

ESTIMATION OF BREEDING VALUE OF BLACKCURRANT GENOTYPES FOR GROWTH VIGOUR, PLANT HABIT AND THEIR SUSCEPTIBILITY TO FUNGAL DISEASES

Łukasz Seliga[✉], Stanisław Pluta^{id}, Agnieszka Masny^{id}

The National Institute of Horticultural Research, Konstytucji 3 Maja 1/3, 96-100 Skierniewice, Poland

ABSTRACT

The study was conducted in 2012–2014 at the Experimental Orchard of the National Institute of Horticultural Research in Skierniewice, central Poland. The aim of the research was to assess the breeding value, based on the general combining abilities (GCA), specific combining abilities (SCA) and reciprocal (RE) effects, of six dessert parental forms of blackcurrant for plant growth vigour, plant habit and resistance to fungal diseases: *Podosphaera mors-uvae* (causal agent of powdery mildew of currant), *Drepanopeziza ribis* (leaf anthracnose) and *Cronartium ribicola* (white pine blister rust). The plant material consisted of seedlings of F₁ generation obtained by crossing of six blackcurrant genotypes: ‘Bona’, ‘Ceres’, clone D13B/11, ‘Sofiivska’, ‘Vernisazh’ and ‘Big Ben’ in a diallel design according to Griffing’s Method III. It was shown that the cultivars ‘Big Ben’, ‘Sofiivska’ and ‘Vernisazh’ had significantly positive GCA effects for growth vigour and resistance of plants to powdery mildew, whereas ‘Ceres’ – for plant habit, which indicated their high breeding value for these traits. The significantly positive SCA values were estimated for the hybrid family: ‘Big Ben’ × ‘Ceres’ for low susceptibility of plants to powdery mildew and anthracnose. Statistically significant effects for reciprocal crosses (RE) were obtained only for few hybrid families.

Key words: morphological traits, powdery mildew, anthracnose, white pine blister rust, Griffing’s diallel desing, combining ability

INTRODUCTION

The blackcurrant (*Ribes nigrum* L.) fruit is prized for its high nutritional, dietary values and health benefits for human. It contains high amounts of vitamins, especially C and PP, and anthocyanin pigments, polyphenols and antioxidants [Lister et al. 2002]. It is assumed that the consumption of fresh blackcurrant fruit will increase after the introduction into cultivation of typical dessert cultivars, the first of which were bred in Scotland, Ukraine, Russia, Lithuania and also in Poland. The dessert cultivars among others include: ‘Big Ben’, ‘Czeresznieva’, ‘Saniuta’, ‘Sofiivska’, ‘Lentyaj’, ‘Gojai’, ‘Svajai’, ‘Dailiai’ and ‘Bona’ [Gwozdecki

1993, Pluta et al. 2012]. The main priorities in breeding of this type of cultivars include large and tasty berries arranged on long, well-filled strigs (at least 10 berries in a strig) and high productivity of blackcurrant shrubs. Also desirable are: vigorous growth and an erect growth habit allowing espalier type of cultivation. High and regular yields also depend on the resistance of plants to pests and diseases. Shrubs should exhibit high field resistance to powdery mildew of currant (*Podosphaera mors-uvae*), leaf anthracnose (*Drepanopeziza ribis*), white pine blister rust (*Cronartium ribicola*), as well as to the blackcurrant reversion

virus (BRV) and the pest – the blackcurrant gall mite „big buds” (*Cecidophyopsis ribis* West.). The mildew pathogen overwinters on shoots; in the spring and summer it infects the leaves and young shoots. The infected leaves become covered with tomentum, plant growth is inhibited, the berries become covered with a dark brown coating. The spreading of the pathogen is promoted by rain. White pine blister rust causes a weakening in plant growth and early leaf fall, which can have a negative impact on fruit bearing in the next growing season [Hummer and Barney 2002]. Blackcurrant shrubs are more susceptible to rust than white or redcurrant shrubs [Vagiri 2012]. Gall mite infection causes heavy losses in blackcurrant production. Gall mite damages floral buds and is a vector of BRV [Mazeikiene et al. 2017]. The blackcurrant gall mites infest new buds mainly during the flowering period [Brennan and Jarret 2014].

In conventional breeding, selection of appropriate parental forms for crossbreeding programmes plays an important role. Knowledge of their breeding value and the genetic determination of quantitative traits at the population, level and how they are inherited increase the likelihood of rapidly achieving the intended breeding purpose. The breeding value of a parental genotype is determined on the basis of the effects of general (GCA) and specific (SCA) combining abilities, genetic correlation between traits, genetic variation in traits and their heritability [Pluta et al. 2014]. The general combining ability of a parent for a quantitative trait under consideration determines its ability to pass on the average level of that trait to its progeny [Baker 1978]. The GCA effect is a measure of the additive action of the parent’s genes on this trait [Griffing 1956a, 1956b]. Crossing parents characterized by significantly positive GCA effects for a given trait increase considerably the likelihood of obtaining hybrid progenies with the desired values of that trait [Bestfleisch et al. 2014, Masny et al. 2014, Pluta et al. 2014]. Specific combining abilities of a pair of parental forms for a given trait is the effect of genetic interaction of both parents, manifesting itself in their progeny [Griffing 1956a, 1956b, Baker 1978]. Therefore, the SCA effect is a result of non-additive gene action (dominance and epistasis). It represents the difference between the average value of the trait showing in the progeny (full siblings of two parental forms) and the sum of the

GCA effects for these parental forms [Bestfleisch et al. 2014]. General combining abilities and SCA effects of parents tested in crossing designs are measures of their breeding value for the traits under consideration, that is, the usefulness of the parents in breeding programmes focused on improving those traits in new cultivars [Baker 1978, Bestfleisch et al. 2014, Pluta et al. 2014]. The probability of success in selecting the most efficient parents in a breeding programme will be further enhanced if the SCA of particular parental combinations is also considered when only genetic variation exists in a breeding gene pool.

For a full interpretation of SCA effects, it is also important the knowledge about the differentiation of the studied traits of progeny obtained from simple and reciprocal crosses (RE). Yao et al. [2013] in their research on rice (*Oryza L.*) reported that RE effects were strongly associated with SCA effects.

Valuable methodological background and justification for these analyses is presented by Baker [1978] and their empirical use for fruit crops is illustrated, for example, by Dossett et al. [2008].

The aim of the study was to determine the usefulness of six blackcurrant genotypes for breeding dessert cultivars based on an estimation of their general and specific combining abilities as well as reciprocal effects (GCA, SCA and RE) for growth vigour, bush habit and the susceptibility of plants to powdery mildew, leaf anthracnose and white pine blister rust.

MATERIALS AND METHODS

Plant material. The study was conducted at the National Institute of Horticultural Research, Skierniewice, Central Poland. The plant material consisted of blackcurrant seedlings of F₁ generation, derived from crosses in a diallel design according to Griffing’s Method III [Griffing 1956b] (including direct and reciprocal crosses) of six parental genotypes: three Polish genotypes: ‘Bona’, ‘Ceres’ and clone D13B/11, two Ukrainian cultivars ‘Sofiivska’ and ‘Vernisazh’, and one British cultivar ‘Big Ben’. Short descriptions of these cultivars are shown in Table 1 and in the literature [Gwozdecki 1993, Pluta et al. 2012]. The programme of crosses was performed in the spring of 2009 on shrubs grown in containers, in a plastic tunnel. A total of 30 combinations of cross-

Table 1. List and short characteristics of the blackcurrant genotypes used in the diallel cross design

Cultivar/ clone	Country of origin	Parentage	Plant		Susceptibility of plants to:		
			growth	habit	PM	A	WPBR
Big Ben	UK	Complex cross including (‘Goliath’ × ‘Ojebyn’) op, Ben Nevis and Vystavochnaya	strong	erect	low	medium	high
Bona	Poland	Ojebyn × (<i>R. dikuscha</i> × Climax)	weak	spreading	low	medium	high
Ceres	Poland	(<i>R. dikuscha</i> × ‘Barxatnaya’) × self	medium	semi-spreading	medium	medium	medium
D 13B/11	Poland	Big Ben × Lentaj	weak	spreading	low	medium	high
Sofiivska	Ukraine	Belorusskaya Sladkaya × C-106	strong	semi-spreading	medium	low	low
Vernisazh	Ukraine	Klussonovskaya × Triton	medium	semi-spreading	low	low	low

PM – powdery mildew, A – leaf anthracnose, WPBR – white pine blister rust

Table 2. Diallel cross design of parental genotypes of blackcurrant (Griffing’s Method III, Skierniewice 2009)

Maternal forms	Paternal forms					
	Bona	Big Ben	Ceres	D13B/11	Sofiivska	Vernisazh
Bona	–	×	×	×	×	×
Big Ben	×	–	×	×	×	×
Ceres	×	×	–	×	×	×
D13B/11	×	×	×	–	×	×
Sofiivska	×	×	×	×	–	×
Vernisazh	×	×	×	×	×	–

es were made (Tab. 2). In the winter of 2009/2010, the seeds were stratified (for about 3 months). The seeds extracted from the fruits were washed out and then dried in the room temperature (+18–20°C) for 24 hours. Dried seeds from each combination of crosses were packed into labeled bags and stored in a refrigerator (at about +4–6°C) until the stratification process. In the autumn (around mid-October 2009), the seeds from each combination of crosses were sown into pots (15 cm in diameter and 12 cm high), filled with a mixture of peat substrate, compost soil and sand in a ratio of 1 : 1 : 1. Then the seeds were covered with a thin layer of sand using a strainer and watered with the solution of Sarfun 500 SC fungicide (0.2%) to protect them against fungal diseases. After that, pots with the seeds were placed in plastic boxes and moved to

cold frame (natural weather conditions), where they were protected against rain and frost with foil and fibre. After about three months of stratification (mid-January 2010), the boxes with pots and seeds were transferred to the greenhouse with artificial lighting and variable temperature (day +20°C; night +16°C), ensuring a 16-hour day photoperiod for their germination. In the spring of 2010 seedlings F₁ were produced in the greenhouse conditions. For experimental purposes, 45 seedlings were randomly taken from each family.

Experimental design. The experiment was established in the field of the Experimental Orchard at Dąbrowice belonging to the National Institute of Horticultural Research in Skierniewice, central Poland (latitude: 51°57'17"N, longitude: 20°09'30"E) in the spring of 2010. Seedlings were planted in the medium

reach soil (class IV), prepared as recommended for the commercial blackcurrant plantations. A randomized block design was used, with 3 replications and 15 seedlings per each plot. In total, 1350 seedlings of F_1 generation were planted. The planting spacing was 2.50×0.5 m. No chemicals were applied against main fungal diseases, but pests were controlled according to monitoring and observation by using insecticides recommended by the actual Program of Protection of Small/Berry Crops. Regular weeding was done manually, mechanically and with herbicides.

Observations and measurements. The evaluation was conducted in three *subsequent* years (2012–2014). All seedlings were subjected to a detailed phenotypic assessment. The assessed traits of seedlings and the method of classification are given in Table 3.

Weather conditions. Weather conditions were determined on the basis of meteorological data from a METOS-COMPACT station located at the Experimental Orchard in Dąbrowice, in the vicinity of the field where the experiment was established. On the basis of unit records, average values of minimum and maximum temperatures and total precipitation for each month of the growing season in 2012–2014 were calculated.

Statistical analysis. A two-stage analysis of both single-year and combined data (across the three test years) was performed for all the evaluated traits [Keuls and Garretsen 1978, Möhring and Piepho 2009]. In the first stage, the SAS Proc Mixed procedure [SAS Institute 2000] was used to perform the analysis of variance of the data from the plots on the basis of a mixed ANOVA model for the randomized complete block design assuming the hybrid families to be a fixed factor, while the blocks a random factor [Möhring and Piepho 2009]. After finding significant variation for the studied traits among the hybrid families, the second stage of the analysis involved performing a fixed model-based diallel analysis of variance of family means (calculated across replications) together with estimating GCA, SCA and RE effects as outlined by Griffing [1956b] for single-year data and for the combined data from a half-diallel complete mating design with parents treated as a fixed factor (Method III, Model 1) [Zhang et al. 2005]. The significance of the GCA, SCA and RE effects was done using the test *t*-Bonferroni, at the significance level $\alpha = 0.05$ and α

$= 0.01$, but for the RE effects: $\alpha = 0.05$. The relative importance of GCA and SCA was estimated using the general predicted ratio (GPR) for the traits observed as follows: $GCA / SCA = (2MS_{GCA}) / (2MS_{GCA} + MS_{SCA})$ [Baker 1978]. A detailed analysis of the significance of the GCA and SCA effects was done using a simultaneous test procedure based on the Bonferroni inequality [Keuls and Garretsen 1978].

RESULTS

Weather conditions. The minimum and maximum temperatures and total precipitation in each month of the growing season in 2012–2014 are given in Table 4. In the summer months of 2012 and 2014, the recorded temperatures were higher than usual. The largest falls in temperature occurred in March 2013. In 2012 and 2014, precipitation occurred periodically throughout the growing season. In 2013, the highest levels of rainfall were recorded in May and June, but the other months were poor in precipitation. As can be seen, the weather conditions during the period of the experiment were favourable for the growth and development of blackcurrant shrubs and their yielding, but were also conducive to the development of fungal diseases.

Analysis of variance. The results of the analysis of variance according to Griffing's fixed model [1956b] for each of the tested traits are presented in Table 5. They showed that the effects of both GCA and SCA varied significantly ($p < 0.05$) for all the traits studied. This means that both the additive and non-additive genetic effects play an important role in the genetic determination of these traits in the progeny.

The values of the GPR for the GCA and SCA effects, determining the relative importance of additive and non-additive effects in the inheritance of evaluated traits in the studied gene pool, were 0.82 for growth vigour, 0.88 for plant habit, 0.85 for resistance to powdery mildew, 0.92 for resistance to anthracnose, and 0.80 for resistance to white pine blister rust (Tab. 5). According to biometricians dealing with this type of analyses, a relatively high value of the GPR indicated superiority of the additive genetic effects over the non-additive effects in the genetic determination of the variability of these traits within the gene pool of the parents involved in the crossing design under consideration [Griffing 1956a, 1956b, Baker 1978].

Table 3. List of the assessed traits and the way they were rated (Skierniewice 2012–2014)

No.	Traits	Rating scale*	Assessment period
plant morphology			
1	plant growth vigour	1 = weak 5 = medium 9 = strong	spring (end of April–May)
2	plant habit	1 = erect 3 = upright 6 = spreading 7 = drooping 9 = creeping	spring (end of April–May)
level of infection of plant diseases			
3	powdery mildew (<i>Podosphaera mors-uvae</i>)	1 = low 5 = medium 9 = high	summer (mid–end of July)
4	leaf anthracnose (<i>Drepanopeziza ribis</i>)	1 = low 5 = medium 9 = high	late summer (August–mid September)
5	white pine blister rust – WPBR (<i>Cronartium ribicola</i>)	1 = low 5 = medium 9 = high	late summer (August–mid September)

* The rating scales for the descriptors are recommended by the UPOV (International Union for the Protection of New Varieties of Plants) or IPGRI (International Plant Genetic Resources Institute, now Bioversity International)

Table 4. Minimum and maximum temperatures and total precipitation during the growing season in 2012–2014, Experimental Orchard in Dąbrowice, central Poland

Months	Temperature (°C)									Precipitation (mm)		
	min.			max.			mean					
	2012	2013	2014	2012	2013	2014	2012	2013	2014	2012	2013	2014
March	–7.7	–21.4	–4.3	20.8	13.9	21.4	4.8	–2.8	6.6	18.4	3.8	20.4
April	–4.9	–4.9	–5.4	29.5	25.6	23.3	9.0	7.5	9.7	51.6	43.2	39.6
May	–0.1	5.2	–1.7	29.8	26.5	28.4	14.7	14.3	13.3	18.0	100.0	65.8
June	3.6	8.6	4.6	32.3	33.0	30.7	16.7	17.5	15.4	64.8	152.6	44.8
July	5.7	7.4	10.7	34.2	36.5	32.1	20.2	19.1	19.9	52.2	5.8	66.0
August	6.2	4.7	6.9	34.6	37.8	30.1	18.6	18.4	17.1	63.0	17.6	64.6
September	1.4	–0.8	1.2	31.0	23.5	26.5	14.2	11.5	14.1	41.4	48.0	35.0
October	–9.8	–4.9	–3.5	21.0	21.5	23.5	7.6	9.4	9.0	51.0	15.2	9.0

Table 5. Variance analysis for five traits of seedlings of 30 hybrid families derived by crossing of six blackcurrant genotypes in a complete diallel design according to Griffing’s Method III (Experimental Orchard, Dąbrowice near Skierniewice, Poland, 2012–2014)

Source of variation	Degrees of freedom	Mean square deviations				
		plant growth vigour	plant habit	powdery mildew	leaf anthracnose	WPBR
GCA	5	0.65	0.15	0.22	0.18	0.02
SCA	9	0.29	0.04	0.08	0.03	0.01
Random error	58	0.06	0.02	0.01	0.05	0.01
GPR	–	0.82	0.88	0.85	0.92	0.80

GPR – the general predicted ratio for the traits calculated as follows: $GCA / SCA = (2 MS_{GCA}) / (2 MS_{GCA} + MS_{SCA})$

Table 6. Estimates of GCA effects for plant growth vigour and plant habit for 6 blackcurrant genotypes crossed in a complete diallel design according to Griffing’s Method III (Experimental Orchard, Dąbrowice near Skierniewice, Poland, 2012–2014)

Genotype	Plant growth vigour				G × E	Plant habit				G × E
	2012	2013	2014	mean		2012	2013	2014	mean	
‘Bona’	–0.06	–0.28	–0.42**	–0.25*	n	–0.07	0.06	–0.09	–0.03	n
‘Big Ben’	0.14	0.38	0.45**	0.32**	n	–0.09	0.15	0.22**	0.09	*
‘Ceres’	–0.14	–0.31	–0.30**	–0.25*	n	0.16*	–0.26	–0.66**	–0.25**	**
D13B/11	–0.19	–0.32	–0.33**	–0.28**	n	0.02	–0.13	0.34**	0.08	**
‘Sofiivska’	0.12	0.23	0.30**	0.22*	n	0.06	0.03	0.26**	0.12*	n
‘Vernisazh’	0.13	0.29	0.29**	0.24*	n	–0.08	0.14	–0.09	–0.01	n
Mean	3.78	5.23	6.81	5.28	–	3.74	3.90	5.55	4.40	–

* – values significantly different from the overall mean at $\alpha = 0.05$

** – values significantly different from the overall mean at $\alpha = 0.01$

General combining ability effects

Growth vigour and plant habit. The estimates of GCA effects for the morphological traits of plants, such as growth vigour and plant habit, are shown in Table 6. In the first two years (2012–2013) of studies, the GCA effects for both of these traits were similar (differences were not significant) to the overall average for the population. This was probably a result of the still young age of the seedlings evaluated in the experiment (2nd and 3rd year after planting).

In the case of plant growth vigour, significantly positive GCA effects were obtained for the cultivars ‘Big Ben’, ‘Sofiivska’ and ‘Vernisazh’, which was a desirable trait in the breeding of dessert cultivars of blackcurrant, especially those grown in the trellising cultivation system. The Polish genotypes (‘Bona’,

‘Ceres’ and clone D13B/11) had significant negative GCA effects for this morphological trait.

For plant growth habit in 2012, the only statistically proven GCA effect (with a positive value) was shown for the cultivar ‘Ceres’. On the contrary, for the same cultivar and trait a significant GCA effect with a negative value (desirable from the breeding point of view) was obtained in 2014. It means that this cultivar passes on to its progeny the ability to form shrubs with an erect habit (despite the tendency of the young, highly flexible shoots to droop, as was observed in the first year of the assessment). This kind of growth habit is particularly useful in the trellising type of cultivation of blackcurrant shrubs, which is the most commonly used method on the plantations of dessert cultivars. For the cultivars ‘Big Ben’, ‘Sofiivska’ and clone

D13B/11, the GCA effects were significantly negative, which indicates that these parental forms were donors of a spreading plant habit of their progenies.

Field resistance of plants to fungal pathogens.

The estimates of GCA effects for the degree of plant infection by *Phodosphaera mors-uvae* (causal agent of the powdery mildew), *Drepanopeziza ribis* (leaf anthracnose) and *Cronartium ribicola* (white pine blister rust – WPBR) are shown in Table 7. For the powdery mildew there were no significant GCA effects in 2012. In 2013, a significantly positive, from the point of view of the resistance breeding, GCA effect (with a negative value) was obtained for the cultivar ‘Big Ben’, and a negative effect (with a positive value) for the cultivar ‘Ceres’. In 2014, significantly positive GCA effects for low susceptibility to powdery mildew were obtained for the cultivars ‘Sofiiwska’, ‘Vernisazh’ and clone D13B/11. It should thus be expected that these genotypes would pass on to their progenies the trait of low susceptibility to this disease. Significantly negative GCA effects for this trait were obtained for the cultivars ‘Bona’ and ‘Ceres’, which indicated their limited usefulness for the resistance breeding aimed at obtaining cultivars resistant to *P. mors-uvae*. Statistically significant genetic interaction with the years (both GCA × Y and SCA × Y) occurred only in the case of the degree of plant infection by *P. mors-uvae*. It means that this trait is highly unstable and strongly

dependent on weather conditions in different seasons (Tab. 4). On the other hand, the lack of G × Y interaction for the other traits under assessment indicates high stability of these traits in the tested hybrids despite the distinctly different weather conditions in the individual years of studies.

For the leaf anthracnose statistically proven GCA effects were obtained only in 2012 (Tab. 7). A significantly positive, for the resistance breeding, GCA effect (with a negative value) was obtained for the cultivar ‘Vernisazh’, and a significantly negative GCA effect (with a positive value) – for the cultivar ‘Bona’.

During the assessment of the population in 2012 there were no symptoms of infection of the seedlings by *C. ribicola* (WPBR), which was most likely due to the young age of the seedlings and low pathogen pressure in the environment of the field experiment. In 2013, the severity of symptoms of white pine blister rust was low and similar in all hybrid families, with the result that there was no significant difference in the GCA effects for the tested parental genotypes. In 2014, a statistically proven, negative GCA effect for this trait was obtained only for the cultivar ‘Bona’. Based on the values of the GCA effects estimated for this cultivar, it could be concluded that it was of little use for the resistance breeding because it passed on to its progeny a high susceptibility to the economically important diseases such as powdery mildew, leaf anthracnose, or white pine blister rust.

Table 7. Estimates of GCA effects for plant susceptibility to fungal diseases for 6 blackcurrant genotypes crossed in a complete diallel design according to Griffing’s Method III (Experimental Orchard, Dąbrowice near Skierniewice, Poland, 2012–2014)

Genotype	Powdery mildew					Leaf anthracnose					WPBR [†]			
	2012	2013	2014	mean	G × E	2012	2013	2014	mean	G × E	2013	2014	mean	G × E
‘Bona’	0.01	–0.09	0.42**	0.11**	**	0.26**	0.17	0.11	0.18	n	–0.02	0.23*	0.08	**
‘Big Ben’	–0.01	–0.19**	–0.08	–0.09**	*	–0.08	–0.17	–0.15	–0.13	n	–0.02	–0.03	–0.02	n
‘Ceres’	0.01	0.29**	0.58**	0.29**	**	0.13	0.18	0.14	0.15	n	0.04	0.12	0.05	n
D13B/11	–0.01	0.02	–0.21**	–0.07	**	0.13	0.01	0.07	0.07	n	0.04	–0.08	–0.04	n
‘Sofiiwska’	–0.01	–0.02	–0.38**	–0.14**	**	–0.15	–0.13	–0.06	–0.11	n	–0.02	–0.12	–0.05	n
‘Vernisazh’	–0.01	–0.01	–0.33**	–0.11**	**	–0.28**	–0.06	–0.11	–0.15	n	–0.02	–0.12	–0.05	n
Mean	1.01	1.20	1.54	1.25	–	1.70	1.70	1.52	1.64	–	1.01	1.14	1.05	–

* – values significantly different from the overall mean at $\alpha = 0.05$

** – values significantly different from the overall mean at $\alpha = 0.01$

† – no evidence of plant infection by *C. ribicola* was found on seedlings in 2012

Specific combining abilities effects

Growth vigour and plant habit. The estimates of SCA effects for growth vigour and plant habit are shown in Table 8. Statistically proven ($p < 0.01$) SCA effects for these morphological traits were obtained only in 2014, that means, in the fourth year after planting of the seedlings. For plant growth vigour, significantly positive SCA effects were obtained for five hybrid families: ‘Bona’ × D13B/11, ‘Bona’ × ‘Vernisazh’, ‘Big Ben’ × ‘Ceres’, ‘Ceres’ × ‘Vernisazh’ and D13B/11 × ‘Sofiivska’. Thus, in the case of hybrids of these families, vigorously growing seedlings were to be expected with high probability. From the viewpoint of the applied breeding, the interaction of both parental forms (genotypes) was especially important in the determination of this trait because the pedigrees of these hybrids included cultivars with a high breeding value (‘Big Ben’, ‘Sofiivska’ and ‘Vernisazh’), as well as with a low breeding value (‘Bona’, ‘Ceres’ and

clone ‘D13B/11) in terms of this trait. Significantly negative SCA effects for this morphological trait were obtained for the following hybrid families: ‘Bona’ × ‘Ceres’, ‘Big Ben’ × D13B/11, ‘Ceres’ × D13B/11, D13B/11 × ‘Vernisazh’, and ‘Sofiivska’ × ‘Vernisazh’.

For plant growth habit, significantly positive SCA effects (with negative values) were obtained for three hybrid families: ‘Bona’ × ‘Ceres’, ‘Big Ben’ × ‘Vernisazh’ and D13B/11 × ‘Sofiivska’ (Tab. 8). This means that in the case of these families the genetic interaction of both parental genotypes determined the erect habit of seedlings, which was a very desirable phenomenon in the breeding work on new dessert type cultivars for trellising cultivation. Significantly negative SCA effects were obtained for four families, i.e. ‘Bona’ × D13B/11, ‘Big Ben’ × ‘Sofiivska’, ‘Ceres’ × ‘Vernisazh’ and ‘Sofiivska’ × ‘Vernisazh’. It should therefore be expected that shrubs of the hybrids of these families would have a spreading habit of seedling population.

Table 8. Estimates of SCA effects for plant growth vigour and plant habit for hybrid families obtained by crossing of six blackcurrant genotypes in a complete diallel design according to Griffing’s Method III (Experimental Orchard, Dąbrowice near Skierniewice, Poland, 2012–2014)

Selected hybrid families	Plant growth vigour				G × E	Plant habit				G × E
	2012	2013	2014	mean		2012	2013	2014	mean	
‘Bona’ × ‘Big Ben’	–0.09	–0.16	–0.59**	–0.27	n	0.03	–0.18	0.04	–0.03	n
‘Bona’ × ‘Ceres’	–0.20	–0.37	–0.75**	–0.44*	n	–0.05	0.10	–0.23*	–0.06	n
‘Bona’ × D 13B/11	0.29	0.57	0.69**	0.52**	n	–0.03	0.28	0.35**	0.20	n
‘Bona’ × ‘Sofiivska’	0.06	–0.08	0.09	0.01	n	0.04	–0.03	–0.09	–0.03	n
‘Bona’ × ‘Vernisazh’	–0.06	0.03	0.55**	0.18	n	0.00	–0.17	–0.07	–0.08	n
‘Big Ben’ × ‘Ceres’	0.42*	0.69	0.75**	0.61**	n	0.05	0.25	0.22	0.17	n
‘Big Ben’ × D13B/11	–0.32	–0.48	–0.42**	–0.41*	n	0.01	–0.30	0.00	–0.09	n
‘Big Ben’ × ‘Sofiivska’	0.19	0.05	0.15	0.13	n	–0.02	0.05	0.26**	0.10	n
‘Big Ben’ × ‘Vernisazh’	–0.19	–0.11	0.11	–0.06	n	–0.08	0.18	–0.52**	–0.14	**
‘Ceres’ × D13B/11	0.00	0.02	–0.40**	–0.13	n	–0.09	0.01	–0.11	–0.06	n
‘Ceres’ × ‘Sofiivska’	–0.40*	–0.30	0.03	–0.22	n	0.00	–0.29	–0.12	–0.13	n
‘Ceres’ × ‘Vernisazh’	0.19	–0.04	0.36**	0.17	n	0.09	–0.06	0.24*	0.09	n
D13B/11 × ‘Sofiivska’	0.07	0.05	0.44**	0.19	n	0.04	0.11	–0.32**	–0.06	n
D13B/11 × ‘Vernisazh’	–0.03	–0.16	–0.33**	–0.18	n	0.06	–0.10	0.07	0.01	n
‘Sofiivska’ × ‘Vernisazh’	0.08	0.28	–0.70**	–0.11	**	–0.07	0.15	0.27**	0.12	n

* – values significantly different from the overall mean at $\alpha = 0.05$

** – values significantly different from the overall mean at $\alpha = 0.01$

Field resistance of plants to fungal pathogens.

The estimates of SCA effects, which measure the influence of their genetic action on the value of the traits of the plant susceptibility to fungal diseases (powdery mildew, anthracnose and white pine blister rust) and result from non-additive action (dominance and epistasis) of parental forms [Baker 1978, Griffing 1956a], are shown in Table 9. For the infection of seedlings by *P. mors-uae*, significantly positive

SCA effects (with negative values meaning the lowest infection by the fungus) were obtained only in 2014 for the following hybrid families: ‘Bona’ × D13B/11, ‘Bona’ × ‘Sofiivska’, ‘Bona’ × ‘Vernisazh’ and ‘Big Ben’ × ‘Ceres’. This means that a numerous progeny resistant or low susceptible to powdery mildew should be expected within these hybrid families. From the viewpoint of the resistance breeding, the occurrence of a significant interaction between parental genotypes

Table 9. Estimates of SCA effects for plant susceptibility to fungal diseases for hybrid families derived by crossing of six blackcurrant genotypes in a complete diallel design according to Griffing’s Method III (Experimental Orchard, Dąbrowice near Skierniewice, Poland, 2012–2014)

Selected hybrid families	Powdery mildew				G × E	Leaf anthracnose				G × E	WPBR [†]			G × E
	2012	2013	2014	mean		2012	2013	2014	mean		2013	2014	mean	
‘Bona’ × ‘Big Ben’	-0,01	-0,29	–	-0,35**	**	–	-0,29*	-0,24	-0,22	n	-0,03	-0,16	-0,06	n
‘Bona’ × ‘Ceres’	0,00	0,09	-0,07	0,01	**	–	0,09	0,02	-0,05	n	-0,03	-0,01	-0,02	*
‘Bona’ × D 13B/11	0,00	0,06	-0,01	0,02	**	–	0,06	0,00	0,03	n	0,02	0,01	0,01	n
‘Bona’ × ‘Sofiivska’	0,00	0,05	0,10	0,05	**	0,26	0,05	0,09	0,14	n	0,02	0,09	0,04	n
‘Bona’ × ‘Vernisazh’	0,00	0,10	0,74**	0,28**	**	0,11	0,10	0,13	0,11	n	0,02	0,07	0,03	n
‘Big Ben’ × ‘Ceres’	0,03	-0,06	0,72**	0,23**	**	0,09	-0,06	0,22	0,07	n	-0,03	0,30	0,09	n
‘Big Ben’ × D13B/11	-0,01	0,07	–	-0,15*	n	0,05	0,07	-0,15	-0,02	n	-0,03	-0,10	-0,04	n
‘Big Ben’ × ‘Sofiivska’	-0,01	-0,01	–	-0,16**	n	–	-0,01	-0,10	-0,10	n	0,02	-0,16	-0,05	n
‘Big Ben’ × ‘Vernisazh’	-0,01	-0,09	–	-0,20**	n	–	-0,09	-0,10	-0,06	n	0,02	-0,11	-0,03	n
‘Ceres’ × D 13B/11	-0,01	-0,05	0,04	-0,01	n	0,21	-0,05	0,14	0,20	n	0,13	0,00	0,04	n
‘Ceres’ × ‘Sofiivska’	-0,01	0,08	0,03	0,04	n	0,11	0,08	0,04	0,06	n	-0,03	0,00	-0,01	n
‘Ceres’ × ‘Vernisazh’	-0,01	0,32*	-0,04	0,09	**	–	0,32*	-0,16	-0,11	n	-0,03	-0,12	-0,06	n
D13B/11 × ‘Sofiivska’	0,01	0,02	0,27**	0,10	n	–	0,02	-0,07	-0,07	n	-0,03	0,05	0,01	n
D13B/11 × ‘Vernisazh’	0,01	-0,13	0,27**	0,05	**	–	-0,13	0,06	-0,05	n	-0,03	0,06	0,01	n
‘Sofiivska’ × ‘Vernisazh’	0,01	-0,15	0,17	0,01	n	0,16	-0,15	0,12	0,08	n	0,02	0,10	0,04	n

* – values significantly different from the overall mean at $\alpha = 0.05$

** – values significantly different from the overall mean at $\alpha = 0.01$

† – no evidence of plant infection by *C. ribicola* was found on seedlings in 2012

in the determination of this trait was very desirable, since both ‘Bona’ and ‘Ceres’, as one of the parents in the pedigrees of these hybrids, were characterized by a low general combining ability (significantly positive GCA effects) – Table 7, and thus had the ability to pass on to their progenies high susceptibility to powdery mildew. Significantly negative SCA effects (with positive values) for this trait were obtained in 2013 for the hybrid family: ‘Ceres’ × ‘Vernisazh’, and in 2014 for the family: ‘Bona’ × ‘Big Ben’. In this case, the occurrence of interactive effects of both parents was undesirable because it deteriorated the value of their progenies despite the estimation of a high breeding value for the cultivars ‘Vernisazh’ and ‘Big Ben’.

For the plant infection by *D. ribis* (leaf anthracnose) and *C. ribicola* (white pine blister rust) there were no statistically proven SCA effects in most hybrid families. Only in 2013, for the seedlings’ infestation by the first disease, one significantly negative SCA effect

was estimated for the family ‘Ceres’ × ‘Vernisazh’ and one positive SCA effect for the hybrids belonging to the family ‘Big Ben’ × ‘Ceres’. Considering that both parental forms had statistically insignificant values of GCA effects, the great importance of interaction in the inheritance of this trait should be emphasized, because these hybrids were expected to have much higher resistance to the leaf anthracnose than that resulting from the sum of the GCA effects for their parental forms.

RECIPROCAL EFFECTS

Growth vigour and plant habit. For morphological traits of shrubs, statistically significant RE effects were obtained only for few pairs of crossing. Two cross combinations D13B/11 × ‘Bona’ and ‘Sofiivska’ × ‘Vernisazh’ for the three-year mean (2012–2014) of the study had significantly positive RE effects for the growth vigor (Tab. 10). The values of RE effects for

Table 10. Estimates of RE effects for growth vigour and plant habit for hybrid families derived by crossing of six blackcurrant genotypes in a complete diallel design according to Griffing’s Method III (Experimental Orchard, Dąbrowice near Skierniewice, Poland, 2012–2014)

Selected hybrid families	Plant growth vigour				Plant habit			
	2012	2013	2014	mean	2012	2013	2014	mean
D13B/11 × ‘Bona’	0,20	0,55	1,57*	0,77*	–0,12	0,42	–0,34*	–0,02
D13B/11 × ‘Big Ben’	–0,30	–0,15	0,54*	0,02	0,09	–0,48	–0,08	–0,16
D13B/11 × ‘Ceres’	0,10	–0,09	–0,99*	–0,32	–0,16	0,04	1,41*	0,43*
D13B/11 × ‘Sofiivska’	–0,10	–0,07	–0,42*	–0,22	0,08	–0,15	–0,12	–0,06
D13B/11 × ‘Vernisazh’	0,05	0,13	–0,75*	–0,19	0,04	–0,11	0,50*	0,14
‘Sofiivska’ × ‘Bona’	0,10	–0,26	–0,22	–0,15	0,02	–0,04	–0,82*	–0,28*
‘Sofiivska’ × ‘Big Ben’	–0,05	–0,21	–0,66*	–0,30	0,04	–0,19	–0,07	–0,07
‘Sofiivska’ × ‘Ceres’	–0,15	–0,23	–0,54*	–0,29	–0,03	0,11	–0,31*	–0,08
‘Sofiivska’ × D13B/11	0,20	0,21	–0,66*	–0,08	–0,26	0,13	0,52*	0,13
‘Sofiivska’ × ‘Vernisazh’	0,45*	0,61	1,08*	0,72*	–0,27	0,42	0,63*	0,27*
‘Vernisazh’ × ‘Bona’	0,55*	0,64	–0,54*	0,20	–0,16	0,39	0,74*	0,32*
‘Vernisazh’ × ‘Big Ben’	0,40	0,86	–0,34*	0,32	–0,08	0,09	0,40*	0,14
Vernisazh’ × ‘Ceres’	0,30	0,44	0,42*	0,40	0,10	0,17	0,47*	0,25*
Vernisazh’ × D13B/11	0,10	0,30	0,71*	0,37	0,07	0,15	–0,01	0,21
Vernisazh’ × ‘Sofiivska’	0,30	0,19	0,35*	0,29	0,00	–0,12	–0,17	–0,09

* – significantly different from the overall mean at $\alpha = 0.05$

Table 11. Estimates of RE effects for plant susceptibility to fungal diseases for hybrid families derived by crossing of six blackcurrant genotypes in a complete diallel design according to Griffing's Method III (Experimental Orchard, Dąbrowice near Skierniewice, Poland, 2012–2014)

Selected hybrid families	Powdery mildew				Leaf anthracnose				WPBR*		
	2012	2013	2014	mean	2012	2013	2014	mean	2013	2014	mean
D13B/11 × 'Bona'	-0,02	-0,02	-0,16	-0,07	-0,25	-0,05	-0,22	-0,17	0,00	-0,21	-0,07
D13B/11 × 'Big Ben'	0,06**	0,07	-0,67**	-0,18**	0,11	-0,23	-0,46	-0,21	0,00	-0,41	-0,14
D13B/11 × 'Ceres'	0,00	-0,08	0,03	-0,02	-0,25	-0,21	0,09	-0,12	0,00	0,05	0,02
D13B/11 × 'Sofievskaia'	0,00	-0,05	-0,12	-0,06	0,04	-0,30	0,03	-0,08	0,00	-0,09	-0,03
D13B/11 × 'Vernisazh'	0,00	-0,02	-0,14	-0,05	-0,08	-0,42	-0,16	-0,22	0,00	0,14	0,05
'Sofievskaia' × 'Bona'	0,00	0,01	0,29**	0,10	-0,01	-0,06	-0,02	-0,03	0,00	0,03	0,01
'Sofievskaia' × 'Big Ben'	0,00	0,03	0,18	0,07	0,04	-0,02	0,14	0,05	0,00	0,02	0,01
'Sofievskaia' × 'Ceres'	0,00	-0,06	0,06	0,00	0,02	-0,07	0,11	0,02	0,00	0,00	0,00
'Sofievskaia' × D13B/11	0,00	0,03	-0,23**	-0,07	-0,04	-0,13	0,13	-0,02	0,00	-0,08	-0,03
'Sofievskaia' × 'Vernisazh'	0,00	-0,05	-0,81**	-0,29**	-0,21	-0,48	-0,26	-0,31	-0,21**	-0,12	-0,11
'Vernisazh' × 'Bona'	0,00	0,20	-0,77**	-0,19**	0,20	-0,41	-0,13	-0,25	0,00	-0,18	-0,05
'Vernisazh' × 'Big Ben'	0,00	0,17	-0,59**	-0,14**	0,03	-0,48	-0,11	-0,19	0,00	0,00	0,00
'Vernisazh' × 'Ceres'	0,00	0,05	0,00	0,02	-0,16	-0,04	-0,02	-0,07	0,00	0,00	0,00
'Vernisazh' × D13B/11	0,00	-0,05	-0,18	-0,08	0,09	-0,01	0,15	0,08	0,00	0,00	0,00
'Vernisazh' × 'Sofievskaia'	0,00	-0,04	0,00	-0,01	-0,16	-0,17	-0,23	-0,18	0,00	0,00	0,00

* – no evidence of plant infection by *C. ribicola* was found on seedlings in 2012

** – significantly different from the overall mean at $\alpha = 0.05$

both combinations were positive in each year of observation, but their significance was confirmed only in 2014. For the combinations 'Sofievskaia' × 'Vernisazh' and 'Vernisazh' × 'Bona' statistically significant effects of RE were found for this trait in 2012. However, in 2013, the RE effects were statistically insignificant. In 2014, the RE effects for the plant growth vigor were statistically significant (positive or negative) for almost all pairs of crossed parental forms, except for the combination 'Sofievskaia' × 'Bona'.

For the bush habit, statistically proven positive RE effects for the three-year means were obtained only for the pair of cross 'Sofievskaia' × 'Bona', while negative for D13B/11 × 'Ceres', 'Sofievskaia' × 'Vernisazh', 'Vernisazh' × 'Bona', 'Vernisazh' × 'Big Ben' and 'Vernisazh' × 'Ceres'. The significant RE effects were obtained for all the above-mentioned pairs of crosses only in 2014. However, in 2012 and 2013 no statistically significant differences of the effects of RE were found for all crossed

parental forms. In 2014 significant and negative RE effects were obtained for seven combinations of crosses D13B/11 × 'Ceres', D13B/11 × 'Vernisazh', 'Sofievskaia' × D13B/11, 'Sofievskaia' × 'Vernisazh', 'Vernisazh' × 'Bona', 'Vernisazh' × 'Big Ben' and 'Vernisazh' × 'Ceres' and significant positive RE effects for three crossed combinations D13B/11 × 'Bona', 'Sofievskaia' × 'Bona' and 'Sofievskaia' × 'Ceres' (Tab. 10).

Field resistance of plants to fungal pathogens. For the susceptibility of plants to fungal diseases, the statistically proven RE effects were obtained in each year and for the three-year means only for the infestation of plants by the powdery mildew. In the first year of the research (2012), only one significant and negative RE effect was noted for the susceptibility to powdery mildew for the crossing pair D13B/11 × 'Big Ben'. In the next two years of the studies (2013–2014), statistically significant positive effects of RE for this trait were obtained for the following cross combinations:

D13B/11 × ‘Big Ben’, ‘Sofiivska’ × ‘Vernisazh’, ‘Vernisazh’ × ‘Bona’ and ‘Vernisazh’ × ‘Big Ben’. For the infestation of seedlings by leaf anthracnose, these values for the individual years and for three-year means were close to overall mean, so they were statistically insignificant. Statistically significant and positive RE effects on plant infestation by white currant rust were found in 2013 only for one combination of ‘Sofiivska’ × ‘Vernisazh’ (Tab. 11).

DISCUSSION

General predicted ratio. In conventional applied breeding of blackcurrant, involving the crossing of selected parental forms and selection within the resulting progeny, it is important to choose for crossbreeding programmes parental cultivars contributing genes that additively determine important traits of plants. So the high GPR for the GCA and SCA effect are important in the genetic determination of traits in the seedling’s population. This makes it possible to increase the effectiveness of creating valuable breeding populations [Mądry et al. 2004]. A significant share of non-additive effects in the genetic determination of traits presents a major difficulty in rapid breeding of valuable cultivars. Another serious obstacle, especially in the breeding of cultivars resistant to fungal pathogens, is the occurrence of a strong genotype-environment ($G \times E$) interaction [Masny et al. 2009].

Żurawicz et al. [1996] obtained a significant influence of non-additive effects in the genetic determination of traits such as the growth vigour and plant habit of blackcurrant shrubs. The same authors showed the predominant share of additive effects over non-additive effects in the inheritance of resistance to powdery mildew, leaf anthracnose and white pine blister rust in blackcurrant. Similar conclusions were also drawn by Ravkin [1981], who stated that the determination of plant resistance of blackcurrants to powdery mildew was resulted by additive effects. Earlier, Trajkowski and Paasuke [1976] proved the high heritability of plant resistance to powdery mildew in blackcurrants. According to Ravkin [1981], the GCA effects played a greater role than the SCA effects for plant resistance to leaf anthracnose in blackcurrant seedling’s population.

In studies on black raspberry (*Rubus occidentalis*), Dossett et al. [2008] found a larger share of GCA ef-

fects in the determination of plant growth vigour. In a report on another species of the genus *Ribes*, i.e. gooseberry (*Ribes grossularia*), Pluta et al. [2014] showed the superiority of SCA effects over GCA effects for traits such as plant growth vigour and the number of thorns per shoot.

General combining abilities effects. In our studies cultivars ‘Big Ben’, ‘Sofiivska’ and ‘Vernisazh’ had significantly positive GCA effects for plant growth vigour and resistance to powdery mildew and anthracnose. So, they are very suitable for the applied breeding of new blackcurrant cultivars.

High values of GCA effects for growth vigour of blackcurrant shrubs was found earlier by Pluta [1994] for ‘Titania’ and ‘Ojebyn’ and low (negative) values – for the cultivar ‘Consort’. In strawberries (*Fragaria × ananassa* Duch.), by comparison, high values of GCA effects for plant growth vigour (determined by rating scale and by measuring the height and diameter of plants) was estimated for the remontant cultivars ‘Ostara’ and ‘Selva’ [Masny et al. 2009].

Plant susceptibility to powdery mildew, anthracnose and white pine blister rust is serious problem for commercial plantations of blackcurrant [Hummer and Barney 2002]. Our studies proved, that cultivar ‘Big Ben’ had significantly positive GCA effect for powdery mildew low susceptibility/resistance. Similar results for this cultivar was also obtained by Pluta and Żurawicz [2009]. In the studies by these authors, the cultivar ‘Big Ben’ in the pedigree of F_1 hybrids contributed to the reduction in their susceptibility to powdery mildew, although this effect was not proven statistically. Significantly negative GCA effects for powdery mildew resistance were obtained for the cultivars ‘Bona’ and ‘Ceres’. Similar results for the cultivar ‘Bona’ was obtained by Pluta and Żurawicz [2009]. In the cited work, ‘Bona’ was also a donor of the plant susceptibility to powdery mildew, whereas the cultivar ‘Storklas’ proved to be a donor of plant resistance to this disease. ‘Storklas’ was also a donor of resistance to anthracnose and white pine blister rust of seedling population [Pluta et al. 2008]. Earlier studies by Pluta [1994] showed that blackcurrant cultivars ‘Ojebyn’ and ‘Titania’ were also good sources of genes of plant resistance to powdery mildew. In our studies, a significantly positive, for resistance to anthracnose, GCA effect was obtained for the cultivar

‘Vernisazh’. In earlier studies on blackcurrant, Pluta [1994] and Pluta and Żurawicz [2009] showed that the donors of the trait of plant resistance to anthracnose were also the cultivars ‘Titania’, ‘Lentyaj’ and ‘Stork-las’. The description of cultivar ‘Bona’ in the literature also pointed out high sensitivity of its plants to *D. ribis* and *C. ribicola*, causing anthracnose and white pine blister rust, respectively [Gwozdecki 1993]. According to Pluta [1994], a good gene donor of the plant resistance to white pine blister rust, and to the other two fungal diseases, was the cultivar ‘Titania’. The varied severity of disease symptoms of evaluated seedlings in the individual years of observations may have been caused by high temperatures and abundant precipitation in vegetation seasons. According to Brennan and Jarret [2014], the development of fungal diseases, such as powdery mildew, leaf anthracnose and white pine blister rust on blackcurrants is stimulated by high temperatures during the spring and summer which had a beneficial effect on the sporulation of fungi and on the release and spread of conidia. Particularly, conducive to infection were years with high precipitation in the spring. In practice, it is needed more intensive protection of plants of the blackcurrant genotypes susceptible to these diseases, especially during the years that are favourable to their development. Additionally, it considerably raises production costs and creates a greater threat to the environment.

Specific combining abilities effects. SCA effect usually appears only to a few pairs of parents, and may improve or decrease the biological and agricultural values of their progenies. It refers to single cross combinations expressing the genetic interaction concerning a given parental pair. In our studies for plant growth vigour, significantly positive SCA effects were obtained for five hybrid families: ‘Bona’ × D13B/11, ‘Bona’ × ‘Vernisazh’, ‘Big Ben’ × ‘Ceres’, ‘Ceres’ × ‘Vernisazh’ and D13B/11 × ‘Sofiiwska’. However, significantly positive values of SCA effects were estimated for the crossing combination ‘Big Ben’ × ‘Ceres’ for low plant susceptibility (or resistance) to powdery mildew and anthracnose. It is known, that powdery mildew caused by *P. mors-uvae* is a serious problem in blackcurrant commercial plantations [Hummer and Barney 2002].

Reciprocal effects. Alike for the plant growth vigour, bush habit and their susceptibility to fungal dis-

eases, statistically significant proven RE effects were obtained only for few crossing pairs. The RE effect is the result of extra-nuclear inheritance and the specific interaction of cytoplasmic maternal factors with nuclear factors of paternal forms [Chukwu et al. 2016]. The absence of reciprocal effects facilitates breeding work because cultivars can be used both as maternal and paternal forms [Dias and Kageyama 1995].

In our studies, the RE effects were insignificant for the plant infestation by leaf anthracnose and white pine blister rust, while they were significant only for powdery mildew susceptibility, for few combinations of crosses. In his scientific work on blackcurrant Pluta [1994] obtained the significance of RE effects for 4 of the 16 traits studied; these were the plant vigor, fruit yield, the uniformity of fruit ripening in the string and the falling off of the fruit. Our results concerning the susceptibility of blackcurrant plants to leaf diseases were similar to those obtained by Rawkin [1981] and Pluta [1994]. These authors found no significant RE effects for the susceptibility of plants of this species to the above-mentioned fungal diseases. In practical resistance breeding, this means that the direction of crosses does not have a significant influence on the inheritance of these traits by the blackcurrant progeny.

CONCLUSIONS

1. The tested blackcurrant cultivars differ significantly in terms of their usefulness for breeding of new dessert cultivars, as determined by their effects of general (GCA), specific (SCA) combining abilities and reciprocal (RE) effects for the plant morphological traits and plant infection by fungal pathogens.

2. Among the tested parental genotypes, ‘Big Ben’, ‘Sofiiwska’ and ‘Vernisazh’ are characterized by the highest usefulness for applied breeding of new blackcurrant cultivars to improve plant growth vigour and increase their resistance to powdery mildew and anthracnose because they have significantly positive GCA effects for these traits.

3. The cultivar ‘Ceres’ is a donor of an erect plant growth habit desired in trellising system of cultivation of the blackcurrants.

4. The least useful parents for breeding of dessert cultivars of blackcurrant seems to be ‘Bona’ and ‘Ceres’, which show the most estimates of negative GCA

effects, including for the plant growth vigour and resistance to powdery mildew.

5. Significantly positive values of SCA effects estimated for the cross combination ‘Big Ben’ × ‘Ceres’ for plant low susceptibility to powdery mildew and anthracnose, are proof of the interaction of both parental genotypes in the creation of cultivars that are resistant or low susceptible to these fungal diseases.

6. Reciprocal crosses (RE) are significant for only few cross combinations of the tested blackcurrant parental forms. The absence or a small number of significant RE effects greatly facilitates breeding work as the cultivars can be used both as maternal and paternal forms.

SOURCE OF FUNDS

This study was supported by the Ministry of Science and Higher Education of Poland as part of the statutory activities of The National Institute of Horticultural Research, within Project No. S1.1.1. „Studies on the usefulness of selected blackcurrant genotypes for breeding of dessert cultivars – assessment of combining abilities in diallel cross design”.

REFERENCES

- Baker, J.R. (1978). Issues in diallel analysis. *Crop Sci.* 18(4), 533–536. <https://doi.org/10.2135/cropsci1978.0011183X001800040001x>
- Bestfleisch, M., Möhring, J., Hanke, M., Peil, A., Flachowsky, H. (2014). A diallel crossing approach aimed on selection for ripening time and yield in breeding of new strawberry (*Fragaria* × *ananassa* Duch.) cultivars. *Plant Breed.*, 133(1), 115–120. <https://doi.org/10.1111/pbr.12120>
- Brennan, R., Jarret, D. (2014). Ribes: currants and gooseberry. In: George R.A.T., Fox T.T.V. (eds.). *Diseases of temperate horticultural plants*. CABI International, UK, 68–83.
- Chukwu, S.C., Okporie, E.O., Onyishi, G.C., Ekwu, L.G., Nwogbaga, A.C., Ede, N.V. (2016). Application of diallel analyses in crop improvement. *Agric. Biol. J. North Am.*, 7(2), 95–106.
- Dias L.A.S., Kageyama P.Y. (1995). Combining ability for cacao (*Theobroma cacao* L.) yield components under southern Bahia conditions. *Theor. Appl. Gen.*, 90, 534–541. <https://doi.org/10.1007/BF00222000>
- Dossett, M., Lee, J., Finn, C.E. (2008). Genetics and breeding inheritance of phenological, vegetative and fruit chemistry traits in black raspberry. *J. Amer. Soc. Hort. Sci.*, 133(3), 408–417. <https://doi.org/10.21273/JASHS.133.3.408>
- Griffing, B. (1956a). A generalised treatments of diallel crosses in quantitative inheritance. *Heredity* 10, 31–50. <https://doi.org/10.1038/hdy.1956.2>
- Griffing, B. (1956b). Concept of general and specific combining ability in relation to diallel crossing systems. *Austral. J. Biol. Sci.*, 9(4), 463–493. <https://doi.org/10.1071/BI9560463>
- Gwozdecki, J. (1993). Two new blackcurrant cultivars. *Acta Hort.*, 352, 325–328. <https://doi.org/10.17660/ActaHortic.1993.352.46>
- Hummer, K.E., Barney, D.L. (2002). Crop reports – currants. *Hort Tech.*, 12, 377–387.
- Keuls, M., Garretsen, F. (1978). A general method for the analysis of genetic variation in complete and incomplete diallels and North Carolina II (NC II) designs. Part II. Procedures and general formulas for the fixed model. *Euphytica*, 27, 49–68.
- Lister, C.E., Wilson, P.E., Sutton, K.H., Morrison, S.C. (2002). Understanding the health benefits of blackcurrants. *Acta Hort.*, 585(2), 443–449. <https://doi.org/10.17660/ActaHortic.2002.585.72>
- Masny, A., Żurawicz, E., Mądry, E. (2009). General combining ability of ten strawberry cultivars for ripening time, fruit quality and resistance to main leaf diseases under Polish conditions. *Acta Hort.*, 842, 601–604. <https://doi.org/10.17660/actahortic.2009.842.128>
- Masny, A., Mądry, W., Żurawicz, E. (2014). Combining ability of selected dessert strawberry cultivars with different fruit ripening periods. *Acta Sci. Pol. Hortorum Cultus*, 13(1), 67–78.
- Mazeikiene, I., Bendokas, V., Baniulis, D., Staniene, G., Juskyte, D. A., Sasnauskas A., Stany, V., Siksnianas, T. (2017). Genetic background of resistance to gall mite in Ribes species. *Agric. Food Sci.*, 26(2), 111–117. <https://doi.org/10.23986/afsci.59410>
- Mądry, W., Krajewski, P., Pluta, S., Żurawicz, E. (2004). Multivariate analysis of breeding value and genetic divergence in blackcurrant (*Ribes nigrum* L.) varieties detected by general combining ability effects. *Acta Sci. Pol., Hortorum Cultus* 3(2), 93–109.
- Möhring, J., Piepho, H.P. (2009). Comparison of weighting in two-stage analyses of series of experiments. *Crop Sci.*, 49(6), 1977–1988. <https://doi.org/10.2135/cropsci2009.02.0083>
- Pluta, S. (1994). Analiza dialleliczna cech użytkowych porzeczki czarnej. Praca doktorska, ISK Skierniewice.
- Pluta, S., Mądry, W., Żurawicz, E. (2008). General combining ability of selected blackcurrant (*Ribes nigrum* L.) genotypes in breeding for dessert quality fruit, ISHS

- Acta Hortic.* 777, 57–62. <https://doi.org/10.17660/ActaHortic.2008.777.4>
- Pluta, S., Żurawicz, E. (2009). Dessert-type cultivars of blackcurrant (*Ribes nigrum* L.) – new breeding aiming at the RIPF, Skierniewice, Poland. *J. Jilin Agric. Univ.* 31(5), 481–485.
- Pluta, S., Żurawicz, E., Pruski, K. (2012). Suitability of fruits of selected blackcurrant (*Ribes nigrum* L.) cultivars for fresh market. *J. Berry Res.* 2(1), 23–31. <https://doi.org/10.3233/JBR-2011-025>
- Pluta, S., Żurawicz, E., Studnicki, M., Mądry, W. (2014). Combining ability analysis for selected plant traits in gooseberry. *J. Amer. Soc. Hort. Sci.*, 139(3), 1–11. <https://doi.org/10.21273/jashs.139.3.325>
- SAS Institute (2000). SAS language and procedure: usage. Ver. 8, 1st ed. SAS Inst., Cary, NC.
- Ravkin, A.S. (1981). Analysis of field resistance of blackcurrant to the American gooseberry mildew by estimation the combining ability of the varieties. *Genetika*, 17(11), 1998–2003. [In Russian].
- Trajkowski, V., Paasuke, R. (1976). Resistance to *Sphaerotheca mors-uvae* (Schw.) Berk in *Ribes nigrum* L. Studies on breeding blackcurrants for resistance to *Sphaerotheca mors-uvae* (Schw.) Berk. *Swedish J. Agric. Res.*, 6(3), 201–214.
- Vagiri, M.R. (2012). Black currant (*Ribes nigrum* L.) – an insight into the crop. Introductory paper at the Faculty of Landscape Planning, Horticulture and Agricultural Science, Dept. of Plant Breeding and Biotechnology, Swedish University of Agricultural Sciences, Alnarp, Sweden, 1654–3580.
- Yao, W.H., Zhang, Y.D., Kang, M.S., Chen, H.M., Liu, L., Yu, L.J., Fan, X.M. (2013). Diallel analysis models: a comparison of certain genetic statistics. *Crop Sci. Gen.*, 53(4), 1481–1490. <https://doi.org/10.2135/cropsci2013.01.0027>
- Zhang, Y., Kang, M.S., Lamkey, K.R. (2005). DIALLEL-SAS05: a comprehensive program for Griffing's and Gardner-Eberhart analyses. *Agron. J.*, 97(4), 1097–1106. <https://doi.org/10.2134/agronj2004.0260>
- Żurawicz, E., Mądry, W., Pluta, S. (1996). Variation and heritability of economically important traits in blackcurrant (*Ribes nigrum* L.) evaluated in a diallel cross design. *Euphytica*, 91, 219–224. <https://doi.org/10.1007/BF00021073>

