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Association between line *per se* and hybrid performance under excessive soil moisture stress in tropical maize (*Zea mays* L.)

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Abstract

Excessive moisture (EM) stress during the summer–rainy season is one of the major production constraints for maize (*Zea mays* L.) in large areas of South and South-East Asia. A key question in breeding for tolerance to excessive moisture is the extent to which the performance of maize hybrids can be predicted on the basis of *per se* performance of inbred lines under excessive moisture. We attempted to identify the relationship between morpho-physiological traits and grain yield measured on inbred parents and their single cross progenies under EM stress. Responses of various morpho-physiological traits, except days to 50% anthesis, differ significantly under normal versus EM stress. Superiority of hybrid progenies over parental inbred lines increased under EM stress, suggesting that hybrids were comparatively more tolerant to EM stress than inbred progenies. Across moisture regimes, all morpho-physiological traits of hybrids, except lodging and root porosity under normal moisture, were found to be positively and significantly correlated with mid-parent traits. Our data suggest that *per se* performance of lines was a relatively more important factor in determining hybrid performance under EM stress, while under optimum soil moisture conditions mid-parent heterosis was relatively more important than *per se* performance of mid-parent. Phenotypic correlation between hybrid and mid-parent yields showed a strong relationship under EM stress ($r = 0.66^{**}$). The relationship was statistically significant under normal moisture as well, though it was comparatively weak ($r = 0.41^{*}$). Our findings suggest that performance of hybrid progenies under excessive moisture can be predicted and improved to some extent on the basis of their inbred parents that have been systematically selected and improved for EM stress.

Keywords: Hybrids; Inbred lines; Excessive moisture; Water logging

1. Introduction

Maize crops grown during the summer–rainy season in tropical or subtropical environments often encounter drought and/or excessive soil moisture. Excessive moisture, caused by a high water table and poor drainage, is one of the most important constraints to maize production in South and South-East Asia, where an estimated 15% of maize growing areas is affected (Rathore et al., 1996). In India about 8.5 million ha of arable soil is prone to this problem. Approximately 2.4 mha, or 33% of total area planted to maize, is subject to excessive moisture/water logging, causing considerable loss of maize production almost every year (AICRP, 2006).

Excessive soil moisture causes major changes in physical and chemical properties of the rhizosphere (Zaidi et al., 2003a). The diffusion rate of gases in flooded soil is about 100 times lower than that in air (Kennedy et al., 1992), and respiration of plant roots, soil micro-flora and fauna leads to a rapid exhaustion of soil oxygen, resulting in hypoxia followed by anoxia. Unlike rice plants, in which there is provision for gaseous transport between aerial parts and inundated roots via aerenchyma, maize has no naturally occurring air spaces in the root. Therefore, plant roots suffer from extreme oxygen deficit, whenever they are exposed to water logging situation for more than a few hours (Dennis et al., 2000; Zaidi et al., 2002). The extent of damage due to EM stress varies significantly with

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developmental stage of crop, and past studies have shown that the maize crop is comparatively more susceptible during early seedling to tasseling stage (Palvadi and Lal, 1976; Mukhtar et al., 1990; Evens et al., 1990; Zaidi et al., 2004a,b). At later growth stages some genotypes, with an inbuilt ability to produce adventitious roots at above-ground nodes and to form aerenchyma in the cortical region of adventitious roots, can tolerate excessive moisture to some extent (Drew et al., 1979; Rathore et al., 1996; Zaidi et al., 2003a). However, considerable genetic variability has been observed in maize for tolerance to EM stress (Torbert et al., 1993; Rathore et al., 1996, 1997; Zaidi and Singh, 2001; Zaidi et al., 2002; Zaidi et al., 2003a), which could be exploited in developing maize varieties that can tolerate these hypoxia/anoxia conditions. However, the extent to which the available variability in inbred progenies is expressed in hybrid combinations, and whether cross performance can be predicted by parental line performance under excess moisture, is still unknown. Genetic improvement for diseases, plant lodging, earliness, etc., on the basis of performance of inbred lines has been successfully demonstrated. However, in the case of grain yield the performance of parental lines and their hybrids are only weakly associated in most studies (Hallauer and Miranda, 1981; Uhr and Goodman, 1995). For abiotic stresses in maize, including drought and low-nitrogen, line-hybrid progenies associations have been reported, and range from weak and non-significant (Balko and Russell, 1980; Lafitte and Edmeades, 1995), weak but significant (Short and Edmeades, 1991) to fairly strong and significant correlations (Presterl et al., 2002; Zaidi et al., 2003b). In most cases where a poor relationship is found, test-crosses were made with early generation lines and testers having high general combining ability but an unknown performance under abiotic stresses. In the this study advanced generation elite inbred lines, systematically selected and improved for EM-stress, and with proven *per se* performance, were evaluated along with their top-crosses.

The objective of this study is to determine whether morpho-physiological traits measured on parental lines can be used to predict hybrid yields under excessive moisture, and to establish the relationship between the performance of inbred lines and their hybrid progenies under EM-stress.

2. Materials and methods

2.1. Germplasm

A total of 12 elite maize inbred lines were selected from the line evaluation trials conducted on tropical/subtropical lines (S_5–S_n) during 1998–2003 to identify tolerant sources of germplasm for EM stress. Germplasm screened in the line evaluation trials include CM lines from the All India Coordinated Maize Improvement Project (AICMIP), advanced generation elite lines from the Regional Research Station, Haryana Agriculture University, India, and CML-lines CIMMYT's from tropical and sub-tropical maize program. CIMMYT lines include those from CIMMYT populations 21, 22, 26, 28, 31, 33, 42, 43, 44, 45, 501 and 502. From the nurseries of different breeding programs, germplasm was selected for line evaluation trials on the basis of morphological traits, such as seedling and plant vigor, brace root development, absence of plant lodging and good yield potential. Beginning from *Kharif* 1998, an average of 100 lines were screened under EM stress every year, and the top-ranking 10–15% entries were selected on the basis of their superior performance under EM-stress and a normal moisture regime. Since the lines had never been exposed to EM stress on this scale before, none of the lines showed good tolerance to the stress when screening began. However, significant genotypic variability was found for EM stress tolerance. Individual tolerant plants from superior entries were tagged, and the line was maintained through intra-entry sib-mating, and planted ear-to-row in the next season. This procedure was followed for several years, with susceptible fractions being systematically discarded. The procedure was continued until the line became consistent in its performance under EM stress. Out of a total of 12 inbred lines identified for the present study, 3 are highly susceptible, 3 moderately tolerant and 6 lines very tolerant to EM stress (Table 1). The 12 lines were crossed in all possible combinations, but only 47 hybrid combinations out of the possible 66 could be retrieved with sufficient amount of seeds. These were used in this study along with their inbred parents.

2.2. Experimental site, cultural practices and stress treatment

The experiment was conducted during the *Kharif* (summer–rainy season) of 2004 and 2005 at the maize research farm, Indian Agricultural Research Institute, New Delhi, India (28.4°N, 77.1°E, 228.2 m a.s.l.). Soil of the experiment station is characterized as sandy loam with a pH of 7.8. Two sets of all the entries, one for EM stress and a second as an unstressed control, were planted in the field using an alpha (0, 1) lattice design (Patterson and William, 1976) with three replications. The F1 progenies and their inbred line parents were evaluated in separate trials under normal and excessive moisture conditions. In both the years, planting was done during the last week of June. All the entries were over sown and thinned to one plant per hill at the V_2 growth stage to give a population density of 55,000 plants ha^{-1}. Each entry was planted in two rows, each 3.0 m long, with 0.25 m spacing within and 0.75 m between rows. Before planting 60 kg nitrogen (N) ha^{-1} in the form of urea, 60 kg phosphorous ha^{-1} as single super phosphate, 40 kg potassium ha^{-1} as muriate of potash and 10 kg zinc as zinc sulfate were applied as a basal dressing. A second and third dose of N (each 30 kg N ha^{-1}) were side-dressed at knee-high and tasseling stages. Pre-emergence application of pendimethalin and atrazine (both at 0.75 kg ha^{-1} a.i. tank mixed) controlled weeds. Experiments were kept free from insect, weeds and diseases using recommended post-emergence chemical measures, and managed under optimal agronomic practices. In EM trials, the water logging treatment was applied at the knee-high stage ($V_{7–8}$ growth stage) continuously for 7 days. All the water logging screening/evaluation experiments were conducted in a field specially designed and laser leveled