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Genetic parameters assessment of siliquae associated with stress indices in rapeseed cultivars

Ocena parametrów genetycznych łuszczyn roślin w odniesieniu do wskaźników stresu w odmianach rzepaku

Summary. The objective of the present study was to determine the genetic control and heritability of siliquae per plant at two places including without and application of nitrogen (Pp and Ps) and its related stress tolerance indices based on half diallel crosses of six spring rapeseed varieties. Significant mean squares of general combining ability (GCA) were detected for Pp and Ps and also the other related stress indices except tolerance index (TOL) and stress susceptibility index (SSI), indicating the importance of additive genetic effect. Significant mean squares of specific combining ability (SCA) were observed for all the studied traits except TOL indicating the importance of non additive genetic effects for them. Low narrow sense heritability estimates for Pp and Ps and also other associated stress indices except geometric productivity (GMP) indicated the prime importance of non additive genetic effects for these traits except GMP. Most of the crosses had significant SCA effects of siliquae per plant at non application of nitrogen condition, therefore selection of combinations based on SCA effect of Ps will be more efficient than SCA effect of Pp. The variations of SCA effects of the crosses for mean productivity (MP) and GMP are higher than the other stress indices, so selection of the crosses based on this two stress indices will have sufficient gain. High parent heterosis effects of TOL, STI and SSI were more variated than SCA effects, therefore selection based on high parent heterosis effects will be more efficient than SCA effects.

Key words: diallel, heterosis, heritability, rapeseed, SCA

INTRODUCTION

Oil seeds are the second source of world food after cereals and according to FAO statistics, rapeseed is the third source of vegetable oil after soybean and palm [FAO 2010]. Seed yield is a quantitative trait, which is largely influenced by the environment and hence has a low heritability [Brandle and McVetty 1989, Downey and Rimer 1993]. In segregating generations, selection based on single plant yield is not reliable and therefore having index selection based on other yield components is undeniable. Among yield components of rapeseed, siliquae per plant has important effect on seed yield and in the various studies [Angadi *et al.* 2003, Morrison and Stewart 2002, Gan *et al.* 2004] were reported significant positive correlation between this trait and seed yield. Counts of flowers and siliquae are useful to breeders and plant physiologists in understanding the reproductive efficiency of the crop [Coffelt *et al.* 1989]. Determination of final siliqua number is the net result of the processes of their initiation, achievement of a maximum number and siliqua abortion [Faraji 2010].

A number of investigations showed that nitrogen fertilizers gave substantial rapeseed yield increases even in diverse and contradicting conditions [Maroni *et al.* 1994, Sieling and Christen 1997]. However, fertilizer nitrogen requirements can differ significantly according to soil type, climate, management practice, timing of nitrogen application and cultivars used [Kalkafi *et al.* 1998, Fageria and Baligar 2005, Rathke *et al.* 2005]. Nitrogen increases yield by influencing on many traits such as branches per plant, buds per plant number of flowering branches, total plant weight, seeds per siliqua, number and weight of siliquae and seeds per plant [Grant and Bailey 1993, Rathke *et al.* 2005]. A great variation in nitrogen uptake in rapeseed has been reported [Holmes 1980].

Significant general and specific combining ability (GCA and SCA) effects were reported for yield and its components, indicating that both additive and non-additive gene action were important in the inheritance of these traits [Amiri-Oghana *et al.* 2009, Brandle and McVetty 1989, Cheema and Sadaqat 2004, Cho and Scott 2000]. Changes in environment influence on gene effects for different traits contributing to yield or yield itself changes in rapeseed (*B. napus* L.), therefore for different environment one has to suggest different selection criteria for the improvement in the yield [Cheema and Sadaqat 2004, Thakur and Sagwal 1997]. In order to obtain selection criteria based on stress and non-stress environments, some selection criteria including geometric productivity (GMP), stress intensity (SI) [Fisher and Maurer 1978], stress tolerance index (STI) [Fernandez 1992], mean productivity (MP) and tolerance index (TOL), [Rosielle and Hamblin 1981] were defined. The range of SI estimates are between zero and one and the larger value of SI, indicates the more severe of stress intensity. A larger value of TOL represents relatively more sensitivity to stress, thus a smaller value of TOL is favored. The higher value of MP, GMP and STI for a genotype indicates its stress tolerance and yield potential [Saba *et al.* 2001].

Although genetic designs i.e. diallel and line x tester analyses are frequently used to assess genetic parameters for yield associated traits in rapeseed but in a few studies were focused on nitrogen deficiency stress effects and its stress indices. The objectives of this study were therefore (I) to identify general and specific combining abilities for nitrogen deficiency stress indices among a set of adapted cultivars and (II) relationship among nitrogen stress tolerance indices and siliquae per plant of rapeseed cultivars and their F_2 progenies at nitrogen application (N_+) and non application of nitrogen (N_0) environments.

MATERIALS AND METHODS

Six spring cultivars of rapeseed (*B. napus* L.) including RGS003, Option500, RW008911, RAS-3/99, 19H and PF7045/91 were crossed in half diallel fashion during 2004–2005. In order to produce F_2 progenies, fifteen F_1s were selfed at Biekol Agriculture Research Station, located in Neka, Iran (53°13′ E longitude and 36°43′ N latitude, 15 m above sea level) during winter 2005–2006. Fifteen F_2 progenies along with 6 parents were grown in a randomized complete block design with four replications at two places including Place 1: Dashtenaz Agriculture Research Station, located in Sari, Iran (52°11′ E longitude and 35°37′ N latitude, 10.5 m above sea level) without nitrogen application as stress condition (N_0) and place 2: Biekol Agriculture Research Station with nitrogen application (N_+: 150 kg nitrogen per hectare) as non stress condition during 2006–2007. The plots related to each experiment were consisted of four rows 5 m long and 40 cm apart. The distance between plants on each row was 5 cm resulting in approximately 400 plants per plot, which were sufficient for F_2 genetic analysis in each experiment. The soil was classified as a deep loam soil (Typic Xerofluents, USDA classification) for two environments and contained an average of 260 g clay kg^{-1}, 521 g silt kg^{-1}, 145 g sand kg^{-1}, and 19.6 g organic matter kg^{-1} with a pH of 6.8 at Place 1 and also contained an average of 280 g clay kg^{-1}, 560 g silt kg^{-1}, 160 g sand kg^{-1}, and 22.4 g organic matter kg^{-1} with a pH of 7.3 at Place 2. Soil samples were found to have 33 and 45 kg ha^{-1} (mineral N in the upper 30-cm profile for Place 1 and place 2, respectively). Fertilized experiment (N_+) received 150 kg ha^{-1} N as Urea (50 kg N at planting time, beginning of stem elongation, and at initial of flowering stage) while unfertilized experiment (N_0) received no N. All the plant protection measures were adopted to make the crop free from insects. Siliquae per plant was measured based on 10 randomly selected plants in each plot.

The stress tolerance indices were determined using the equations including stress intensity: SI = 1-(µs/µp), tolerance index: TOL = Pp-Ps, stress susceptibility index: SSI = [1-(Ps/Pp)]/SI, stress tolerance index: STI = $(Pp.Ps)/(Pp)^2$, mean productivity: MP = (Ps + Pp)/2 and geometric mean productivity: GMP = $(Ps.Pp)^{0.5}$, respectively. Ys and Yp are the mean yield of all genotypes per trial under stress and non-stress conditions and also µs and µp are the mean yield of all genotypes per trial under stress and non-stress conditions.

Analysis of variance for the crosses and their parents was based on Griffing's method 2, model 1 for fixed genotypes [Griffings 1956]. The analysis was performed using the diallel-SAS program written by Zhang and Kang [1997]. A *t*-test was used to test whether the GCA and SCA effects were different from 0. For each hybrid and each stress tolerance index, the difference between hybrid and the mean of high parents was computed. A least significant difference (LSD) was used to test whether these differences were different from 0 [Kearsey and Pooni 1996].

RESULTS

Diallel analysis of variance

Significant mean square of genotypes for siliquae per plant at N_+ and N_0 (Pp and Ps) and also the other stress tolerance indices including MP, GMP, STI and SSI revealed significant genetic variation of parents and their half diallel crosses for this trait and also its associated stress tolerance indices except TOL (Table 1). Significant GCA mean square for Pp and Ps and also the other related stress indices except TOL and SSI, indicating the importance additive genetic effect and also significant SCA mean square of all the studied traits except TOL indicating the importance of non additive genetic effects for them. Low narrow sense heritability estimates for Pp and Ps and also other associated stress indices except GMP indicated the prime importance of non additive genetic effects for these traits except GMP.

Table 1. Analysis of variance for Pp and Ps , MP, GMP, TOL, STI and SSI based on Griffing's method two with mixed-B model in six parents of oil seed rape and their 15 F_2 progenies
Tabela 1. Analiza zmienności dla Pp, Ps, MP, GMP, TOL, STI i SSI w oparciu o metodę Griffinga z dwoma modelami mieszanymi B dla 6 roślin rodzicielskich rzepaku oraz 15 roślin potomnych F_2

S.O.V	df	M. S						
		Pp	Ps	MP	GMP	TOL	STI	SSI
Replication Powtórzenie	3	1057.04**	119.46**	226.26*	170.32*	1446.33**	0.03*	0.893**
Genotypes Genotyp	20	1478.50**	1382.23**	1354.46**	1364.13**	300.48	0.20**	0.304*
GCA	5	1404.01**	700.13**	964.46**	903.58**	355.70	0.12**	0.237
SCA	15	1503.32**	1609.59**	1484.46**	1517.65**	282.07	0.22**	0.326*
Error – Błąd	60	234.57	16.89	57.34	46.80	273.31	0.01	0.173
Narrow sense heritability Dziedziczność w wąskim znaczeniu		0.14	0.07	0.11	0.46	0.09	0.09	0.05

*Significant at 0.05 probability level
**Significant at 0.01 probability level
GCA – general combining ability, SCA – specific combining ability, Pp and Ps – Siliquae per plant at N_+ and N_0, respectively, MP – mean productivity, GMP – geometric mean productivity. TOL – tolerance index, STI – stress tolerance index, SSI – stress susceptibility index
*Istotne przy poziomie istotności 0,05
**Istotne przy poziomie istotności 0,01
GCA – ogólna zdolność kombinacyjna, SCA – specyficzna zdolność kombinacyjna, Pp i Ps – liczba łuszczyn na roślinę przy, odpowiednio, N_+ and N_0, MP – średnia wydajność, GMP – średnia wydajność geometryczna, TOL – wskaźnik tolerancji, STI – wskaźnik tolerancji stresu, SSI – wskaźnik podatności na stres

Table 2. Estimates of GCA effects for Pp and Ps , MP, GMP, TOL, STI and SSI in six parents of *B. napus* L.
Tabela 2. Oznaczenia efektów GDA dla Pp and Ps , MP, GMP, TOL, STI i SSI dla sześciu roślin rodzicielskich *B. napus* L.

Parents Rośliny rodzicielskie	Pp	Ps	MP	GMP	TOL	STI	SSI
1-RAS-3/99	-6.91*	-7.41**	-7.15**	-7.15**	0.51	-0.086**	0.08
2-RW008911	1.97	1.28	1.61	1.61	0.65	0.024	0.04
3-19H	-3.45	0.38	-1.53	-1.22	-3.80	-0.015	-0.10
4-RGS 003	1.06	3.09**	2.09	2.15	-2.01	0.019	-0.11
5-Option 500	-4.33	-3.13**	-3.75*	-3.65*	-1.25	-0.039*	0.01
6-PF7045/91	11.66**	5.78**	8.73**	8.25**	5.90	0.096**	0.10

*Significant at 0.05 probability level
**Significant at 0.01 probability level
Pp and Ps – siliquae per plant at N_+ and N_0, respectively, MP – mean productivity, GMP – geometric mean productivity, TOL – tolerance index, STI – stress tolerance index, SSI – stress susceptibility index
*Istotne przy poziomie istotności 0,05
*Istotne przy poziomie istotności 0,01
Pp i Ps – liczba łuszczyn na roślinę przy, odpowiednio, N_+ and N_0, MP – średnia wydajność, GMP – średnia wydajność geometryczna, TOL – wskaźnik tolerancji, ST – wskaźnik tolerancji stresu, SSI – wskaźnik podatności na stres

General combining ability effects of the parents

The result of GCA effects of parents for studied traits is presented in Table 2. PF7045/91 with significant positive GCA effect of Pp and Ps and also RGS003 with positive and significant positive GCA effect of Pp and Ps, respectively were considered as good combiner for this trait at two nitrogen application conditions. PF7045/91 with significant positive GCA effect for MP and GMP was suitable combiner for these stress tolerance indices. Non significant GCA effect was observed for TOL but the parents including 19H, RGS003 and Option500 with negative GCA effect of TOL were good combiners. Significant positive GCA effect of STI was observed for PF7045/91, so it was considered the best combiner based on this stress index. No parents had significant GCA effect for STI.

Table 3. Estimates of SCA effects for Pp and Ps , MP, GMP, TOL, STI and SSI in the half diallel crosses of six parents of *B. napus* L.
Tabela 3. Oznaczenia efektów SCA dla Pp, Ps , MP, GMP, TOL, STI i SSI w półdiallelicznych krzyżowaniach sześciu roślin rodzicielskich *B. napus* L.

Crosses Krzyżówki	**Pp**	**Ps**	MP	GMP	TOL	STI	SSI
1- RAS-3/99 × RW008911	32.41**	29.13**	30.80**	30.91**	3.34	-0.07*	0.25
2- RAS-3/99 × 19H	8.38	13.78**	11.07**	11.33**	-5.42	0.38**	-0.12
3- RAS-3/99 × RGS 003	-3.68	-3.94*	-3.82	-3.94	0.23	0.12**	-0.26
4- RAS-3/99 × Option 500	-25.81**	-20.97**	-23.37**	-23.25**	-4.81	-0.05	0.02
5- RAS-3/99 × PF7045/91	-6.48	-1.12	-3.81	-3.25	-5.38	-0.25**	-0.02
6-RW008911 × 19H	28.97**	22.10**	25.55**	25.37**	6.92	-0.05	-0.12
7-RW008911 × RGS 003	-13.01	-7.13**	-10.05**	-9.65**	-5.85	0.32**	0.04
8- RW008911 × Option 500	13.35	17.09**	15.02**	15.46**	-4.14	-0.12**	-0.14
9- RW008911 × PF7045/91	-7.36	5.44**	-0.94	0.09	-12.76	0.17**	-0.22
10-19H × RGS 003	-11.34	-11.47**	-11.42**	-11.37**	0.10	-0.01	-0.35
11- 19H × Option 500	10.88	-3.25*	3.84	3.08	14.17	-0.14**	0.12
12- 19H × PF7045/91	9.80	16.85**	13.31**	13.86**	-7.06	0.02	0.42*
13- RGS 003 × Option 500	19.94*	18.28**	19.13**	18.71**	1.70	0.18**	-0.26
14- RGS 003 × PF7045/91	5.71	1.63	3.66	3.17	4.07	0.23**	-0.14
15- Option 500 × PF7045/91	13.44	23.35**	18.42**	19.27**	-9.85	0.06	-0.01

*Significant at 0.05 probability level
**Significant at 0.01 probability level
Pp and Ps – siliquae per plant at N_+ and N_0, respectively, MP – mean productivity, GMP – geometric mean productivity, TOL – tolerance index, STI – stress tolerance index, SSI – stress susceptibility index
*Istotne przy poziomie istotności 0,05
**Istotne przy poziomie istotności 0,01
Pp i Ps – łuszczyny na roślinę przy, odpowiednio, N_+ and N_0, MP – średnia wydajność, GMP – średnia wydajność geometryczna, TOL – wskaźnik tolerancji, STI – wskaźnik tolerancji stresu, SSI – wskaźnik podatności na stres

Specific combining ability effects of the crosses

Significant positive SCA effect of Pp was observed for the crosses including RAS--3/99 × RW008911, RW008911 × 19H and RGS 003 × Option 500 (Table 3). Out of 15 crosses, 8 crosses had significant positive SCA effects of Ps. The crosses including RAS--3/99 × RW008911, Option 500 × PF7045/91, Option 500 × PF7045/91 and RW008911 × 19H with high significant positive SCA effects of Ps were detected as good combinations. Out of 15 crosses, 7 crosses showed significant positive SCA effects for MP and GMP and also most of these crosses had significant positive SCA effects of Ps. Non of combinations had significant SCA effects of TOL. Among the crosses, 19H × PF7045/91 had only significant positive SCA effect for SSI. Significant positive correlation was observed between Pp and Ps SCA effects and also their respective stress indices including MP and GMP (Table 4).

Table 4. Pearson correlation coefficient among SCA effects of crosses and also among their high parent heterosis effects for siliquae per plant at N_+ (Pp), and N_0 (Ps) and the other stress tolerance indices

Tabela 4. Wskaźnik korelacji Pearsona dla efektów SCA krzyżówek oraz ich wskaźników heterozji dla liczby łuszczyn na roślinie przy N_+ (Pp), i N_0 (Ps) oraz inne wskaźniki tolerancji na stres

	SCA							Heterosis/Heteroza						
	Pp	Ps	MP	GMP	TOL	STI	SSI	Pp	Ps	MP	GMP	TOL	STI	SSI
Pp	1							1						
Ps	0.91**	1						0.76**	1					
MP	0.97**	0.97**	1					0.95**	0.91**	1				
GMP	0.97**	0.97**	0.99**	1				0.93**	0.94**	0.99**	1			
TOL	0.42	-0.01	0.22	0.19	1			0.42	-0.21	0.13	0.08	1		
STI	-0.11	0.01	-0.05	-0.05	-0.27	1		0.92**	0.94**	0.99**	0.99**	0.05	1	
SSI	0.23	0.25	0.25	0.25	0.01	-0.26	1	0.09	-0.43	-0.16	-0.20	0.90**	-0.23	1

**Significant at 0.01 probability levels

Pp and Ps – Siliquae per plant at N_+ and N_0, respectively, MP – mean productivity, GMP – geometric mean productivity, TOL – tolerance index, STI – stress tolerance index and SSI – stress susceptibility index

**Istotne przy poziomie istotności 0.01

Pp i Ps – liczba łuszczyn na roślinę przy, odpowiednio, N_+ and N_0, MP – średnia wydajność, GMP – średnia wydajność geometryczna, TOL – wskaźnik tolerancji, STI – wskaźnik tolerancji stresu, SSI – wskaźnik podatności na stres

High parent heterosis effects

Out of 15 combinations, 4 and 10 crosses 00, had significant positive high parent heterosis effects for Pp and Ps, respectively (Table 5). The crosses including RAS-3/99 × RW008911, RW008911 × 19H, RW008911 × Option 500 and 19H × Option 500 with significant positive high parent heterosis effects for Pp and Ps were considered as merit combinations. MP and GMP were the same indicators with regard to nitrogen deficiency stress. The crosses including RAS-3/99 × RW008911, RW008911 × 19H and RW008911 × Option 500 with significant positive high parent heterosis effects for MP and GMP were good combiners. The crosses including RAS-3/99 × PF7045/91, RW008911 × PF7045/91, 19H × PF7045/91 and Option 500 × PF7045/91 displayed significant negative high parent heterosis effects for TOL and therefore were considered as suitable combinations. Out of 15 combinations, 8 crosses had significant positive high parent heterosis effects for STI and the crosses including RW008911 × 19H, RAS-3/99 × RW008911, RW008911 × Option 500 and Option 500 × PF7045/91 were five best combinations for STI. The crosses including 19H × PF7045/91, Option 500 × PF7045/91, RW008911 × PF7045/91, RGS 003 × PF7045/91 and with significant negative high parent heterosis effects for TOL were suitable combinations. Significant positive correlation was observed between Pp and Ps heterosis effects and also their respective stress indices except SSI and TOL (Table 4).

Table 5. High parent heterosis estimates for Pp and Ps, MP, GMP, TOL, STI and SSI in 15 F_2 progenies of *B. napus* L.
Tabela 5. Wskaźnik heterozji dla Pp i Ps , MP, GMP, TOL, STI i SSI u 15 roślin potomnych *B. napus* L.

Crosses Krzyżówki	Pp	Ps	MP	GMP	TOL	STI	SSI
1- RAS-3/99 × RW008911	43.70**	46.25**	44.98**	45.56**	-3.04	0.57**	-0.47
2- RAS-3/99 ×x 19H	14.25	25.00**	22.13**	23.16**	-15.75	0.27**	-0.70*
3- RAS-3/99 × RGS 003	-12.84	-15.75**	-14.31**	-14.79**	-8.31	-0.18**	-0.42
4- RAS-3/99 × Option 500	-20.83	-8.25**	-14.54**	-13.86**	-12.58	-0.13	-0.36
5- RAS-3/99 × PF7045/91	-17.50	8.75**	-4.38	-2.08	-26.25*	-0.03	-0.69*
6-RW008911 × 19H	50.73**	42.00**	49.86**	49.33**	-3.78	0.61**	-0.50
7-RW008911 × RGS 003	-13.29	-10.25**	-11.78*	-11.75*	-14.75	-0.14*	-0.68*
8- RW008911 ×Option 500	34.23**	38.75**	36.90**	37.35**	-12.28	0.44**	-0.66*
9- RW008911 × PF7045/91	-9.50	24.00**	7.25	10.01*	-33.50**	0.13	-0.97**
10-19H × RGS 003	-17.04	-15.50**	-16.28**	-16.29**	-1.55	-0.20**	0.05
11- 19H × Option 500	27.66*	12.25**	22.59**	21.79**	10.17	0.24**	0.15
12- 19H × PF7045/91	2.25	34.50**	18.38**	20.97**	-32.25**	0.28**	-1.02**
13- RGS 003 × Option 500	13.36	10.75**	12.05*	11.36*	-0.52	0.16*	-0.42
14- RGS 003 × PF7045/91	2.66	3.00	9.06	7.73	-19.34	0.12	-0.77**
15- Option 500 × PF7045/91	5.00	37.50**	21.26**	23.94**	-32.48**	0.32**	-1.02**
LSD – NIR (α = 0.05)	21.6	5.7	10.7	9.6	23.4	0.14	0.58
LSD – NIR (α = 0.01)	28.7	7.7	14.2	12.6	31.1	0.18	0.77

*Significant at 0.05 probability level
**Significant at 0.01 probability level
Pp and Ps – Siliquae per plant at N_+ and N_0, respectively, MP – mean productivity, GMP – geometric mean productivity, TOL – tolerance index, STI – stress tolerance index, SSI – stress susceptibility index
*Istotne przy poziomie istotności 0,05
*Istotne przy poziomie istotności 0,01
Pp i Ps – liczba łuszczyn na roślinę przy, odpowiednio, N_+ and N_0, MP – średnia wydajność, GMP – średnia wydajność geometryczna, TOL – wskaźnik tolerancji, STI – wskaźnik tolerancji stresu, SSI – wskaźnik podatności na stres

DISCUSSION

Additive and non additive genetic effects were important for Pp and Ps and also other related stress indices except TOL and also for SSI non additive genetic effect had more important role. But due to low narrow sense heritability estimates for Pp and Ps and all the associated stress indices except GMP, indicated the prime importance of non additive genetic effects for this trait and related stress indices except GMP. These results are similar to the earlier finding of Saba *et.al.* [2001], who reported that due to negligible narrow- sense heritability estimates of SSI and TOL for drought tolerance, these stress indices are not useful for selection of drought tolerant genotypes in plant breeding programs. Due to significant positive correlations between siliquae per plant and seed yield at N_+ and N_0 (0.59** and 0.61**, respectively), any selection based on siliquae per plant will have important effect on seed yield. In earlier studies [Angadi *et al.* 2003, Morrison and Stewart 2002, Gan *et al.* 2004] were reported significant positive correlation between siliquae per plant and seed yield. The parent PF7045/91 had significant positive GCA effect for Pp, Ps, MP, GMP and STI, therefore these three stress indices are suitable indicators for prediction of GCA effects of siliquae per plant in stress and non stress conditions. The parents under study did not any significant variations for TOL and SSI.

Most of the crosses had significant SCA effects of siliquae per plant at N_0, therefore selection of combinations based on SCA effect of Ps will be more efficient than SCA effect of Pp. The variations of SCA effects of the crosses for MP and GMP are more than the other stress indices, so selection of the crosses based on this two stress indices will have sufficient gain. Although significant correlations of SCA effects were observed among Pp, Ps, MP and GMP but SCA effect of MP and GMP affected by Ps SCA effect than Pp SCA effect. Non of the crosses had significant SCA effects for TOL, so this stress index was not suitable indicator for SCA effects of the crosses for siliquae per plant. Most of the crosses with significant positive SCA effect of STI had at least one parent with significant positive GCA effect for Pp or Ps. Non significant correlation was observed between SCA effect of STI with Pp and Ps. Significant general combining ability (GCA and SCA) effects were reported for yield and its component characters, indicating that both additive and non-additive gene action were important in the inheritance of these traits in normal condition [Amiri-Oghana *et al.* 2009, Brandle and McVetty 1989, Cheema and Sadaqat 2004, Cho and Scott 2000].

Significant high parent heterosis effects were observed for Ps, therefore the crosses are more sustainable than parents in stress condition. Most of the crosses with significant positive high parent heterosis effects MP and GMP had also significant positive high parent heterosis effects Ps. Due to significant correlation between MP and GMP, these two stress indices are the same indicators for siliquae per plant with regard to nitrogen deficiency stress. Although non significant SCA effects of the crosses were observed for TOL but significant high parent heterosis effects were observed for this stress index. Significant positive correlation was observed between Pp and Ps heterosis effects and also their respective stress indices except SSI and TOL, therefore selection based on SSI and TOL for siliquae per plant will have less efficiency than other stress tolerance indices. High parent heterosis effects of TOL, STI and SSI of were more variated than SCA effects. In earlier research [Rezai and Saeidi 2005] was reported significant GCA, SCA and high parent heterosis effects for STI and TOL related to shoot dry weight of rapeseed in early stage of growth.

CONCLUSIONS

Due to significant positive correlations between siliquae per plant and seed yield at N_+ and N_0, any selection based on siliquae per plant will have important effect on seed yield. Among the stress tolerance indices for siliquae per plant, GMP was more heritable than the others. Most of the crosses with significant positive SCA effect of STI had at least one parent with significant positive GCA effect for Pp or Ps. The crosses had more significant high parent heterosis effects than SCA effects for all of the stress indices. Most of the crosses displayed significant SCA and high parent heterosis effects for Ps than Pp. Although correlation Pp and Ps with STI were not significant for SCA effect but for high parent heterosis effects they were significant.

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Streszczenie. Celem badań było ustalenie metod genetycznej kontroli oraz odziedziczalności łuszczyn w dwóch stanowiskach, z zastosowaniem azotu i bez niego (Pp i Ps), oraz wskaźników tolerancji na stres na podstawie krzyżówek diallelicznych sześciu odmian rzepaku. Dla Pp i Ps, a także pozostałych wskaźników stresu stwierdzono istotne średnie kwadraty ogólnej zdolności kombinacyjnej (GCA), z wyjątkiem wskaźnika tolerancji (TOL) oraz indeksu podatności na stres (SSI), co wskazuje na znaczenie efektu genetycznego addytywnego. Istotne średnie kwadraty swoistej wartości kombinacyjnej (SCA) zaobserwowano dla wszystkich badanych cech z wyjątkiem TOL, co wskazuje na wpływ efektu genetycznego nieaddytywnego. Małe wartości odziedziczalności w wąskim znaczeniu dla Pp i Ps, a także dla innych wskaźników związanych ze stresem, z wyjątkiem wydajności geometrycznej (GMP), wskazują na duży wpływ efektów genetycznych nieaddytywnych na te cechy oprócz GMP. Większość krzyżówek wykazała znaczące efekty SCA dla łuszczyn na roślinie w warunkach niestosowania azotu. Wybór kombinacji opartych na efekcie SCA dla Ps będzie zatem lepszy niż dla Pp. Wariancje efektów SCA krzyżówek w odniesieniu do średniej wydajności (MP) oraz GMP są większe niż w przypadku pozostałych wskaźników stresu, a więc wybór krzyżówek w oparciu o te dwa wskaźniki stresu jest wystarczający. Wskaźniki heterozji dla TOL, STI oraz SSI były bardziej zróżnicowane niż efekty SCA, zatem selekcja odmianprzeprowadzona na podstawie wskaźników heterozji będzie więc bardziej skuteczna niż dla efektów SCA.

Słowa kluczowe: diallele, heterozja, dziedziczność, rzepak, SCA