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# Multi-environment Manifestation of Heterosis for Morphological and Quality Traits in Maize (*Zea mays* L.)

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***Authors' contributions***

*This work was carried out in collaboration among all authors. Author AK carried out the experiment and prepared the first hand manuscript. Authors NK, PB and KK carried out collection of reviews and data analysis. Author AD provided guidance during conduction of experiment, while proof reading and correction of manuscript was carried out by author MKS. All authors have read the manuscript thoroughly and approved it.*

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## ABSTRACT

An investigation was carried out with 10 parents, their 45 hybrids mated in half-diallel fashion and 4 checks in RBD for estimation of heterosis in two environment (*Kharif,* 2014 and *Rabi,* 2014-15) at the Instructional farm, RCA, MPUAT, Udaipur, India. The average productivity of maize in USA is 11.07 MT ha$^{-1}$ while, in India it is only 3.02 MT ha$^{-1}$ during 2018-19. We lag far behind USA and are still not able to harness the optimum yield potential in maize that could partly be addressed by evolving hybrid maize cultivar. The present study aims to ~~is~~ identify heterotic hybrids that could yield

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stably with better grain quality over a range of environments. Environment wise Analysis of variance revealed that mean squares due to genotypes were significant for all the traits in both the environments. Partitioning of total genotypic variance indicated significant contribution of parents for all the traits. Mean squares due to crosses were significant for all the traits under study except for days to 50% tasseling. Mean squares due to parents $v_s$. crosses were significant for all the traits except for days to 75% brown husk. Bartlett test showed homogeneity of error variance only for one trait *i.e.* grain oil content. The pooled analysis for grain oil content revealed significant differences between the environments. The mean squares due to genotypes including parents, crosses and parents vs. crosses were also significant. Significance of GE interaction for oil content indicates the influence of environments on the expression of this trait. The partitioning of GE interaction into those that by parents×environment and crosses×environment interaction were also significant. Two hybrids in $E_1$, *viz.,* $P_3 \times P_6$ and $P_2 \times P_4$ has shown significant negative economic heterosis for days to 50% tasseling, days to 50% silking and days to 75% brown husk. None of the hybrids has shown significant negative economic heterosis for these traits in $E_2$ environment. The hybrid $P_3 \times P_5$ exhibited maximum positive economic heterosis (6.71%) for grain oil content over the best check HQPM-5 on pooled basis. The hybrid $P_5 \times P_7$ (2.78%) in $E_1$ and $P_5 \times P_{10}$ (2.58%) in $E_2$ exhibited maximum positive economic heterosis for grain starch content over the best check HQPM-1. The maximum positive economic heterosis for grain protein content was exhibited by hybrid $P_5 \times P_8$ (4.14 %) in $E_1$ and by $P_3 \times P_5$ (2.49%) in $E_2$ over the best check HQPM-5.

*Keywords: Heterosis; environment; quality traits; Zea mays; maize protein; economic heterosis.*

## 1. INTRODUCTION

Maize is the third most widely cultivated cereal crop in the world after Rice and Wheat [1]. It is grown round the year in diverse ecologies and it records highest production and productivity among cereals. It is the primary staple food in many developing countries [2]. It caters to the dietary need of not only the humans but as feed to cattles and as an industrial input. It is believed to be originated in Southern Mexico or Northern Guatemala [3]. Maize grain is becoming increasingly popular in our country due to its huge demand particularly in poultry feed industry. Globally, maize is cultivated on an area of 191.16 mha, with total production of 1122.69 MT and average productivity of 5.87 $MTha^{-1}$. In India, maize is cultivated on an area of 9.20 mha with a total production of 27.80 MT and average productivity of 3.02 $MTha^{-1}$[4]. Maize is highly cross pollinated crop and shows handsome magnitude of hybrid vigour for various traits of economic importance. Information on extent of genetic diversity of parents and degree and direction of heterosis proves to be pivotal in developing superior $F_1$'s. Dominance gene action that culminates into hybrid vigour has direct bearing on the breeding methodology to be adopted for varietal improvement [5]. Maize consumption in World and India has grown up to 1130.60 MT and 27.50 MT, respectively [6] and with the exploitation of heterosis in development of hybrid maize varieties, India has become self reliant in meeting its domestic demand. Maize improvement program is under technological transition from open pollinated varieties (OPVs) and multi-parent hybrids (MHs) to single cross hybrids. The single cross hybrids exploit heterosis to the maximum extent and it eases maintenance of parental lines as well as hybrid seed production [7]. Nowadays, corn breeders endeavour to capitalize genetic material in order to develop new maize genotypes characterized by high yielding potentiality and better quality. For this, they need thorough knowledge about the type and relative magnitude of genetic variance components and their interaction with environments as well as heterosis for yield and its components. One of the most informative biometrical tool in this concern is diallel analysis which is widely and extensively used [8]. The degree of heterotic effect in $F_1$ is correlated with genetic diversity of the parental lines. Greater the divergence among the parents, higher is the heterosis and *vice-versa* [9,10]. However, environment can differentially affect the performance of inbred lines and hybrids and distort this relationship [7]. Keeping in view the above facts, the present study was designed with the objective to determine~~ing~~ extent and magnitude of heterosis for various morphological and quality traits in maize over the environments that could ultimately be utilized to develop maize hybrids with high yielding potential and better quality.

## 2. MATERIALS AND METHODS

### 2.1 Experimental Site and Design

The experimental materials consisted of 10 inbred lines which were crossed in half diallel fashion to generate 45 single cross hybrids, during *Rabi,* 2014 at the Instructional farm, Rajasthan College of Agriculture, Maharana Pratap University of Agriculture and Technology, Udaipur, India. These 45 hybrids, along with 10 parents and 4 standard checks (Table 1) were evaluated in Randomized Block Design with three replications during *Kharif,* 2014 ($E_1$) and *Rabi,* 2014-15 ($E_2$). The materials were evaluated in a single row plot of 4 m length, maintaining plant to plant distance of 25 cm. The recommended package of practices of Zone IVA of Rajasthan was adopted to raise a healthy crop stand.

### 2.2 Data Recording

The data for 8 quantitative traits *viz.,* days to 50% tasseling, days to 50% silking, days to 75% brown husk, plant height, ear height, grain oil content, grain starch content and grain protein content were recorded for both the environments ($E_1$ and E2) on 5 randomly selected plants in each entry~~,~~ except for days to 50% tasseling, days to 50% silking and days to 75% brown husk where, visual observations were recorded on plot basis. The mean data were subjected for statistical analysis.

### 2.3 Statistical Analysis

The trait mean values were subjected to ~~a~~Analysis of ~~v~~Variance (ANOVA) using the statistical analysis procedures of Panse and Sukhatme [11]. Average Heterosis [5], Heterobeltiosis [12] and Economic Heterosis [13] were calculated for individual as well as over the environments. The test for homogeneity of error variance for pooled analysis of variance was carried out as procedure suggested by Bartlett [14].

## 3. RESULTS AND DISCUSSION

Environment wise analysis of variance revealed significant difference among mean of genotypes for all the traits. The total genotypic variance was further partitioned into that assignable to parents, crosses and to parents $v_s$. crosses. Genotypic variance due to parents was significant for all the traits. Fraction of genotypic variance assignable to the crosses was significant for all the traits under study except for days to 50% tasseling. And proportion of genotypic variance assignable to parents $v_s$. crosses was significant for all the traits except for days to 75% brown husk. This suggested the presence of heterosis for most of the traits (Table 2). Similar results were observed by Sadaiah [15] and Avinashe[16].

Results from Bartlett test indicated that error variance was homogenous only for grain oil content, therefore, pooled analysis was carried out (Table 2). The pooled analysis revealed significant difference among the environments for this trait. The mean sum of squares was significant for all the sources of variation *i.e.* genotypes, crosses and the parents $v_s$. crosses. Significance of mean sum of squares due to GE interactions for grain oil content indicates the influence of environment on the expression of this trait. The partitioning of GE interaction into

**Table 1. List of maize parental inbreds and checks**

| Sl. No. | Inbred line, Code | Source |
|---|---|---|
| 1. | EIQ – 105 ($P_1$) | AICRP* on Maize, Udaipur |
| 2. | EIQ – 106 ($P_2$) | AICRP* on Maize, Udaipur |
| 3. | EIQ – 107 ($P_3$) | AICRP* on Maize, Udaipur |
| 4. | EIQ – 108 ($P_4$) | AICRP* on Maize, Udaipur |
| 5. | EIQ – 109 ($P_5$) | AICRP* on Maize, Udaipur |
| 6. | EIQ – 110 ($P_6$) | AICRP* on Maize, Udaipur |
| 7. | EIQ – 111 ($P_7$) | AICRP* on Maize, Udaipur |
| 8. | EIQ – 112 ($P_8$) | AICRP* on Maize, Udaipur |
| 9. | EIQ – 113 ($P_9$) | AICRP* on Maize, Udaipur |
| 10. | EIQ – 114 ($P_{10}$) | AICRP* on Maize, Udaipur |
| 11. | Pratap QPM Hybrid- 1 (Check-1) | AICRP* on Maize, Udaipur |
| 12. | Vivek QPM- 9 (Check-2) | VPKAS$^\dagger$, Almora |
| 13. | HQPM- 1 (Check-3) | CCSHAU$^\downarrow$, Karnal |
| 14. | HQPM- 5 (Check-4) | CCSHAU$^\downarrow$, Karnal |

**All India Coordinated Research Project, $^\dagger$Vivekanand Parvatiya Krishi Anusandhan Shala and $^\downarrow$Choudhary Charan Singh Haryana Agricutural University* that due to parents×environment and crosses×environment were also found to be significant (Table 3).

Among maturity related traits, the exploitable average heterosis ranged from -20.23 ($P_2 \times P_4$) to -2.26 % ($P_1 \times P_3$) in $E_1$ and from -7.52 ($P_3 \times P_{10}$) to -3.60% ($P_3 \times P_6$) in $E_2$ for days to 50% tasseling. A total of 36 and 17 hybrids exhibited significant negative average heterosis for this trait in $E_1$ and $E_2$ environments, respectively. For days to 50% silking, the exploitable average heterosis ranged from -22.63 ($P_2 \times P_4$) to -2.08% ($P_1 \times P_4$) in $E_1$ and from -7.65 ($P_3 \times P_{10}$) to -3.46% ($P_4 \times P_9$) in $E_2$. A total of 35 and 19 hybrids showed significant negative average heterosis for this trait in $E_1$ and $E_2$ environments, respectively. For days to 75% brown husk, the exploitable average heterosis ranged from -13.97 ($P_2 \times P_4$) to -1.72% ($P_3 \times P_8$) in $E_1$ and 28 hybrids showed significant superiority over the mid parental value. In $E_2$, negative significant average heterosis was exhibited only by 3 hybrids *viz.,* $P_1 \times P_6$ (-3.17%), $P_5 \times P_6$ (-2.61%) and $P_8 \times P_9$ (-2.61%) (Table 4).

Among plant type traits, the exploitable average heterosis ranged from -12.41 ($P_2 \times P_4$) to -16.78% ($P_3 \times P_6$) in $E_1$ while none of the hybrids in $E_2$ exhibited significant negative average heterosis for plant height. For ear height, 4 hybrids *viz.*, $P_3 \times P_6$ (-32.34%), $P_3 \times P_7$ (-21.03 %), $P_2 \times P_4$ (-20.15 %) and $P_3 \times P_8$ (-16.54%) in $E_1$ and only one hybrid $P_1 \times P_5$ (-18.88%) in $E_2$ exhibited significant negative average heterosis for this trait. Two hybrids exhibited significant negative average heterosis for plant height whereas, 4 hybrids exhibited significant negative average heterosis for ear height in $E_1$ environment. In $E_2$ environment, none of the hybrid showed significant superiority over average parental value for plant height while one hybrid showed significant superiority over average parental value for ear height (Table 5).

Among quality traits, the exploitable average heterosis for grain oil content ranged from 1.36 ($P_3 \times P_4$) to 102.49% ($P_3 \times P_5$) in $E_1$ and from 4.95 ($P_4 \times P_6$) to 59.59% ($P_1 \times P_8$) in $E_2$. Pooled analysis indicated 35 hybrids to be significantly superior over mid parental value for grain oil content. The number of hybrids exhibiting significant positive average heterosis were 32 and 35 in $E_1$ and $E_2$ environment, respectively (Table 7). For grain starch content, the exploitable average heterosis varied from 1.49 ($P_9 \times P_{10}$) to 15.74% ($P_5 \times P_7$) in $E_1$ and from 0.99 ($P_9 \times P_{10}$) to 16.71% ($P_5 \times P_{10}$) in $E_2$ environment, respectively. The number of hybrids exhibiting significant positive average heterosis were 31 and 43 in $E_1$ and $E_2$ environment, respectively. For grain protein content, the exploitable average heterosis ranged from 1.18~~%~~ ($P_1 \times P_4$) to 58.8% ($P_6 \times P_8$) and 40 hybrids showed significant positive average heterosis (Table 6). In $E_2$, the exploitable average heterosis ranged from 3.89% ($P_1 \times P_2$) to 53.66% ($P_6 \times P_8$) and 38 hybrids showed significant positive average heterosis. Assuncao [17], Amanullah [18] and Amiruzzaman [19] reported average heterosis for maturity related traits, whereas Ji [20], Muraya [21] and Vieira [22] for plant type traits. Average heterosis for grain oil content and grain starch content was reported by Assuncao [17] and for grain protein content by Yusuf [23].

Perusal of Table 4 showed that 19 hybrids exhibited significant negative heterobeltiosis for days to 50% tasseling, 17 hybrids for days to 50% silking and days to 75% brown husk each in $E_1$ environment. In $E_2$ environment, 7 hybrids showed significant negative heterobeltiosis for days to 50% tasseling and 6 hybrids for days to 50% silking. None of the hybrids showed significant negative heterobeltiosis for days to 75% brown husk in $E_2$ environment. Two hybrids in $E_1$ and none of the hybrid in $E_2$ environment exhibited significant negative heterobeltiosis for plant height. Similarly, 2 hybrids in $E_1$ and none of the hybrid in $E_2$ environment showed significant negative heterobeltiosis for ear height (Table 5). 25 hybrids showed significant positive heterobeltiosis for grain oil content while 33 hybrids showed significant positive heterobeltiosis for grain starch content in $E_1$ environment. Similarly, 26 hybrids showed significant positive heterobeltiosis for grain oil content while 37 hybrids showed significant positive heterobeltiosis for grain starch content in $E_2$ environment. For grain protein content, 32 hybrids in $E_1$ and 31 hybrids in $E_2$ showed significant positive heterobeltiosis. The presence of heterobeltiosis indicated that over dominance played an important role in the expression of all these traits. However, its magnitude and number of hybrids which exhibited significant heterobeltiosis were variable. Amanullah [18], Silva [24] and Khanorkar [25] reported heterobeltiosis for maturity and plant type traits.

Among maturity related traits, 2 hybrids in $E_1$, *viz.,* $P_3 \times P_6$ and $P_2 \times P_4$ has shown significant negative economic heterosis for days to 50% tasseling, days to 50% silking and days to 75% brown husk against the best check Vivek QPM-9.

**Table 2. Mean squares for different traits in maize (*Zea mays* L.)**

| SN | Traits | Env | Source | | | | | | Bartlett |
|---|---|---|---|---|---|---|---|---|---|
| | | | Rep | Genotype | Parent | Crosses | Parents vs crosses | Error | |
| | | | [2] | [54] | [9] | [44] | [1] | [108] | [1] |
| 1 | Days to 50% tasseling | 1 | 14.8061** | 28.2061** | 31.8667** | 22.7246** | 236.446** | 0.843098 | 130.755** |
| | | 2 | 41.2788* | 21.7246** | 31.8556** | 12.169 | 350.99** | 9.55657 | |
| 2 | Days to 50% silking | 1 | 6.66061** | 35.6135** | 31.8704** | 32.7569** | 194.99** | 0.808754 | 132.931** |
| | | 2 | 45.2788** | 24.9488** | 28.3852** | 16.5044** | 365.577** | 9.3899 | |
| 3 | Days to 75% brown husk | 1 | 3.07879* | 38.6123** | 36.6704** | 35.7306** | 182.885** | 0.942985 | 102.648** |
| | | 2 | 11.4606 | 17.3912** | 36.0926** | 13.8832** | 3.43468 | 7.7569 | |
| 4 | Plant height (cm) | 1 | 177.188* | 1211.56** | 574.578** | 673.232** | 30630.8** | 56.0768 | 9.35888** |
| | | 2 | 23.4606 | 1234.17** | 901.07** | 378.492** | 41882** | 30.9915 | |
| 5 | Ear height (cm) | 1 | 290.036** | 275.027** | 330.607** | 192.818** | 3392.01** | 27.3018 | 25.2005** |
| | | 2 | 218.806 | 450.418** | 902.207** | 250.415** | 5184.44** | 73.1085 | |
| 12 | Grain oil content (%) | 1 | 0.000447602 | 1.55289** | 1.54659** | 1.32145** | 11.793** | 0.00111516 | 0.3006 |
| | | 2 | 0.00381346* | 1.63659** | 1.29464** | 1.45774** | 12.5834** | 0.00100347 | |
| 13 | Grain starch content (%) | 1 | 1.12755* | 21.3268** | 4.01818** | 18.6917** | 293.05** | 0.323773 | 11.1071** |
| | | 2 | 0.0491102 | 23.0797** | 7.25162** | 18.5051** | 366.813** | 0.16955 | |
| 14 | Grain protein content (%) | 1 | 0.00373568 | 3.03108** | 2.08455** | 2.32621** | 42.5642** | 0.00426491 | 47.997** |
| | | 2 | 0.00424793 | 2.83954** | 1.89798** | 2.18448** | 40.1362** | 0.0170065 | |

*,** *Significant at 5 and 1 percent respectively (Model I)*

**Table 3. Pooled mean squares for grain oil content in maize (*Zea mays* L.)**

| Traits | Source | | | | | | | | | | | Bartlett |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Env | Rep/Env | Genotype | Parents | Crosses | Parents vs crosses | G×E | Parent×Env | Crosses×E | Parents vs Crosses×E | Pool Error | |
| | [1] | [4] | [54] | [9] | [44] | [1] | [54] | [9] | [44] | [1] | [216] | [1] |
| **Oil content (%)** | 0.162369** | 0.00213053 | 3.12674** | 2.80007** | 2.71076** | 24.3699** | 0.0627409** | 0.0411598** | 0.0684356** | 0.00640804* | 0.00105932 | 0.3006 |

*,** *Significant at 5 and 1 percent respectively (Model I)*

**Table 4. Extent of heterosis for days to 50% tasseling and days to 50% silking**

| SN. | Crosses | Env | Days to 50% tasseling | | | Days to 50% silking | | | Days to 75% brown husk | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | RH | Hb | EH | RH | Hb | EH | RH | Hb | EH |
| 1 | P1 ×P2 | E1 | -3.37** | -1.15 | | -2.66** | -1.61 | | 0.37 | | |
| 2 | P1×P2 | E2 | -1.99 | -1.34 | | -0.66 | -0.26 | | 0.53 | | |
| 3 | P1×P3 | E1 | -2.26* | | | 5.15** | | | 4.80** | | |
| 4 | P1×P3 | E2 | -1.32 | | | -1.56 | -0.26 | | 0.32 | | |
| 5 | P1 ×P4 | E1 | -3.83** | -3.30** | | -2.08* | -1.05 | | -1.97** | -0.72 | |
| 6 | P1×P4 | E2 | -1.47 | -1.34 | | -0.66 | -0.53 | | 2.93* | | |
| 7 | P1×P5 | E1 | -2.79* | -1.14 | | -3.92** | -3.16** | | -3.40** | -2.17* | |
| 8 | P1×P5 | E2 | -0.13 | | | -0.13 | | | -0.11 | | |
| 9 | P1×P6 | E1 | -2.54* | -0.00 | | 0.00 | | | 0.74 | | |
| 10 | P1×P6 | E2 | -4.17* | -1.60 | | -3.33 | -0.79 | | -3.17* | -0.87 | |
| 11 | P1×P7 | E1 | -1.42 | | | -2.69** | -0.55 | | -3.66** | -2.59** | |
| 12 | P1 ×P7 | E2 | -1.47 | -1.34 | | -0.26 | | | 1.53 | | |
| 13 | P1×P8 | E1 | -7.83** | -2.45 | | -6.18** | | | -5.07** | -1.56 | |
| 14 | P1×P8 | E2 | -5.00** | -3.48 | -0.00 | -5.70** | -4.21* | -0.00 | -0.64 | | |
| 15 | P1×P9 | E1 | -7.40** | -7.14** | | -6.60** | -6.35** | | -5.45** | -5.11** | |
| 16 | P1×P9 | E2 | -2.60 | | | -1.03 | | | 1.59 | | |
| 17 | P1×P10 | E1 | -6.84** | -2.75* | | -4.59** | -1.58 | | -2.46** | | |
| 18 | P1×P10 | E2 | -2.45 | | | -2.41 | | | 2.33 | | |
| 19 | P2×P3 | E1 | -4.05** | -3.49** | | -3.56** | -1.68 | | -1.12 | -0.75 | |
| 20 | P2×P3 | E2 | -3.28 | -2.64 | | -2.98 | -2.09 | | -1.04 | | |
| 21 | P2×P4 | E1 | -21.23** | -18.97** | -4.08** | -22.63** | -20.97** | -3.92** | -13.97** | -11.57** | -2.87** |
| 22 | P2×P4 | E2 | -1.06 | -0.53 | | -0.00 | | | 0.43 | | |
| 23 | P2×P5 | E1 | -10.29** | -9.77** | | -11.87** | -10.22** | | -6.72** | -4.10** | |
| 24 | P2×P5 | E2 | -1.33 | -0.80 | | -2.08 | -1.57 | | -0.63 | -0.42 | |
| 25 | P2×P6 | E1 | -6.05** | -5.78** | | -8.65** | -8.15** | | -4.51** | -3.79** | |
| 26 | P2×P6 | E2 | -3.75* | -1.85 | | -4.21* | -2.09 | | 0.73 | | |
| 27 | P2×P7 | E1 | -3.79** | -2.37 | | -2.72** | -1.65 | | -0.37 | -0.00 | |
| 28 | P2×P7 | E2 | -2.92 | -2.40 | | -3.00 | -2.87 | | 2.69* | | |
| 29 | P2×P8 | E1 | -0.89 | | | 1.14 | | | 2.48** | | |
| 30 | P2 ×P8 | E2 | -3.01 | -2.11 | | -3.48* | -2.35 | | -0.74 | -0.63 | |
| 31 | P2×P9 | E1 | -10.36** | -8.05** | | -10.40** | -9.68** | | -6.64** | -5.60** | |

| SN. | Crosses | Env | Days to 50% tasseling | | | Days to 50% silking | | | Days to 75% brown husk | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | RH | Hb | EH | RH | Hb | EH | RH | Hb | EH |
| 32 | P2×P9 | E2 | -2.46 | -0.53 | | -1.40 | | | 0.21 | | |
| 33 | P2×P10 | E1 | -8.60** | -2.30 | | -6.19** | -2.15 | | -0.71 | | |
| 34 | P2 ×P10 | E2 | -3.33 | -0.53 | | -3.04 | | | -1.36 | -0.63 | |
| 35 | P3×P4 | E1 | -6.18** | -2.91* | | -7.24** | -3.35** | | -4.92** | -1.88* | |
| 36 | P3×P4 | E2 | 0.13 | | | 0.13 | | | 1.06 | | |
| 37 | P3×P5 | E1 | -5.75** | -4.65** | | -7.53** | -3.91** | | -5.65** | -2.63** | |
| 38 | P3×P5 | E2 | -0.66 | | | -0.64 | -0.26 | | -0.42 | | |
| 39 | P3×P6 | E1 | -19.42** | -19.19** | -5.44** | -20.11** | -18.99** | -5.23** | -11.70** | -11.36** | -4.10** |
| 40 | P3×P6 | E2 | -3.60* | -2.34 | | -2.78 | -1.54 | | -0.72 | -0.62 | |
| 41 | P3×P7 | E1 | 1.47 | | | 0.83 | | | -0.00 | | |
| 42 | P3×P7 | E2 | -3.03 | -1.87 | | -4.13* | -3.39 | | -0.32 | | |
| 43 | P3×P8 | E1 | -5.07** | -2.45 | | -4.35** | -0.60 | | -1.72* | | |
| 44 | P3×P8 | E2 | -4.42* | -4.17* | | -4.35* | -4.10* | | -0.52 | | |
| 45 | P3×P9 | E1 | -4.79** | -1.74 | | -1.63 | | | -1.85* | -0.38 | |
| 46 | P3×P9 | E2 | -5.40** | -4.17* | | -4.05* | -2.82 | | 1.04 | | |
| 47 | P3×P10 | E1 | -5.95** | | | -1.84 | | | -0.72 | | |
| 48 | P3×P10 | E2 | -7.52** | -5.47** | | -7.65** | -5.64** | | -1.34 | -1.04 | |
| 49 | P4×P5 | E1 | -6.67** | -4.55** | | -9.56** | -9.33** | | -8.48** | -8.48** | |
| 50 | P4×P5 | E2 | -1.87 | -1.87 | | -2.34 | -1.57 | | 1.07 | | |
| 51 | P4×P6 | E1 | -7.56** | -4.62** | | -8.47** | -5.98** | | -7.86** | -4.55** | |
| 52 | P4×P6 | E2 | -4.03* | -1.60 | | -3.71* | -1.31 | | 1.59 | | |
| 53 | P4×P7 | E1 | -3.12** | | | -3.19** | -0.00 | | -4.16** | -1.85* | |
| 54 | P4×P7 | E2 | 0.27 | | | -0.65 | -0.26 | | 2.51 | | |
| 55 | P4×P8 | E1 | -1.44 | | | 3.89** | | | 1.11 | | |
| 56 | P4×P8 | E2 | -4.34* | -2.93 | | -4.79** | -3.41 | | 1.39 | | |
| 57 | P4×P9 | E1 | -6.27** | -6.01** | | -4.96** | -3.70** | | -3.05** | -1.46 | |
| 58 | P4×P9 | E2 | -3.77* | -1.33 | | -3.46* | -1.05 | | 0.42 | | |
| 59 | P4×P10 | E1 | -7.85** | -4.35** | | -5.05** | -3.09** | | -2.96** | -1.41 | |
| 60 | P4×P10 | E2 | -0.77 | | | -0.76 | | | 0.95 | | |
| 61 | P5×P6 | E1 | -2.58* | -1.73 | | -5.57** | -3.26** | | -4.57** | -1.14 | |
| 62 | P5×P6 | E2 | -3.25 | -0.80 | | -2.41 | -0.78 | | -2.61* | -1.48 | |
| 63 | P5×P7 | E1 | -4.93** | -2.96* | | -6.13** | -3.30** | | -5.97** | -3.70** | |
| 64 | P5×P7 | E2 | -1.07 | -1.07 | | -2.20 | -1.82 | | 0.54 | | |

| **SN.** | **Crosses** | **Env** | **Days to 50% tasseling** | | | **Days to 50% silking** | | | **Days to 75% brown husk** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | **RH** | **Hb** | **EH** | **RH** | **Hb** | **EH** | **RH** | **Hb** | **EH** |
| 65 | P5×P8 | E1 | -2.06 | | | -5.29** | | | -5.56** | -0.78 | |
| 66 | P5×P8 | E2 | -1.18 | | | -2.70 | -2.07 | | 1.37 | | |
| 67 | P5×P9 | E1 | -4.18** | -2.27 | | -6.28** | -5.29** | | -3.77** | -2.19* | |
| 68 | P5×P9 | E2 | -2.47 | 0.00 | | -3.18 | -1.55 | | -1.89 | -1.06 | |
| 69 | P5×P10 | E1 | -4.28** | | | -5.82** | -3.63** | | -6.09** | -4.59** | |
| 70 | P5×P10 | E2 | -3.09 | | | -4.03* | -1.55 | | 0.10 | | |
| 71 | P6×P7 | E1 | -1.75 | -0.59 | | -1.09 | -0.55 | | 0.00 | | |
| 72 | P6×P7 | E2 | -4.29* | -1.87 | | -4.59** | -2.60 | | 0.21 | | |
| 73 | P6×P8 | E1 | -4.76** | -1.84 | | -4.57** | | | -1.73* | -0.39 | |
| 74 | P6×P8 | E2 | -6.15** | -5.18* | | -6.82** | -5.87** | | -1.25 | -0.42 | |
| 75 | P6×P9 | E1 | -5.62** | -2.89* | | -2.95** | -1.63 | | 0.00 | | |
| 76 | P6×P9 | E2 | -5.58** | -5.58** | | -5.25** | -5.25** | | 0.52 | | |
| 77 | P6×P10 | E1 | -2.96** | | | -2.59** | | | 1.80* | | |
| 78 | P6×P10 | E2 | -5.16** | -4.31* | | -4.09* | -3.25 | | 0.41 | | |
| 79 | P7×P8 | E1 | 0.00 | | | 2.87** | | | 3.98** | | |
| 80 | P7×P8 | E2 | -2.76 | -1.33 | | -3.87* | -2.86 | | 0.21 | | |
| 81 | P7×P9 | E1 | -0.57 | | | 1.89 | | | 0.00 | | |
| 82 | P7×P9 | E2 | -4.81** | -2.40 | | -5.87** | -3.91 | | 0.75 | | |
| 83 | P7×P10 | E1 | -5.72** | | | -2.60** | | | -5.69** | -1.85* | |
| 84 | P7×P10 | E2 | -1.29 | | | -1.64 | | | 3.20* | | |
| 85 | P8×P9 | E1 | -1.16 | | | 0.85 | | | -0.56 | | |
| 86 | P8×P9 | E2 | -5.38** | -4.40* | | -6.06** | -5.10* | | -2.61* | -2.10 | |
| 87 | P8×P10 | E1 | -5.82** | | | -2.72** | | | -1.28 | | |
| 88 | P8×P10 | E2 | -4.19* | -2.33 | | -4.63** | -2.81 | | -0.21 | | |
| 89 | P9×P10 | E1 | -6.04** | -2.19 | | -4.35** | -1.06 | | -4.59** | -1.46 | |
| 90 | P9×P10 | E2 | -0.88 | | | -0.37 | | | 0.10 | | |

**Table 5. Extent of heterosis for plant height and ear height**

| SN. | Crosses | Env | Plant height (cm) | | | Ear height | | |
|---|---|---|---|---|---|---|---|---|
| | | | RH | Hb | EH | RH | Hb | EH |
| 1 | P1×P2 | E1 | 25.16** | | -22.05** | 24.41** | | -18.13** |
| 2 | P1×P2 | E2 | 36.49** | | -21.25** | 1.74 | | -24.91** |
| 3 | P1×P3 | E1 | 24.08** | | -18.76** | 9.80 | | -12.95 |
| 4 | P1×P3 | E2 | 34.80** | | -4.48 | -4.74 | | -15.38* |
| 5 | P1×P4 | E1 | 56.49** | | -3.29 | 75.53** | | |
| 6 | P1×P4 | E2 | 37.80** | | -5.85* | 9.76 | | -7.33 |
| 7 | P1×P5 | E1 | 41.89** | | -14.51** | 58.74** | | -8.29 |
| 8 | P1×P5 | E2 | 42.73** | | -4.29 | -18.88** | -9.58 | -20.51** |
| 9 | P1×P6 | E1 | 9.44 | | -28.24** | 22.09* | | -21.24** |
| 10 | P1×P6 | E2 | 34.80** | | -4.48 | -3.82 | | -7.69 |
| 11 | P1×P7 | E1 | 27.15** | | -11.22** | 17.88* | | -7.77 |
| 12 | P1×P7 | E2 | 28.61** | | -0.97 | -4.84 | | -9.89 |
| 13 | P1×P8 | E1 | 58.56** | | -2.32 | 46.08** | | |
| 14 | P1×P8 | E2 | 42.38** | | -7.99** | -4.55 | | -15.38* |
| 15 | P1×P9 | E1 | 42.72** | | -13.73** | 63.20** | | |
| 16 | P1×P9 | E2 | 43.96** | | -5.85* | 6.22 | | -12.45 |
| 17 | P1×P10 | E1 | 40.59** | | -21.28** | 38.89** | | -9.33 |
| 18 | P1×P10 | E2 | 35.65** | | -8.77** | -2.89 | | -7.69 |
| 19 | P2×P3 | E1 | 31.12** | | -8.32* | 9.94 | | -2.59 |
| 20 | P2×P3 | E2 | 36.99** | | -12.28** | 29.53* | | -29.30** |
| 21 | P2×P4 | E1 | -12.41* | -11.76* | -41.97** | -20.15* | -14.84 | -43.52** |
| 22 | P2×P4 | E2 | 32.81** | | -18.32** | 27.01* | | -36.26** |
| 23 | P2×P5 | E1 | 45.59** | | -5.80 | 48.26** | | -0.52 |
| 24 | P2×P5 | E2 | 55.66** | | -6.24* | 37.93** | | -12.09 |
| 25 | P2×P6 | E1 | 26.52** | | -11.41** | 34.04** | | -1.04 |
| 26 | P2×P6 | E2 | 55.25** | | -0.58 | 64.39** | | |
| 27 | P2×P7 | E1 | 15.89** | | -13.93** | 9.47 | | -4.15 |
| 28 | P2×P7 | E2 | 22.50** | | -14.04** | 42.42** | | -13.92 |
| 29 | P2×P8 | E1 | 39.09** | | -8.12* | 25.84** | | |
| 30 | P2×P8 | E2 | 58.52** | | -8.38** | 38.72** | | -24.54** |
| 31 | P2×P9 | E1 | 30.55** | | -15.28** | 30.77** | | -3.11 |

| SN. | Crosses | Env | Plant height (cm) | | | Ear height | | |
|---|---|---|---|---|---|---|---|---|
| | | | RH | Hb | EH | RH | Hb | EH |
| 32 | P2×P9 | E2 | 50.42** | | -11.89** | 66.54** | | -19.78* |
| 33 | P2×P10 | E1 | 41.44** | | -14.51** | 30.56** | | -2.59 |
| 34 | P2×P10 | E2 | 32.58** | | -19.88** | 35.54** | | -17.58* |
| 35 | P3×P4 | E1 | 33.70** | | -7.16 | 9.54 | | -7.77 |
| 36 | P3×P4 | E2 | 25.07** | | -6.63* | 32.58** | | -13.55 |
| 37 | P3×P5 | E1 | 37.61** | | -6.58 | 22.83** | | -1.04 |
| 38 | P3×P5 | E2 | 22.97** | | -9.75** | 20.47* | | -5.13 |
| 39 | P3×P6 | E1 | -16.78** | -16.67** | -39.07** | -32.34** | -18.57* | -40.93** |
| 40 | P3×P6 | E2 | 13.38** | | -12.48** | 28.40** | | -1.47 |
| 41 | P3×P7 | E1 | 9.61* | | -15.09** | -21.03** | -20.21** | -20.21** |
| 42 | P3×P7 | E2 | 24.21** | | | 28.16** | | -3.30 |
| 43 | P3×P8 | E1 | 34.92** | | -6.58 | -16.54** | -13.59 | -17.62** |
| 44 | P3×P8 | E2 | 41.48** | | | 42.48** | | -1.10 |
| 45 | P3×P9 | E1 | 41.19** | | -3.87 | 17.75** | | |
| 46 | P3×P9 | E2 | 45.92** | | | 49.57** | | -5.49 |
| 47 | P3×P10 | E1 | 39.51** | | -11.22** | 1.18 | | -10.88 |
| 48 | P3×P10 | E2 | 30.33** | | -4.09 | 18.84* | | -9.89 |
| 49 | P4×P5 | E1 | 37.05** | | -11.99** | 46.28** | | -8.29 |
| 50 | P4×P5 | E2 | 34.25** | | -4.87 | 24.14** | | -7.69 |
| 51 | P4×P6 | E1 | 34.91** | | -6.19 | 50.75** | | |
| 52 | P4×P6 | E2 | 26.11** | | -5.85* | 16.46 | | -15.75* |
| 53 | P4×P7 | E1 | 24.51** | | -8.12* | 32.71** | | |
| 54 | P4×P7 | E2 | 17.01** | | -5.46* | 4.64 | | -25.64** |
| 55 | P4×P8 | E1 | 36.58** | | -10.44** | 15.38* | | -6.74 |
| 56 | P4×P8 | E2 | 28.77** | | -11.89** | 21.69* | | -20.88** |
| 57 | P4×P9 | E1 | 35.74** | | -12.57** | 22.68** | | -14.51* |
| 58 | P4×P9 | E2 | 48.17** | | | 57.01** | | -7.69 |
| 59 | P4×P10 | E1 | 25.81** | | -24.56** | 17.34* | | -17.62** |
| 60 | P4×P10 | E2 | 29.22** | | -8.19** | 23.59* | | -11.72 |
| 61 | P5×P6 | E1 | 26.88** | | -13.73** | 53.54** | | |
| 62 | P5×P6 | E2 | 38.91** | | | 16.42* | | 0.00 |
| 63 | P5×P7 | E1 | 35.21** | | -2.32 | 40.72** | | |
| 64 | P5×P7 | E2 | 27.21** | | | 11.26 | | -5.86 |

| SN. | Crosses | Env | Plant height (cm) | | | Ear height | | |
|---|---|---|---|---|---|---|---|---|
| | | | RH | Hb | EH | RH | Hb | EH |
| 65 | P5×P8 | E1 | 46.53** | | -6.19 | 41.61** | | |
| 66 | P5×P8 | E2 | 30.62** | | -12.28** | 27.27** | | 0.00 |
| 67 | P5×P9 | E1 | 48.31** | | -6.77 | 72.55** | | |
| 68 | P5×P9 | E2 | 57.25** | | | 55.44** | | |
| 69 | P5×P10 | E1 | 52.32** | | -11.03** | 55.64** | | |
| 70 | P5×P10 | E2 | 44.69** | | | -3.88 | -0.45 | -18.32* |
| 71 | P6×P7 | E1 | 5.49 | | -18.18** | 8.11 | | -6.74 |
| 72 | P6×P7 | E2 | 20.94** | | | 25.94** | | |
| 73 | P6×P8 | E1 | 43.93** | | -0.19 | 32.72** | | |
| 74 | P6×P8 | E2 | 40.66** | | -0.19 | 32.06** | | |
| 75 | P6×P9 | E1 | 39.01** | | -5.22 | 45.91** | | |
| 76 | P6×P9 | E2 | 38.04** | | -0.97 | 48.96** | | |
| 77 | P6×P10 | E1 | 23.52** | | -21.28** | 31.45** | | -3.63 |
| 78 | P6×P10 | E2 | 34.57** | | -0.97 | 9.49 | | -9.16 |
| 79 | P7×P8 | E1 | 20.11** | | -11.61** | 0.27 | | -2.07 |
| 80 | P7×P8 | E2 | 28.45** | | -0.97 | 18.73* | | -10.62 |
| 81 | P7×P9 | E1 | 23.63** | | -10.44** | 27.54** | | |
| 82 | P7×P9 | E2 | 31.66** | | | 51.72** | | |
| 83 | P7×P10 | E1 | 29.45** | | -11.99** | 13.69* | | -1.04 |
| 84 | P7×P10 | E2 | 15.89** | | -7.60** | 11.66 | | -8.79 |
| 85 | P8×P9 | E1 | 19.28** | | -23.40** | 4.00 | | -12.44 |
| 86 | P8×P9 | E2 | 30.06** | | -14.81** | 43.02** | | -9.89 |
| 87 | P8×P10 | E1 | 42.39** | | -14.89** | 18.04** | | -0.00 |
| 88 | P8×P10 | E2 | 34.59** | | -9.36** | 35.11** | | |
| 89 | P9×P10 | E1 | 45.21** | | -14.89** | 28.87** | | -5.18 |
| 90 | P9×P10 | E2 | 35.62** | | -7.60** | 16.62 | | -19.05* |

**Table 6. Extent of heterosis for grain starch content (%) and grain protein content (%)**

| SN. | Crosses | Env | Grain starch content (%) | | | Grain protein content (%) | | |
|---|---|---|---|---|---|---|---|---|
| | | | RH | Hb | EH | RH | Hb | EH |
| 1 | P1×P2 | E1 | 6.03** | 4.79** | | 6.75** | 1.08 | |
| 2 | P1×P2 | E2 | 6.08** | 4.25** | | 3.89** | | |
| 3 | P1×P3 | E1 | 2.76** | 0.12 | | 0.24 | | |
| 4 | P1×P3 | E2 | 4.25** | 0.29 | | -0.06 | | |
| 5 | P1×P4 | E1 | 1.72* | | | 1.18* | 0.53 | |
| 6 | P1×P4 | E2 | 2.02** | | | 1.19 | 0.86 | |
| 7 | P1×P5 | E1 | 10.21** | 9.69** | | 4.79** | 4.29** | |
| 8 | P1×P5 | E2 | 13.80** | 13.48** | | 0.70 | 0.45 | |
| 9 | P1×P6 | E1 | 6.21** | 4.23** | | 25.83** | 10.62** | |
| 10 | P1×P6 | E2 | 9.71** | 6.56** | | 18.92** | 4.98** | |
| 11 | P1×P7 | E1 | 3.92** | 3.08** | | -6.92** | | |
| 12 | P1×P7 | E2 | 3.54** | 1.41* | | -5.08** | | |
| 13 | P1×P8 | E1 | 13.82** | 11.48** | 1.93** | 35.97** | 29.54** | 2.03** |
| 14 | P1×P8 | E2 | 12.33** | 8.65** | | 32.69** | 26.65** | 0.79 |
| 15 | P1×P9 | E1 | 1.95** | 0.82 | | 10.93** | | |
| 16 | P1×P9 | E2 | 1.39** | 0.03 | | 10.94** | | |
| 17 | P1×P10 | E1 | 5.13** | 2.29** | | 8.17** | 8.17** | |
| 18 | P1×P10 | E2 | 8.55** | 5.62** | | 11.31** | 7.62** | |
| 19 | P2×P3 | E1 | 5.24** | 3.73** | | 8.65** | 0.28 | |
| 20 | P2×P3 | E2 | 4.37** | 2.13** | | 8.17** | 0.87 | |
| 21 | P2×P4 | E1 | 7.28** | 6.18** | | 16.17** | 9.34** | |
| 22 | P2×P4 | E2 | 6.45** | 5.88** | | 11.94** | 6.26** | |
| 23 | P2×P5 | E1 | 9.03** | 8.26** | | -8.23** | | |
| 24 | P2×P5 | E2 | 12.23** | 10.61** | | -10.31** | | |
| 25 | P2×P6 | E1 | -2.60** | | | 23.28** | 13.94** | |
| 26 | P2×P6 | E2 | -1.50** | | | 23.35** | 13.89** | |
| 27 | P2×P7 | E1 | 13.31** | 12.89** | 1.34 | 21.52** | 20.42** | |
| 28 | P2×P7 | E2 | 10.66** | 10.28** | | 17.54** | 15.03** | |
| 29 | P2×P8 | E1 | 2.04** | 1.11 | | 20.52** | 19.74** | |
| 30 | P2×P8 | E2 | 3.10** | 1.44** | | 15.88** | 15.59** | |
| 31 | P2×P9 | E1 | 8.46** | 8.40** | | 25.88** | 16.78** | |

| SN. | Crosses | Env | Grain starch content (%) | | | Grain protein content (%) | | |
|---|---|---|---|---|---|---|---|---|
| | | | RH | Hb | EH | RH | Hb | EH |
| 32 | P2×P9 | E2 | 8.42** | 7.99** | | 28.84** | 19.22** | |
| 33 | P2×P10 | E1 | 3.92** | 2.29** | | 16.08** | 9.92** | |
| 34 | P2×P10 | E2 | 4.77** | 3.71** | | 18.80** | 16.94** | |
| 35 | P3×P4 | E1 | 5.00** | 4.57** | | 7.83** | 5.60** | |
| 36 | P3×P4 | E2 | 6.41** | 4.68** | | 5.96** | 3.98** | |
| 37 | P3×P5 | E1 | 7.60** | 5.32** | | 26.28** | 22.32** | 1.81** |
| 38 | P3×P5 | E2 | 9.27** | 5.42** | | 25.61** | 23.16** | 2.49* |
| 39 | P3×P6 | E1 | 8.62** | 7.83** | | 22.41** | 5.13** | |
| 40 | P3×P6 | E2 | 6.94** | 5.90** | | 23.33** | 6.81** | |
| 41 | P3×P7 | E1 | -0.31 | | | 9.00** | | |
| 42 | P3×P7 | E2 | -1.68** | | | 7.22** | | |
| 43 | P3×P8 | E1 | 1.85** | 1.31 | | 3.46** | | |
| 44 | P3×P8 | E2 | 1.82** | 1.25* | | 6.49** | | |
| 45 | P3×P9 | E1 | 9.08** | 7.45** | | 44.18** | 24.25** | 3.41** |
| 46 | P3×P9 | E2 | 8.14** | 5.41** | | 40.14** | 21.62** | 1.21 |
| 47 | P3×P10 | E1 | 3.20** | 3.06** | | -8.51** | | |
| 48 | P3×P10 | E2 | 4.68** | 3.46** | | -9.57** | | |
| 49 | P4×P5 | E1 | 7.15** | 5.31** | | 6.41** | 5.22** | |
| 50 | P4×P5 | E2 | 7.98** | 5.86** | | 5.41** | 5.32** | |
| 51 | P4×P6 | E1 | 2.82** | 2.49** | | 16.58** | 1.93** | |
| 52 | P4×P6 | E2 | 4.61** | 3.91** | | 19.22** | 4.95** | |
| 53 | P4×P7 | E1 | 5.41** | 3.94** | | 16.07** | 8.31** | |
| 54 | P4× P7 | E2 | 6.89** | 6.68** | | 8.23** | 0.65 | |
| 55 | P4×P8 | E1 | 7.32** | 7.19** | | -7.17** | | |
| 56 | P4×P8 | E2 | 6.72** | 5.57** | | -7.20** | | |
| 57 | P4×P9 | E1 | 0.47 | | | 14.91** | 0.82 | |
| 58 | P4×P9 | E2 | 3.30** | 2.35** | | 13.96** | 0.53 | |
| 59 | P4×P10 | E1 | -2.15** | | | 6.52** | 5.84** | |
| 60 | P4×P10 | E2 | 0.99* | 0.51 | | 8.21** | 4.30** | |
| 61 | P5×P6 | E1 | 9.23** | 7.69** | | 24.95** | 10.31** | |
| 62 | P5×P6 | E2 | 11.54** | 8.64** | | 21.33** | 6.89** | |
| 63 | P5×P7 | E1 | 15.74** | 15.35** | 2.78** | 30.54** | 23.10** | |
| 64 | P5×P7 | E2 | 13.91** | 11.88** | | 29.99** | 20.98** | |

| **SN.** | **Crosses** | **Env** | **Grain starch content (%)** | | | **Grain protein content (%)** | | |
|---|---|---|---|---|---|---|---|---|
| | | | **RH** | **Hb** | **EH** | **RH** | **Hb** | **EH** |
| 65 | P5×P8 | E1 | 12.79** | 10.99** | 1.48* | 39.74** | 33.74** | 4.33** |
| 66 | P5×P8 | E2 | 14.65** | 11.21** | 1.41** | 33.25** | 26.89** | 1.47 |
| 67 | P5×P9 | E1 | 4.93** | 4.25** | | 26.35** | 11.95** | |
| 68 | P5×P9 | E2 | 5.88** | 4.76** | | 30.69** | 15.37** | |
| 69 | P5×P10 | E1 | 13.19** | 10.65** | 2.53** | 12.50** | 11.96** | |
| 70 | P5×P10 | E2 | 16.71** | 13.88** | 2.58** | 14.21** | 10.16** | |
| 71 | P6×P7 | E1 | 7.70** | 6.54** | | 35.97** | 26.73** | |
| 72 | P6×P7 | E2 | 6.25** | 5.35** | | 31.43** | 23.83** | |
| 73 | P6×P8 | E1 | 12.34** | 12.11** | 2.51** | 58.58** | 45.70** | 3.91** |
| 74 | P6×P8 | E2 | 12.90** | 12.43** | 2.52** | 53.66** | 41.55** | 2.39* |
| 75 | P6×P9 | E1 | 4.70** | 3.89** | | 42.49** | 41.91** | |
| 76 | P6×P9 | E2 | 6.93** | 5.24** | | 41.24** | 40.90** | |
| 77 | P6×P10 | E1 | 0.05 | | | 25.40** | 10.25** | |
| 78 | P6×P10 | E2 | 1.76** | 1.56** | | 28.65** | 17.07** | |
| 79 | P7×P8 | E1 | 3.93** | 2.61** | | 36.62** | 34.51** | |
| 80 | P7×P8 | E2 | 5.16** | 3.83** | | 38.04** | 34.75** | |
| 81 | P7×P9 | E1 | 5.22** | 4.89** | | 34.33** | 25.69** | |
| 82 | P7×P9 | E2 | 3.95** | 3.18** | | 40.10** | 32.30** | |
| 83 | P7×P10 | E1 | 1.29 | | | 28.50** | 20.62** | |
| 84 | P7×P10 | E2 | 3.37** | 2.68** | | 30.24** | 25.50** | |
| 85 | P8×P9 | E1 | 3.11** | 2.11** | | 46.01** | 34.65** | |
| 86 | P8×P9 | E2 | 2.34** | 0.30 | | 43.31** | 32.31** | |
| 87 | P8×P10 | E1 | 3.15** | 2.47** | | 4.13** | | |
| 88 | P8×P10 | E2 | 1.91** | 1.29* | | 12.07** | 10.59** | |
| 89 | P9×P10 | E1 | 1.49* | | | 17.92** | 4.04** | |
| 90 | P9×P10 | E2 | 2.02** | 0.60 | | 19.32** | 8.82** | |

**Table 7. Extent of heterosis for grain oil content (%)**

| SN. | Crosses | Env | Grain oil content (%) | | |
|---|---|---|---|---|---|
| | | | RH | Hb | EH |
| 1 | P1×P2 | E1 | 16.47** | 15.59** | |
| 2 | P1×P2 | E2 | 10.74** | 10.08** | |
| 3 | P1×P2 | Pool | 13.58** | 12.81** | |
| 4 | P1×P3 | E1 | 32.32** | 30.22** | |
| 5 | P1×P3 | E2 | 33.82** | 29.70** | |
| 6 | P1×P3 | Pool | 33.07** | 29.95** | |
| 7 | P1×P4 | E1 | 12.57** | | |
| 8 | P1×P4 | E2 | 11.43** | | |
| 9 | P1×P4 | Pool | 12.00** | | |
| 10 | P1×P5 | E1 | 48.99** | 43.78** | |
| 11 | P1×P5 | E2 | 43.88** | 39.60** | |
| 12 | P1×P5 | Pool | 46.41** | 41.67** | |
| 13 | P1×P6 | E1 | -17.68** | | |
| 14 | P1×P6 | E2 | -13.12** | | |
| 15 | P1×P6 | Pool | -15.40** | | |
| 16 | P1×P7 | E1 | 16.72** | | |
| 17 | P1×P7 | E2 | 25.23** | 6.02** | |
| 18 | P1×P7 | Pool | 20.92** | 0.96* | |
| 19 | P1×P8 | E1 | 64.11** | 51.12** | 0.98* |
| 20 | P1×P8 | E2 | 59.59** | 43.91** | 1.84** |
| 21 | P1×P8 | Pool | 61.80** | 47.40** | 1.41** |
| 22 | P1×P9 | E1 | 43.98** | 33.98** | |
| 23 | P1×P9 | E2 | 43.34** | 37.25** | |
| 24 | P1×P9 | Pool | 43.66** | 35.58** | |
| 25 | P1×P10 | E1 | 27.96** | 21.84** | |
| 26 | P1×P10 | E2 | 26.44** | 17.27** | |
| 27 | P1×P10 | Pool | 27.19** | 19.47** | |
| 28 | P2×P3 | E1 | 23.21** | 20.34** | |
| 29 | P2×P3 | E2 | 26.88** | 22.26** | |
| 30 | P2×P3 | Pool | 25.05** | 21.31** | |
| 31 | P2×P4 | E1 | 38.22** | 23.22** | |

| **SN.** | **Crosses** | **Env** | **Grain oil content (%)** | | |
|---|---|---|---|---|---|
| | | | **RH** | **Hb** | **EH** |
| 32 | P2×P4 | E2 | 39.20** | 23.91** | |
| 33 | P2×P4 | Pool | 38.71** | 23.57** | |
| 34 | P2×P5 | E1 | 54.25** | 47.77** | |
| 35 | P2×P5 | E2 | 59.54** | 53.89** | |
| 36 | P2×P5 | Pool | 56.93** | 50.85** | |
| 37 | P2×P6 | E1 | -12.20** | | |
| 38 | P2×P6 | E2 | -7.54** | | |
| 39 | P2×P6 | Pool | -9.87** | | |
| 40 | P2×P7 | E1 | 15.05** | | |
| 41 | P2×P7 | E2 | 13.83** | | |
| 42 | P2×P7 | Pool | 14.45** | | |
| 43 | P2×P8 | E1 | 31.81** | 22.23** | |
| 44 | P2×P8 | E2 | 36.97** | 24.19** | |
| 45 | P2×P8 | Pool | 34.44** | 23.24** | |
| 46 | P2×P9 | E1 | 22.76** | 15.04** | |
| 47 | P2×P9 | E2 | 19.87** | 15.43** | |
| 48 | P2×P9 | Pool | 21.32** | 15.24** | |
| 49 | P2×P10 | E1 | 30.33** | 25.00** | |
| 50 | P2×P10 | E2 | 17.78** | 9.84** | |
| 51 | P2×P10 | Pool | 23.91** | 17.14** | |
| 52 | P3×P4 | E1 | 1.36* | | |
| 53 | P3×P4 | E2 | 8.72** | | |
| 54 | P3×P4 | Pool | 5.05** | | |
| 55 | P3×P5 | E1 | 102.49** | 98.51** | 8.09** |
| 56 | P3×P5 | E2 | 97.20** | 96.99** | 5.34** |
| 57 | P3×P5 | Pool | 99.84** | 97.97** | 6.71** |
| 58 | P3×P6 | E1 | -2.72** | | |
| 59 | P3×P6 | E2 | 5.47** | | |
| 60 | P3×P6 | Pool | 1.35** | | |
| 61 | P3×P7 | E1 | -2.00** | | |
| 62 | P3×P7 | E2 | -3.10** | | |
| 63 | P3×P7 | Pool | -2.54** | | |
| 64 | P3×P8 | E1 | -8.96** | | |

| SN. | Crosses | Env | Grain oil content (%) | | |
|---|---|---|---|---|---|
| | | | RH | Hb | EH |
| 65 | P3×P8 | E2 | -5.41** | | |
| 66 | P3×P8 | Pool | -7.16** | | |
| 67 | P3×P9 | E1 | 22.59** | 12.39** | |
| 68 | P3×P9 | E2 | 27.30** | 18.30** | |
| 69 | P3×P9 | Pool | 24.91** | 15.28** | |
| 70 | P3×P10 | E1 | 41.72** | 32.90** | |
| 71 | P3×P10 | E2 | 37.81** | 24.18** | |
| 72 | P3×P10 | Pool | 39.73** | 28.38** | |
| 73 | P4×P5 | E1 | 26.07** | 8.24** | |
| 74 | P4×P5 | E2 | 21.26** | 4.60** | |
| 75 | P4×P5 | Pool | 23.64** | 6.40** | |
| 76 | P4×P6 | E1 | -1.24* | | |
| 77 | P4×P6 | E2 | 4.95** | | |
| 78 | P4×P6 | Pool | 1.86** | | |
| 79 | P4×P7 | E1 | -2.50** | | |
| 80 | P4×P7 | E2 | -7.45** | | |
| 81 | P4×P7 | Pool | -4.95** | | |
| 82 | P4×P8 | E1 | 37.30** | 31.54** | |
| 83 | P4×P8 | E2 | 40.38** | 37.54** | 1.44** |
| 84 | P4×P8 | Pool | 38.87** | 34.56** | |
| 85 | P4×P9 | E1 | 17.64** | 11.49** | |
| 86 | P4×P9 | E2 | 26.37** | 16.43** | |
| 87 | P4×P9 | Pool | 21.98** | 13.98** | |
| 88 | P4×P10 | E1 | -5.39** | | |
| 89 | P4×P10 | E2 | -15.32** | | |
| 90 | P4×P10 | Pool | -10.46** | | |
| 91 | P5×P6 | E1 | 6.73** | | |
| 92 | P5×P6 | E2 | 11.23** | | |
| 93 | P5×P6 | Pool | 8.98** | | |
| 94 | P5×P7 | E1 | 17.36** | | |
| 95 | P5×P7 | E2 | 13.27** | | |
| 96 | P5×P7 | Pool | 15.33** | | |
| 97 | P5×P8 | E1 | 61.09** | 43.60** | |

| SN. | Crosses | Env | Grain oil content (%) | | |
|---|---|---|---|---|---|
| | | | RH | Hb | EH |
| 98 | P5×P8 | E2 | 44.34** | 26.70** | |
| 99 | P5×P8 | Pool | 52.51** | 34.88** | |
| 100 | P5×P9 | E1 | 28.16** | 15.40** | |
| 101 | P5×P9 | E2 | 37.61** | 28.00** | |
| 102 | P5×P9 | Pool | 32.86** | 21.56** | |
| 103 | P5×P10 | E1 | 41.85** | 30.58** | |
| 104 | P5×P10 | E2 | 42.56** | 28.58** | |
| 105 | P5×P10 | Pool | 42.21** | 29.54** | |
| 106 | P6×P7 | E1 | -27.11** | | |
| 107 | P6×P7 | E2 | -31.54** | | |
| 108 | P6×P7 | Pool | -29.29** | | |
| 109 | P6×P8 | E1 | 39.18** | 23.66** | 6.36** |
| 110 | P6×P8 | E2 | 38.13** | 27.19** | 6.95** |
| 111 | P6×P8 | Pool | 38.65** | 25.41** | 6.66** |
| 112 | P6×P9 | E1 | -4.13** | | |
| 113 | P6×P9 | E2 | -4.56** | | |
| 114 | P6×P9 | Pool | -4.34** | | |
| 115 | P6×P10 | E1 | -0.78 | | |
| 116 | P6×P10 | E2 | 0.53 | | |
| 117 | P6×P10 | Pool | -0.12 | | |
| 118 | P7×P8 | E1 | 9.82** | | |
| 119 | P7×P8 | E2 | 19.32** | 11.13** | |
| 120 | P7×P8 | Pool | 14.57** | 3.96** | |
| 121 | P7×P9 | E1 | -4.98** | | |
| 122 | P7×P9 | E2 | -6.77** | | |
| 123 | P7×P9 | Pool | -5.85** | | |
| 124 | P7×P10 | E1 | -0.12 | | |
| 125 | P7×P10 | E2 | 5.34** | | |
| 126 | P7×P10 | Pool | 2.61** | | |
| 127 | P8×P9 | E1 | 4.55** | 3.37** | |
| 128 | P8×P9 | E2 | 5.70** | | |
| 129 | P8×P9 | Pool | 5.13** | 1.26** | |
| 130 | P8×P10 | E1 | 34.05** | 29.41** | |

| SN. | Crosses | Env | Grain oil content (%) | | |
|---|---|---|---|---|---|
| | | | RH | Hb | EH |
| 131 | P8×P10 | E2 | 27.62** | 23.78** | |
| 132 | P8×P10 | Pool | 30.72** | 26.51** | |
| 133 | P9×P10 | E1 | 27.83** | 24.78** | |
| 134 | P9×P10 | E2 | 23.30** | 19.26** | |
| 135 | P9×P10 | Pool | 25.55** | 24.93** | |

**Table 8. Crosses exhibiting high economic heterosis in both the environments, $E_1$ and $E_2$**

| Traits | Crosses |
|---|---|
| Grain oil content | $P_1$×$P_8$, $P_3$×$P_5$, $P_6$×$P_8$ |
| Grain starch content | $P_5$×$P_8$, $P_5$×$P_{10}$, $P_6$×$P_8$ |
| Grain protein content | $P_3$×$P_5$, $P_6$×$P_8$ |

None of the hybrids has shown significant negative economic heterosis for these traits in $E_2$ environment. Therefore, these 2 hybrids can be recommended for their large scale multi-location testing in *Kharif* season ($E_1$) for the development of early maturing hybrids (Table 4).

For plant height, the exploitable economic heterosis ranged from -41.97 ($P_2$×$P_4$) to -8.12% ($P_2$×$P_8$ and $P_4$×$P_7$) and 32 hybrids showed significant negative economic heterosis over the best check (HQPM-5) in $E_1$ environment. Whereas, in $E_2$ environment, the exploitable economic heterosis ranged from -21.25 ($P_1$×$P_2$) to -5.46% ($P_4$×$P_7$) and 24 hybrids exhibited significant negative economic heterosis over the best check Pratap QPM Hybrid-1. The hybrid $P_2$×$P_4$ (-41.97%) manifested maximum negative economic heterosis in $E_1$ environment, whereas, the hybrid $P_1$×$P_2$ (-21.25%) manifested maximum negative economic heterosis in $E_2$ environment.

Eight hybrids with magnitude ranging from -43.52 ($P_2$×$P_4$) to -17.62% ($P_4$×$P_{10}$) and 14 hybrids with magnitude ranging from -36.26 ($P_2$×$P_4$) to -15.38% ($P_1$×$P_3$ and $P_1$×$P_8$) exhibited significant negative economic heterosis for ear height over the best check Vivek QPM-9 in $E_1$ and Pratap QPM Hybrid-1 in $E_2$, respectively. The hybrid $P_2$×$P_4$ exhibited maximum negative economic heterosis in both environments, the $E_1$ (-43.52%) and the $E_2$ (-36.26%) (Table 5).

Among quality traits, only 3 hybrids showed significant positive economic heterosis for grain oil content. The hybrid $P_3$×$P_5$ exhibited maximum positive economic heterosis (6.71%) for grain oil content over the best check HQPM-5 on pooled basis. Five hybrids in $E_1$ and three hybrids in $E_2$ showed significant positive economic heterosis for grain starch content. The hybrid $P_5$×$P_7$ (2.78%) in $E_1$ and $P_5$×$P_{10}$ (2.58%) in $E_2$ exhibited maximum positive economic heterosis for grain starch content over the best check HQPM-1. In case of grain protein content, 5 hybrids in $E_1$ and 2 hybrids in $E_2$ exhibited significant positive economic heterosis ~~for this trait~~. The maximum positive economic heterosis for this trait was exhibited by hybrid $P_5$×$P_8$ (4.14%) in $E_1$ and by $P_3$×$P_5$ (2.49%) in $E_2$ over the best check HQPM-5. Abuali [26], Singh [27], Chahar [28], Lahane [29] and Bisen [30] reported economic heterosis to the similar tunes for quality traits in maize.

## 4. CONCLUSION

It is inferred from the above findings that heterotic effects were evident for maturity, plant type and quality traits in maize hybrids indicating genetic diversity existing among the parents involved in these crosses. For grain oil content, the same three hybrids ($P_1$×$P_8$, $P_3$×$P_5$, $P_6$×P8) have shown significant positive economic heterosis in pooled environment. Further, for feasible exploitation of above single cross hybrids in the field for quality traits, it is wise to recommend their large scale multi location testing to have an idea about their stability in performance over environment to be ultimately used as popular hybrids.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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