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RESEARCH PAPER

Multi-environment field testing to identify better performing and stable genotypes for water logging stress tolerance in tropical maize

Bhupender Kumar[1] · Vishal Singh[1] · Shyam Bir Singh[1] · Krishan Kumar[1] · Shankar Lal Jat[1] · Sonu Kumar[1] · Brijesh Kumar Singh[1] · Chayanika Lahkar[1] · C. M. Parihar[2] · Zahoor Ahmed Dar[3] · Sujay Rakshit[1]

Abstract: Maize is the third most important cereal crop after wheat and rice in the world. Nearly 80 per cent of maize in India is grown under rainfed ecology. In the era of climate change, its production and productivity are limited by several biotic and abiotic stresses. Amongst the abiotic stresses, drought and water logging stresses are the major one. Considering it, the current study was carried out to evaluate and select water logging tolerant genotypes suitable for stress-prone ecology. A set of 70 maize varieties consisting of 61 single cross hybrids and 09 composites of late-medium duration and 13 single cross hybrids of early duration were evaluated in two separate trials at three different environments. Two same sets were constituted in each trial for evaluation one under water logging stress and another as control set where no water stress was imposed. The overall grain yield under stress conditions in different environments was varied from 4806.7 to 1715.4 kg/ha in late-medium trials and 3727.2 to 1418.3 kg/ha in early. Similarly, the yield under non-stress was varied from 5949.3 to 2926.3 kg/ha in late-medium and 5324.0 to 2873.2 in early duration trials. The analyses done using the Additive Main effect and Multiplicative Interaction (AMMI) model, has differentiated the test genotypes based on their performance and interaction with the target environments. Based on AMMI selection, in the late-medium group, three hybrids, such as IMH 1527, DMRH 1419 and CMH-08-292 (yielded > 5000 kg/ha) and in the early, VMH 51 and IMH 1533 (> 4000 kg/ha) were repeatedly found in first four selection in more than one environments. Further, tolerant hybrids of medium duration were validated by planting in large plots size under water logged and control conditions with respect to the susceptible one. The non-significant yield reduction ranging from 5.7 per cent to 12.8 per cent was observed in the tolerant hybrids, however in susceptible, it was highly significant ranging from 64.9 per cent to 82.1 per cent. The anatomical study showed a sufficient number of well-developed aerenchymatous cells in the roots tissues of tolerant hybrids under water stress conditions. The identified tolerant hybrids can be explored in stress-prone ecologies and can be used as source germplasm for further diversification of water logging stress breeding programme.

Keywords: Anatomical study · Genotype stability · Maize · Multi-environments · Water logging stress

✉ Bhupender Kumar: bhupender.icar@gmail.com

[1]ICAR–Indian Institute of Maize Research, Punjab Agricultural University, Ludhiana-141004, Punjab, India

[2]ICAR–Indian Agricultural Research Institute, New Delhi-110012, India

[3]Dryland Agriculture Research Station, Srinagar, SKUAST, Kashmir, J&K, India

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Introduction

Maize (*Zea mays* L.) is one of the diverse cereal crops that can be cultivated in a wide range of ecologies and seasons. In India, maize growing ecology has been categorized in five different zones for effective evaluation and its cultivation. The harvest of maize has diverse uses such as it can be used as feed, food, fodder as well as to prepare industrial by-products. In India, more than 1000 products and in the USA and other countries nearly 3500 products are being developed from maize. Maize is being grown as a rainfed crop in India where nearly 80 per cent of the total area is under rainfed and the remaining 20 per cent is irrigated (Kumar *et al.*, 2016). Being a rainfed crop, it has to face several abiotic and biotic stresses due to the country's unpredictable and extremely changing weather patterns. The prominent abiotic stresses in the rainfed ecology are drought and water logging stress (Kumar *et al.*, 2016). Now due to climate change, the plant has to face both of these stresses very frequently in the same growing season (Kumar *et al.*, 2020). Around 15 per cent of the maize-growing areas are affected by flooding in Southeast Asia, resulting in a yearly production loss of 25–30 per cent (Chen *et al.*, 2014).

Maize is susceptible to water logging especially at its early vegetative stages. Water logging stress at early growth stages causes severe reductions in plant height, dry matter accumulation, and ultimately affects yield (Mukhtar *et al.*, 1990; Rosenzweig *et al.*, 2002; Rao and Li, 2003; Liu *et al.*, 2010). In water logged conditions, the root's ability to supply nutrients and water for plant growth and development is severely inhibited (Simone *et al*., 2002; Smethurst and Shabala, 2003).

Yield stability is one of the prime objectives in the development of plant varieties that have high yield potential in combination with the wider adaptability over different ago-climatic conditions (Kumar *et al.*, 2016 & 2017). Genotypes which yield better over different agro-climatic conditions are more adaptive and stable. Thus, a comprehensive study of the adaptability and stability of genotypes is a major aim in plant breeding programs (Das *et al*., 2011). The evaluation of the genotypic performance of hybrid maize cultivar candidates in many environments gener-ates valuable data to determine how stable and adapted genotypes are (Crossa, 1990). To increase accuracy and to study the genotype × environment interaction (GEI), the different statistical analyses like Additive Main effect and Multiplicative Interaction (AMMI) and Genotypic & Genotypic-by-Environment (GGE) are being used worldwide for interpreting Multiple Environment Trial (MET) (Choudhary *et al.*, 2020). In AMMI analyses we considered the combination of ANOVA and principal component analysis (PCA) together for interpreting G × E and stability of the genotypes (Sadeghi *et al.*, 2011; Choudhary *et al.*, 2020). Measurement of the performance of the genotypes and their stability over several environments particularly in terms of their yields in normal and stress-prone ecology is the primary objective in any maize breeding programme. Considering the facts, the current study was carried out to evaluate the different maize hybrids and varieties in multiple environments under water logging stress as well as in normal (non-stress) conditions to identify high yielding and stable tolerant genotypes for high moisture stress. The development of genotypes having the ability to withstand waterlogged stress conditions could be beneficial and suitable for maize-growing farmers of the country.

Materials and methods

Experimentation

In the current study, 70 maize varieties (9 OPVs and 61 hybrids) of medium-late and 13 hybrids of early maturity were used as experimental materials which were evaluated for water logging stress in three different environments as Begusarai, Delhi and Ludhiana during *Kharif* season of 2018. The maize genotypes were evaluated using randomized block design with two rows of 3 m length in two different replications. Two sets of 70 genotypes were constituted for each location to evaluate one under water logging stress and another as control where no stress was applied. The water logging stress was imposed at the seedling stage i.e. 25 days after sowing by stagnating water up to 5–8 cm above the soil surface in the stress plots continuous for ten days. Remaining, all packages of practices were adopted as followed in the control plots. In the control plots, no stress was imposed and normal packages of practices were followed to raise the healthy crop. The hand weeding was done to keep the field weed-free. To further supplement the managed water logging stress, the sowing was taken up in the first week of July, so that it gets coincide with more rainfall at the critical plant growth stage. The observations were recorded for aerial roots development, per cent death of the seedlings, lodging, days to anthesis and silking, and plots yield. The tolerant hybrids identified based on the multiple environments evaluation were further validated under water logging conditions with the susceptible checks on large plots size (45.5 m^2) to confirm their performance. The trial for validation was conducted during *kharif* season of 2019 at the Delhi location.

Statistical analysis

The data recorded on grain yield was subjected to AMMI analysis which combines Analysis of Variance (ANOVA) with additive and multiplicative parameters into a single model (Gauch, 1988) using GenStat 17th Ed. (2014). The output was used for analyzing the yield performance and stability of the genotypes in the water logging and normal conditions in different environments. The simultaneous study of the genotype plus genotype-environment interaction was also performed.

Results and discussion

The grain yield under stress conditions in different environments was varied from 4806.7 to 1715.4 kg/ha in late-medium trials and 3727.2 to 1418.3 kg/ha in early maturing trials (Table 1). Similarly, the yield under non-stress was varied from 5949.3 to 2926.3 kg/ha in late-medium and 5324.0 to 2873.2 in early (Table 1). The highest and lowest yielding environments in both the trials were Delhi and Begusarai, respectively.

The Begusarai center is in the north east plain zone in which generally, heavy rains occurred during *kharif* season and hence resulting in more yield loss. The sowing was taken up in the first week of July that also has further contributed to face heavy rainfall by the plants at their critical growth stage. The AMMI analysis shows that all three environments were different and clearly categorized the test entries with respect to their interaction with the target environment (Figure 1).

This also indicated that these testing sites can be considered to provide three different testing environments for the evaluation of genotypes under water logging stress (Baraki *et al.*, 2014). The genotype main effect plus genotype by environment interaction (GGE) biplot used principal component comprised of a set of elite genotypes scores multiplied by environment scores which gives a two-dimensional biplot (Ding *et al.*, 2008; Sadeghi *et al.*, 2011; Ayed *et al.*, 2016). The best four genotypes were selected using AMMI selection based on their performance under water logging stress. The details of the first four genotypes selected based on AMMI selection are given in Table 2. In the late-medium group, three hybrids, such as IMH 1527, DMRH 1419 and CMH-08-292 of the medium maturity group were repeatedly found in first four performing genotypes under water logging stress in more than one environment (Table 2). They were yielding, more than 5.0 t/ha under water logging stress. Similarly, in the early maturity group, two hybrids such as VMH 51 and

Table 1. Overall mean yield observed at various locations for different maturity trials under water logging stress and non-stress conditions

Locations	Late-medium maturing trial		Early maturing trial	
	Non-stress (kg/ha)	Stress WL (kg/ha)	Non-stress (kg/ha)	Stress WL (kg/ha)
Delhi (E1)	5949.3	4806.7	5324.0	3727.2
Ludhiana (E2)	5447.2	3724.0	4732.3	2177.2
Begusarai (E3)	2926.3	1715.4	2873.2	1418.3

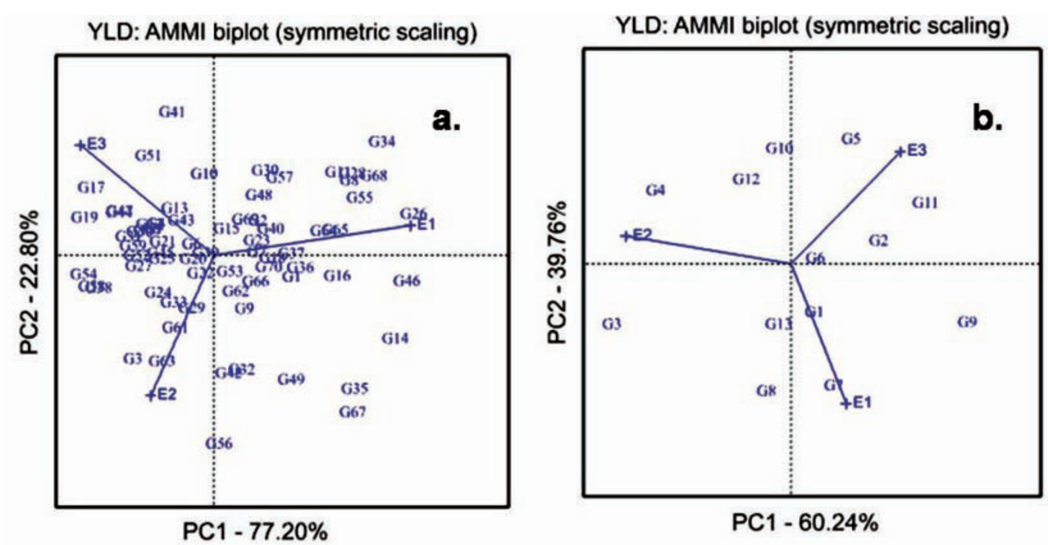

Figure 1. The AMMI biplot graphs, **a.** Late-medium group and **b.** Early group showing the interaction of genotypes in different environments (E1: Delhi; E2: Ludhiana; E3: Begusarai).

IMH 1533 were repeatedly found in the first four performing genotypes under water logging stress in more than one environment (Table 2). The grain yield of these hybrids under water logging stress was more than 4.0 t/ha. The IMH 1527 in the medium group and VMH 51 in early were the hybrids that repeatedly found a place in the first four in all three environments. These genotypes were also performing relatively better in non-stress conditions, hence can be considered for cultivation in water logging prone maize ecologies of the country.

To further validate the performance of water logging stress-tolerant hybrids, during *kharif* season of 2019, medium-duration hybrids such as IMH 1527, DMRH 1419 and CMH-08-292 were planted along with three susceptible checks *viz.*, SMH 1, SMC 6 and SMC 4 at Delhi location. All three tolerant hybrids have yielded > 6.0 t/ha grain yield, however, the susceptible one was yielding ranging from 2.0 to 3.2 t/ha. In the tolerant hybrids, there was a non-significant yield reduction observed from their control treatment (Figure 2). The yield reduction was ranging from 5.7 per cent, in the case of IMH 1527, to 12.8 per cent in the case of DMRH 1419. Similarly, in the case of the susceptible entries, a significant yield reduction was observed ranging from 64.9 per cent in the case of SMC 4 to 82.1 per cent in the case of SMH 1 (Figure 2). IMH 1527 was yielded the highest amongst the tolerant ones with a yield of 6871 kg/ha.

The roots tissues were studied for aerenchyma development for these selected tolerant and susceptible hybrids under water logging stress and control conditions. The anatomical study showed a sufficient number of well-developed aerenchymatous cells in the intercellular regions of tolerant genotypes as compared to the susceptible one (Figure 3).

Aerenchyma can facilitate the movement of various gases (O_2, CO_2, ethylene, and methane) in and out of tissues, and move oxygen from the stem to the root in plants exposed to flooding conditions which reduce hypoxic stress. The identified water logging tolerant hybrids in the current study can be explored in stress-prone maize growing ecologies of the country. These hybrids further can be utilized in breeding programme to develop new germplasm for water logging stress tolerance.

Table 2. Best four maize performing genotypes under water logging stress in different locations selected based on AMMI analysis

Locations	Late-medium maturing				Early maturing			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th
Delhi	IMH1527	DMRH1419	CO(H)M9	CMH08-292	PMH2	VMH39	VMH51	IMH1533
Ludhiana	CMH-08-287	CMH08-292	DMRH 1384	IMH1527	IMH1533	PMH5	VHM51	VMH47
Begusarai	DMRH1419	IMH1527	DMRH 1415	KMH22168	LQMH1	VHM51	IMH1529	VQPM9

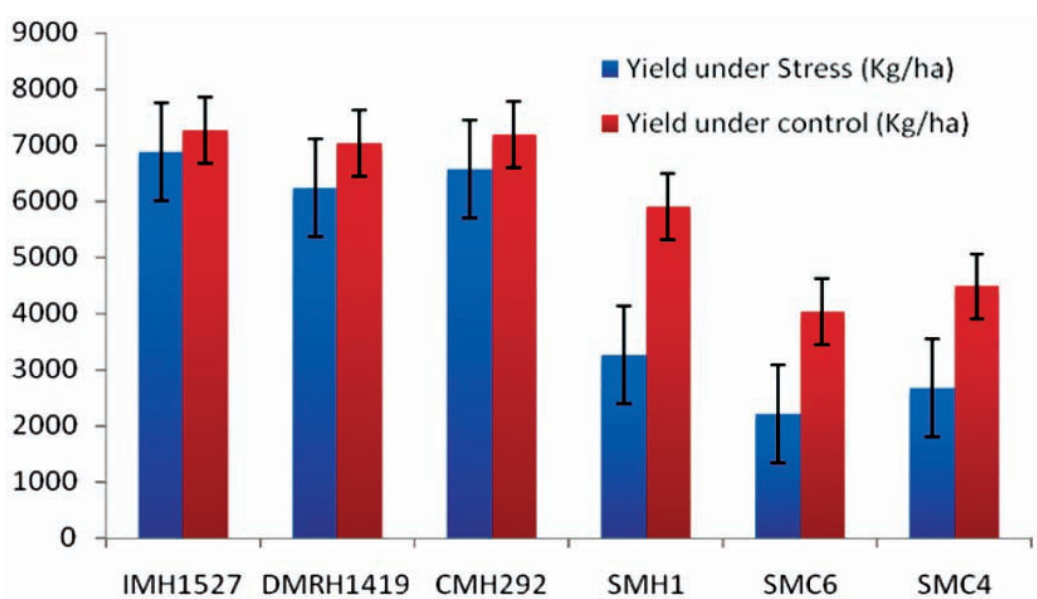

Figure 2. Performance of the selected water logging tolerant and susceptible maize hybrids and varieties on large plots size under high moisture stress and control conditions at Delhi location. The trial was conducted to validate the response of cultivars under water logging stress.

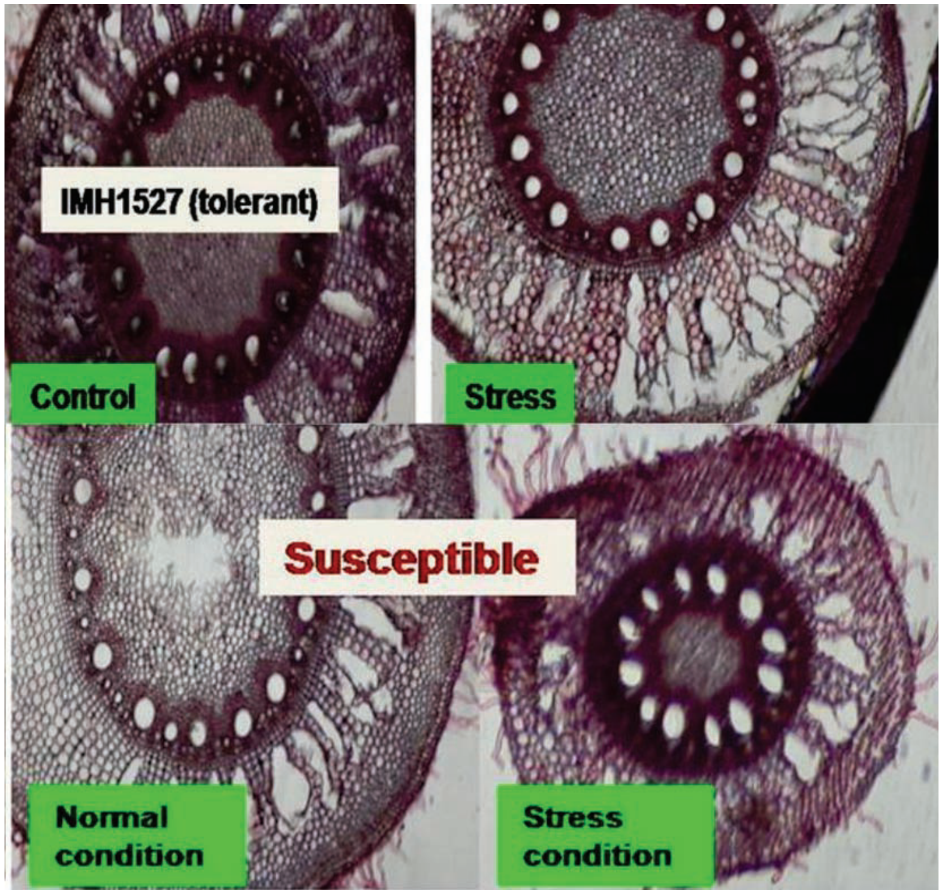

Figure 3. Aerenchyma development under water logging stress and non-stress conditions in the tolerant IMH 1527 and susceptible (SMH 1) maize hybrids. Comparing the roots dissection of stress versus non-stress, sufficient numbers of aerenchyma can be seen in IMH 527 under stress conditions. On the contrary, the susceptible maize genotypes produced a comparatively much lesser number of aerenchyma cells in water logging stress.

Conclusion

In the current study, through multi-environments, testing of maize genotypes under water logging stress as well as non-stress conditions, the three tolerant hybrids under medium duration *viz.*, IMH 1527, CMH-08-292 and DMRH 1419 and two under early such as VMH 51 and IMH 1533 were identified and selected. The medium duration hybrids were further validated for their performance under water logging stress by planting in large plots size. The aanatomical study showed a sufficient number of well-developed aerenchymatous cells in the intercellular regions of tolerant genotypes as compared to the susceptible ones. The selected hybrids can be recommended for the cultivation of water stress-prone ecologies and also can be utilized as source germplasm for further diversification of water logging stress breeding programme.

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