Research Article

EVALUATION OF HEAT TOLERANT MAIZE *(Zea mays L.)* INBRED LINES UNDER NATURAL FIELD CONDITIONS IN INDIA

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ABSTRACT

Heat stress is becoming an eminent constraint of maize production in all the major maize producing regions, including South Asia. Effect of natural heat stress on flowering, height, grain yield, and other major secondary traits were evaluated in Hyderabad and Bhubaneswar, India during spring season of 2016. Two hundred and two double haploid (DH) maize inbred lines were tested for heat tolerance using α-lattice design with two replication. Differences observed for days to anthesis (AD), days to silking (SD), plant height (PH), ear height (EH), tassel blasting (TB), leaf firing (LF), senescence (SEN), soil plant analysis development (SPAD) index, and grain yield (GY) among the tested maize lines. The GY of heat tolerant parent ranged 0.227-0.375 t ha^{-1} and susceptible tester ranged 0.10-0.15 t ha^{-1} while grain yield of population ranged from 0.014 to 0.935 t ha^{-1}. The wider range of genotypic variation was recorded among inbred lines for TB (205.7-234.3), LF (534.7-559.5), and SEN (132.4-163.4). Moderate to high heritability (0.63 to 0.95) and transgressive segregations were observed in both directions for these secondary traits. As major and additive genes can be expected for moderate to high heritability of these traits, selection could be a best tool to be applied for reliable improvement of maize against heat stress. Indirect selection of the secondary traits can play influential roles in GY improvement of maize under heat stress. Such information could be useful in inbred lines selection and development of novel heat tolerant maize hybrids in the future.

Key words: Double haploid (DH), genotypic variation (σ^2_g), heat stress, heritability (h^2), and inbred lines

INTRODUCTION

Maize is one of the most important cereal crops in South Asia (SA), contributing considerably for food security along with rice and wheat (Shiferaw et al., 2011). It plays an important role in the livelihoods of millions of poor farmers in food, feed, fuel, and fodder. It is one of the key ingredients for animal feed, and used extensively in industrial purposes (Osti, 2019). The demand of maize grains for feed is growing in SA, where rapid economic growth is enabling many to afford livestock and poultry products. Increasing demand of maize grains and production shortfalls in supplies have contributed to surging regional prices (Shiferaw et al., 2011). The crop is highly productive under better crop management and optimal conditions, reasonably well under sub-optimal condition, and generally poor under stress condition (Hosamani et al., 2019). Winter, spring, and summer are the major growing seasons in SA where spring maize is one of the potential options to diversify and intensify the maize production of this region (Prasanna, 2011). In spring maize, high temperature is likely to coincide with the sensitive reproductive stage, and often results in reduced crop productivity, mainly due to heat related stresses. The maize is more sensitive to drought and heat stresses at the reproductive stages (Hussain et al., 2019).

Heat stress has become an emerging concern because of its negative impact on future global food security in the context of climate change. The higher growing seasonal temperatures in the tropics and sub-tropics will exceed even beyond the most extreme seasonal temperature recorded so far (Battisti & Naylor, 2009). If the current trends persist until 2050, major crop yields and food production capacity of SA will decrease by 16% for maize, 12% for wheat, and 10% for rice due to climate change induced heat and water stress (Bandara & Cai, 2014; Knox et al., 2012). The unprecedented rise in temperature may have dramatic impacts on agricultural productivity, farm incomes, and food security (Bandara & Cai, 2014; Battisti & Naylor, 2009). Since SA has high population density, large numbers of smallholder farmers, diverse production environment, and limited resources available for adaptation, the region is more vulnerable due to global warming (Ahmed & Suphachalasai, 2014; Tesfaye et al., 2016).

Genetic variability in the population and the relationship among the traits is the basis for any successful plant breeding program (Govindaraj et al., 2018; Noor et al., 2019; Thiry et al., 2016). The presence of genetic variability in the base population ensures better chances of developing desired plant types. The knowledge of genetic parameters viz., population structure, heritability, and genotypic variance among the traits under selection is useful in order to develop efficient breeding lines (Falconer & Mackay, 1996). Heat tolerant cultivars would be an economic solution to deliver climate smart cultivars to the farmers. Selection of high yielding genotypes by using secondary trait is an effective means of yield improvement under heat stress (Govindaraj et al., 2018; Noor et al., 2019; Thiry et al., 2016). As suggested earlier by Grierson et al. (2011), challenges imposed by global warming in food security can only be met by strong fundamental understanding of crop biology and translations of this knowledge into field-based solutions. Therefore, the present study investigated the effect of heat stress on DH maize inbred lines and determined relationship between the traits when the crop exposed to natural heat stress.

MATERIAL AND METHODS

The study was conducted at two locations, International Crop Research Institute for the Semi-Arid Tropics (ICRISAT), Hyderabad (HBD) (17°31'4"N, 78°16'43"E and 545 m asl,) and Orissa University of Agriculture and Technology (OUAT), Bhubaneswar, Odisha (ODS) (20°26'50"N, 85°81'17"E and 25.9 m asl), India, during the spring of 2016. The experimental materials consist of 202 Double Haploid (DH) maize per se inbred lines developed by International Centre for Maize and Wheat Improvement (CIMMYT) derived from crosses of (CML165×KI145)-B-14-1-B*4-1-BB/CML286-BB.The experiment was done by using α-lattice design, with two replication. Each plot consisted of single row of 2.5-m long with between rows and plants spacing of 0.75-m and 0.20-m, respectively.

The maize crop was grown under CIMMYT-Asia maize program standard management practice. Seeding was done on the third week of March in both the locations where natural heat stress was expected to be at the peak during flowering time. Fertilizer was applied @ 120:60:40 NPK kg ha^{-1} where full dose of phosphorus used in the form of DAP, 80% potash in the form of MoP, and full dose of ZnSo4 as basal applications. The remaining nitrogen supplied through Urea in three split doses as top-dressing, and 20% MoP added at the time of second top dressing. Crops were irrigated based on crop requirements at regular intervals.

In this study, days to anthesis (AD), days to silking (SD), plant height (PH), ear height (EH), leaf firing (LF), tassel blasting (TB), senescence (SEN), soil plant analysis development index chlorophyll meter reading (SPAD index), and grain yield (GY) were recorded. All data were recorded by using maize descriptor developed by CIMMYT-Asia maize program (Zaidi et al., 2016). Analysis of variance for all the traits was done by using META-R software, developed by CIMMYT (Alvarado et al., 2015).(H. A. Hussain et al., 2019)

RESULTS

In this section, we illustrate the experimental results of DH maize lines evaluated under field condition of Hyderabad and Odisha, India. The result of this analysis has been compared with parents and population for flowering dynamics, morphological features, secondary traits, and grain yield (Table 1-2). The estimated genetic correlation between all pairs of traits is presented for two sites separately (Table 3). The crop was imposed to T_{max} beyond 40°C and T_{min} of slightly below 25°C along with relative humidity (RH) less than 50% starting from the 4^{th} week of planting to the end of silking in Hyderabad. Similarly, T_{max} was exceeded 40°C and T_{min} was above 25°C with over 60% RH after the 2^{nd} week of planting until completion of flowering in Odisha. The temperature fluctuated according to rainfall pattern during the flowering time but T_{max} never dropped below 35°C. The temperature often always crossed the threshold limits of 38°C during peak flowering time. The annual mean land surface air temperature for 2016 was around 0.71°C, higher than average, thus making the year 2016 among the warmest year on record in last 137 years (Anomaly & Anomaly, 2017). Hence, the crop must have exposed to highest heat load of the season during flowering time. Because of higher vapor pressure deficit, the crop was imposed to remarkable heat pressure in Hyderabad even though there was constant higher temperature in Odisha.

Flowering and morphological traits

Table 1. Mean performance of maize inbred lines for flowering and morphological traits in Hyderabad and Odisha, India in 2016

Traits	Location[£]	Parents		Population			
		Female	Male	Mean±SE	Range	h^2	σ^2_g
Days to anthesis	HBD	58	65	63±1.4	59-69	0.73	5.15**
	ODS	53	57	55±1.3	49-62	0.81	7.19**
Days to silking	HBD	59	66	64±1.7	60-69	0.70	6.40**
	ODS	53	59	58±1.0	53-63	0.85	5.70**
Plant height (cm)	HBD	99	83	87±6.9	70-103	0.63	81.68**
	ODS	111	99	100±5.3	67-120	0.80	112.06**
Ear height (cm)	HBD	49	41	43±5.1	34-55	0.54	30.35**
	ODS	50	46	40±6.10	9-62	0.77	126**

[£,] HBD=Hyderabad and ODS=Odisha, ** significant at ≤0.01 level of significance

The analysis of variance revealed significant differences (p<0.01) on AD, SD, PH, and EH in both locations (Table 1). In general, heat tolerant (female) parent had 4-7 days early anthesis and 6-7 days earlier silking as compared with susceptible (male) tester in both the locations. Flowering time of maize in Odisha was almost one week earlier than Hyderabad. Higher heritability was observed for AD and SD in Odisha as compared to Hyderabad, with low genotypic variance in both the locations.

The plant and ear height of female parent was always taller than male parent in both the locations whereas plants in Odisha were always taller than Hyderabad (Table 1). However, ear height of both parents and population was almost comparable in both the locations. High heritability was recorded for plant height, so as the medium to high heritability for ear height. In general, high genotypic variance was found for ear height than plant height. Higher genotypic variance was found in HBD than ODS for plant height, but opposite was the results recorded for ear height.

Key secondary traits

In this study, contrasting result was observed for the trait tassel blasting with respect to parental performance where heat tolerant parent (female) showed higher degree of tassel blasting than heat susceptible tester (male) in both the locations (Table 2). Interestingly, population mean tassel blasting and leaf firing was higher in Hyderabad than Odisha, but parental mean for tassel blasting and leaf firing was higher in Odisha as compared to Hyderabad. Similarly, susceptible tester had displayed relatively more leaf firing whereas heat tolerant parent had demonstrated comparatively higher tassel blasting in both the locations. The distribution pattern of leaf firing and tassel blasting in the population was skewed in both the locations. Higher degree of heritability (0.92-0.95) and genotypic variation was observed for both the traits across locations.

Table 2. Mean performance of maize inbred lines for secondary and grain yield traits in Hyderabad and Odisha, India in 2016

Traits	Location[£]	Parents		Population			
		Female	Male	Mean±SE	Range	h^2	σ^2_g
Tassel blasting (%)	HBD	16.6	12.4	8.2±4.5	0.0-76.2	0.92	234.28**
	ODS	0.60	0.50	4.5±3.5	0.0-88.7	0.95	205.69**
Leaf firing (%)	HBD	18.2	23.6	14.9±6.6	0.0-87.8	0.92	534.73**
	ODS	0.40	0.70	10.6±5.7	0.0-94.9	0.94	559.53**
Senescence (%)	HBD	26.7	29.9	40.8±7.3	23.4-69.9	0.71	132.36**
	ODS	7.9	14.6	28.1±7.2	11.2-73.2	0.76	163.43**
SPAD index	HBD	29.1	18.5	18.4±4.0	8.98-35.0	0.66	30.51**
	ODS	37.5	19.6	16.8±4	5.8-33.8	0.78	55.19**
Grain yield(t ha^{-1})	HBD	0.227	0.10	0.237±0.01	0.014-0.935	0.82	0.06**
	ODS	0.375	0.15	0.125±0.08	0.023-0.506	0.63	0.01**

[£,] HBD=Hyderabad and ODS=Odisha, ** significant at ≤0.01 level of significance

The senescence was faster in susceptible tester than heat tolerant parent, and the mean SPAD index of heat tolerance parent was always higher at both the locations. Here, faster senescence was recorded in Hyderabad (hot and dry) as compared to Odisha (hot and wet). Higher genotypic variation and heritability was recorded for senescence than SPAD index in both the locations. Likewise, relatively low genotypic variation and heritability was observed for SPAD index in Hyderabad compared to Odisha.

Grain yield

In both the locations, female parent produced the higher grain yield than male parent (Table 2). The analysis of variance revealed highly significant differences (P<0.01) among the genotypes for grain yield. The population means, range, heritability, and genotypic variation for grain yield were higher in the Hyderabad than in the Odisha. The mean grain yield in the Odisha was nearly 50% less than that of Hyderabad.

Table 3. Genetic correlation (rg) of maize inbred lines variables for Hyderabad (below diagonal) and Odisha (above diagonal), India, in 2016

Traits	AD	SD	PH	EH	SEN	TB	LF	SPAD	GY
AD	-	-0.61**	-0.68**	-0.23**	0.40**	-0.25**	-0.14*	-0.19**	0.36**
SD	-0.56**	-	0.82**	0.44**	-0.18*	-0.26**	-0.10ns	-0.31**	-0.07ns
PH	-0.54**	0.53**	-	0.36**	-0.13ns	-0.14*	-0.49*	-0.29**	-0.24**
EH	0.23**	0.22**	0.16*	-	0.13ns	-0.15*	0.04ns	-0.21**	0.08ns
SEN	0.26**	0.22**	0.25**	0.91**	-	-0.30**	-0.07ns	-0.05ns	0.44**
TB	-0.43**	0.31**	0.13ns	-0.23**	-0.12ns	-	0.11ns	0.48**	-0.64**
LF	-0.06ns	0.07ns	0.06ns	0.05ns	0.01ns	0.24**	-	0.28**	0.05ns
SPAD	-0.14ns	0.01ns	0.01ns	-0.08ns	-0.22*	0.33**	0.38**	-	-0.18*
GY	0.49**	-0.33**	-0.35**	-0.05ns	-0.06ns	-0.42**	-0.20**	-0.28**	-

* significant at ≤0.05, ** significant at ≤0.01 level of significance, and ns=non-significant at p=0.05

Correlations

The strong positive genetic correlations (rg=0.49 in Hyderabad, rg=0.36 in Odisha) was observed between the traits grain yield and days to anthesis (Table 3). The grain yield was negatively associated with plant height, tassel blasting, and SPAD index in both the locations. SPAD index had strong positive correlations with leaf firing and tassel blasting, whereas tassel blasting had strong negative associations with days to anthesis. The strong positive correlation was observed between days to anthesis and senescence whereas highly significant negative associations were found between tassel blasting and ear height.

DISCUSSION

A comparative study of flowering dynamics over locations showed days to anthesis was more affected than days to silking due to high ambient temperature. Interaction of genotypes with temperature might be the major contributing factors for this variation. This was in agreement with the earlier finding of Jill E. Cairns et al. (2013). High temperature in crop season might have induced asynchrony of male and female flowering, reduced fertilization, and post-fertilization processes, and finally leading to a decreased grain yield. This was in accordance with earlier findings (Cicchino et al., 2010; Xie et al., 2010).

Plant height was strongly associated with the flowering date whereas late flowering maize is usually taller. This result ties well with studies of Zsubori et al. (2002) wherein floral initiation stops inter node formation which means that earlier flowering maize is usually shorter. The ear height was positively correlated to plant height but more fluctuation was found in PH than EH. Taller plants were observed in Odisha, but ear height was almost comparable in both the locations. Stability of EH across the environment might be due to the action of few genes for determining EH as compared to plant height. This finding was in agreement with the earlier finding of Thompson, Hanson, and Shaw (1971). This dramatic fluctuation in PH might be due to shortening of inter node length above the cob due to heat stress. This enforces the previous results (Cairns et al., 2012; Hall, 1992; Weaich et al., 1996) that heat stress inhibits inter node length elongation and ultimately reduces plant height.

The frequency of leaf firing and blasting was more in the Hyderabad than in the Odisha. It is worthy to note that the maize crop of Hyderabad had received more favorable situation for expression of these secondary traits than in the Odisha. The TB and LF were highly correlated with each other, but had no direct association with grain yield. However, Hussain et al., (2006) reported that TB and LF had the positive significant association with each other and highly significant negative correlation with grain yield under heat stress. In the case of this result, reduction in grain yield was directly associated with increasing anthesis silking interval (ASI) where TB contributed for increased ASI. On the other hand, LF was more closely associated with senescence and SPAD index where these traits were more related to grain yield. Kaur et al., (2010) had also observed similar findings. It indicated that LF and TB did not have any direct contribution on grain yield but they can influence indirectly to other secondary traits that contribute to grain yield. It can be argued that yield reduction might be associated with a direct effect of heat stress on the expression of secondary traits, and indirect effect of these traits may effect on grain yield and yield component traits.

In this study, heritability was high for tassel blasting and leaf firing (greater than 90%), and was greater than 70% for plant height, ear height, and senescence. High heritability indicates that variation for the particular trait is mostly due to the heterogeneity in the genotypes Karen Sabadin et al., (2008). Earlier research findings (Bolaños & Edmeades, 1996; Monneveux et al., 2008) supported that heritability of grain yield generally decreases but genetic correlation and heritability of secondary traits usually increases under stress condition. These secondary characters, therefore, can be used as criteria for yield improvement. Comparatively low heritability for grain yield might be due to the involvement of many genes. Therefore, the chance of progress through direct selection is low for this trait. The genetic variation that was low for days to anthesis and days to silking may be compensated by their high heritability. Ogunniyan & Olakojo (2014) also reported that high heritability may not always associate with large genetic variation. So, high heritability along with large genetic variation may be better considered to predict the effect of selection.

CONCLUSION

The population evaluated in this study exhibited a wider range of variation for the traits of inbred maize lines. Heat stress exhibited greater impact in the expression of grain yield and key secondary traits. In comparison to grain yield, genetic variation and heritability increased for key secondary traits under natural heat stress. Moderate to high heritability for secondary traits indicated the relevance of using secondary traits for yield improvement of maize. Under heat stress, tassel blasting, leaf firing, and senescence could be the key secondary traits for improvement of grain yield. Therefore, indirect selection of inbred lines of maize based on key secondary traits might be useful to consider in exploring the high yielding genotypes under heat stress condition. This information could help in development of heat tolerant maize hybrids in the future.

ACKNOWLEDGMENTS

We gratefully acknowledge HTMA project funded by USAID through CIMMYT, India-Asia Maize Program to carry out this research. We also feel immense pleasure to all CIMMYT, Hyderabad staffs for making this research successful. We would like to extend my sincere gratitude to Sanjaya Gyawali and Dipak Sharma Poudel for their unconditional support and inspirations.

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