.3	4.2	6.1	3.0	38.5	30.0	16.8	33.7
April	9.1	11.9	10.4	8.2	45.0	17.0	23.0	32.0
May	11.4	15.4	17.8	13.5	125.0	37.5	26.9	55.3
June	18.8	19.0	18.3	16.8	44.0	33.5	133.9	66.2
July	22.8	18.6	22.1	18.4	64.0	169.0	95.4	82.1

Tab. 2 Spring wheat genotypes infected by *B. graminis*, *P. recondita*, *M. graminicola* and the average FHB index during the three years of observations (Dłóń).

Genotype name	Country of origin	Spikes	Leaves		
		FHB index (%)	powdery mildew	brown rust	septoria leaf blotch
PI 191921 Cologne Abastardado	Italy	0.2* ^a	7.6** ^{ab}	5.0	5.0
PI 69302 6905	China	0.3 ^a	7.7 ^a	6.5	3.3
Cltr 14371 8475-59	Brazil	0.3 ^a	7.4 ^{abcd}	2.0	1.5
PI 94551 368	Italy	0.3 ^a	8.4 ^a	1.0	1.0
PI 202790 Frontana	Brazil	0.4 ^a	7.7 ^a	1.5	3.8
PI 191347 Shirokawa Shiro	Japan	0.8 ^a	7.4 ^{abcd}	2.0	3.0
PI 70665 Sha Polo	China	0.8 ^a	7.8 ^a	3.0	3.5
PI 214392 Colotana 266/51	Brazil	1.3 ^{ab}	7.1 ^{abcde}	3.5	2.5
PI 202771	Peru	1.5 ^{ab}	8.2 ^a	2.5	6.3
PI 69301 6901	China	1.8 ^{ab}	8.1 ^a	4.0	2.0
Ning 8343	China	1.8 ^{ab}	8.7 ^a	6.0	2.5
Nyu Bai	Japan	1.8 ^{ab}	6.6 ^{abcde}	2.5	5.5
PI 54029 Universal	Argentina	1.9 ^{ab}	8.3 ^a	4.5	3.5
Waluta	Poland	1.9 ^{ab}	4.8 ^{cdef}	4.0	1.0
Colotana 266(51)	Brazil	2.2 ^{abc}	7.5 ^{abc}	5.0	1.0
PI 382153 Nobeoka Bozu	Japan	2.7 ^{abc}	8.7 ^a	6.5	2.3
16-52-2	Brazil	2.8 ^{abc}	7.8 ^a	1.0	1.0
PI 382154 Nyu Bai	Japan	3.0 ^{abc}	8.3 ^a	1.0	5.0
PI 344190 Missioneiro	Brazil	3.1 ^{abc}	7.4 ^{abcd}	3.5	6.3
Cj 9311	China	3.4 ^{abc}	8.3 ^a	3.5	6.8
CJ W14	China	3.4 ^{abc}	8.1 ^a	6.0	6.0
PI 382140 Abura	Brazil	3.5 ^{abc}	7.8 ^a	5.0	5.0
Cltr 17427 16-52-2	Brazil	3.6 ^{abc}	8.3 ^a	3.0	2.0
CM-82036	Mexico	3.7 ^{abc}	8.3 ^a	1.5	1.0
Katoda	Poland	3.7 ^{abc}	3.4 ^{fg}	2.5	1.3
Ning 8331	China	3.7 ^{abc}	8.8 ^a	6.0	3.0
PI 124330 352	China	4.0 ^{abc}	6.3 ^{abcde}	3.0	2.3
PI 278462 2433	Russia	4.0 ^{abc}	7.4 ^{abcd}	1.5	1.0
Veneny 3787	Hungary	4.3 ^{abc}	7.6 ^{abc}	3.0	1.0
PI 500147 Frontana	Brazil	4.4 ^{abc}	7.9 ^a	1.0	2.0
Shinchunaga	Japan	5.2 ^{abc}	8.7 ^a	3.5	6.5
PI 155280 Shinchunaga	Japan	5.4 ^{abc}	7.5 ^{abc}	7.5	8.5
Ning 7840	China	6.0 ^{abc}	7.7 ^a	5.0	3.5
Sichuan 9418	China	6.2 ^{abc}	8.3 ^a	7.0	5.5

Tab. 2 Continued

Genotype name	Country of origin	Spikes	Leaves		
		FHB index (%)	powdery mildew	brown rust	septoria leaf blotch
PI 189816 Sel. 49-4830 H944	Argentina	6.3 ^{abc}	8.3 ^a	5.5	6.8
PI 228309 Fram I	Norway	6.4 ^{abc}	7.9 ^a	3.0	5.3
PI 352040 B 576	Switzerland	6.4 ^{abc}	4.5 ^{efg}	2.5	6.0
Cltr 9348 Swan	Sweden	6.7 ^{abc}	7.7 ^a	1.0	5.5
PI 271129 MULT 760	Peru	6.7 ^{abc}	9.0 ^a	1.5	2.0
Cltr 12470 Frontana	Brazil	6.8 ^{abc}	7.6 ^{ab}	3.5	1.1
Pi 81791 TRO5ID SD Sapporo haru komug	Japan	7.1 ^{abcd}	8.5 ^a	2.0	1.0
PI 481542 Sumai No. 3	China	7.5 ^{abcd}	8.6 ^a	1.0	4.0
PI 182577 Norin 52	Japan	7.6 ^{abcd}	8.6 ^a	6.5	4.8
PI 197664 L-104	Argentina	7.7 ^{abcd}	7.6 ^{ab}	3.0	5.0
Cologne Abastrado	Italy	7.8 ^{abcd}	7.8 ^a	4.5	5.5
Cltr 13136 Rio negro	Brazil	8.0 ^{abcd}	8.5 ^a	3.0	2.3
Sumai 3 (PL)	China	8.2 ^{abcd}	7.0 ^{abcde}	1.5	5.8
PI 337149 Magnif 98	Argentina	8.7 ^{abcde}	7.0 ^{abcde}	2.0	4.0
Norin 61	Japan	9.0 ^{abcde}	7.9 ^a	5.5	5.5
PI 202770	Peru	9.1 ^{abcde}	7.2 ^{abcd}	3.0	6.0
Łagwa	Poland	10.2 ^{abcde}	2.0 ^g	3.0	1.3
PI 197128 Shinchunaga	Japan	10.7 ^{abcde}	7.9 ^a	3.0	4.8
Sumai 3 (PL2)	China	10.8 ^{abcde}	7.0 ^{abcde}	2.0	2.5
PI 192634 Trintecincio	Brazil	11.2 ^{abcde}	8.7 ^a	3.0	1.5
PI 62364 Lebarata	Venezuela	11.7 ^{abcde}	8.7 ^a	8.0	8.0
Zadra	Poland	12.7 ^{bcde}	4.9 ^{bcdef}	6.0	2.5
PI 434987 Estanzuela young	Uruguay	12.7 ^{bcde}	8.2 ^a	3.0	1.0
PI 468990 MG 27043	Greece	13.7 ^{cde}	8.0 ^a	3.5	4.5
PI 382144 Encruzilhada	Brazil	13.8 ^{cde}	7.1 ^{abcde}	6.5	2.0
Nawra	Poland	18.5 ^{de}	4.8 ^{def}	4.5	3.8
PI 272457 Veneny 3787	Hungary	20.2 ^e	8.9 ^a	4.0	6.0
Mean		8.5	7.6	3.6	3.6

* Values marked with different letters in the columns are statistically different, according to Tukey's test ($p \leq 0.05$). ** 9-point scale: 1 – no symptoms of infection; 9 – complete infection.

Tab. 3 Infection of spring wheat by fungal pathogens in the years of the study.

Fungal pathogens	2010	2011	2012
Powdery mildew	8.2* ^a	6.6 ^b	7.9 ^a
Septoria leaf blotch	2.3 ^b	-	4.9 ^a
Brown rust	2.5 ^b	-	4.7 ^a

* Values marked with different letters are statistically different between years, according to Tukey's test ($p \leq 0.05$). "-" means absence of diseases.

considered to be sources of *Fusarium* ssp. resistance was high, ranging from 7 in a 9-point scale for Sumai 3 (PL2) up to 8.8 for Ning 8331.

Both brown rust and septoria leaf blotch were observed in 2010 and 2012. More than 50% of the analyzed genotypes (56.5%) showed very little symptoms of infection by *P. recondita* – they were infected at a level of 1–3 on the 9-point scale. In the case of septoria leaf blotch, a markedly lower number of genotypes showed no symptoms of the disease. None of the genotypes was completely infected by *P. recondita* or *M. graminicola*. The genotypes of Sumai 3 exhibited high resistance to *M. graminicola* amounting to 1–2 on the 9-point scale, resistance of Frontana fell within the range of 1 up to 3.5, while the Ning genotypes were in-

fectured by *M. graminicola* at a level of 5–6. In turn, in the case of *P. recondita* infection, the greatest resistance to this disease among the sources of resistance to *Fusarium* ssp. was observed in Frontana Cltr 12470 (1.1) and Frontana PI 500147 (2), followed by Ning 8343 (2.5) and Sumai 3 (2.5).

All studied traits have a normal distribution as well as a multivariate normality. The results of MANOVA indicate that the genotypes were significantly different for all observed traits [Wilk's $\lambda = 0.4931$; $F(60, 467) = 1.50$; $p < 0.0001$; Pillai–Bartlett trace = 0.5899; Roy's maximum root test = 0.3987; Lawley–Hotelling trace = 0.8689]. Statistically significant and positive correlations were established only between leaf rust and septoria leaf blotch ($r = 0.3243$, $p = 0.0108$; Tab. 4 and Fig. 1).

Based on all observed resistance traits, the cluster analysis distinguished six groups of spring wheat genotypes (Fig. 1). The main clusters in the dendrogram are: Cluster I – with Schinchunaga (Japan) and Lebarata (Venezuela); Cluster II – with varieties from Hungary, Brazil, and Poland; Cluster III – with only Polish varieties; and other clusters with foreign cultivars.

Discussion

Resistance to *Fusarium* ssp. is quantitatively inherited in all cereal species with a highly significant genetic variation among breeding materials [7,10,16]. No completely resistant genotype has been found [1]. The most resistant wheat germplasm can be divided into three gene pools: winter wheats from Eastern Europe, spring wheats from China and Japan, and spring wheats from Brazil [10]. Spring wheat cultivars showing resistance to *F. graminearum* include Frontana and Encruzilhada (Brazil), Nobeokabozu Komugi (Japan), Sumai 3, and several Ning selections (China) [10,17,18]. However, most of these non-adapted sources lack the agronomic character needed in modern wheat varieties. The most common sources of genetic resistance to FHB are derived from the Chinese Sumai 3 [19–21]. Sumai 3 lacks resistance to almost any other disease.

In addition, it is early-maturing cultivar (maturing about 3 weeks earlier than elite varieties), and shatters easily [22]. This study was conducted on Sumai 3 imported directly from the gene bank (PI 4815) as well as two genotypes of Sumai 3 (PL and PL2) subjected to several years of selection under Polish environmental conditions. The genotypes Sumai 3 PL and PL2 proved to be more resistant both to *Fusarium* ssp. strains and powdery mildew found in

Tab. 4 Correlation coefficients for observed traits.

Trait	FHB index	Powdery mildew	Leaf rust	Septoria leaf blotch
FHB index	1.0000			
Powdery mildew	-0.1235	1.0000		
Leaf rust	0.1401	0.0839	1.0000	
Septoria leaf blotch	0.1508	0.1821	0.3243*	1.0000

* $p < 0.05$

Fig. 1 Dendrogram generated by UPGMA clustering based on means of all observed traits for 61 genotypes.

Poland than Sumai 3 originated from the gene bank. Unfortunately, the genotypes were relatively highly infected by *P. recondita* (2.5, 4.75, and 5.75, respectively). In a study by Wiśniewska and Kowalczyk [23], the resistance of Sumai 3 to *B. graminis* infection was classified as 5, on average in 1998–2002 period, with a proportion of *Fusarium* ssp.: damaged kernels of 12%. In the experiment conducted by Góral [6], the FHB index for Sumai 3 was 5.0.

This study analyzed three different genotypes of Frontana imported from the gene bank in the USA. Frontana (Cltr 12470) was donated to the gene bank by the University of Minnesota in 1945, genotype PI 202790 received from Peru in 1952, with genotype PI 500147 being donated in 1985 by the Chinese Academy of Agricultural Sciences (CAAS) [24]. These genotypes were together in one cluster in the dendrogram. These three genotypes originate from the same cross of Frontana × Mentana, but they have adapted to the diverse environmental conditions under which they were grown. Because of this fact, these genotypes exhibit different responses to fungal diseases under Polish conditions. For this reason, the FHB index for Frontana ranged from 0.4% to 6.8%, resistance to powdery mildew from 7.7% to 7.9%, to brown rust it ranged from 1% to 3%, and to septoria leaf blotch – from 1% to 4%. In the study by Góral [6], the FHB index of Frontana for the years 2003–2004 was as high as 25.5. In a study by Wiśniewska and Kowalczyk [23], the index of *Fusarium* ssp. damaged kernels in that cultivar was 20 (while in Polish spring cultivars it was higher – 28.3%), with simultaneous very high resistance to powdery mildew at a mean of 2. The differences in the infection rates may result from different weather conditions.

Among the genotypes analyzed, there were also three Ning selections: Ning 8343, Ning 8331, and Ning 7840. These genotypes with FHB index values from 1.8% to 6.0% were very strongly infected by *B. graminis* (7.7–8.8), moderately by septoria leaf blotch (5.0–6.0), and weakly by brown rust (2). These genotypes were also located together in one cluster.

Among these genotypes tested and exhibiting both low FHB values and relatively low infection by *B. graminis*, we need to focus on Polish cultivars and on B 576 (PI 352040), 352 (PI 124330), and Nyu Bai genotypes. Genotype B 576 is from Switzerland and was donated to the gene bank in 1969 as breeding material obtained after crossing LNL × B74. Genotype 352 was received from China in 1937 and Nyu Bai was donated from Japan in 1973, both of unknown provenance [24].

All Polish cultivars used in the experiment exhibited moderate or low rates of infection by the fungal pathogens and also varied in the infection rates by *Fusarium* ssp. The Waluta and Katoda cultivars generated by DANKO HR are of very high quality and at the same time they exhibited high resistance to the above-mentioned diseases. The Łagwa cultivar, registered in 2009 by Małopolska Hodowla Roślin, exhibited high resistance to powdery mildew (2.0), septoria leaf blotch (3.0), and brown rust (1.25) at a FHB index of 10.2. The other Polish cultivars, i.e., Nawra and Zadra, had FHB indexes over 10%. However, it needs to be remembered that the resistance of wheat cultivars to FHB is not sufficient, because the sources of resistance genes used by breeders over a long period lead to the appearance of new virulence of the pathogen [23].

When analyzing spring wheat genotypes, high resistance to FHB, septoria leaf blotch, and brown rust was found in Cltr 14371 8475-59 from Brazil, PI 94551 368 from Italy, 16-52-2 from Brazil, and CM-82036 from Mexico. These genotypes appear to be a better initial material in breeding *Fusarium* ssp. resistant cultivars in comparison to genotypes traditionally recognized as sources of *Fusarium* ssp. resistance, including Sumai 3 and Frontana.

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Charakterystyka genotypów pszenicy jarej o wysokim stopniu odporności na grzyby z rodzaju *Fusarium* pod kątem odporności na inne choroby grzybowe

Streszczenie

Doświadczenie polowe prowadzono w latach 2010–2016 w Rolniczym Gospodarstwie Doświadczalnym Dłóń, należącym do Uniwersytetu Przyrodniczego w Poznaniu. Oceniano stopień porażenia przez mączniaka prawdziwego, rdzę brunatną oraz septorię paskowaną liści 61 genotypów pszenicy jarej o różnym stopniu odporności na grzyby z rodzaju *Fusarium*. Zdecydowana większość genotypów zdefiniowana w kolekcji zasobów genowych w USA jako odporna na *Fusarium* potwierdziła swą odporność w warunkach polskich. Porażenie genotypów, uznawanych jako źródła odporności na fuzariozę, przez mączniaka prawdziwego było wysokie i wynosiło od 7 stopni w skali 9-cio stopniowej dla Sumai 3 (PI) do 8.8 dla Ning 8331. Udokumentowano porażenie większości analizowanych genotypów (56.5%) przez rdzę brunatną na poziomie 1–3 w skali 9-stopniowej. Analizowane genotypy Sumai 3 cechowały się dużą odpornością na septoriozę (porażenie 1–2 stopnie w skali 9-cio stopniowej), odporność Frontana mieściła się w granicach od 1 do 3.5 stopni, natomiast badane genotypy Ning porażone były przez septoriozę na poziomie 5–6 stopni.