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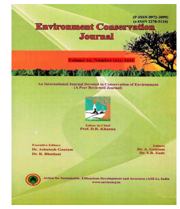

Morphological characterization of maize (*Zea mays* L.) hybrids under excessive soil moisture stress

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ABSTRACT

A critical assessment of 32 maize hybrids with two replications for excessive soil moisture stress (ESM) was carried out during *Kharif* 2019-20. The plants were exposed to waterlogging stress for 12 days at the flowering stage by maintaining a water level of 3-5 cm. High genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) were attained for maize plants with adventitious roots and senescence percentage after stress. High heritability along with high genetic advance was determined for number of plants with adventitious roots, senescence percentage, plant height and 100 kernel weight. Plant yield depicted a highly significant positive genotypic and phenotypic correlation with plant height, ear height, number of plants with adventitious roots and number of kernels per row, along with a significant negative correlation with senescence percentage. Kernels per row and plant height manifested the highest positive direct effect on plant yield at phenotypic and genotypic levels, respectively, reflecting that the characters can be considered for plant selection under ESM stress.

Introduction

Maize (*Zea mays* L.) or "The queen of cereals" originated from the Andean region of South America. It is a tall, monoecious, cross-pollinating, diploid cereal (2n=2x=20) of family Poaceae, domesticated from a wild grass teosinte by the indigenous people in Mesoamerica from ancient times. Maize is the third predominant cereal after rice and wheat globally. It is cultivated from 58^0N latitude in Canada and Russia to 40^0S in South America, from altitudes higher than 3000m to regions lying below sea level and in areas receiving 250 mm to more than 5,000 mm of annual rainfall (Dowswell *et al.,* 1996). Its versatility and wider adaptability than rice and wheat have led to greater adoption among the cultivators. The total global production was around 1.15 billion tonnes in 2018 (FAOSTAT, 2018). The United States is the leading producer with about 392.5 million tonnes of production per year. USA contributes 34.2%, followed by China and Brazil with 22.4% and 7.2% of the total production respectively (FAOSTAT, 2018). In India, maize is cultivated in almost all agro-ecological regions. India produces about 27.8 million tonnes of maize per year which is about 2.4% of the total global production (FAOSTAT, 2018). The primary maize growing states are

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Andhra Pradesh (20.9%) followed by Karnataka (16.5%), Rajasthan (9.9%), Maharashtra, Bihar, Uttar Pradesh, Madhya Pradesh and Himachal Pradesh (Kavita *et al.,* 2018). These states contribute to more than 80% of the total maize production in the country. The average productivity in India is 2.43 t/ha against the global average of 4.92 t/ha. The reasons for its low productivity include both biotic and abiotic constraints. It is estimated that maize yield is reduced by around 25% due to biotic agents (Kaul, 2011). The most common pests include corn earworm, stem borer and termites. Acute water availability in form of drought and excess soil moisture (ESM), is the predominant abiotic constraints limiting the production and productivity of maize. Abiotic stresses are an integral part of any agro-ecosystem. Drought is the chief major factor for lower productivity in the Asian regions followed by ESM stress, which may be caused by flooding, waterlogging, or high water table (Sahoo *et al.,* 2020). More than 15% of the total maize growing areas are affected by floods and water-logging problems in South Asia alone. In India, out of the total 6.6 million ha of the area under maize, about 2.5 million ha is subjected to ESM stress, leading to an annual average loss of 25-30% of the total national production (Zaidi *et al.,* 2004). Further, most of the coastal regions receive higher rainfall due to prolonged low pressure, leading to waterlogging at critical stages of crop growth. Therefore, screening and development of genotypes tolerant to ESM stress can prevent a huge loss in corn production. Considering all these facts, the following investigation was carried out with the objective of identifying the important morphological traits that can be considered for isolating waterlogging tolerant genotypes and to isolate some genotypes that can withstand ESM stress at flowering stage. Genetic variability is a prerequisite of any breeding programme, and it aids in the selection and development of economically important plant species. A critical analysis of genetic variability is essential for developing cultivars to supplement human needs. The selection efficiency can be maximized for certain traits using the estimates of genetic parameters. These components allow a breeder to recognise the nature of the gene action involved in controlling the quantitative traits and evaluate the effectiveness of different breeding methods to obtain higher genetic gain. The genetic estimates in the form of variance, coefficients of variation, heritability, genotypic, phenotypic and environmental correlations help the scientific community to know the magnitude of a population's genetic variability, deducing inter-relationships between traits, thus assisting in the plant selection process. Further, the study of direct and indirect effects of traits on a basic variable provides a better picture of the correlation between plant yield and other yield contributing traits, facilitating the plant selection process.

Material and Methods

Experimental details

The present investigation was carried out using 32 single cross maize hybrids, with two replications laid out in Randomized Complete Block Design (RCBD). The research was conducted at the EB-II section of the Department of Plant Breeding and Genetics, College of Agriculture, OUAT, Bhubaneswar during *kharif* 2019-20. The experimental plot is located at about 64 km west of Bay of Bengal, at 20°15'N latitude; 82°52'E longitude and at an altitude of 25.9 m above the mean sea level. This region comes under humid and sub-tropical climatic zone of Odisha and receives an average annual rainfall of 1628 mm. Each hybrid was sown in a single line of 3 m row length maintaining a spacing of 60cm x 25cm after thinning. Waterlogging stress was imposed by flooding the field at the beginning of the flowering stage for 12 days. Earthen bunds were provided to maintain a continuous water level of 3-5 cm.

Morphological analysis

Twenty plants were evaluated plot-wise for both the replications and for different traits like days to 50% tasseling (DT), days to 50% silking (DS), days to 75% dry husk (DH), shelling per cent (S) and the number of plants with adventitious roots (after stress) per plot (AR). The mean value was then recorded. The root portion was marked with blue paint before stress to observe the growth of adventitious roots after stress (Figure 1). Five randomly selected plants were observed for leaf senescence per cent after stress (SP), plant height (PHT), ear height (EHT), length of cob (LC), cob girth (GC), number of kernel rows per cob (KR/C) and number of kernels per row (K/R). The angular transformed values for leaf senescence per cent after stress (SP) was considered for statistical analysis. For seed yield, ears from all the plants in each plot were weighed. 100 kernels were manually counted and weighed to measure 100 kernels weight (KW). The moisture content of the kernels was determined by 'Steinlight Moisture Meter'. Fresh ear weight per plot at harvest (at 15% moisture) was then calculated using the following formula:

$$\text{Shelled weight} = \frac{\text{Fresh weight of cobs x Shelling percentage}}{100}$$

$$\text{Moisture corrected yield} = \frac{\text{Shelled weight x } (100 - \text{ moisture \%})}{85}$$

$$\text{Grain yield (GY) (q/ha)} = \frac{\text{Moisture corrected yield x } 10{,}000}{\text{Area of the plot}}$$

Statistical Analysis

The collected data was analyzed to estimate variability among hybrids (Dash *et al.,* 2022) phenotypic and genotypic coefficient of variation (%) (Awad-Allah *et al.,* 2022), broad-sense heritability (Nishad *et al.,* 2022) and the expected genetic advance due to selection (Sasipriya *et al*., 2022). Further, the genotypic and phenotypic correlation between the associated traits and yield (Al-Jibouri *et al.,* 1958, and Pooja *et al.,* 2022) and path co-efficient analysis was carried out (Kumar *et al.,* 2022; Dash *et al.,* 2022; Sasipriya *et al*., 2022, and Nishad *et al.,* 2022) under water logging condition.

Results and Discussion

Study of genetic variability

The results from ANOVA (Table 1) suggested that all the traits were highly significant at 1% level of significance except length of cob which was significant at 5% level of significance. The results reflected the use of diverse base population for deriving such hybrids. For most of the traits, the CVe value (Table 2) was low which depicted good precision in experiment. However, this value was in the moderate range for number of plants with adventitious roots after stress and yield which represented higher influence of environment on such traits. Similar studies were performed in maize (Lakshmi *et al.,* 2018) under water logging condition.

Phenotypic and genotypic coefficient of variation

The study of phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) is not only important for analyzing the amount of phenotypic and genotypic variations among various traits but also useful in predicting the scope of improvement through selection. High value of PCV and GCV is desirable as it represents higher variability in genotypes. The GCV estimate is considered more and is most commonly used for plant selection (Bello *et al.,* 2012). The results (Table 3) depicted that, other than yield, the PCVs were slightly higher than GCVs for all other traits. This report portrayed that the environmental impact was low for expression of most of the traits except yield. High value of PCV and GCV were obtained for number of plants with adventitious roots after stress and senescence percentage after stress, while traits like plant height, ear height, kernels per row and 100 kernel weight had moderate values. High GCV estimates indicated low amenability of a trait to environmental fluctuations (Hefny, 2011). This reflects that such characters can be considered for selection of plants. Similar inference and suggestions were also proposed in previous studies for plants under ESM stress (Lakshmi *et al.,* 2018) and under normal condition (Bello *et al.,* 2012). Days to 50% tasseling, days to 50% silking, days to 75% dry husk, length of cob, girth of cob, kernel rows per cob and shelling percentage had low PCV and GCV, which revealed low genotypic variability among the hybrids for these traits which are similarly to the previous reports (Sravanti *et al.,* 2017; Siluveru *et al.,* 2015; Bartaula, 2019, and Mallikarjuna *et al.,* 2011) available for maize.

Heritability and genetic advance

The estimates of heritability aid the breeders in allocating resources necessary to effectively select for desirable traits and to achieve maximum genetic gain with less time and resources (Smalley *et al.,* 2004). Heritability was classified as low (below 30%), medium (30-60%) and high (above 60%) (Sasipriya *et al*., 2022). High broad sense heritability was observed for senescence percentage (after stress), number of plants with adventitious roots (after stress), days to 50% tasseling, days to 50% silking, 100 kernel weight, days to 75% dry husk, kernels per row, plant height, ear height and girth of cob. The measure of high heritability

Table 1: Analysis of variance for 14 traits in 32 maize hybrids

SN	Character	Source	d.f	S.S	M.S.S	F- value
1	Days to 50% tasseling (DT)	Replication	1	1.266	0.391	0.548
		Genotype	31	137.859	4.419	6.196**
		Error	31	17.234	0.713	
2	Days to 50% Silking (DS)	Replication	1	1.266	1.266	2.277
		Genotype	31	127.984	4.129	7.426**
		Error	31	17.234	0.556	
3	Days to 75% Dry Husk (DH)	Replication	1	0.391	0.391	0.326
		Genotype	31	193.484	6.241	5.214**
		Error	31	37.109	1.197	
4	Plant Height (PHT)	Replication	1	93.123	93.123	0.313
		Genotype	31	38658.830	1247.059	4.193**
		Error	31	9219.387	297.400	
5	Ear Height (EHT)	Replication	1	33.785	33.785	0.584
		Genotype	31	7579.306	244.494	4.227**
		Error	31	1793.240	57.846	
6	Number of plants with Adventitious Root (AR)	Replication	1	7.563	7.563	2.915
		Genotype	31	1155.750	37.282	14.368**
		Error	31	80.438	2.595	
7	Senescence per cent (after stress) (SP)	Replication	1	0.281	0.281	1.837
		Genotype	31	3369.236	108.685	709.901**
		Error	31	4.746	0.153	
8	Length of cob (LC)	Replication	1	2.800	2.800	1.644
		Genotype	31	104.773	3.380	1.984*
		Error	31	52.796	1.703	
9	The girth of Cob (GC)	Replication	1	0.222	0.222	0.644
		Genotype	31	43.974	1.419	4.114**
		Error	31	10.689	0.345	
10	Number of Kernel rows per Cob (KR/C)	Replication	1	0.276	0.276	0.379
		Genotype	31	60.144	1.940	2.668**
		Error	31	22.544	0.727	
11	Number of Kernels per row (K/R)	Replication	1	16.134	16.134	3.248
		Genotype	31	679.904	21.932	4.416**
		Error	31	153.972	4.967	
12	100 Kernel weight	Replication	1	5.018	5.018	1.261
		Genotype	31	825.078	26.615	6.690**
		Error	31	123.332	3.978	
13	Shelling % (S)	Replication	1	0.004	0.004	0.330
		Genotype	31	0.884	0.029	2.379**
		Error	31	0.372	0.012	
14	Yield (t/ha)	Replicatin	1	2.551	2.551	1.688
		Genotype	31	128.843	4.156	2.749**
		Error	31	46.868	1.512	

***significant at 5% level of significance (1.82); **significant at 1% level of significance (2.35)**

indicated that the environmental impact was minimal on such traits (Ogunniyan and Olakojo 2014). Therefore, the breeders may perform superior selection of genotypes based on the phenotypic performance of these traits (Sravanti *et al.,* 2017; Siluveru *et al.,* 2015; Bartaula *et al.* ,2019; Khan *et al.,* 2018; Mallikarjuna *et al.,* 2011; Bello *et al.,* 2012). Genetic advance exhibits the extent of genetic gain acquired by a trait under a specific selection pressure. The values of genetic advance as percentage of mean population ranged from 1.30% to 79.52%. High genetic advance as percentage of mean (GAM) was estimated for number of plants with adventitious roots after stress, senescence percentage after stress, plant height, 100 kernel weight and yield (Sasipriya *et al*., 2022). High genetic advance along with high heritability estimates offers the most satisfactory condition for selection (Sasipriya *et al*., 2022). This indicates prevalence of additive genes in these traits and further portrays definitive crop improvement through selection of such traits is easier. Considering this delineation, traits like number of plants with adventitious roots after stress, senescence percentage after stress, plant height and 100 kernel weight can be examined for selection of plants under ESM stress. Similar results were also reported for senescence percentage after stress under ESM stress (Lakshmi *et al.,* 2018; Sravanti *et al.,* 2017; Bartaula *et al.,* 2019; Khan *et al.,* 2018).

Character Association

The knowledge of the degree of association between yield and its component traits and within the component characters themselves, can improve the selection efficiency in plant breeding. The correlation studies (Table 4) reflected that the genotypic correlation coefficients were higher than phenotypic correlation coefficients for most of the characters under study. This indicated a strong inherent relationship among the characters studied, which was majorly regulated by genetic causes (Lakshmi *et al.,* 2018). This further suggested that, predominance of environmental components might have suppressed the expression of traits at phenotypic level (Lone *et al.,* 2010). Similar results were also acquired previously (Lone *et al.,* 2010; Pavan *et al.,* 2011; Begum *et al.,* 2016; Usha Rani *et al.,* 2017, and Lakshmi *et al.,* 2018). Under ESM stress, plant height showed highly significant, positive correlation with yield at both phenotypic and genotypic levels. Some hybrids (ZH17367, ZH17375) exhibited greater biomass accumulation under ESM stress with plant height greater than 200 cm. This was in accordance with the previous findings (Lizaso and Riche, 1997; Lone *et al.,* 2010). This relationship between plant height and yield was due to higher biomass accumulation because of greater plant height, which led to higher yield (Begum *et al.,* 2016, and Nzuve *et al.,* 2014). Yield and number of plants with adventitious roots (after stress) were positively correlated. This suggested that plants bearing adventitious roots assisted in avoiding lodging and facilitated oxygen availability to submerged roots (Lone *et al.,* 2010) which led to an overall higher yield. Under normal soil conditions, this trait shows poor expression, but, there is significant increase in this traits (Shah *et al.,* 2012, and Zaidi *et al.,* 2007) under waterlogging environment.

Scientists inferred similar significant correlations and further emphasized in considering this trait as selection criteria for screening maize genotypes for ESM stress tolerance (Lakshmi *et al.,* 2018). Length of cob and yield exhibited positive correlation under water-logging (Lone *et al.,* 2010). The girth of cob and number of kernels row per cob had significant positive correlation with yield at phenotypic level. Moreover, kernels per row and 100 kernel weight under ESM stress, delineated positive correlation with yield. Such relationships were also depicted by plants grown under normal soil moisture regime (Pandey *et al.,* 2017; Belay N, 2018; Pavan *et al.,* 2011; Kumar *et al.,* 2014, and Lakshmi *et al.,* 2018) under ESM conditions. Yield and senescence percentage (after stress) manifested highly negative correlation. Lowest senescence percentage after stress was observed for the hybrids ZH17446 and VH15676. Scientists proposed that corn genotypes with three or less dead leaves during ESM stress exhibited higher biomass as well as yield grain (Campbell *et al.,* 2015 and Shah *et al.,* 2012). Foliar senescence was also approved to be the most common and immediate symptom of water-logging (Shin *et al.,* 2016). Further, days to 75% dry husk and days to silking correlated to yield which was partly in accordance with the findings of Lakshmi *et al.* (2018) under ESM stress.

Path coefficient studies

Plant selection based on correlation coefficients is often misleading due to the impact of third factor in the correlation between two variables. The most beneficial selection criteria was the traits with high positive correlation along with high direct effects (Pavan *et al.,* 2011). The genotypic path coefficient was more useful to a breeder than phenotypic path coefficients with regard to more effective selection. Considering this, both genotypic (Table 5) as well as phenotypic (Table 6) path coefficient analysis

Table 2: Mean performance of 32 Maize hybrids for 14 characters

Sl. No.	Hybrids	DT	DS	DH	PHT (cm)	EHT (cm)	AR	SP (%)	LC (cm)	GC (cm)	KR/C	K/R	KW (g)	S (%)	Y (t/ha)
1	VH19559	55.5	56.5	88.0	175.4	83.9	8.0	19.90	16.59	13.67	14.0	29.33	30.35	85.00	7.38
2	ZH17368	53.0	54.0	85.0	215.0	99.1	5.5	31.11	16.02	14.41	13.0	25.30	34.31	88.30	7.64
3	VH16921	52.5	54.0	87.0	152.7	70.2	5.5	15.83	18.32	13.13	14.4	34.10	28.88	87.30	6.26
4	VH19487	56.0	56.0	88.5	189.0	91.5	13.5	19.76	17.48	16.42	16.4	32.40	28.11	85.95	7.41
5	VH15676	57.0	57.0	87.5	189.1	95.1	9.5	11.84	15.33	14.77	14.0	31.30	26.85	85.45	6.69
6	ZH17814	53.0	54.0	85.0	193.3	92.3	8.0	18.86	16.29	14.09	13.8	32.70	27.94	85.15	6.70
7	ZH161418	51.5	53.5	83.5	126.4	59.2	9.0	19.66	14.78	13.21	13.2	24.80	29.77	85.85	5.83
8	ZH161384	53.5	55.5	85.5	121.3	59.9	5.0	19.79	13.81	15.17	12.0	27.70	23.95	82.50	4.37
9	VH131019	54.5	56.5	91.0	177.5	78.9	5.5	15.31	18.45	15.25	14.4	37.00	29.52	87.10	6.48
10	ZH17463	56.0	58.0	89.0	164.7	79.2	11.5	15.70	16.65	13.70	13.6	30.90	28.99	84.35	6.37
11	ZH17820	55.5	57.5	87.5	154.1	76.3	7.5	20.47	14.79	15.70	12.0	29.90	25.98	82.95	4.73
12	ZH17446	55.0	57.0	90.0	181.6	88.3	15.0	11.21	16.06	15.03	14.0	31.50	29.71	87.40	8.43
13	ZH17362	56.0	57.0	86.5	196.0	87.8	11.5	13.78	16.03	14.20	14.0	28.60	34.34	85.00	6.43
14	ZH17815	55.5	56.5	88.5	180.1	85.8	5.5	21.84	15.79	14.26	14.0	34.10	24.49	83.00	7.91
15	ZH17470	55.5	56.5	89.0	146.6	74.1	7.5	15.84	15.07	14.09	16.0	24.00	30.16	83.75	5.03
16	ZH17835	55.0	56.0	87.5	161.4	78.2	7.5	19.88	14.32	14.83	15.2	28.20	27.39	85.95	5.10
17	ZH161484	56.0	57.0	88.0	172.3	87.4	15.5	15.64	17.15	15.53	13.6	35.70	27.37	83.35	7.23
18	VH133157	55.0	56.0	86.0	203.2	99.8	14.5	13.75	15.74	14.13	13.2	29.40	29.39	85.10	7.76
19	ZH161054	54.5	56.5	87.5	156.9	74.0	17.0	17.73	16.43	14.17	14.2	26.60	32.73	83.55	5.53
20	ZH17367	54.0	55.0	87.0	208.1	96.7	16.0	13.58	17.81	14.44	12.8	27.70	36.71	84.65	6.53
21	ZH138269	55.5	57.5	87.5	138.2	64.2	11.5	24.51	16.62	13.25	14.4	26.30	29.68	86.15	5.75
22	ZH17509	53.0	55.0	90.0	146.0	70.0	11.5	15.19	16.71	13.22	14.4	32.00	24.88	85.90	4.82
23	ZH17375	57.5	57.5	89.0	206.1	94.7	10.5	14.51	16.56	14.52	14.0	26.30	34.09	86.05	5.63
24	ZH17251	57.0	58.0	88.5	133.3	67.9	13.5	14.85	14.28	14.01	13.8	25.60	28.66	85.95	5.97
25	ZH17793	56.0	57.5	90.0	177.7	79.9	16.0	21.98	17.56	13.80	13.4	27.50	36.07	85.80	6.33
26	ZH17749	53.0	54.0	88.5	144.4	67.4	7.5	22.11	17.75	13.27	13.8	26.10	30.13	83.55	4.38
27	ZH17800	56.5	59.5	90.5	158.1	82.6	3.5	44.99	14.77	14.42	13.6	27.65	23.32	76.30	2.59
28	ZH17833	54.5	57.0	88.0	147.9	76.65	2.5	51.49	14.02	13.66	13.0	25.20	24.22	84.80	3.22
29	ZH17363	53.5	56.0	90.5	144.5	73.0	4.0	63.83	17.43	13.95	13.3	28.85	30.52	87.10	2.99
30	CAH1821*	54.5	56.0	88.5	149.3	76.3	16.0	13.75	16.10	16.12	15.6	26.70	34.09	83.20	7.05
31	BIO 9544*	52.5	54.5	87.0	187.7	86.6	16.0	22.99	18.09	14.09	13.6	27.90	35.42	84.50	7.28
32	OMH 14-27*	54.5	58.0	90.0	173.2	79.6	11.0	14.93	17.31	14.87	15.2	30.8	27.74	86.95	6.33
	G.M.	54.77	56.27	87.98	167.85	80.52	10.6	21.14	16.25	14.36	13.93	29.13	29.55	84.93	6.00
	C.D.	1.73	1.53	2.24	35.34	15.58	3.30	0.62	2.67	1.20	1.74	4.57	4.09	0.22	2.52
	C.Ve	1.54	1.33	1.24	10.27	9.45	16.0	1.13	8.03	4.09	6.12	7.65	6.75	1.17	20.48

*** indicates check hybrids; DT: Days to 50% tasseling; DS: Days to 50% silking; DH: Days to 75% dry husk; PHT: Plant height (cm); EHT: Ear height (cm); AR: Number of Adventitious roots/ stilt/ brace roots bearing plants (after stress); SP: Senescence per cent (After Stress); LC: Length of cob (cm); GC: Girth of cob (cm); KR/C: Number of kernel rows per cob (KR/C); K/R: Number of kernels per row; KW: 100 kernel weight (g); S: Shelling %; Y: Grain yield (t/ha).**

Table 3: Estimates of variability parameters and expected genetic advance for 14 characters

Sl. No.	Characters	Mean	Range	PCV %	GCV %	h^2 (%)	GA (%)	GA % of population mean
1	Days to 50% tasseling (days)	54.77	51.50 - 57.5	2.89	2.55	77.78	2.53	4.62
2	Days to 50% Silking (days)	56.27	53.50 - 59.5	2.72	2.38	76.26	2.40	4.27
3	Days to 75% Dry Husk (days)	87.98	83.50 -91.0	2.19	1.81	67.81	2.69	3.06
4	Plant Height (cm)	167.85	121.30 - 215	16.56	12.98	61.49	35.20	20.97
5	Ear Height (cm)	80.52	59.20- 99.80	15.27	12.00	61.73	15.64	19.42
6	Number of plants with Adventitious roots (after stress) (number)	10.06	2.50 -17.0	44.38	41.39	86.99	8.00	79.52
7	Senescence Percentage (after stress) (%)	21.14	11.21- 63.83	27.40	27.37	99.83	15.16	56.34
8	Length of Cob (cm)	16.25	13.81-18.45	9.81	5.63	32.99	1.08	6.67
9	Girth of Cob (cm)	14.36	13.13-16.42	6.54	5.10	60.89	1.18	8.20
10	Kernel Rows per Cob (number)	13.93	12 .00-16.40	8.29	5.59	45.47	1.08	7.76
11	Kernels per row (number)	29.13	24.00 -37.00	12.59	10.00	63.07	4.77	16.36
12	100 Kernel Weight (g)	29.55	23.32 -36.71	13.23	11.38	73.99	5.96	20.17
13	Shelling Percentage (%)	84.93	76.30 -88.30	1.55	0.99	40.82	0.12	1.30
14	Yield (t/ha)	6.00	2.59 - 8.43	28.04	19.15	46.65	1.62	26.95

Table 4: Phenotypic (rp) and Genotypic (rg) correlation coefficients among 32 maize hybrids for 14 characters

Characters		DT	DS	DH	PHT	EHT	AR	SP	LC	GC	KR/C	K/R	KW	S	Y
DT	r_p	1.000	0.874**	0.450**	0.205	0.275*	0.182	-0.183	-0.159	0.316*	0.196	0.048	-0.105	0.051	0.059
	r_g	1.000	0.871**	0.448**	0.247*	0.377**	0.152	-0.203	-0.302*	0.420**	0.308*	0.091	-0.135	0.155	0.087
DS	r_p		1.000	0.588**	-0.009	0.055	0.089	0.054	-0.189	0.250*	0.094	0.004	-0.184	0.013	-0.119
	r_g		1.000	0.608**	-0.063	0.079	0.044	0.07	-0.372**	0.241	0.048	0.041	-0.296*	-0.054	-0.296*
DH	r_p			1.000	0.004	0.011	0.016	0.137	0.268*	0.168	0.332**	0.237	-0.046	-0.129	-0.128
	r_g			1.000	-0.192	-0.123	-0.01	0.176	0.400**	0.104	0.389**	0.289*	-0.207	-0.322**	-0.398**
PHT	r_p				1.000	0.943**	0.217	-0.223	0.330**	0.231	0.051	0.263*	0.406**	0.274*	0.499**
	r_g				1.000	0.974**	0.336**	-0.277*	0.448**	0.251*	-0.041	0.268*	0.496**	0.498**	0.786**
EHT	r_p					1.000	0.179	-0.15	0.181	0.272*	0.015	0.256*	0.253*	0.221	0.415**
	r_g					1.000	0.318*	-0.187	0.271*	0.435**	0.024	0.249*	0.356**	0.427**	0.759**
AR	r_p						1.000	-0.554**	0.263*	0.167	0.165	-0.002	0.514**	-0.167	0.499**
	r_g						1.000	-0.588**	0.433**	0.24	0.245	-0.03	0.593**	-0.214	0.621**
SP	r_p							1.000	-0.111	-0.197	-0.238	-0.241	-0.198	0.054	-0.554**
	r_g							1.000	-0.168	-0.232	-0.337**	-0.293*	-0.217	0.072	-0.792**
LC	r_p								1.000	0.111	0.221	0.477**	0.475**	0.052	0.341**
	r_g								1.000	-0.477**	0.258*	0.373**	0.550**	0.291*	0.294*
GC	r_p									1.000	0.257*	0.304*	0.042	-0.261*	0.256*
	r_g									1.000	0.134	0.283*	-0.216	-0.555**	0.233
KR/C	r_p										1.000	0.143	0.093	-0.168	0.268*
	r_g										1.000	0.096	-0.01	-0.431**	0.095
K/R	r_p											1.000	-0.268*	0.109	0.337**
	r_g											1.000	-0.416**	0.189	0.464**
KW	r_p												1.000	-0.042	0.405**
	r_g												1.000	-0.199	0.319*

DT: Days to 50% tasseling; DS: Days to 50% silking; DH: Days to 75% dry husk; PHT: Plant height (cm); EHT: Ear height (cm); AR: Number of Adventitious roots/ stilt/ brace roots bearing plants (after stress); SP: Senescence per cent (After Stress); LC: Length of cob (cm); GC: Girth of cob (cm); KR/C: Number of kernel rows per cob (KR/C); K/R: Number of kernels per row; KW: 100 kernel weight (g); S: Shelling %; Y: Grain yield (t/ha)

Table 5: Genotypic path coefficient analysis of 14 component traits on yield.

Characters	DT	DS	DH	PHT	EHT	AR	SP	LC	GC	KR/C	K/R	KW	S	Y (correlation)
DT	-1.006	0.951	-0.307	0.472	-0.461	0.026	0.060	-0.054	0.178	0.165	0.004	0.037	0.021	0.087
DS	-0.876	1.091	-0.417	-0.121	-0.097	0.008	-0.021	-0.066	0.102	0.026	0.002	0.081	-0.007	-0.296*
DH	-0.450	0.663	-0.686	-0.368	0.150	-0.002	-0.052	0.071	0.044	0.208	0.012	0.057	-0.044	-0.398**
PHT	-0.248	-0.069	0.132	1.914	-1.191	0.058	0.082	0.080	0.106	-0.022	0.011	-0.136	0.069	0.786**
EHT	-0.379	0.086	0.084	1.864	-1.223	0.055	0.055	0.048	0.185	0.013	0.010	-0.098	0.059	0.759**
AR	-0.153	0.048	0.007	0.644	-0.388	0.173	0.174	0.077	0.102	0.131	-0.001	-0.163	-0.029	0.621**
SP	0.204	0.076	-0.121	-0.530	0.229	-0.102	-0.296	-0.030	-0.098	-0.180	-0.012	0.060	0.010	-0.792**
LC	0.304	-0.406	-0.275	0.858	-0.331	0.075	0.050	0.178	-0.202	0.138	0.016	-0.151	0.040	0.294*
GC	-0.422	0.263	-0.071	0.480	-0.532	0.042	0.069	-0.085	0.424	0.072	0.012	0.059	-0.077	0.233
KR/C	-0.310	0.053	-0.267	-0.078	-0.029	0.043	0.100	0.046	0.057	0.535	0.004	0.003	-0.059	0.095
K/R	-0.091	0.044	-0.198	0.512	-0.305	-0.005	0.087	0.066	0.120	0.052	0.042	0.115	0.026	0.464**
KW	0.136	-0.323	0.142	0.950	-0.435	0.103	0.064	0.098	-0.092	-0.005	-0.017	-0.275	-0.027	0.319*
S	-0.156	-0.059	0.221	0.953	-0.522	-0.037	-0.021	0.052	-0.235	-0.230	0.008	0.055	0.138	0.165

Genotypic residual effect = 0.061 * Significant at 5% level ** Significant at 1%

Table 6: Phenotypic path- coefficient analysis of 14 component traits on yield.

Characters	DT	DS	DH	PHT	EHT	AR	SP	LC	GC	KR/C	K/R	KW	S	Y (correlation)
DT	**-0.077**	0.117	-0.124	0.076	-0.035	0.033	0.031	0.024	-0.008	0.041	0.022	-0.035	-0.004	0.059
DS	-0.068	**0.134**	-0.162	-0.003	-0.007	0.016	-0.009	0.028	-0.006	0.020	0.002	-0.061	-0.001	-0.119
DH	-0.035	0.079	**-0.276**	0.001	-0.001	0.003	-0.023	-0.040	-0.004	0.069	0.106	-0.015	0.009	-0.128
PHT	-0.016	-0.001	-0.001	**0.372**	-0.121	0.039	0.038	-0.049	-0.006	0.011	0.117	0.135	-0.019	0.499**
EHT	-0.021	0.007	-0.003	0.351	**-0.128**	0.032	0.025	-0.027	-0.007	0.003	0.114	0.084	-0.016	0.415**
AR	-0.014	0.012	-0.004	0.081	-0.023	**0.180**	0.094	-0.039	-0.004	0.034	-0.001	0.171	0.012	0.499**
SP	0.014	0.007	-0.038	-0.083	0.019	-0.100	**-0.169**	0.016	0.005	-0.050	-0.107	-0.066	-0.004	-0.554**
LC	0.012	-0.025	-0.074	0.123	-0.023	0.047	0.019	**-0.148**	-0.003	0.046	0.212	0.158	-0.004	0.341**
GC	-0.024	0.033	-0.046	0.086	-0.035	0.030	0.033	-0.016	**-0.025**	0.054	0.135	0.014	0.018	0.256*
KR/C	-0.015	0.013	-0.091	0.019	-0.002	0.030	0.040	-0.033	-0.006	**0.208**	0.064	0.031	0.012	0.268*
K/R	-0.004	0.001	-0.065	0.098	-0.033	0.000	0.041	-0.071	-0.008	0.030	**0.446**	-0.089	-0.008	0.337**
KW	0.008	-0.025	0.013	0.151	-0.032	0.093	0.033	-0.070	-0.001	0.019	-0.120	**0.333**	0.003	0.405**
S	-0.004	0.002	0.036	0.102	-0.028	-0.030	-0.009	-0.008	0.007	-0.035	0.049	-0.014	**-0.070**	-0.004

Phenotypic residual effect = 0.384; * Significant at 5% level; ** Significant at 1% level

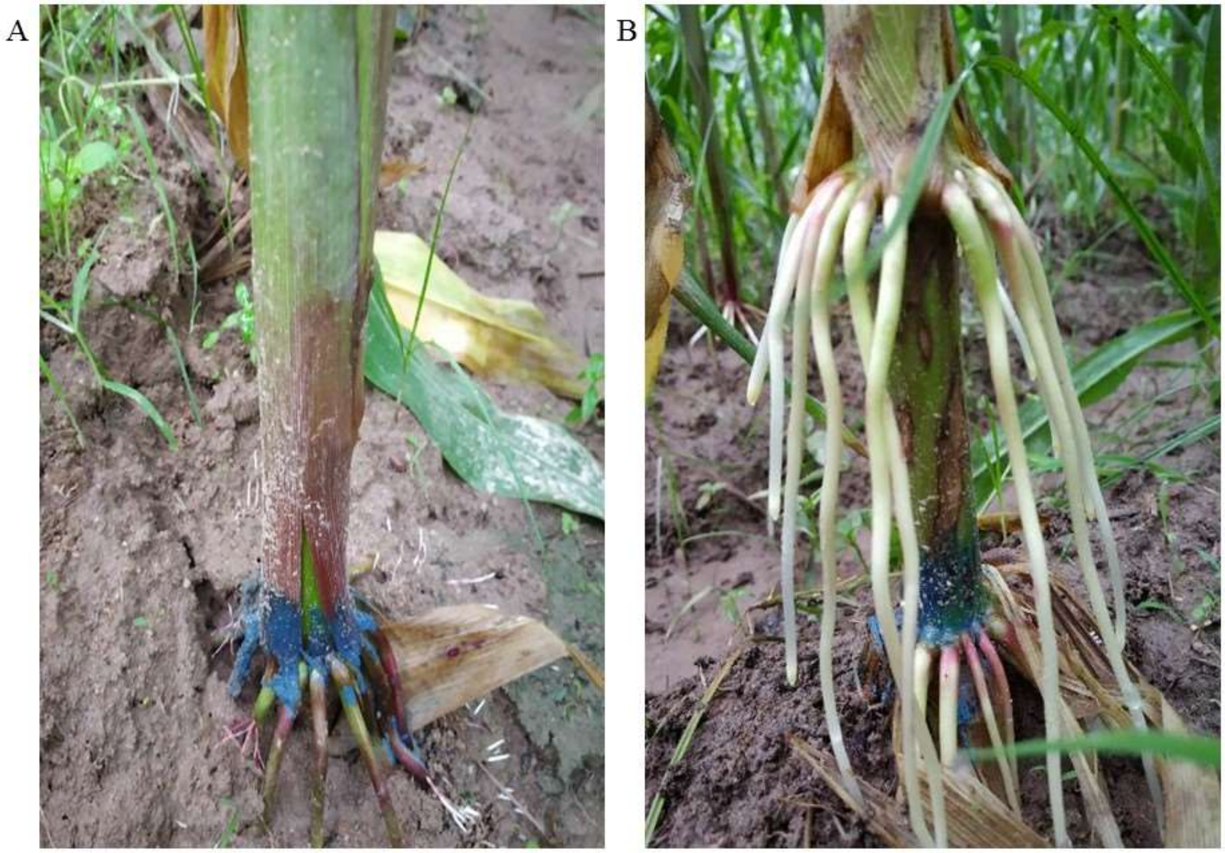

Figure 1: Illustration showing the development of adventitious roots in maize hybrid ZH17367 under excessive soil moisture stress (A: before stress; B: after stress)

was performed. The genotypic path analysis reflected that plant height had highest direct positive impact as well as high positive correlation with yield (Khodarahmpour, 2012) under heat stress that tall plants gave better yield. On the contrary, ear height showed highest direct negative effect but positive correlation with yield via higher positive indirect effects of plant height. Days to silking also depicted positive direct effect on yield, which was counter balanced by negative indirect impact of days to tasseling and days to 75% dry husk leading to an overall negative correlation with yield (Pandey *et al.,* 2017). Kernel row per cob and girth of cob reflected positive direct effect on yield even though their correlation with yield was non-significant. Tulu (2014) also detected similar trend for cob diameter. Number of plants with adventitious roots after stress showed direct positive effect as well as positive correlation with yield. This confers the trait to be an important selection parameter for plants under ESM stress. The low yielding hybrids (ZH17800, ZH17833) showed very poor adventitious root development under stress. The length of cob and shelling percentage also exerted positive direct effect on yield. Kernels per row had highly significant positive correlation and its direct effect on grain yield was positive but low (Begum *et al.,* 2016).

Furthermore, senescence percentage after stress had direct negative effect as well as negative correlation with yield similar to the findings of Lakshmi *et al.,* (2018) and Sesay *et al.,* (2017) under ESM stress. Days to tasseling delineated negative direct effect on yield (Begum *et al.,* 2016). Negative selection can be applied for days to 75% dry husk as it had higher negative direct effect and negative correlation with yield. It was noteworthy that 100 kernel weight exhibited negative direct effect on grain yield but a positive correlation via indirect effect of plant height. This indicated that selection for higher grain yield can be done through indirect selection from the yield components. The residual effect of genotypic path coefficient was 0.061 which indicated that the traits studied were sufficient enough to determine their effect on dependent variable i.e. plant yield. The path coefficient analysis through phenotypic correlation revealed that kernels per row had highest direct positive effect along with positive correlation on yield followed by plant height, 100 kernel weight, kernel row per cob, number of plants with adventitious roots (after stress) and days to silking. Ear height depicted highest indirect effect on yield via plant height. On the other hand, highest direct negative effect on yield was exerted by days to 75% dry husk followed by senescence percentage, length of cob, ear height, days to tasseling, shelling percentage and girth of cob. It was noteworthy that days to silking had highest negative indirect effect on yield via days to 75% dry husk (Patil *et al.,* 2016; Upadhyay *et al.,* 2017).

Conclusion

The results obtained indicate that plants with greater plant height, low senescence percentage after stress, higher number of plants with adventitious roots after stress and greater number of kernels per row were detected to be good indicators of ESM stress tolerance. Considering these attributes, among 32 hybrids, ZH17368, VH19487, ZH17446, ZH17815, and VH133157 were the best performing hybrids under ESM stress. These hybrids were found to withstand 12 days of waterlogging stress at the flowering stage and can be considered for planting in the areas where yield loss due to ESM is prevalent.

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Conflict of interest

The authors declare that they have no conflict of interest.

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