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Heterosis Studies for Some Morphological, Seed Yield and Quality Traits in Rapeseed (Brassica napus L.)

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Abstract
Heterosis has a significant position in rapeseed breeding. To assess the heterosis for seed yield and quality traits, three *Brassica napus* L. testers and five lines were crossed using line × tester design in RCBD with three replications to obtain cross seeds of fifteen hybrids. Data of fifteen characters were recorded. Mean sum of squares of analysis of variances for genotypes were significant or highly significant for all of the fifteen traits. Low to High degree of desirable heterosis over mid, better and commercial parents were observed. Cross 13 showed maximum values of siliqua length (14.3%, 11.1%), seed yield/plant (45.3%, 35.9%) and LnicC (-43.7%, -37.6%) for *MPH* and *BPH* as well as LnicC (-38.3%) for *CH*. Cross 3 revealed highest PC (5.5%, 4.4%), Cross 4 for NSP (28.4%, 25.3%), Cross 10 for GLC (-13.5%, -33.2%) and Cross 15 for NSS (22.8%, 10.8%) over *MPH* and *BPH*. Maximum OC (9.3%, 6.9%) was revealed by Cross 8 for *BPH* and *CH*. Cross No. 1 possessed highest heterosis over commercial variety 'Punjab Sarson' for PC (21.2%), OAC (10.8%), LeicC (46.8%), DM (-6.8%), EAC (-36.9%) and GLC (-29.3%). Cross 6 revealed maximum *CH* for SY (73.3%) and DF (-10.8%). The present study provides valuable facts of noble hybrids with improved traits related to nutrition and yield, as well as valuable information for further molecular and genetic studies of heterosis for these agronomic traits in *B. napus*.
Keywords: *Brassica napus* L., Line × Tester, Heterosis, Morphological, Seed quality

Introduction

Heterosis, or hybrid vigor, refers to a natural phenomenon whereby hybrid offspring of genetically diverse individuals out-perform their parents in multiple traits including yield, adaptability and resistances to biotic and abiotic stressors (Birchler *et al*. 2010, Fu *et al*. 2015). This phenomenon has long been utilized with success in the breeding of the agronomically most important crops such as maize, rice (Virmani *et al*. 1982, Hua *et al*. 2003) and many other crops (Schnable and Springer 2013). Rapeseed (*Brassica napus* L.) is the second important edible oilseed crop over the world (after soybean). It provides about 13.0% of the vegetable oil supply in the world (Hajduch *et al*. 2006). Heterosis of up to 200% the parental lines has been observed in terms of seed yield in rapeseed (Fu *et al*. 1990, Azizinia 2012, Ahsan *et al*. 2013). Thus, rapeseed heterosis has been extensively studied during the past two decades (Ali *et al*. 1995, Atlin 1995, Yu *et al*. 2005, Radoev *et al*. 2008, Shen *et al*. 2008, Basunanda *et al*. 2010, Zou *et al*. 2010, Tochigi *et al*. 2011, Girke *et al*. 2012, Yamagishi 2014), and was successfully used in rapeseed breeding (Chen *et al*. 2012, Fu and Zhou 2013). Today, the hybrid rapeseed is widely cultivated all around the world and accounts for more than 70% of total rapeseed growth area in China (Fu and Zhou 2013). In 2004/2005, Germany planted more than 50% area with hybrid genotypes of winter rapeseed. The most significant reasons for increasing the hybrid cultivars are that they have better yield stability as well as enhanced adaptation to abiotic stresses and low-input over conventional varieties (Snowdon *et al*., 2007).

Pakistan is an agricultural country, of which agriculture remains a dominant sector and contributes 21.4% to national GDP. The total requirement of edible oil of Pakistan is 2.325 million tons from which local production is only 0.606 million tons (26%). Cotton has the highest contribution (71.1%) in local edible oil production, then sunflower (16.7%) and rapeseed/mustard in Pakistan. Rapeseed/mustard was sown on 586 thousand acres with 68 thousand tons oil production during 2013-2014 and have only 11.2% share in local production (Pak. Economic Survey, 2014). Therefore, more consideration should be given for rapeseed production in Pakistan by using modern breeding and molecular tools.

B. napus L. belongs to genus Brassica containing 100 species which has great importance due to vital agricultural and horticultural crops including annual and biannual crops and shrubs (Noor-Ul-Abideen *et al*., 2013). Its cultivation had been recorded 2000 years ago in India and 13th century in Europe where its oil was mostly used for burning of lamps. It has 35-53% oil contents (Singh, 2007 and Shehzad *et al*., 2015b) and 19-26% protein contents (Ahmad *et al*., 2012 and Shehzad *et al*., 2015b).

The present study is planned to evaluate 1. Significance of lines, testers and their hybrids 2. Heterosis in rapeseed for oil and seed yield traits.

The objectives of this study were to evaluate the agronomic potential of hybrids derived from crosses between three testers and 5 lines of spring oilseed rape (2) analyze the relation between GD and heterosis.

Materials and Methods

Plant materials

The experimental material consisted of eight rapeseed genotypes of spring type named Duncled, K-258, ZN-R-1, ZN-R-8, ZN-M-6, Punjab Sarson, Legend and Durre-NIFA, respectively. These breeding materials were obtained from the Germplasm Collection of the Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad, Pakistan.

Field experiments

All the field experiments were conducted in the experimental field of University of Agriculture of Faisalabad, Pakistan. During October 2012-2013, five lines i.e. Duncled, K-258, ZN-R-1, ZN-R-8, ZN-M-6 and three testers e.g. Punjab Sarson, Legend and Durre-NIFA were crossed manually in line × tester design (Table 1) to obtain cross seeds of 15 hybrids. Seeds of eight parents and 15 hybrids were sown in RCBD (Randomized Complete Block Design) with three replications during October 2013-2014. Each sowing plot consisted of 23 rows having dimension 3m × 10m. All the entries were randomized in each replication. The plant to plant distance was 30cm and row to row distance was 45 cm. Thinning between younger plants was done to maintain recommended plant to plant distance. Recommended dose of NPK fertilizers were used (Shehzad *et al*., 2015a). Plant protection approaches were applied to keep the experimental crop healthy (Shehzad *et al*., 2015b). At the maturity stage of F_1 hybrids, ten plants of each parent and hybrid were randomly chosen to record data of morphological traits. Seeds of selected F_1 plants were collected to take data of quality traits.

Data analysis

Data were recorded for fifteen traits i.e. plant height (cm), siliqua length (cm), number of siliquae/plant, number of seed/siliqua, 1000 seed weight (g), seed yield/plant (g), days taken to 50% flowering, days taken to maturity, oil content (%), protein content (%), erucic acid content (%), oleic acid content (%), glucosinolate content (μmol/g), linoleic acid content (%), and linolenic acid content (%). Near-Infrared Reflectance (NIR) spectroscopy (FOSS 6500 equipped with ISI version 1.02 a software of Infra Soft International) was used to measure the oil, protein, erucic acid, glucosinolate, oleic acid, linoleic acid and linolenic acid contents at biochemical laboratory, crop breeding section of Nuclear Institute for Food and Agriculture (NIFA) Peshawar (Ahmad *et al*., 2012). Data were subjected to analysis of variance (Steel *et al.,* 1997) to evaluate the significance of differences among F_1 hybrids and their parents. Heterosis (mid parent, better parent and commercial) was calculated as percent increase or decrease over mid parent, better parent and commercial variety values, respectively, as proposed by Falconer and Mackay (1996). Punjab Sarson, a very famous variety in Punjab province of Pakistan, was used as commercial variety for commercial heterosis calculation in this study. Statistical software package of TNAUSTAT (L × T analysis with parents) was practiced to evaluate ANOVA and heterosis (https://sites. google. com/site/tnaustat/plant-breeding-heterosis).

Results

In this study, we used eight rapeseed genotypes of spring type, three as testers and five as lines in a 'tester x line' design, to realize fifteen crosses for heterosis analysis (Table 1). The eight parents and 15 hybrids were then planted in RCBD (Randomized Complete Block Design) with three replications. Data of fifteen characters were recorded from these twenty-three genotypes (8 parents + 15 hybrids). The values of mean sum of squares of analysis of variances of these recorded data were summarized in Table 2. It is observed that the mean sum of squares of analysis of variances for genotypes, parents, crosses, parents vs. crosses, lines, testers, and line x tester, were significant for all or most of the fifteen traits, indicating the existing of a large genetic variability among the studied materials. The data for Mid parent heterosis (*MPH*), Better parent heterosis (*BPH*) and Commercial heterosis (*CH*) were presented in Table 3, 4 and 5, respectively.

Plant height (cm)

Maximum plant height value was observed in Cross 1 (172.4cm) and minimum height was observed in Cross 7 (144.3cm). Nine hybrids showed their *MPH* in positive direction and one revealed negative *MPH*, with an overall range of -2.9% to 7.8% (Table 3). For *BPH*, Cross 5 and 10 showed a positive hybrid vigor of 5.2%, while seven other crosses exhibited negative *BPH*, with an overall range of -3.4% to 5.2% (Table 4). The *CH* values were calculated by comparing with the commercial variety 'Punjab Sarson'. The range of *CH* values for plant height was -2.3% to 16.7% (Table 5).

Siliqua length (cm)

The range of the mean values for siliqua length was 5.4 cm (Cross 12) to 8.1 cm (Cross 7). *MPH* for siliqua length ranged from -11.1% to 14.3% (Table 3); *BPH* ranged from -26.5% to 11.1% (Table 4); *CH* ranged from -5.6% to 40.0%, with the highest value of 40.0% in Cross 7 (Table 5).

Number of seeds/siliqua
The range of number of seeds/siliqua was 19.0 to 30.4 with a mean value of 25.99. *MPH* for number of seeds/siliqua ranged from -3.3% to 22.8% with the highest value in Cross 15 (Table 3); *BPH* ranged from -11.1% to 10.8% (Table 4); *CH* ranged from -11.3% to 23.9% (Table 5). Cross 5 and 11 revealed both a *CH* value superior to 23%.

Number of siliquae/plant
The mean number of siliquae per plant was ranged 360.7 to 837.4 with a mean value of 639.41. Maximum siliquae per plant were observed in Cross 5 (837.4) followed by Cross 7 (787.2). The range of *MPH* for number of siliquae per plant was 2.7% (Cross 13) to 28.4% (Cross 4) (Table 3). The range of *BPH* was -4.4% to 25.3% (Table 4). Twelve hybrids out of fifteen showed highly significant positive *BPH*. The maximum positive effect of *BPH* was showed by Cross 4 (25.3%) followed by Cross 2 (19.3%). Cross 5 revealed the highest significant result of *CH* in positive direction (72.5%) followed by Cross 7 (62.2%) and Cross 6 (56.8%) (Table 5).

1000 seed weight (g)
The mean values of 1000 seed weight among the crosses were ranged from 3.2g to 3.8g. Maximum 1000 seed weight was observed in Cross 5. The range of *MPH* was -1.7% to 6.1% (Table 3). The range of *BPH* was -5.1% to 3.9% (Table 4). The range of *CH* was -5.8% to 12.8% (Table 5). Four crosses (Cross 2, 5, 10 and 11) exhibited a *CH* superior to 10% for 1000 seed weight.

Seed yield/plant (g)
The mean values for seed yield/plant ranged from 18.0g (Cross 14) to 75.9g (Cross 6). The range of *MPH* for seed yield/plant was -0.1% (Cross 4) and 45.3% (Cross 13) (Table 3). Three Crosses (11, 12 and 13) exhibited a positive *MPH* of ~40%. The range of *BPH* was -5.6% to 35.9% (Table 4). Cross 11 and 13 exhibited a positive *BPH* of ~35%. *CH* ranged from -58.9% to 73.3% (Table 5). Cross 6 revealed a *CH* value as high as 73.3%, followed by Cross 15 (45.7%), Cross 7 (40.1%) and Cross 2 (36.5). However, Cross 14 showed a negative *CH* as high as -58.9%, followed by Cross 12 (-55.2%) and Cross 13 (-52.0%).

Days taken to 50% flowering
Maximum days taken to 50% flowering was observed in Cross 3 (80) and minimum days to flowering was observed for Cross 6 (64). The range of *MPH* for Days taken to 50% flowering was -1.7% to 2.9% (Table 3). The range of *BPH* was -3.7% to 2.9% (Table 3). Three crosses (6, 7 and 8) showed significant positive *MPH* (Table 3) as well as *BPH*（Table 4）. The range of *CH* was -10.6 to 6.4% (Table 5). Cross 3 showed the highest positive *CH* of 6.4, while Cross 6 showed the highest negative *CH* of -10.6%.

Days taken to maturity
Maximum days taken to maturity was observed in Cross 10 (160.3) and minimum days taken to maturity was observed for Cross 1 (140.3). The range of *MPH* was -1.4% (Cross 4) to 1.8% (Cross 10) (Table 3). The range of *BPH* was -2.3% to 0.6% (Table 4). The range of *BPH* was -6.8% to 1.7% (Table 5). Eight crosses showed significant negative *CH* while none of the crosses showed significant positive *CH*. Cross 1 showed the highest *CH* in negative direction (-6.8%) followed by Cross 9 (-6.6%).

Oil contents (%)
Maximum oil content value was observed in Cross 8 (52.4%) and minimum oil content value was observed in Cross 3 (46.8%). The range of *MPH* was 0.9% (Cross 5) to 11.6% (Cross 8) (Table 3). Eleven of 15 crosses showed highly significant *MPH* in positive direction. The range of *BPH* was 0.7% to 4.1% (Table 4). Cross 6 showed highly significant positive hybrid vigor (4.1%) over better parent. The range of *CH* was -4.6% to 6.9% (Table 5). Nine hybrids showed significant/highly significant effects of *CH* (Table 5). Cross 8 revealed the highest *CH* in positive direction (6.9%) followed by Cross 1 (5.6%).

Protein contents (%)
Maximum protein content value was observed in Cross 13 (26.5%) and minimum protein content value was observed in Cross 4 (19.5%). The range of *MPH* for protein content was -8.9% (Cross 9) to 5.5% (Cross 3) (Table 3). All crosses except Cross 1 revealed significant *BPH* either in negative or positive direction, and the range of *BPH* was -11.7% to 4.4% (Table 4). The range of *CH* was -10.8% (Cross 4) to 21.2% (Cross 1) (Table 5).

Erucic acid (%)
The erucic acid content values ranged from 4.7% (Cross 1) to 40.6% (Cross No. 2). The range of *MPH* for erucic acid content was -64.3% (Cross 14) to 91% (Cross 2), and all the crosses revealed significant *MPH* (Table 3). The range of *BPH* was --57% (Cross 11) to 446.1% (Cross 2) (Table 4). The range of *CH* was -36.9% (Cross 1) to 446.1% (Cross 2). All the hybrids showed highly significant effects of *CH* showed in Table 5. Cross 1 revealed highly significant heterosis in negative direction (-36.9%) followed by Cross 11 (-22.6%).

Oleic acid (%)
The mean values for oleic acid were ranged 42.7% (Cross 12) to 62.5% (Cross 1). Cross 4 exhibited maximum *MPH* (Table 3) effects in negative direction (-13.7%). The range for the *MPH* was -0.3% (Cross 8) and -13.7% (Cross 4). Three crosses (No. 4, 9 and 14) exhibited highly negative significant *BPH* (Table 4). The range for

better parent was -2.6 to 20.1%. According to Table 5, the range of *CH* for oleic acid was -24.3-10.8%. Cross 1 showed positive and highly significant results (10.8%) followed by Cross 11 (10.1%).

Glucosinolate (µmol/g)

The average values for glucosinolate contents were 19.3-65.5 µmol/g. Cross 11 had highly significant *MPH* in positive direction for glucosinolate contents (Table 3). The range of *BPH* was -33.2% to 34.9% (Table 4). Cross 1 and 11 exhibited highly significant positive heterosis effects (34.9%) followed by Cross 6 (22.7%), while most of other crosses (No. 3, 4, 5, 8, 9, 10, 13, 14 and 15) exhibited highly significant negative heterosis effects of -27.3% to - 33.2%. For the *CH* values (Table 5), Cross 13 revealed the highest significant heterosis in positive direction (140.5%) followed by Cross 9 (130.4%), No. 15 (128.6%), No. 8 (119.2%) and No. 4 (110.3).

Linoleic acid (%)

Maximum linoleic acid contents were observed in Cross 1 (15.2%) and minimum in Cross 2 and 3 (9.5%). For *MPH* (Table 3), the highest significant value was observed for Cross 8 (18.2%), followed by Cross 10 (15.1%) and Cross 3 (13.6%). For *BPH* (Table 4), highly significant value was observed for all crosses with a range of -11.6% to 16.7%, of which nine showed highly significant negative values, the maximum positive heterosis was observed in Cross 8 (16.7%) followed by Cross 10 (13.66%). For *CH* (Table 5), Cross 1 revealed the highest significant result in positive direction (46.8%) followed by Cross 6 (26.1%) and 4 (19.4%).

Linolenic acid (%)

Maximum linolenic acid was observed in Cross 3 (9.5%) and minimum was observed in Cross 13 (5.4%). For *MPH* and *BPH*, majority of the crosses showed highly significant values in positive/negative direction (Table 3,4). The overall range was -43.7% (Cross 13) to 1.6% (Cross 3) for *MPH* and -37.6% (Cross 13) to 8.4% (Cross 3) for *BPH*. For *CH*, Cross 3 exhibited the highest positive value (8.4%) followed by Cross 7 (6.4%), while Cross 13 exhibited the highest negative value (-38.3%) followed by Cross 1 (-28.4%) (Table 5).

Discussion

Seed yield is a complex trait and contains numerous components which have positive or negative effects on it. Seed yield is the product of the number of siliquae/plant, population density, individual seed weight and number of seeds/siliqua (Azizinia 2012). Combination of these components results in a highly yielding plant (Diepenbrock 2000, Azizinia 2012). Hybrid seed production is a significant method to encourage the seed yield of rapeseed/mustard. This method has comparatively 15% higher yield of hybrids over conventional breeding methods (Ahsan *et al*. 2013).

Medium plant height is useful to avoid plant losses due to lodging caused by heavy winds. For this reason, negative heterosis for plant height is desirable (Nassimi *et al*. 2006). Only Cross 13 showed significant negative *MPH* for PH (-2.9%) and Cross 1 revealed negative *CH* (-2.3%) over commercial variety 'Punjab Sarson'.

The range of SL for all crosses was 5.4-8cm. Majority of the crosses revealed significant and desirable positive *MPH*, *BPH* and CH. All the crosses except Cross 14 revealed useful positive *CH* for SL. The Cross 6 exhibited maximum *CH* (40%) followed by Cross 11 (22.5%) which is useful to increase seed yield (Table 5). Rameeh (2012) observed significant mid and better parent positive heterosis for siliqua length that is approximately similar to these findings (Table 3, 4 and 5). Nasim *et al*. (2014) conducted his experiment in *B. rapa* and found positive *MPH* for 14 hybrids ranged 0.1-18.4 % and 12 hybrids ranged 0.3-14.7% (*BPH*).

Short stature with more number of branches and siliquae/plant provides more yield, therefore, positive heterosis is preferred in this case (Nassimi *et al*., 2006). All the crosses exhibited significant results of *MPH*, *BPH* and *CH* for NSP (Table 3, 4, 5) indicated the presence of significant genetic variation. All the crosses (Table 3) showed positive percentage for NSP. Cross 4 showed maximum *MPH* (28.4%) and *BPH* (25.3%) for NSP (Table 3 and4). In case of *CH*, desirable variation was identified. Cross 5 unveiled maximum *CH* (72.5%) followed by Cross 7 (62.2%) and Cross 2 (55.9%) showed in Table 5. Nasim *et al*. (2014) found *MPH* ranged 0.1-22.5 % and *BPH* from 0.8 to 9.8 % for siliquae/plant. Dar *et al.* (2012) also observed highly significant positive heterosis for number of siliquae per plant which strengthen these results. In Table 3, Cross 15 unveiled 22.8% *MPH* for NSS followed by Cross 5 (19.6%). Three crosses (11, 14. 15) revealed 10.8% *BPH* showed in Table 4. Cross 5 and 11 showed 23.9% and 23.3% *CH* for NSS (Table 5).

For SW, significant lower variations were found for *MPH*, *BPH* and *CH*. The maximum value was indicated by Cross 2 (12.8%) for *CH* while this was 6.1% for *MPH* and -5.1% for *BPH*. It indicated fewer chances of selection and ultimately less improvement in yield through SW.

Significant variations were exposed by SY (Table 3, 4 and 5). Crosses 13 and 11 showed maximum *MPH* (45.3% and 44.9%) and in *BPH* (35.9% and 35.2%) respectively. Cross 6 unveiled *CH* (73.3%) followed by Cross 15 (45.7%) for SY. Radoev *et al.* (2008) predicted 30% heterosis increase for seed yield/plant which is lower than the present findings. According to Table 5, the Cross 6 is performing better over others in highest positive *CH* (73.3%) for SY and minimum DF (-10.6%) in addition to average positive heterosis for siliqua length (16.7%), number of seeds per siliqua (4.4%) and number of siliquae/plant (56.8%). In *B. napus*, there exists a highly significant positive correlation between genetic distance and heterosis for seed yield and morphological traits (number of pods/plant, and number of seeds/pod) (Ali *et al*. 1995). Nasim *et al*. (2014) predicted significant *MPH* for 18 hybrids and *BPH* for 14 hybrids ranging 48.6-163.9 % and 25.9-145.8 % respectively. Thakur and Sagwal (1997), Marjanović- Jeromela *et al*. (2008) observed positive and negative effects of heterosis for seed yield/plant.

Early flowering in rapeseed provides more time for grain formation and ultimately early maturity and good yield, so, negative heterosis is useful to avoid yield and oil losses due to increase in temperature (Nassimi *et al*., 2006). Small variations existed in crosses (*MPH*, *BPH* and *CH*) for DF and DM. In case of *MPH*, none of the cross showed significant negative *MPH* for DF and DM. Maximum negative values were -3.7% and -2.3% for DF and DM respectively (Table 4). In Table 5, Cross 6 showed maximum DF (-10.6%) but it possessed non-significant values for DM (1.1%). Cross 1 is performing better for decreased DF (-4.3%) and maximum DM (6.8%) but its seed yield is decreasing (-9.8%). So, Cross 2 is superior as it possessed desired decreased values for DF (-5.3%) and DM (-4.5%) with increased SY (36.5%), SW (12.8%), NSP (55.9%), NSS (7.9%) and SL (15.7%). Grant and Beversdorf (1985) predicted intermediate heterosis for days taken to flowering. Dar *et al.* (2012) and Saeed *et al.* (2013) observed highly significant mid and better parent negative heterosis for days taken to 50% flowering. Dar *et al.* (2012) and Saeed *et al.* (2013) predicted medium negative *MPH* and *BPH* for days taken to maturity.

B. napus is a vigorous source of edible oil possessing low amount of saturated fatty acids (5-7%) and high quantity of PUFA with approximately 17-22% linoleic and 7-11% linolenic acids. The nutritional standards of numerous edible oils depend upon the composition of the different fatty acids (El-Beltagi *et al*. 2010). So, quality of edible oil can be improved by altering the concentration of fatty acids and minimizing the anti-nutritional components especially erucic acid and glucosinolates.

Azizinia (2012) and Noor-Ul-Abideen *et al*. (2013) determined the range of oil contents (42.7-53.3%) in their studies. Similar oil contents were predicted in the present studies (46.8-52.4%). Both of the traits i.e. OC and PC showed the absence of high percentage of heterosis (Table 3, 4 and 5). Maximum OC (9.7%) was showed by Cross 9 followed by Cross 3 (4.8%) with PC (5.5%) (Table 3). Cross 8 unveiled maximum OC (6.9%) for *CH* but it possessed negative PC (-7.9%). Cross 1 is performing better as it is showing increased *CH* for OC (5.6%) and PC (21.2%). Riungu and McVetty, 2004 and Cuthbert, 2011 predicted the absence of high percentage heterosis for oil concentration in their canola crosses which support the present studies. The range of protein contents (20-25.1%) determined by Ahmad *et al.* (2008) and Ahmad *et al.* (2012) which are approximately similar to present research (19.5-26.5%). Girke *et al*. (2012 predicted significant mid and *BPH* for protein contents. Grant and Beversdorf, 1985 reported negative low parent heterosis for protein contents in canola hybrids. Sernyk and Stefansson (1983) and Cuthbert (2011) observed negatively correlation between oil and protein contents. Commercial Crosses No. 3, 8, 9, 10 and 15 showed negative relations between oil and protein contents (Table 5). In such cases, selection would be conducted by improving two traits simultaneously (Grami and Stefansson, 1977).

For edible oil, high concentration of protein, oleic acid and low concentration of glucosinolate, erucic acid and linolenic acid are required (Ahmad *et al.*, 2012). *B. napus* oil with specific concentration of erucic acid is suitable for diet and margarine but high concentration is a health hazard.

The range of erucic acid concentration (0.15-86.5%) determined by El-Beltagi *et al.* (2010) and Girke *et al*. (2012) which is higher than present investigation (4.7-40.6%). Highly significant variations were predicted in erucic acid for *MPH*, *BPH* and *CH*. Cross 14 showed maximum decreased *MPH* (-64.3%), Cross 11 unveiled -57% *BPH* and Cross 1 revealed *CH* (-36.9%) for EAC showed in Tables 4, 5 and 6 respectively. Girke *et al.* (2012) and Nasim and Farhatullah (2013) also predicted significant negative heterosis for erucic acid which support the present studies. In case of positive heterosis, Cross 2 showed maximum *BPH* (446.1%) and *CH* (446.1%) followed by Cross 5 having *BPH* (423.7%) and *CH* (423.7%) displayed in Table 4 and 6 respectively. In such type crosses, their related better and commercial parent/parents possessed approximately many folds less EAC. So, these crosses (2, 3, 4, 5, 7, 10 and 15) showed nearly three or four hundred percent increase *BPH* and *CH* for EAC (Table 4 and 5).

The range of oleic acid contents (8.9-58.7%) determined by Ahmad *et al.* (2008), El-Beltagi *et al.* (2010) and Ahmad *et al.* (2012) which is approximately close to the present studies. Heterosis percent is predicted lower for OAC due to less variation in germplasm. All the crosses showed negative *MPH* and *BPH* for OAC (Table 3 and4). Cross 1 exhibited maximum increase *CH* (10.8%) followed by Cross 11 (10.1%) while eleven hybrids showed negative *CH* showed in Table 5.

High concentration of glucosinolates affects goitrogenic disorder. In cooking oil, glucosinolates concentration must be present lower than 30 µmoleg^{-1} (Snowdon *et al.*, 2007). The Crosses No. 1, 10 and 11 showed negative significant *CH* (-29.3%, -20.1 and -26.9%) for GLC. The range of glucosinolates in present studies is 19.3-65.5 µmol/g. Glucosinolate range (0-132 µmol/g) in rapeseed/mustard were calculated by Velasco *et al*. (1999), Ahmad *et al.* (2012) and Mahmood *et al.* (2012).

Low percent heterosis was predicted for LeicC exposed in Table 3, 4 and. Cross 8 revealed maximum positive *MPH* (18.2%), Cross 8 showed *BPH* (16.7%) and Cross 1 possessed 46.6% *CH*. Higher proportion of linolenic acid promotes oxidation which negatively affects the flavor and quality of cooking oil. Low concentration of linolenic acid is mandatory for normal immunological and vascular system control (Burns *et al.* (2003). If linolenic acid contents would be decreased from 10% (average) to 3%, then shelf life of edible oil can be increased (Snowdon *et al*., 2007). Cross 13 showed maximum negative *MPH* (-43.7%), *BPH* (-37.6%) and *CH* (-43.7%) for LnicC.. The range of linolenic acid contents (3.5-14.5%) determined by Velasco *et al*. (1999), Ahmad *et al.* (2008), Ahmad *et al.* (2012 and Mahmood *et al.* (2012) which are higher than present studies (5.4-9.5%).

Conclusion

The results showed the presence of genetic variation in the studied germplasm which is very important for selection of superior hybrids. It also revealed the presence of lower to high degree of desirable heterosis over mid, better and commercial parents were predicted in many crosses for studied traits. Cross 13 revealed maximum *MPH* and *BPH* for positive siliqua length, seed yield/plant and negative LnicC as well as *CH* for negative LnicC. Cross 3 showed maximum positive PC, Cross 4 for positive NSP, Cross 10 for negative GLC and Cross 15 for positive NSS over *MPH* and *BPH*. Cross No. 1 exposed highest heterosis over commercial variety 'Punjab Sarson' for positive PC, OAC, LeicC and negative DM, EAC and GLC. Cross 6 revealed maximum positive SY and negative DF. These hybrids performed good in the climate of Faisalabad, Punjab. It is suggested to assess above precious hybrids in different climatic zone of Pakistan to recognize their potential and stability and commercialize the noble hybrids.

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Heterosis Studies for Some Morphological, Seed Yield and Quality Traits in Rapeseed (*Brassica napus* L.)

Table 1 Cross Numbers with their Names (tester x line)

No.	Cross name	No.	Cross name	No.	Cross name
1	Punjab Sarson × Duncled	**6**	Legend × Duncled	**11**	Durre-NIFA × Duncled
2	Punjab Sarson × K-258	**7**	Legend × K-258	**12**	Durre-NIFA × K-258
3	Punjab Sarson × ZN-R-1	**8**	Legend × ZN-R-1	**13**	Durre-NIFA × ZN-R-1
4	Punjab Sarson × ZN-R-8	**9**	Legend × ZN-R-8	**14**	Durre-NIFA × ZN-R-8
5	Punjab Sarson × ZN-M-6	**10**	Legend × ZN-M-6	**15**	Durre-NIFA × ZN-M-6

Table 2 Mean sum of squares of analysis of variances for fifteen characters in rapeseed

SOV / Traits	Replication	Genotypes	Parents	Crosses	Parents vs. Crosses	Lines	Testers	Line x Tester
d.f.	2	22	7	14	1	4	2	8
PH	267.6	176.6*	145	179.8*	352.8*	187.7	63.1	205*
NSL	0.2	1.8**	3.4**	1.1**	0.3	0.9	1	1.2**
NSS	3.3	31.2**	32	29.4**	50.9**	17.1*	40.9**	32.6**
SP	1110.9	77666.7**	13927.3	72752.2**	592644.4**	50289.3*	227841**	45211.5**
SW	0.1	0.1*	0.1	0.2*	0.1	0.1	0.2	0.2**
SY	80.6	823.8**	90.3	815.6**	6073.7**	548.9**	2061.2**	637.6**
DF	0.3	38.8**	13.8**	53.3**	11.4**	73.1**	55.7**	42.8**
DM	4.9	54.7**	23.5**	72.8**	19.9**	35.9**	181.4**	64.2**
OC	0.1	13.4**	12.6**	9.5**	73.6**	12.7**	2.5**	9.6**
PC	0.7	12.3**	8.2**	15.1**	1.3	1.7**	12.6**	22.5**
EAC	1	439.0**	435.2**	471.8**	6.8	1063.7**	673.1**	125.5**
OAC	1.5	100.9**	68.3**	106.5**	251.1**	212.8**	63.9**	64.1**
GLC	3.7	789.6**	816.5**	832.6**	0.4	1834.6**	87.5**	517.9**
LeicC	0.2	6.2**	4.9**	7.2**	2.0**	15.0**	0.3	4.9**
LnicC	0	6.3**	2.3**	4.7**	58.4**	2.3**	6.2**	5.5**

Table 3 Mid parent heterosis (*MPH*) for fifteen characters in rapeseed

Cross No./ Characters	PH	SL	NSS	NSP	SW	SY	DF	DM	OC	PC	EAC	OAC	GLC	LeicC	LnicC
1	4.3**	3.5**	12.4**	23.1**	6.1**	19**	1.4	-1.2	2.4**	4.0**	-54.9 **	-10.2 **	44.0**	6.4**	-37.2 **
2	4.8**	-11**	-3.3**	25.2**	6.1**	15.3**	1.8	0.2	1.1	4.8**	91.0**	-5.9**	24.2**	-0.7	-4.7**
3	1.9	11.9**	-0.5	10.7**	2.5*	19.3**	1.6	0.1	4.8**	5.5**	76.2**	-2.2*	-1.2	13.6**	-1.6
4	5.6**	7.7**	9**	28.4**	0.5	-0.1	0.2	-1.4	3.1**	0	59.1**	-13.7**	-5.9**	-2.7**	-16.2**
5	6**	10.6**	19.6**	19.7**	-0.7	0.3	-1.7	0.2	0.9	5.0**	95.7**	-3.0**	-6.8**	10.8**	-2
6	6.1**	3.7**	11.6**	15.5**	5.9**	22.6**	2.5*	0.2	8.8**	-5.5**	-15.8**	-8.6**	28.5**	10.4**	-13.7**
7	6.7**	-10.9**	-3.9**	17.4**	5.9**	18.6**	2.9**	1.5	7.4**	-4.9**	26.5**	-4.1**	12.5**	2.8**	-6.6**
8	3.7**	12.1**	-1.1	4.5**	2.3*	22.9**	2.7**	1.6	11.6**	-4.4**	-3.7**	-0.3	-8.7**	18.2**	-16.1 **
9	7.4**	7.9**	8.3**	20.2**	0.3	2.4**	1.2	0.2	9.7**	-8.9**	-29.9 **	-12.2 **	-12.8 **	0.6	-23.0 **
10	7.8**	10.8**	18.7**	12.5**	-0.9	2.9**	-0.5	1.8	7.2**	-4.8**	26.9**	-1.1	-13.5 **	15.1**	-31.1 **
11	-0.7	5.5**	15.2**	13.3**	5**	44.9**	1.2	0.1	2.9**	-3.4**	-59.1**	-10.2**	59.2**	-1.2	-22.8**
12	-0.3	-9.5**	-1.3	15.1**	5**	39.4**	1.6	1.4	1.6	-2.7**	2.4*	-5.9**	35.5**	-7.3**	-22.0 **
13	-2.9**	14.3**	1.6	2.7**	1.4	45.3**	1.4	1.5	5.3**	-2.2*	-33.7 **	-2.2*	5.8**	5.0**	-43.7 **
14	0.3	9.9**	11.6**	17.8**	-0.4	17.6**	0.3	-0.5	3.7**	-6.9**	-64.3 **	-13.7 **	0.4	-9.1**	-26.9 **
15	0.7	12.9**	22.8**	10.4**	-1.7	18.1**	-1.7	1.6	1.4	-2.6*	44.2**	-3.0**	-0.6	2.6*	-6.8**

Table 4 Better parent heterosis (*BPH*) for fifteen characters in rapeseed

Cross No./ Characters	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
PH	2	3**	-2.4*	4.4**	5.2**	2	3**	-2.4*	4.4**	5.2**	-3.4**	-3.4**	-3.4**	-3.4**	-3.4**
SL	-4.2**	-26.5**	11.1**	3.2**	8.6**	-4.2**	-26.5**	11.1**	3.2**	8.6**	-4.2**	-26.5**	11.1**	3.2**	8.6**
NSS	5.8**	-11.1**	-6.1**	5.8**	5.8**	4.4**	-11.1**	-6.1**	4.4**	4.4**	10.8**	-11.1**	-6.1**	10.8**	10.8**
NSP	15.6**	19.3**	-4.4**	25.3**	9.7**	15.5**	15.5**	-4.4**	15.5**	9.7**	11.2**	11.2**	-4.4**	11.2**	9.7**
SW	3.9**	3.9**	1.1	-2.6*	-5.1**	3.6**	3.6**	1.1	-2.6*	-5.1**	1.8	1.8	1.1	-2.6*	-5.1**
SY	6.3**	6.3**	6.3**	-5.6**	-4.9**	12.2**	12.2**	12.2**	-5.6**	-4.9**	35.2**	25.9**	35.9**	-5.6**	-4.9**
DF	0.7	0.7	0.7	-0.3	-3.7**	2.1*	2.9**	2.5*	-0.3	-3.7**	0.3	0.3	0.3	-0.3	-3.7**
DM	-2.3*	-2.3*	-2.3*	-2.3*	-2.3*	0.6	0.6	0.6	-0.6	0.6	-0.1	0.4	0.4	-0.6	0.4
OC	0.7	0.7	0.7	0.7	0.7	4.1**	1.5	9.3**	5.7**	1.2	1.7	1.5	1.7	1.7	1.2
PC	1.6	3.1**	4.4**	-5.8**	3.4**	-11.7**	-11.7**	-11.7**	-11.7**	-11.7**	-7.9**	-7.9**	-7.9**	-7.9**	-7.9**
EAC	-36.9**	446.1**	365.1**	414.7**	423.7**	7.2**	70.4**	22.2**	3.9**	62.5**	-57.0**	72.7**	4.5**	-33.1**	130.0**
OAC	-14.0**	-6.2**	-6.2**	-20.1**	-6.2**	-14.0**	-5.6**	-2.6*	-20.1**	-2.6*	-14.0**	-6.2**	-6.2**	-20.1**	-6.2**
GLC	34.9**	4.0**	-27.3**	-32.3**	-33.2**	22.7**	4.0**	-27.3**	-32.3**	-33.2**	34.9**	4.0**	-27.3**	-32.3**	-33.2**
LeicC	4.7**	-8.2**	8.1**	-11.6**	8.1**	4.7**	-8.2**	16.7**	-11.6**	13.6**	-6.4**	-11.6**	-6.4**	-11.6**	-6.4**
LnicC	-28.4**	4.0**	8.4**	-11.9**	2.6*	-6.6**	-3.0**	-12.0**	-22.8**	-31.2**	-11.5**	-14.5**	-37.6**	-22.7**	-1.8

Table 5 Commercial heterosis (*CH*) for fifteen characters in rapeseed (continue)

Cross No./ characters	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
PH	-2.3*	8.8**	6.6**	13.0**	9.1**	1.3	16.7**	13.7**	7.9**	1	8.4**	3.5**	8.0**	2.5*	4.0**
SL	18.4**	15.7**	3.9**	5.6**	18.4**	16.7**	40.0**	11.7**	8.7**	9.9**	22.5**	-5.6**	15.5**	-0.6	8.9**
NSS	3.6**	7.9**	13.6**	15.2**	23.9**	4.4**	6.0**	16.6**	11.0**	-11.3**	23.3**	-22.6**	3.2**	-9.0**	2.3*
NSP	16.7**	55.9**	46.7**	49.7**	72.5**	56.8**	62.2**	7.2**	45.2**	48.4**	48.5**	-16.6**	-22.5**	-25.7**	30.7**
SW	-4.1**	12.8**	1.1	3.5**	12.0**	0.7	1.6	-4.8**	-5.8**	11.2**	10.5**	4.1**	8.4**	8.6**	-0.2
SY	-9.8**	36.5**	15.4**	10.7**	23.2**	73.3**	41.0**	-5.5**	24.0**	-2.7**	9.3**	-55.2**	-52.0**	-58.9**	45.7**
DF	-4.3**	-5.3**	6.4**	1.1	2.1*	-10.6**	2.1*	-1.1	0	5.3**	2.1*	3.5**	3.2**	4.3**	2.1*
DM	-6.8**	-4.5**	-1.1	-0.9	-0.4	1.1	1.5	1.7	-6.6**	2.8*	-4.5**	-4.3**	-4.5**	-3.6**	-4.7**
OC	5.6**	-1.4	-4.6**	-1	0.2	0.5	4.8**	6.9**	-3.3**	-2.2*	4.8**	4.3**	0	-1	-3.0**
PC	21.2**	12.1**	7.5**	-10.8**	-4.6**	-6.0**	4.6**	-7.9**	11.3**	14.8**	14.8**	1.7	18.3**	17.3**	4.6**
EAC	-36.9**	446.1**	365.1**	414.7**	423.7**	92.9**	374.5**	240.2**	189.2**	352.5**	-22.6**	243.3**	107.7**	32.9**	357.0**
OAC	10.8**	-18.9**	-10.3**	-9.2**	-19.3**	2.3*	-3.6**	-8.4**	-4.6**	3.3**	10.1**	-24.3**	-0.1	-16.3**	-4.1**
GLC	-29.3**	33.3**	96.2**	110.3**	10.2**	25.0**	39.8**	119.2**	130.4**	-20.1**	-26.9**	10.4**	140.5**	47.7**	128.6**
LeicC	46.8**	-8.4**	-7.7**	19.4**	-1.3	26.1**	0.3	-2.9**	13.5**	-0.6	6.5**	1.6	17.4**	13.5**	-2.9**
LnicC	-28.4**	4.0**	8.4**	-11.9**	2.6*	2.5*	6.4**	-3.5**	-15.3**	-24.5**	-12.5**	-15.4**	-38.3**	-23.6**	-2.9**

* = Significant at level of *P*=0.05, ** = Significant at level of *P* = 0.01, **SOV** = source of variation, **d.f.**= degrees of freedom, ***BPH***= Better parent heterosis, ***MPH***= Mid parent heterosis,
CH= Commercial heterosis, **PH** = Plant height, **SL** = Siliqua length, NSS = Number of seed/siliqua, **NSP** = Number of siliquae/plant, **SW** = 1000 seed weight, **SY** = Seed yield/plant, **DF** = Days taken to 50% flowering, **DM** = Days taken to maturity, **OC** = Oil content, **PC** = Protein content, **EAC** = Erucic acid content, **OAC** = Oleic acid content, **GLC** = Glucosinolate content, **LeicC** = Linoleic acid content, **LnicC** = Linolenic acid content.