Performance of intermediate maturing maize cultivars in drought-stressed and non-stressed environments in Ghana

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ABSTRACT

Drought stress is a major production constraint of maize (*Zea mays* L.) in the lowland tropics. A study was conducted to determine the yield potential and stability of five maize hybrids, three improved composites, and one local maize variety in favourable and drought-stressed maize production environments in Ghana. The nine genotypes were evaluated at a total of 20 sites in the major agro-ecological zones of Ghana from 1995 to 1997. The 20 sites were divided into two environments (stress and non-stress) of 10 sites each, based on rainfall data during the growing season. Effects due to genotype (G), location (L), and G × L interaction were highly significant (P<0.01) for mid-silk, plant height, ear-acceptability, lodging, and grain yield in the stressed and non-stressed environments. Grain yields averaged 3.58 Mg ha^{-1} in the stressed environment and 6.67 Mg ha^{-1} in the non-stressed environment. On the average, the hybrids out-yielded the improved composites by 17.3 per cent and the local variety by 50.7 per cent in the stressed environment. In the non-stressed environment, the hybrids had an overall yield advantage of 11.6 and 60.2 per cent over the improved composites and the local variety, respectively. Estimates of Eberhart and Russel's stability parameters across both environments for grain yield were b = 1.07, s^2 = 0.006 for the hybrids; b = 1.00, s^2 = 0.006 for the improved composites; and b = 0.61, s^2 = 0.008 for the local variety. It was concluded from the study that the hybrids were more productive than the improved composites in the favourable as well as in the stressed environments, the hybrids were as stable as the improved composites across these diverse environments, and that the local variety showed low yield potentials in both environments.

RÉSUMÉ

OBENG-ANTWI, K., SALLAH, P. Y. K. & FRIMPONG-MANSO, P. P.: *Performance des variétés de maïs de la maturité intermédiaire dans les environnements de tension de sécheresse et de non-tension au Ghana.* La tension de sécheresse est une contrainte majeure de la production de maïs (*Zea mays* L.) dans les tropiques de la plaine. Une étude se déroulait pour déterminer le potentiel de rendement et la stabilité de cinq hybrides de maïs, trois composées améliorées et une variété de maïs local dans les environnements favorables et tendus de sécheresse pour la production de maïs au Ghana. Les neuf génotypes étaient évalués à 20 sites au total dans les zones agro-écologiques majeures du Ghana de 1995 à 1997. Les 20 sites étaient divisés en deux environnements (tension et non-tension) de 10 sites chacun, basé sur les données de pluie pendant la période de pousse. Les effets dû au génotype (G), emplacement (E), et l'interaction G × E étaient hautement considérables (P< 0.01) pour mi-soies, taille de plante, acceptabilité d'épi, la verse et le rendement de grain dans les environnements de tension et de non-tension. Les rendements de grain étaient 3.58 Mg ha^{-1} de moyenne dans l'environnement de tension et 6.67 Mg ha^{-1} dans l'environnement de non-tension. En moyenne, les hybrides surrendaient les composées améliorées par 17.3 pour cent et la variété locale par 50.7 pour cent dans l'environnement de tension. Dans l'environnement de non-tension, les hybrides avaient un avantage de rendement total de 11.6 et 60.2 pour cent respectivement sur les composées améliorées et la variété locale. Les estimations des paramètres de stabilité d'Eberhart et Russel à travers les deux environnements pour le rendement de grain étaient b = 1.07, s^2 = 0.006 pour les hybrides; b = 1.00, s^2 = 0.006 pour les composées améliorées; et b = 0.61, s^2 = 0.008 pour la variété locale. La conclusion était tirée de l'étude que: les hybrides étaient plus productifs que les composées améliorées dans l'environnement favorable ainsi que dans celui de tension; les hybrides étaient aussi stables que les composées améliorées à travers ces

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environnements divers, et la variété locale montrait des faibles potentiels de rendement dans les deux environnements.

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Introduction

Maize is the most important cereal in terms of total production and use in Ghana. The crop is produced in all the five agro-ecologies, namely, the coastal savanna, forest, forest-savanna transition, Guinea, and Sudan savannas. These production zones collectively fall under the lowland tropic mega-environment (Vasal & McLean, 1994), which is characterized by significant climatic variations with frequent periods of drought stress, resulting in crop losses (Santos *et al.*, 1997).

Drought effects have not been well quantified (San Vicente *et al.*, 1997; White & Elings, 1997), but they are believed to be a limiting factor in most maize-producing areas of the lowland tropics. It is estimated that 95 per cent of the maize area in the tropics suffers from erratic rainfall distribution (Hallauer & Miranda, 1988), and 80 per cent of the maize in the lowland is affected by drought annually (Edmeades *et al.*, 1989). Wolf *et al.* (1974) attributed much of the low productivity of maize throughout the tropics to periodic drought stress, which is caused by irregular rainfall distribution; and estimated an average loss of 15 per cent of production in tropical areas, even when total rainfall is reasonably high.

Drought stress is a major factor that limits maize productivity in Ghana (Mercer-Quarshie *et al.*, 1993; Ohemeng-Dapaah, 1994; SARI, 1995; Kasei, Mercer-Quarshie & Sallah, 1995). For example, in 1982, drought stress occurred throughout Ghana and accounted for a 30 per cent reduction in maize production (GGDP, 1983). Farmers have often cited drought as one of the important constraints to high maize productivity in the Guinea, Sudan, and coastal savanna zones in the main growing season, and in the coastal savanna, forest, and transition zones in the minor season.

Small-scale farmers can reduce the adverse effects of drought on maize by avoiding periods of low moisture availability and growing improved varieties which can withstand low moisture stress. Therefore, plant breeding programmes have focused on breeding high-yielding genotypes with a range of maturities to fit the growing season as determined by moisture availability. This has been done through multi-locational field evaluations to select genotypes that are tolerant to the major stresses that prevail in the target area. It is expected that the varieties will be exposed to random stress in the life cycle of the crop, and at different intensities at one or more locations during the testing process to enable selection for tolerance to the stresses.

The Ghana Maize Improvement Programme evaluates potentially new varieties at 10 research locations in the various ecological zones of the country. Superior varieties selected across the different locations are again evaluated on-farm at 10 to 20 sites in each ecological zone for at least 2 years before the best varieties are released for commercial production. Through these strategies, several high and stable-yielding varieties that are tolerant to the major stresses in the maize-growing zones of the country were developed and released to meet the needs of growers throughout the country (Badu-Apraku *et al.*, 1992; Twumasi-Afriyie *et al.*, 1997; Sallah *et al.*, 1997). Sallah, Obeng-Antwi & Ewool (2002) studied the performance of early maize composites in drought-stressed and favourable conditions in Ghana and concluded that the productivity of the varieties was enhanced in both environments through selection in alternating favourable and stressed environments.

This study was conducted to assess the productivity and yield stability of intermediate maturing maize varieties under the favourable and drought-stressed conditions prevailing in the major agro-ecological zones of Ghana.

Materials and methods

Five quality protein maize (QPM) three-way hybrids, one QPM composite, and three normal maize composites were evaluated in drought-stressed and non-stressed environments in Ghana. Table 1 shows the characteristics of the varieties studied.

seedling establishment. A randomized complete block design with four replications per location was used at each site. A plot consisted of four 5-m rows of each variety, with rows spaced at 0.75 m and hills at 0.45 m. Hills were over planted and thinned to a uniform stand of two plants per hill for a target density of 60,000 plants ha^{-1}.

A combination of Pendimethalin [N-(1-ethylpropyl)-3, -4-dimethyl-2, 6-dinitrobenzenamine] and Gesaprim [2-chloro-4-(ethylamino)-

TABLE 1

Characteristics of Nine Maize Varieties Evaluated Under Drought-stressed and Non-stressed Environments in Ghana, 1995-1997

Name of variety	*Source*	*Type*	*Endosperm type+*
GH110-5	(Ent. 6 × Ent. 70) × Ent. 5	3-way hybrid	QPM
GH132-28	(Ent. 27 × Ent. 24) × P28	3-way hybrid	QPM
GH110-28	(Ent. 6 × Ent. 70) × P28	3-way hybrid	QPM
GH2823-88	(P28 × P23) × Ent. 88	3-way hybrid	QPM
GH2823-140T	(P28 × P23) × Ent. 140T	3-way hybrid	QPM
Obatanpa	8363-SR	Open-pollinated	QPM
Abeleehi	Pop 49-SR	Open-pollinated	Normal maize
EV EJ 105-DWD Pop	GH105-DWDP	Open-pollinated	Normal maize
Local variety	Landrace (farmer's)	Open-pollinated	Normal maize

+QPM = Quality protein maize

The maize varieties were evaluated at Fumesua and Kwadaso (forest zone; coarse sandy-loam, Paleustult), Ejura and Kpeve (transition zone; fine-coarse sandy-loam, Oxisol), Ohawu and Pokuase (coastal savanna zone; fine sandy-loam, Dystrochrept), Damongo, Nyankpala and Wa (Guinea savanna zone; fine sandy-loam, Alfisol), and Manga (Sudan savanna zone; fine sandy-loam, Alfisol), from 1995 to 1997.

Planting was on the flat under zero-tillage in the forest, coastal savanna, and transition zones. In zero-tilled fields, Glyphosate [N-(phosphonomethyl) glycine] (Roundup) was applied at 1.5 kg a.i. ha^{-1} 2 weeks before planting. In the interior savanna zones, the fields were ploughed and harrowed before planting either on ridges or on the flat, followed by ridging after

6-(isopropyl amino)-s-triazine] was applied at planting as pre-emergence herbicide at 1.5 and 1.0 kg a.i. ha^{-1}, respectively. Fertilizer was applied by spot-application of 45 kg N ha^{-1} and 45 kg P_2O_5 ha^{-1} at 10-15 days after planting at all sites. In addition, N was side-dressed at 45 kg N ha^{-1} at 3-4 weeks after planting with urea or ammonium sulphate. Hand weeding or chemical hoeing with Paraquat at 1.0 kg a.i. ha^{-1} or a combination of the two was done when necessary to keep plots free of weeds.

Data were recorded from the two central rows of the plot of each variety on days to mid-silk, plant height, number of ears per plant, total lodging, ear acceptability, and grain yield. Grain yield was expressed in Mg ha^{-1} adjusted at 15 per cent moisture. Ear acceptability was rated on a 5-

point scale, with 1 signifying very good ears and 5 denoting very poor ears. Rainfall data were also recorded during the growing season in the year at each site, and these were used to group the sites into a stressed set (stressed environment) and a non-stressed (favourable) set (non-stressed environment) of 10 locations each (Sallah *et al.*, 2002). The data were analysed by location and combined over locations within each environment, assuming the mixed model (Steel & Torrie, 1980). Locations were assumed random and entries fixed. Correlations between grain yields in the stressed and non-stressed environments and between yield and the other traits were calculated.

Stability analysis of grain yield was done with Eberhart & Russell's (1966) stability parameters b_i and s^2, where b_i is the regression coefficient of the i[th] variety on the environmental index measured as the mean yield of all varieties in that environment minus the mean of all environments, and s^2 is the deviation from regression of the i^{th} variety minus the average variance of a variety mean at the j^{th} location.

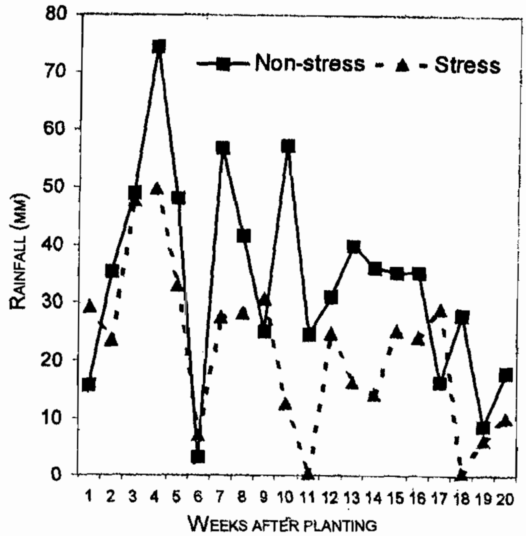

Fig. 1. Mean weekly rainfall during the growing season in the stressed and non-stressed environments used for the evaluation of the nine maize varieties in Ghana, 1995-1997.

Results and discussion

Fig. 1 shows mean weekly rainfall during the growing season for the two environments, calculated as averages of weekly rainfall from the week of sowing to harvest at the 10 sites. Trials in the stressed environment received a total of 442 mm rainfall whilst the non-stressed environment received 680 mm during the growing season (Fig. 1). The rainfall distribution patterns were different, favouring maize growth, development, and productivity in the non-stressed than in the stressed environment. For example, the stressed environment received 128 mm rain compared to 256 mm for the non-stressed environment from the 8th week to the 14th week after sowing (Fig. 1). Three important growth phases of the crop (flowering, pollination and grain filling) were observed during this period when the stressed environment received 50 per cent less rainfall than the non-stressed environment.

The combined-over-location analyses of variance for the traits measured are presented in Table 2 for the stressed environment and in Table 3 for the non-stressed environment. The location effects were highly significant (P<0.01) for all traits in the stressed (Table 2) and non-stressed (Table 3) environments. The effects due to varieties were also highly significant for mid-silk, plant height, ears per plant, total lodging, ear acceptability rating, and grain yield in the two environments. The interactions between varieties and locations for all the traits in the two environments were highly significant (P<0.01). This shows that the varieties varied in their responses across the sites within each environment. Thus, locations within each of the two environments were different. These differences probably arose from variations in soil characteristics at the sites.

Number of days to mid-silk, an indicator of the maturity period of the varieties, ranged 54-58 days for the stressed environment and 51-56 days for the non-stressed environment (Table 4). GH2823-88 was the earliest variety under stress while EV EJ 105-DWD Pop was the earliest variety under non-stressed conditions (Table 4). In both

TABLE 2

Mean Squares from the Combined Analysis of Variance for Six Traits in Nine Maize Varieties Measured in the Stressed Environment in Ghana, 1995-1997

Source	df	Mid-silk	Plant height	Lodging	Ears plant⁻¹	Ear acceptability	Grain yield
Location	9	310.1**	25013**	9976**	0.175**	3.414**	12761808**
Error (a)	30	4.4	334	153	0.008	0.313	1806794
Varieties	8	76.2**	4774**	618**	0.037**	1.898**	11810031**
Location × varieties	72	12.3**	672**	161*	0.010**	0.513**	1153731**
Error (b)	240	1.9	247	64	0.007	0.255	617765
Total	359						

*, **, Significant at 5 and 1% levels of probability, respectively

TABLE 3

Mean Squares from the Combined Analysis of Variance for Six Traits in Nine Maize Varieties Measured in the Non-stressed Environment in Ghana, 1995-1997

Source	df	Mid-silk	Plant height	Lodging	Ears plant⁻¹	Ear acceptability	Grain yield
Location	9	228**	15542**	4554**	0.014**	1.430**	20463199**
Error (a)	30	1.3	204	135	0.001	0.306	1009868
Varieties	8	100**	11687**	169**	0.005**	2.734**	40220128**
Location × varieties	72	9.2**	48(**	111**	0.007**	0.609**	1891657**
Error (b)	240	1.5	167	51	0.002	0.319	698230
Total	359						

*, **, Significant at 5 and 1% levels of probability, respectively

environments, the local variety was the latest to flower. The varieties flowered 2-3 days later in the stressed environment compared to the non-stressed environment. A similar delay in days to mid-silk was reported by Subramanyam (1992) who observed delays of up to 9 days under stress in India. Silk delay has been attributed to inadequate flow of carbohydrates to the developing ears compared to the male inflorescence under drought stress (Schussler & Westgate, 1995).

Drought stress reduced heights of maize plants in the stressed environment compared with the non-stressed environment (Table 4). On the average, the plants were 17 per cent shorter under stressed than under non-stressed conditions. In both environments, the local variety was the tallest while Abeleẹhi, an open-pollinated commercial variety, was the shortest. However, GH110-5 was the variety that lodged most, followed by the local variety (Table 4). Lodging was 6 per cent higher in the drought-stressed than in the non-stressed environments, and this may be attributed to dehydration of the stem in the stressed environment (Edmeades, Bolanos & Chapman, 1997).

Differences among the varieties for number of ears per plant were small, but highly significant in the stressed and non-stressed environments (Tables 2-4). Ear acceptability ratings also differed significantly among the varieties in the stressed

TABLE 4

Means of Characters of Intermediate Maturing Maize Varieties Evaluated in Stressed and Non-stressed Environments in 1995-1997

Variety	Mid-silk		Plant height		Total lodging		Ears plant[1]		Ear acceptability	
	Stress	Non-stress	Stress	Non-stress	Stress	Non-stress	Stress	Non-stress	Stress	Non-stress
	----- days -----		----- cm -----		----- no. -----		------ no. ------		----- score[+] -----	
GH132-28	57	55	162	199	21.0	18.0	1.02	1.02	2.5	1.9
GH110-5	55	52	154	176	30.7	19.5	1.00	1.00	2.8	2.1
GH110-28	56	54	159	183	21.5	18.0	1.04	1.04	2.2	2.1
GH2328-88	54	52	164	191	19.7	15.4	1.00	1.00	2.6	2.5
Obatanpa	56	53	174	201	24.4	15.9	0.99	0.99	2.6	2.7
GH2823-140T	57	54	167	196	19.3	14.2	0.98	0.98	2.4	2.2
EV EJ105-DWDP	54	51	160	174	22.6	16.5	1.02	1.02	2.5	2.6
Abeleehi	56	53	145	167	19.9	16.8	0.98	0.98	2.5	2.4
Local variety	58	56	182	223	27.6	20.7	1.00	1.00	3.4	3.0
Mean	56	53	163	190	23.0	17.2	1.00	1.00	2.6	2.4
CV (%)	2.5	2.3	9.7	6.8	34.8	41.4	4.3	4.3	19.3	23.8
LSD (0.05)	0.4	0.4	4.9	4.0	2.5	2.2	0.02	0.02	0.3	0.2

[+]Ears rated for acceptability on 1-5 scale; 1, denoting very good ear; and 5, denoting very poor ear.

and non-stressed environments (Tables 2-4). GH132-28 was the least rated, and hence had the most acceptable ears under non-stressed conditions, while GH110-28 had the most acceptable ears under stress. The local variety produced ears that were less acceptable than the other varieties under both conditions.

Fig. 2 shows mean grain yields of the varieties in the stressed and non-stressed environments. Grain yields were more variable in the stressed environment (CV=22.0 %) than in the non-stressed environment (CV=12.5 %), averaging 3.58 Mg ha^{-1} in the stressed and 6.67 Mg ha^{-1} in the non-stressed environments. Yields, on the average, were 47 per cent lower in the stressed environment compared to the non-stressed environment (Fig. 2). The hybrids yielded 17.3 per cent higher than the improved composites, and 50.7 per cent higher than the local variety in the stressed environment.

The yield superiority of the hybrids over

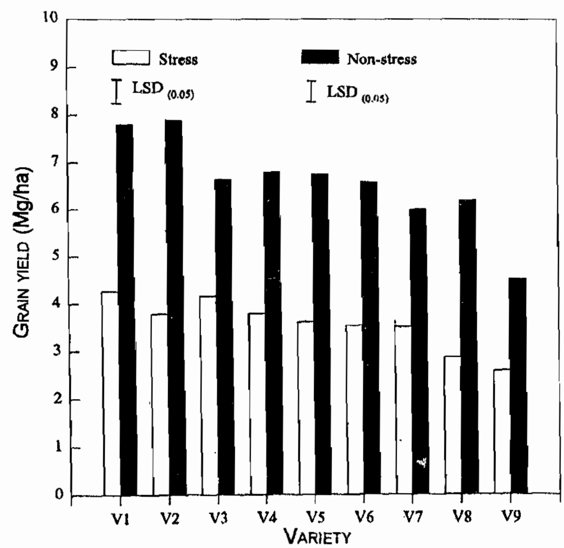

Fig. 2. Mean grain yield of nine maize varieties evaluated in the stressed and non-stressed environments in Ghana, 1995-1997. The varieties were designated as follows: VI=GH132-28, V2=GH110-5, V3=GH110-28, V4=GH2328-88, V5=Obatanpa, V6=GH2823-140T, V7=EV EJ105-DWDP, V8=Abeleehi, V9=Local variety.

the open-pollinated composites and the local variety was again manifested in the favourable environment. In this environment, the hybrids yielded 11.6 and 60.2 per cent higher than the composites and the local variety, respectively (Fig. 2). These results support Vasal *et al.* (1997) who reported that hybrids maintain their yield advantage over open-pollinated (composite) varieties in favourable and stressed environments. The yield reductions observed in the stressed environment were attributed to the moisture stress that was observed during the reproductive stages of the varieties. Similar yield reductions in maize under stress during flowering have been reported by various researchers (Robins & Domingo, 1953; Fischer, Johnson & Edmeades, 1983; Grant *et al.*, 1989; Edmeades *et al.*, 1997; Westgate, 1997; Sallah *et al.*, 2002).

Table 5 shows phenotypic correlation coefficients between grain yield and five other parameters in the stressed and non-stressed environments. Plant height and number of ears per plant were positively correlated with grain yield in both environments, but were only significant under stress. Edmeades *et al.* (1997) and Vasal *et al.* (1997) reported similar positive associations of grain yield with ears per plant. Days to mid-silk and ear acceptability ratings showed highly (P<0.01) negative association with grain yield under stressed and non-stressed conditions. The relationship between grain yield and total lodging was not significant in both environments. There was a strong, positive association of grain yield in the stressed and non-stressed environments. This meant that varieties that had high yields under non-stressed conditions maintained their supremacy under stressed conditions.

TABLE 5
Correlation Between Grain Yield and Other Traits in Nine Intermediate Maturing Maize Varieties Evaluated in Stressed and Non-Stressed Environments in Ghana, 1995-1997

Trait	*Correlation coefficient*	
	Stress	*Non-stress*
Mid-silk (days)	-0.377**	-0.285**
Plant height (cm)	0.301**	0.048
Ears per plant (no.)	0.778*	0.228
Total lodging (%)	-0.013	0.049
Ear accept rating (score)$^+$	-0.674*	-0.805**
Grain yield (Mg/ha) (stress)$^{++}$	-	0.813**

$^+$Rated on 1-5 scale; 1, denoting very good ear; and 5, denoting very poor ear
*,**, Significant at 5 and 1% levels of probability, respectively
$^{++}$ Correlation between yields in the stressed and non-stressed environments

A newly developed cultivar should, desirably, show stable performance over a range of environments (Saeed *et al.*, 1967). The significant genotype × environment interaction observed in this study offers an opportunity for assessing genotypes for stability of performance across the different environments. Regression analysis of genotype response to an environmental index is often used by plant breeders to estimate stability of performance across varying environments (Sallah *et al.*, 2002). The regression coefficient or slope indicates the response of a genotype to differences among environments, while deviations from regression describe the unpredicted variation in response to environmental variation. A stable genotype is one that has unit regression coefficient (b_1=1.0) and a very small deviation from regression (s^2=0) (Eberhart & Russell, 1966). Stable genotypes are expected to give high yields under normal conditions and under stress.

Estimated stability parameters (Eberhart & Russell, 1966) for grain yield (Mg ha^{-1}) across the 20 sites averaged b=1.07 and s^2 = 0.006 for the hybrids, b=1.00 and s^2=0.006 for the improved composites, and b=0.61 and s^2=0.008 for the local variety (Table 6). The b and s^2 values for the hybrids and improved composites were not significantly different from unity and zero, respectively. The b value for the local variety, however, was significantly different from unity. These results showed that all the hybrids and improved composite varieties tested were stable

TABLE 6

Eberhart and Russell's Stability Parameters for Grain Yield for Nine Maize Varieties Evaluated Across 20 Sites in Ghana, 1995-1997

Variety	*b*	R^2	s^2
GH110-5	1.32 ± 0.085	0.97	0.008
GH132-28	1.19 ± 0.085	0.91	0.008
GH110-28	0.86 ± 0.073	0.94	0.005
GH2328-88	1.00 ± 0.068	0.96	0.004
GH2823-140T	0.99 ± 0.058	0.97	0.005
Obatanpa	1.08 ± 0.057	0.98	0.004
Abeleehi	1.09 ± 0.060	0.97	0.005
EV EJ 105-DWD Pop	0.84 ± 0.081	0.93	0.009
Local variety	0.61 ± 0.095	0.83	0.008

in performance across the 20 locations used for the study. In other words, the hybrids and improved composites performed well in both environments. The local variety was the least stable among the varieties used because it had a *b* value which was significantly different from 1, and also had consistently low yields across the environments.

From the data presented, the study concluded that: (1) The hybrids were more productive than the improved composites and the local variety in the stressed as well as in the non-stressed environments. (2) The hybrids were as stable as the improved composites across the diverse environments in which they were tested. (3) The local variety was the least stable among the varieties, showing low yield potential in both environments.

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