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Evaluation of Maize (*Zea mays* L.) Hybrids for Economic Heterosis under Different Soil Moisture Regimes at North Eastern Plain Zone of India

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Authors' contributions

This work was carried out in collaboration among all authors. Author AS designed the study, performed the statistical analysis, and wrote the original draft of the manuscript. Authors JPS and PHZ supervised the study and provided necessary resources. Author KS reviewed and edited the original draft. Authors KM and JPV managed the field data recordings and literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The present experiment was conducted to understand the effect of soil moisture status on the economic or standard heterosis in fifty maize hybrids for grain yield and flowering traits. The trials were planted at Agricultural Research Farm, Banaras Hindu University, Varanasi in alpha-lattice design with two replications. The analysis of variance revealed the significant differences for grain yield and flowering related traits such as days to 50% anthesis, days to 50% silking and anthesis-silking interval under all the moisture conditions including optimal, managed drought and managed waterlogging conditions. Significant amount of heterosis was observed over the selected check P3502 for all the traits under study; however, the magnitude and direction varied with traits and with soil moisture level. For days to 50% anthesis, hybrids ZH17192, VH112926, VH123021, ZH114250, ZH16929 and ZH16930 were showed significant negative heterosis under all the moisture

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conditions that explained earliness under both moisture-stress and normal conditions. Among the tested hybrids, VH123021 and ZH16929 were recorded significant negative standard heterosis for flowering traits; and significant positive heterosis for grain yield under all the three moisture conditions. Six hybrids under drought, seven hybrids under optimal and two hybrids under waterlogged condition showed positive standard heterosis for grain yield. Further evaluation of these hybrids at multi-locations and multi-year is advisable to confirm the promising findings observed in our study. This study could be valuable for development of climate-resilient maize hybrids.

Keywords: Standard heterosis; drought; waterlogging; soil moisture; Zea mays L.

ACRONYMS

DA: Days TO 50% Anthesis
DS: Days TO 50% Silking
ASI: Anthesis-Silking Interval
GY: Grain Yield
DT: Drought
OPT: Optimal
WL: Waterlogging

1. INTRODUCTION

Maize (*Zea mays* L.) is a versatile crop with a greater genetic variability and capable to grow successfully across the globe covering tropical, subtropical and temperate agro-climatic zones. Its production is limited by many climatic and agronomic factors including soil moisture status, low soil fertility, nitrogen availability, pests and diseases and use of traditional varieties [1]. Among all, lack of required soil moisture level influences more on induced yield losses made 'the maize is sensitive to soil moisture' [2]. Occasional or temporarily drought situations and unexpected flooding or waterlogged soil conditions during the crop growing period causing major yield losses. Consistently, it is becoming a persistent problem in India especially North East Plain Zone (NEPZ) of maize growing area. This reason could be substantial and maize breeders have been attempting to improve the tolerance towards limiting supplies and waterlogging situations for decades. Their efforts from previous reports have resulted in increased knowledge of moisture-stress tolerance and genetic enhancement for stress tolerance. The International Maize and Wheat Improvement Centre (CIMMYT) focused on extensive research by screening and developing maize hybrids for soil moisture stress including drought and waterlogging tolerance through conventional and molecular methods from past few decades.

Low soil moisture and excess soil moisture are two important climatic factors affecting maize crop distribution and production [3]. Both moisture-stresses causes delayed in flowering with its effect being constantly severe on the interdependent and sequential flowering stages such as initiation of tasseling, anthesis or pollen-shed and emergence of silking. Maize silk has relatively high water content and depend highly on a favorable water status in the field to emerge and emerge out from the husk [4]. Anthesis-silking interval also very sensitive trait towards the water-stress which results in large gap between anthesis and silking results in poor fertilization [5] consequently results in poor seed set. On other hand, moisture stress reduces biomass accumulation and photosynthetic rate, eventually shortens the life cycle of crops causing in a shorter kernel filling period and the production of lighter, shriveled and smaller grains, culminating in lower grain yields and poor grain quality [6-11]. Ultimately, the grain yield was the major criterion for selecting best hybrids under the drought and waterlogging conditions. Although, a vast literature is available on standard or economic heterosis estimation for the flowering traits, yield and several yield related traits but heterosis assessment for a specific set of hybrids under different soil moisture conditions are very less. Ulaganathan et al. [12] made an attempt for estimation of standard heterosis for yield and its attributing characters in few crosses of quality protein maize inbred lines under both normal and moisture-stress condition. Kumawat [13] estimated the standard heterosis for several yield and its related traits under waterlogged condition whereas Gebre, Nedi and Mesenbet [14,15,16] explained heterosis over standard check in maize under optimal irrigated condition.

Production and productivity of maize can be increased by use of an appropriate agronomic practices and use of improved hybrid maize cultivars. Understanding of gene action and heterosis or hybrid vigor also helps in identification of superior F_1 hybrids in order to use further in future breeding programs. The success of any plant breeding programme depends on the availability of genetic variability in germplasm available. Utilization of more diverse parents in hybridization programmes has been resulted in better hybrids with great yield potential. Understanding and exploitation of heterosis is another possibility for enhancing grain yield potential. The term heterosis was used by Shull [8] and conceptualized it as increased in vigor, size, development and fruitfulness, resistance to biotic and abiotic stresses manifested by cross pollinated species as compared with corresponding progeny. The extent of heterosis has been estimated as the superiority of hybrid over their mid parent (mid-parent heterosis), superiority of hybrid over the better parent (Heterobeltiosis) and superiority over standard check (standard/economic heterosis). The concept of heterosis and its exploitation was first initiated in the 1930s for large-scale production of hybrid maize. Practically, standard heterosis is more important for the exploitation of heterotic vigour among the three types of heterosis particularly in a commercial point of view [17]. The concept of heterosis has been widely used in cross-pollinated crops such as maize and other allied species by several workers [18-21]. With the criteria of influence of flowering traits and differential expression of grain yield potential of hybrids on soil water status, we carried out the experiment to estimate the magnitude and direction of standard heterosis under different soil moisture regimes. It could assist the maize breeders to develop climate resilient maize hybrids that best suited to any soil moisture conditions.

2. MATERIALS AND METHODS

2.1 Description of Study Area

The experiment was carried out at the Agricultural Research Farm, Banaras Hindu University, Varanasi, India that geographically located at 25.26’ N, 82.99’ E, and at an altitude of 82 m above mean sea level. The experimental station is one of the major centers of All India Coordinated Research Project (AICRP) on Maize situated in North East Plane Zone (NEPZ) of maize growing area in India. The soil type of experimental site is sandy loam with pH of 7.4 and average annual rainfall of 1110 mm. Study was conducted in *Rabi* 2017-18 season and subsequent Kharif 2018 season. The metrological data during the both the crop seasons were depicted in a standard week wise in Fig. 1.

2.2 Experimental Material

The plant material comprised of forty-five newly developed medium duration (95-100 days) normal maize hybrids procured from CIMMYT, Hyderabad and planted along with five commercial checks *viz*, CAH 153, DKC9144, 900MG, P3502 and Hytech5106 (Table 1). The evaluated hybrids obtained from a pool of F_1 hybrids developed through biparental crosses made between 600 lines of CIMMYT Maize germplasm and two testers *viz*, CML451 and CL02450. Among all the checks, P3502 was considered for the estimation of magnitude of heterosis as it offers an excellent abiotic stress tolerance across different soil moisture conditions because of its deep root characteristics and also has outstanding ear and grain attributes along with biotic stress tolerance. The selected standard check, P3502 was notified in the year 2012.

2.3 Experimental Design and Soil Moisture Level Management

Each hybrid was planted manually in alpha lattice design [22] in two replications with 4 m row length and planting spacing of 0.75 m inter-row and 0.25 m within-row. The material was evaluated across different soil moisture conditions including drought (DT), optimal (OPT) and waterlogging (WL) conditions. Irrigation was given based on recommended critical stages of growth stages of maize *i.e.* knee height (30-35 DAS) stage, flowering and followed by grain filling stages for optimal soil moisture trial. Whereas, the moisture stresses at specific growth stage of crop were precisely maintained by altering irrigation patterns that ensures that targeted crop stage must exposed to the moisture stress period. In case of manage drought trial, water deficit or drought period at flowering stage was imposed in the field by suspending irrigation for a period of 550 cumulative growing degree days (GDD) to 1000 GDD [23]. Waterlogging stress given continuously for seven days at ‘Knee high’ (V_6-V_7) stage of crop growth, and draining of excess water in the experimental plots was done from the seventh day [24].

2.4 Data Recording and Analysis

Data on flowering trait such as days to 50% anthesis, days to 50% silking and anthesis-silking interval, and grain yield for all the entries evaluated were collected on plot basis in each individual experimental trial including three soil moisture environments. Days to 50% anthesis (DA) refers to the number of days taken from planting to the date when half of the plants in a plot started pollen shedding. Whereas, days to 50% silking (DS) is the number of days taken from the planting date to the date when 50% of the plants showed silk emergence. Anthesis-silking interval (ASI) was recorded as the difference between number of days to 50% anthesis and number of days to 50% silking. Fresh weight per plot was recorded for all the entries along with shelling percentage and standardized moisture content 12.5% and further grain yield per hectare (GY) was calculated as follows [25]:

$$\text{Grain yield (GY; t/ha)} = \frac{\text{Fresh ear weight (kg/plot)} \times 10 \times (100 - \text{MC}) \times \text{SH}}{(100 - \text{adjusted MC}) \times \text{Plot Area (m}^2)}$$

Where, MC is moisture content, SH is shelling percentage and adjusted MC is required standardized moisture percentage (12.5%). The data collected on above traits were subjected to simple analysis of variance (ANOVA) to reveal the presence of genetic variability among the tested genotypes under individual environments using ADEL-R software [26] before estimating standard heterosis. Standard / Economic heterosis of the studied F_1 hybrids was estimated in percentage with respect to standard check P3502 for four traits that showed significant variations through the method suggested by Falconer [27]:

$$Standard\ Heterosis\ (SH)\% = \left(\frac{\overline{F_1} - \overline{SC}}{\overline{SC}}\right) \times 100$$

Where, $\overline{SC}$ =mean performance of standard check and $\overline{F_1}$=mean performance of hybrid

The variations in the magnitude of heterosis of each entry were tested by the procedure of Panse and Sukhatme [28]. Standard error ($SE(d)$) and critical difference (CD) were also estimated as:

$$SE(d) = \frac{\sqrt{2MSe}}{r}$$

$$CD = SE(d) \times t$$

Where, *SE(d)* is standard error of the difference, *MSe* is mean square of error from ANOVA, *r* is number of replications, *CD* is critical difference and *t* is the value of *t* at error degree of freedom.

The test of significance of heterosis with respect to standard check was computed by 't-test' as reported by Snedecor [29] as follows:

$$Heterosis\ (t) = \frac{(\overline{F_1} - \overline{SC})}{\frac{\sqrt{2MSe}}{r}}$$

The t-values computed were compared with the t-value at error degree of freedom corresponding to 5% or 1% level of significance.

3. RESULTS AND DISCUSSION

3.1 Analysis of Variance (Anova)

The analysis of variance (ANOVA) of each individual trial under different soil moisture levels revealed that the fifty maize hybrids along with five commercial checks showed significant differences for grain yield (GY) and flowering related traits such as days to 50% anthesis (DA), days to 50% silking (DS) and anthesis-silking interval (ASI). The presence of ample amount of variation among the hybrids evaluated under each moisture regime represented the presence of inherent variation (genetic) among the material and also under different moisture level which allows selection possible for further breeding program. The existent sufficient genetic variability among the genotypes under each test environment ensures the plant breeder to conduct a pertinent selection of the most desirable hybrids those suitable across the moisture conditions of the field. According to mean sum squares of each traits, the genotypes evaluated showed highly significant ($p<0.01$) variation for GY, DA and DS whereas a little low significant ($p<0.05$) difference for ASI than DA, DS and GY (Table 2). Similar results were reported by Gebre and Mogesse et al., [5,30] by evaluating maize hybrids.

3.2 Estimation of Standard Heterosis

The hybrid maize breeding programme is a major breakthrough in improvement of grain yield and quality since few decades. In the present study, the performance of experimental maize hybrids compared with P3502, a standard check in order to high yield and earliness to estimate the magnitude of standard heterosis. Although five commercial checks were used for evaluation of test material, among all, P3502 was selected as standard check for estimating heterosis. It showed relatively high mean performance for grain yield and earliness in flowering along with lower ASI values. These characters have prime concern in developing of suitable maize hybrids for moisture stress conditions. Comparatively a good plant stand across the three test environments with desired phenotypical characteristics like well foliage, deep rooting system with more surface and brace roots, low senescence and stay green behavior were also taken under consideration in selecting P3502 as standard check. Significant amount of heterosis was observed for all the traits under study; however, the magnitude and range varied with traits and with soil moisture level (Table 3 and Table 4). A negative significant heterosis is desirable in case of flowering traits such as DA, DS and ASI. Negative heterosis for DA and DS represents the earliness in flowering, whereas for ASI represents lower gap between the anthesis and silk emergence which is the major factor of adequate seed set.

3.2.1 Estimation of standard heterosis for flowering traits

According to the results, DA for studied hybrids showed standard heterosis (%) ranged from -4.48 to 9.45 under drought, -9.82 to 7.48 under optimal and -10.26 to 7.69. Under water deficit condition, hybrids viz, T16, T34 and T1 were recorded with maximum negative significant standard heterosis (-4.48%) followed by T9 (-3.48%) and T30 (-2.89%); whereas hybrids viz, T21 (-9.82%) followed by T3 (-8.04%) and T1, T16, and T31 recorded with -2.89%. Similarly, under waterlogging condition, T13 showed highest negative heterosis with -10.26% followed by T14 (-9.40%) and T21, T33, T40 with -8.55%. Overall, six hybrids showed negative significant standard heterosis for DA under well-water condition while 9 and 11 hybrids under water deficit and waterlogging conditions respectively (Table 4). For this trait, hybrids T13 (ZH17192), T14 (VH112926), T16 (VH123021), T21 (ZH114250), T31 (ZH16929) and T33 (ZH16930) were showed significant negative standard heterosis under all the three moisture conditions which explained the earliness of the hybrids under moisture-stress as well as normal condition. Hybrids T16 (ZH16929) and T31 (ZH16930) recorded with significant negative standard heterosis under both drought and optimal conditions for DA. However, many hybrids showed negative heterosis for DS under flooding condition which could be desirable for increased yields, but only one hybrid T40 (VH112888) showed significantly negative heterosis. Our results are in line of conformity with the previous reports in maize by Gebre, Shushay and Mahantesh [14,31,32] under normal irrigated condition whereas with Kumawat et al. [13] under waterlogging condition.

Among all the tested hybrids, 19 hybrids showed negative significant heterosis for DS under optimal soil moisture condition, whereas three hybrids under drought and only one under waterlogging condition. Hybrids viz, T34, T2 and T16 recorded negative significant heterosis for DS under managed drought field with -6.60%, -4.71% and -4.15%, respectively. Whereas T21 (-10.17%) followed by T13 (-9.32%), T33 (-8.47%), T14 (-8.47%) and T31 (-7.63%) recorded significant negative heterosis under optimum moisture condition. Only one hybrid T40 found with negative significant heterosis (-7.38%) for DS under waterlogging condition.

Anthesis-silking interval (ASI) is the most important character in determining soil moisture drought tolerance. Hybrids viz, T16 (-52.38%) followed T34 (-28.57%), T31 (-28.57%), T13 (-28.57%) and T2 (-16.67%) under low water stress condition and hybrids viz, T5 (-55.5%) followed by T45 (-44.4%), T32 (-44.4%), T49 (44.4%) and T39 (-33.3%) under waterlogging stress condition showed negative standard heterosis for ASI but not significant. Five hybrids viz, T5 (-55.5%) followed by T45 (-44.4%), T32 (-44.4%) and T49 (-44.4%) recorded significant negative heterosis under optimal irrigation condition. The hybrids which exhibited low anthesis-silking interval T28 (VH12132), T13 (ZH17192), T31, (ZH16929), T5 (ZH17191), T16 (VH123021) and T44 (ZH161529) under moisture stress-free condition indicates that the hybrids had less gaps between days to anthesis and silking, which was desirable character for good seed setting. Moreover, there was no single hybrid significantly showed negative heterosis under stress condition but T31 (ZH16929), T34 (ZH137998) and T13 (ZH17192) under drought and T5 (ZH17191), T45 (ZH161035), T32 (ZH161035) and T39 (ZH116105) under waterlogged condition showed negative heterosis which could select for earliness for respective environments. On the other hand, if the interval between days to anthesis and silking is more, the grain yield would be reduced due to loss of pollen viability and consequently abnormal fertilization might take place or fertilization may not happen. The results were in accordance with the reports of Mogesse and Bolafios [30,33].

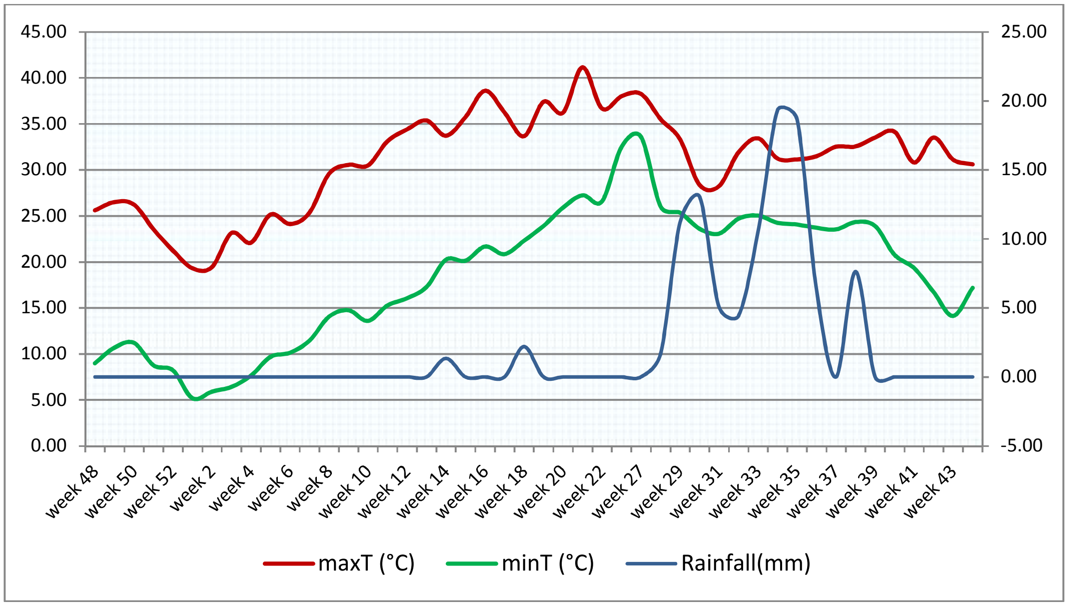

Fig. 1. Graph showing meteorological data of experimental site during the crop growing seasons including Rabi 2017-18 and Kharif 2018

Note: maxT, maximum temperature; minT, minimum temperature

Table 1. List of 50 maize hybrids evaluated based on standard heterosis under different soil moisture conditions during rabi 2017-18 and kharif 2018

Hybrid code	Name of the hybrid	Hybrid code	Name of the hybrid
T1	VH12148	T26	VH12263
T2	ZH161032	T27	VH1253
T3	VH113014	T28	VH12132
T4	VH11130	T29	ZH161529
T5	ZH17191	T30	VH112563
T6	VH131167	T31	ZH16929
T7	ZH161531	T32	ZH161035
T8	ZH114233	T33	ZH16930
T9	VH12186	T34	ZH137998
T10	VH12148	T35	ZH161034
T11	ZH161532	T36	VH112986
T12	VH11129	T37	VH112744
T13	ZH17192	T38	VH121082
T14	VH112926	T39	ZH116105
T15	VH112733	T40	VH112888
T16	VH123021	T41	VH112732
T17	VH123045	T42	VH121043
T18	ZH161530	T43	VH12254
T19	VH112967	T44	ZH161529
T20	VH12316	T45	ZH161035
T21	ZH114250	T46	CAH 153
T22	VH12264	T47	DKC9144
T23	VH1230	T48	900 MG
T24	ZH14435	T49	P 3502 (SC)
T25	VH12229	T50	Hytech 5106

SC, standard check used for the estimating standard heterosis

Table 2. Mean squares for grain yield and flowering traits in 50 maize hybrids under different soil moisture conditions including drought, waterlogging and optimal

Source of variation	df	DA			DS			ASI			GY		
		DT	OPT	WL	DT	OPT	WL	DT	OPT	WL	DT	OPT	WL
Genotypes	49	14.96**	14.15**	14.44**	15.88**	15.76**	23.18**	4.19*	0.90*	6.78*	3.93**	2.65**	3.15**
Replications	1	37.21**	2.56*	73.96**	2.56**	0.36*	72.25**	20.25*	1.00*	0.01*	17.92**	12.34**	0.30**
Block(Rep)	8	15.10**	4.94**	4.15**	9.25*	4.29*	5.50**	5.25*	1.16*	1.12*	1.56**	1.56**	0.40*
Error	41	1.50	0.88	3.46	4.06	1.03	3.93	3.79	0.63	2.57	0.67	0.90	0.29
CV%	-	1.19	0.93	3.24	1.87	0.97	3.18	38.53	19.58	33.07	11.42	10.40	16.94

*** = Significant at $P<0.01$ level of probability and * = Significant at $P<0.05$ level of probability*

CV%, co-efficient of variation (%); df, degree of freedom; DA, days to 50% anthesis; DS, days to 50% silking; ASI, anthesis-silking interval; GY, grain yield; DT, drought; OPT, optimal; WL, waterlogging

Table 3. Standard heterosis over P3502 for grain yield and flowering traits of maize hybrids evaluated under different soil moisture conditions including drought, optimal and waterlogging

Hybrid code	DA			DS			ASI			GY		
	DT	OPT	WL	DT	OPT	WL	DT	OPT	WL	DT	OPT	WL
T1	4.48**	-5.36**	-2.56	3.30	-2.54	1.64	7.14	28.57	11.11	-0.49	-4.62	-32.89**
T2	-2.49*	-3.57	-7.69*	-4.72*	-5.08**	-4.10	-16.67	-42.86	0.00	2.15	12.53	-9.30
T3	1.00	-8.04**	-8.55*	-0.47	-7.63**	-3.28	-4.76	-14.29	22.22	-14.09	19.24	-46.95**
T4	3.48**	-1.79	0.85	2.36	-3.39	2.46	7.14	-42.86	-22.22	-2.15	1.27	-41.75**
T5	1.49	-2.68	-3.42	0.47	-5.08**	-4.10	7.14	-57.14*	-55.56	14.64	17.09	24.92*
T6	0.00	-4.46	-3.42	0.47	-5.93**	-2.46	42.86	-42.86	-33.33	28.59	12.59	22.59
T7	1.99	-3.57	-8.55*	0.94	-5.08**	-3.28	7.14	-42.86	22.22	30.74**	16.46	11.96
T8	2.49*	5.36**	0.85	0.94	6.78**	3.28	-4.76	14.29	-11.11	-32.89**	-20.58*	-47.95**
T9	-3.48**	0.00	3.42	0.94	-5.08**	9.84**	19.05	-42.86	44.44	-21.72	26.58**	-54.82**
T10	5.97**	0.89	0.85	5.66**	4.24	10.66**	30.95	42.86	88.89*	-3.26	-18.10	-46.07**
T11	5.97**	4.46	0.00	4.72*	2.54	8.20	7.14	-42.86	66.67	-1.87	-0.13	-55.15**
T12	2.49*	2.68	3.42	1.89	5.08**	4.10	19.05	28.57	-33.33	-34.14**	4.05	-38.21**
T13	-2.69*	-7.14**	-10.26**	-3.30	-9.32**	-6.56	-28.57	-57.14*	0.00	-2.29	6.52	-23.37
T14	-2.99*	-7.14**	-9.40**	2.36	-8.47**	-4.10	78.58**	-42.86	22.22	9.65	18.80	-30.34*
T15	1.99	-5.36**	-3.42	3.30	-4.24	-1.64	66.67	0.00	-22.22	-6.80	20.25*	-25.80*
T16	-4.48**	-5.36**	-5.56*	-4.15*	-4.75**	-0.82	-52.38	-57.14*	-33.33	45.59**	26.52**	4.54
T17	3.98**	-3.57	-7.69*	1.89	-5.08**	-1.64	-16.67	-42.86	33.33	8.54	-5.70	-34.22**
T18	-1.00	-4.46	0.00	0.94	-4.24	3.28	78.57	-14.29	0.00	-14.23	-4.18	-50.94**
T19	0.00	-2.68	7.69*	0.00	-0.85	9.84**	30.95	-14.29	-11.11	-6.87	-16.27	-66.89**
T20	2.49*	-2.68	-5.13	3.30	-2.54	1.64	54.76	-14.29	44.44	-30.26	3.10	-32.12*
T21	-2.49*	-9.82**	-8.55*	-0.94	-10.17**	-1.64	66.67	-28.57	44.44	-6.52	13.54	-44.63**
T22	1.49	2.68	6.84*	1.42	2.54	7.38*	30.95	-14.29	-33.33	10.41	14.37	-64.89**
T23	3.98**	-2.68	5.13	1.89	-1.69	9.02**	-16.67	0.00	11.11	-14.23	-31.27**	-81.06**
T24	0.00	-1.79	0.00	-0.47	-4.24*	7.38*	19.05	-28.57	55.56	-12.07	3.73	-40.97**
T25	1.00	0.89	1.71	0.94	0.00	8.20*	30.95	-28.57	44.44	-16.17	14.87	-26.69
T26	4.98**	1.79	3.42	4.72*	3.39	13.93**	30.95	14.29	100.00**	-36.50**	-21.96*	-68.66**
T27	1.00	0.89	1.71	0.47	2.54	5.74	19.05	14.29	11.11	-11.66	1.65	-42.64**
T28	0.50	-0.89	0.00	2.36	-4.24*	8.20*	78.57	-71.43**	66.67	-21.93	8.67	-63.90**
T29	-0.50	1.79	-3.42	0.47	0.85	-1.64	54.76	-28.57	-22.22	-30.60*	14.68	-4.21
T30	-2.89*	-4.46	-5.13	-2.36	-2.54	-3.28	30.95	14.29	-22.22	16.45	-8.99	-25.36*

Hybrid code	DA			DS			ASI			GY		
	DT	OPT	WL	DT	OPT	WL	DT	OPT	WL	DT	OPT	WL
T31	-2.49*	-5.36*	-7.69*	-4.72*	-7.63**	-5.74	-28.57	-57.14*	-22.22	31.50**	28.99**	10.19
T32	1.00	0.00	-0.85	0.00	-0.85	-0.82	7.14	-28.57	-44.44	8.26	-11.46	-22.04
T33	-2.49*	-8.04*	-8.55*	-0.94	-8.47**	-6.56	66.67	-28.57	-22.22	16.66	25.38*	8.97
T34	-4.48**	-2.68	-5.98	-6.60**	4.24*	1.64	-28.57	100.00**	55.56	20.54	0.00	-46.73**
T35	0.50	-4.46	-0.85	1.42	-2.54	0.82	54.76	14.29	-22.22	30.60*	20.76*	18.60
T36	2.99*	0.89	2.56	2.36	-4.41*	3.28	19.05	-14.29	-33.33	0.14	20.25*	-55.59**
T37	4.48**	-3.57	-1.71	4.25	-1.69	9.02**	30.95	14.29	100.00**	-18.04	-6.52	-44.30**
T38	5.47**	-4.46	-4.27	3.30	-4.24*	-3.28	-16.67	-14.29	-33.33	11.73	7.15	31.01*
T39	2.99*	-0.89	-0.85	3.77	-1.69	0.82	54.76	-28.57	-22.22	-34.70**	-32.09**	-53.60**
T40	4.48**	1.79	-8.55*	2.36	0.85	-7.38*	-16.67	-28.57	-33.33	-15.96	-2.41	-3.10
T41	5.47**	-2.68	-3.42	6.13**	-3.39	1.64	54.76	-28.57	22.22	-20.61	-11.39	-25.80*
T42	5.47**	1.79	0.85	3.77	5.08**	2.46	-4.76	42.86	-22.22	14.50	11.96	-35.77**
T43	9.45**	7.14	6.84*	8.02**	9.32**	16.39**	7.14	28.57	88.89	-21.37	-26.52**	-62.13**
T44	-1.99	-1.79	0.85	-2.83	-4.24*	3.28	7.14	-57.14	-11.11	8.47	3.99	-27.91*
T45	1.00	2.68	-1.71	-0.94	3.39	-1.64	-16.67	0.00	-44.44	20.06	3.61	-38.10**
T46	1.99	-0.89	-3.42	0.47	-3.39	-0.82	-4.76	-57.14	-11.11	-0.76	-3.35	11.07
T47	3.98**	-4.46	-2.56	3.30	-4.24*	1.64	19.05	-14.29	11.11	12.35	-8.23	-1.55
T48	1.99	-0.89	-3.42	0.47	0.85	4.10	-4.76	14.29	55.56	2.71	3.16	-10.08
T50	1.00	-1.79	-5.98	1.89	-0.85	-4.10	54.76	0.00	-22.22	2.15	17.34	-31.45*

*** = Significant at P<0.01 level of probability and * = Significant at P<0.05 level of probability*

CV%, co-efficient of variation (%); df, degree of freedom; DA, days to 50% anthesis; DS, days to 50% silking; ASI, anthesis-silking interval; GY, grain yield; DT, drought; OPT, optimal; WL, waterlogging

Table 4. Range of standard heterosis for grain yield and flowering traits along with number hybrids showed significant standard heterosis over commercial check

Trait	Soil moisture condition	Range of standard heterosis		Number of hybrids with significant standard heterosis	
		Minimum	Maximum	Negative	Positive
DA	DT	-4.48	9.45	10	19
	OPT	-9.82	7.14	6	1
	WL	-10.26	7.69	11	3
DS	DT	-6.60	8.09	4	5
	OPT	-10.17	9.37	19	4
	WL	-7.38	16.39	1	11
ASI	DT	-52.38	138.09	0	1
	OPT	-71.43	100.00	5	0
	WL	-55.56	100.00	0	3
GY	DT	-36.50	45.59	5	6
	OPT	-32.09	28.99	5	7
	WL	-81.06	31.09	32	2

DA, days to 50% anthesis; DS, days to 50% silking; ASI, anthesis-silking interval; GY, grain yield; DT, drought; OPT, optimal; WL, waterlogging

3.2.2 Estimation of standard heterosis for grain yield (GY)

Improvement in grain yield is ultimate goal of any plant breeder. Commercial production of newly developed hybrids cannot be achievable, if it is not performed better than standard commercial cultivar/ check. Positive and significant heterosis is desirable for the grain yield as it indicates increased grain yield potential over the existing standard check. Standard heterosis for grain yield was ranged from -30.029 to 45.59 under drought plots, -32.09 to 28.99 under normal moisture condition while, -89.06 to 31.09 under excess soil moisture condition. Among all the corn hybrids evaluated, six hybrids viz, T16 (45.59), T7 (30.79), T29 (30.60), T35 (30.60), T31 (30.18), and T6 (29.59) had positive and significant heterosis over check under drought environment while, two hybrids viz, T38 (31.01%) and T5 (24.92%) under waterlogging condition. Seven hybrids viz, T31 (28.99%) followed by T9 (26.58%), T16 (26.52%), T33 (25.38%), T35 (20.76%), T36 (20.25%), and T15 (20.25%) showed positive significant heterosis over check under well-water condition. According to the finding, hybrids T16 (VH123021), T31 (ZH16929) and T35 (ZH161034) were showed positive significant heterosis over standard check under both drought and normal condition whereas hybrids T8 (ZH114233), T26 (VH12263) and T39 (VH12186) had negative significant heterosis under all the three soil moisture conditions. Our results revealed that, heterosis was more affected because of excess soil moisture than drought stress as most of the hybrids showed negative heterosis. Among all, 33 hybrids had negative significant heterosis over standard check under the waterlogging condition. Among all the tested hybrids, VH123021 and ZH16929 were recorded significant standard heterosis in terms of magnitude with acceptable direction for studied flowering traits and mean grain yield under almost all the three moisture conditions (negative heterosis for ASI but not significant under both moisture stress conditions). Few previously reported works pertaining to standard heterosis in maize hybrids [13,15,16,31,34,35,36]. Considerable amount of positive and negative significant standard heterosis for DA, DS and GY along with other agronomic traits of maize was reported by Gebre [14] at Southeastern Ethiopia. Legesse et al. [37] also reported positive and negative standard heterosis over checks for mid altitude maize growing areas of Ethiopia. Significant variation among genotypes for grain yield and yield related traits in maize at eastern Ethiopia was reported by Mogesse [30]. Along with these, the findings of present study are also in accordance with results reported by Bullo, Matin and Shrestha [38,39,40]. However, further evaluation of hybrids with desired standard heterosis along with other hybrids used at multi-locations and multi-seasons is advisable to confirm the promising findings observed in our study. In general, present study may be concluded that the results could be valuable for maize workers who aimed to develop climate resilient maize cultivars.

4. CONCLUSION

The results revealed significant variation for grain yield and flowering related traits such as days to

50% anthesis, days to 50% silking and ASI under all the moisture conditions including optimal, managed drought and managed waterlogging conditions. Significant amount of heterosis was observed over the selected check P3502 for the traits under study; however, the magnitude and direction varied with traits and with soil moisture level. Hybrids VIZ., ZH17192, VH112926, VH123021, ZH114250, ZH16929 and ZH16930 were showed significant negative heterosis for days to 50% anthesis under all the moisture conditions that explained earliness under both moisture-stress and normal conditions. Among the tested hybrids, VH123021 and ZH16929 were showed significant negative standard heterosis for flowering traits; and significant positive heterosis for grain yield across all the three moisture conditions. Six hybrids under drought, seven hybrids under optimal and two hybrids under waterlogged condition showed positive standard heterosis for grain yield.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Claassen MM, Shaw RH. Water deficit effects on corn II. Grain components. Agronomy J. 1970;62:652-655. Available:https://doi.org/10.2134/agronj1970.00021962006200050032x
2. Daryanto S, Wang L, Jacinthe PA. Global synthesis of drought effects on maize and wheat production. PloS one. 2016;11(5), e0156362. DOI: 10.1371/journal.pone.0156362
3. Wattoo FM, Saleem M, Ahsan M, Sajjad M, Ali W. Genetic analysis for yield potential and quality traits in maize (*Zea mays* L.). Am Euras J Agric and Environmental Sci. 2009;6(6),723-729.
4. Menkir A, Akintunde AO. Evaluation of the performance of maize hybrids, improved open-pollinated and farmers' local varieties under irrigated and drought stress conditions. Maydica. 2001;46:227-238.
5. Edmeades GO, Bolanos J, Elings A, Ribaut JM, Bänziger M, Westgate ME. The role and regulation of the anthesis-silking interval in maize. Physiology and Modeling Kernel Set in Maize. 2000;29,43-73. DOI: 10.2135/cssaspecpub29.c4
6. Bu LD, Zhang RH, Chang Y, Xue J, Han M. Response of photosynthetic characteristics to water stress of maize leaf in seeding. Acta Ecologica Sinica. 2010;30(5),1184-1191.
7. Chang J, Yang D, Tan W, Lu Y. Effects of water stress on maize leaf photosynthesis. Journal of Northeast Agricultural University. 2008;11.
8. Chaves MM, Pereira JS, Maroco J, Rodrigues ML, Ricardo CPP, Osório ML, et al. How plants cope with water stress in the field? Photosynthesis and growth. Annals of botany. 2002;89(7),907-916. DOI: 10.1093/aob/mcf105
9. NeSmith DS, Ritchie JT. Short-and long-term responses of corn to a pre-anthesis soil water deficit. Agronomy Journal. 1992;84(1),107-113. DOI:10.2134/agronj1992.00021962008400010021x
10. Ge TD, Sui FG, Bai LP, Lu YY, Zhou GS. Effects of different soil water content on the photosynthetic character and pod yields of summer maize. Journal of Shanghai Jiaotong University (Agricultural Science). 2005;2.
11. Weiqing Z, Xiuying S. Effects of water stress and rewatering on photosynthetic rate of maize leaf. Acta Agriculturae Boreali-Sinica. 1994;9(3),44-47.
12. Ulaganathan V, Vinoth R, Baghyalakshmi K, Chimili, SR, Gurusamy, A. Standard heterosis for grain yield and other agronomic characters in maize (*Zea mays* L.) under normal and moisture stress conditions. The Bioscan. 2015;10(3):1251-1253.
13. Kumawat G, Shahi JP, Kumar M. Assessment of genetic diversity of maize (*Zea mays* L.) hybrids under water logging condition. Electron. J. Plant Breed. 2020; 11(1):252-258.
14. Gebre AB, Mohammed H, Abakemal D. Standard heterosis of hybrids maize (*Zea mays* L.) for grain yield and yield related

traits at Kulumsa, Southeastern Ethiopia. Int J Agric Sci. 2019;5 (9):1-7. DOI: 10.20431/2454-6224.0509001

15. Nedi G, Tulu L, Alamerew S. Standard heterosis of the selected maize (*Zea mays* L.) inbred lines hybrids for grain yield and yield component at Jimma, South West Oromia Region, Ethiopa. Journal of Biology, Agriculture and Healthcare. 2017;7(15):51-58.
16. Mesenbet Z, Zeleke H, Wolde L. Standard heterosis of pipeline maize (*Zea mays* L.) hybrids for grain yield and yield related traits at Pawe, Northwestern Ethiopia. J Plant Breed Crop Sci. 2016;3(2):135-144.
17. Shull GH. The composition of a field maize. Am Breed Assoc Rep. 1908;4:296-301.
18. Devi B, Barua NS, Barua PK, Talukar P. Analysis of mid parent heterosis in a variety diallel in rainfed maize. Indian J. Genet. and Plant Breed. 2007;67(2):67-70.
19. Alam AK, Ahmed MM, Begum SM, Sultan MK. Heterosis and combining ability for yield and its contributing characters in maize. Bangladesh J Agric Res. 2008; 33(3):375-37. DOI:10.3329/bjar.v33i3.1596
20. Pratap N, Shekhar R, Singh PK, Soni SK. Combining ability, gene action and heterosis using cms lines in hybrid rice (*Oryza sativa* L.). The Bioscan. 2013; 8(4):1521-1528.
21. Thakare IS, Patel AL, Mehta AM. Line × tester analysis using cms system in rice (*Oryza sativa* L.). The Bioscan. 2013;8(4):1379-1381.
22. Patteraon HD, Williams ER. A new class of resolvable incomplete block designs. Biometrika. 1976;63:83-12.
23. Zaman-Allah M, Zaidi PH, Trachsel S, Cairns JE, Vinayan MT, Seetharam K. Phenotyping for abiotic stress tolerance in maize-Drought stress. A field manual. CIMMYT, Mexico; 2016.
24. Zaidi PH, Vinayan MT, Seetharam K. Phenotyping for abiotic stress tolerance in maize: waterlogging stress. A field manual. CIMMYT: Hyderabad, India; 2016.
25. ASTM. Annual Book of ASTM Standards. In American Society for Testing and Materials, 100 Barr Harbor Drive; ASTM:West Conshohocken, PA, USA; 2001.
26. Pacheco A, Rodríguez F, Alvarado G, Burgueño J. ADEL-R. Analysis and design of experiments with R for windows. Version 2.0. CIMMYT Research Data & Software Repository Network. 2017;3. Available: https://hdl.handle.net/11529/10857
27. Falconer DS, Mackay TFC. Introduction to quantitative genetics. 4th ed. Longman, London; 1996.
28. Panse VG, Sukhatme PV. Statistical methods for agricultural workers ICAR Publication, New Delhi. 1967;pp.259.
29. Snedecor GW, Cochran WG. Statistical Methods. The Iowa State College Press, Ames, Iowa. USA. 1967;160-413.
30. Mogesse W, Zelleke H, Nigussie M. Standard heterosis for grain yield and yield related traits in maize (*Zea mays* L.) inbred lines in Haramaya district, Eastern Ethiopia. East Afr J Sci. 2020;14(1):51-64.
31. Shushay W. Standard heterosis of maize (*Zea mays* L.) inbred lines for grain yield and yield related traits in central rift valley of Ethiopia. Journal of Biology, Agriculture and Healthcare. 2014;4(23):31-37.
32. Mahantesh. Combining ability and heterosis analysis for grain yield components in single cross hybrids of maize (*Zea mays* L.). M.Sc. Thesis, College of Agriculture, Dharwad University of Agricultural Sciences, India. 2006;103.
33. Bolafios J, Edmeades GO. The importance of the anthesis-silking interval in breeding for drought tolerance in tropical maize. Field Crops Res. 1996;48(1):65-80. DOI: 10.1016/0378-4290(96)00036-6
34. Gayatri K, Shahi JP, Kumar M, Singamsetti A, Choudhary MK, Shikha K. Standard heterosis analysis in maize hybrids under water logging condition. J Exp Biol Agric Sci. 2020;8(2):90-97. DOI: 10.18006/2020.8(2).90.97
35. Hailegebrial K, Getachew A, Legesse W, Yemane T. Estimation of heterosis of elite maize (*Zea mays* L.) hybrids at Bako, Ethiopia. Journal of Biology, Agriculture and Healthcare. 2015;5(15):53-62.
36. Reddy V, Jabeen F, Sudarshan MR. Heterosis studies in diallel crosses of maize for yield and yield attributing traits in maize (*Zea mays* L.) over locations. Int J Agric Environ Biotechnol. 2015;8(2):271-283. DOI:10.5958/2230-732X.2015.00034.0
37. Legesse BW, Pixley KV, Botha AM. Combining ability and heterotic grouping of highland transition maize inbred lines. Maydica. 2009;54:1-9.

38. Bullo N, Dagne W. Combining ability of inbred lines in quality protein maize (QPM) for varietal improvement. Int. J. Plant Breed. Genet. 2016;3(1):079-089.
39. Matin MQI, Rasul MG, Islam A, Mian MK, Ivy NA, Ahmed JU. Combining ability and heterosis in maize (*Zea mays* L.). Am J Agric Biol Sci. 2017;4(6):84-90. DOI: 10.11648/j.ajbio.20160406.12
40. Shrestha J, Gurung DB, Rijal TR. Standard heterosis for grain yield in maize hybrids. *Fmg. & Mngmt.* 2018;3(1):30-36. DOI: 10.31830/2456-8724.2018.0001.6

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