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Genetic Analysis of Heterosis for agronomic traits in Rapeseed (*Brassica napus* L.)

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Abstract

Genetic study was carried out to estimate heterobeltiosis (better parent heterosis) and mid parent heterosis for isolation of superior cross combinations of Brassica napus L. Forty-two F1 crosses were evaluated for six traits, plant height, days to flower initiation, days to 50% flowering, number of primary branches per plant, seed yield per plant and 1000 seed weight. Analysis of variance showed highly significant differences for all accessions indicating the great genetic diversity among the accessions. The cross combination, Dunkeled x ZMR-4 showed highest heterosis for days to 50% flowering, Dunkeled x ZMR-4 for number of primary branches per plant, ZM-17 x dunkeled for seed yield per plant, ZMR-4 × ZM-17 for days to flower initiation, L.siliqua x ZM-5 for plant height, ZM-17 × Dunkeled for 1000 seed weight. Thus, on the basis of these results it is concluded that these parental lines may show good promise to a breeder for exploiting variability in the studied characters. Heterosis studies indicated significant heterosis in desired way for all traits under study. So, hybrid vigor was found to be effective in present genetic material.

Key words: Heterosis, Brassica napus L., yield

Introduction

Canola and sunflower are main crops which are growing for oil purpose. Cotton has also major contribution in oilseed so major work should be done on cotton for its oil productivity. These crops also play important role in health of human beings. There is necessity of breeding and advance biotechnology tools to increase the potential of crops to fulfill the current demand in country. Edibles oils are imported in in Pakistan from abroad due to shortage of improved cultivars, poor oil extraction methods, lack of awareness, shortage of high yielding cultivars, undefined policy, and ignorance of oilseed crops, unavailability of marketing system and competition with other major crops. Pakistan is unable to fulfill the demand of edible oil because there is less availability of certified seed of rapeseed, improved varieties of rapeseed, growing of oilseed crops on marginal lands, less adaptability of hybrids to environmental conditions, lack of perfect marketing system, lack of lodging and shattering resistant cultivars. The area under the cultivation of oilseed crops also very low. To reduce the trading and to increase the production we have to manage the oilseed research properly in order to meet the current demand of edible oil (Shah *et al*., 2007). *Brassica* napus known as a key in Pakistan crops of oilseeds well as in the entire world. Rapeseed has oil content varies from 34% to 46%. *Brassica napus* oil could be used for development of margarine. (Singh, 2007).

Oleic acid, linoleic acid, linolenic acid, erucic acid, glucosinolates and proteins are the important parameters which effects the quality of *brassica* oil. Oil with high amount of oleic acid and protein content has beneficial role in development of human health. On the other hand oil with high amount of erucic acid and glucosinolates have adverse effects on the human health. (Ahmad *et al*., 2012). Oil of *brassica* can be used for making chicks feed due to high % of protein having range from 37% to 40% (Iqbal *et al*., 2008). Important amino acids like methionine, cysteine and lysine are present oilseed. These amino acids prevents from liver damage, helps in rigidity of protein and recovery from injury respectively (Iqbal *et al*., 2008 and Abideen *et al*., 2013). *Brassica napus* L is a cross between *Brassica rapa* and *brassica olerecea* genome AA and CC with chromosome numbers of 20, 18 respectively. (Kang *et al*., 2014).

Genus *brassica* includes Horticultural and agricultural crops. *Brassica napus* locally known as Ghobi sarsoon, family brassicaseae including 374 genera and 3200 species (Abideen *et al*., 2013). About 200 year prior *Brassica napus* was mainly grown in India. Oil of *brassica* was used for burning not for culinary purpose at that time. *Brassica* plant having height from 1.3 to 1.6m. Inflorescence having bisexual flower and terminal raceme. 4 sepals, 4 petals, 6 stamens are present in *brassica* flower. Ovary is superior in *brassica napus* with 2 carpels in pistil. Both self and cross pollination are reported in *brassica napus* because of entomophiles. Silique having lengths ranging from 5cm to 8cm and single silique contain 15-40 seed are present in silique. Color of seed in *brassica napus* is dark brown to black (Australian Govt., 2008). To attain maximum yield in *Brassica* species there is need to develop cultivars having short duration through breeding with other genetically diverse species. Heterosis breeding is key rule to increase production and oil with better quality. We can exploit heterosis can be exploited by crossing genetically diverse lines of *brassica* to get maximum potential in oil as well as yield. Hybrid vigor ranging from 22% to 78% in winter rapeseed which is higher as compared to spring rapeseed which is 20% to 52%.

Materials and methods

Seven lines of *Brassica napus* were used for research purpose to develop high yielding cultivars. Those lines were Long silique, Legend, ZM-5, ZMR-4, ZM-17, Dunkeled and cyclon obtained from the Department of Plant Breeding Genetics, UAF, Pakistan. These lines were grown in the field area during the period of 2017 and crossed in all possible combination by using full Diallel fashion through careful pollinations. The seed was collected and then prepared for next sowing. Seeds of 49 crosses were sown in the field according to randomized complete block design within three replications by dibbler during October 2017. Distance between plants was 23 cm apart while the rows were maintained 45 cm apart. All agronomic practices were carried out properly which are recommended for *Brassica napus* L, throughout the cropping season.

Evaluation of genetic material

Experiment-1

- **Selfing**

For this purpose flowers were protected with the help of butter paper bags before opening to avoid contamination. Plants were influenced to self-pollination for almost one week. After one week paper bags were removed. After mellowing data was collected from the self-pollinated plants.

- **Crossing**

Male parts from flowers were removed with the help of forceps by avoiding damage to female part. Emasculation was done in afternoon nearly 4-5 O" clock. Flowers were untied with the help of needles and forceps. After emasculation flowers were covered by butter paper bags to avoid contamination and marked with tag for identification.

- **Pollination**

Pollination was done next day early in the morning. Fresh pollen from the healthy selected male plant were collected in the petri dishes. Butter paper bags were removed from the emasculated female plant and pollination was done by shedding the pollen with help of brush. After pollination plants were again covered with paper bags. After maturity seeds from all crosses were harvested from each line.

Epmeriment-2

Seeds collected from crosses were sown during October 2017-2018 according to Randomized complete block design within three replications to record data for following traits, days taken to flower initiation, days taken to 50% flowering, number of primary branches, plant height, seed yield per plant and 1000 seed weight.

Statistical Analysis

The data of three repetitions for the hybrids and their parents for all attributes was subjected to statistical analysis given by Steel *et al*., (1997). After that data was investigated for heterosis were checked out.

Table 1- List of *Brassica napus* genotypes used in the research

Sr. No.	**CROSSES**
1	L.siliqua x Legend
2	L.siliqua x ZM-5
3	L.siliqua x ZMR-4
4	L.siliqua x ZM-17
5	L.siliqua x Dunkeled
6	L.siliqua x Cyclon
7	Legend x L.siliqua
8	Legend x ZM-5
9	Legend x ZMR-4
10	Legend x ZM-17
11	Legend x Dunkeled
12	Legend x Cyclon
13	ZM-5x L.siliqua
14	ZM-5 x Legend
15	ZM-5 x ZMR-4
16	ZM-5x ZM-17
17	ZM-5 x Dunkeled
18	ZM-5 x Cyclon
19	ZMR-4x L.siliqua
20	ZMR-4x Legend
21	ZMR-4x ZM-5
22	ZMR-4x ZM-17
23	ZMR-4x Dunkeled
24	ZMR-4x Cyclon
25	ZM-17 x L.siliqua
26	ZM-17 x Legend
27	ZM-17 x ZM-5
28	Zm-17 x ZMR-4
29	ZM-17 x Dunkeled
30	ZM-17 x Cyclon
31	Dunkeled × L.siliqua
32	Dunkeled × Legend
33	Dunkeled × ZM-5
34	Dunkeled × ZMR-4
35	Dunkeled × ZM-17
36	Dunkeled × Cyclon
37	Cyclon × L.siliqua
38	Cyclon × Legend
39	Cyclon × ZM-5
40	Cyclon × ZMR-4
41	Cyclon × ZM-17
42	Cyclon × Dunkeled

Results and discussion

Table 1 shows results of analysis of variance for different traits. All entries showed significant differences among them, Akbar *et al*., (2008) Aghao *et al*., (2010) and Azizinia, (2012) also observed highly significant variances for these attributes in *Brassi ca*. It is clear from these results that genetic variability is present in the breeding material and we can exploit it for further analysis.

Plant height

Heterosis index for plant height depicted that maximum positive value for mid parent heterosis was shown by cross Legend × cyclon that is 12.25% and minimum value was given by cross L, silique × ZM-4 that is 0.39% while maximum negative value for mid parent was given by cross L (Table 2). silique × Legend that is 12.77%. For better parent heterosis cross dunkeled × legend showed maximum positive value that is 14.38% and minimum value is given by cross Zm-17 × cyclon that is 0.22%. While maximum negative value was given by cross cyclon × legend that is -18.50% and minimum value was given by the cross ZM-17 × ZM-5 that is -0.33 respectively. Akbar *et al*., (2008), Marjanovic-Jeromela *et al*., (2008), Rameeh (2012) reported same results for this trait.

Days taken to flower initiation

Heterosis index for days to flower initiation depicted that cross cyclon × Legend exhibited maximum positive significant value for mid parent heterosis that was 39.36% while minimum positive value was given by the cross Dunkeled × L.silique that was 0.72% respectively (table 3). Similarly, cross Dunkeled × ZMR-4 showed maximum negative value for mid parent heterosis that was recorded -22.50% and minimum was given by cross ZM-5 and ZMR-4 that was -1.24%. For better parent heterosis cross cyclon × Legend showed maximum positive value that was 37.80% while minimum value was given by ZMR-4 × L.silique that is 0.16%. similarly, maximum negative value was given by cross cyclon × ZM-17 that is -37.80% and minimum value was showed by cross Legend × Dunkeld that is -0.45% respectively. Singh *et al*, (2011), Rameeh (20 11) and Abideen *et al*, (2013) also described same results for this trait.

Days taken to 50% flowering

Heterosis index for days taken to 50% flowering depicted that range of mid parent and better parent heterosis for days to 50% flowering was calculated from 0.06 to 6.29% and 0.79 to -5.26%. ZM-17 × Dunkeled showed mazimun and high positive MP heterosis that was 6.29% (Table 4). While minimum positive MP heterosis given by Legend × L.siliqua that was 0.06%. Maximum highly negative MP heterosis was given by Dunkeled × ZMR-4 that was -3.95%. While minimum negative mid patent heterosis was given by Cyclon × L.siliqua that was -0.26% respectively. While for better parent heterosis ZM-17 × Dunkeled showed maximum positive significant results that was 3.76%. Minimum positive better parent heterosis revealed by ZM-5 × cyclon that was 0.45%. ZM-5 × Legend showed maximum value for negative better parent heterosis that was -5.26% and minimum negative value was given by ZM-17 × L.siliqua that was recorded -0.38%. Singh *et al.*, (2011), Rameeh (20 11) and Abideen *et al.*, (2013) reported same results for this attribute.

Number of primary branches per plant

Heterosis index for number of primary branches per plant depicted that range of mid parent and better parent heterosis for primary branches per plant was calculated from 0.13 to 36.46% and 2.28 to -45.08%. ZM-5 × Dunkeled showed maximun and high positive MP heterosis that was 28.67% (Table 5). While minimum positive MP heterosis given by ZM-17 × Legend that was 0.13%. Maximum highly negative MP heterosis was given by ZMR-4 × Legend that was -36.46%. While minimum negative mid patent heterosis was given by ZM-17 × Cyclon that was -2.27% respectively. While for better parent heterosis ZM-5× Dunkeled showed maximum positive significant results that was 21.64%. Minimum positive better parent heterosis revealed by ZMR-4 × Dunkeled that was 2.28%. ZMR-4 × Legend showed maximum value for negative better parent heterosis that was -45.08% and minimum negative value was given by Legend × ZMR-4 that was recorded -2.48%. Khan *et al*., (2008), Aytac and Kinaci (2009), Singh e*t al*., (2011) reported same results for this attribute.

1000-seed weight

Heterosis index for 1000-seed weight depicted that range of mid parent and better parent heterosis for 1000-seed weight was calculated from -0.84 to 40.39% and 2.81 to 62.35%. Legend × Cyclon showed mazimun and high positive MP heterosis that was 40.39% (table 6). While minimum positive MP heterosis given by cyclon × ZMR-4 that was 0.95%. Maximum highly negative MP heterosis was given by ZM-5 × ZMR-4 that was

-39.78%. While minimum negative mid patent heterosis was given by ZM-17 × L.siliqua that was -0.43% respectively. While for better parent heterosis ZMR-4 × ZM-17 showed maximum positive significant results that was 62.35%. Minimum positive better parent heterosis revealed by Dunkeled × Legend that was 2.81%. ZM-5 × ZMR-4 showed maximum value for negative better parent heterosis that was -43.85% and minimum negative value was given by L.silique × ZMR-4 that was recorded -3.92%. Dar *et al*., (2011), Singh *et al*., (2011) and reported same results for this trait.

Seeds yield per plant

Heterosis index for seeds yield per plant depicted that cross Cyclon × Legend exhibited maximum significant positive value for mid parent heterosis that was 27.40% which showed that hybrid from these parents is desirable while minimum positive mid parent heterosis revealed by cross Dunkeled × ZMR-4 that was 1.81% respectively (table 7). On the other hand, maximum significant positive results for better parent heterosis given by cross cyclon × Legend that was 16.30% while minimum positive results for better parent heterosis showed by cross ZM-5 × ZM-17 that was 3.20% respectively. ZMR-4 × L.silique showed maximum negative results for better parent heterosis that was -48.18% while minimum negative results was given by cross ZM-5 × ZMR-4. Dar *et al*., (2011) and Marjanovic- Jeromela *et al*., (2011) also described same result for this trait.

Conclusions

From the present study the high yielding cross combinations can be utilized in future breeding programs for developing high yielding genotypes; parents used in developing heterotic hybrids shall be converted to well adapted cytoplasmic male sterile or restorer lines.

Table 1. Analysis of variance for yield related traits in a 7 x 7 diallel cross of *B. napus* L.

SOV	D.F	50%	FI	PH	PB	SY/P	1000-SW
Replications	2	31.53**	1.22	45.67**	0.24	6.03**	0.083
Genotypes	48	230.19**	301.66**	2474.64**	25.63**	2661.30**	2.49**
Error	96	91.37	2.29	94.35	0.57	60.07**	0.70

***Significant (**α=0.05) ** Highly Significant (α=0.01)

Table 2. Heterosis index for plants height (cm)

Genotype	Mid Parent Heterosis	Better Parent Heterosis
L.siliqua x Legend	11.40**	0.40
L.siliqua x ZM-5	-12.25***	-11.25*
L.siliqua x ZMR-4	0.39	-7.10*
L.siliqua x ZM-17	5.19	-9.50*
L.siliqua x Dunkeled	7.50	14.38*
L.siliqua x Cyclon	2.39	-9.70*
Legend x L.siliqua	-0.55	-5.07
Legend x ZM-5	1.68	-4.83
Legend x ZMR-4	2.70	-2.67
Legend x ZM-17	5.18	-1.22
Legend x Dunkeled	-4.84	-10.60**
Legend x Cyclon	5.88	-4.22
ZM-5x L.siliqua	6.83*	5.19
ZM-5 x Legend	-5.55	-7.27*
ZM-5 x ZMR-4	5.22	2.53
ZM-5x ZM-17	0.55	-3.65
ZM-5 x Dunkeled	11.44**	5.48
ZM-5 x Cyclon	2.44	0.97
ZMR-4x L.siliqua	-1.23	-1.44
ZMR-4x Legend	-0.11	-1.27
ZMR-4x ZM-5	-8.66*	-10.76**
ZMR-4x ZM-17	1.71	-3.40
ZMR-4x Dunkeled	0.95	-0.67
ZMR-4x Cyclon	-0.79	-1.10
ZM-17 x L.siliqua	-2.19	-3.24
ZM-17 x Legend	-12.7***	-16.90**
ZM-17 x ZM-5	6.13	-0.33
Zm-17 x ZMR-4	-1.25	-3.77
ZM-17 x Dunkeled	2.58	1.70
ZM-17 x Cyclon	0.87	0.22
Dunkeled × L.siliqua	-2.73	-7.53*
Dunkeled × Legend	-11.21***	-14.00**
Dunkeled × ZM-5	4.81	6.30
Dunkeled × ZMR-4	2.55	3.75
Dunkeled × ZM-17	-0.17	-3.67
Dunkeled × Cyclon	11.40	14.70
Cyclon × L.siliqua	0.13	-3.65
Cyclon × Legend	-9.10**	-13.50**
Cyclon × ZM-5	9.78	11.60
Cyclon × ZMR-4	-10.05	-7.58
Cyclon × ZM-17	-8.20	18.40
Cyclon × Dunkeled	-8.40	-12.30

Table 3. Heterosis index for days taken to flower initiations

Genotype	Mid Parent Heterosis	Better Parent Heterosis
L.siliqua x Legend	2.41*	-4.77**
L.siliqua x ZM-5	-2.38	-4.48**
L.siliqua x ZMR-4	-4.69**	-7.21**
L.siliqua x ZM-17	16.42**	15.41**
L.siliqua x Dunkeled	-10.79**	-15.22**
L.siliqua x Cyclon	16.88**	8.76**
Legend x L.siliqua	-7.87**	-16.22**
Legend x ZM-5	23.97**	17.89**
Legend x ZMR-4	11.72**	2.77
Legend x ZM-17	16.34**	13.74**
Legend x Dunkeled	1.74	-0.45
Legend x Cyclon	3.16*	-6.24**
ZM-5x L.siliqua	-7.21**	-11.47**
ZM-5 x Legend	-8.31**	-9.48**
ZM-5 x ZMR-4	-1.24	-8.36**
ZM-5x ZM-17	-4.69**	-7.21
ZM-5 x Dunkeled	17.31**	11.55**
ZM-5 x Cyclon	-1.65	-6.24**
ZMR-4x L.siliqua	-22.50***	-30.70**
ZMR-4x Legend	6.62**	3.26*
ZMR-4x ZM-5	3.78**	2.77*
ZMR-4x ZM-17	-27.51***	-37.85
ZMR-4x Dunkeled	-8.51**	-9.59**
ZMR-4x Cyclon	-3.36*	-6.22**
ZM-17 x L.siliqua	10.80**	4.12**
ZM-17 x Legend	18.61**	12.38**
ZM-17 x ZM-5	16.56**	14.47**
Zm-17 x ZMR-4	1.23	-6.24**
ZM-17 x Dunkeled	-20.9***	-75.22**
ZM-17 x Cyclon	-6.32**	-12.26**
Dunkeled × L.siliqua	0.72	3.60
Dunkeled × Legend	-19.15	-25.40
Dunkeled × ZM-5	6.13*	2.43
Dunkeled × ZMR-4	-12.10**	-10.30**
Dunkeled × ZM-17	14.46*	3.20
Dunkeled × Cyclon	-6.30	2.20
Cyclon × L.siliqua	8.31*	7.40**
Cyclon × Legend	39.36**	37.80**
Cyclon × ZM-5	-6.07	-19.04**
Cyclon × ZMR-4	5.68	-3.48
Cyclon × ZM-17	6.28	-4.62
Cyclon × Dunkeled	-19.96	-30.99

Table 4. Heterosis index for days taken to 50% flowerings

Genotype	Mid Parent Heterosis	Better Parent Heterosis
L.siliqua x Legend	-2.42**	-2.19**
L.siliqua x ZM-5	-1.53	-3.04*
L.siliqua x ZMR-4	-1.29	-3.05*
L.siliqua x ZM-17	-3.42**	-4.06**
L.siliqua x Dunkeled	-1.77	-2.37
L.siliqua x Cyclon	-0.61	-1.05
Legend x L.siliqua	0.06	-2.13
Legend x ZM-5	-1.88	-4.17**
Legend x ZMR-4	-2.05	-2.13
Legend x ZM-17	0.87	0.79
Legend x Dunkeled	-3.84**	-4.09**
Legend x Cyclon	-2.81*	-4.85**
ZM-5x L.siliqua	0.78	0.76
ZM-5 x Legend	-3.25*	-5.26**
ZM-5 x ZMR-4	-2.73*	-4.70**
ZM-5x ZM-17	-1.65	-3.26
ZM-5 x Dunkeled	-0.82	-3.27
ZM-5 x Cyclon	0.63	0.45
ZMR-4x L.siliqua	-2.39	-4.38**
ZMR-4x Legend	-2.42	-4.56**
ZMR-4x ZM-5	-3.26*	-3.68*
ZMR-4x ZM-17	-1.37	-1.40
ZMR-4x Dunkeled	-1.84	-3.87*
ZMR-4x Cyclon	-2.21	-4.39**
ZM-17 x L.siliqua	-0.26	-0.38
ZM-17 x Legend	-1.73	-2.47*
ZM-17 x ZM-5	-1.65	-1.66
Zm-17 x ZMR-4	5.65**	3.39*
ZM-17 x Dunkeled	6.29**	3.76**
ZM-17 x Cyclon	1.87	1.79
Dunkeled × L.siliqua	-2.38	-4.31
Dunkeled × Legend	0.34	-1.76
Dunkeled × ZM-5	-1.40	-2.90
Dunkeled × ZMR-4	-3.95**	-4.85
Dunkeled × ZM-17	4.40	5.10
Dunkeled × Cyclon	-3.85	-5.20
Cyclon × L.siliqua	-3.750**	-5.10**
Cyclon × Legend	-2.85	-3.90
Cyclon × ZM-5	4.40	6.30
Cyclon × ZMR-4	-1.30	-2.65
Cyclon × ZM-17	-2.85	-3.85
Cyclon × Dunkeled	3.50	4.90

Table 5. Heterosis index for numbers of primary branches per plants

Geotype	Mid Parent Heterosis	Better Parent Heterosis
L.siliqua x Legend	22.81***	6.56
L.siliqua x ZM-5	-3.62	-8.78
L.siliqua x ZMR-4	-7.41	-15.65*
L.siliqua x ZM-17	-11.62	-15.59*
L.siliqua x Dunkeled	-10.02	-15.46*
L.siliqua x Cyclon	-12.92	-24.64**
Legend x L.siliqua	-28.79**	-35.21**
Legend x ZM-5	2.87	-2.64
Legend x ZMR-4	8.11	-2.48
Legend x ZM-17	11.90	-7.27
Legend x Dunkeled	-27.15**	-31.38**
Legend x Cyclon	12.42	2.56
ZM-5x L.siliqua	-9.14	-12.54
ZM-5 x Legend	3.64	2.54
ZM-5 x ZMR-4	-9.89	-19.65**
ZM-5x ZM-17	4.77	-4.64
ZM-5 x Dunkeled	-9.24	-11.54
ZM-5 x Cyclon	-3.99	-7.52
ZMR-4x L.siliqua	12.83	7.37
ZMR-4x Legend	18.30***	9.90
ZMR-4x ZM-5	-11.65	-15.54*
ZMR-4x ZM-17	-5.45	-14.73
ZMR-4x Dunkeled	3.74	2.48
ZMR-4x Cyclon	-5.22	-9.85
ZM-17 x L.siliqua	-21.64**	-29.51**
ZM-17 x Legend	0.13	-5.78
ZM-17 x ZM-5	9.42	-9.70
Zm-17 x ZMR-4	-5.69	-15.78*
ZM-17 x Dunkeled	-13.73	-25.59**
ZM-17 x Cyclon	-2.27	-11.86
Dunkeled × L.siliqua	-5.60	-16.34
Dunkeled × Legend	-5.20	-13.34
Dunkeled × ZM-5	12.90**	9.52**
Dunkeled × ZMR-4	28.67***	21.64**
Dunkeled × ZM-17	13.26**	10.55*
Dunkeled × Cyclon	-22.31	-27.74
Cyclon × L.siliqua	-24.83**	-31.43**
Cyclon × Legend	12.26**	13.25*
Cyclon × ZM-5	8.66	12.46
Cyclon × ZMR-4	-10.13	-31.25
Cyclon × ZM-17	-11.33	-32.65
Cyclon × Dunkeled	12.81	9.88

Table 6. Heterosis index for 1000-seeds weights

Genotype	Mid Parent Heterosis	Better Parent Heterosis
L.siliqua x Legend		
L.siliqua x ZM-5	-22.57**	-33.82**
L.siliqua x ZMR-4	12.73	-3.92
L.siliqua x ZM-17	35.75**	28.9**
L.siliqua x Dunkeled	-8.62	-24.24**
L.siliqua x Cyclon	6.33	3.57
Legend x L.siliqua	-10.48	-18.03**
Legend x ZM-5	-9.76	-19.24**
Legend x ZMR-4	-12.49	-15.53*
Legend x ZM-17	-0.84	-16.35*
Legend x Dunkeled	26.16**	12.15
Legend x Cyclon	-29.8**	-23.5**
ZM-5x L.siliqua	7.25	5.47
ZM-5 x Legend	-14.66*	-22.48**
ZM-5 x ZMR-4	-39.78**	-43.85**
ZM-5x ZM-17	39.36***	34.20**
ZM-5 x Dunkeled	-12.14	-21.30**
ZM-5 x Cyclon	40.39***	25.92**
ZMR-4x L.siliqua	-4.11	-14.78
ZMR-4x Legend	-12.29	-16.80*
ZMR-4x ZM-5	-6.34	-9.97
ZMR-4x ZM-17	-4.63	-24.5*
ZMR-4x Dunkeled	-11.41	-17.49*
ZMR-4x Cyclon	17.23**	6.34
ZM-17 x L.siliqua	-0.43	-14.55*
ZM-17 x Legend	-17.90*	-31.90**
ZM-17 x ZM-5	23.19**	3.70
Zm-17 x ZMR-4	-26.27**	-31.68**
ZM-17 x Dunkeled	45.71***	42.35**
ZM-17 x Cyclon	-20.60**	-31.68**
Dunkeled × L.siliqua	-9.96	-21.60
Dunkeled × Legend	4.31	2.81
Dunkeled × ZM-5	20.10**	9.52**
Dunkeled × ZMR-4	6.93	2.98
Dunkeled × ZM-17	-10.40	-4.20
Dunkeled × Cyclon	-8.84*	-12.99**
Cyclon × L.siliqua	-5.01	-14.93
Cyclon × Legend	-1.32	-6.23
Cyclon × ZM-5	14.45**	20.41**
Cyclon × ZMR-4	0.95	-15.20
Cyclon × ZM-17	4.88	12.30
Cyclon × Dunkeled	-11.56**	-15.58**

Table 7. Heterosis index for seeds yields per plants

Genotype	Mid Parent Heterosis	Better Parent Heterosis
L.siliqua x Legend	-8.24	-14.00
L.siliqua x ZM-5	24.60	5.84
L.siliqua x ZMR-4	-28.33**	-41.61**
L.siliqua x ZM-17	-33.12**	-34.84**
L.siliqua x Dunkeled	-15.25	-16.93
L.siliqua x Cyclon	-14.28	-19.54
Legend x L.siliqua	9.86	-15.00
Legend x ZM-5	-13.48	-34.01**
Legend x ZMR-4	-32.79**	-33.01**
Legend x ZM-17	-23.23*	-29.01**
Legend x Dunkeled	6.47	-11.53
Legend x Cyclon	-31.39**	-44.01**
ZM-5x L.siliqua	-8.09	-14.80
ZM-5 x Legend	-28.7**	-42.06**
ZM-5 x ZMR-4	8.59	-6.48
ZM-5x ZM-17	21.13	17.90
ZM-5 x Dunkeled	24.83***	23.20
ZM-5 x Cyclon	11.73	7.90
ZMR-4x L.siliqua	-31.11**	-48.18**
ZMR-4x Legend	-29.31**	-43.51**
ZMR-4x ZM-5	-24.90*	-27.06**
ZMR-4x ZM-17	-16.31	-21.00
ZMR-4x Dunkeled	12.31	-10.82
ZMR-4x Cyclon	-8.90	-29.35**
ZM-17 x L.siliqua	-27.54**	-32.70**
ZM-17 x Legend	-28.57**	-31.95**
ZM-17 x ZM-5	-31.01**	-38.01**
Zm-17 x ZMR-4	-4.79	-17.757
ZM-17 x Dunkeled	27.40***	16.30**
ZM-17 x Cyclon	-11.66	-18.11
Dunkeled × L.siliqua	8.40	-13.60
Dunkeled × Legend	-22.40**	14.20
Dunkeled × ZM-5	-19.70**	-22.45**
Dunkeled × ZMR-4	1.80	3.30
Dunkeled × ZM-17	9.35*	-8.70
Dunkeled × Cyclon	-16.32	-19.98
Cyclon × L.siliqua	22.50***	18.20**
Cyclon × Legend	10.30*	12.26**
Cyclon × ZM-5	-16.99	-7.45
Cyclon × ZMR-4	-8.70	-12.10
Cyclon × ZM-17	9.30*	14.16**
Cyclon × Dunkeled	8.50	11.31

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