Evaluation of maize genotypes using parametric and non-parametric stability estimates

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Summary

High and stable yield is very desirable in maize (*Zea mays* L.) genotypes. Stable yield of a genotype means that its rank relative to other genotypes remains unchanged in a given set of environments. Grain yield of 10 maize genotypes was tested in a randomised block design with four replications across 15 environments (five locations in three years) in Ethiopia. The combined analysis of variance for environment (E), genotypes (G) and GE interaction was highly significant, suggesting differential responses of the genotypes and the need for stability analysis. The parametric stability measure of Wricke's ecovalence (Wi) and the regression coefficient (bi) showed that BH-660 was the most stable genotype. Nassar and Huehn's non-parametric measures S(1) and S(2), were significantly and positively correlated with Eberhart and Russell's Sdi^2 and Wi. The stability measures are useful in characterising cultivars by showing their relative performance in various environments. Results revealed that high-yielding cultivars can also be stable cultivars. The stability statistics generally identified BH-660, L2 and Gibe-1 as the most stable genotypes, whereas Kulani and BH-140 were the least stable.

Keywords: GE interaction, stability parameters, *Zea mays*

Introduction

The agronomic concept of cultivar stability is that performance, in changing environments, should be at a level corresponding to the prediction. This is the dynamic concept of stability (BECKER and LEON 1988), which is equivalent to the Type 2 stability described by LIN *et al.* (1986). Because each plant or cultivar has its inherent and characteristic ability to buffer and respond to fluctuating growing conditions, the differential responses of cultivars to a range of environments leads to genotype-environment (GE) interactions. With GE interaction, effects of cultivars and environments become statistically non-additive, which indicates that differences in yields among cultivars would depend on the environment. Thus, significant GE interaction makes selection using cultivar means across environments less efficient (HOPKINS *et al.* 1995).

Because GE interaction is a general and widespread phenomenon for all field crops, stability estimates from different models using GE data have been developed to characterize genotypes and to provide indices for selection in addition to cultivar means. Among the parametric models, WRICKE's (1962) ecovalence (Wi) and EBERHART and RUSSELL's (1966) Sdi^2 and bi have been adopted by many researchers to identify superior crop cultivars. However, parametric models require assumptions such as normality, homogeneity of variance, and additivity or linearity of genotype and environmental effects. Non-parametric models, which use rank interactions, are distribution free and require no such assumptions (NASSAR and HUEHN 1987, HUEHN 1990). Non-parametric models offer a modified

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concept of interaction as the rank interaction, where interaction is used only in environments that are of importance and significance in breeding programmes. Thus, stability estimates from non-parametric models provide useful alternatives to parametric models.

HUEHN (1990) further indicated that knowledge of relations between different statistical measures of phenotypic stability (parametric and non-parametric), consistency of relationships among stability parameters, and repeatability of stability parameters are essential for an efficient use of stability estimation and in practical applications. The aim of this study was, therefore, to identify stable maize and to compare the different measures of stability.

Materials and methods

Ten maize genotypes, which are in their final screening stage, including the checks (BH660, Kulani and BH140), from Africa and CIMMYT were included in this study. They were three-way crosses, single crosses, top-crosses and open-pollinated varieties (Table 1). Two of the four maize producing mega-environments in Ethiopia were used in this study, namely a mid-altitude and a high altitude sub-humid zone. These locations are believed to represent the major maize growing regions of the country in the intermediate to high land areas, where maize is grown predominantly. They are located in the altitude ranges of 1650 to 2240m above sea level with an annual rainfall of between 850 to 1595 mm. Bako (the main testing center), Jimma and Awassa represent the intermediate altitude regions whereas Alemaya and Adet represent the higher altitude maize growing regions of Ethiopia.

Table 1. Description of the maize genotypes tested for three years across five locations

No	Genotypes	Code	Status	Source	Year of release
1	(A-7032xF-7189) x142-1-e	L1	TWC	East Africa	Experimental
2	(A-7032xF-7215) x144-7-b	L2	TWC	East Africa	Experimental
3	(A-7016xG-7462) x142-1-e	L3	TWC	East Africa	Experimental
4	(A-7032xG-7462) x142-1-e	L4	TWC	East Africa	Experimental
5	(A-7033xF-7215) x144-7-b	L5	TWC	East Africa	2001
6	BH-660		TWC	East Africa	1990s
7	BH-540		SC	East Africa	1990s
8	BH-140		TC	East Africa, CIMMYT	1980s
9	Kulani		OPV	CIMMYT	1990s
10	Gibe-1		OPV	East Africa, Pioneer & CIMMYT	2000

TWC = Three way cross, SC = Single cross, TC = Top-cross hybrid, OPV = Open-pollinated variety

The genotypes were planted in a completely randomised block design at the five different locations. Four replications were planted each year from 1999 to 2001 at each location. The plots consisted of four rows, 5.1m in length. Only the middle two rows were harvested. The spacing between rows was 75cm, while spacing between plants was 30cm. Phosphorus (P) was applied at planting. Nitrogen (N) was applied in two splits; the first half at planting and the remaining half was given 40-45 days after planting. Urea and diammonium phosphate (DAP) were used as source of nitrogen and phosphorus fertilizers respectively. The trial was conducted during the main rainfall season of the country, between May and September. All the trial management practices were based on the recommendation of each location.

The grain yield (t ha^{-1}) was calculated using the average shelling percentage of 80%, adjusted to 12.5% moisture. The collected yield data was analysed with AGROBASE (2000). Analysis of variance was done for the individual trials. Thereafter a combined analysis of variance was performed on the pooled data of the test environments. Parametric measures were performed in accordance with FRANCIS and KANNENBERG's (1978) coefficient of variability (square root of variance divided by mean) for each genotype, SHUKLA's (1972) stability variance and LIN and BINNS' (1988) cultivar superiority measure. The non-parametric approaches were done for the mean of absolute rank difference (S1) and variance of rank (S2), as suggested by NASSAR and HUEHN (1987) and HUEHN (1990). Stability ranks were started from the smallest values or variances to the largest ones. An overall stability rank was estimated from the five stability values. The Spearman coefficient of rank correlation was computed for all possible pair-wise comparisons of the five stability parameters.

Results and discussion

Variation relative to environments, genotypes and their interaction was highly significant (data not shown). Mean yield of the 10 genotypes across five locations and three years showed significant changes in ranks (Table 2). These significant differences and reversal in yield ranks reflect the fluctuations of genotypes in their responses to the different environments of locations and years. The significant GE interaction for grain yield suggests that some genotypes were unstable. The GE interactions significantly reduce correlations between phenotypic and genotypic values (KANG and GORMAN 1989). That means, GE interactions of multi-location trials tend to confound varietal selection and make varietal recommendations difficult. These conditions imply the need for analysing stability of genotypes across environments. PHAM and KANG (1988) also indicated that GE interactions minimize the usefulness of genotype means. It is thus imperative to undertake adaptation and stability analyses in multi-location trials. Furthermore, BAKER (1988) and CROSSA (1990) elaborated that only qualitative or crossover interactions are relevant in agriculture, and appropriate statistical analysis is required to quantify them. To detect the relative stability of genotypes, the analysis of stability is necessary by applying either parametric or non-parametric methods both. Thus, better understanding of the relative contribution of cultivars, environments and their interaction as a source of variation could potentially help breeders to develop cultivars with more stable performance (BASFORD and COOPER 1998).

Table 2. Mean yield (t ha^{-1}) and five stability parameters of 10 maize genotypes tested at 15 environments in Ethiopia, 1999-2001.

No	Geno-types	Mean	R	Cv%	R	Sv	R	Pi	R	S(1)	S(2)	R
1	L1	8.16c	6	18.8	9	1.9601	2	1.494	6	3.048	6.249	3
2	L2	8.96bc	1	16.1	5	2.2111	5	0.454	1	2.305	3.982	1
3	L3	8.72bc	4	12.2	1	3.8105	7	0.763	4	3.752	9.529	7
4	L4	8.78bc	2	15.9	4	2.1954	4	0.554	2	3.352	8.107	6
5	L5	8.73bc	3	18.5	8	4.0721	8	0.649	3	4.038	11.049	9
6	BH-660	8.35c	5	17.6	7	1.5427	1	1.144	5	3.200	6.907	4
7	BH-540	7.46	8	17.3	6	2.5108	6	2.774	8	3.314	7.582	5
8	BH-140	8.08c	7	14.9	2	5.1243	9	2.087	7	3.771	9.662	8
9	Kulani	7.09	9	19.0	10	6.6476	10	4.302	10	4.286	12.782	10
10	Gibe-1	6.95	10	15.2	3	2.0987	3	4.136	9	3.029	6.249	2

Means within columns followed by different letters differ significantly from check entries at $P \geq 0.05$. CV% = Coefficient of variability; Sv = Stability variance; Pi = Cultivar's superiority measure; S(1) = mean absolute difference of ranks; S(2) = variance of ranks

FRANCIS and KANNENBERG's (1978) coefficient of variability (CV) is one of the parametric methods (LIN *et al.* 1986) used to determine the stability of genotypes depending on the mean yield and CV values. According to this method, genotypes with yield above mean and CV below mean are considered more stable than the others (Table 2). Hence, the most stable genotypes were L2, L3, L4 and BH-660. ROZMAN *et al.* (1997) reported similar results in their study of yield stability in long term released maize hybrids. The first three genotypes were three-way crosses, the fourth being one of the standard varieties released by Bako Research Center. Likewise, L5 and L1 were classified as group II, whereas Gibe-1 and BH-140 were classified in group III with their intermediate stability, unlike the remaining two (Kulani and BH-540) genotypes, which were clustered in the fourth group and thus were judged as unstable. In general, this method can be useful to select varieties above certain yield and variance levels, and thus required in reducing the risks of falling below certain yield limits.

The computed SHUKLA (1972) stability variance, mean yield and the ranks of genotypes in the line with these values are given in Table 2. According to this stability parameter, entries with minimum stability variance are considered more stable. Hence, BH-660, L1 and Gibe-1 were the most stable genotypes, whereas Kulani, BH-140 and L5 were classified as the least stable ones. BH-660 was judged as the most stable genotype according to both coefficient of variability and stability variance. According to LIN and BINNS (1988), the superiority measure (Pi) of cultivars is estimated by the squares of differences between an entry mean and maximum entry mean, summed and divided by twice the number of locations.

Cultivars with the lowest Pi values are considered the most stable. Accordingly, the superiority measure of the tested entries revealed that L2, L3 and L5 were the most stable genotypes, whereas Kulani and Gibe-1 were the least stable ones. In most cases, the ranks of cultivar superiority measure were in agreement with that of the overall mean yield (Table 2) and it has shown some deviations from the other stability measures. PURCHASE (1997) also indicated that LIN and BINNS' procedure showed the greatest deviation from the other stability procedures, having negative rank correlation in the studies of wheat GE interaction at the Free State, South Africa.

NASSAR and HUEHN's (1987) non-parametric measures of stability for seed yield of 10 maize genotypes evaluated in 15 environments of Ethiopia are presented in Table 2. Both S1 (mean absolute rank differences) and S2 (variance of ranks) values of the genotypes across the tested environments were used as measurements of stability (HUEHN 1990b). The S(1) and S(2) statistics are based on ranks of the genotypes across locations and they give equal weight to each location or environment. Genotypes with fewer changes in rank are considered to be more stable (BECKER and LEON 1988). The estimates of S(1) are all possible pair-wise rank differences across locations for each genotype, whereas that of S(2) are variances of ranks for each genotype across locations (NASSAR and HUEHN 1987). According to HUEHN (1990a), the use of S(1) was preferred to S(2) for many practical applications; it was reported to be easy to calculate, interpret and it has an efficient test of significance. Accordingly, L2 had the smallest changes in ranks and was thus regarded as the most stable genotype unlike Kulani, which was unstable. The next most stable variety was Gibe-1, followed by L1 and BH-660. These results are in agreement with most of the above parametric stability measurements.

FRANCIS and KANNENBERG's (1978) coefficient of variability, SHUKLA's (1972) stability variance, NASSAR and HUEHN's (1987) mean difference and variance of ranks indicated Gibe-1 as one of the stable genotypes (Table 2). Only cultivar superiority measure ranked this variety as 9th, categorizing it in the unstable group. All the stability measures considered L4 of intermediate stability except NASSAR and HUEHN's (1987) stability measure which ranked it 6th.

Generally, most of these stability parameters were closely related in determining the relative stability of the evaluated maize genotypes. Some deviations were, however, observed specifically for the cultivar superiority measure. PURCHASE (1997) reported similar results, indicating that it was more of a performance measurement than a yardstick for stability of cultivars across environments. In addition, Spearman's rank correlation was computed for these stability measures (data not shown). There was highly significant rank correlation between variance of ranks and stability variance ($r = 0.86$) and this also verified their good measurement of phenotypic stability. Similarly, PHAM and KANG (1988) reported high rank correlation among these measures of stability. NASSAR and HUEHN's (1987) variance of ranks and SHUKLA's (1972) stability variance were useful in determining the relative stability of maize genotypes under the tested environments of Ethiopia. Similarly, FRANCIS and KANNENBERG's (1978) coefficient of variability can also help in minimizing the risk of falling below certain yield levels.

PIEPHO and LOTITO (1992) reported high rank correlation between parametric and non-parametric measures. TRUBERG and HUEHN (2000) suggested an alternative use of non-parametric measures, whenever assumptions, such as normal distribution, homogeneity of error variances, absence of outliers, etc. are violated. Moreover, the repeatability of different stability parameters has to be compared and the ones with high repeatability should be selected to identify both the stable genotypes and better methods. For an efficient estimation and practical application of phenotypic stability, however, knowledge of relationship, consistency and repeatability between parametric and non-parametric stability are very important as suggested by HUEHN (1990b). Furthermore, relevant computer software is necessary for analysing stability and to select the best genotypes in the presence of GE interactions. In conclusion, the above five stability measures identified L2, Bh-660 and Gibe-1 as the most stable genotypes, and BH-540, Bh-140 and Kulani as unstable ones. The remaining genotypes were intermediate. The current study indicated the possibility of progress from selections under diverse environmental conditions by applying different analytical parameters of stability.

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