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Original scientific paper

COMBINING ABILITY OF PLANT HEIGHT, SEED YIELD AND QUALITY TRAITS IN RAPESEED

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General and specific combining ability (GCA and SCA) effects of plant height, seed yield, oil and protein contents and also oil and protein yields were estimated for three testers and six lines of spring type of rapeseed using line × tester mating design. Analysis of variance for parents and crosses for all the traits indicated significant genetic variation among the parents and their F_1 offspring. Parents vs crosses mean squares, indicating average heterosis effects, were significant for all the traits except oil and protein contents. High narrow-sense heritability estimates were found for all the traits, except protein yield, indicating the prime importance of additive genetic effects. Correlation analysis based on GCA effects and means value indicating that oil percentage and seed yield had important effects on oil yield. Opt×R01, RG06×R01, RG06×R08 and RG3×R08 with 3241.91, 3213.68, 3334.28 and 3237.45 kg ha^{-1} of seed yield were merit cross combinations for improving this trait and all of these combinations had also positive SCA effect for this trait.

Keywords: genetic variation, oil content, line × tester**,** seed yield**.**

INTRODUCTION

Rapeseed (*Brassica napus* L.) is one of the most important oilseed crops cultivated in the world, ranking second in oil production after soybean. Rapeseed has high protein content, and hence defatted rapeseed meal may constitute a valuable source of proteins for human consumption (DIEPENBROCK, 2000; WANG, 2005). Seed yield of rapeseed is a quantitative trait, largely influenced by the different environmental effects and hence it has low heritability (HABEKOTTE, 1997; DIEPENBROCK, 2000; ZHANG and ZHU, 2006; WANG *et al.*, 2007; RAMEEH, 2010). In commercial rapeseed breeding programs f, general and specific combining ability effects (GCA and SCA) are important indicators of the potential of inbred lines to make superior hybrid combinations. The variances of GCA and SCA are related to the type of gene action

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involved. The variance for GCA includes the additive portion of the total variance, whereas that for SCA includes the non-additive portion of the total variance, arising largely from dominance and epistatic deviations (MALIK *et al.*, 2004; TEKLWOLD and BECKER, 2005; VARIATH *et al.*, 2009). Information and exact study of combining abilities can be useful in regard to selection of breeding methods and germplasm for hybrid crosses (NASSIMI *et al.*, 2006; WANG *et al*., 2010; RAMEEH, 2011). Most of previous studies on combining abilities have shown significant GCA and SCA effects for yield and its component characters, indicating that both, additive and non-additive gene action are important in the inheritance of these traits (YADEV *et al*., 2005; AKBAR *et al.*, 2008; HUANG *et al.*, 2010; SINGH *et al.*, 2010). Variability of results indicates that the inheritance patterns of plant traits imparting yield varies with the genetic material and the environmental conditions that suggested exploring the genetic information about the breeding material before performing selection (GAMI and CHAUHAN, 2013; RAHMAN *et al.,* 2016). Oil content is the character related closely with oil yield in rapeseed. It is known as a heritable character and it's heritability variated in different rapeseed segregating populations (WU *et al.*, 2006; ZHANG *et al.,* 2006). Many inheritance studies (SWETHA *et al.,* 2020; LAGHARI *et al.,* 2020) of this character found that it is a quantitative trait, and gene action follows additive-dominant model. However, the proportion of gene action was different depending on genetic materials used in the study. SHEN *et al.* (2002) reported that oil content was controlled by additive gene effect and dominant gene effect was not significant. Reports of DELOURME *et al*., (2006) and DONG *et al*., (2007) showed that both additive and non-additive gene effects were important for this character. Many studies showed that oil content was influenced by both gene effects and genotype × environment (GE) interaction (WU *et al.*, 2006). DONG *et al.* (2007) reported that the heritability of protein content in rapeseed was 74.21% for broad sense and 8.98% for narrow sense heritability. The inheritance of protein content in *B. napus* L. was reported by many workers (FARSHADFAR *et al.*, 2013; MEENA *et al.*, 2015; SHEHZAD *et al.*, 2015) to be controlled mostly by non- additive gene effects played a little role (DONG *et al.*, 2007). The objectives of the present study were to examine the combining ability patterns of selected canola (*B. napus* L.) genotypes in a line × tester analysis, to assess genetic parameters of plant height, seed yield, oil and protein contents using a mixed model and to identify candidates for promising hybrid combinations.

MATERIALS AND METHODS

Nine spring rapeseed (*B. napus* L.) genotypes including six lines (Opt, RW, 19H, RG06, Sarigol and RG3) and three testers (R01, R08 and R020) which have enough variation for agronomic and quality traits, were crossed based on line × tester method during 2010-11. Eighteen F_1 offspring along with their parents were planted in a randomized complete block design with three replications at Biekola Agriculture Research Station, located in Neka, Iran (53°, 13′ E longitude and 36° 43′ N latitude, 15 m above sea level) during winter 2011-12. Each plot consisted of four rows 5 m long and 40 cm apart. The distance between plants in each row was 5 cm resulting in approximately 300 plants per plot, which were sufficient for F_1 genetic analysis. The soil was classified as a deep loam soil (Typic Xerofluents, USDA classification) containing 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. Soil samples were found to have 45 kg ha^{-1} of mineral N in the upper 30-cm profile. Fertilizers were applied at the rates of 100: 50: 90 kg ha^{-1} of N: P: K, respectively. All the plant protection practices were applied. Seed yield (adjusted to kg ha^{-1}) was recorded based on two middle rows of each plot. The data were recorded on ten randomly selected plants of each entry of each replication for plant height.

Seed yield (adjusted to kg ha^{-1}) of three middle rows of each plot, was measured at the stage physiological maturity, so the yield was adjusted to 12.5% seed moisture content. Oil content was estimated with the help of nuclear magnetic resonance spectrometry (MADSON, 1976). For analysis of nitrogen content, 100 mg of dried seed was digested with sulphuric acid and o-phosphoric acid in Kjeldhal digestion unit estimated by the method of LEMAIRE and MEYNARD (1997). Data related to the studied traits were subjected to line × tester analysis (MATHER and JINKS, 1982) to estimate general combining ability (GCA) and specific combining ability (SCA). A *t*-test was used to test whether the GCA and SCA effects were significant.

RESULTS AND DISCUSSION

Analysis of variance

Significant mean squares of treatments, parents and their crosses for plant height, seed yield, oil and protein contents and also oil and protein yields, indicating sufficient genetic variations among the genotypes and their cross combinations for these traits (Table 1).

Table 1. Analysis of variance for plant height, seed yield and quality traits of rapeseed (Brassica napus L.) based on line x tester fashion.

S.O.V	Df	MS					
		Plant height	Seed yield	Oil%	Protein%	Oil yield	Protein yield
Replication	2	1158.20**	275545.04*	3.43**	8.07**	29712.16	2482.44
Treatment	26	279.34**	417220.10**	13.26**	11.24**	97707.46**	31654.29**
parents	8	428.71**	491032.4*	16.67**	15.63**	84278.64**	54624.7**
parents vs crosses	1	333.37**	2429541.7**	0.09	1.96	493860.2**	143435.5**
crosses	17	205.87**	264113.1**	12.43**	9.72**	80723.8**	14269.32*
Lines	5	499.95**	559781.39*	15.91**	13.28**	173030.02**	16981.52*
testers	2	94.46	92944.47	22.08**	24.85**	53829.94	5818.38
Line x tester	10	81.11*	150512.74	8.76**	4.91**	39949.47*	14603.41*
Error	52	35.81	97770.68	0.83	1.16	18819.92	6542.90
Heritability		0.88	0.79	0.67	0.83	0.83	0.12
line%		0.71	0.62	0.38	0.40	0.63	0.35
tester%		0.05	0.04	0.21	0.30	0.08	0.05
L x T %		0.23	0.34	0.41	0.30	0.29	0.60

*, ** Significant at p<0.05 and 0.01, respectively.

For all of the traits, variations of lines were more than testers. Parents vs crosses mean squares which indicating average heterosis effects were significant for all the traits except oil and protein contents. High narrow-sense heritability estimates were found for all the traits except protein yield, indicating the prime importance of additive genetic effects for these traits. In earlier studies (DIEPENBROCK, 2000; WANG *et al.*, 2007; RAMEEH, 2010) were reported high narrow-sense heritability estimates for some of yield components. SHEN *et al.* (2002) reported that oil content was controlled by additive gene effect and dominant gene effect was not significant. Some reports showed that both additive and non-additive gene effects were important for this character (DELOURME *et al.*, 2006; DONG *et al.*, 2007). DONG *et al.* (2007) noted that the heritability of protein content in rapeseed was 74.21% for broad sense and 8.98% for narrow sense heritability.

Means of the parents and their general combining ability estimates

The means value of the parents including lines and testers for all the traits are presented in Table 2.

Table 2. Means of parents for plant height, seed yield and quality traits of rapeseed (Brassica napus L.) based on line x tester fashion.

Parents	Plant height (cm)	Seed yield (kg ha^{-1})	Oil%	Protein%	Oil yield (kg ha^{-1})	Protein yield (kg ha^{-1})
1-R01	151.46	2559.23	45.16	22.53	1151.64	581.36
2-R08	142.03	2166.64	41.19	25.27	893.32	546.76
3-R020	143.74	2902.01	45.32	24.19	1319.07	704.15
4-Opt	133.81	2554.64	46.30	21.26	1181.00	545.14
5-RW	155.91	2934.24	40.30	26.24	1183.13	770.62
6-19H	135.33	3132.64	43.15	24.93	1352.56	779.91
7-RG06	128.84	2212.31	45.36	21.95	1002.31	486.43
8-Sarigol	116.28	1897.32	46.43	21.18	881.59	401.82
9-RGS3	142.25	2658.67	41.51	27.53	1103.89	731.98
LSD(α=0.05)	9.97	520.82	1.52	1.79	228.50	134.73
LSD(α=0.01)	13.44	702.09	2.05	2.42	308.03	181.62

Among the testers, plant height was varied from 142.3 to 151.46cm in R08 and R01, respectively and also among the lines, this trait ranged from 116.28 to 155.91cm in Sarigol and RW, respectively. R08 and RG06 with negative GCA effects for plant height will have reduction effects for this trait in their cross combinations (Table 3). Sarigol with significant positive GCA effect for plant height will have increasing effect in its crossing to other genotypes. The high means value of seed yield was belonged to 19H, RW and R020. Among the testers, R08 and also among the lines, Opt and RG06 were good combiners for breeding this trait. The high means value of oil content was found for R01, R020, Opt, RG06 and Sarigol. Opt and RG06 with significant positive GCA effects for oil content were superior combiners for improving this trait. The protein contents were varied from 22.53 to 25.27% in testers viz. R01 and R08 and also it ranged from 21.18 to 27.53% in lines in Sarigol and RGS3, respectively. R01 and Sarigol with significant positive GCA effects for protein contents were good combiners for improving this trait. The high oil and protein yields means value were belonged to R020 and 19H and both of these genotypes had high seed yield.

Table 3. Estimates of GCA effects for plant height, seed yield and quality traits of rapeseed (Brassica napus L.).

Parents	Plant height	Seed yield	Oil%	Protein%	Oil yield	Protein yield
1-R01	-0.09	-23.44	0.11	0.41*	-6.24	6.51
2-R08	-0.71	24.43	0.30	-0.37*	20.53	-5.28
3-R020	0.81	-0.99	-0.41*	-0.04	-14.29	-1.23
4-Opt	1.49	105.53*	0.34*	-0.17	55.41*	21.61*
5-RW	-0.58	-52.41	-0.34*	0.03	-32.68	-11.46
6-19H	1.79	-70.26	0.28	-0.06	-23.02	-18.72
7-RG06	-3.94**	83.72	0.43*	-0.31	49.12*	9.79
8-Sarigol	2.72*	-90.34	-0.70**	0.79**	-59.11*	0.55
9-RGS3	-1.48	23.75	-0.02	-0.27	10.28	-1.77
S.E(gca(tester)	0.92	47.91	0.14	0.17	21.02	12.39
S.E(gca(line)	1.30	67.75	0.20	0.23	29.72	17.53

*, ** Significant at p<0.05 and 0.01, respectively.

Table 4. Correlation among the traits for means of the crosses, GCA of the parents and SCA of the crosses.

Mean (n=18)						
Traits	Plant height	Seed yield	Oil%	Protein%	Oil yield	Protein yield
Plant height	1					
Seed yield	-0.22	1				
Oil%	-0.27	0.14	1			
Protein%	0.37	-0.45	0.67**	1		
Oil yield	-0.28	0.93**	0.70**	-0.60**	1	
Protein yield	0.06	0.71**	-0.09	0.31	0.51*	1
GCA (n=9)						
Traits	Plant height	Seed yield	Oil%	Protein%	Oil yield	Protein yield
Plant height	1					
Seed yield	-0.52	1				
Oil%	-0.46	0.65*	1			
Protein%	0.59	-0.68*	-0.68*	1		
Oil yield	-0.56	0.97**	0.81**	-0.73*	1	
Protein yield	0.14	0.73*	0.25	0.01	0.65*	1
SCA (n=18)						
Traits	Plant height	Seed yield	Oil%	Protein%	Oil yield	Protein yield
Plant height	1					
Seed yield	0.54*	1				
Oil%	0.19	0.09	1			
Protein%	-0.10	0.05	-0.83**	1		
Oil yield	0.47*	0.77**	0.47*	-0.31	1	
Protein yield	0.36	0.82**	-0.39	0.61**	0.43	1

*, ** Significant at p<0.05 and 0.01, respectively.

Significant positive correlation of oil yield with oil percentage and also seed yield for GCA effects and means value (Table 4) indicating both these two traits had significant roles for high means value of oil yield but for high means value of protein yields only seed yield had more important role. Most of previous studies on combining abilities have shown significant GCA effects for yield and its component characters. These results indicate that both additive and non-additive gene action are important in the inheritance of these traits (YADEV *et al.*, 2005; AKBAR *et al.*, 2008; HUANG *et al.*, 2010; SINGH *et al.*, 2010).

Means of the crosses and their specific combining ability estimates

The lowest genetic variation (0.23) of line ×tester was determined for plant height, therefore the crosses had lowest genetic diversity for this trait (Table 1). The means value of the crosses for all the traits are presented in Table 5.

Table 5. Means of crosses for plant height, seed yield and quality traits in crosses of two testers and six lines of rapeseed.

Crosses	Plant height (cm)	Seed yield (kg ha^{-1})	Oil%	Protein%	Oil yield (kg ha^{-1})	Protein yield (kg ha^{-1})
1-Opt ×R01	145.29	3241.91	46.61	24.41	1512.03	791.62
2- Opt ×R08	145.60	3075.29	47.41	21.25	1457.72	653.08
3- Opt ×R020	151.99	3407.32	40.59	25.47	1382.07	866.98
4-RW ×R01	146.42	2746.16	42.03	26.53	1154.49	728.12
5- RW ×R08	133.99	2613.95	43.62	23.21	1143.88	604.78
6- RW ×R020	143.86	2942.98	42.91	23.19	1260.60	681.14
7-19H ×R01	141.61	2302.04	43.61	25.57	1003.30	589.87
8- 19H ×R08	151.28	3003.01	45.27	24.34	1358.98	729.67
9- 19H ×R020	152.67	2837.31	45.27	22.23	1283.66	629.14
10-RG06 ×R01	128.81	3213.68	45.30	24.85	1454.31	796.80
11- RG06×R08	136.63	3334.28	46.56	21.17	1552.79	704.69
12- RG06×R020	128.54	2980.28	43.62	23.90	1288.05	703.84
13-Sarigol×R01	152.84	2636.75	42.24	26.92	1113.92	711.07
14- Sarigol×R08	145.31	2725.27	41.21	26.58	1120.84	730.12
15- Sarigol×R020	155.76	2599.69	41.85	26.27	1086.33	680.93
16-RGS3 ×R01	142.27	2986.98	45.34	24.52	1355.81	734.12
17- RGS3 ×R08	133.29	3237.45	44.57	22.21	1441.51	716.93
18- RGS3 ×R020	140.61	2764.06	41.53	23.54	1148.28	650.23
LSD(α=0.05)	9.97	520.82	1.52	1.79	228.50	134.73
LSD(α=0.01)	13.44	702.09	2.05	2.42	308.03	181.62

Due to low means value of this trait makes possible resistance to lodging, the cross combinations including RG06 ×R01, RG06 × R020, RW × R08, RG3 × R08 with 128.81, 128.54, 133.99 and 133.29cm of plant height were suitable combinations for improving this trait. RW×R08, 19H×R01 and RG06×R020 with significant negative SCA effects were preferred for improving plant height (Table 6). Opt×R020, RG06×R01, RG06×R08 and RG06×R020 with high means value of seed yield were considered as suitable combinations for improving this trait.

Opt×R01, RG06×R01, RG06×R08 and RG3×R08 with 3241.91, 3213.68, 3334.28 and 3237.45 kg ha^{-1} were considered as good combinations for improving this trait and all of these combinations had also positive SCA effect for this trait. Most of combinations with high means value of oil content had at least on parent with significant positive GCA effect for this trait. Opt×R08 had only significant positive SCA effect for oil content. Protein content ranged from 21.17 to 26.92 percentage in RG06×R08 and Sarigol×R01, respectively. Most of the crosses with high means value of protein content had at least one parent with high mean value of this trait. Opt×R020 with significant positive SCA effect for protein content was considered as good combination for improving this trait. Oil yields were varied from 1003.30 to 1552.79 kg/ha in 19H×R01 and RG06×R08, respectively. The crosses including Opt×R01, Opt×R08, RG06×R08 and RGS3×R08 with 1512.03, 1457.72, 1552.79 and 1441.51 kg ha^{-1} of oil yield had high amount of this trait. Protein yield ranged from 650.23 to 866.98 kg/ha in RG06×R020 and Opt×R020, respectively. Opt×R020 with significant positive SCA effect for protein yield was good combination. Significant positive correlation of seed yield means value with oil and protein yields means value indicating most of the genotypes with high seed yield had high amounts of these two quality traits (Table 4). This trend was justified for GCA and SCA effects. Significant SCA effect of yield and its component characters were reported in rapeseed breeding program. These results indicate that both additive and non-additive genetic effects were important in the inheritance of these traits (AKBAR *et al.*, 2008; HUANG *et al.*, 2010; SINGH *et al.*, 2010).

Table 6. Estimates of SCA effects for plant height, seed yield and quality traits in crosses of two testers and six lines of rapeseed.

Crosses	Plant height	Seed yield	Oil%	Protein%	Oil yield	Protein yield
1-Opt ×R01	-0.69	23.58	0.47	-0.18	26.71	0.51
2- Opt ×R08	-0.13	-79.84	0.54*	-0.45	-18.16	-33.88*
3- Opt ×R020	0.64	56.26	-1.02**	0.63**	-43.38	33.37*
4-RW ×R01	1.76	16.26	-0.38	0.33	-4.37	12.41
5- RW ×R08	-1.93*	-75.68	-0.05	0.00	-34.68	-16.91
6- RW ×R020	-0.01	59.42	0.43	-0.33	4.23	4.49
7-19H ×R01	-2.21*	-113.92*	-0.48	0.10	-64.43	-26.41
8- 19H ×R08	1.47	71.86	-0.12	0.46	27.36	31.99
9- 19H ×R020	0.56	42.05	0.60**	-0.56*	2.25	-5.58
10-RG06 ×R01	-0.74	35.98	-0.06	0.10	13.77	14.05
11- RG06×R08	2.31*	28.30	0.16	-0.34	19.83	-4.86
12- RG06×R020	-1.75*	-64.28	-0.10	0.24	-68.42**	-9.19
13-Sarigol×R01	0.61	17.72	0.05	-0.30	8.54	-5.28
14- Sarigol×R08	-1.45	-0.64	-0.49**	0.36	-15.93	12.87
15- Sarigol×R020	0.66	-17.08	0.44	-0.06	-27.43	-7.59
16-RGS3 ×R01	1.28	20.38	0.40	-0.05	19.78	4.72
17- RGS3 ×R08	-1.26	56.00	-0.05	-0.04	21.57	10.79
18- RGS3 ×R020	-0.19	-76.38	-0.35	0.08	-76.17	-15.50

*, ** Significant at $p<0.05$ and 0.01, respectively.

CONCLUSION

In general, significant positive correlation of oil yield with oil percentage and also seed yield for GCA effects and means value indicating both these two traits had significant roles for high means value of oil yield but for high means value of protein yields only seed yield had more important role. Significant positive correlation of SCA effects of plant height with seed and oil yields indicating the cross combinations with high SCA effects of plant height will have high SCA effects for these traits. Parents vs crosses mean squares which indicating average heterosis effects were significant for all the traits except oil and protein contents. High narrow-sense heritability estimates were found for all the traits except protein yield, indicating the prime importance of additive genetic effects for these traits except protein yield.

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KOMBINACIONA SPOSOBNOST ZA VISINU BILJKE, PRINOS ZRNA I SVOJSTVA KVALITETA KOD ULJANE REPICE

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Izvod

Opšti i specifični efekti kombinacione sposobnosti (GCA i SCA) za visinu biljke, prinos semena, sadržaja ulja i proteina kao i prinos ulja i proteina procenjeni su za tri testera i šest linija ozimog tipa uljane repice koristeći dizajn linija × tester. Analiza varijanse za roditelje i ukrštanja za sve osobine pokazala je značajnu genetsku varijaciju roditelja i njihovog F_1 potomstava. Srednji kvadrati roditelja i ukrštanja, koji ukazuju na prosečne efekte heterozisa, bili su značajni za sve osobine osim za sadržaj ulja i proteina. Pronađene su visoke procene heritabilnosti u užem smislu za sve osobine, osim prinosa proteina, što ukazuje na glavni značaj aditivnih genetskih efekata. Korelaciona analiza zasnovana na GCA efektima i srednjoj vrednosti ukazala je da su procenat ulja i prinos semena imali važan uticaj na prinos ulja. Opt × R01, RG06 × R01, RG06 × R08 i RG3 × R08 sa 3241,91, 3213,68, 3334,28 i 3237,45 kg ha-1 prinosa semena bile su pogodne kombinacije ukrštanja za poboljšanje ove osobine i sve ove kombinacije su takođe imale pozitivan efekat SCA za tu osobinu.

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