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Wartość hodowlana wybranych odmian jabłoni (*Malus domestica*) pod względem odporności na parcha i mączniaka jabłoni

Breeding value of selected apple cultivars (*Malus domestica*) for the resistance to apple scab and powdery mildew

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Celem badań była ocena przydatności kilku odmian jabłoni do hodowli nowych genotypów odpornych/mało podatnych na parcha i mączniaka jabłoni w oparciu o ich ogólną (GCA) i specyficzną zdolność kombinacyjną (SCA). Stopień porażenia siewek jabłoni, stanowiących potomstwo 11 genotypów jabłoni, krzyżowanych w układzie czynnikowym: ♀4 × ♂7 – 4 odmiany mateczne (‘Alwa’, ‘Golden Delicious’, ‘Free Redstar’, ‘Gold Milenium’) i 7 odmian ojcowskich (‘Glogierówka’, ‘Kronselka’, ‘Kosztela’, ‘McIntosh’, ‘Oliwka Żółta’, ‘Malinowa Oberlandzka’, ‘Koksa Pomarańczowa’) przez oba patogeny oceniono w lipcu 2019 r. Istotnie ujemną wartość efektu GCA dla stopnia porażenia siewek przez parcha jabłoni oszacowano dla odmiany ‘Free Redstar’. Wskazuje to, że odmiana ta jest donorem genów warunkujących ‘odporność’ lub małą podatność na parcha jabłoni u potomstwa. Istotnie ujemną wartość efektu GCA dla stopnia porażenia siewek przez mączniaka jabłoni oszacowano dla odmiany ‘Free Redstar’. Oznacza to, że genotyp ten jest donorem genów warunkujących ‘odporność’ lub małą podatność na mączniaka jabłoni u siewek. Negatywne efekty SCA dla stopnia porażenia siewek przez parcha jabłoni uzyskano dla 3 rodzin mieszańców: ‘Free Redstar’ × ‘McIntosh’, ‘Alwa’ × ‘Malinowa Oberlandzka’ i ‘Alwa’ × ‘McIntosh’. Oznacza to, że w przypadku tych rodzin genetyczne współdziałanie obu genotypów rodzicielskich warunkuje ‘odporność’ lub małą podatność roślin na parcha jabłoni.

Słowa kluczowe: jabłoń, *Malus domestica* L., mączniak jabłoni, parch jabłoni

The aim of the study was to assess the suitability of several apple cultivars for breeding of new genotypes resistant/low susceptible to apple scab and powdery mildew based on their general (GCA) and specific (SCA) combining abilities. Infection degree of the apple seedlings, being the progeny of 11 cultivars crossed in the model: ♀4 x ♂7 – 4 maternal cultivars (‘Alwa’, ‘Golden Delicious’, ‘Free Redstar’, ‘Gold Milenium’) and 7 paternal cultivars (‘Glogierówka’, ‘Kronselka’, ‘Kosztela’, ‘McIntosh’, ‘Oliwka Żółta’, ‘Malinowa Oberlandzka’, ‘Koksa Pomarańczowa’) by both apple pathogens was evaluated in July 2019. Significantly negative value for the GCA effect for the infection degree by apple scab was estimated for ‘Free Redstar’. This indicates that this cultivar is a good donor of genes responsible for resistance to apple scab in the progeny. Negative value of GCA effect for susceptibility to powdery mildew was also stated for ‘Free Redstar’. This means that this cultivar may serve as good donor of genes determining resistance/low susceptibility to powdery mildew in its progeny. Negative SCA effects for resistance/low susceptibility to apple scab, moreover, were indicated for 3 cross combinations: ‘Free Redstar’ x ‘McIntosh’, ‘Alwa’ x ‘Malinowa Oberlandzka’ and ‘Alwa’ x ‘McIntosh’. This indicates that genetic interaction of both parental genotypes results in genetic determination of resistance or high tolerance to apple scab in their progeny.

Key words: apple, apple scab, *Malus domestica* L., powdery mildew

Introduction

Apple is the most important species of plants grown for fruit in the temperate climate zone and is well adapted to the natural conditions of Poland. The global production of apples is about 70 million tonnes. According to the estimates of Polish Statistics, 3 million tonnes of apples were produced in Poland in 2019.Thus, Poland is the largest producer of apples in the European Union, and the third largest in the world after China (35–40 million tonnes) and the USA (4.5–5 million tonnes).Most apples grown in Poland represent foreign cultivars, such as 'Idared', 'Champion', ' Jonagold ' and ' Golden Delicious ' (Kruczyńska, 2008; Badowska-Czubik et al., 2012). The further dynamic development of apple production in Poland is determined by the systematic introduction of new valuable apple cultivars into commercial orchards, since these cultivars are the most important driver of biological progress in fruit production. Only such genotypes allow for the implementation of innovative cultivation technologies and can increase the competitive edge and profitability of apple production,

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consistent with the requirements of environmental protection and the principles of food safety. That is why growers are constantly looking for new apple cultivars, better than those currently grown, which would have a combination of many traits, often difficult to bring together, but decisive for high production volume and consumer satisfaction, such as: different times of fruit ripening, high yield and quality of fresh fruit (increased content of extract, vitamin C and acidity), appealing colour and shape of fruit, suitability of apples for long-term storage, low growth vigour of trees and their high resistance to frost (Lewandowski and Żurawicz, 2007). The consumer market is increasingly interested in cultivars with a uniform skin colour (green, yellow or red).Colour is often associated with the quality of fruit and, consequently, its price. Cultivars with a high ability of self-thinning are also desired since they do not require hand-thinning for abundant fruiting each year. Success in apple cultivation is also strongly driven by the creation of new cultivars with high resistance or low susceptibility of trees to apple scab (*Venturia inaequalis*), powdery mildew (*Podosphaera leucotricha*) and fire blight (*Erwinia amylovora*).Growers of resistant apple cultivars can reduce production costs by reducing the number of treatments in orchards. This is a very important issue, especially now, when there is a significant drop in profitability of apple production and large interest in organic methods of cultivation (Żurawicz et al., 2004; Żurawicz and Lewandowski, 2011; Żurawicz et al., 2013).

The aim of the study was to assess the suitability of parental apple cultivars for the breeding of new genotypes resistant to apple scab and powdery mildew based on their general (GCA) and specific (SCA) combining abilities and assessment of progeny from 28 cross combinations.

Material and Methods

We analysed a population of 2,800 apple seedlings obtained from the crossing of 11 apple cultivars: 4 maternal forms ♀ (cultivars with a short juvenile period - 'Alwa', 'Golden Delicious', 'Free Redstar', 'Gold Milenium') and 7 paternal forms ♂ ("old" cultivars, today no longer grown in Poland on a commercial scale, but known for their specific, unique fruit flavour - 'Glogierówka', 'Kronselska', 'Kosztela', 'McIntosh', 'Oliwka Żółta', 'Malinowa Oberlandzka', 'Koksa Pomarańczowa') (Tab.1). The analysed seedlings represented 28 combinations obtained from crosses in the ♀4 × ♂7 factorial model (Tab.2). All seedlings were grafted on M.9 rootstock. Seedlings were planted on a field plot in autumn 2017 in the Experimental Orchard in Dąbrowice in a randomized complete block design with 4 replicates, 25 seedlings per plot, spaced 3.50 x 1.0 m. Between 8 and 12 July 2019 each plant/seedling was inspected for the severity of apple scab and powdery mildew.

1. Infection of seedlings with apple scab (*Venturia inaequalis)* was assessed using a grading system (1 to 5) according to Shay and Hough (1952) and Crosby et al.(1992), where: class 1 – no macroscopic symptoms of infection on the leaves, class 2 – small spots on the leaves with no sporulation, class 3 - irregular chlorotic or necrotic lesions on the leaves with no sporulation, class 4 - small and sparse sporulating lesions on the leaves, class 5 - large and numerous sporulating lesions on the leaves.
2. Infection of seedlings with apple powdery mildew (*Podosphaera leucotricha*) was assessed using a grading system (1 to 5) proposed by Borecki (1987), considering the percentage of the leaf surface covered with white scurf formed by the *Podosphaera leucotricha* mycelium. The grading system comprises the following classes:1 – no symptoms of powdery mildew, single leaves covered with mycelium, 1% on average, 2 – from 1 to 10% of the leaf surface covered with mycelium, 5% on average, 3 – from 11 to 30% of the leaf surface covered with mycelium, 20% on average, 4 – from 31 to 50% of the leaf surface covered with mycelium, 40% on average, 5 – from 51 to 100% of the leaf surface covered with mycelium, 75% on average.

Statistical analysis. The obtained data were analysed in several stages. Findings from the inspection of individual plants for each trait were used to calculate arithmetic means for each replicate. Means were used for their preliminary statistical analysis using one-way analysis of variance according to the random block system, in which the factor was hybrid families. When significant differences in mean traits were found in the analysed hybrids, an analysis of variance for the factorial model (♀ 4 × ♂ 7) was performed based on a fixed model to estimate the effects of GCA and SCA and the quotient of the mean squares of deviations for GCA and SCA for the examined traits. The significance of the GCA and SCA effects was analysed in detail using a simultaneous procedure based on Bonferroni inequality. All calculations regarding the estimation of GCA and SCA effects

in the above model, analysis of variance and detailed simultaneous testing were done using SERGEN software, developed by scientists from the Institute of Plant Genetics of the Polish Academy of Sciences in Poznań (Caliński et al., 2003).

Results and Discussion

We analysed the phenotypic value of the population of apple seedlings based on the individual assessment of their infection with apple scab and powdery mildew. The suitability of the selected 11 genotypes (parental forms) of apple for the crossing programme was assessed based on general (GCA) and specific (SCA) combination ability (Mądry and Ubysz-Borucka, 1982). According to these authors, GCA is the mean value of the quantitative trait in the progeny of the analysed parental form. It is a measure of the additive effect of genes on this trait.SCA is an interaction of both parental forms revealed in their progeny as a result of single cross combinations. It results from the non-additive genetic influence (domination and epistasis) (Ubysz-Borucka et al., 1985).

In practice, the most valuable progeny in terms of the desired trait is obtained by crossing parental forms that are characterized by significant and positive values of GCA effects (Griffing, 1956 a, b).Our genetic studies revealed that among the 11 apple parental genotypes, only 3 cultivars(‘Free Redstar’, ‘Alwa’ and ‘Oliwka Żółta’) had significant (positive or negative) values of GCA effects for the degree of seedling infection with apple scab and powdery mildew (Tab.1). These results show that the values of the GCA effects significantly different from zero for the degree of infection of the seedlings with apple scab were estimated for the cv. 'Free Redstar'. The value of the effect was negative, but for growers it means that this genotype is a donor of genes determining resistance or low susceptibility to apple scab in progeny. On the other hand, significantly positive values of the GCA effects for this trait were found for cvs ‘Alwa’ and ‘Oliwka Żółta’. These cultivars when used as parental forms, are therefore donors of genes determining susceptibility to apple scab in seedlings. Significantly negative values of GCA effects for the degree of infection of seedlings with powdery mildew were estimated for the cv. 'Free Redstar'. This means that this genotype is a donor of genes determining resistance or low susceptibility to powdery mildew in the apple progeny. On the other hand, significantly positive values of the GCA effects for this trait were found for cv. ‘Alwa’. This cultivar used as a parental form is a donor of genes determining susceptibility to powdery mildew in the apple progeny. Our findings are consistent with literature reports which indicate that 'Free Redstar' is a cultivar resistant to apple scab (V_f), while cvs 'Alwa' and ‘Oliwka Żółta’ are moderately susceptible to this pathogen (Rejman, 1994; Żurawicz , 2003; Lewandowski and Żurawicz, 2007; Żurawicz et al., 2013). Studies conducted in 2004–2006 in field conditions by Lewandowski and Żurawicz (2007) found no symptoms of apple mildew on leaves and fruit of cv. ‘Free Redstar’. This genotype is therefore resistant to or has low susceptibility to apple mildew.

Differences in SCA effects within the studied cross combination prove the significant importance of the genetic interaction of both parental forms in determining traits in progeny (Baker, 1978). Thus, the effects of SCA are revealed only in certain cross combinations and may improve or worsen the value of the analysed traits in the progeny. It has been reported that the high values of SCA effects found in individual hybrid populations usually concern single performance traits. Because of this, it is difficult or impossible to create new cultivars with several traits improved (Spangelo et al., 1971; Hortyński, 1987; Simpson and Sharp, 1988; Żurawicz et al., 1996; Mądry et al., 2004; Masny et al., 2008; Pluta et al., 2008). In our research on the combination ability of 11 parental forms (4 maternal and 7 paternal), significant (positive or negative) values of SCA effects were found for the severity of apple scab and powdery mildew in seedlings (Tab.2). Considering the severity of apple scab in seedlings, a negative value of SCA effects was found for 3 hybrid families: ‘Free Redstar’ × ‘McIntosh’, ‘Alwa’ × ‘Malinowa Oberlandzka’ and ‘Alwa’ × ‘McIntosh’. This means that in these families the interaction of both parental genotypes determines the resistance or low susceptibility of plants to apple scab. The positive value of SCA effects for this trait was found for 6 hybrid families: ‘Free Redstar’ × ‘Kosztela’, ‘Free Redstar’ × ‘Malinowa Oberlandzka’, ‘Gold Milenium’ × ‘McIntosh’, ‘Alwa’ × ‘Kronselska’, ‘Alwa’ × ‘Koksa Pomarańczowa’ and ‘Golden Delicious’ × ‘Oliwka Żółta’. Therefore, it is expected that hybrids from these families will be susceptible to apple scab. Considering the severity of apple powdery mildew in seedlings, a positive value of SCA effects was found for 3 hybrid families: ‘Gold Milenium’ × ‘Malinowa Oberlandzka’, ‘Alwa’ × ‘Kronselska’ and ‘Alwa’ × ‘Koksa Pomarańczowa’. Therefore, it is expected that hybrids from these families will be susceptible

to apple powdery mildew.

So far, no studies have been conducted in Poland on the combining ability of parental apple genotypes used in breeding programmes, as evidenced by the lack of relevant literature. Foreign reports addressing these issues in apple are also very limited. Similar studies were conducted only in Romania (Dan et al., 2015). The lack of such studies is mainly related to the difficulties with implementing a complete crossing programme (diallel or factorial system) and obtaining a large population of seedlings for phenotypic evaluation. This type of research is also tedious and very demanding when it comes to individual observations, measurements, and evaluation of many functional traits for several thousand seedlings, which is another obstacle. Such studies also require a large budget.

Conclusions

1. Preliminary findings indicate differences between the analysed parental genotypes of apple in terms of combining abilities (GCA and SCA) for the severity of apple scab and powdery mildew in seedlings.
2. The GCA and SCA effects estimated for 11 parental forms are positive or negative. Parental genotypes of apple used for crossing determine different resistance/susceptibility to apple scab and powdery mildew in their progeny.

Tabela 1
Table 1

Ocena efektów GCA dla stopnia porażenia przez parcha i mączniaka jabłoni siewek 11 odmian jabłoni krzyżowanych w układzie czynnikowym (♀4 × ♂7), Dąbrowice, 2019

Estimates of GCA effects for the infection level by apple scab and powdery mildew of 11 apple genotypes crossed in the factorial design (♀4 × ♂7), Dąbrowice, 2019

Nr matki lub ojca Maternal or paternal No.	Formy rodzicielskie Parental forms	Stopień porażenia siewek jabłoni Infection level of apple seedlings			
		Parch jabłoni Apple scab		Mączniak jabłoni Powdery mildew	
		Ocena efektu głównego Main effect evaluation	Statystyka F dla efektu głównego F statistics for the main effect	Ocena efektu głównego Main effect evaluation	Statystyka F dla efektu głównego F statistics for the main effect
Analiza względem form matecznych - ♀ Analysis in relation to maternal forms - ♀					
1	**Free Redstar**	**-0,131****	17,14	**-0,064****	12,96
2	Gold Milenium	0,004	0,02	-0,039	4,84
3	**Alwa**	**0,140****	19,55	**0,082****	21,16
4	Golden Delicious	-0,013	0,18	0,021	1,44
Analiza względem form ojcowskich - ♂ Analysis in relation to paternal forms - ♂					
1	Glogierówka	-0,182	6,78	-0,064	1,52
2	Kosztela	0,099	2,01	-0,046	0,76
3	Malinowa Oberlandzka	-0,038	0,30	0,079	2,33
4	Kronselska	-0,157	5,05	-0,064	1,52
5	**Oliwka Żółta**	**0,287****	16,79	0,048	0,86
6	Koksa Pomarańczowa	-0,063	0,82	-0,033	0,40
7	McIntosh	0,055	0,63	0,079	2,33

*Objaśnienie: * - wartości istotnie różne od średniej wartości ogólnej przy poziomie α=0,05*

***- wartości istotnie różne od średniej wartości ogólnej przy poziomie α=0,01*

*Explanation: * - values significantly different from the average general value at the level of α = 0.05*

*** - values significantly different from the average general value at the level of α = 0.01*

Tabela 2
Table 2

Ocena efektów SCA dla stopnia porażenia przez parcha i mączniaka jabłoni siewek należących do 28 rodzin mieszańcowych uzyskanych ze skrzyżowania 11 odmian jabłoni w układzie czynnikowym (♀4 × ♂7), Dąbrowice, 2019

Estimates of SCA effects for the infection degree by apple scab and powdery apple seedlings belonging to 28 hybrid families obtained from 11 apple genotypes crossed in the factorial design (♀4 × ♂7), Dąbrowice, 2019

Nr rodziny Family No.	Rodziny mieszańcowe Hybrid families	Stopień porażenia siewek Infection level of apple seedlings			
		Parch jabłoni Apple scab		Mączniak jabłoni Powdery mildew	
		Ocena efektu głównego Main effect evaluation	Statystyka F dla efektu głównego F statistics for the main effect	Ocena efektu głównego Main effect evaluation	Statystyka F dla efektu głównego F statistics for the main effect
1	Free Redstar × Glogierówka	-0,031	0,16	-0,196	7,19
2	**Free Redstar × Kosztela**	**0,350****	20,31	-0,096	1,72
3	**Free Redstar × Malinowa Oberlandzka**	**0,306****	15,55	-0,146	3,98
4	Free Redstar × Kronselska	-0,125	2,59	-0,096	1,72
5	Free Redstar × Oliwka Żółta	-0,087	1,27	-0,196	7,19
6	Free Redstar × Koksa Pomarańczowa	-0,106	1,87	-0,196	7,19
7	**Free Redstar × McIntosh**	**-0,306****	15,55	-0,096	1,72
8	Gold Milenium × Glogierówka	-0,117	2,27	-0,096	1,72
9	Gold Milenium × Kosztela	-0,186	5,72	-0,071	0,94
10	**Gold Milenium × Malinowa Oberlandzka**	0,196	6,34	**0,254***	12,18
11	Gold Milenium × Kronselska	-0,211	7,36	-0,021	0,08
12	Gold Milenium × Oliwka Żółta	-0,173	4,97	-0,221	9,15
13	Gold Milenium × Koksa Pomarańczowa	-0,142	3,34	-0,121	2,73
14	**Gold Milenium × McIntosh**	**0,633****	66,44	0,029	0,16
15	Alwa × Glogierówka	0,022	0,08	0,204	7,86
16	Alwa × Kosztela	0,029	0,14	-0,046	0,39
17	**Alwa × Malinowa Oberlandzka**	**-0,440****	32,12	-0,096	1,72
18	**Alwa × Kronselska**	**0,254***	10,66	**0,404****	30,77
19	Alwa × Oliwka Żółta	-0,009	0,01	0,179	6,06
20	**Alwa × Koksa Pomarańczowa**	**0,422****	29,57	**0,254***	12,18
21	**Alwa × McIntosh**	**-0,278***	12,78	0,129	3,15
22	Golden Delicious × Glogierówka	0,126	2,63	0,154	4,49
23	Golden Delicious × Kosztela	-0,193	6,17	-0,146	3,98
24	Golden Delicious × Malinowa Oberlandzka	-0,062	0,63	0,079	1,19
25	Golden Delicious × Kronselska	0,082	1,12	0,204	7,86
26	**Golden Delicious × Oliwka Żółta**	**0,270***	12,05	-0,096	1,72
27	Golden Delicious × Koksa Pomarańczowa	-0,174	5,03	-0,121	2,73
28	Golden Delicious × McIntosh	-0,049	0,40	0,154	4,49

*Objaśnienie: * - wartości istotnie różne od średniej wartości ogólnej przy poziomie α=0,05*

***- wartości istotnie różne od średniej wartości ogólnej przy poziomie α=0,01*

*Explanation: * - values significantly different from the average general value at the level of α = 0.05*

*** - values significantly different from the average general value at the level of α = 0.01*

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