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Ocena zdolności kombinacyjnej wybranych form rodzicielskich borówki wysokiej (*Vaccinium corymbosum* L.) dla siły wzrostu siewek

Assessment of the combining ability of selected highbush blueberry (*Vaccinium corymbosum* L.) parental forms for seedling's growth

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Celem badań było określenie wartości hodowlanej 12 genotypów rodzicielskich borówki wysokiej (*Vaccinium corymbosum* L.) na podstawie oceny ich ogólnej i specyficznej zdolności kombinacyjnej (GCA i SCA) dla siły wzrostu siewek. Materiał badawczy stanowiła populacja 2100 siewek F_1 uzyskanych z programu krzyżowania w 2014 roku. Krzyżowania 7 form matecznych (♀) – 'Aurora', 'Bluecrop', 'Brigitta Blue', 'Chandler', 'Draper', 'Duke', 'Northland' oraz 5 form ojcowskich (♂) – 'Earliblue', 'KazPliszka', 'Polaris', 'Toro', 'Weymouth' były wykonane w układzie czynnikowym (7x5). Jesienią 2014 r. założono doświadczenie polowe w układzie kompletnych bloków losowych, w 4 powtórzeniach, z 15 siewkami na poletku. W 2019 r. wykonano ocenę fenotypową populacji siewek pod kątem siły wzrostu roślin. Stwierdzono, że siewki różniły się istotnie tą cechą morfologiczną roślin. Na podstawie wyników oceny fenotypowej populacji siewek określono efekty GCA dla 12 rodzicielskich odmian i efekty SCA dla 35 rodzin mieszańcowych dla tej cechy. Analiza statystyczna wykazała, że formy rodzicielskie różniły się istotnie pod względem zdolności kombinacyjnej (efekty GCA i SCA) dla siły wzrostu. Formy rodzicielskie posiadające istotne i dodatnie wartości efektów GCA były potencjalnie przydatnymi dawcami genów determinujących silny wzrost, natomiast istotne i negatywne wartości efektów innych form rodzicielskich wskazywały na pogorszenie tej cechy u ocenianego potomstwa. Statystycznie istotne dodatnie lub ujemne wartości efektów SCA były wynikiem interakcji genetycznej obu form rodzicielskich w tych rodzinach mieszańcowych, a zatem mogły wpłynąć na poprawę lub pogorszenie siły wzrostu siewek borówki wysokiej.

Słowa kluczowe: borówka wysoka, GCA, hodowla, ocena fenotypowa, SCA, siła wzrostu.

The aim of the study was to determine the breeding value of 12 highbush blueberry (*Vaccinium corymbosum* L.) parental genotypes based on the estimation of their general and specific combining ability (GCA and SCA) for seedling growth. The research material was a population of 2,100 F_1 plants obtained from the 2014 crossing program. Crosses of 7 maternal forms (♀) - ‚Aurora', ‚Bluecrop', ‚Brigitta Blue', ‚Chandler', ‚Draper', ‚Duke', ‚Northland' - and 5 paternal forms (♂) - ‚Earliblue', ‚KazPliszka', ‚Polaris', ‚Toro', ‚Weymouth' - were made in a factorial design (7x5). In autumn 2014, the field experiment was established in complete randomized block design, in 4 replications, with 15 seedlings per plot. In 2019, a phenotypic evaluation of the seedling population was done for plant growth . We found that the seedlings differed significantly in this plant morphological trait. Based on the results of the phenotypic evaluation of the seedling population, the GCA effects for 12 parental cultivars and SCA effects for 35 hybrid families for this trait were determined. Statistical analysis showed that the parental forms differed significantly in their combining ability (GCA and SCA effects) for plant growth. The parental forms possessing significant and positive values of GCA effects were potentially useful donors of genes determining strong growth, while, conversely, significant and negative effects in other parental forms influenced the deterioration of this trait in the assessed offspring. Statistically significant positive or negative values of SCA effects were the results of genetic interaction of both parental forms within these hybrid families, and could, therefore, inform the breeder of the improvement or deterioration of plant growth in blueberry seedlings.

Key words: highbush blueberry, breeding, GCA, phenotypic evaluation, plant growth, SCA

Introduction

In the traditional breeding of crop plants, including highbush blueberry (*Vaccinium corymbosum* L.), it is important to select the right parental forms for crossing programmes. Knowledge of the breeding value of parental forms, genetic analyses of quantitative traits in the population, and the level and type of their inheritance increase the likelihood of rapid achievement of breeding goals. The breeding value of the parental genotype is determined based on the effects of general (GCA) and specific combining ability (SCA), genetic correlation between traits, genetic variance of traits and their heritability (Sprague and Tatum, 1942; Sherrif et al., 1985; Żurawicz et al., 2006; Pluta et al., 2014).

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The general combining ability (GCA) of the parental form for the analysed quantitative trait determines its ability to transmit the average value of that trait into its progeny (Baker, 1978; Vieira et al., 2009). The GCA effect is a measure of the additive effect of the parental genes on this trait (Griffing 1956 a, b). Parental genotypes used in crossing programmes characterized by significantly positive GCA effects for a given trait significantly increase the probability of obtaining seedlings (hybrids) that have the desired values of this trait (Bestfleisch et al., 2014; Masny et al., 2014; Pluta et al., 2014).

The specific combining ability (SCA) of a pair of parental forms for a given trait is the effect of the genetic interaction of both parents manifested in their offspring (Griffing, 1956 a, b; Baker, 1978). The SCA effect is the result of the non-additive effects of genes (dominance and epistasis). It shows the difference between the mean value of a trait in the offspring (full siblings of two parental forms) and the sum of the GCA effects for these parental forms (Bestfleisch et al., 2014).

The GCA and SCA effects of the parental forms tested in crossing combinations are measures of their breeding value for the analysed performance traits. This indicates the suitability of parental genotypes for breeding programmes aimed at improving these traits in new cultivars (Baker, 1978; Masny et al., 2005; 2016; Bestfleisch et al., 2014; Pluta and Żurawicz 2014). The successful selection of valuable parental forms in a breeding programme can be further enhanced if the SCA effects of individual parent combinations are considered. Moreover, differences in SCA effects in a given crossing programme indicate the importance of the genetic interaction between both parental forms in inheriting traits by offspring (Baker, 1978). Both the GCA and SCA effects can have significant positive or negative values. This means that the parental forms tested in breeding programmes may have a positive or negative impact on the occurrence of traits in the assessed seedlings.

The aim of the study was to determine the general and specific combining ability (GCA and SCA) of 12 parental forms of highbush blueberry and 35 hybrid families based on the phenotypic evaluation of seedling growth in a field experiment.

Materials and Methods

Research material. The research material was a population of 2,100 F_1 plants representing 35 hybrid families obtained by crossing of 12 parental forms in a factorial design (7x5). In the crossing programme conducted in spring 2014 we used parental genotypes, i.e. 7 maternal forms (♀): 'Aurora', 'Bluecrop', 'Brigitta Blue', 'Chandler', 'Draper', 'Duke' and 'Northland', and 5 paternal forms (♂): 'Earliblue', 'KazPliszka', 'Polaris', 'Toro' and 'Weymouth'. Parental cultivars come from various geographic regions (USA, New Zealand and Poland), have many valuable functional traits and are characterised by a high phenotypic and genetic variability (growth vigour and shape of the shrub, flowering and ripening date, yielding, fruit weight and attractiveness, and resistance to major diseases and pests). Seedlings representing 35 hybrid families were planted in autumn 2014 on an experimental field in the Pomological Orchard in Skierniewice. The experiment was established in a complete block design, in 4 replicates with 15 seedlings per plot. The seedlings were planted in rows lined with fabric ground cover. The cultivation, maintenance of seedlings, soil fertilization and plant feeding were consistent with the recommendations for commercial highbush blueberry plantations. In the spring, the rows of seedlings were fertilized with ammonium sulphate (21% N) at a dose of 100 kg/ha, divided (50%: 50%) at an interval of 3–4 weeks. After flowering of the shrubs (the second half of May), the multi-component Yara Mila Complex fertilizer (12–11–18+Mg+S+Micro) was spread at the dose of 150 kg/ha. Potassium sulphate (42% K_2O) was applied at a dose of 120 kg/ha in autumn (end of September). During the growing season, the seedlings were watered using the drip system twice a day, in the morning and in the evening. In early spring, sawdust was spread on the fabric ground cover between rows and replenished every year. Weeds were removed manually or mechanically, and herbicides were applied as needed (Fusilade Forte 150 EC and Basta 150 SL). Based on the monitoring of seedlings, a limited integrated pest management was used to protect plants against fungal diseases and pests (pest control: Calypso 480 SC, Spin Tor 240 SC, control of fungal diseases: Switch 62,5 WG, Topsin M 500 SC), consistently with the recommendations of the 2019 Guide for Integrated Protection of Berry Plants. The plantation was protected against birds (starlings, fieldfares, blackbirds and pigeons), which are a serious problem in the blueberry cultivation, with polyethylene mesh stretched above the shrubs and attached with wires on the tops of 3.5 m tall impregnated wooden poles.

Weather conditions were determined based on meteorological data from the METOS-COMPACT station (Pessl Instruments). Data on weather conditions in each month of the growing season in 2019 are presented in Table 1.

The lowest air temperature at 2 m above the ground level was recorded on 16 April (-4.92°C). The highest air temperature was measured in June (36.6°C), although high temperatures were also recorded in the summer months (July-September). Precipitation occurred throughout the growing season in 2019, with the highest rainfall recorded in May, August and September. Lower rainfalls were recorded in the remaining months of 2019, but they did not deteriorate the growth of blueberry shrubs in the field experiment because the plants were watered by the drip system.

Phenotypic evaluation. In the growing season of 2019, seedlings were phenotypically evaluated for their growth vigour. The height and width of seedlings in cm were measured on two dates: in spring, at the beginning of plant growth, and in autumn, after the end of growth. The height was measured for each seedling, from the ground level to the top of the plant; the width of each seedling was measured transversely to the rows of plants.

Combining ability. Results of phenotypic evaluation for the growth of highbush blueberry seedlings were used to estimate the general combining ability (GCA effects) for 12 parental cultivars and the specific combining ability (SCA effects) for 35 hybrid families.

Statistical analysis. Obtained results (data) were analysed with statistical methods in a two-step procedure. Based on the observations and measurements of plant growth, arithmetic means were calculated for each experimental plot. Means were used for preliminary statistical analysis using one-way analysis of variance (ANOVA) according to the random block system, in which the factor was hybrid families. If significant differences in the mean of this trait were found for the tested hybrids, the analysis of variance for the complete factorial design (♀7 x ♂ 5) was performed in order to estimate the effects of the general (GCA) and specific (SCA) combining ability for the examined morphological traits of plants. All calculations concerning the estimation of GCA and SCA effects in the above model, analysis of variance and detailed simultaneous testing were performed using SERGEN software, developed by scientists from the Institute of Plant Genetics, the Polish Academy of Sciences in Poznań (Caliński et al., 2003).

Results

Phenotypic evaluation

Statistics on the growth of the tested highbush blueberry seedlings determined based on measured plant height and width are presented in Table 2.

The evaluated highbush blueberry seedlings showed moderate vigour in the field experiment. A detailed analysis of the results obtained on the first date (spring) and on the second date (autumn) indicated an increasing trend in the vigour of seedlings. In the growing season of 2019, the seedlings had stronger vigour (plant height and width) within individual hybrid families, as well as between them, during the second evaluation in autumn, after the end of plant growth (Table 2).

Tabela 1.
Table 1.

Minimalne i maksymalne temperatury oraz suma opadów w okresie wegetacji w roku 2019, środkowa Polska

Minimum and maximum temperatures and total precipitation during the growing season in 2019, central Poland

Miesiące/Months	Temperatura powietrza (°C)/Air temperature (°C)			Suma opadów (mm) Sum of precipitation (mm)
	Minimalna/ Min	Maksymalna/ Max.	Średnia/ Average	
Marzec/March	-3,49	17,35	5,73	34,60
Kwiecień/April	-4,92	27,59	9,51	17,00
Maj/May	-1,99	26,05	12,56	61,00
Czerwiec/June	7,68	36,60	24,63	46,20
Lipiec/July	6,49	33,48	18,24	55,40
Sierpień/August	6,25	33,48	19,74	77,80
Wrzesień/September	2,59	31,44	13,79	82,80
Październik/October	-3,25	23,78	10,23	21,60

Mean values for the height and width of seedlings measured on both dates indicated the strongest vigour of highbush blueberry seedlings from the following hybrid families: 'Aurora' x 'Polaris', 'Bluecrop' x 'Polaris', 'Bluecrop' x 'KazPliszka', 'Bluecrop' x 'Toro', 'Bluecrop' x 'Weymouth', 'Chandler' x 'Polaris', 'Duke' x 'Earliblue', 'Duke' x 'Toro', 'Duke' x 'Weymouth', 'Northland' x 'Toro' and 'Northland' x 'Weymouth'. The lowest vigour of seedlings was found for 9 hybrid families from the following crosses: 'Aurora' x 'Weymouth', 'Aurora' x 'KazPliszka', 'Brigitta B.' x 'KazPliszka', 'Brigitta B.' x 'Polaris', 'Brigitta B.' x 'Toro', 'Chandler' x 'Earliblue', 'Chandler' x 'KazPliszka', 'Chandler' x 'Weymouth', 'Draper' x 'Toro', 'Northland' x 'KazPliszka' and 'Northland' x 'Polaris'. Plants from other hybrid families were characterised by moderate vigour (Tab. 2).

Combining ability (GCA and SCA)

The results of the statistical analysis concerning the general and specific combining ability (GCA and SCA) for the vigour of highbush blueberry seedlings are presented in Tables 3–4. The values of GCA and SCA effects are positive or negative and may have a positive or negative impact on the inheritance of performance traits by the analysed offspring.

GCA effects

The values of the GCA effects (positive and negative) for 12 parental cultivars of highbush blueberry in terms of vigour determined based on the height and width of all seedlings measured in 2019 are presented in Table 3.

The analysis of data in Table 3 showed that for the height of the blueberry seedlings, statistically significant and positive values of GCA effects were found for 2 maternal forms (cultivars): 'Bluecrop' and 'Duke'. This means that both cultivars used as parental forms in the crossing programme transfer to their offspring the ability to produce taller shrubs compared to other tested cultivars. Significantly negative values of GCA effects for this plant trait were found for one maternal cultivar ('Brigitta Blue') and one paternal cultivar ('KazPliszka'). In crossing programmes these cultivars are therefore donors of genes that determine weak vigour in the offspring of highbush blueberry seedlings. Considering the width of shrubs, statistically significant and positive values of GCA effects were obtained for 2 maternal cultivars: 'Bluecrop' and 'Duke'. Significantly negative values of GCA effects for this morphological trait were found for two other maternal cultivars ('Brigitta Blue' and 'Chandler') and one paternal cultivar ('KazPliszka'). In practice, the latter three parental forms used in crossing programmes most likely transmit to the offspring their ability to create narrower and more erect shrubs (significant and negative GCA effects), and the two previously mentioned – wider and more branchy shrubs (significant and positive GCA effects).

SCA effects

The effects of specific combining ability (SCA) estimated for the vigour of seedlings from 35 hybrid families are presented in Table 4. The values of SCA effects (positive or negative) assessed for a specific pair of parental forms may have a positive or negative effect on a given trait in the population of seedlings.

The analysis of data indicated that the SCA effects estimated for the height and width of highbush blueberry seedlings were significantly different for several hybrid families. For plant height, statistically significant and positive values of the SCA effects were obtained in 2019 only for 2 hybrid families: 'Aurora' x 'Polaris' and 'Chandler' x 'Polaris'. It should therefore be expected that the offspring obtained as a result of the genetic interaction of the two parental forms will be characterized by strong vigour. Significantly negative SCA values for this plant trait were calculated for another 4 cross combinations: 'Aurora' x 'Weymouth', 'Draper' x 'Toro', 'Duke' x 'Polaris' and 'Northland' x 'Polaris'. This means that in the case of these hybrid families, the genetic interaction of both parental cultivars (forms) determines the weak growth of the obtained offspring (Tab. 4).

For the second morphological trait (plant width) significantly positive values of SCA effects were obtained for 4 hybrid families: 'Aurora' x 'Polaris', 'Chandler' x 'Polaris', 'Draper 'x 'KazPliszka' and 'Northland' x 'Weymouth'. Thus, highbush blueberry seedlings from these hybrid families will produce shrubs that are wider and more branchy. Significantly negative values of SCA effects for this plant trait were obtained for another 3 hybrid families: 'Aurora' x 'Weymouth', 'Draper' x 'Toro' and 'Northland' x 'Polaris'. The negative value of the estimated SCA effect indicates a high probability that seedlings from these hybrid families will produce narrower and more erect bushes (Table 4).

Tabela 2
Table 2

Siła wzrostu siewek borówki wysokiej rosnących w doświadczeniu polowym

Growth strength of highbush blueberry seedlings grown in the field

Lp.	Nr kombinacji Combination no	Rodowód Pedigree ♀ x ♂	Siła wzrostu siewek Growth strength of seedlings			
			Wysokość roślin (cm) Plant height (cm)		Szerokość roślin (cm) Plant width (cm)	
			I termin [a] 1st term [a]	*II termin [b] 2nd term [b]*	*I termin [a] 1st term [a]*	*II termin [b] 2nd term [b]*
1	1\1	Aurora x Earliblue	40,3	52,6	38,0	57,4
2	1\2	Aurora x KazPliszka	35,1	42,9	38,2	45,7
3	1\3	Aurora x Polaris	50,9	66,5	51,6	65,3
4	1\4	Aurora x Toro	48,7	59,0	51,4	54,2
5	1\5	Aurora x Weymouth	26,4	32,8	29,6	33,7
		średnia average	*40,3*	*50,8*	*41,7*	51,2
6	2\1	Bluecrop x Earliblue	42,1	60,5	39,9	56,0
7	2\2	Bluecrop x KazPliszka	46,8	67,1	47,5	66,2
8	2\3	Bluecrop x Polaris	48,4	66,9	48,4	62,7
9	2\4	Bluecrop x Toro	47,0	69,2	45,4	64,1
10	2\5	Bluecrop x Weymouth	52,3	68,3	58,4	71,3
		średnia average	*47,3*	*66,4*	47,9	64,1
11	3\1	Brigitta B. x Earliblue	42,5	46,8	42,8	58,1
12	3\2	Brigitta B. x KazPliszka	41,2	41,7	37,5	42,4
13	3\3	Brigitta B. x Polaris	32,0	44,1	34,3	45,3
14	3\4	Brigitta B. x Toro	33,9	41,1	36,3	41,3
15	3\5	Brigitta B. x Weymouth	36,1	50,7	37,7	48,7
		średnia average	*37,1*	44,9	37,7	47,2
16	4\1	Chandler x Earliblue	32,7	42,6	32,6	41,6
17	4\2	Chandler x KazPliszka	27,1	34,3	33,7	36,4
18	4\3	Chandler x Polaris	52,8	72,0	48,2	65,8
19	4\4	Chandler x Toro	40,6	54,1	40,6	58,1
20	4\5	Chandler x Weymouth	30,1	40,6	29,6	38,1
		średnia average	36,7	48,7	36,9	48,0
21	5\1	Draper x Earliblue	37,7	53,4	38,0	50,5
22	5\2	Draper x KazPliszka	46,3	61,9	54,2	66,9
23	5\3	Draper x Toro	45,6	60,2	49,1	60,7
24	5\4	Draper x Polaris	32,3	43,6	38,4	43,3
25	5\5	Draper x Weymouth	40,7	56,8	41,1	55,4
		średnia average	40,5	55,2	44,2	55,4
26	6\1	Duke x Earliblue	49,9	63,2	48,5	61,0
27	6\2	Duke x Polaris	40,6	55,2	40,8	51,4
28	6\3	Duke x KazPliszka	36,3	48,6	39,9	50,2
29	6\4	Duke x Toro	46,3	65,3	51,0	69,5
30	6\5	Duke x Weymouth	51,2	68,5	54,1	64,9
		średnia average	*44,9*	*60,2*	*46,9*	*59,4*
31	7\1	Northland x Earliblue	42,5	49,6	47,8	51,6
32	7\2	Northland x KazPliszka	28,6	41,1	34,1	42,7
33	7\3	Northland x Polaris	32,9	40,5	35,5	43,9
34	7\4	Northland x Toro	44,2	66,2	50,7	66,6
35	7\5	Northland x Weymouth	50,1	65,3	56,8	68,2
		średnia average	*39,7*	*52,6*	*45,0*	*54,6*

[a] – I termin – ocena wykonana 15–16.05.2019 r., [b] – II termin – ocena wykonana 22–24.10.2019 r.
[a] – 1st term – evaluation done on 15–16.05.2019, [b] – 2nd term – evaluation done on 22–24.10.2019.

Tabela 3
Table 3

Wartości efektów GCA 12 odmian rodzicielskich borówki wysokiej dla siły wzrostu siewek w doświadczeniu

Values of GCA effects of 12 highbush blueberry parental cultivars for seedling's growth in the experiment

Nr matki lub ojca No of mother or father	Formy rodzicielskie Parental forms	Wysokość roślin (cm) [a] Plant height (cm)		Szerokość roślin (cm) [a] Plant width (cm)	
		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	Aurora	-3,34	2,70	-3,02	2,88
2	Bluecrop	12,31**	36,67	9,80**	30,44
3	Brigitta Blue	-9,22**	20,57	-7,11**	16,01
4	Chandler	-5,37	6,98	-6,25**	12,39
5	Draper	1,09	0,29	1,10	0,38
6	Duke	6,08*	8,94	5,14*	8,36
7	Northland	-1,55	0,58	0,34	0,04
Wartości krytyczne dla testowania indywidualnego na poziomie Critical values for individual testing at the level		0,10	2,76	0,10	2,76
		0,05	3,93	0,05	3,93
		0,01	6,89	0,01	6,89
Wartości krytyczne dla testowania jednoczesnego na poziomie *Critical values for simultaneous testing at the level*		0,10	6,21	0,10	6,21
		0,05	7,54	0,05	7,54
		0,01	10,75	0,01	10,75
Analiza względem form ojcowskich Analysis in relation to paternal forms (♂)					
8	Earliblue	-1,44	0,75	-0,53	0,13
9	KazPliszka	-4,91*	8,76	-4,01*	7,64
10	Polaris	2,90	3,05	2,00	1,91
11	Toro	2,82	2,88	2,47	2,90
12	Weymouth	0,63	0,15	0,06	0,00
Wartości krytyczne dla testowania indywidualnego na poziomie Critical values for individual testing at the level		0,10	2,76	0,10	2,76
		0,05	3,93	0,05	3,93
		0,01	6,89	0,01	6,89
Wartości krytyczne dla testowania jednoczesnego na poziomie Critical values for simultaneous testing at the level		0,10	5,59	0,10	5,59
		0,05	6,89	0,05	6,89
		0,01	10,06	0,01	10,06

** – wartości efektów GCA istotnie różne od zera przy poziomie α=0,05*
** – values of GCA effects significantly different from zero at the level of α = 0.05*
***- wartości efektów GCA istotnie różne od zera przy poziomie α=0,01*
*** – values of GCA effects significantly different from zero at the level of α = 0.01*
[a] – na podstawie średnich wyników pomiaru siewek wykonanego w II terminie, jesienią 2019 roku
[a] – based on average results of seedling measurement done in the second term, in autumn 2019

Tabela 4
Table 4

Wartości efektów SCA dla siły wzrostu siewek borówki wysokiej należących do 35 rodzin mieszańcowych

Values of SCA effects for the growth of highbush blueberry seedlings belonging to 35 hybrid families

Nr rodziny mieszańcowej No of hybrid family	Krzyżowane formy rodziciel-skie Crossed parental forms	Wysokość roślin (cm) [a] Plant height (cm)		Szerokość roślin (cm) [a] Plant width (cm)	
		Ocena efektu głównego Main effect value	Statystyka F dla efektu głównego F statistics for the main effect	Ocena efektu głównego Main effect value	Statystyka F dla efektu głównego F statistics for the main effect
1	Aurora x Earlibblue	3,26	0,64	6,68	3,53
2	Aurora x KazPliszka	-2,92	0,52	-1,54	0,19
3	Aurora x Polaris	12,87*	10,03	12,05*	11,51
4	Aurora x Toro	5,40	1,77	0,45	0,02
5	Aurora x Weymouth	-18,61**	20,97	-17,64**	24,66
6	Bluecrop x Earliblue	-4,49	1,22	-7,53	4,50
7	Bluecrop x KazPliszka	5,64	1,92	6,15	3,00
8	Bluecrop x Polaris	-2,40	0,35	-3,34	0,88
9	Bluecrop x Toro	-0,04	0,00	-2,43	0,47
10	Bluecrop x Weymouth	1,29	0,10	7,16	4,06
11	Brigitta B. x Earliblue	3,34	0,67	11,42	10,34
12	Brigitta B. x KazPliszka	1,74	0,18	-0,73	0,04
13	Brigitta B. x Polaris	-3,65	0,80	-3,89	1,20
14	Brigitta B. x Toro	-6,62	2,65	-8,28	5,44
15	Brigitta B. x Weymouth	5,19	1,63	1,48	0,17
16	Chandler x Earliblue	-4,71	1,35	-5,86	2,73
17	Chandler x KazPliszka	-9,49	5,45	-7,56	4,53
18	Chandler x Polaris	20,40**	25,2	15,76**	19,69
19	Chandler x Toro	2,56	0,40	7,61	4,60
20	Chandler x Weymouth	-8,76	4,64	-9,95	7,85
21	Draper x Earliblue	-0,37	0,01	-4,34	1,49
22	Draper x KazPliszka	11,63	8,19	15,54**	19,16
23	Draper x Polaris	2,12	0,27	3,31	0,87
24	Draper x Toro	-14,40*	12,55	-14,51**	16,7
25	Draper x Weymouth	1,01	0,06	0,00	0,00
26	Duke x Earliblue	4,49	1,22	2,13	0,36
27	Duke x KazPliszka	-0,06	0,00	-3,99	1,26
28	Duke x Polaris	-14,44*	12,62	-11,18	9,91
29	Duke x Toro	2,29	0,32	7,60	4,59
30	Duke x Weymouth	7,72	3,61	5,44	2,35
31	Northland x Earliblue	-1,51	0,14	-2,48	0,49
32	Northland x KazPliszka	-6,53	2,58	-7,87	4,91
33	Northland x Polaris	-14,92*	13,47	-12,71*	12,81
34	Northland x Toro	10,81	7,08	9,55	7,23
35	Northland x Weymouth	12,15	8,93	13,51**	14,48

* – *wartości efektów SCA istotnie różne od zera przy poziomie α=0,05*
* – *values of SCA effects significantly different from zero at the level of α = 0.05*
**- *wartości efektów SCA istotnie różne od zera przy poziomie α=0,01*
** – *values of SCA effects significantly different from zero at the level of α = 0.01*
[a] – *na podstawie średnich wyników pomiaru siewek wykonanego w II terminie, jesienią 2019 roku*
[a] – *based on average results of seedling measurement done in the second term, in autumn 2019*

Tabela 4 cd.
Table 4 cd.

Wartości efektów SCA dla siły wzrostu siewek borówki wysokiej należących do 35 rodzin mieszańcowych

Values of SCA effects for the growth of highbush blueberry seedlings belonging to 35 hybrid families

Nr rodziny mieszańcowej No of hybrid family	Krzyżowane formy rodzicielskie Crossed parental forms	Wysokość roślin (cm) [a] Plant height (cm)		Szerokość roślin (cm) [a] Plant width (cm)	
		Ocena efektu głównego Main effect value	Statystyka F dla efektu głównego F statistics for the main effect	Ocena efektu głównego Main effect value	Statystyka F dla efektu głównego F statistics for the main effect
Wartości krytyczne dla testowania indywidualnego na poziomie Critical values for individual testing at the level		0,10	2,76	0,10	2,76
		0,05	3,93	0,05	3,93
		0,01	6,89	0,01	6,89
Wartości krytyczne dla testowania jednoczesnego na poziomie Critical values for simultaneous testing at the level		0,10	9,34	0,10	9,34
		0,05	10,75	0,05	10,75
		0,01	14,12	0,01	14,12

* – *wartości efektów SCA istotnie różne od zera przy poziomie α=0,05*
* – *values of SCA effects significantly different from zero at the level of α = 0.05*
**- *wartości efektów SCA istotnie różne od zera przy poziomie α=0,01*
** – *values of SCA effects significantly different from zero at the level of α = 0.01*
[a] – *na podstawie średnich wyników pomiaru siewek wykonanego w II terminie, jesienią 2019 roku*
[a] – *based on average results of seedling measurement done in the second term, in autumn 2019*

Discussion

Phenotypic evaluation of seedlings

Highbush blueberry (northern type) has specific cultivation requirements. Proper growth and development, flowering and yielding of plants and fruit size (weight) depend on genetic factors (genotype), environmental conditions and their interaction. The interaction between the genotype and environment (GxE) is a biological phenomenon, which is defined in terms of its mechanisms or usually its phenotypic effects for a given trait. Hence, it is defined as a different response of genotypes to environmental conditions (location in particular years, location on average years, years in individual locations, years in average locations) or as heterogeneous differences in genotypic mean values in different environments (Mądry et al., 2006).

The second group of factors includes: selection of an appropriate site, acidic soil (pH 4.5–5.5) and its preparation (enrichment with organic matter), as well as all maintenance and agrotechnical treatments, including the necessary drip irrigation (Smolarz, 2003; 2006; Smolarz and Pluta, 2014). The influence of genetic factors is also very important, because cultivars (genotypes) of highbush blueberry differ in terms of vigour and other performance traits.

Our study revealed the influence of parental highbush blueberry genotypes used in the crossing programme on the vigour of the evaluated population of seedlings (offspring). The performed phenotypic evaluation of seedlings in terms of the above-mentioned morphological traits of plants was in many cases consistent with the descriptions and pomological characteristics of the highbush blueberry parental cultivars (Smolarz, 2000; Pliszka, 2002). The evaluation of vigour of all seedlings in the field experiment provided different results and depended on the pedigree (parental cultivars). Results of phenotypic evaluation (observations and measurements of plants) of seedlings confirmed the suitability of some parental genotypes for the improvement of vigour in the offspring of the analysed plants. This is an important trait, because highbush blueberry seedlings are generally characterized by slow and weaker growth compared to blackcurrant and raspberry seedlings.

GCA and SCA effects

In 2019 the phenotypic and genetic value of the population of highbush blueberry seedlings was analysed based on an individual assessment of vigour (measurement of plant height and width). The genetic potential of 12 selected parental cultivars (forms) for the crossing programme in a factorial design (7 maternal forms and 5 paternal forms) was determined based on general (GCA) and specific (SCA) combining ability (Griffing, 1956 a, b; Mądry and Ubysz-Borucka, 1982).

The general combining ability (GCA) in terms of the considered trait determines the general suitability of parental forms for the creation of new cultivars of crop plants. The specific combining ability (SCA) for the considered trait refers to a pair of parental forms and is an interaction between both parental forms revealed by the preservation of this trait in their offspring. Significantly positive or negative effects of SCA are assessed only in some cross combinations and indicate an improvement (positive) or deterioration (negative) of traits in the offspring. High and significant values of SCA effects found for individual hybrid populations most often concern single performance traits of plants (Spangelo et al., 1971).

In practice, the most valuable offspring in terms of the desired trait are obtained by crossing parental forms that are characterized by significant and positive values of GCA effects (Griffing, 1956 a, b). Our study revealed that among 12 parental genotypes of highbush blueberry crossed in the factorial design (7x5), most of the maternal forms had significant (positive or negative) values of GCA effects for the morphological traits of the analysed plants. Considering growth vigour, we found significant and positive GCA effects for 'Bluecrop' and 'Duke', and significant and negative GCA effects for 'Brigitta Blue', 'Chandler' and 'KazPliszka'. These cultivars used in crossing programmes are very likely to be donors of genes responsible for the formation of taller/shorter shrubs or narrower/wider shrubs by offspring. The values of the GCA effects estimated for 12 selected parental forms of highbush blueberry and the results of phenotypic evaluation of the examined traits of seedlings grown in the field experiment are often correlated. For example, seedlings that are the offspring of 'Bluecrop' or 'Duke' showed stronger vigour compared to the overall mean value for this morphological trait.

The values of SCA effects and their differentiation within the studied crossing system proves the great importance of the genetic interaction between both parental forms in the determination of traits in offspring (Baker, 1978). High and statistically significant values of SCA effects found in specific crosses (hybrid families) most often concern single functional traits. Because of this it is very difficult to obtain new cultivars with several traits improved, and a similar problem was encountered with the strawberry (Spangelo et al., 1971; Hortyński, 1987; Simpson and Sharp, 1988; Masny et al., 2008, Żurawicz, 1990), and the blackcurrant (Pluta, 1994; Żurawicz et al., 1996; Mądry et al., 2004; Pluta et al., 1993; 2008).

Our research on the combining ability of 12 highbush blueberry parental forms revealed several significant values of SCA effects (positive or negative) for the vigour of seedlings. For this trait (defined based on plant height and width), significantly positive values of the SCA effects for plant height were estimated for only 2 hybrid families, and significantly negative effects for another 4 families. A greater number of significant SCA effects were identified for seedling width (positive values for 4 hybrid families, and negative for 3 families). This means that the genetic interaction between both parental genotypes within these hybrid families is likely to determine the tall/short or wide/narrow growth of the offspring (seedlings). Of note is the fact that the results of the phenotypic evaluation for the above-mentioned morphological traits of highbush blueberry seedlings grown in the experiment were in most cases consistent with the estimated values of the SCA effects for the analysed hybrid families.

After the review of the Polish literature we found no information or scientific reports on the combining ability of highbush blueberry parental forms (genotypes). The foreign literature addressing these issues with respect to highbush blueberry is also very limited. This is mainly due to the difficulties with performing a complete crossing programme (in a diallel or factorial design) and obtaining a large population of F_1 seedlings for phenotypic evaluation. This type of research is also costly, 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.

On the basis of the obtained research results, the breeding value and the suitability of selected parental forms for highbush blueberry crossing programmes were determined in order to produce valuable progeny. After the phenotypic and genotypic evaluation of the population of F_1 seedlings, we selected over 30 valuable plants (individuals) to be vegetative propagated and included in the collection of clones.

Conclusions

1. The phenotypic evaluation of highbush blueberry seedlings revealed differences in their vigour.
2. The analysed highbush blueberry parental cultivars differ in terms of combining ability (GCA and SCA effects) for the assessed morphological trait of seedlings.
3. Estimated values of GCA effects for 12 selected parental cultivars (forms) of highbush blueberry and SCA effects for 35 hybrid families are positive or negative. Therefore, these

cultivars, when used in crossing programmes, may contribute to the improvement or deterioration of the analysed trait in offspring.

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