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RESEARCH PAPER

# Heterosis for yield contributing head traits in cabbage (*Brassica oleracea* var. *capitata*)

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**Abstract**

**B. Kibar, O. Karaağaç, and H. Kar. 2015. Heterosis for yield contributing head traits in cabbage (*Brassica oleracea* var. *capitata*). Cien. Inv. Agr. 42(2):205-216.** The present investigation was carried out to study the direction and magnitude of heterosis in twenty-four hybrids for yield contributing head traits in cabbage (*Brassica oleracea* var. *capitata* L.). A field experiment was conducted during the cabbage growing season of 2011-2012 at the Black Sea Agricultural Research Institute, Samsun, Turkey. Hybrids and parents were evaluated in a randomized block design with three replications. Measurements were performed for head weight, head diameter and head length to estimate mid parent and better parent heterosis in each hybrid. The direction and magnitude of mid parent and better parent heterosis among hybrids for all the head traits was found to be highly variable. The maximum and significant heterosis in favorable directions both over mid parent and better parent for head weight (73.6 and 62.3%, respectively), head diameter (39.6 and 39.1%, respectively) and head length (25.3 and 21.6%, respectively) was observed in the hybrid P8 × P14. In this study, the hybrids P8 × P14, P3 × P13, P3 × P14 and P8 × P13 were found to be promising hybrid combinations with regard to their per se performance for head traits and the magnitude of heterosis. These hybrids can be selected for commercial exploitation of hybrid vigor. Thus, the information generated from this study might be vital and useful for breeders to develop hybrid varieties with better head traits and high yield through heterosis breeding.

**Key words:** Cabbage, hybrid vigor, breeding, head traits, yield, yield components.

## Introduction

Cabbage (*Brassica oleracea* var. *capitata* L.), a member of Brassicaceae family, is an economically and nutritionally important vegetable crop that is grown and consumed widely around the globe (Chiang *et al.,* 1993). Cabbage is gaining popularity worldwide because it is inexpensive, has wider adaptability, and is available year-round (Singh *et al.,* 2010a). It is cultivated for its heads, which are consumed fresh in salads and in different culinary dishes and also preserved by pickling, dehydration or freezing (Posta and Berar, 2006). In addition, it is an important source of dietary nutrients and antioxidants (Kopsell *et al.,* 2004; Hounsome *et al.,* 2009; Singh *et al.,* 2009a).

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Cabbage is also an integral part of Turkish cuisine owing to its excellent taste, rich chemical composition, availability at local markets and low cost. In Turkey, cabbage is grown in an area of 14685 ha with a production of 496864 tons and productivity of 33.8 ton $ha^{-1}$ (TUIK, 2014). Approximately 20% of the total cabbage produced is derived from Samsun province in the Black Sea Region. Although domestic cultivars are available in Turkey, $F_1$ hybrids are used for intensive cabbage production owing to the presence of heterosis (Kar *et al.,* 2008). Heterosis, or hybrid vigor, refers to the superiority in performance of hybrid individuals compared with their parents (Shull, 1952). Today, heterosis is utilized as the most successful approach to increase the productivity of plants and hybrid breeding based on the heterosis effect, it is intensively used in cross-pollinated vegetable crops such as cabbage. High-yielding hybrids of cabbage can be developed successfully using heterosis breeding. Hybrid varieties have several advantages such as high yield, earliness, improved quality, uniformity, vigorous development and also resistance to diseases and pests. Hybrid varieties account for a significant proportion of cabbage production in Turkey; however, all hybrids are foreign and are very expensive. Information on the magnitude of heterosis is an important prerequisite for developing a good economically viable hybrid cabbage variety. Therefore, there is a great need to accelerate studies on heterosis with the aim of developing high-yielding hybrid varieties of cabbage in Turkey.

It is important to understand the degree and direction of hybrid vigor for its commercial exploitation. The magnitude of heterosis serves to guide the choice of desirable parents for developing superior $F_1$ hybrids. In addition to this, heterotic studies provide useful information for identifying true heterotic cross combinations, combining the abilities of the parents and their usefulness in hybridization programs (Singh *et al.,* 2004). Different rates of heterosis have been reported in cabbage for quality traits and yield, as well as its various components, by various researchers (Pandey *et al.,* 2004; Prakash and Verma, 2004; Pathak *et al.,* 2007; Singh, 2007; Singh *et al.,* 2009a,b). The results obtained in different studies on heterosis may vary according to environmental conditions, experimental materials and the properties of the experiments.

It was considered that head traits, such as head weight, head diameter and head length, play very important roles in cabbage yield, as these traits had highly significant and positive correlations with yield (Posta and Berar, 2006; Antonova, 2009; Singh *et al.,* 2010b). Thus far, no studies have been performed describing heterosis for head traits associated with cabbage yield in Turkey. Thus, the present study was conducted to estimate the magnitude and the direction of heterosis over mid parent and better parent for yield contributing head traits in twenty-four hybrids and to identify promising parents and hybrids with better head traits for increasing cabbage productivity.

## Materials and methods

The present investigation was carried out at the Black Sea Agricultural Research Institute, Samsun, Turkey during the cabbage growing period of 2011-2012. The experimental area is geographically situated at 41°13' NL and 39°29' EL at an altitude of 6 m above mean sea level (masl). It has a mild and humid climate with an average annual rainfall of 721.4 mm, annual relative humidity of 73.5%, and mean annual air temperature of 14.4°C (TUMAS, 2013). The soil of the experimental area is clay-loam with a pH value of 6.9, organic matter content of 1.36%, and lime ratio of 7.24%.

The experimental materials consisted of 14 diverse inbred lines that were used as parents and 24 $F_1$ hybrids. The parental lines were improved at the Black Sea Agricultural Research Institute after inbreeding during 10 generations and chosen for the present study after preliminary evaluation of different traits. A detailed description of the parental lines used in the study is presented in Table 1. Twelve female parents (P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, P11 and P12) were crossed with two male parents (P13 and P14) during the flowering period (April to May, 2011), and 24 cross combinations were obtained. Crosses were made manually using the standard procedure of hand emasculation and pollination. The seeds of $F_1$ hybrids were harvested 30-35 days after pollination and kept in cold storage.

The seeds of 38 cabbage materials were sown in multi-pot plastic trays on 18 July 2011, and seedlings were grown in a greenhouse according to standard procedures. The experiment was laid out in a randomized block design (RBD) with three replications. Each experimental plot consisted of two rows that were 7 m long with a row-to-row distance of 1 m and plant-to-plant distance of 0.7 m. Thirty-five-day-old seedlings of 24 $F_1$ hybrids along with 14 parents were transplanted in plots at the 4-5 true leaf stage. There were 20 plants for each hybrid and parent in each replication. The recommended agronomic practices and plant protection measures were followed uniformly to all the hybrids and parents for the duration of the experiment. At maturity, ten competitive plants were selected randomly from each of the $F_1$ hybrids and parents in each plot for observations. Data were recorded for head weight (kg), head diameter (cm) and head length (cm), and the means were computed to estimate heterosis.

The data were subjected to statistical analysis using SPSS 10.0 and the SAS package (SAS Institute Inc., Version 9.0., Cary, NC, 2004).

The magnitude of heterosis was expressed as a percentage increase or decrease in the $F_1$ hybrid over its mid parent (MP) and better parent (BP). Mid parent heterosis (relative heterosis) and better parent heterosis (heterobeltiosis) for all traits in each hybrid were calculated as suggested by Fonseca and Patterson (1968) using the following formulae.

**Table 1.** Description of the parental lines used in the study.

| Parental lines | Origin | Plant height (cm) | Plant diameter (cm) | Days to maturity | Shape of head in longitudinal section | Density of head | Length of interior stem (cm) | Diameter of interior stem (cm) | Opening status of leaves | Internal color of head |
|---|---|---|---|---|---|---|---|---|---|---|
| P1 | Samsun/Turkey | 32.0 | 63.0 | 134 | Transverse elliptic | Very dense | 8.5 | 3.0 | Bad | Whitish |
| P2 | Sakarya/Turkey | 44.5 | 94.5 | 93 | Transverse elliptic | Medium | 9.0 | 4.0 | Good | Cream |
| P3 | Samsun/Turkey | 44.0 | 86.5 | 100 | Transverse elliptic | Medium | 9.2 | 3.2 | Medium | Cream |
| P4 | Tokat /Turkey | 66.0 | 111.0 | 101 | Transverse elliptic | Medium | 12.0 | 3.5 | Good | Cream |
| P5 | USDA/USA | 41.0 | 72.0 | 91 | Circular | Dense | 8.0 | 3.7 | Bad | Yellowish |
| P6 | USDA/USA | 36.0 | 49.0 | 133 | Circular | Loose | 10.5 | 3.0 | Good | Yellowish |
| P7 | USDA/USA | 49.0 | 98.0 | 94 | Transverse narrow elliptic | Loose | 11.5 | 4.0 | Good | Cream |
| P8 | USDA/USA | 39.5 | 88.5 | 92 | Transverse elliptic | Loose | 9.0 | 3.0 | Good | Whitish |
| P9 | Bursa/Turkey | 57.5 | 106.0 | 124 | Transverse narrow elliptic | Medium | 9.5 | 3.2 | Good | Whitish |
| P10 | Tokat/Turkey | 53.5 | 96.5 | 99 | Transverse elliptic | Medium | 9.0 | 4.0 | Medium | Cream |
| P11 | Samsun/Turkey | 60.0 | 116.0 | 131 | Transverse narrow elliptic | Medium | 8.0 | 4.0 | Good | Yellowish |
| P12 | Balıkesir/Turkey | 50.5 | 114.0 | 95 | Transverse narrow elliptic | Medium | 10.0 | 4.0 | Medium | Cream |
| P13 | Samsun/Turkey | 42.5 | 84.5 | 102 | Circular | Medium | 10.5 | 3.5 | Medium | Cream |
| P14 | USDA/USA | 40.0 | 85.0 | 123 | Transverse narrow elliptic | Medium | 9.0 | 2.5 | Good | Whitish |

Mid parent heterosis (%) = $\frac{(F1-MP)}{MP} x100$

Better parent heterosis (%) = $\frac{(F1-BP)}{BP} x100$

where $F_1$ = mean value of the $F_1$ hybrid, MP = mean value of the two parents $\frac{(P1+P2)}{2}$, and BP = mean value of the better parent.

The statistical significance of heterosis was determined by t-test (Wynne *et al.,* 1970).

## Results and discussion

*Analysis of variance*

Analysis of variance for head traits is presented in Table 2, revealing significant differences (P≤0.01) among the genotypes with respect to head weight, head diameter and head length. This indicates the existence of sufficient genetic variability among hybrids and their parents, which is a prerequisite for improving traits through breeding. Melaku (1993) noted the importance of genetic diversity for the expression of heterosis. The differences among parents and crosses for all the traits were also highly significant (P≤0.01). These results are in agreement with the findings of Pathak *et al.* (2007) and Singh *et al.* (2009a), who observed significant differences in mean squares among parents and hybrids for various traits in cabbage. The mean squares of parents vs. crosses for all the traits investigated were significantly different (P≤0.01). In addition, the variance among lines was found to be highly significant (P≤0.01) for all the traits. Similarly, testers showed highly significant differences (P≤0.01) for all head traits studied except for head diameter. Additionally, as shown in Table 2, the line x tester interaction was significant (P≤0.01) for all the traits. Our findings were similar to the results of Singh *et al.* (2009c) and Singh *et al.* (2011) for cabbage.

*Mean performances of the parents and their crosses*

The mean performances of 14 parents and 24 $F_1$ hybrids regarding head traits are provided in Table 3. Head weight is the most important component affecting yield in cabbage; thus, a large head weight is of prime importance when breeding high-yield varieties. The mean values of head weight among the parents ranged from 1.00 to 3.70 kg, whereas the mean data for this trait in $F_1$ hybrids ranged from 2.00 to 4.15 kg. In all the parents examined, the maximum head weight was observed in parent P4, while the minimum head weight was noted in parent P6. The highest head weight among the hybrids was found in the hybrid P3 × P13 followed by the hybrids P2 × P13 and P8 × P14. However, the cross P10 × P13 was identified as having the lowest mean value for head weight.

Head diameter directly influences cabbage yield and is an important parameter in cabbage breeding. It is apparent from Table 3 that the mean head diameters of parents and $F_1$ hybrids varied from 18.8 (P5) to 26.7 cm (P11) and 17.3 (P11 × P14) to 30.8 cm (P8 × P14), respectively. The parents P11, P7 and P9 possessed high mean head diameter values, and the cross combinations P8 × P14, P8 × P13 and P3 × P13 showed better performance (> 28.0 cm) than the other hybrids for this trait.

Head length is also a major yield contributing character in cabbage. The parental head length means indicated that parents P4 and P10 had a maximum head length of 20.0 cm, whereas parents P1 and P5 had the lowest head length of 15.5 cm. Among the 24 $F_1$ hybrids, the hybrid P11 × P13 displayed the highest value of head length (23.2 cm), closely followed by hybrid P12 × P13, with a mean value of 23 cm. Conversely, the minimum head length was recorded in the cross P6 × P14 (13.5 cm).

**Table 2.** Analysis of variance for head traits in cabbage.

| Source of variation | Degrees of freedom | Mean squares | | |
|---|---|---|---|---|
| | | Head weight (kg) | Head diameter (cm) | Head length (cm) |
| Repetitions | 2 | 0.007NS | 2.970* | 4.717** |
| Genotypes | 37 | 1.384** | 26.644** | 15.217** |
| Parents | 13 | 1.867** | 23.305** | 7.475** |
| Crosses | 23 | 1.150** | 27.714** | 18.527** |
| Parents vs. Crosses | 1 | 0.485** | 45.434** | 39.819** |
| Lines | 11 | 2.063** | 27.171** | 7.000** |
| Testers | 1 | 1.500** | 3.375NS | 20.167** |
| Line x Tester | 11 | 0.206** | 30.469** | 29.904** |
| Error | 74 | 0.011 | 0.906 | 0.800 |
| Total | 113 | | | |
| CV (%) | | 3.80 | 3.98 | 4.80 |
| Mean | | 2.69 | 23.89 | 18.63 |

*P≤0.05, **P≤0.01, NS: Non-significant.

From the mean performance of the genotypes, it is evident that, in general, hybrids exhibited greater variation compared to their parents with respect to head weight, head diameter and head length, and the mean values of hybrids were desirably higher than those of the parents for head traits. The higher mean value and range of hybrids in comparison with parents indicate the presence of positive heterosis in general. The prime criterion used for the evaluation of hybrids was based on *per se* performance of different traits. The hybrids P3 × P13, P8 × P14 and P8 × P13 showed the highest *per se* performance with regard to the three traits studied.

The values of head weight, head diameter and head length of the parents and hybrids determined in this study were higher than those of Singh *et al.* (2009a). These differences may be attributed to diversity in experimental materials or other environmental factors.

*Heterosis*

In the present study, heterosis values estimated over mid parent (MP) and better parent (BP) for the head traits of hybrids are presented in Table 4. The magnitude and the direction of heterosis in hybrids showed great differences with respect to cross combinations and the studied traits. The number of crosses displaying significantly positive and negative heterosis, the range of heterosis and the best crosses for head traits are depicted in Table 5.

Head weight is considered to be associated directly with yield; therefore, positive heterosis for this trait is desirable. The heterosis values over mid parent for head weight among different $F_1$ hybrids ranged from -34.4 (P10 × P13) to 73.6% (P8 × P14). In general, mid parent heterosis values were significant in most of the crosses for head weight. Although sixteen crosses exhibited positive heterosis over mid parent, heterosis at a significant level was observed in eleven crosses. Among the twenty-four cross combinations, five crosses had positive but non-significant mid parent heterosis for this trait. Eight cross combinations showed significantly negative heterosis over mid parent. The highest significant mid parent heterosis value was obtained from the hybrid P8 × P14, which showed a value as high as 73.6%. Similarly, highly significant heterosis in the desired positive direction over mid parent was determined in four hybrids: P3 × P13 (62.7%),

**Table 3.** Mean performance of the parents and their crosses with respect to head traits in cabbage.

| S. No. | Genotypes | Head weight (kg) | Head diameter (cm) | Head length (cm) |
|---|---|---|---|---|
| Parents | | | | |
| 1 | P1 | 1.90 | 19.0 | 15.5 |
| 2 | P2 | 2.70 | 22.8 | 17.8 |
| 3 | P3 | 2.10 | 21.5 | 17.2 |
| 4 | P4 | 3.70 | 24.5 | 20.0 |
| 5 | P5 | 1.80 | 18.8 | 15.5 |
| 6 | P6 | 1.00 | 19.0 | 17.0 |
| 7 | P7 | 3.10 | 26.5 | 18.7 |
| 8 | P8 | 2.30 | 22.2 | 17.0 |
| 9 | P9 | 3.60 | 26.0 | 19.5 |
| 10 | P10 | 3.10 | 25.0 | 20.0 |
| 11 | P11 | 3.50 | 26.7 | 18.0 |
| 12 | P12 | 2.70 | 25.5 | 18.2 |
| 13 | P13 | 3.00 | 23.5 | 19.7 |
| 14 | P14 | 2.00 | 22.0 | 16.0 |
| | Mean of lines | 2.63 | 23.1 | 17.9 |
| | Mean of testers | 2.50 | 22.8 | 17.8 |
| Crosses (♀×♂) | | | | |
| 1 | P1 × P13 | 2.32 | 24.3 | 16.2 |
| 2 | P1 × P14 | 2.07 | 23.2 | 18.0 |
| 3 | P2 × P13 | 3.73 | 24.2 | 21.3 |
| 4 | P2 × P14 | 3.40 | 23.5 | 19.0 |
| 5 | P3 × P13 | 4.15 | 29.0 | 20.8 |
| 6 | P3 × P14 | 3.00 | 26.0 | 19.0 |
| 7 | P4 × P13 | 2.45 | 23.3 | 16.5 |
| 8 | P4 × P14 | 2.58 | 23.8 | 19.0 |
| 9 | P5 × P13 | 3.20 | 26.3 | 22.0 |
| 10 | P5 × P14 | 2.22 | 22.4 | 16.8 |
| 11 | P6 × P13 | 2.12 | 22.2 | 17.0 |
| 12 | P6 × P14 | 2.03 | 22.3 | 13.5 |
| 13 | P7 × P13 | 3.17 | 26.8 | 22.2 |
| 14 | P7 × P14 | 2.70 | 25.8 | 18.0 |
| 15 | P8 × P13 | 3.48 | 30.3 | 21.3 |
| 16 | P8 × P14 | 3.73 | 30.8 | 20.7 |
| 17 | P9 × P13 | 2.47 | 23.8 | 21.0 |
| 18 | P9 × P14 | 2.27 | 22.3 | 16.8 |
| 19 | P10 × P13 | 2.00 | 20.0 | 16.0 |
| 20 | P10 × P14 | 2.65 | 24.3 | 18.7 |
| 21 | P11 × P13 | 2.48 | 22.0 | 23.2 |
| 22 | P11 × P14 | 2.13 | 17.3 | 19.1 |
| 23 | P12 × P13 | 3.06 | 26.2 | 23.0 |
| 24 | P12 × P14 | 2.42 | 24.8 | 19.0 |
| | Mean of hybrids | 2.74 | 24.4 | 19.1 |
| | LSD (0.01) | 0.21 | 2.05 | 1.93 |
| | CV (%) | 25.2 | 12.8 | 12.7 |

P3 × P14 (46.3%), P2 × P14 (44.7%) and P6 × P14 (35.1%). The cross P10 × P13 (-34.4%) displayed the lowest significant heterosis over mid parent followed by the crosses P4 × P13 (-26.9%) and P9 × P13 (-25.3%). The extent of heterosis exhibited by the hybrids over better parent for head weight varied from -39.0 (P11 × P14) to 62.3% (P8 × P14). Significantly better parent heterosis was observed in all except four crosses for the trait. Out of twenty-four crosses, twelve crosses had greater head weight than the better parent; however, only eight of them showed desirable and highly significant positive heterobeltiosis. In terms of head weight, the hybrids P1 × P14, P6 ×

P14, P7 × P13 and P12 × P13 had non-significant positive heterosis over better parent. Percentages of negative heterosis in twelve crosses over better parent were found to be highly significant. The maximum positive and highly significant heterobeltiosis for this trait was recorded in the cross P8 × P14 (62.3%) followed by P3 × P14 (42.9%) and P3 × P13 (38.3%). The minimum significantly negative level of better parent heterosis for head weight was determined in P11 × P14 hybrid with -39.0%. In relation to head weight, the crosses P8 × P14, P3 × P13, P3 × P14, P2 × P14 and P6 × P14 for mid parent heterosis were the top five crosses, while the crosses P8 × P14, P3 × P14, P3 × P13, P2 × P14 and P2 × P13 were the best crosses for better parent heterosis (Tables 4 and 5). According to Swaminathan *et al.* (1972) heterobeltiosis of more than 20% could offset the cost of hybrid seed. Thus, the crosses showing more than 20% of heterobeltiosis (viz., P8 × P14, P3 × P14, P3 × P13, P2 × P14 and P2 × P13) may be exploited for hybrid cabbage production. In this study, the mean mid parent heterosis value of all combinations for head weight was positive with a value of 10.2%, indicating that the hybrids had a greater head weight than their respective parents. On the other hand, the average heterosis for all crosses over better parent for the trait was in the undesirable negative direction, with a value of -3.8% (Table 4). Heterosis breeding was recommended to improve the net head weight of cabbage by Singh (2007). In contrast to the present study, Pandey *et al.* (2004), Pathak *et al.* (2007) and Singh *et al.* (2009a) observed higher percentages of heterosis for net head weight in cabbage.

Head diameter is also considered as one of the important yield components in cabbage, and positive heterosis for this trait is preferable. All twenty-four crosses exhibited highly significant ($P \leq 0.01$) mid parent and better parent heterosis for head diameter in both directions. The magnitude

**Table 4.** Heterosis (%) over mid parent (MP) and better parent (BP) for head traits of cabbage hybrids.

| | | Head weight (kg) | | Head diameter (cm) | | Head length (cm) | |
|---|---|---|---|---|---|---|---|
| S. No. | Crosses | MP | BP | MP | BP | MP | BP |
| 1 | P1 × P13 | -5.4* | -22.8** | 14.5** | 3.5** | -8.1** | -17.8** |
| 2 | P1 × P14 | 6.0 | 3.3 | 13.0** | 5.3** | 14.3** | 12.5** |
| 3 | P2 × P13 | 31.0** | 24.4** | 4.3** | 2.8** | 13.8** | 8.5** |
| 4 | P2 × P14 | 44.7** | 25.9** | 4.8** | 2.9** | 12.3** | 6.5** |
| 5 | P3 × P13 | 62.7** | 38.3** | 28.9** | 23.4** | 12.7** | 5.6** |
| 6 | P3 × P14 | 46.3** | 42.9** | 19.5** | 18.2** | 14.5** | 10.5** |
| 7 | P4 × P13 | -26.9** | -33.8** | -2.8** | -4.8** | -16.8** | -17.5** |
| 8 | P4 × P14 | -9.4** | -30.2** | 2.5** | -2.7** | 5.6** | -5.0** |
| 9 | P5 × P13 | 33.3** | 6.7** | 24.5** | 12.1** | 25.1** | 11.9** |
| 10 | P5 × P14 | 16.7** | 10.8** | 9.6** | 1.7** | 6.9** | 5.2** |
| 11 | P6 × P13 | 5.8 | -29.4** | 4.3** | -5.7** | -7.3** | -13.6** |
| 12 | P6 × P14 | 35.1** | 1.3 | 8.6** | 1.2** | -18.2** | -20.6** |
| 13 | P7 × P13 | 3.8 | 2.2 | 7.2** | 1.1** | 15.7** | 12.7** |
| 14 | P7 × P14 | 5.9* | -12.9** | 6.5** | -2.5** | 3.8** | -3.6** |
| 15 | P8 × P13 | 31.4** | 16.1** | 32.8** | 29.1** | 16.4** | 8.5** |
| 16 | P8 × P14 | 73.6** | 62.3** | 39.6** | 39.1** | 25.3** | 21.6** |
| 17 | P9 × P13 | -25.3** | -31.5** | -3.7** | -8.3** | 7.2** | 6.8** |
| 18 | P9 × P14 | -19.0** | -37.0** | -6.9** | -14.1** | -5.2** | -13.7** |
| 19 | P10 × P13 | -34.4** | -35.5** | -17.5** | -20.0** | -19.3** | -20.0** |
| 20 | P10 × P14 | 3.9 | -14.5** | 3.3** | -2.9** | 3.7** | -6.7** |
| 21 | P11 × P13 | -23.6** | -29.0** | -12.3** | -17.5** | 23.0** | 17.8** |
| 22 | P11 × P14 | -22.4** | -39.0** | -28.8** | -35.0** | 12.2** | 5.9** |
| 23 | P12 × P13 | 7.3** | 1.9 | 6.9** | 2.7** | 21.6** | 16.9** |
| 24 | P12 × P14 | 2.8 | -10.5** | 4.6** | -2.6** | 11.4** | 4.8** |
| Mean | | 10.2 | -3.8 | 6.8 | 1.1 | 7.1 | 1.6 |

*$P \leq 0.05$, **$P \leq 0.01$.

of heterosis for the trait changed from -28.8 to 39.6% over mid parent. Out of twenty-four cross combinations, eighteen showed highly significant and positive heterosis over mid parent for head diameter. The remaining six combinations exhibited significantly negative mid parent heterosis. Among all crosses, the cross P8 × P14 had the highest significant mid parent heterosis value (39.6%), followed by crosses P8 × P13 (32.8%), P3 × P13 (28.9%) and P5 × P13 (24.5%). Conversely, the lowest mid parent heterosis value (-28.8%) was observed in the hybrid P11 × P14. The better parent heterosis ranged from -35.0 to 39.1% for this trait. A total of thirteen hybrids showed significantly better parent heterosis in the desirable positive direction, while eleven hybrids had significantly negative better parent heterosis in head diameter. The heterosis over better parent for this trait was the maximum in the hybrid P8 × P14 with a value of 39.1%. On the contrary, minimum significant negative heterobeltiosis was exhibited by the hybrid P11 × P14 (-35.0%). Three hybrids, P8 × P14, P8 × P13 and P3 × P13, demonstrated more than 20% significant desired positive heterobeltiosis. Regarding mid parent heterosis, the crosses P8 × P14, P8 × P13, P3 × P13 and P5 × P13 were the best crosses for head diameter. The crosses P8 × P14, P8 × P13 and P3 × P13 with highly significant positive heterobeltiosis effects were found to be as superior cross combinations for this trait (Tables 4 and 5). The mean mid parent heterosis value of all $F_1$ hybrids was 6.8%, which indicates that hybrids are superior to parents with respect to head diameter. The mean heterobeltiosis value for the trait was in the desirable positive direction (1.1%), but it was relatively low (Table 4). In relation to better parent heterosis values for this trait in cabbage almost similar results were also reported by Singh *et al.* (2009a).

The positive direction of heterosis for head length, which is one of the main yield components in cabbage, is also considered to be desirable. The values of mid parent and better parent heterosis were highly significant ($P \leq 0.01$) in all of the crosses for the trait under consideration. Heterosis over mid parent ranged from -19.3 to 25.3%. A total of eighteen cross combinations showed significant mid parent heterosis in the desired positive direction. Significant negative mid parent heterosis values for this trait were obtained from only six of the twenty-four cross combinations. Among the twenty-four hybrids studied, the highest significant positive heterosis over mid parent was achieved by the hybrid P8 × P14 (25.3%) followed by the hybrids P5 × P13 (25.1%), P11 × P13 (23.0%) and P12 × P13 (21.6%). Contrary to this, the lowest heterosis over mid parent was provided by the hybrid P10 × P13 (-19.3%) followed by P6 × P14 (-18.2%). Regarding head length, the magnitude of heterobeltiosis was found in the range of -20.6 to 21.6%. Out of twenty-four crosses tested, fifteen crosses displayed significantly positive heterobeltiosis. With respect to head length, significant heterobeltiosis in the negative direction was noted in nine combinations. The highest significant percentage of heterobeltiosis for the trait was also noted in the hybrid P8 × P14 (21.6%), whereas the hybrid P6 × P14 (-20.6%) had the lowest significant better parent heterosis. Only one hybrid, P8 × P14, showed more than 20% heterobeltiosis. The hybrids P8 × P14, P5 × P13, P11 × P13 and P12 × P13, which exhibited high mid parent heterosis for this trait, were promising hybrid combinations. Likewise, the crosses P8 × P14, P11 × P13 and P12 × P13, which showed high significant positive heterobeltiosis, were good combinations for improving this trait (Tables 4 and 5). The average mid parent heterosis for the trait was positive, with a value of 7.1%. Similarly, the mean better parent heterosis over all crosses was in the desirable positive direction with value of 1.6%, which means that hybrids have a greater head length than their respective better parents (Table 4). These findings are supported by the results of Singh *et al.* (2009a), who also found similar better parent heterosis values for this trait in cabbage.

The results of the heterosis studies showed that some of the hybrids manifested positive heterosis while others exhibited negative heterosis, mainly

**Table 5.** Number of crosses showing significant heterosis, ranges of heterosis and best crosses for head traits in cabbage.

| Heterosis | Traits | Number of crosses showing significant heterosis | | Range of heterosis | The best crosses | Heterosis (%) |
|---|---|---|---|---|---|---|
| | | Positive | Negative | | | |
| Mid parent heterosis | Head weight | 11 | 8 | -34.4 to 73.6 | P8 × P14 | 73.6** |
| | | | | | P3 × P13 | 62.7** |
| | | | | | P3 × P14 | 46.3** |
| | | | | | P2 × P14 | 44.7** |
| | | | | | P6 × P14 | 35.1** |
| | Head diameter | 18 | 6 | -28.8 to 39.6 | P8 × P14 | 39.6** |
| | | | | | P8 × P13 | 32.8** |
| | | | | | P3 × P13 | 28.9** |
| | | | | | P5 × P13 | 24.5** |
| | Head length | 18 | 6 | -19.3 to 25.3 | P8 × P14 | 25.3** |
| | | | | | P5 × P13 | 25.1** |
| | | | | | P11 × P13 | 23.0** |
| | | | | | P12 × P13 | 21.6** |
| Better parent heterosis | Head weight | 8 | 12 | -39.0 to 62.3 | P8 × P14 | 62.3** |
| | | | | | P3 × P14 | 42.9** |
| | | | | | P3 × P13 | 38.3** |
| | | | | | P2 × P14 | 25.9** |
| | | | | | P2 × P13 | 24.4** |
| | Head diameter | 13 | 11 | -35.0 to 39.1 | P8 × P14 | 39.1** |
| | | | | | P8 × P13 | 29.1** |
| | | | | | P3 × P13 | 23.4** |
| | Head length | 15 | 9 | -20.6 to 21.6 | P8 × P14 | 21.6** |
| | | | | | P11 × P13 | 17.8** |
| | | | | | P12 × P13 | 16.9** |

**P≤0.01.

due to varying extent of genetic diversity between parents of different cross combinations for the head traits studied. The exploitation of hybrid vigor was judged by the *per se* performance of hybrids and magnitude of heterosis (Richharia and Singh, 1983). A good hybrid should manifest a high level of heterosis for commercial exploitation (Malini *et al.,* 2006). Four hybrids, P8 × P14, P3 × P13, P3 × P14 and P8 × P13, were found to be optimal, as they exhibited a higher magnitude of heterosis and also possessed high *per se* performance for head traits. Thus, these hybrids have the potential to improve the head traits in cabbage through heterosis breeding. In addition, a total of eleven hybrids (P1 × P14, P2 × P13, P2 × P14, P3 × P13, P3 × P14, P5 × P13, P5 × P14, P7 × P13, P8 × P13, P8 × P14 and P12 × P13) showed positive heterosis both over mid parent and better parent for all the traits studied. The high heterosis response observed in most of the hybrids may most likely be due to the dominant nature of genes responsible for the traits studied. On the other hand, the crosses P4 × P13, P9 × P14 and P10 × P13 presented significantly negative heterosis over both mid parent and better parent for all the head traits. Such crosses are worthless for hybrid vigor in yield improvement. The negative heterosis observed in some of the crosses for different traits may be due to the combination of the unfavorable genes of the parents. Singh *et al.* (2009b) determined negative heterobeltiosis for all mineral elements in cabbage. Hladni *et al.* (2007) also reported that heterosis does not appear in all hybrid combinations of the $F_1$ generation and heterotic effects are different for different traits. Based on the overall hybrid effects of parental combinations, the two female parents P8 and P3 showed good performance in cross combinations for head traits. As the male parent of $F_1$ hybrids, the performance of the inbred line P14 was better compared to that of P13. These cabbage genotypes can be utilized as promising parents in future breeding programs to improve hybrid varieties, as they exhibited desirable hybrid effects for head traits.

In the present study, highly significant positive heterosis regarding head traits was observed by a majority of the hybrids, indicating that this trait can be improved through heterosis breeding. The data on heterosis indicated that the best hybrid was P8 × P14, as it exhibited the maximum positive and highly significant heterosis over both mid parent and better parent for head weight, head diameter and head length. Likewise, the hybrids P3 × P13, P3 × P14 and P8 × P13 showed desirable and significant heterosis both over mid parent and better parent for all the traits studied. These hybrids also showed a good *per se* performance for head traits. Taken together, our data indicate that the hybrids P8 × P14, P3 × P13, P3 × P14 and P8 × P13 were highly suitable for heterosis breeding based on *per se* performance and the magnitude of heterosis. Hence, these hybrids could be utilized for commercial exploitation of heterosis to develop high-yielding hybrid varieties of cabbage.

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## Resumen

**B. Kibar, O. Karaağaç y H. Kar. 2015. Heterosis de las características productivas de la cabeza del repollo (*Brassica oleracea* var. *capitata*). Cien. Inv. Agr. 42(2):205-216.** Esta investigación se ha realizado para investigar la dirección y la dimensión de heterosis en los veinticuatro mestizajes correspondiendo con las características cabezales productivas del repollo (*Brassica oleracea* var *capitata* L.). El experimento de area se hizo durante la temporada 2011-2012, en el Instituto de Investigaciones Agriculturas en Samsun, Turkía. Los mestizajes y los portainjertos se evaluaron en el diseño en bloques aleatorizados, con tres repeticiones. Para hacer la estimación de heterosis de portainjerto superior y media de cada mestizaje se midió el peso, el diámento y la longitud de la cabeza de repollo. Para todas las caracteristicas de la cabeza, la dirección y la dimención del heterosis medio y superior entre los mestizajes fue muy variable. En los mestizajes de P8 × P14, el peso de la cabeza (73,6 y 62,3%, respectivamente), el diámetro (39,6 y 39,1, respectivamente), y la longitud de la cabeza (25,3 y 21,6%, respectivamente), se observó un maáimo y una cantidad importante de heterosis en el portainjerto medio y superior suficiente. En este estudio, las combinaciones de mestizajes P8 × P14, P3 × P13, P3 × P14 y P8 × P13, resultaron ser prometedoras en cuanto al rendimiento *per se* de las caracteristicas de la cabeza y la magnitud de la heterosis. Estos mestizajes se pueden elegir para aprovechar de vigor híbrido de heterosis, en el comercio. Por lo cual, las informaciones obtenidas gracias a estos estudios, pueden ser beneficiosos y vitales para cultivar unos tipos de mestizajes que tienen una productividad superior y mejores características de la cabeza del repollo a través del mejoramiento de heterosis por los agricultores.

**Palabras clave**: Características de la cabeza, col, componentes de rendimiento, mejoramiento, repollo, productividad, vigor híbrido.

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