



## Evaluation of maize (*Zea mays*) hybrids for leaf thermo-stability, photosynthetic rate, stem reserves and productivity under rain-dependent conditions

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### ABSTRACT

Maize (*Zea mays* L.) is one of the most versatile crops probably due to its wider adaptability and photosynthetic efficiency but drought and higher temperature tolerance are prerequisite for cultivation under rain-dependent conditions. Fifteen maize hybrids were evaluated for yield and yield attributes during two consecutive years, i.e. 2011 and 2012, and heat tolerance and stem reserves (starch + sugars) during 2012. Leaf photosynthetic rate ( $P_N$ ) was measured during 2012 and 2013. Analysis of variance of grain yield and its attributes during two years showed significant variations in genotype (G), year of cultivation (Y) and their interaction (G × Y). Tasseling and silking intervals were least in PHM-1 and Parakash during both the years. Leaf relative injury index (RI) varied between 40% in both Parakash and PHM-1, and 74% in HQPM-1. Thus, hybrids were classified based on RI values such as tolerant (RI between 40 and 49%), moderately tolerant (RI between 50 and 59%) and susceptible (RI ≥ 60). In general,  $P_N$  enhanced from vegetative to anthesis and thereafter declined during grain filling stages. This was attributed to reproductive sink-driven demand. Stem reserves (non-structural carbohydrates) were higher in Parakash, HQPM 7 and JH-3459. In addition, grain protein and starch contents during milking stage were higher in DHM-117, Parakash and DHM-3. Average values of biomass and grain yields recorded during two consecutive years ranged between 1 874 and 4 769 g/m<sup>2</sup>, and 809 and 1 669 g/m<sup>2</sup>, respectively. Also, associations between various attributes of grain yield, photosynthesis, leaf temperature, RI and stem reserves were established, and potential hybrids were identified. Especially, hybrids Parakash and PHM-1 were found efficient in most of the parameters studied, such as, heat tolerance, lesser tassling and silking interval, relatively lower stem diameter at final harvest, higher stem reserves,  $P_N$ , 1 000-seed mass, HI, grain and biomass yields.

**Key words:** Biomass, Drought tolerance, Heat tolerance, Stem reserves, Tasseling and silking intervals

Under rain-dependent conditions, productivity and yield stability are greatly affected by water-deficit and associated high temperatures. For example, in India, productivity of maize (*Zea mays* L.) is about half (2.50 tonnes/ha) of that in Asia (4.8 tonnes/ha) and one-fourth of that in USA (9.6 tonnes/ha) (FAO 2014). Temperatures above 35°C for a long period are considered to be unfavourable and over 40°C may cause irreversible damage to the crop. Under rain-dependent conditions, maize usually encounters with water-deficit stress, especially during tasseling, silking and early grain filling stages (Bokszczanin *et al.* 2013, Cairns *et al.* 2013). In tropical maize, yield under water-deficit at flowering is associated with kernels number/plant and, interval between anthesis and silking (Bolanos and Edmeades 1996). Hence, this parameter is often used

as a surrogate measure of ear growth rate under water-deficit (Vega *et al.* 2001). While under heat stress the cell membrane is the first site which gets damaged physiologically (Blum 1988) therefore, cell membrane stability test has emerged as a reliable tool for measuring heat tolerance in several crop plants (Nautiyal *et al.* 2005, 2008, Coskum *et al.* 2011). It is expected that maize yield under water-deficit mainly reflects tolerance of kernel setting mechanism during anthesis. Whereas, genetic improvement can probably contribute about 20–25% of the yield gaps between drought-affected and optimal conditions (CIMMYT 2013). Moreover, heat tolerance is becoming more important as climate changes, and the genetic controls of heat and drought tolerance are meagrely understood (Bokszczanin and Fragkostefanakis 2013).

In addition, the process by which grasses produce, transport and store carbohydrate is important for expanding knowledge to optimize whole-plant carbohydrate partitioning for increased productivity (Slewinski 2012). Integrated approaches that improve the efficiency of agricultural water use and development of plant varieties that can alleviate the negative impacts of environmental stresses to maintain yield stability are essential to sustain

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and increase agriculture production. The objective of the study was to evaluate maize hybrids for heat tolerance, photosynthetic efficiency and stem reserves (non-structural carbohydrates) and grain and biomass yields, under rain-dependent conditions.

#### MATERIALS AND METHODS

Experiment was conducted during 2011, 2012 and 2013, yield and yield attributes were recorded during 2011 and 2012 while leaf cell membrane thermo-stability during 2012, and photosynthetic rate during 2012 and 2013.

Weather, i.e. temperatures, rainfall and relative humidity during crop growth period, i.e. June-October in 2011 and 2012 were recorded. These data showed more or less similar trends during both the years, for example, mean maximum temperatures ranged between 26° and 43°C in 2012, and 28° and 42°C in 2013. Similarly, mean minimum temperatures ranged between 14° and 24°C in 2011, and 15° and 22°C in 2012. Total rainfall varied between 57.32 and 49.42 cm during 2011 and 2012, respectively. In addition, distribution of rainfall and minimum and maximum temperatures over the growth period was more or less similar and crop was not given any irrigation after emergence, during both the years.

Experiment was conducted with 15 maize hybrids. Seeds were procured from the ICAR-Institute of Maize Research, New Delhi. Field trials were conducted during rainy seasons (June-October) of 2011, 2012 and 2013 in complete randomized block design (CRBD) with three replicates at experimental site of the Water Technology Centre, ICAR-IARI, New Delhi. The plot size constituted of four rows of 3 m length each. Seed-to-seed distance was 15 cm while row-to-row distance was 60 cm. Basal doses of 120 kg of N/ha in the form of urea; 60 kg P<sub>2</sub>O<sub>5</sub>/ha (26.16 kg/ha, elemental P) in the form of single super phosphate and 40 kg of K<sub>2</sub>O/ha in the form of muriate of potash which were applied before sowing. Recommended plant protection measures were followed to maintain healthy crop stand. After sowing crop was irrigated to the field capacity and after one week second irrigation was provided with to ensure maximum emergence, thereafter crop remain rain-dependent. Yield and yield attributes were recorded during 2011 and 2012.

Flowering such as days to initiation of flower, i.e. male (tasseling) or anthesis and female (silking) and full blooming, i.e. 50% plants showed tassling or silking were recorded on individual plant of two rows of each hybrid and replicate, daily up to 100% tassling or silking. Time taken for 50% tasseling and silking was recorded, and anthesis-silking interval (ASI) was computed.

Leaf cell membrane thermo-stability (LCMT) was measured between 40 and 50 days after emergence (DAE) in field trial conducted during 2012. Leaf samples were collected by selecting the leaf situated just below the cob from three plants belonging to each hybrid and replicate. After collecting leaf samples in ice box these were brought to the laboratory for analysis. Fifty per cent heat killing temperature and time was worked out by exposing the leaf

discs for 15, 30, 45 and 60 min at the water bath temperature range of 45, 50, 54, 55 and 60°C. This experiment was conducted on two selected genotypes until having consistency in results. After identifying the time and temperature for 50% heat killing, experiment with all the hybrids was conducted. Leaf samples were cut in to three major pieces, i.e. 5 cm top and 5 cm bottom portions from each leaf were discarded and only middle portion was used for measuring LCMT. Cut pieces of leaf were arranged into three parts and 10 leaf discs of 8 mm diameter were punched by avoiding the mid-rib. Thus total six replicates for each genotype were arranged. The leaf discs were washed thoroughly three times for about 3 min with distilled water to remove the electrolyte adhering to leaf surface released from the cut edge. Ten leaf discs were placed in each test tube containing 25 ml of distilled water. After 1 hr at ambient laboratory temperature (26-28°C) the initial conductivity (I) of the solution was measured with an EC meter (Model: APX 185). Afterward tubes were capped with aluminum foil and exposed to 54°C in a water bath for 45 min, allowed to cool at room temperature for 1 h. Then electrical conductivity (E) was recorded. The samples were subsequently autoclaved at 120°C for 15 min to completely disrupt the cell membrane and then the final conductivity (F) was recorded. RI induced during the time course was calculated following Hossian *et al.* (1995) such as RI (%) = [(E-I)/(F-I)] × 100. The same set of experiment was repeated next day, the value of respective RI presented in this manuscript are average of 12 replicates in two sets.

Photosynthetic rate (P<sub>N</sub>) was measured during 2012 and 2013 between 09:00 and 10:00 h local time at vegetative (30-33DAE), flowering (45-48 DAE) and grain filling (60-63DAE) with the help of portable photosynthesis system (Model LI: 6400, LICOR, Lincoln, NE, USA). Measurements on P<sub>N</sub>, stomatal conductance (gs), transpiration (E) and leaf temperature (T<sub>leaf</sub>) were recorded in three selected plants of each hybrid and replicate on the leaf situated just below the cob at the natural leaf angles facing sun in the canopy. The measurements were performed on three consecutive days and three observations on single leaf of three different plants of each hybrid were recorded on each day during 2012 and 2013, values presented in this paper are average of two years.

Non-structural carbohydrates, i.e. reducing sugars, non-reducing sugars and starch (NSCs) were analyzed during different growth stages, i.e. pre-anthesis (30 DAE), flowering or anthesis (45 DAE) and post-anthesis (60 DAE) during 2012 rainy season. For determination of NSCs, stem and leaf samples were collected on cloudless day from three plants of each hybrid and replicate during 2012. In case of both stem and leaf middle portions were selected for analysis. One gram fresh weight of stem or leaf was plunged in 80% ethanol in glass vials and preserved. Extraction of sugars was repeated 3-4 times by boiling the samples with 15-20 ml of 80% (v/v) ethanol in water each time. The reducing sugar was determined by following Nelson (1944) and improved copper reagent of Somogyi (1952). The sugar

extract (5ml) was hydrolyzed by boiling with 2.5 ml of 0.5 N HCl for 30 min in water bath and later neutralized to slightly acidic side with 0.5 N NaOH and used for the determination of total sugars. Non-reducing sugars were calculated by subtracting the reducing sugars from the total sugars. Starch was analyzed from the dry powdered samples; 100 mg of powdered samples were hydrolyzed and boiled with 10 ml of 1N HCl for 30 min in a glycerine bath at 112-115°C. The extract with distilled water was used for starch estimation by Anthrone method (McCready *et al.* 1950, Scott and Melvin 1953).

The nitrogen, protein and starch content in grain were analyzed with the help of Brix Meter (Model: RA250WA Pocket Brix Meter) during milking stage i.e. between 65 and 70 d after sowing. Single plant was selected from each replicate and in the cob three middle grains were selected for the measurement in each hybrid.

Before harvest number of leaves/plant, plant height (cm), cob height in mother plant (cm), stem diameter (cm) and grain mass ( $m^{-2}$ ) were measured on three plants from each replicate and hybrid. Plants were sampled for the measurement of vegetative mass and biomass in  $1 m^{-2}$  area in each replicate and hybrid, after thorough drying in sunlight plant samples were weighted. Biomass was measured by adding the vegetative mass and cob mass while harvest index (HI) was calculated by dividing the total biomass with grain mass. Test weight (1 000-seed mass) was recorded between 8-10% seed moisture.

Data of field trials on yield and yield attributes collected for 2011 and 2012 showed almost similar pattern in plant characteristics, such as, grain yield and yield attributes. Hence, this data was pooled and analyzed following a Completely Randomized Block Design (CRBD) in two ways ANOVA as suggested by Gomez and Gomez (1984). While data collected on LCMT and stem reserves (non-structural carbohydrates) were analyzed in CRD following two ways ANOVA. Photosynthetic rate recorded during 2012 and 2013 was pooled and analyzed following two ways ANOVA in CRD. Analysis of variance in all the cases was used to examine the effect of treatment ( $P = 0.05$ ).

## RESULTS AND DISCUSSION

**Flowering:** Among hybrids, interval between anthesis and silking ranged between 1 and 5 days being lower in PHM-1 and Parakash and higher in HM-4 and PHM-3. Inherent potential in lesser anthesis and silking interval in Parakash and PHM-1 along with heat tolerance indicated that these hybrids possess cross tolerance. Maize is reported to be highly susceptible to heat and water-deficit stresses during flowering, silk growth, pollination and kernel set (Shaw 1977). Water-deficit slows ear growth and consequently silk emergence is influenced more than tassel growth or anthesis resulting in a widening interval between anthesis and silking, therefore, it could serve as surrogate trait for drought tolerance (Vega *et al.* 2001). Also, grain yield in tropical maize under stress during flowering was strongly dependent on kernel number/plant and interval

between anthesis and silking (Bolanos and Edmeades 1996).

**Genotypic variation in heat stress tolerance:** In two selected maize hybrids relative leaf injury (RI) values were plotted against heat exposure time and temperature to identify 50% heat killing time and temperature, and it was 54°C for 45 min. At this temperature and time of exposure significant ( $P=0.05$ ) variation in RI was recorded among the hybrids, and RI varied between 40% in both Parakash and PHM-1, and 74% in HQPM 1. Heat injury increased with the increase in temporal heat-intensity thus full potential of individual hybrid was indicated in RI. Hybrids were classified based on RI values, and least significant difference (i.e.1.6) was multiplied six times and added or subtracted from 50% RI values. Such as, RI between 40 and 49% as tolerant, i.e. Parakash and PMH-1 (both 40%), DHM-117 (41%), Vivek QPM-9 (44%), HQPM-7 (46%) and Vivek H-9 (48%), RI between 50 and 59% as moderately tolerant, i.e. Seed Tech. 8324 (55%), BIO-9637, BIO-9681, PMH-3 and HM-4 (all 56%), and HM-10 (59%), and  $RI \geq 60$  as susceptible, i.e. JH-3453 (60%), HQPM-5 (68%) and HQPM-1 (74%). Parakash, PMH-1 and DHM-117 were identified as most tolerant hybrids as RI in these hybrids ranged between 40 and 41%. In addition, higher antioxidant activity was recorded in Parakash and PHM-1 during seedling stage under water-deficit stress (data not shown). Also, in Parakash higher antioxidant activity was reported during water-deficit stress by Chugh *et al.* (2011). Testing of the vegetative part by exposing leaf discs to higher temperatures caused irreversible changes in membrane structure and cell membrane instability which was indicated in RI values (Nguyen and Joshi 1992). A possible reason for such a wide genotypic variability in heat tolerance among these hybrids could be the cell membrane system that remain functional during heat stress and play an important role in plant adaptation (Larkindale and Vierling 2008). Further, heat tolerance was attributed to inherent and acquired potential in heat stress tolerance as expressed in heat-shock proteins, such as, in groundnut (Nautiyal 2008) and tomato (Nautiyal *et al.* 2005, Nautiyal *et al.* 2010) crops. In addition, water-deficit and heat stress tolerance mechanisms in maize may vary during vegetative stage, pollination and embryo development (John *et al.* 2004, Yadav *et al.* 2016).

**Genotypic variation in photosynthetic rate:** Measurements on  $P_N$ ,  $g_s$  and  $E$  and  $T_{leaf}$  during vegetative, anthesis and post-anthesis stages showed wide variations. Among growth stages,  $P_N$ ,  $g_s$  and  $E$ , increased from vegetative to anthesis and thereafter declined during post-anthesis, stages. Among hybrids  $P_N$  ranged between 8.78 and 30.71  $\mu mol/m^2/s$  from vegetative to anthesis and post-anthesis stages. Irrespective of growth stages,  $P_N$  was higher in HM-10, Vivek-H9, HQPM-1, HQPM-7, PMH-1 and JH-3459. In addition,  $P_N$  was closely associated with  $g_s$  and  $E$  during all the stages. Thus higher  $P_N$ ,  $g_s$  and  $E$  during anthesis indicated a strong sink driven demand though this varied among hybrids. In addition, decline in  $P_N$  during grain filling (milking stage) indicated that in monocarp

Table 1 Non-structural carbohydrates (NSCs) in leaf and stem at 30, 45 and 60 days after emergence (DAE), and protein and starch in developing grain at 70 DAE, in 15 maize hybrids during 2012 rainy season

Hybrids	Leaf NSCs						Stem NSCs						Developing grain		
	Total sugars (mg/g fr. wt.)			Starch (mg/g fr. wt.)			Total sugars (mg/g fr. wt.)			Starch (mg/g fr. wt.)			Protein (%)	Starch (%)	
	30 DAE	45 DAE	60 DAE	60 DAE	45 DAE	30 DAE	30 DAE	45 DAE	60 DAE	60 DAE	45 DAE	30 DAE	60 DAE	70 DAE	70 DAE
JH-3459	1.60	0.86	0.21	0.43	0.55	2.23	0.95	0.32	0.21	0.24	0.86	10.6	57.4		
BIO-9681	1.33	0.83	0.16	0.33	0.40	1.79	0.82	0.38	0.15	0.31	0.67	9.3	58		
BIO-9637	1.90	1.18	0.15	0.27	0.46	1.93	1.07	0.31	0.21	0.34	0.48	12.3	57.9		
HQPM-5	2.22	0.86	0.21	0.43	0.58	2.44	0.87	0.39	0.24	0.41	0.47	8.9	50		
HQPM-1	2.39	0.82	0.19	0.37	0.47	1.28	0.40	0.46	0.29	0.51	0.56	10.6	54.1		
Parakash	1.73	0.85	0.22	0.38	0.99	2.04	0.89	0.39	0.32	0.35	0.99	11.7	60		
Vivek-H9	2.46	1.12	0.18	0.36	0.55	2.43	1.02	0.31	0.20	0.39	0.55	10.1	57.8		
Seed Tech. 8324	2.30	0.84	0.21	0.17	0.31	2.61	0.83	0.38	0.22	0.35	0.36	10.8	56.4		
HQPM-7	2.11	0.78	0.20	0.23	0.40	2.20	0.66	0.30	0.17	0.53	0.91	9.1	51.6		
HM-10	1.95	0.88	0.17	0.14	0.50	2.43	0.85	0.38	0.13	0.28	0.52	9.4	50.2		
PMH-1	1.99	0.78	0.12	0.13	0.50	2.10	0.82	0.39	0.33	0.53	0.83	10.7	59.4		
HM-4	1.90	0.68	0.14	0.19	0.51	2.17	0.87	0.37	0.17	0.34	0.56	9.9	55.4		
PMH-3	1.35	0.55	0.14	0.31	0.45	1.43	0.51	0.38	0.21	0.51	0.83	11.4	63.6		
DHM-117	1.46	0.86	0.22	0.24	0.36	2.20	0.64	0.29	0.19	0.36	0.62	12.4	70.7		
Vivek QPM-9	1.20	1.11	0.22	0.19	0.45	1.63	0.77	0.38	0.23	0.55	0.79	12	59.5		
LSD (P=0.05)	0.389	0.158	0.033	0.099	0.148	0.385	0.181	0.046	0.05	0.101	0.203	0.10	0.09		

Table 2 Analysis of variance (ANOVA) for grain yield and its attributes in 15 maize hybrids during two consecutive rainy seasons, i.e. 2011 and 2012

Source of variation	df	Mean squares											
		Number of leaves	Plant height	Number of nodes	Stem diameter	Cob height	Plant dry mass	Cob mass	Biomass	Grain mass	Number of 1 000-seed grain/row <sup>-1</sup> cob mass	HI (%)	
Replicates	2	0.65	0.472	0.50	0.009	5.62	22.64	55.76	259	0.813	0.722	122	0.529
Genotypes (G)	14	3.65*	3128*	1.0*	2.2*	359*	1478*	1344*	8688*	942.1*	4.21*	2305*	61.9*
Year (Y)	1	25.6*	8692*	43*	129*	1396*	8080*	6007*	776*	21.0*	21.9*	4798*	1.2*
G × Y	14	1.64*	1169*	7.8*	0.99*	61.7*	997*	1310*	1123*	373.7*	1.55*	1287*	27.9*
Trials (T)	1	64.6*	25.6*	2.6*	0.86*	1543*	136*	338*	50.88*	1003.3*	64.6*	20.0*	163*
Error	58	0.87	30.58	6.2	0.05	1.48	9.0	208	1009	0.01	0.051	60.3	1.87
CV (%)		1.23	3.08	2.6	3.61	1.46	2.23	9.27	11.01	1.40	1.65	2.97	3.57
LSD (P=0.05)		12.65	1.42	2.9	2.61	28.9	72.36	1.42	0.94	42.6	18.67	5.33	6.95

plants grain filling proceeds toward natural senescence and this point of time current  $P_N$  becomes limiting factor for continuous supply of photosynthates to developing grain. Thus, there seems to be a balance between pre- and post-anthesis  $P_N$  with stem reserves. In maize decline in  $P_N$  during grain filling however could be compensated by remobilization of stem reserves (Borras *et al.* 2004).

**Stem reserves:** Among hybrids, NSCs in leaf and stem varied significantly ( $P>0.05$ ) at 30, 45 and 60 DAE (Table 1). Leaf total sugars decreased while starch increased from 30, 45 to 60 DAE. Leaf sugar ranged between 1.33 and 2.42, 0.55 and 1.18, and 0.12 and 0.22 mg/g fr. wt. at 30, 45 and 60 DAE, respectively. While leaf starch ranged between 0.05 and 0.25, 0.17 and 0.43, 0.31 and 0.99 mg/g fr. wt. at 30, 45 and 60 DAE, respectively. On the other hand, stem total sugars decreased and starch increased from 30, 45 to 60 DAE (Table 1). Stem sugar ranged between 2.43 and 1.43, 0.51 and 1.07, and 0.29 and 0.46 mg/g fr. wt. at 30, 45 and 60 DAE, respectively. While stem starch content ranged between 0.13 and 0.29, 0.24 and 0.53, and 0.36 and 0.99 mg/g fr. wt. at 30, 45 and 60 DAE, respectively (Table 1). This clearly indicated that starch content during anthesis and post-anthesis stages increased in stem reserves. It is reported that NSCs could be remobilized in the form of sucrose through phloem during grain filling (Slewinski *et al.* 2009). Though our study does not have direct indication of remobilization of stem reserves to developing seed but some indirect evidence do exist. Such as, positive but weak associations were established between stem starch and 1 000-seed mass, and stem starch and HI. It is presumed that if remobilization efficiency of NSCs is improved, it may facilitate grain filling with enhanced HI. As this was the case in rice that drought tolerant cultivars were efficient in remobilization of stem reserves leading to enhanced 1 000-

seed mass and HI (Deshmukh 2015). In maize, it is reported that grain filling is mainly dependent on current  $P_N$  and this usually decline due to natural senescence, and buffering through remobilization of NSCs from stem reserves may compensate this deficit (Smalley and Blake 2003, Vacca *et al.* 2004, Donaghy *et al.* 2008). Since, hybrids Parakash, JH-3459, Vivek H-9, HQPM-7, PMH-1 and PMH-3 exhibited higher starch in stem reserves their potential could be exploited (Table 1) as starch is major fraction of NSCs (Eveland and Jackson 2011).

**Grain protein and starch contents:** Grain protein and starch contents during milking stage varied significantly ( $P=0.05$ ) (Table 1). Among hybrids both starch and protein were higher in DHM-117 (70.7 and 12.4, respectively), Parakash (60 and 11.7, respectively) and PHM-1 (59.4 and 10.7, respectively). Grain starch content showed association with stem reserves NSCs, in addition, significant association was established between grain protein and grain starch contents ( $r=0.78$ ,  $P>0.05$ ).

**Biomass and yield attributes:** Significant ( $P=0.05$ ) variations in plant height, stem diameter at final harvest, cob height in mother plant, vegetative dry mass, biomass, grain mass, 1 000-seed mass and HI were recorded (Table 2). For example, biomass ranged between 4269 g/m<sup>2</sup> in HQPM-1 and 1874 g/m<sup>2</sup> in Vivek H-9 while grain weight between 1669 g/m<sup>2</sup> in PMH-3 and 809 g/m<sup>2</sup> in Vivek H-9 (Table 3). Thousand seed mass varied between 300 g in PMH-1 and 218 g in HQPM 1, while HI between 44 and 33% in Vivek- H9 and both, HM-10 and DHM-117, respectively. This study was conducted under rain-dependent conditions however there was no water-deficit stress at any of the crop growth stages. But inherent potential for both water-deficit and heat stresses were exhibited in interval between anthesis and silking, and leaf

Table 3 Plant height, stem diameter, cob height in mother plant, biomass, grain mass (g/m<sup>2</sup>), 1 000-seed mass and harvest index (HI) in 15 maize hybrids during 2011 and 2012 rainy seasons (values are average of two years).

Hybrids	Plant height (cm)	Stem diameter (cm)	Cob height in mother plant (cm)	Grain weight (g/m <sup>2</sup> )	Biomass (g/m <sup>2</sup> )	1 000-seed weight (g)	HI (%)
JH-3459	158.0	6.7	82.1	1326	3977	260	37
BIO-9681	174.3	7.1	96.3	1250	3231	294	34
BIO-9637	198.3	5.9	89.5	1631	4212	283	39
HQPM-5	182.8	6.8	81.1	1137	3521	248	35
HQPM-1	131.5	7.8	68.9	1481	4269	218	35
Parakash	185.3	6.0	76.0	1440	4018	280	37
Vivek-H9	162.8	5.9	68.8	809	1874	231	44
Seed Tech. 8324	187.8	7.2	86.4	1287	3627	251	37
HQPM-7	176.6	6.0	72.2	1344	3239	255	35
HM-10	173.2	7.1	80.6	1334	4769	273	33
PMH-1	198.3	6.4	88.9	1609	3833	300	37
HM-4	147.1	6.1	66.0	1337	3429	259	39
PMH-3	174.1	6.6	79.8	1669	3765	262	37
DHM-117	210.8	6.3	85.2	1292	4036	255	33
Vivek QPM-9	177.8	5.9	67.1	1041	2815	216	38
LSD (P=0.05)	23.0	0.6	9.8	45.2	498.7	26.8	3.1

cell membrane thermostability. In maize, effects of water-deficit and heat stresses on respiration, photosynthesis, timing of the circadian clock, anthesis and silking intervals, protein unfolding and their aggregation and degradation, cell membrane integrity and senescence were reported (Iba 2002, Coskun *et al.* 2011 and Araus *et al.* 2011).

**Correlation analysis:** Correlations among various parameters studied were established such as plant height and RI ( $r=-0.61$ ,  $P>0.05$ ), and stem diameter and RI ( $r=0.66$ ,  $P>0.05$ ). In addition, stem diameter was inversely associated with HI ( $r=-0.54$ ,  $P>0.05$ ). Direct association between cob height in mother plant and 1 000-seed mass was established ( $r=0.73$ ,  $P>0.05$ ). Also, associations between  $T_{leaf}$  and RI ( $r=0.68$ ,  $P>0.05$ ) and  $T_{leaf}$  and HI ( $r=-0.55$ ,  $P>0.05$ ) were established. These associations clearly indicated that  $T_{leaf}$  could be an important parameter for the use as selection tool for heat tolerance in maize as also reported by O'Neill *et al.* (2006). Further, positive association between  $P_N$  and biomass ( $r=0.46$ ,  $P>0.05$ ) and starch content in grain and cob dry mass ( $r=0.41$ ,  $P>0.05$ ) were established. In maize, it is reported that identification of the traits associated with yield responses to drought or heat stress such as  $T_{leaf}$ , early seedling vigour, grain filling, stay green characteristics, measurement of source traits affecting individual kernel mass and remobilization of stem reserves may indicate sensitivity or otherwise (Araus *et al.* 2012).

Based on the results of this study, potential hybrids, especially Parakash and PHM-1 were identified based on various secondary traits which are associated with grain yield under rain-dependent cultivation, such as, heat tolerance, lesser anthesis and silking interval *vis-à-vis* drought tolerance, assimilation of stem reserves, grain and biomass yields, HI and 1 000-seed mass these hybrids either may be utilized directly for cultivation by the farmers under rain-dependent conditions, and/or identification of molecular markers for understanding cross tolerance.

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