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# HETEROSIS AND HETEROBELTIOSIS OF YIELD ASSOCIATED TRAITS IN RAPESEED CULTIVARS UNDER LIMITED NITROGEN APPLICATION

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Half $F_2$ diallel crosses of six spring cultivars of rapeseed (*Brassica napus* L.) were used to estimate heterosis effects of yield components, seed yield, oil percentage, and oil yield under limited nitrogen condition. Significant mean squares of general and specific combining abilities (GCA and SCA) were detected for pods per main axis, pods per plant, length of pod, seeds per pods, 1000-seed weight, seed yield, and oil content and oil yield indicated respectively the importance of additive and non-additive genetic effects for these traits. High narrow-sense heritability estimates for 1000-seed weight, oil percentage, and oil yield indicating the prime importance of additive genetic effects for these traits. Most of the cross combinations with significant positive heterobeltiosis for seed yield had also significant heterobeltiosis effects for pods per plant and pods on main axis; therefore these traits can be used as indirect selection criteria for improving seed yield. Significant positive correlation of mean performances with heterosis and heterobeltiosis effects for most of the traits except 1000-seed weight indicated that selection of the superior crosses based on heterosis and heterobeltiosis effects will be effective for their mean performances improving these traits except 1000-seed weight. Significant positive correlation was determined between pods per plant and seed yield, indicating that this trait can be used as good selection criterion for seed yield improvement. The crosses including RAS-3/99 × RW-008911 and RAS-3/99 × RGS-003 with high significant positive heterobeltiosis effects of seed yield were superior combinations for seed yield increasing.

Key words: correlation, combinations, diallel crosses, narrow-sense heritability

Rapeseed (*Brassica napus* L.) is an important oil seed crop of the world; and due to its autumn cultivation in Iran and therefore low need of irrigation, it plays a major role in catering edible oil. Hence it is necessary to develop the new ideotype varieties or hybrid of rapeseed with high yield and yield components. A great variation in nitrogen uptake and also tolerance to other stress condition has been reported in rapeseed varieties (Holmes 1980; Rezai & Saeidi 2005). Information regarding the nature of combining ability of parents and heterosis of their crosses is available for use in the hybridization program in normal condition (Downeyand & Rimer 1993; Shen *et al.* 2002; Qian *et al.* 2007; Amiri-Oghan *et al.* 2009; Huang *et al.* 2010; Rameeh 2010; Sabaghnia *et al.* 2010; Singh *et al.* 2010) and also stress conditions (Rameeh *et al.* 2004). Estimation of genetic parameters for yield components can also be important for indirect selection for seed yield (Downe and & Rimer 1993; Nassimi *et al.* 2006b; Teklewold & Becker 2005) and this correlation of the traits is regarded important for detecting selection criteria (Ali *et al.* 2003; Marjanovic-Jeromela *et al.* 2007; Hashemi Ameneh *et al.* 2010: Khan *et al.* 2008). Heterosis is defined as the superior performance of crossbred characteristics as compared with corresponding inbred ones (Mather & Jinks 1982). The utilization of heterosis has become a major strategy to increase the productivity of plants. Despite the successful utilization of heterosis in many crops, there still exists a challenge between the agricultural practice of heterosis utilization and our understand-

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ing of the genetic basis of heterosis, and this hampers the effective utilization of this biological phenomenon (Brandle & McVetty 1990). Breeding for heterosis is one of the most successful technological options being engaged for the improvement of crop varieties. Heterosis is also considered a justification for increased vigor, size, productivity, and speed of developing resistance to disease, insect, pest or climatic vigor, manifested by cross-bred organisms as compared with related inbreds. One of the basic requirements for developing hybrid varieties in oilseed *Brassica* is the availability of proven heterosis. It is often observed that better heterosis could be expressed if it involves parents of indigenous/adapted and exotic germplasm (Riaz *et al.* 2001). Development of hybrid cultivars has been successful in many *Brassica spp*. Mid parents and high parent heterosis (heterobeltiosis) have extensively been explored and utilized for boosting various quantity and quality traits in rapeseed (Nassimi *et al.* 2006a). Heterosis is commercially exploited in rapeseed and its potential use has been demonstrated in turnip rape (*B. rapa* L.) and Indian mustard (*B. juncea* L.) for seed yield and most of the agronomic traits (Teklwold & Becker 2005; Zhang & Zhu 2006). With sufficient level of heterosis, commercial production of hybrid varieties would be justified (Nassimi *et al.* 2006a). Qi *et al.* (2000) reported heterosis in hybrids of six cultivars of *B. campestris*. Significant heterosis for yield was found in some hybrids, with the highest being 96.4%. Most hybrids showed lower levels of heterosis, with the lowest being 1.4%. Katiyar *et al.* (2000) reported that in *B. juncea* 64 hybrids showed heterosis for seed yield over the better parent. For seed yield in spring rapeseed hybrids, an average high parent heterosis of 30% with a range of 20 to 50% was observed, while for winter rapeseed hybrids an average high parent heterosis of 50% was reported, ranging from 20 to 80% as reviewed by McVetty (1995).

Although diallel analyses are frequently used in rapeseed breeding to heterosis for traits but the most of these studies were conducted at high N levels. The objectives of this study were therefore to evaluate whether $F_2$ rapeseed hybrids utilize nitrogen more efficiently than pure lines at low N level, and to identify heterosis for a set of adapted $F_2$ crosses under non-application of nitrogen.

## MATERIALS AND METHODS

Six cultivars of rapeseed including RGS-003, Option-500, RW-008911, RAS-3/99, 19-H, and PF7045/91 were crossed in half diallel mating design during 2004–05. In order to produce F2 seeds, fifteen F1 populations from a 6 × 6 diallel cross were selfed at Bayekola Agriculture Research Station, located in Neka, Iran (13°53′ E longitude and 43°36′ N latitude, 15 m above sea level) during winter 2005–06. $F_2$ progenies along with 6 parents were planted in a randomized complete block design with four replications during 2006–07. The plots consisted of four rows 5 m long and 40 cm apart and the distance between plants on each row was 5 cm. The soil was classified as a deep loam soil (Typic Xerofluents, USDA classification) contained an average of 280 g/clay/kg, 560 g/silt/kg, 160 g/sand/kg, and 22.4 g organic matter/kg with a pH of 7.3. Soil samples were found to have 45 kg/ha of mineral nitrogen (N) in the upper 30-cm profile. Field experiment received 50 kg/ha P, 75 kg/ha K and any N. All the plant protection measures were adopted to make the crop free from insects. Seed yield (adjusted to kg/ha) was recorded based on two middle rows of each plot and yield components including pods per main axis, pods per plant, length of pod, seeds per pod, and 1000-seed weight were measured based on 10 randomly selected plants in each plot. Oil content was determined with the help of nuclear magnetic resonance spectrometry (Madsen 1976).

The combining ability analysis was performed using mean values of their $F_2$ generation along with parents by using Griffing's method 2 with mixed–B model (Griffing 1956). The least significant difference (LSD) was applied to examine the effects of means, heterosis, and heterobeltiosis of the crosses. All the analyses were performed using MS-Excel and SAS.

## RESULTS AND DISCUSSIONS

*Diallel analysis of variance*

Significant mean squares of GCA for the parents and also SCA for their crosses were displayed for the traits including pods per main axis, pods per plant, length of pod, seeds per pod, 1000-seed weight, seed yield, and oil content and oil yield indicating respectively the importance of additive and non-additive genetic effects

T a b l e 1

Analysis of variance of yield associated traits for rapeseed genotypes based on Griffing's method two with mixed-B model under limited nitrogen application condition

| Source of variability | df | MS | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Pods on main axis | Pods per plant | Length of pod [cm] | Seeds per pod | 1000-seed weight [g] | Seed yield [kg/ha] | Oil [%] | Oil yield [kg/ha] |
| Replication | 3 | 43$^{+}$ | 119$^{+}$ | 0.36$^{++}$ | 14.30$^{+}$ | 0.16$^{+}$ | 257,213$^{+}$ | 14.36$^{++}$ | 67,902$^{++}$ |
| Genotypes | 20 | 296$^{++}$ | 1,382$^{++}$ | 1.20$^{++}$ | 12.29$^{++}$ | 0.59$^{++}$ | 1,031,000$^{++}$ | 19.47$^{++}$ | 197,402$^{++}$ |
| GCA | 5 | 428$^{++}$ | 700$^{++}$ | 0.52$^{++}$ | 8.90$^{+}$ | 1.54$^{++}$ | 988,738$^{++}$ | 16.60$^{++}$ | 204,668$^{++}$ |
| SCA | 15 | 252$^{++}$ | 1,609$^{++}$ | 1.43$^{++}$ | 13.42$^{++}$ | 0.27$^{++}$ | 1,046,000$^{++}$ | 20.43$^{++}$ | 194,980$^{++}$ |
| Error | 60 | 6 | 16 | 0.07 | 3.02 | 0.05 | 81,014 | 1.56 | 14,947$^{++}$ |
| Narrow-sense heritability | | 0.12 | 0.07 | 0.35 | 0.11 | 0.53 | 0.14 | 0.53 | 0.60 |

$^{+}$, $^{++}$ Significant at $P$ = 0.05 and 0.01, respectively

for these traits (Table 1). Due to low narrow-sense heritability estimates for pods per main axis, the pods per plant, length of pod, seeds per pods, and seed yield indicate the prime importance of non-additive genetic effects for these traits. Similarly, significant GCA and SCA effects were reported for some important agronomic traits in *Brassica napus* L. (Downeyand & Rimer 1993; Amiri-Oghana *et al.* 2009; Rameeh 2010) and other brassica species (Nassimi *et al.* 2006b).

*Means performances of the parents and their crosses*

Means of parents and their $F_2$ crosses are presented in Table 2. The means of parents for pods per main axis were varied from 18.25 to 37.75 related to Option-500 and RW-008911, respectively. The means of this trait were also ranged from 24.50 to 55 in 19-H × Option-500 and RAS-3/99 × PF7045/91, respectively (Table 2). Most of the crosses with high number of pods per main axis had at least one parent with high amount of this trait. Significant positive correlation was detected between pods per main axis, and seed yield imply that this trait can be used in selection breeding program for seed yield improving (Table 3). The high number of pods per plant was related to RGS-003 and PF7045/91 and also the crosses including RAS-3/99 × RW-008911, RW-008911 × 19-H, 19-H × PF7045/91, and Option-500 × PF7045/91 had high amounts of this trait. Significant positive correlation was determined between pods per plant and seed yield, indicating that this trait can be used as good selection criterion for improving seed yield. Significant positive correlation of seed yield with other important yield components was reported in earlier studies (Ali *et al.* 2003; Hashemi Ameneh *et al.* 2010; Khan *et al.* 2008). Length pod was more variated in the crosses than their parents. This trait was ranged from 5.08 to 6.25 cm in the crosses and was also positive correlated significantly with seed yield. Seed per pod was varied from 17 to 20.25 in the parents and it ranged from 13.5 to 20.25 in their F2 crosses. Due to compensation in yield components, 1000-seed weight was not correlated with seed yield but it was more heritable than the other traits. 19-H had higher amount of 1000-seed weight than the other parent and the crosses viz. RAS-3/99 × 19-H, RW-008911 × 19-H, and 19-H × RGS-003 with high amounts of this trait that had at least one parent with high amount of this trait. The parents including PF7045/91, RGS-003, and 19-H had high amounts of seed yield, and most of the crosses with high amount of seed yield had at least one parent with high amount of this trait. The average mean of oil percentage and oil yield in the crosses were more than their parents, and the crosses including RAS-3/99 × PF7045/91, RW-008911 × PF7045/91, 19-H × PF7045/91, and Option-500 × PF7045/91 had high amount of seed yield, oil percentage, and oil yield; therefore these genotypes were classified as superior cross combinations.

*Heterosis and heterobeltiosis*

The result of heterosis and heterobeltiosis effects of crosses for the studied traits are presented in Table 4 and 5, respectively. Out of 15 crosses, 14 and 6 crosses had significant positive heterosis and heterobeltiosis effects of pods on main axis, respectively. Significant

T a b l e 2

Means of rapeseed varieties and their crosses for yield associated traits under limited nitrogen application condition

| Genotypes | Pods on main axis | Pods per plant | Length of pod [cm] | Seeds per pod | 1000-seed weight [g] | Seed yield [kg/ha] | Oil [%] | Oil yield [kg/ha] |
|---|---|---|---|---|---|---|---|---|
| 1. RAS-3/99 | 33.50 | 93.75 | 4.85 | 17.50 | 3.35 | 1650.00 | 38.48 | 635.34 |
| 2. RW-008911 | 37.75 | 86.25 | 4.40 | 20.25 | 3.31 | 1370.25 | 38.00 | 521.15 |
| 3. 19-H | 21.75 | 98.75 | 5.48 | 17.00 | 4.08 | 1705.00 | 39.25 | 670.90 |
| 4. RGS-003 | 27.50 | 124.50 | 5.23 | 15.75 | 3.31 | 1720.00 | 40.00 | 688.75 |
| 5. Option-500 | 18.25 | 93.50 | 4.65 | 20.00 | 3.05 | 1171.25 | 39.50 | 463.22 |
| 6. PF7045/91 | 34.50 | 105.50 | 5.15 | 18.50 | 3.00 | 2165.00 | 39.75 | 861.33 |
| 7. RAS-3/99 × RW-008911 | 36.25 | 140.00 | 6.18 | 13.50 | 3.38 | 2700.00 | 36.75 | 993.38 |
| 8. RAS-3/99 × 19-H | 40.25 | 123.75 | 5.73 | 18.50 | 4.15 | 2160.00 | 41.88 | 904.65 |
| 9. RAS-3/99 × RGS-003 | 37.00 | 108.75 | 5.25 | 16.50 | 3.45 | 2796.25 | 39.25 | 1097.19 |
| 10. RAS-3/99 × Option-500 | 38.25 | 85.50 | 5.08 | 15.25 | 3.00 | 1890.00 | 37.65 | 709.63 |
| 11. RAS-3/99 × PF7045/91 | 55.00 | 114.25 | 5.85 | 17.50 | 2.90 | 2520.25 | 42.75 | 1076.93 |
| 12. RW-008911 × 19-H | 42.75 | 140.75 | 5.98 | 16.25 | 4.08 | 2285.00 | 42.50 | 972.78 |
| 13. RW-008911 × RGS-003 | 41.00 | 114.25 | 5.58 | 18.25 | 3.30 | 2375.00 | 39.13 | 927.13 |
| 14. RW-008911 × Option-500 | 32.75 | 132.25 | 5.20 | 18.75 | 3.15 | 1552.50 | 36.50 | 568.18 |
| 15. RW-008911 × PF7045/91 | 47.25 | 129.50 | 6.08 | 15.75 | 2.88 | 2532.50 | 44.00 | 1118.83 |
| 16. 19-H × RGS-003 | 31.50 | 109.00 | 5.85 | 18.00 | 3.55 | 1377.50 | 41.13 | 567.94 |
| 17. 19-H × Option-500 | 24.50 | 111.00 | 6.10 | 17.00 | 2.97 | 2337.50 | 39.20 | 918.05 |
| 18. 19-H × PF7045/91 | 38.25 | 140.00 | 5.18 | 17.25 | 3.10 | 2855.00 | 41.25 | 1177.50 |
| 19. RGS-003 × Option-500 | 47.25 | 135.25 | 6.10 | 15.25 | 3.44 | 2226.00 | 44.75 | 997.70 |
| 20. RGS-003 × PF7045/91 | 37.25 | 127.50 | 6.25 | 18.25 | 2.99 | 2280.00 | 40.25 | 918.80 |
| 21. Option-500 × PF7045/91 | 37.25 | 143.00 | 6.16 | 20.25 | 3.06 | 2730.00 | 41.25 | 1125.85 |
| $LSD_{0.05}$ | 3.46 | 5.65 | 0.37 | 2.45 | 0.32 | 402.53 | 1.77 | 172.89 |
| $LSD_{0.01}$ | 4.61 | 7.52 | 0.50 | 3.27 | 0.42 | 535.36 | 2.35 | 229.91 |

T a b l e 3

Correlation among the traits of rapeseed varieties and their crosses under limited nitrogen application condition (n=21)

| Traits | Pods on main axis | Pods per plant | Length of pod [cm] | Seeds per pod | 1000-seed weight [g] | Seed yield [kg/ha] | Oil [%] | Oil yield [kg/ha] |
|---|---|---|---|---|---|---|---|---|
| 1. Pods on main axis | 1 | | | | | | | |
| 2. Pods per plant | 0.37 | 1 | | | | | | |
| 3. Length of pod | 0.37 | $0.68^{++}$ | 1 | | | | | |
| 4. Seeds per pod | –0.23 | –0.26 | –0.37 | 1 | | | | |
| 5. 1000-seed weight | –0.10 | 0.07 | 0.06 | –0.11 | 1 | | | |
| 6. Seed yield | $0.54^{+}$ | $0.61^{++}$ | $0.58^{++}$ | –0.36 | –0.15 | 1 | | |
| 7. Oil [%] | $0.54^{+}$ | 0.42 | $0.49^{+}$ | –0.09 | 0.10 | 0.33 | 1 | |
| 8. Oil yield | $0.62^{++}$ | $0.65^{++}$ | $0.63^{++}$ | –0.34 | –0.13 | $0.98^{++}$ | $0.52^{+}$ | 1 |

$^{+}$, $^{++}$ Significant at $P$ = 0.05 and 0.01, respectively

positive correlation was detected between heterosis and heterobeltiosis effects of this trait; therefore most of the crosses with significant positive heterosis of pods on main axis had significant positive heterobeltiosis effects for this trait (Table 6). The crosses including RAS-3/99 × PF7045/91 and RGS-003 × Option-500 with high significant positive heterobeltiosis effects for pods on main axis were superior cross combinations. Out of 15 crosses, 12 crosses had significant positive heterosis effects of pods per plant and 10 crosses had significant positive heterobeltiosis effects for this trait. The crosses viz. RAS-3/99 × RW-008911, RW-008911 × Option-500, 19-H × PF7045/91, and Option-500 × PF7045/91 with high significant positive heterobeltiosis effects for pods per plant were considered as favorite cross combinations for improving this trait. Due to significant positive correlation among heterosis and heterobeltiosis effects and mean performances of pods per plant, selection based on heterosis and also heterobeltiosis effects of this trait will be effective for improving its mean performances. For length of pod, significant positive heterosis and heterobeltiosis effects were detected in 12 and 9 cross combinations, respectively. None of the cross combinations had significant positive heterosis and heterobeltiosis effects for seeds per pod. RAS-3/99 × 19-H had significant positive heterosis effects for 1000-seed weight and none of the cross combinations had significant positive heterobeltiosis effects for this trait. Significant positive correlation was displayed between heterosis effects and mean performances for 1000-seed weight but the correlation between its heterobeltiosis effects and mean performances was not significant. Out of 15 crosses, 12 and 9 crosses had significant positive heterosis and heterobeltiosis effects of seed yield, respectively. Due to significant positive correlation between heterosis effects and mean performances and also between heterobeltiosis effects and mean performances of seed yield, selection of the cross combinations based on heterosis and also heterobeltiosis effects for this trait will improve its mean performances. The crosses including RAS-3/99 × RW-008911 and RAS-3/99 × RGS-003 with high significant positive heterobeltiosis effects for seed yield were superior combinations for seed

T a b l e 4

Mean parents heterosis of rapeseed crosses for yield associated traits under limited nitrogen application condition

| Crosses | Pods on main axis | Pods per plant | Length of pod [cm] | Seeds per pod | 1000-seed weight [g] | Seed yield [kg/ha] | Oil [%] | Oil yield [kg/ha] |
|---|---|---|---|---|---|---|---|---|
| 1. RAS-3/99 × RW-008911 | 0.63 | 50.00$^{++}$ | 1.55$^{++}$ | –5.38$^{++}$ | 0.05 | 1189.88$^{++}$ | –1.49 | 414.33$^{++}$ |
| 2. RAS-3/99 × 19-H | 12.63$^{++}$ | 27.50$^{++}$ | 0.56$^{++}$ | 1.25 | 0.44$^{++}$ | 482.50$^{+}$ | 3.01$^{++}$ | 251.53$^{++}$ |
| 3. RAS-3/99 × RGS-003 | 6.50$^{++}$ | –0.38 | 0.21 | –0.13 | 0.12 | 1111.25$^{++}$ | 0.01 | 435.15$^{++}$ |
| 4. RAS-3/99 × Option-500 | 12.38$^{++}$ | –8.13$^{++}$ | 0.33 | –3.50$^{++}$ | –0.20 | 479.38$^{+}$ | –1.34 | 160.35 |
| 5. RAS-3/99 × PF7045/91 | 21.00$^{++}$ | 14.63$^{++}$ | 0.85$^{++}$ | –0.50 | –0.27 | 612.75$^{++}$ | 3.64$^{++}$ | 331.10$^{++}$ |
| 6. RW-008911 × 19-H | 13.00$^{++}$ | 48.25$^{++}$ | 1.04$^{++}$ | –2.38 | 0.38$^{+}$ | 747.38$^{++}$ | 3.88$^{++}$ | 371.75$^{++}$ |
| 7. RW-008911 × RGS-003 | 8.38$^{++}$ | 8.88$^{++}$ | 0.77$^{++}$ | 0.25 | –0.01 | 829.88$^{++}$ | 0.13 | 325.18$^{++}$ |
| 8. RW-008911 × Option-500 | 4.75$^{++}$ | 42.38$^{++}$ | 0.68$^{++}$ | –1.38 | –0.03 | 281.75 | –2.25$^{+}$ | 75.99 |
| 9. RW-008911 × PF7045/91 | 11.13$^{++}$ | 33.63$^{++}$ | 1.30$^{++}$ | –3.63$^{++}$ | –0.27 | 764.88$^{++}$ | 5.13$^{++}$ | 427.59$^{++}$ |
| 10. 19-H × RGS-003 | 6.88$^{++}$ | –2.63 | 0.50$^{+}$ | 1.63 | –0.14 | –335.00 | 1.50 | –115.99 |
| 11. 19-H × Option-500 | 4.50$^{+}$ | 14.88$^{++}$ | 1.04$^{++}$ | –1.50 | –0.60$^{++}$ | 899.38$^{++}$ | –0.18 | 350.99$^{++}$ |
| 12. 19-H × PF7045/91 | 38.25$^{++}$ | 37.88$^{++}$ | –0.14 | –0.50 | –0.44$^{++}$ | 920.00$^{++}$ | 1.75 | 411.39$^{++}$ |
| 13. RGS-003 × Option-500 | 47.25$^{++}$ | 26.25$^{++}$ | 1.16$^{++}$ | –2.63$^{+}$ | 0.26 | 780.38$^{++}$ | 5.00$^{++}$ | 421.71$^{++}$ |
| 14. RGS-003 × PF7045/91 | 37.25$^{++}$ | 12.50$^{++}$ | 1.06$^{++}$ | 1.13 | –0.16 | 337.50 | 0.38 | 143.76 |
| 15. Option-500 × PF7045/91 | 37.25$^{++}$ | 43.50$^{++}$ | 1.26$^{++}$ | 1.00 | 0.04 | 1061.88$^{++}$ | 1.63 | 463.58$^{++}$ |

$^{+}$, $^{++}$ Significant at $P$ = 0.05 and 0.01, respectively

T a b l e 5

High parents heterosis (heterobeltiosis) of rapeseed crosses for yield associated under limited nitrogen application condition

| Crosses | Pods on main axis | Pods per plant | Length of pod [cm] | Seeds per pod | 1000-seed weight [g] | Seed yield [kg/ha] | Oil [%] | Oil yield [kg/ha] |
|---|---|---|---|---|---|---|---|---|
| 1. RAS-3/99 × RW-008911 | –1.50 | 46.25$^{++}$ | 1.33$^{++}$ | –6.75$^{++}$ | 0.03 | 1050.00$^{++}$ | –1.73 | 358.05$^{++}$ |
| 2. RAS-3/99 × 19-H | 6.75$^{++}$ | 25.00$^{++}$ | 0.25 | 1.00 | 0.07 | 455.00$^{+}$ | 2.63$^{++}$ | 233.75$^{++}$ |
| 3. RAS-3/99 × RGS-003 | 3.50$^{+}$ | –15.75$^{++}$ | 0.03 | –1.00 | 0.10 | 1076.25$^{++}$ | –0.75 | 408.44$^{++}$ |
| 4. RAS-3/99 × Option-500 | 4.75$^{+}$ | –8.25$^{++}$ | 0.23 | –4.75$^{++}$ | –0.35$^{+}$ | 240.00 | –1.85$^{+}$ | 74.29 |
| 5. RAS-3/99 × PF7045/91 | 20.50$^{++}$ | 8.75$^{++}$ | 0.70$^{++}$ | –1.00 | –0.45$^{++}$ | 355.25 | 3.00$^{++}$ | 215.60$^{++}$ |
| 6. RW-008911 × 19-H | 5.00$^{++}$ | 42.00$^{++}$ | 0.50$^{++}$ | –4.00$^{++}$ | 0.00 | 580.00$^{++}$ | 3.25$^{++}$ | 301.88$^{++}$ |
| 7. RW-008911 × RGS-003 | 3.25 | –10.25$^{++}$ | 0.35 | –2.00 | –0.01 | 655.00$^{++}$ | –0.88 | 238.38$^{++}$ |
| 8. RW-008911 × Option-500 | –5.00$^{++}$ | 38.75$^{++}$ | 0.55$^{++}$ | –1.50 | –0.16 | 182.25 | –3.00$^{++}$ | 47.03 |
| 9. RW-008911 × PF7045/91 | 9.50$^{++}$ | 24.00$^{++}$ | 0.93$^{++}$ | –4.50$^{++}$ | –0.43$^{++}$ | 367.50 | 4.25$^{++}$ | 257.50$^{++}$ |
| 10. 19-H × RGS-003 | 4.00$^{+}$ | –15.50$^{++}$ | 0.38$^{+}$ | 1.00 | –0.53$^{++}$ | –342.50 | 1.13 | –120.81$^{++}$ |
| 11. 19-H × Option-500 | 2.75 | 12.25$^{++}$ | 0.63$^{++}$ | –3.00$^{+}$ | –1.11$^{++}$ | 632.50$^{++}$ | –0.30 | 247.15$^{++}$ |
| 12. 19-H × PF7045/91 | 3.75$^{+}$ | 34.50$^{++}$ | –0.30 | –1.25 | –0.98$^{++}$ | 690.00$^{++}$ | 1.50 | 316.18$^{++}$ |
| 13. RGS-003 × Option-500 | 19.75$^{++}$ | 10.75$^{++}$ | 0.88$^{++}$ | –4.75$^{++}$ | 0.13 | 506.00$^{+}$ | 4.75$^{++}$ | 308.95$^{++}$ |
| 14. RGS-003 × PF7045/91 | 2.75 | 3.00 | 1.03$^{++}$ | –0.25 | –0.31$^{+}$ | 115.00 | 0.25 | 57.48 |
| 15. Option-500 × PF7045/91 | 2.75 | 37.50$^{++}$ | 1.01$^{++}$ | 0.25 | 0.01 | 565.00$^{++}$ | 1.50 | 264.53$^{++}$ |

$^{+}$, $^{++}$ Significant at $P$ = 0.05 and 0.01, respectively

T a b l e 6

Correlation between trait mean and its respected mid parent heterosis and heterobeltiosis and also between heterosis and its respected heterobeltiosis in 15 diallel crosses of rapeseed cultivars under limited nitrogen application condition (n=15)

| Traits | Mean and its respected mid parent heterosis | Mean and its respected heterobeltiosis | Mid parent heterosis and its respected heterobeltiosis |
|---|---|---|---|
| 1. Pods on main axis | 0.35 | 0.78$^{++}$ | 0.46 |
| 2. Pods per plant | 0.91$^{++}$ | 0.81$^{++}$ | 0.97$^{++}$ |
| 3. Length of pod [cm] | 0.85$^{++}$ | 0.81$^{++}$ | 0.97$^{++}$ |
| 4. Seeds per pod | 0.86$^{++}$ | 0.87$^{++}$ | 0.97$^{++}$ |
| 5. 1000-seed weight [g] | 0.81$^{++}$ | 0.33 | 0.51 |
| 6. Seed yield [kg/ha] | 0.88$^{++}$ | 0.80$^{++}$ | 0.94$^{++}$ |
| 7. Oil [%] | 0.98$^{++}$ | 0.99$^{++}$ | 0.99$^{++}$ |
| 8. Oil yield [kg/ha] | 0.89$^{++}$ | 0.82$^{++}$ | 0.95$^{++}$ |

$^{+}$, $^{++}$ Significant at $P$ = 0.01

yield increasing. Mid parents and high parent heterosis (heterobeltiosis) have extensively been explored and utilized for boosting various quantity and quality traits in rapeseed (Nassimi *et al.* 2006a). Qi *et al.* (2000) reported heterosis in hybrids of 6 cultivars of *B. campestris*. Significant heterosis for yield was found in some hybrids, with the highest being 96.4%. Most hybrids showed lower levels of heterosis, with the lowest being 1.4%. Katiyar *et al.* (2000) reported that in *B. juncea* 64 hybrids showed heterosis for seed yield over the better parent. For seed yield in spring rapeseed hybrids, an average high parent heterosis of 30% with a range of 20–50% was observed, while for winter rapeseed hybrids an average high parent heterosis of 50% was reported, ranging from 20 to 80% as reviewed by McVetty (1995). Five crosses had significant positive heterosis and heterobeltiosis effects for oil percentage. Out of 15 crosses, 11 crosses had significant positive heterosis and heterobeltiosis effects for oil yield. The correlation between heterosis and heterobeltiosis effects of oil yield and also with mean performances of this trait was significant and positive.

## CONCLUSION

In general significant positive correlation was determined between pods per plant and seed yield, indicating that this trait can be used as good selection criterion for seed yield improvement studies. Among the yield components, 1000-seed weight was more heritable and for this trait heterosis was more efficient than heterobeltiosis for detecting favorable cross combinations. Due to significant positive correlation between heterosis effects and mean performances and also between heterobeltiosis effects and mean performances for most of the traits, selection of the superior crosses based on heterosis and heterobeltiosis effects will be effective for their mean performances improving under limited nitrogen application.

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