Combining ability of quantitative and qualitative traits in rapeseed (*Brassica napus* L.) varieties at two nitrogen levels

V. Rameeh

Mazandaran Agricultural and Natural Resources Research Center, Sari, Iran.
Corresponding author. E-mail: valvandi225@yahoo.com

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ABSTRACT

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The combining ability of quantitative and qualititative traits has been studied quite frequently in rapeseed (*Brassica napus* L.), but rarely at different nitrogen levels. Twenty-one genotypes, including 6 parents and their 15 F_2 diallel progenies, were evaluated at two nitrogen rates, N_0 and N_{150}. A combined analysis of variance revealed significant mean squares of general (GCA) and specific (SCA) combining abilities for all of the traits. The nitrogen × GCA mean square was not significant for all of the traits, indicating the stability of additive genetic effects in different environments. Days to end of flowering, days to maturity, oil content and oil yield had significant nitrogen × SCA mean squares, which showed significant variation of SCA effects on these traits at different nitrogen levels. Days to flowering, days to end of flowering and days to maturity showed high narrow-sense heritability at two nitrogen levels, but plant height and seed yield had high narrow-sense heritability estimates at N_0. Most of the crosses had significant positive or negative SCA effects for seed yield at N_0; however, at N_{150} only two crosses had significant SCA effects. Therefore, selection of hybrids based on SCA effects at N_0 would be more effective.

Key words: additive, diallel, GCA, environment, narrow-sense heritability, rapeseed

INTRODUCTION

Understanding of a crop's phenological characteristics, yield components and seed yield responses to diverse environments allows breeders to develop varieties that are better adapted to target production areas. A number of investigations have shown that nitrogen fertilizers substantially increase rapeseed yield even under diverse and contrasting conditions (Maroni *et al.*, 1994; Sieling and Christen, 1997). However, nitrogen fertilizer requirements differ significantly, depending on soil type, climate, management practices, timing of nitrogen application and the cultivar (Holmes and Ainsley, 1977; Kalkafi *et al.*, 1998). Great variation in rapeseed's nitrogen uptake has been reported (Holmes, 1980). Compared to cereal crops, rapeseed requires more nutrients; thus available nitrogen frequently restricts seed yield. Colnenne *et al.* (1998) proposed that rapeseed has higher critical N demand for biomass formation than wheat. While a substantial amount of N is provided when crop residues and soil organic matter are converted into soluble soil N, additional mineral N is a prerequisite for high seed yield (Rathke *et al.*, 2005).

Although most of the seed is produced by open-pollinated rapeseed cultivars, it is well known that canola has sufficient heterosis to justify efforts to developing hybrid cultivars (Sernyk and Stefansson, 1983; Grant and Beversdorf, 1985; Lefort-Buson *et al.*, 1986, 1987; Brandle and McVetty, 1989). Several systems for commercial production of F_1 hybrid seed are now available, including cytoplasmic male-sterility (CMS) systems (Buzza, 1995) and the dominant genetic male-sterility (GMS) system (Mariani *et al.*, 1990; Mariani *et al.*, 1992; Goldberg *et al.*, 1993). Many studies on heterosis in canola have been conducted on either spring types (Sernyk and Stefansson, 1983; Grant and Beversdorf, 1985; Brandle and McVetty, 1989; Diers *et al.*, 1996) or winter types (Lefort-Buson *et al.*, 1986, 1987; Ali *et al.*, 1995). Information on general and specific combining ability effects related to the phenological traits, yield components and seed yield of brassica is very important for the success of breeding programs aimed at obtaining sufficient heterosis (Ali *et al.*, 1995; Malik *et al.*, 2004). In addition, information on the nature of gene action in the expression of economically important quantitative and qualitative traits is required to develop desirable lines. Combining ability for different traits in brassica has been studied by many researchers (Amrithadevarathinam *et al.*, 1976; Sachan and Singh, 1988; Thakur and Sagwal, 1997).

Various studies on spring cultivars of rapeseed have shown flowering time to be a highly heritable trait conferred by genes that exhibit some degree of dominance (Thurling and Vijendra Das, 1979; Singh and Yadev, 1980; Lefort-Buson and Dattee, 1982a,b). Likewise, studies on winter cultivars have found that both additive and dominance gene effects play a significant role in the inheritance of flowering time (Olivieri and Parrini, 1979). Singh and Yadev (1980) showed that only non-additive gene actions were important in controlling days to maturity in oilseed rape.

Most of the studies showed significant GCA and SCA effects for yield and its components, indicating that both additive and non-additive gene actions were important in the inheritance of these traits (Cheema and Sadaqat, 2004; Thurling and Vijendra Das, 1979). Earlier breeders concluded that with the changes in environment, gene effects for different traits contributing to yield or yield itself would also change in rapeseed. Therefore, for different environments, different selection criteria should be used to improve seed yield (Cheema and Sadaqat, 2004; Thurling and Vijendra Das, 1979). For traits that are controlled by additive gene action, simple selection in early segregating generations is suggested, whereas selection in later segregating generations would be more effective for traits controlled by non-additive gene action (Cheema and Sadaqat, 2004).

Although data on F_1 diallel crosses are mostly used to estimate genetic parameters in Griffing's method (1956), with rapeseed it is usually difficult to obtain sufficient F_1 seeds, especially for multi-location testing. Due to the production of large quantities of F_2 seeds, many researchers use the F_2 generation for diallel analysis to estimate combining abilities (Cho and Scott, 2000; Kao and Mc Vetty, 1987). These researchers reported that F_2 diallel analysis provided better and more reliable information than the F_1 generation. Multi-locations testing of GCA and SCA effects and other genetic parameters will reveal the stability of these parameters when used as selection criteria (Mather and Jinks, 1982).

Although diallel analyses are frequently used in rapeseed breeding to assess general and specific combining abilities for different traits, most are conducted at high N levels. The objectives of this study were: (1) to determine whether F_2 rapeseed hybrids utilize N more efficiently than pure lines at low and high N levels; and (2) to identify general and specific combining abilities for N utilization in a set of adapted cultivars.

MATERIALS AND METHODS

Six spring cultivars of rapeseed including RGS-003, Option500, RW008911, RAS-3/99, 19H and PF7045/91 (Table 1) which were selected based on their different agronomic characters, were crossed using the half diallel method during 2004-05. To produce F_2 progenies, fifteen F_1 plants were selfed at Baiekola Agricultural Research Station (13° 53′ E longitude, 43° 36′ N latitude, 15 m above sea level), Neka, Mazandaran, Iran, in the 2005-06 growing season. F_2 progenies and 6 parents were grown in a randomized complete block design with four replications in two separate experiments, without nitrogen and with 150 kg nitrogen per hectare in the 2006-07 cropping season. Plots in each experiment consisted of four rows 5 m in length and 40 cm apart. The distance between plants in each row was 5 cm, resulting in about 400 plants per plot, which were sufficient for F_2 genetic analysis in each experiment. The soil is classified as a deep loam (Typic Xerofluents, USDA classification) containing 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 nitrogen in the upper 30-cm profile. The fertilized experiment (N_+) received 150 kg ha^{-1} N as urea (50 kg ha^{-1} at planting, 50 kg ha^{-1} at the beginning of stem elongation, and 50 kg ha^{-1} at the beginning of flowering), while the unfertilized experiment (N_0) received no nitrogen. All the plant protection measures were practiced to keep the crop free from insects. Seed yield was harvested from the three middle rows of each plot. Oil content was measured using nuclear magnetic resonance spectrometry.

Table 1. Origin and some traits of the studied rapeseed genotypes.

Genotypes	Origin	Growth habit	Seed quality
1-RAS-3/99	Germany	Spring	Double zero[1]
2-RW008911	Germany	Spring	Double zero
3-19H	Pakistan	Spring	Double zero
4-RGS 003	Germany	Spring	Double zero
5-Option 500	Canada	Spring	Double zero
6-PF7045/91	Germany	Spring	Double zero

1: Double zero: Fatty acid of oil is less than 2% and meal glucosinolate s less than 30 μM/g.

An analysis of variance for the crosses was performed based on Griffing's method 2; model 1 was used for fixed genotypes (Griffing, 1956). An analysis of variance was performed for the individual environments using the diallel-SAS program written by Kang (1994) and a combined analysis of variance was performed across environments using the diallel-SAS program written by Zhang and Kang (1997). The general linear model for an individual environment was:

$Y_{ijk}=\mu+G_i+G_j+S_{ij}+B_k+E_{ijk}$, where Y_{ijk} is the response of the kth observation in the ith environment of the plant; μ is general mean; G_i the general combining ability (GCA) of the ith parent; G_j the general combining ability (GCA) of the jth parent; S_{ij} the specific combining ability associated with the ith and jth crosses; B_k the effect of the kth replicate, and E_{ijk} is the error associated with each observation.

The general linear model for the combined analysis of variance was:

$$Y_{ijkl}= \mu+L_k + B_{l(k)}+ T_{ij}+G_i +G_j+S_{ij}+(LT)_{ijk}+(LG)_{ik}+(LG)_{jk} +(LS)_{ijk}+E_{ijk(l)}$$

where μ is a general constant; L_k is the main environmental effect (nitrogen level) k; $B_{l(k)}$ is the main effect of block l within the environment; T_{ij} is the treatment effect; G_i and G_j are the general combining ability (GCA) of parents i and j; S_{ij} is the specific combining ability (SCA) of hybrid ij; $(LG)_{ik}$, $(LG)_{jk}$, and $(LS)_{ijk}$ are interactions of GCA and SCA with the environment; and E_{ijkl} is the residual effect. Each effect was tested using its interaction with the block as the error term. A *t*-test was used to test whether the GCA and SCA effects were different from 0 (Mather and Jinks, 1982).

RESULTS

Significant mean squares of two nitrogen levels (N_0 and N_+) for all studied traits revealed significant differences between nitrogen levels (Table 2). Significant mean squares of GCA were found for days to flowering, days to end of flowering, duration of flowering and days to maturity, which indicated a greater role of additive genetic effects for these traits. Significant mean squares of SCA were also detected for traits. This indicates the importance of non-additive genetic effects for these traits. High narrow-sense heritability was estimated for days to flowering, days to end of flowering and days to maturity at both nitrogen levels, suggesting that selection for these traits would be more efficient as compared to other traits.

General combining ability of the parents

The GCA × N level interaction was not significant for all traits. For days to flowering, the parents RW008911 and PF7045/91 had significant positive GCA effects at N_0 (Table 2) and N_+ (Table 3). Means for this trait for RW008911 and PF7045/91 at N_0 were 134.25 and 137.25 and at N_+ they were 138.75 and 140.38, respectively. The parent RGS003 had significant negative GCA effect for days to flowering and its means at N_0 and N_+ were 116 and 121, respectively. For days to end of flowering, RAS-3/99 and RGS003 had significant negative GCA effects at N_0 and N_+, and their means at N_0 were 162.25 and 162, respectively. However, means for both parents at N_+ were 168.81. For duration of flowering, the parents RAS-3/99 and RW0089/11 had significant GCA effects and RGS003 had significant positive GCA effect at N_0, while at N_+ RAS-3/99 and RGS003 had significant negative and positive GCA effects, respectively. The parents RGS003 and PF7045/91 had significant negative and positive GCA effects for days to maturity at N_0 and N_+. Means of this trait for these parents in the N_0 were 200.50 and 216.25, respectively, while at N_+ the means were 209 and 225, respectively.

For plant height, 19H and RGS003 had significant negative and positive GCA effects at N_0 and N_+, respectively, whereas Option500 had significant negative GCA effect at N_+. Means of plant height for 19H and RGS003 were 115 and 150.25 cm at N_0, and 140.43 and 178.4 cm at N_+, respectively. PF7045/91, which showed significant positive GCA effect for seed yield at N_0 and N_+, was the best combiner for this trait; its means were 2165 and 3131.92 kg ha^{-1} at N_0 and N_+, respectively. PF7045/91 had significant positive GCA effect at N_0 for oil content, and RGS003 and Option500, with significant positive GCA effect at N_+, were good combiners for this trait. RGS003 with an average of 40% and 46.2% at N_0 and N_+, respectively, had high oil content in both environments. However, Option500 had the highest oil content (47.13%) at N_+. Oil yield at N_0 varied from 463.22 to 861.33 kg ha^{-1} for Option500 and PF7045/91, respectively. It also varied from 1045.80 to 1372.63 kg ha^{-1} at N_+ for Option500 and RGS003, respectively. PF7045/91 had significant positive GCA effects at N_0 and N_+ for oil yield, with averages of 861.33 and 1297.61 kg ha^{-1}, respectively.

Specific combining ability of the crosses

Significant negative SCA effect for days to flowering was observed for RAS-3/99 × RW008911 and Option500 × PF7045/91 at N_0 (Table 6), as well as for RAS-3/99 × Option500, RW008911 × Option500, RGS003 × Option500 and Option500 × PF7045/91 at N_+ (Table 5). The average for days to flowering at N_0 varied from 119 to 132.50 for RGS003 × Option500 and RW008911 × PF7045/91, respectively. It also varied at N_+ from 123 to 137.38 for RGS003 × Option500 and RAS3/99 × PF7045/91, respectively. Significant negative SCA effect for days to the end of flowering was observed for 19H × RGS003 at N_0 and N_+. The average for days to the end of flowering ranged from 160.75 to 175.25 at N_0 and from 167.88 to 179.13 at N+. Significant positive SCA values for duration of flowering were observed for RW008911 × PF7045/91 at N_0, and any combination had significant positive SCA value at N+. Significant negative SCA effects for days to maturity were observed for RAS-3/99 × 19H, RAS3-99 × RGS003, RW008911 × PF7045/91, 19H × RGS003 and

Table 2. Combined analysis of variance for phenological traits, plant height, seed yield, oil content and oil yield of rapeseed based on Griffing's (1956) method.

Source of variation	df	Mean Squares							
		Days to flowering	Days to end of flowering	Duration of flowering	Days to maturity	Plant height	Seed yield	Oil content	Oil yield
Nitrogen (N)	1	658.07**	1276.23**	61.07	2086.10**	25855.75**	27607326.07**	610.29**	7856717.05**
N(R)	6	19.78	61.49	140.92	12.49	117.81	269432.97	9.99	86827.42
Genotypes (G)	20	185.06**	137.49**	101.67**	198.72**	588.40**	1344284.53**	31.27**	265647.19**
GCA	5	77.29**	49.96**	29.74	65.85**	123.87	174805.97	2.09	31880.53
SCA	15	220.98**	166.67**	125.64**	242.98**	743.26**	1734110.07**	40.99**	343569.41**
N × G	20	4.06	11.61**	15.67	18.35**	32.78	144202.28*	5.62**	28788.72*
N × GCA	5	0.23	0.7	1.43	5.29	6.27	11265.41	1.21	4012.42
N × SCA	15	5.33	15.25**	20.41	22.70**	41.36	188514.50	7.09**	37046.66*
Pooled error	120	9.63	5.64	20.48	5.73	57.24	113421.46	1.73	17264.41
h^2_{N1}		0.74	0.49	0.35	0.90	0.71	0.57	0.12	0.16
h^2_{N2}		0.76	0.71	0.48	0.52	0.34	0.15	0.08	0.11

*** and ** Significant at the 0.05 and 0.01 probability levels, respectively.**
h^2_{N1}: Narrow-sense heritability estimate at N_0.
h^2_{N2}: Narrow-sense heritability estimate at N_+.

Table 3. Estimates of GCA effects for phenological traits, plant height, seed yield, oil content and oil yield of rapeseed in the N_0 environment.

Parents	Days to flowering	Days to end of flowering	Duration of flowering	Days to maturity	Plant height	Seed yield	Oil content	Oil yield
1-RAS-3/99	0.55	-1.83**	-2.39*	-0.92	2.03	70.86	-0.73*	10.49
2-RW008911	1.68*	0.01	-1.67*	-0.98	2.19	-76.78	-0.77*	-43.81
3-19H	1.24	0.82	-0.42	1.05	-6.03**	-46.84	0.42	-12.08
4-RGS 003	-5.54**	-3.55**	1.99*	-5.35**	3.69*	-38.12	0.43	-10.64
5-Option 500	-1.20	-0.05	1.15	0.30	-2.88	-215.15**	-0.34	-90.55**
6-PF7045/91	3.27**	4.60**	1.33	5.90**	1.00	306.02**	0.99**	146.60**

*** and ** Significant at the 0.05 and 0.01 probability levels, respectively.**

Table 4. Estimates of GCA effects for phenological traits, plant height, seed yield, oil content and oil yield of rapeseed in the N_+ environment.

Parents	Days to flowering	Days to end of flowering	Duration of flowering	Days to maturity	Plant height	Seed yield	Oil content	Oil yield
1-RAS-3/99	0.43	-1.30*	-3.25*	-0.07	2.04	42.75	-0.55	3.75
2-RW008911	1.88*	0.20	-1.39	-0.43	1.30	-31.98	-0.48	-27.91
3-19H	0.96	0.97*	0.31	0.34	-4.77**	-80.93	0.13	-34.58
4-RGS 003	-5.85**	-3.00**	3.15*	-2.92**	6.65**	55.05	0.64*	44.01
5-Option 500	-0.61	-0.54	0.38	-0.57	-4.69**	-173.48*	0.63*	-59.21
6-PF7045/91	3.19**	3.68**	0.80	3.65**	-0.53	188.60*	-0.37	73.94*

*** and ** Significant at the 0.05 and 0.01 probability levels, respectively.**

Table 5. Estimates of SCA effects for phenological traits, plant height, seed yield, oil content and oil yield in the progenies of half diallel crosses of six rapeseed parents at N_0.

Crosses	Days to flowering	Days to end of flowering	Duration of flowering	Days to maturity	Plant height	Seed yield	Oil%	Oil yield
1- RAS-3/99 × RW008911	-2.92*	-4.52**	-1.60	0.99	-0.72	591.68**	-1.90**	173.01**
2- RAS-3/99 × 19H	-0.48	1.67	2.15	-3.79*	3.50	21.74	2.03**	53.35
3- RAS-3/99 × RGS 003	1.55	0.04	-1.51	-3.39*	-13.97**	649.27**	-0.60	244.45**
4- RAS-3/99 × Option 500	0.46	3.29*	2.84	0.46	5.34	-79.95	-1.44*	-63.20
5- RAS-3/99 × PF7045/91	-1.02	2.38	3.40	-0.64	-2.03	29.15	2.34**	69.45
6-RW008911 × 19H	-0.86	1.32	2.18	-1.23	5.10	294.37*	2.70**	170.77**
7-RW008911 × RGS 003	-0.33	-0.80	-0.48	-1.82	6.13	375.65**	-0.68	131.68*
8- RW008911 × Option 500	-0.67	-1.05	-0.38	-1.48	3.19	-269.82*	-2.54**	-150.36*
9- RW008911 × PF7045/91	-0.64	3.29*	3.93*	-4.07**	11.57**	189.02	3.63**	163.14**
10-19H × RGS 003	2.36	-3.87**	-6.23**	-5.11**	-0.16	-651.79**	0.12	-266.34**
11- 19H × Option 500	-0.73	-3.12*	-2.39	2.99	-0.34	485.24**	-1.04	167.79**
12- 19H × PF7045/91	-0.45	-0.52	-0.07	0.15	1.78	481.59**	-0.32	190.09**
13- RGS 003 × Option 500	-2.45	-0.24	2.21	-7.85**	-1.32	365.02**	4.51**	246.00**
14- RGS 003 × PF7045/91	1.08	1.35	0.27	7.06**	-12.44**	-102.14	-1.32*	-70.06
15- Option 500 × PF7045/91	-5.02**	-8.40**	-3.39	-0.10	3.13	524.90**	0.45	216.91**

*** and ** Significant at the 0.05 and 0.01 probability levels, respectively.**

Table 6. Estimates of SCA effects for phenological traits, plant height, seed yield, oil content and oil yield in the progenies of half diallel crosses of six rapeseed parents at N_+.

Crosses	Days to flowering	Days to end of flowering	Duration of flowering	Days to maturity	Plant height	Seed yield	Oil%	Oil yield
1- RAS-3/99 × RW008911	-1.84	-1.01	2.40	0.30	0.76	411.34*	-1.55*	124.12
2- RAS-3/99 × 19H	-1.30	1.01	3.84	-3.02**	5.30	95.33	2.49**	120.01
3- RAS-3/99 × RGS 003	-0.61	0.13	2.40	-2.76**	-19.14**	351.84	-0.30	142.58
4- RAS-3/99 × Option 500	2.16*	1.73	1.14	-0.82	4.71	-178.90	-1.29*	-111.13
5- RAS-3/99 × PF7045/91	1.61	1.01	0.97	0.63	-0.85	71.08	1.96*	88.70
6-RW008911 × 19H	-0.25	-1.24	-1.28	-0.90	2.24	75.04	1.48*	75.62
7-RW008911 × RGS 003	0.82	-0.64	-1.72	-0.85	3.87	249.47	-1.24	69.45
8- RW008911 × Option 500	-3.55**	-2.17*	1.12	-1.45	4.40	-44.93	-3.35**	-108.50
9- RW008911 × PF7045/91	-0.85	2.39*	2.98	-2.67**	6.73*	20.30	3.65**	118.62
10-19H × RGS 003	1.24	-2.91**	-4.45*	-3.91**	1.53	-115.55	-1.73*	-96.19
11- 19H × Option 500	0.38	-1.16	-1.82	1.78	2.95	285.71	-2.71**	50.06
12- 19H × PF7045/91	-0.43	-2.10*	-1.72	-0.69	1.70	290.61	-1.61*	73.96
13- RGS 003 × Option 500	-2.69*	-0.03	2.39	-1.67	1.88	164.32	2.67**	154.03
14- RGS 003 × PF7045/91	0.14	-0.50	-0.91	3.07**	-4.70	-522.87**	-1.30	-267.84**
15- Option 500 × PF7045/91	-4.22**	-1.12	2.84	-0.57	2.41	493.47**	0.88	258.32**

*** and ** Significant at the 0.05 and 0.01 probability levels, respectively.**

RGS003 × PF7045/91 at N_0 and N_+. The majority of these crosses had at least one parent with significant GCA effect for days to maturity.

Significant negative SCA effect for plant height was observed for RAS3-99 × RGS003 at N_0 and N_+ and the average of plant height ranged from 122.75 to 146.75 cm at N_0 and from 146.37 to 168.33 cm at N_+. RAS-3/99 × RW008911 and Option500 × PF7045/91 had significant positive SCA values for seed yield at N_0 and N_+. The average seed yield ranged from 1377.50 to 2796.25 kg/ha for 19H × RGS003 and RAS3/99 × RGS003, respectively, at N_0 and varied from 2615.83 to 3431.17 kg/ha for RAS-3/99 × Option500 and Option500 × PF7045/91, respectively, at N+. RAS-3/99 × 19H, RAS-3/99 × PF7045/91, RW008911 × 19H, RW008911 × PF7045/91 and RGS 003 × Option500 had significant positive SCA values for oil content in the N_0 and N_+. Option500 ×PF7045/91 had significant positive SCA values for oil yield in the N_0 and N_+. The average oil yield ranged from 568 to 1177.50 kg ha^{-1} in the N_0 and from 1090 to 1549.91 kg ha^{-1} in the N_+, respectively.

DISCUSSION

The high narrow-sense heritability estimates for days to flowering, days to end of flowering and days to maturity at N_0 and N_+ indicated the importance of additive genetic effects for controlling these traits. Therefore, breeding programs based on selection would be efficient for improving these traits. Various studies on spring cultivars of rapeseed have shown flowering time to be a highly heritable character determined by genes that exhibit some degree of dominance (Olivieri and Parrini, 1979; Thurling and Vijendra Das, 1979; Singh and Yadev, 1980; Lefort-Buson and Dattee, 1982a,b). Likewise, studies on winter (i.e., autumn-sown) cultivars of this species (Olivieri and Parrini, 1979) found that both additive and dominance gene effects have a significant role in the inheritance of flowering time. Singh and Yadev (1980) showed that only non-additive gene actions were important for controlling days to maturity in rapeseed. For plant height and seed yield, high narrow-sense heritability values were obtained at N_0, indicating that improving these traits based on selection breeding program is more efficient at N_0 than at N_+. Most combinations with significant negative SCA effects for phenological traits at both N_0 and N_+ had at least one parent with negative GCA effect. Therefore, GCA effect can be used as a selection criterion for predicting SCA effects in crosses. Averages for phenological traits increased at N_+ due to the important role N plays in biomass production and duration of vegetative growth stage (Colnenne *et al.*, 1998). The GCA x N interaction was not significant for all traits, indicating the parents had the same degree of GCA effects for these traits at N_0 and N_+. The correlation between absolute values of traits and GCA will give an indication of the possibility of using the means of the two parents to predict the value of the hybrid (Ali *et al.*, 1995). Significant positive correlations between GCA values of each trait except oil yield at N_0 and N_+ revealed the stability of GCA effects for the traits at both nitrogen levels. The significant positive correlations between the mean and GCA effect of each trait at N_0 and N_+ indicated it is possible to select parents based on their means and GCA effects.

CONCLUSION

Rapeseed breeders are interested in developing hybrids targetted towards low-input cropping systems. This is facilitated by the high observed GCA effects. The GCA x N interaction indicated that results normally obtained at high N levels would not be enough to identify parents for low nitrogen environments, and that specific experiments using low N levels are necessary to achieve this objective. Of the six test parents, PF7045/91 was the best combiner for seed yield under N_0. This variety also showed high GCA under N_+, but its low oil content at N_+ is certainly not desirable, as the quality of the hybrid is often intermediate between the two parents. For oil content, good combiner parents varied according to the nitrogen level. PF7045/91 was a good combiner for oil content under N_0, while RGS003 and Option500 showed good combiners under N_+.

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