Research Application Summary

Genetic analysis of tropical maize inbreds and hybrids for grain yield and traits associated with drought tolerance

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Abstract

Drought tolerance is a complex trait, hence genetic improvement of this trait in maize requires indirect selection methods based on highly heritable traits that correlate strongly with grain yield. This study aimed at determining the modes of gene action for grain yield and stress related traits under well watered and water stressed environments. Fifteen inbred lines were crossed using the NCII Design (L10 x T5). The resultant 50 hybrids, 4 checks and the parental lines were evaluated under optimum and managed drought stress environments using a 0,1 alpha lattice design. The study showed significant GCA and SCA effects for grain yield and its secondary traits suggesting existence of both additive and non additive gene effects for the traits under review. GCA and heritability across environments for GY, ASI, EPP and SEN under drought were higher than in well watered environments. Correlations of secondary traits ASI, EPP and SEN with GY were stronger under drought than under optimum conditions. SCA and STI had better predictive value for F1 grain yield performance under drought. L2 and L7 can be released as CML lines and the AMMI stability analysis confirmed L2 x T2 hybrid can be used a new single cross tester for heterotic group A. Overall, selection in both stress and non-stress gives a better picture of the best performing hybrids across environments.

Key words: Abiotic stress, combining ability, genetic variance, heritability, heterosis

Résumé

La tolérance à la sécheresse est un caractère complexe, d’où l’amélioration génétique de ce caractère dans le maïs exige des méthodes de sélection indirectes basées sur des caractères très héréditaires qui se corrèlent fortement avec le rendement en grain. Cette étude visait à déterminer les modes d’action des gènes pour le rendement en grain et les traits liés au stress dans les environnements bien arrosés et ceux hydriquement stressés. Quinze lignées innées ont été croisées avec le procédé NCII (L10 x T5). Les 50 hybrides résultants, 4 contrôles et les lignées parentales ont été évalués et gérés dans les meilleurs environnements, aménagés contre le stress dû à la sécheresse en utilisant une conception de treillis alpha de 0,1. L'étude a montré d'importants effets de GCA et SCA pour le rendement en grain et ses traits secondaires suggérant l'existence à la fois des effets génétiques additifs et non additifs pour les caractères étudiés. Le GCA et l'héritabilité au sein des environnements pour GY, ASI, EPP et SEN dans les conditions de sécheresse ont été plus élevés que dans les milieux bien arrosés. Les corrélations de traits secondaires ASI, PPE et SEN avec GY étaient plus fortes en cas de sécheresse que dans des conditions optimales. SCA et IST avaient une meilleure valeur prédictive de la performance du rendement en grains de F1 en cas de sécheresse. L2 et L7 peuvent être libérés sous forme de lignées de CML et l'analyse de la stabilité d'AMMI a confirmé que l'hybride L2 x T2 peut être utilisé comme un nouveau testeur de croix unique pour le groupe hétérotique A. En général, la sélection à la fois du stress et du non-stress donne une meilleure image des hybrides plus performants dans les environnements.

Mots clés: Stress abiotiques, capacité de combinaison, variance génétique, héritabilité, hétérosis

Background

Maize yield losses in the tropics range from an average of 17% up to 80% depending on the severity and timing of the drought (Chapman *et al*., 1999; Araus *et al*., 2008). Sub-Saharan Africa is the most severely affected region where almost half of the land surface is exposed to a high risk of meteorological drought (FAO,2010). The drought effects are mainly pronounced among the low income peasant and subsistence farmers who are found in the marginal environments and cannot afford supplementary irrigation (Tuberosa *et al*., 2005). The unpredictability of the weather patterns implies that improved crop genotypes should perform well not only under water-limited conditions but also when rainfall is adequate. Understanding the use of plant genetics to improve biotic and abiotic stress tolerance such a drought is therefore important for stabilising maize production. The understanding of gene action in maize under stress and non stress environments helps in selecting the most efficient breeding method for introgression or accumulation of desired traits in lines to improve their performance.

Literature Summary

Grain yield is a complex trait whose breeding value or heritability is known to decrease with increased stress intensity hence the need to use secondary traits in selection under stress environments. These secondary traits which act as proxies to grain yield and have higher additive genetic variance than non additive variance and are easy to measure will therefore be ideal in selecting genotypes that perform better under stress environments. Traits such has leaf senescence, anthesis-silking interval, and plant height have been traditionally used as secondary traits for grain yield (Cooper *et al*., 2006). Indirect selection of drought tolerance in maize has been successfully done using highly heritable traits that correlate with drought tolerance such as anthesis-silking interval, ears per plant and senescence rate (Derera *et al*., 2008). The significance of delayed senescence or stay green characteristics were highlighted by Lee and Tollenaar (2007) and Zheng *et al*. (2009) who reported that the yield differences between old and new drought tolerant hybrids were mainly attributed to delayed senescence, which is a measure of the functional stay green characteristics. Zheng *et al*. (2009) also observed a positive correlation of grain yield with the functional stay green trait suggesting that senescence can be an indirect measure for drought tolerance.

Study Description

Fifteen CIMMYT inbred lines comprising on 5 testers (males) and 10 lines (females) were used in a line x tester NCII crossing (Table 1). The inbred lines used as males are known CML lines while the female lines are newly formed or candidate lines for CML line status.

Table 1. Inbred lines and selection criteria used in the testcross development.

Name	Pedigrees	Heterotic Group		Selection Criteria
T1	CML312-B	A		MSV and Drought
T2	CML442-B	A		MSV and Drought
T3	CML537	A		MSV and Drought
T4	CML538	A		MSV and Drought
T5	CKL05005	B		MSV
L1	[CML445/ZM621B]-2-1-2-3-1-B*8	B		MSV and Drought
L2	[CML312/[TUXPSEQ]C1F2/P49-SR]F2-45-3-2-1-	A		MSV and Drought
L3	[MSRXPOOL9]C1F2-205-1(OSU23i)-5-3-X-X-1-	A		Drought
L4	[TS6C1F238-1-3-3-1-2-#-BB/[EV7992#/EV8449-SR]C1F2-	A		MSV and Drought
L5	P501SRc0-F2-47-3-1-1-BB	A		MSV and Drought
L6	ZM521B-66-4-1-1-B*5	B		MSV and Drought
L7	[SYN-USAB2/SYN-ELIB2]-12-1-1-1-B*5	B		MSV
L8	[SYN-USAB2/SYN-ELIB2]-35-2-3-1-B*4	B		MSV
L9	Z97SYNGLS(B)-F2-188-2-1-3-B*4	B		MSV and Drought
L10	MAS[206/312]-23-2-1-3-B*5	A		MSV and Drought

This resulted in the crossing program giving a total of 50 single crosses (testcrosses). The standard CIMMYT heterotic classifications of A and B designation were used in the general line classification. All the trials under study were conducted in Zimbabwe. A total of six optimum and four drought field experiments were done. Five sites were used and these include Harare ART Farm (31.5^{0}E, 17.43^{0}S), Rattary Arnold (31.3^0 E, 17.35^0 S), Kadoma (30.9^{0}E, 18.32^{0}S), Chiredzi (31.58^{0}E, 21.02^{0}S) and Chisumbanje (33.0^{0}E, 20.0^{0}S) and CIMMYT Harare (17.48S, 31.04 E). The Chiredzi and Chisumbanje sites hosted both optimum and managed drought trials. The managed drought trials were done during the off season (dry winter) under irrigation. Irrigation water was withdrawn 4 weeks before and after flowering for stress environments to coincide with peak pollination and early grain filling. The testcross evaluation was done using the alpha (0,1) lattice design. Trials were replicated twice, with each entry being planted in one row plots 4 m long, while a 75 cm between rows x 25 cm between plants within rows was used. Two seeds per station were planted and later thinned to give a plant population of 53000 plants/ha. A separate parental inbred line trial was also planted in the same environment as the testcrosses at each site. In all the trials raw data for flowering dates (at 50% anthesis and 50% silking), plant and ear height, plant standability, leaf senescence, disease and normalised difference vegetative index scores and grain weight were recorded. Some derived traits such anthesis-silking interval (ASI), lodging percentage, ear per plant (EPP) and yield per hectare (at 12.5% moisture adjustment) were also calculated according to the CIMMYT guidelines.

The relative importance of general and specific combining ability on progeny performance was estimated using the Baker's ratio.

$2\delta^2 gca/ (2\ \delta^2 gca + \delta^2 sca)$……………………… (Baker, 1978)

Trait breeding value (narrow sense heritability), mid parent heterosis and drought indices were also calculatedAMMI analysis was computed using the same mean values to assess relations between hybrids and environments. This was done because hybrids and environments that are close together tend to be similar (Vargas and Crossa, 2000).

Research Application

There was a significant and positive correlation ($P<0.05$) between additive genetic variance (GCA) and grain yield of inbred lines under drought conditions as shown by the correlation of (r = 0.541*). GCA of PH had a positive correlation (r = 0.822**) for both stress and well-watered environments. Most inbred lines contributed to a *per se* decrease in PH as shown by the GCA values which were mostly negative in both environments. Under drought conditions significant negative GCA values SEN, ASI while AD and significant positive GCA value for GY and EPP. Both per plot and across environment heritability values for this trait were higher under stress than under optimum conditions. The Baker's ratios show that there was a consistent increase in the additive variance contribution for GY, AD, EPP and SEN from optimum to drought stress environments.

The coefficients of additive genetic variability which estimate heritability (h^2) were higher for ASI, EPP and SEN under drought compared to optimum environments, while for GY, AD and PH heritability reduced under drought. There was a general decline in heritability from per plot values to across environment values in all traits except for ASI, EPP and SEN under drought. Additive genetic variance of the traits increased from the optimum to the drought environments for ASI, EPP and SEN while GY and PH values were higher under well watered environments. Grain yield under drought was positive and significantly (P<0.01) correlated to SCA and (P<0.05) to PH, EPP while negatively correlated to ASI (r = -0.38*) and SEN (r = -0.63**). ASI was positively correlated to SEN (r=0.29*) under drought. Under drought, parental lines L2 and T1 had positive effects on GY performance of the resultant testcross hybrids as they contributed 3 of the best 5 best yielding testcross hybrids (Fig. 1).

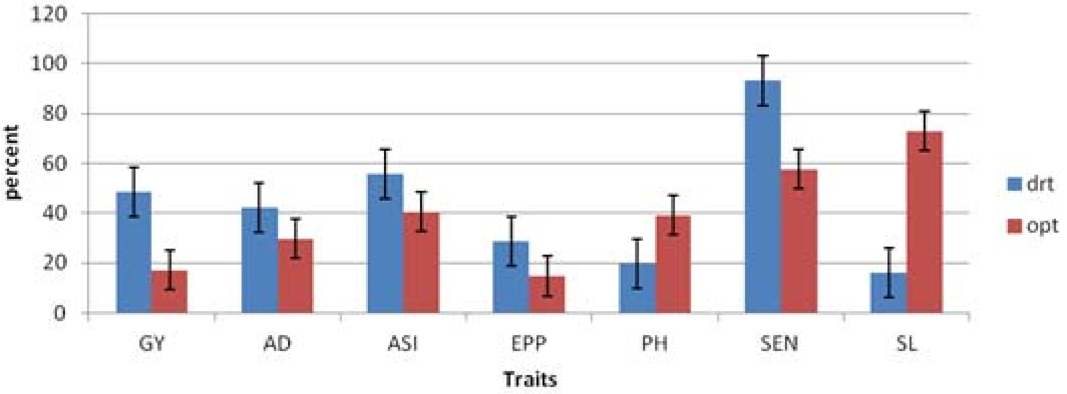

Figure 1. Summary of trait additive genetic variance across the environments.

The two interaction components IPCA1 and IPCA2 were significant (P<0.01) and explained (68.9 %) of the interaction. The underlying causes of the interactions observed can be due to both genetic differences among genotypes and the different environments. The magnitude of GEI sum of squares was 5.6 times more than that of genotypes indicating that there were distinct differences in genotypic response across environments. However under parental inbred lines, sum of squares attributable to genotypic effects (26.4%) were greater than the environmental effects (15.2%) with GEI contributing 58.4%. Grain yield GCAm, GCAf and SCA significant effects indicate that both additive and non additive effects were important under both optimum and managed drought conditions. This implies that parental selection and combination for drought or optimum environment yield performance can exploit both non additive and additive gene affects. The significance of SCA x environment interaction for GY, under both environments implies that testcross hybrids responded differently to drought and optimum conditions. The Baker's ratio for GY was significantly higher under drought implying that additive gene action was predominant for this trait under drought. This finding is also confirmed by the GCA: SCA variance ratio which was greater than 1 with similar findings having been reported by Araus *et al* 2008 and Derera *et al*. (2008) working on southern Africa region maize germplasm.

ASI heritability was higher under drought conditions implying that additive gene action contribution for the trait was higher under drought. Similar to findings have been reported by Campos *et al.* (2004) and Tuberosa *et al* 2006. Across environments ASI heritability was higher than per plot implying that higher precision of measuring this trait is obtained with an across site assessment. This implies that ASI can be used reliably as a proxy to yield under drought as its heritability increases with stress intensity hence selection and higher breeding progress can be realised. Leaf senescence GCAm and GCAf significances under drought indicate that parental choice is important in determining functional stay green traits in genotypes under drought conditions since this trait is mainly controlled by additive gene effects. The Baker's ratio also shows that additive genes had the greatest contribution to the phenotypic variance of hybrids for this trait under stress conditions. However the significance of EPP at (P<0.05) for SCA x environment in both environment is an indication that additive and non additive (dominance and epistatic effects) contribute to genotype prolificacy. Increase in additive genetic variance for ASI, EPP and SEN with increase in stress intensity implies that breeding progress can be made when selecting for these traits under drought to produce genotypes that are drought tolerant.

Conclusion

Additive effects are more important under drought conditions as shown by the consistent increase of additive variance contribution for ASI, EPP and SEN from optimum to drought stress environments. Under drought ASI, EPP and SEN had higher across environment than per plot heritability estimates and the converse was true for all traits under optimum conditions. This further confirms that the three traits can be reliably used for selection of genotypes under stress conditions since good breeding progress can be achieved. Reduced or negative ASI values or protogynous hybrids are desirable under drought stress. Under drought stress GY negative association with ASI and SEN is desirable for selection purposes.

Genetic correlation for grain yield with proxy traits decreases from optimal to drought environments. GCA effects of parents are a measure of breeding value since significant GCA estimates increase the trait value in the hybrid hence can be used for selection especially under drought stress conditions making it possible to use inbred line information to predict hybrid performance under drought stress.

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