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Multidimensional GCA and SCA effects in doubled haploid lines of winter rape in the analysis of yield structure characteristics and oil content of F_1 line × tester crosses

Wielowymiarowe efekty GCA i SCA linii podwojonych haploidów rzepaku ozimego uzyskane w analizie cech struktury plonu oraz zawartości tłuszczu mieszańców F_1 linia × tester

Key words: *Brassica napus* L., winter oilseed rape, MANOVA, line × tester diagram, GCA, SCA

In the study, a multidimensional approach to the investigation of general and specific combining ability of doubled haploid (DH) lines of winter rape based on the analysis of line × tester hybrids has been proposed. For yield structure characteristics, i.e. for silique length, number of seeds per silique, number of branches, number of siliques per plant, thousand seed weight and for oil content multidimensional effects of general combining ability (GCA) and specific combining ability (SCA) of parental lines were estimated. The estimates of these effects have been obtained on the basis of observations of 6 characters in hybrids resulting from the crossing of 7 DH lines of winter rape with 4 testers. Simultaneous testing procedures have been used to test significance of these effects. Mahalanobis distance has been proposed as a measure of similarity among parental forms due to the multi-character nature of GCA and SCA effects. Analysis of canonical variates is applied for the graphic representation of lines and testers in terms of these effects.

Słowa kluczowe: *Brassica napus* L., rzepak ozimy, wielozmienna analiza wariancji, schemat linia × tester, GCA, SCA

W pracy zaproponowano wielowymiarowe podejście do badania ogólnej i specyficznej zdolności kombinacyjnej linii podwojonych haploidów (DH) rzepaku ozimego na podstawie analizy mieszańców otrzymanych w wyniku krzyżowania typu linia × tester. Dla cech struktury plonu, tj. dla długości łuszczyny, liczby nasion w łuszczynie, liczby rozgałęzień, liczby łuszczyn na roślinie, masy tysiąca nasion (MTN) oraz zawartości tłuszczu dokonano oceny wielowymiarowych efektów ogólnej zdolności kombinacyjnej (GCA) i specyficznej zdolności kombinacyjnej (SCA) linii rodzicielskich. Oszacowanie tych efektów przeprowadzono na podstawie obserwacji wymienionych 6 cech u mieszańców pochodzących z krzyżowania 7 linii DH rzepaku ozimego z 4 testerami. Dla testowania istotności tych efektów wykorzystano procedury testowania jednoczesnego. Jako miarę podobieństwa form rodzicielskich ze względu na wielocechowe efekty GCA i SCA zaproponowano odległość Mahalanobisa. Graficzne rozmieszczenie linii i testerów ze względu na te efekty uzyskano stosując analizę zmiennych kanonicznych.

Schemat krzyżowania linia × tester okazał się w pełni przydatny dla oceny i wyboru linii DH charakteryzujących się najlepszymi parametrami badanych cech struktury plonu.

Zastosowanie w pracy równolegle różnych jedno- i wielocechowych metod analizy w znacznym stopniu uwiarygodniło uzyskane rezultaty badań. Przeprowadzona wnikliwa analiza statystyczna linii DH pozwoliła w sposób jednoznaczny wyróżnić linię DH W-15 (L3) o szczególnie korzystnych wartościach cech: liczby nasion w łuszczynie, liczby rozgałęzień i liczby łuszczyn na roślinie oraz linię DH H6-55 (L6) odznaczającą się dodatkowo najdłuższymi łuszczynami. Pod względem zawartości tłuszczu żadna z linii DH nie odbiegała od wartości średniej. Spośród par linii testerów najkorzystniej zaprezentowały się kombinacje z testerami wyróżnionych linii: L3, L4, tj. L4 × T1, L3 × T3 i L4 × T4 o istotnych wielowymiarowych efektach SCA i przynajmniej trzech dodatnich i istotnych efektach pojedynczych cech struktury plonu. Wyjątek stanowi masa 1000 nasion. Pod względem tej cechy dwie pierwsze pary lokują się w grupie średnich, a trzecia para istotnie odbiega od średniej.

Introduction

Usefulness of initial materials in breeding of new rape cultivars may be assessed using combining values. The determination of the actual combining ability of strains or lines taken into consideration for crossing is essential for genetic progress in rape breeding (Krzymański 1994). An appropriate selection of components is especially important in breeding synthetic varieties of rape, where the condition for the generation of a variety with yielding capacity and good quality is to select parents not only exhibiting the best general combining ability, but also good specific combining ability. The size of GCA and SCA effects play a considerable role in rape breeding due to the low heritability of seed yield (Krzymański et al. 1993, 1994). Their progenies obtained from a specific crossing system are used to estimate general and specific combining abilities of genotypes. One of the crossing systems used most commonly in breeding work is the line × tester system, consisting in the crossing of each parental line with all testers. Statistical analysis of data obtained as a result of this crossing is not difficult when it refers to one character or many characters treated independently (Singh, Chandhary 1979; Kaczmarek et al. 1984, 1986). Due to the fact that in genetic and breeding experiments characters under observation are to a bigger or lesser extent correlated, it is advisable for a proper interpretation of the obtained results to perform statistical analysis utilizing multivariate methods. The multidimensional approach to the analysis of line × tester experiments was presented by Kaczmarek and Krajewski (1994, 1996), Marciniak et al. (2003), as well as Kaczmarek et al. (2005). The applied methods are founded on the general multivariate model of observations, discussed e.g. by Caliński and Kaczmarek (1973) and Morrison (1976). The multivariate analysis of variance (MANOVA) is also based on it.

The aim of this study was to apply these methods to estimate combining ability of doubled haploid lines of winter rape based on the experiment with line × tester hybrids and the selection of the best lines and pairs of lines and testers.

Materials and methods

In order to perform multidimensional (multi-character) estimation of the effects of general and specific combining ability of parental lines, line × tester system crossing was performed. Experimental material consisted of F_1 hybrids obtained as a result of crossing 7 DH lines [O-120 (L1), H2-26 (L2), W-15 (L3), MR-5 (L4), H3-2 (L5), H6-55 (L6), B21 (L7)] of winter rape with 4 testers. Tested lines came from different suppliers. Selected testers included a high-yielding variety Lisek (T1) and three DH lines differing in at least one different character; line DH H5-105 (T2) had short siliquae, DH L-59 (T3) was a partly yellow-seeded line, whereas DH A1-2 (T4) was a line with high oil content. Plant material for this experiment included selected DH lines which were obtained from isolated microspores of different F_1 hybrids of winter oilseed rape (Cegielska-Taras et al. 2002).

The experiment with 39 genotypes (apart from 28 F_1 hybrids there were 7 DH lines and 4 testers) was conducted in a randomized complete block design with three replications.

Observations resulting from the field experiment concerned the following yield structure characters: silique length, number of seeds per silique, number of branches, number of siliquae per plant, thousand seed weight and oil content in seeds. They were analyzed using multivariate analysis of variance, which facilitated testing the general hypotheses of no differences between vectors of GCA and SCA effects in DH lines and testers, as well as hypotheses concerning established contrasts between them. The significance of uni- and multivariate effects of general combining ability for doubled haploid lines and testers, as well as for specific combining ability for pairs of DH lines and testers was tested. The above mentioned hypotheses were verified using a simultaneous testing procedure described by Caliński et al. (1979).

Due to the multi-character nature of GCA and SCA effects, Mahalanobis distance was proposed and tested as a measure of similarity between parental forms. The additional application of analysis of the canonical varietes made it possible to find on the plane the graphic dispersion of lines, testers and pairs of lines and testers characterized by multivariate effects of combining ability.

Results

Arithmetic means from 3 replications for individual characters and hybrids are given in Table 1. Starting the analysis of the results of the described line × tester experiment, firstly it is necessary to determine the “discrimination power” of individual characters. This power, expressed by the values of *F* statistics in terms of the general and specific combining ability of DH lines and testers, is presented in Table 2. It is clearly evident from the Table that the characters most effectively differentiating lines and testers are the number of seeds and the silique length, while the least discriminating character is oil content.

Table 1

Mean values of yield structure characters and oil contents in F_1 line × tester hybrids of winter rape — *Wartości średnie cech struktury plonu i zawartości tłuszczu mieszańców F_1 linia × tester rzepaku ozimego*

DH Lines *Linie DH*	Testers *Testery*	Traits — *Cecha*					
		length of silique *długość łuszczyny* (cm)	number of seeds per silique *liczba nasion w łuszczynie*	number of branches per plant *liczba rozgałęzień na roślinie*	number of siliquae per plant *liczba łuszczyn na roślinie*	TSW *MTN* (g)	oil content *zawartość tłuszczu* (%)
L1 O-120	Lisek	8.93	25.10	7.67	107.40	4.93	43.63
	H5-105	9.20	27.43	7.87	127.60	5.03	44.47
	L-59	8.93	27.97	7.60	128.73	4.53	44.37
	A1-2	9.70	24.90	6.57	84.40	4.60	46.57
L2 H2-26	Lisek	8.70	24.10	8.87	116.60	5.07	45.63
	H5-105	7.77	17.33	8.53	163.67	5.50	44.77
	L-59	6.43	14.67	8.07	135.73	4.83	45.77
	A1-2	5.40	12.20	6.00	69.60	4.37	45.20
L3 W-15	Lisek	7.93	24.63	9.07	131.27	5.03	43.23
	H5-105	8.43	24.37	9.00	170.67	5.13	45.40
	L-59	8.07	25.77	10.67	189.67	4.83	45.30
	A1-2	8.30	23.87	8.93	144.13	4.73	45.80
L4 MR-5	Lisek	9.07	26.60	9.20	150.40	5.10	46.37
	H5-105	7.33	16.10	8.87	176.00	6.50	44.63
	L-59	5.93	13.63	7.50	113.27	4.87	44.37
	A1-2	8.93	26.23	9.20	178.13	4.53	45.83
L5 H3-2	Lisek	8.30	25.53	7.73	131.13	4.97	45.40
	H5-105	7.53	15.43	7.47	144.07	6.23	45.07
	L-59	7.03	16.70	5.93	107.10	5.07	44.57
	A1-2	8.73	23.43	7.53	117.87	4.47	46.13
L6 H6-55	Lisek	9.83	29.63	9.07	151.93	4.87	44.10
	H5-105	9.47	27.93	8.27	153.20	5.05	44.63
	L-59	8.80	23.77	7.20	113.87	4.53	45.57
	A1-2	9.60	26.87	7.93	135.93	4.53	46.67
L7 B-21	Lisek	9.43	27.57	9.67	171.30	4.90	45.10
	H5-105	8.03	21.40	7.73	117.93	4.97	44.30
	L-59	8.90	27.07	6.37	104.93	4.50	45.03
	A1-2	8.07	24.13	6.80	108.07	4.70	44.60

Table 2

Discrimination power of traits expressed by *F*-statistic values with regard to general (GCA) and specific (SCA) combining ability of DH lines and testers — *Moc dyskryminacyjna cech wyrażona wartościami statystyki F ze względu na ogólną (GCA) i specyficzną (SCA) zdolność kombinacyjną linii DH i testerów*

Traits *Cechy*	*F*-statistic value— *Wartość statystyki F*		
	GCA lines DH *linie DH*	GCA testers *testery*	SCA lines DH and testers *linie DH i testery*
Length of silique — *Długość łuszczyny*	22.42	13.12	5.72
Number of seeds per silique *Liczba nasion w łuszczynie*	33.02	21.22	7.84
Number of branches *Liczba rozgałęzień*	9.01	8.21	2.81
Number of siliquae per plant *Liczba łuszczyn na roślinie*	5.08	5.02	2.69
Thousand seeds weight *Masa tysiąca nasion*	3.68	25.29	2.21
Oil content — *Zawartość tłuszczu*	1.14	7.39	2.81
Critical values for $F_{0.05}$ *Wartość krytyczna dla* $F_{0,05}$	3.26	4.33	2.34
Critical values for $F_{0.01}$ *Wartość krytyczna dla* $F_{0,01}$	4.16	5.78	2.83

Estimates and testing results for the significance of effects in case of general combining ability of DH lines for individual characters and all characters jointly are presented in Table 3. Multidimensional GCA effects turned out to be highly significant for all lines. Among analyzed DH lines the following need to be distinguished. Line L3, exhibiting positively significant effects of general combining ability for three yield structure characters: number of seeds per silique, number of branches and number of siliquae per plant, but non-significant effects for the other characters, as well as line L6, exhibiting positive GCA effects for silique length, number of seeds per silique and number of siliquae per plant. Lines L1, L4 and L5 showed a significant positive combining ability for some characters and a negative combining ability for others. Among them, line L4 needs to be mentioned, as it exhibits a significant and positive estimate of GCA for the number of branches, number of siliquae per plant and thousand seed weight. Unfortunately, in terms of silique length and the number of seeds per silique the GCA effect turned out to be significantly negative. Line L7, in which for most characters no significant GCA effects were found, has proved to be a line with an average multidimensional general combining ability. The number of seeds per silique,

Table 3

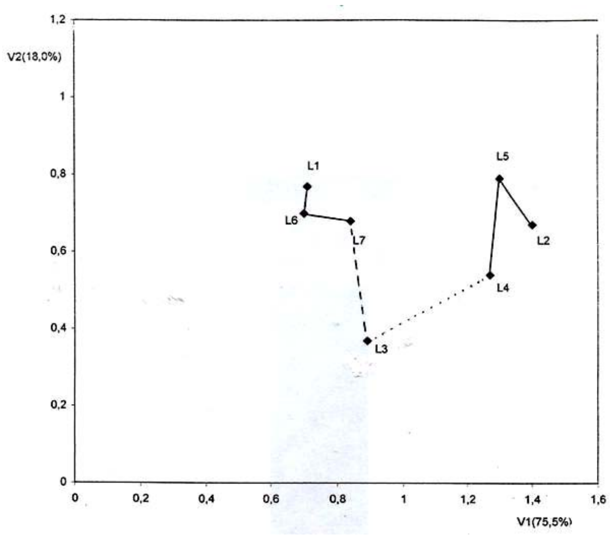
Multivariate effects of general combining ability (GCA) of DH lines for yield structure characters — *Wielowymiarowe efekty ogólnej zdolności kombinacyjnej (GCA) linii DH dla cech struktury plonu*

Lines DH *Linie DH*	Estimation of effects of GCA — *Efekty ogólnej zdolności kombinacyjnej*						
	length of silique *długość łuszczyny* (cm)	number of seeds per silique *liczba nasion w łuszczynie*	number of the branches per plant *liczba rozgałęzień na roślinie*	number of siliquae per plant *liczba łuszczyn na roślinie*	TSW *MTN* (g)	oil content *zawartość tłuszczu* (%)	*F*-statistic value *Wartość statystyki F*
L1 O-120	0.88**	3.34**	-0.63*	-21.69**	-0.17	-0.33	12.53
L2 H2-26	-1.24**	-5.94**	-0.18	-12.33	0.00	0.26	17.90
L3 W-15	-0.13	1.64*	1.37**	25.20**	-0.01	-0.15	10.97
L4 MR-5	-0.49**	-2.37**	0.64**	20.72**	0.31**	0.22	9.23
L5 H3-2	-0.41**	-2.74**	-0.88**	-8.69	0.24**	0.21	11.65
L6 H6-55	1.11**	4.04**	0.07	5.0**	-0.19	0.16	12.16
L7 B-21	0.30	2.03**	-0.41	-8.17	-0.17	-0.33	4.48
Critical values for simultaneous testing *Wartości krytyczne testowania równoczesnego*							$F_{0.05}$ = 3.39 $F_{0.01}$ = 4.32

* GCA effect significant at $\alpha = 0.05$ — *efekt GCA istotny na poziomie* $\alpha = 0{,}05$

** GCA effect significant at $\alpha = 0.01$ — *efekt GCA istotny na poziomie* $\alpha = 0{,}01$

higher than the total mean, is an exception here. Similarities and differences between DH lines due to their multi-character effects of general combining ability are well illustrated by Fig. 1, presenting the dispersion of lines, described by multidimensional GCA effects, on a plane in the system of the first two canonical variates. The Table of Mahalanobis distances for individual pairs of DH lines calculated in terms of their multidimensional GCA effects (Table 4) and the dendrite plotted in Fig. 1 linking the closest DH lines (in terms of these effects), makes it possible also in this approach to distinguish line L3 as the one for which the multi-character GCA effect is significantly different from GCA effects of the other lines. Table 5 gives estimates and testing results of GCA effects for testers. The multidimensional GCA effect of each tester proved to be highly significant. Of the four testers, a high-yielding cv. Lisek, of which GCA effects for three yield structure characters were positive and significant, and for the other characters –



---- lines are different at the level of α = 0.05 — *linie różnią się na poziomie* α *= 0,05*
...... lines are different at the level of α = 0.01 — *linie różnią się na poziomie* α *= 0,01*

Fig. 1. Representation of multivariate GCA effects of DH lines in the system of two first canonical variates — *Rozmieszczenie linii DH, opisanych wielowymiarowymi efektami GCA, w układzie dwóch pierwszych zmiennych kanonicznych*

Table 4

Mahalanobis distances between DH lines as a measure of their similarities with regard to multivariate effects of GCA — *Odległości Mahalanobisa między liniami DH, będące miarą ich podobieństwa pod względem wielowymiarowych efektów GCA*

Line DH — *Linia DH*	L1	L2	L3	L4	L5	L6
L2	5.17**					
L3	3.23**	4.47**				
L4	4.44**	2.01	3.20**			
L5	4.38**	1.78	4.36**	1.86		
L6	1.14	5.33**	2.93**	4.35**	4.52**	
L7	1.18	4,24**	2.35*	3.52**	3.60**	1.61

* distance significant at α = 0.05 — *odległość istotna na poziomie* α *= 0,05*
** distance significant at α = 0.01 — *odległość istotna na poziomie* α *= 0,01*

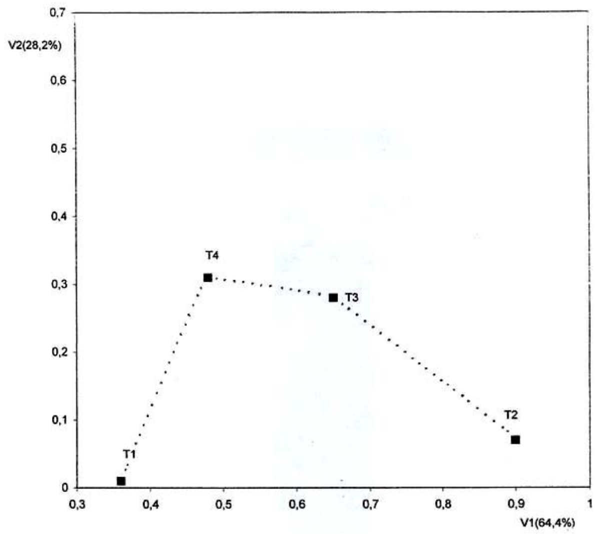
Table 5

Multivariate effects of general combining ability (GCA) of testers for yield structure characters
Wielowymiarowe efekty ogólnej zdolności kombinacyjnej (GCA) testerów dla cech struktury plonu

Testers *Testery*	Estimation of effects of GCA — *Efekty ogólnej zdolności kombinacyjnej*						
	length of silique *długość łuszczyny* (cm)	number of seeds per silique *liczba nasion w łuszczynie*	number of branches per plant *liczba rozgałęzień na roślinie*	number of siliquae per plant *liczba łuszczyn na roślinie*	TSW *MTN* (g)	oil content *zawartość tłuszczu* (%)	*F*-statistic value *Wartość statystyki F*
T1 cv Lisek	0.57**	3.16**	0.70**	3.42	0.04	-0.30**	18.09
T2 DH H5–105	-0.06	-1.58**	0.15	16.72**	0.55**	-0.33**	21.87
T3 DH L-59	-0.58**	-1.04**	-0.44*	-6.12	-0.20**	-0.09	6.41
T4 DH A1–2	0.08	0.08	-0.48**	-14.00**	-0.38**	0.74**	8.95
	Critical values for simultaneous testing *Wartości krytyczne testowania równoczesnego*						$F_{0.05} = 3.07$ $F_{0.01} = 3.99$

* GCA effect significant at α = 0.05 — *efekt GCA istotny na poziomie α = 0,05*
** GCA effect significant at α = 0.01 — *efekt GCA istotny na poziomie α = 0,01*

close to zero, turned out to be the best component for crossing. In this respect the significantly lower and negative estimate of the effect for oil content turned out to be an exception. Tester T2, with significant GCA effects for the number of siliquae per plant and thousand seed weight and the number of seeds significantly lower than the mean, proved to be a tester of interest. Negative GCA effects, significant almost for all characters, were observed in a yellow-seeded DH line DH L-59 (T3). Moreover, high oil content in line DH A1-2 (tester T4) was also confirmed, at the simultaneous negative or close to zero estimates of general combining ability for the other characters. The dispersion of testers, characterized by multidimensional effects of general combining ability, in the system of the first two canonical varietes is presented in Fig. 2. A considerable scatter of points presenting testers on a plane and significant Mahalanobis distances (Table 6) for pairs closest in terms of multi-character GCA effects justifies the selection made due to the wide range of their phenotypic diversity.



lines are different at the level of α = 0.01 — *linie różnią się na poziomie α = 0,01*

Fig. 2. Representation of multivariate GCA effects of testers in the system of two first canonical variates — *Rozmieszczenie testerów, opisanych wielowymiarowymi efektami GCA, w układzie dwóch pierwszych zmiennych kanonicznych*

Table 6

Mahalanobis distances between testers as a measure of their similarities with regard to multivariate effects of GCA — *Odległości Mahalanobisa między testerami będące miarą ich podobieństwa pod względem wielowymiarowych efektów GCA*

Tester — *Tester*	T1	T2	T3
T2	3.99**		
T3	3.01**	2.56**	
T4	2.58**	3.53**	1.84**

** distance significant at α = 0.01 — *odległość istotna na poziomie α = 0,01*

Table 7 lists multidimensional estimates of effects of specific combining ability (SCA) for 28 pairs of lines and testers. Significance of individual estimates of SCA effects and multidimensional SCA effects were tested by calculating values of the *F* statistic and giving appropriate critical values (with significant effects being marked with asterisks). Taking into consideration all characters jointly, i.e. estimated multidimensional SCA effects, the following pairs of lines and testers may be distinguished: pair L4 and T1 with positive and significant SCA estimates for three characters, i.e. silique length, number of seeds per silique and oil content, and non-significant estimates of the other characters, pair L4 and T4 exhibiting positive and significant values of four morphological characters, as well as pair L3

Table 7

Multivariate effects of specific combining ability (SCA) of DH lines and testers for the yield structure characters — *Wielowymiarowe efekty specyficznej zdolności kombinacyjnej (SCA) par linii i testerów dla cech struktury plonu*

Lines DH *Linie DH*	Testers *Testery*	Estimation effects of SCA — *Efekty specyficznej zdolności kombinacyjnej*						
		length of silique *długość łuszczyny* (cm)	number of seeds per silique *liczba nasion w łuszczynie*	number of branches per plant *liczba rozgałęzień na roślinie*	number of siliques per plant *liczba łuszczyn na roślinie*	TSW *MTN* (g)	oil content *zawartość tłuszczu* (%)	*F*-statistic value Wartość statystyki F
L1 O-120	Lisek	-0.83**	-4.40**	-0.46	-8.04	0.12	-0.82*	4.08
	H5-105	0.07	2.67*	0.24	-1.14	-0.29	0.04	3.18
	L-59	0.33	3.26**	0.60	22.82	-0.04	-0.30	2.84
	A1-2	0.43	-1.53	-0.38	-13.63	0.20	1.07**	5.26
L2 H2-26	Lisek	1.05**	3.87**	0.29	-8.21	0.09	0.60	4.25
	H5-105	0.75**	1.84	0.46	25.54*	0.01	-0.24	1.79
	L-59	-0.05	0.76	0.63	20.44	0.10	0.52	1.16
	A1-2	-1.75**	-4.95**	-1.39**	-37.79**	-0.19	-0.88*	8.77
L3 W-15	Lisek	-0.82**	-3.18**	-1.05*	-31.07*	0.06	-1.39**	4.37
	H5-105	0.31	1.28	-0.62	-4.97	-0.35*	0.80*	1.69
	L-59	-0.47	2.75*	1.68**	36.85**	0.10	0.46	4.18
	A1-2	0.04	-0.86	0.00	-0.79	0.18	0.11	0.66
L4 MR-5	Lisek	0.68*	2.80*	-0.20	-7.45	-0.19	1.37**	3.35
	H5-105	-0.42	-2.96**	-0.03	4.83	0.70**	-0.33	6.31
	L-59	-1.30**	-5.36**	-0.76	-35.06**	-0.18	-0.84*	5.69
	A1-2	1.04**	5.51**	0.99*	37.68**	-0.33*	-0.20	8.41
L5 H3-2	Lisek	-0.17	2.10	-0.14	2. 67	-0.25	0.42	2.25
	H5-105	-0.30	-3.25**	0.10	2.31	0.50**	0.11	4.93
	L-59	-0.28	-1.92	-0.80	-11.81	0.09	-0.63	1.78
	A1-2	0.76**	3.08**	0.85*	6.82	-0.33*	0.10	4.88
L6 H6-55	Lisek	-0.16	-0.57	0.24	9.79	0.08	-0.83*	0.91
	H5-105	0.10	2.47*	-0.05	-2.24	-0.23	-0.27	2.41
	L-59	-0.04	-1.63	-0.49	-18.74	-0.01	0.42	1.43
	A1-2	0.10	-0.26	0.29	11.00	0.16	0.68	1.20
L7 B-21	Lisek	0.25	-0.62	1.32**	42.32**	0.10	0.65	3.17
	H5-105	-0.50	-2.05	-0.11	-24.32*	-0.35*	0.12	1.99
	L-59	0.87**	3.67**	-0.85*	-14.50	-0.06	0.37	3.07
	A1-2	-0.61*	-0.98	-0.36	-3.48	0.31	-0.90*	2.52
	Critical values for simultaneous testing *Wartości krytyczne testowania równoczesnego*							$F_{0.05} = 2.34$ $F_{0.01} = 2.83$

* SCA effect significant at $\alpha = 0.05$ — *efekt SCA istotny na poziomie $\alpha = 0,05$*

** SCA effect significant at $\alpha = 0.01$ — *efekt SCA istotny na poziomie $\alpha = 0,01$*

and T3 with a high and significant number of seeds per silique, number of branches and number of siliquae per plant. Moreover, interesting hybrids were produced by crossing line L2 with testers T1 and T2. Estimates of SCA effects for silique length and the number of seeds per silique were positive and significant for the first combination, while for silique length and the number of siliquae per plant – for the second combination. For thousand seed weight, combinations of lines L4 and L5 with tester T2 proved to be advantageous in terms of SCA effects, whereas for oil content such were combinations of pairs L4 and T1, L1 and T4, as well as L3 and T2. Combinations of L6 and T4, L7 and T1, as well as L2 and T1 exhibited high, although non-significant SCA estimates for oil content.

Conclusions

1. The line × tester crossing system has proved to be fully suitable for the estimation and selection of DH lines exhibiting the best parameters of analyzed yield structure characters.
2. The multidimensional approach to the estimation of genetic and breeding parameters provided an additional, comprehensive estimation of effects of general and specific combining ability for lines and testers.
3. The simultaneous application in the study of different uni- and multi-variate methods of analysis to a considerable degree increases the reliability of testing results.
4. Statistical analysis of DH lines has made it possible to distinguish unambiguously line DH W15 (L3) with especially advantageous values of the following characters: number of seeds per silique, number of branches and number of siliques per plant, as well as line DH H6-55 (L6), additionally exhibiting the longest siliques. In terms of oil content none of the DH lines has diverged significantly from the mean value.
5. Among pairs of lines and testers the most advantageous combinations have appeared to be those of lines L3 and L4, i.e. L4 × T1, L3 × T3 and L4 × T4, with significant multidimensional SCA effects and at least three positive and significant effects of individual yield structure characters. In this respect, thousand seed weight is an exception. In terms of this character the first two pairs are found in the group of means and the third pair significantly diverges from the mean.

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