
RESEARCH ARTICLE

Assessment of combining ability of maize inbreds under normal and waterlogged conditions

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Abstract

A full diallel analyses of 9 x 9, was made during 2016 Rabi season and evaluated under water-logging condition during *Kharif* 2017 and normal condition during Rabi 2017-18 in RCBD design in the Agriculture research farm, BHU, Varanasi. Remarkable genetic variability has been observed. The means of secondary traits viz., ASI, nodes and with brace roots indicated a strong relationship with grain yield which suggests that both additive and non-additive gene actions are important for water-logging tolerance in maize. Maximum average change was observed by the characters brace roots per plant, total nodes bearing brace roots, leaf area and 100 seed weight. A narrow difference was observed for percent protein and TSS. The yield traits like 100 seed weight (2.06 % reduction) and declined yield of about 0-45 % has been recorded. An overall 1-3 % reduction in protein, 0.2-1.2 percent increase in sugar, 0.3-10.5 % increased starch content has observed. There were about 10-11% increase in brace roots has also recorded. Among the inbreds HKI-193-1 and HKI 1105 showed better response for various characters under waterlogging, HKI 193-1 x PBNI 3-1, PBNI 3-1 x HKI 193-1, PBNI 3-1 x CML-161, HKI 193-1 x HUZM-152, HKI 193-1 x CML 163

and HKI 193-1 x HKI 1105 cross combination showed promising response and minimum yield loss. The cross combinations expressed better as compared to their parental lines.

Key words: Combining ability, maize, hybrids, inbreds, water logging

Introduction

In tropical/sub-tropical environment, the extreme climatic condition and biotic/abiotic stresses are the major factors responsible for low yield potential of crop plants. Changing climate has resulted in increase of abiotic stresses which limit the crop yields worldwide (Gosal *et al.*, 2009; Wani and Gosal, 2011; Sanghera *et al.*, 2011; Wani *et al.*, 2013; Wani and Sah, 2014; Gayatonde *et al.*, 2017 and Lone *et al.*, 2018). Among the abiotic stresses, extremes of water availability i.e. drought and excess water are major constraints for production and productivity of most of the crops, including maize. Excessive soil moisture caused by waterlogging or a high water table, is the most important constraints for maize production and productivity in Asian region (Zaidi *et al.*, 2008). In India, waterlogging is one of the most serious constraints. The present genetic study analyzed the tolerance of maize to water-logging stress (Campbell *et al.*, 2015).

Utilization of stress tolerant maize is the key to sustainable production and food security (Anonymous, 2014). Pokhrel *et al.*, (2019) carried out screening at an early seedling stage for identification of drought tolerant genotypes in maize. Maize is a C4 crop, requires rainfall of 60 cm to 110 cm annually. According to the estimates of IFPRI and ADB, 2009, maize may undergo a severe yield loss upto -17 per cent by 2050 as comparing to rice (-10 %) and wheat (-12 %). Out of total 9.4 million hectare area of maize, about 2.5 million hectare is affected by excess soil moisture problem that causes an average 25-30 per cent loss of national maize production almost every year (Anonymous, 2014). In case of June planting it may coincide with flowering which may interfere with the normal pollination behavior and seed setting. The commonly observed effects of waterlogging on maize are, depletion of Oxygen in root zone- Anoxia and hypoxia condition, reduction in vitamin and amino acid accumulation in source. Yadav *et al.*, (2017) observed stunted growth whereas differences in anthesis and silking were observed (Zaidi *et al.*, 2010), increased total soluble sugars and starch, high ROS and other secondary metabolites accumulation, reduced crop duration, lodging and sterility, high yield penalty (Savita *et al.*, 2004) etc. In a broad classification there are two Basis for waterlogging tolerance i.e Genetic basis (Polygenic in nature, high G×E and low heritability and several genes responsible are *Adhl*, *adh2*, *aldl*, *enol*, *eno2*, *gpcl*, *gpc2*, *gpc3*, *gpc4*, *phi*, *pdcl*, *pdcl2*, *pdcl3*, *shl*, *wusl1005*) and Physiological and biochemical basis (Increase in brace roots and number of nodes bearing brace roots for Oxygen uptake, SOD activation as first line of defense against ROS, Conversion of Hydrogen peroxide to water and oxygen and increased starch due to loss of CHO due to partial integrity loss of cell membrane). The chief physiological differences viz., impaired growth, reduced pollen production, changed position of silk formation, barren cobs etc. (Picture 1).

Inbred lines have been a basic resource for fundamental and applied investigations in maize improvement program. Combining ability analysis provides useful information for parental selection based on the progeny performance which also provides information on the nature and magnitude of gene action involved (Gayatonde, 2018) in the expression of quantitative traits (Dhillon and Singh, 1976). By keeping these factors in view the present study lays on the objective; assessing the physiological and biochemical changes under waterlogged and normal conditions and comparing the yield and yield related traits.

Material and methods

The assessment of changes under waterlogging conditions in maize consists of nine inbreds, mated in 9 x 9 full diallel fashion in Rabi 2016-17. The material was procured from AICRP (All India Coordinated Research Program) on maize, BHU, Varanasi. The 72 cross combinations along with their parents were evaluated in RCBD design in two consecutive seasons (Kharif 2017 and Rabi 2017-18). Each plot consisted of single row of 5m long. The spacing between rows was 60cm and plant to plant was 20cm. One plant per hill was maintained after proper thinning. Observations were recorded on ten randomly selected plants from each plot for Leaf area in cm²(LA), ASI (Anthesis-silking interval), TSS (Total soluble solids), Yield per plot in kgs (YPP), 100 seed weight in grams (HSW), starch (%), sugar (%), Protein (%), No. of nodes bearing brace roots (NBB) and Total brace roots (BR). The total soluble sugar content was determined according to the phenol-sulfuric acid method and a reading was made in the spectrophotometer at a wavelength of 540 nm (Dubois *et al.*, 1956). For the crude protein content, grains were first dried in an oven at 65oC until they reached a constant weight and ground in a pestle and mortar with a sieve diameter of 1 mm and made ready for analysis.

The crude protein content by Kjeldahl method (Bradstreet, 1954) of the grains was calculated as % by multiplying the value found with the coefficient of 6.25 (Bremner, 1965). The method of acid hydrolysis for starch estimation was adapted from Grotelueschen and Smith, 1967. The mean rainfall of the two seasons during the critical stages (mm) has taken for the comparison (figure 1). The consecutive seasons (*Kharif* and *Rabi*) were chosen to see the clear effect of seasonal differences as well as moisture stress

effect rather than comparing the same set of material for two different conditions (normal and waterlogging) in a single season. Data were analyzed for variance study. General combining ability (GCA) and specific combining ability (SCA) were estimated following Model I, Method II of Griffing (1956). For Statistical analysis, Indowstat, software was utilized. Ten characters under normal and waterlogging stress are presented here for the comparison.

Picture 1: Various effects of Maize under waterlogged conditions: A: impaired ASI, B: Low/no pollen production, C: Increased brace roots, D: No silk formation, E: Changed silk position, F & G: poor seed set and H: hollow rind

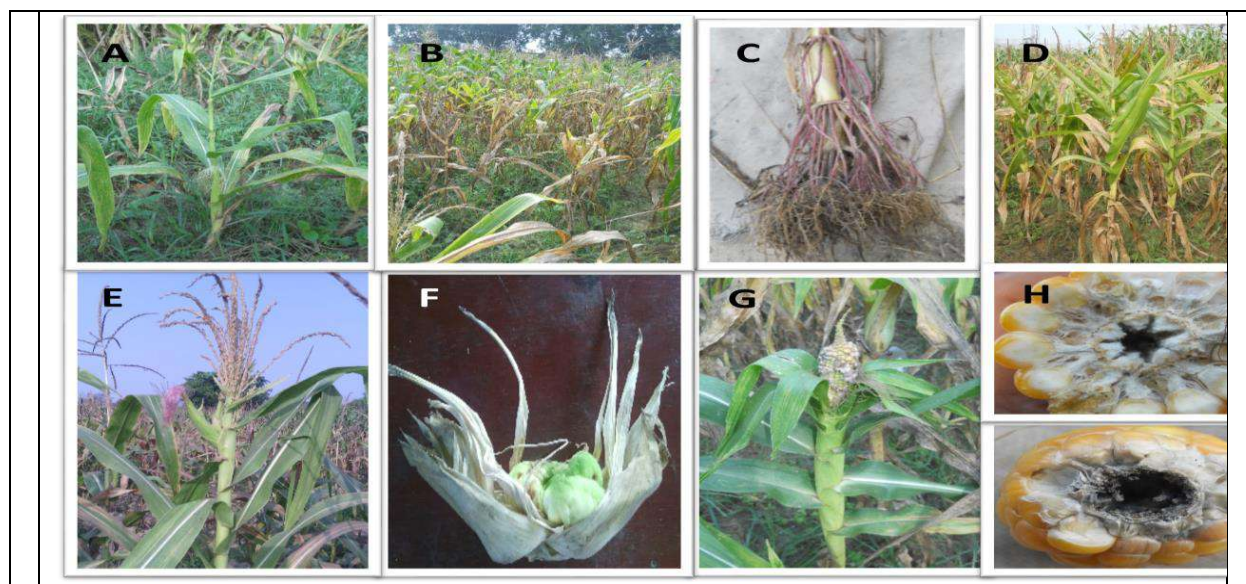
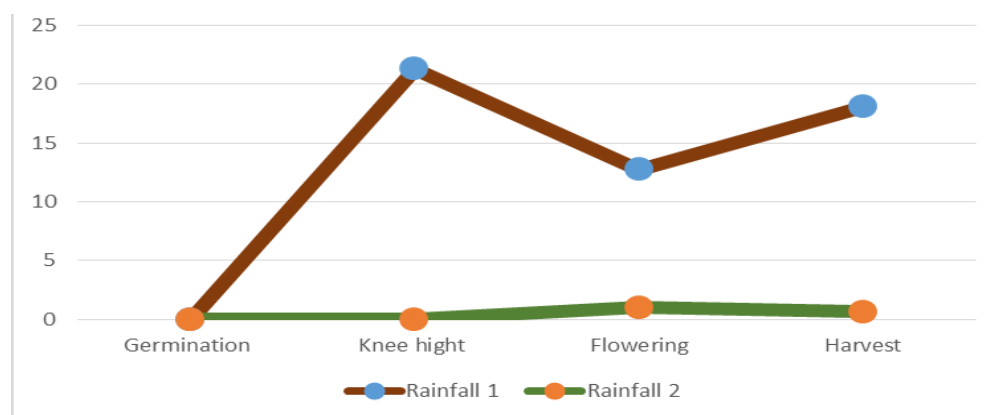


Figure 1: Mean rainfall data of Kharif 2017 and Rabi 2017-18 at critical stages of plant growth



Results and discussion

The mean rainfall data of *Kharif* and *Rabi* season were compared at the critical stages (Fig 1). At different stages knee height stage, flowering as well as physiological maturity stages due to stress several susceptible lines were lost. In the present investigation, only the lines which could reach the physiological maturity stage were considered for phenotypic as well as biochemical analysis. The pooled analysis of variance (Table 1), revealed that the genotypes differed significantly for majority of the traits. GCA (Table 2) of the Nine inbred parents and SCA (Table 3) of the promising cross combinations revealed the significance differences between and variability among the lines studied.

Further, analysis of variance for combining ability showed that the estimates of mean squares due to GCA and SCA were highly significant for all the characters except protein content for GCA (Table 2). This indicated the importance of both additive and non-additive components of genetic variances in controlling these traits. Debnath and Sarker, (1990) and Derera *et al.*, (2007) reported similar results for yield and yield components in maize. The higher magnitudes of GCA variances were found for leaf area and number of brace roots which indicated the predominance of additive gene action. According to Dhillon and Singh (1976), GCA was more important than SCA for the inheritance of brace root characters, sugar % and yield but not for the phonological characters. Murthy *et al.* (1981) observed predominance of additive gene action for days to silking and non-additive gene action for grain yield per plant. Das and Islam (1993) also reported predominance of non-additive gene action for grain yield. Combining ability studies revealed higher SCA variance than GCA variance and thus the GCA to SCA variance

ratio was less than the unity indicating the predominance of non-additive gene action. These results confirmed the findings of Singh *et al.*, (1983), Paul and Duara (1991), Vara Prasad and Shivani (2017) and Maiga *et al.*, (2021). Means of secondary traits viz., ASI, nodes and with brace roots indicated a strong relationship with grain yield which suggests that both additive and non-additive gene actions are important for water-logging tolerance in maize. Therefore, reciprocal recurrent selection under managed water-logging stress conditions may be an effective approach to increase the level of tolerance to water-logging in maize and could be used in developing water-logging tolerant synthetic varieties and hybrids.

Out of ten character considered are further checked for the average changes over the two conditions (Table 4). Increasing trend has been shown by percent sugar, starch, and root characters under water stress, whereas other characters showed moderate to high decline for the trait under consideration. Out of all the characters studied, inbred line HKI 193-1 found promising for majority of the traits supporting stress tolerance. Among the cross combinations, HKI 193-1 x PBNI 3-1, PBNI 3-1 x HKI 193-1, PBNI 3-1 x CML-161, HKI 193-1 x HUZM-152, HKI 193-1 x CML 163 and HKI 193-1 x HKI 1105 (concluded from the figures 2-8) were the promising crosses with minimum deviation in yield per plot and related characters. Increasing the brace roots prevent the plants from stress and the best crosses also showed better brace rooting habit. Increase in the development of brace root in tolerant genotypes under water logged conditions was identified as one of the stress adaptive traits in maize (Subbaiah and Sach, 2003; Mano *et al.*, 2005; Zaidi *et al.*, 2007).

Table 1: Diallele ANOVA

Particulars	DF	Leaf area in (cm ²)	Anthesis-silking interval	Total soluble solids	HSW	GP	Starch	Sugar	No. of nodes bearing brace roots	Total brace roots	Yield per plot in (kgs)
Replicates	1	619.107	0.044	0.007	0.017	2127.319	0.531	1.6	0.9	1.6	0.001
Treatments	44	6351.7**	2.9**	0.2**	1.692	2079.5**	52.561**	5.1**	1.066**	15.9**	0.11**
Parents	8	6762.3**	3.9**	0.10*	1.5**	0.331	80.6**	4.25*	0.75	24.9**	0.053**
Hybrids	35	6006.7**	2.7**	0.2**	1.762	2600.5**	47.18**	4.722**	1.137**	14.3**	0.134**
Parent Vs. Hybrids	1	15139.23 *	1.111	0.022	0.158	480.619	16.129	26.6**	1.111	0.003	0.013
Error	44	923.114	0.885	0.038	0.185	2085.535	13.423	1.918	0.491	4.895	0.017
Total	89	3603.495	1.875	0.141	0.928	2083.063	32.627	3.505	0.78	10.31	0.066
GCA	8	1168.7*	1.4**	0.1*	0.3**	830.7	20.0**	3.5**	0.561*	14.614**	0.086**
SCA	36	3621.8**	1.4**	0.1*	0.948	1086.258**	27.6**	2.3**	0.52**	6.483**	0.052**
Error	44	461.557	0.443	0.019	0.093	1042.767	6.712	0.959	0.245	2.448	0.009

Table 2: General combining ability of the traits

Parents	Leaf area in (cm ²)	Anthesis-silking interval	Total soluble solids	HSW	GP	Starch	Sugar	No. of nodes bearing brace roots	Total brace roots	Yield per plot in (kgs)
HKI- 193-1	-13.982	-0.081	1.048*	1.552	-0.183	0.049	0.48	0.283	1.258*	0.22*
HKI 1105	-0.477	-0.717	-0.542	0.503	-0.268	1.325	0.343	0.081	-0.394	-0.015
CML 161	2.911	0.192***	-0.483	0.789	-0.137	1.267	0.116	0.081	-0.348	-0.043
LM 10	18.318**	0.556	2.076**	-0.274	0.248**	0.546	0.207	0.49**	2.424**	0.015
CML 163	0.027	0.101**	-1.079	-1.92	0.191*	-1.062	0.889**	0.035	-0.121	-0.086
PBNI 3-1	-3.705	-0.308	-0.088	-0.565	0.028	1.844*	-0.202	-0.01	1.015*	-0.027
HUZH 343	9.323	-0.035	0.135	0.698	0.226*	-1.172	-0.975	-0.01	0.333	0.008
HUZH 152	1.932	0.328	-0.297	1.189**	-0.014	-2.151	-0.475	-0.192	-1.258	-0.013
HUZH 242	-14.348	0.116	-0.77	1.13	-0.091	-0.645	-0.384	-0.192	-0.394	-0.059
h ² Narrow Sense	0.034	0.818	0.155	0.174	0.054	0.081	0.165	0.098	0.254	0.214**
h ² Broad Sense	0.729	0.778	0.767	0.822	0.87	0.908	0.005	0.777	0.66	0.867
GCA/SCA Ratio	0.095	0.048	0.108	0.134	0.163	0.031	-0.443	0.058	0.166	0.155

Table 3. Specific combining ability of selected cross combinations and traits

Crosses	Leaf area in (cm ²)	Anthesis-silking interval	Total soluble solids	HSW	GP	Starch	Sugar	No. of nodes bearing brace roots	Total brace roots	Yield per plot in (kgs)
HKI-193-1 X HKI-1105	-12.136	0.727	3.557*	2.152	0.966**	4.356*	3.946	0.591	5.218*	0.009
HKI-193-1 X CML-161	22.776	1.364	4.498**	3.215*	0.619*	4.06**	2.704	0.091	-1.327	0.131
HKI-193-1 X LM-10	19.419	-1.045	1.439	5.129**	0.25	4.073**	5.22*	-0.318	-1.6	0.259**
HKI-193-1 X CML-163	-18.29	-0.909	-1.406	-2.775	-0.628	-15.755	5.763**	-0.864	-2.055	0.19
HKI-193-1 X PBNI-3-1	46.841*	-0.955	1.353	1.12	0.284	4.357**	3.042	0.182	2.809**	0.166
HKI-193-1 X HUZM 343	76.514**	-2.045	4.28**	0.706	0.347	-15.263	1.103	0.682	1.991*	0.315*
HKI-193-1 X HUZM-152	3.355	-1.318	-2.688	-3.385	0.297	3.7	6.947**	-0.636	-2.418	0.286*
CML -161 x HUZM -242	38.385	-1.182	-2.165	-2.275	-0.076	3.791	2.051	0.364	-1.782	0.098
CML- 163 x HUZM -242	18.471	1.409	1.789	-3.189	-0.25	3.776	-1.868	0.227	0.309	0.087
PBNI -3-1 x HUZM -152	15.614	0.5	-4.97	-4.425	-1.1	3.449	1.744	-1.182	-2.464	0.269**
CML -161 X HKI -1105	7.255	-0.364	-1.515	0.62	-1.248	-16.164	0.977	-0.227	-1.918	0.21
CML- 163 x CML -161	-19.513	0.091	-1.506	1.715	-0.91	3.543	-2.435	-0.182	-1.555	-0.129
PBNI -3-1 x HKI- 193-1	89.16**	-1.5	4.971**	0.902	1.423**	-15.407	3.187	0.818	4.127**	0.101
PBNI -3-1 x HKI -1105	40.8*	-2.273	2.903*	3.361	1.093**	4.091**	1.355	1*	1.718	-0.123
PBNI -3-1 x CML -161	26.03	-0.136	-1.625	1.57	1.454**	3.791	-3.435	-0.5	-1.145	-0.202
PBNI -3-1 x CML- 163	103.176**	-0.864	3.47*	-3.662	1.699**	4.033	0.091	0.818	-0.009	0.107
HUZM- 343 x CML- 163	27.816	-0.727	2.125	0.484	1.136**	-15.345	4.395	-0.227	2.536	-0.048
HUZM -152 x LM -10	6.298	-0.773	-2.865	1.979	0.809**	4.091	-1.677	1.318*	3.9*	-0.162
HUZM -152 x CML- 163	20.571	-0.364	-4.088	-6.135	-1.079	-15.829	-2.255	-1.182	-1.918	-0.087
HUZM -242 x LM -10	17.362	-0.136	-0.906	-1.675	-0.654	3.894	-7.627	0.5	1.673	-0.131
HUZM -242 x HUZM -152	-20.934	2**	-0.184	2.334	-0.817	4.03	0.237	0.864	2.309*	-0.134

Table 4: Average changes observed for different characters and for different cross combinations

Sl. No.	Inbreds and cross combinations	Anthesis-silking interval	% Leaf area in (cm ²)	% protein	% Sugar	% starch	NB	No. of nodes bearing brace roots	Total brace roots	HSW	Yield per plot in (kgs)
1	HKI-193-1 X HKI-1105	3	-45	-1.00	0.34	3.50	2	9	-8.34	-3.00	-0.21
2	HKI-193-1 X CML-161	-1	-43	-0.38	0.71	7.90	1	11	-4.63	-5.80	-0.47
3	HKI-193-1 X LM-10	3	-57	-1.26	0.70	8.80	2	8	-3.97	-2.00	-1.13
4	HKI-193-1 X CML-163	2	-29	-0.92	0.53	10.30	1	6	-3.37	-2.30	-0.06
5	HKI-193-1 X PBNI-3-1	2	-136	-1.97	0.87	7.10	2	8	-4.98	-1.20	0.00
6	HKI-193-1 X HUZM 343	3	-113	-2.25	0.30	4.50	3	8	-4.88	-2.30	-0.54
7	HKI-193-1 X HUZM-152	3	-103	-1.10	1.13	4.20	2	8	-4.24	-0.25	-0.25
8	CML -161 x HUZM -242	1	-83	-1.84	0.20	3.90	3	4	-5.96	-3.70	-0.53
9	CML- 163 x HUZM -242	-1	-97	-1.84	0.27	6.30	3	9	-6.74	-2.30	-0.54
10	PBNI -3-1 x HUZM -152	2	-114	-0.30	0.73	3.00	3	9	-5.84	-1.80	-0.16
11	CML -161 X HKI -1105	1	-41	-1.16	1.04	2.70	2	8	-6.01	-3.70	-0.25
12	CML- 163 x CML -161	1	-39	-1.68	0.29	0.30	2	7	-6.00	-0.67	-0.70
13	PBNI -3-1 x HKI- 193-1	1	-63	-0.51	0.24	2.30	3	7	-6.76	-1.16	0.03
14	PBNI -3-1 x HKI -1105	1	-83	-0.10	1.17	0.30	3	5	-6.87	-1.12	-0.65
15	PBNI -3-1 x CML -161	3	-43	-0.70	0.26	1.50	3	4	-8.02	-1.22	-0.06
16	PBNI -3-1 x CML- 163	1	-95	-0.80	1.07	2.00	3	3	-8.25	-1.30	-0.45
17	HUZM- 343 x CML- 163	2	-10	-0.58	0.34	1.06	3	8	-7.98	-0.95	-0.66
18	HUZM -152 x LM -10	3	-50	-0.17	0.49	2.23	2	7	-6.42	-0.98	-0.94
19	HUZM -152 x CML- 163	4	-28	-1.01	0.23	1.04	1	8	-4.55	-1.90	-1.16
20	HUZM -242 x LM -10	1	-10	-1.48	0.5	0.81	1	5	-3.20	-5.68	-1.24
21	HUZM -242 x HUZM -152	2	-33	-0.79	0.24	1.50	1	9	-4.86	-2.20	-1.09
22	HKI- 193-1	1	-11	-0.41	0.23	0.90	3	6	-3.95	-2.26	-0.04
23	HKI 1105	1	-23	-1.00	0.52	3.98	3	7	-2.24	-1.18	-0.04
24	CML 161	3	-42	-1.66	0.31	0.92	2	4	-5.22	-1.10	-0.04
25	HUZM 242	1	-55	-0.12	0.24	1.20	1	3	-7.00	-1.50	-0.05
	Average	2	-57.84	-1.00	0.51	3.28	2	7	-5.61	-2.06	-0.45

The yield traits like 100 seed weight (2.06 %) and yield of about 0-45 % reduction has been recorded. An overall 1-3 % reduction in protein, 0.2-1.2 percent increase in sugar, 0.3-10.5 % increased starch content has observed. There were about 10-11% increase in brace roots has also recorded. Ethylene production is a typical response in waterlogged plants (Bailey-Serres and Voesenek, 2008). Submergence dependent ethylene accumulation plays an important role in adventitious root emergence by favoring cell-wall loosening through regulation of apoplastic pH or up-regulation of expansin genes, which promote cell-wall disassembly (Steffens and Sauter, 2009). Jackson (1985) suggested that, in flooded plants, only the outgrowth of preformed primordia might be stimulated by ethylene, whereas de novo root formation needs other stimuli. Unlike rice plants, maize plants have no naturally occurring air spaces in their roots. Therefore, due to gradual decline in oxygen, plant roots suffers from hypoxia (low oxygen) followed by anoxia (no oxygen) and root rot

diseases which causes reduction of growth and loss of yield (Dennis et al. 2000).

In conclusion the present study for the screening of the inbreds under normal and waterlogged conditions, 100 seed weight, leaf area, TSS and brace root number showed maximum variations. the parental lines, HKI 193-1, and HKI 1105 were found to be the best general combiners for yield and other desirable traits the cross combinations, HKI 193-1 x PBNI 3-1, PBNI 3-1 x HKI 193-1, PBNI 3-1 x CML-161, HKI 193-1 x HUZM-152, HKI 193-1 x CML 163 and HKI 193-1 x HKI 1105 showed significant and positive SCA effects. These parental lines and cross combinations could be used for commercial hybrid variety development with desirable traits along with waterlogged tolerant checks in order to identify the best hybrids for water stress conditions. The stable inbreds can be further subjected to molecular analyses and gene introgressions to address multiple stress conditions for varied or extreme climates across India.

Figure2: Maize inbred lines and their cross combinations under normal and stressed conditions for Leaf area (cm²). 1. Waterlogged 2. Normal condition

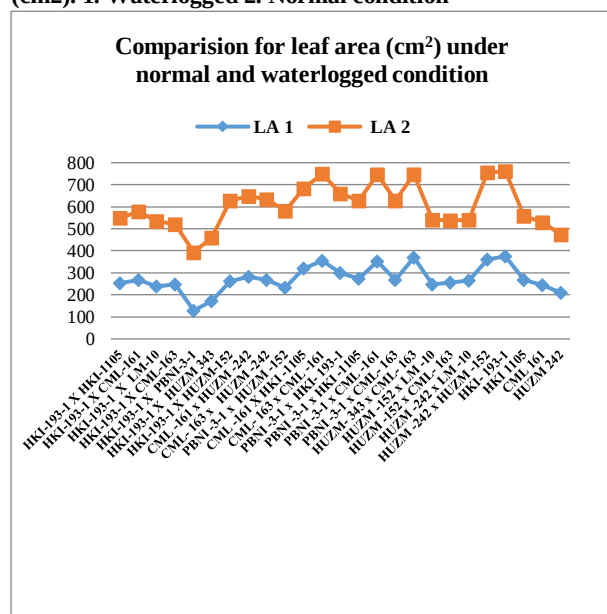


Figure3: Maize inbred lines and their cross combinations under normal and stressed conditions for protein content

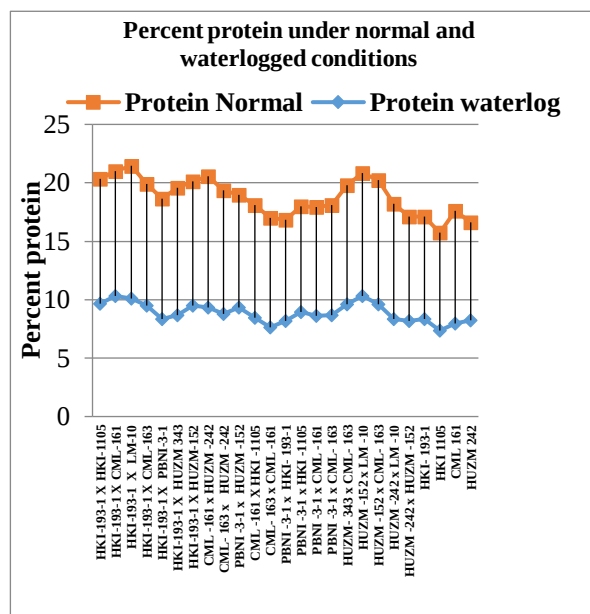


Figure 4: Maize inbred lines and their cross combinations under normal and stressed conditions for sugar content. 1. Waterlogged 2. Normal condition

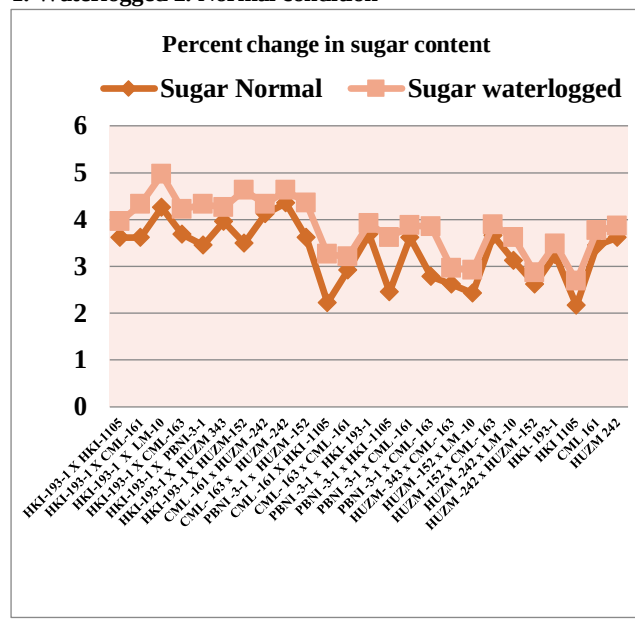


Figure 5: Maize inbred lines and their cross combinations under normal and stressed conditions for starch content. 1. Waterlogged 2. Normal condition

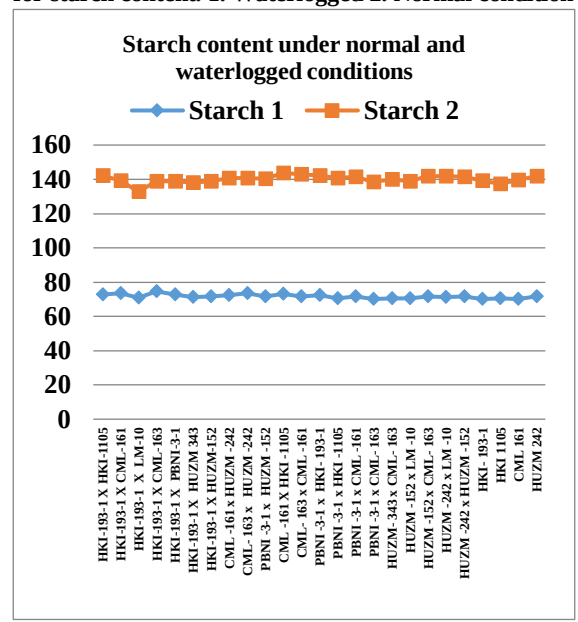


Figure 6: Maize inbred lines and their cross combinations under normal and stressed conditions for 100seed weight. 1. Waterlogged 2. Normal condition

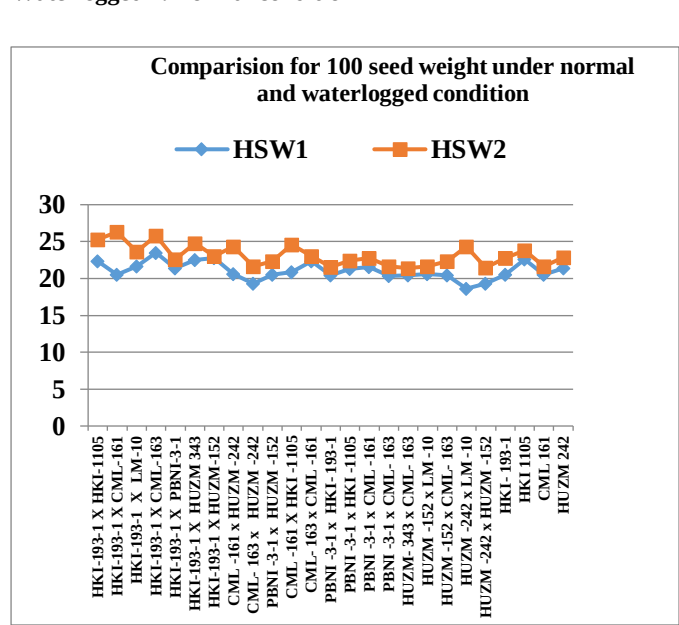


Figure 7: Maize inbred lines and their cross combinations under normal and stressed conditions for yield per plot. 1. Waterlogged 2. Normal condition

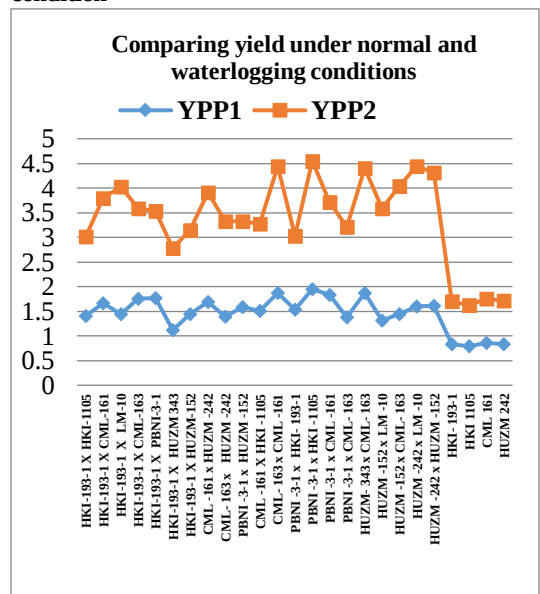
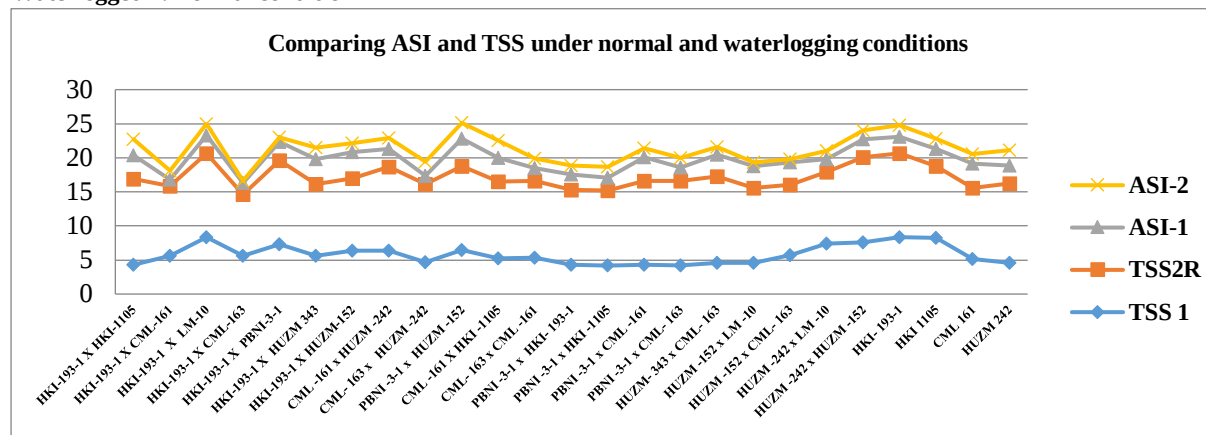


Figure 8: Maize inbred lines and their cross combinations under normal and stressed conditions for ASI and TSS. 1. Waterlogged 2. Normal condition



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