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Exploiting genotype x environment interaction in maize breeding in Zimbabwe

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Agriseeds Company produces several hybrids yearly. These hybrids need to be evaluated for yield stability before release. In this study, fifty-eight newly developed hybrids were planted at five sites and evaluated for grain yield and other traits. The objective was to assess the stability of Agriseeds hybrids in Zimbabwe and to identify strategies of minimizing evaluation cost of hybrids in multi-locations. Across site, analysis of variance indicated significant differences ($p<0.001$) in grain yield, days to silking, days to anthesis and anthesis-silking interval on genotypes, environments and genotype × environment interactions (GEI). Stable hybrids were 10A3WH04 (6.7 tha^{-1}) and 10A3WH24 (6.7 tha^{-1}) while hybrid 10A3WH03 (6.5 tha^{-1}) showed specific adaptability. Since all the evaluation sites fell into one mega-environment, a few representative sites with a few replications will be ideal to capture much of the variance due to GEI. Furthermore, Agriseeds should not establish separate breeding programmes for these environments. Rather, suitable culling and discriminating environments must be captured in few sites to be utilized and these sites are Harare, Gwebi and any one of Kadoma, Matopos and Shamwa.

Key words: *Zea mays* L., Genotype × environment interactions, grain yield, bi-plots, stability analysis.

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INTRODUCTION

The huge demand for maize (*Zea mays* L.) as food and feed in Zimbabwe has resulted in the rise of the private seed companies. Agriseeds is one of the private companies aimed at developing and marketing improved maize seeds in Zimbabwe. This company develops several new hybrids every year. These hybrids need to be evaluated for the presence of genotype × environment interactions (GEI) in grain yield and other agronomic traits (Mohammadi and Haghparast, 2010; Tiawari et al., 2011). The number of materials evaluated and the number of test environments required in multi-location trials affects the cost of plant breeding, particularly to young emerging companies such as Agriseeds. Reduction in the number of test sites requires a thorough understanding of the genotype and GEI (Bernardo, 2002).

Southern Africa has been divided into mega-environments by CIMMYT based on maize regional trials data (Setimela et al., 2005). Zimbabwe was also found to have diverse agro-ecological environments and has been divided into natural regions based on their potential in crop production (Rukuni et al., 2006). Natural regions 2a and 2b normally experience adequate rainfall, followed by natural regions 3 and 4, where rainfall distribution and amount vary from season to season. However, maize is grown in all agro-ecological regions of the country which are highly variable in terms of soil characteristics, rainfall and temperature during the growing season (Muungani

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et al., 2007; Rukuni et al., 2006).

Breeding programmes are intended to develop new varieties with superior agronomic performance compared to those in current production by farmers. Prior to release of the new varieties, they are evaluated in yield trials at several locations for two or more seasons in multi-environmental trials (METs). The variety trials provide important information that enables selection and recommendation of crop cultivars (Yan and Tinker, 2006; Yang et al., 2009). Comparisons are made with the performance of the commonly grown commercial varieties (checks). Genotype x environment interactions (GEI) are a major challenge when identifying superior genotypes using MET data because it slows down the selection process and makes genotype recommendations difficult (Hassanpanah, 2009). A genotype is defined as an individual's genetic makeup while an environment refers to a set of non-genetic factors that affect the phenotypic value associated with a cultivar (Fan et al., 2007). Crop varieties show wide fluctuations in their yielding ability when grown over varied environments or agro-climatic zones (Fan et al., 2007). Each genotype may have a specific environment for its maximum performance, but successful new varieties must show high performance for yield and other essential agronomic traits, and their superiority should be reliable over wide range of environments (Fan et al., 2007). Plant breeders desire stable cultivars with good performance under all conditions within the targeted production region (Caliskan et al., 2007).

The regression models have been used often by plant breeders to assess yield stability (Finlay and Wilkinson, 1963). Yield stability is a measure of the ability of a genotype to maintain relative performance across a wide range of environments. In general stable genotypes should perform more or less the same across environments. An appropriate stable cultivar is capable of utilizing resources that are available in high yield environments, while maintaining above average in all other environments (Finlay and Wilkinson, 1963). Furthermore, biplots have also been developed and they display the genotype + genotype x environment interaction (GGE) of a MET data. The GGE refers to the genotype main effect (G) plus the genotype x environment interaction (GEI), which are the two sources of variation (Yan et al., 2001). Yang et al. (2009) described a biplot as a descriptive statistical tool. The biplots allow the researcher to concentrate on the part of the MET data that is most useful to cultivar selection (Kang, 2003; Yan and Tinker, 2006).

Currently, the stability of the recently developed Agriseeds hybrids is unknown, yet this is crucial in cultivar recommendation in specific or general environments. Furthermore, the logical number of test environments needed for early and advanced generation testing for Agriseeds hybrids is unknown because of the poor understanding of GEI patterns. However, this is essential in reducing the cost of cultivar evaluation in multiple locations. The objective of this study was to assess the stability of Agriseeds hybrids across major production environments in Zimbabwe and to identify strategies of minimizing the evaluation cost of hybrids in multi-locations.

MATERIALS AND METHODS

Fifty-eight experimental maize hybrids from Agriseeds (Pvt) Ltd together with 12 commercial check hybrid varieties from various seed companies in Zimbabwe were evaluated at five sites during the 2011-2012 summer season. The sites represent the major maize growing agro-ecological regions in Zimbabwe (Table 1). The experiments were grown using an α-lattice (0,1) design with three replications. Two row-plots of 4 m length, with an inter-row spacing of 0.75 m and an intra-row spacing of 0.25 m were used. Basal fertilizer (N-7, P_2O_5-14, K_2O-7) was broadcasted at 400 kg ha^{-1} and disced into the soil before planting. All sites received two applications of 200 kg ha^{-1} of ammonium nitrate as top dressing. The first and second applications were at four and eight weeks after crop emergence, respectively. All the sites were rain fed and hand weeding was done to control weeds. Data was recorded for grain yield (GY) (shelled grain weight per plot adjusted to 12.5% grain moisture and converted to tons per hectare), anthesis date (MF) (number of days after planting when 50% of the plants shed pollen), silking date (FF) (number of days after planting when 50% of the plants extrude silks) and anthesis-silking interval (ASI) (the difference between silking date and anthesis date, FF – MF).

Data analyses

Individual site and across site analysis of variance for all the agronomic traits were done using Genstat Software version 13 (Genstat, 2010) and the appropriate denominators were used for the F-test. The variance components due to error, genotypes and genotype x environment interaction were calculated and used to estimate the broad sense coefficient of genetic determination (fixed parent equivalent of broad sense heritability). The means of genotypes per site were ranked to assess the importance of cross-over genotype x environment interactions. Stability analysis for yield was done based on the Finlay and Wilkinson (1963) regression model. The genotype + genotype x environment interaction (GGE) scatter plots (Yan and Tinker, 2006) were generated using Genstat Version 13 (Genstat, 2010) to identify genotypes adapted to specific environments, the most discriminating and suitable culling environments. Decisions on the number of testing sites and number of replications per site were calculated by making replication and environment the subject of the formula in the following equation as stated by Bernardo (2002) as (V_E/re)+ (V_{GE}/e)}, where, 5% LSD is the least significant difference, V_E is the error variance, V_{GE} is the genotype x environment interaction variance, r is the number of replications, and e is the number of environments used in the experiment.

RESULTS

The hybrids showed significant differences ($p<0.001$) in for grain yield (GY), number of days to silking (FF), number of days to anthesis (MF) and anthesis-silking interval (ASI) (Table 2). The five sites used in the experiment, that is, Harare, Gwebi, Shamva, Kadoma and Matopos were significantly different ($p<0.001$) in term

Table 1. Description of the evaluation sites for the Agriseeds experimental hybrid trials.

Trial site	GIS position	[a]Soil type	[b]Altitude (masl)	[b]Mean rainfall (mm)	[c]Natural region
Agriseeds Research Station, Harare	30°56'E and 17°44'S	Red clay	1400	750-1000	**2a**
Gwebi Variety Testing Station, Gwebi	31°32'E and 17°41'S	Red clay	1448	750-1000	**2a**
Panmure Experiment Station, Shamva	31°47'E and 17°35'S	Red clay	881	650-800	**2b**
Cotton Research Station, Kadoma	29°53'E and 18°19'S	Sandy loamy soil	1149	650-800	**3**
Matopos Experiment Station, Matopos	28°28'E and 20°24'S	Red clay	1138	450-650	**4**

Source: [a]Nyamapfene (1991); [b]Rukuni et al. (2006). [c]Natural region 2 is subdivided into a and b based on various agro-ecological factors

Table 2. Across sites analysis of variance mean squares, variance components and broad sense coefficient of genetic variation values.

Source	DF	Grain yield	Silking date	Anthesis date	Anthesis-silking interval
Site	4	1813.555***	5062.94***	6848.84***	549.287***
Rep /site	10	10.584***	81.49***	60.68***	8.188***
Block(Rep/Site)	195	1.6477***	8.046***	7.057***	1.776***
Hybrid	69	7.094***	56.75***	53.35***	6.577***
Site*Hybrid	276	2.151***	8.99***	7.91***	2.373***
Error	495	1.118	4.349	4.114	1.131
Total	1049				
Error variance component		1.118	4.349	4.114	1.131
GxE variance component		0.344	1.547	1.265	0.414
Genotype variance component		0.329	3.184	3.029	0.28
Broad sense heritability					
Single plot basis (%)		18.4	35.1	36.0	15.4
Across environments basis (%)		69.7	84.2	85.2	63.9

*** Significant at 0.1% probability level.

terms of their average performance for all traits studied (Table 2). Harare site had an average yield of 10.5 tha^{-1}, followed by Gwebi (7.1 tha^{-1}), Shamva (5 tha^{-1}), Kadoma (4.1 tha^{-1}) and Matopos (3 tha^{-1}). There were significant interactions ($p<0.001$) between the sites (environments) and the hybrids (genotypes) for all the traits measured in the study.

The genotype x environment interaction (GEI) variance component for grain yield was higher than the genotype and error variance components. However, the error term was higher than the genotype and GEI variance components. The broad sense coefficients of genetic variation were low (less than 40%) on single plot basis but high on across environments basis (above 63%) for all traits measured.

Selected genotypes yield ranks across environments

Genotype ranks across environments were non-consistent (Table 3). Genotypes that had high means for yield in Harare changed over the other four sites. The changes were subjectively high with few hybrids that remained in the top 10 in some environments.

Grain yield stability

The existence of genotype x environment interaction (GEI) raised the need to identify stable and high yielding genotypes. The Finlay and Wilkinson (1963) regression model showed that hybrids such as 10A3WH04 (6.70 tha^{-1}) and 10A3WH24 (6.70 tha^{-1}) as well as a check from Seed Co (SC 533) had mean yield greater than average mean, 5.95 tha^{-1}, and they showed average stability based on the regression coefficient (b=1) (Table 4).

Experimental hybrids such as 10A3WH03 (6.50 tha^{-1}) and some check hybrids from Seed Co (SC 727 and SC 637) and Pannar Seeds (Pan 5M-35) were high yielding but had below average stability (b>1). Hybrids such as 10A3WH02 (5.87 tha^{-1}) and 10A3WH14 (5.20 th^{-1}) had below average yields and below average stability (b>1). Hybrids such as10A3WH29(4.8 tha^{-1}) and 10AH37 (5.0 tha^{-1}) as well as checks that include SC 403, Pan 4M-21 and ZS 259 gave below average yield and had above average stability (b<1). Checks like SC 727 (7.24 tha^{-1}), SC 637 (7.21 tha^{-1}) and Pan 5M-35 (6.43 tha^{-1}) are high yielding checks, but have below average stability. Pan 4M-19 (4.94 tha^{-1}) and Pan 7M-97 (5.71 tha^{-1}) are low yielding check hybrids and they have average stability.

Table 3. Genotype means of the top 10 yielding hybrids (based on Harare site) and their rank changes across other sites.

Genotype name	Harare		Gwebi		Shamva		Matopos		Kadoma	
	Grain yield	Rank	Grain yield	Rank	Grain yield	Rank	Grain yield	Rank	Grain yield	Rank
SC727	16.7	1	4.747	67	7.818	1	2.688	58	5.246	7
10A3WH41	13.474	2	7.773	25	5.239	31	3.221	25	4.796	16
10AH09	13.039	3	8.144	15	5.091	36	3.056	35	5.177	8
09A3WH07	12.63	4	8.652	9	6.297	5	3.695	5	5.142	9
10A3WH03	12.263	5	8.929	4	5.939	11	3.214	26	3.236	58
10A3WH10	12.132	6	8.082	16	6.007	10	3.446	13	5.101	12
10A3WH06	11.999	7	7.109	34	5.552	22	3.222	24	5.537	3
Pan5M-35	11.921	8	7.311	31	4.552	54	3.036	38	4.627	20
10AH03	11.906	9	7.725	27	5.534	23	2.871	46	4.627	15
10AH05	11.874	10	8.37	11	6.107	7	3.232	22	5.348	6

On the other hand, checks like Pan 4M-21 (4.79 tha^{-1}), SC 403 (4.57 tha^{-1}) SC411 (5.32 tha^{-1}) and ZS 259 (4.84 tha^{-1}) showed to be low yielding, but have above average stability.

Genotypes for specific environments

A significant cross-over genotype x environment interactions raised the need to identify hybrids that performed better in specific environments. The genotype + genotype x environment interaction (GGE) scatter plot showed that most of the hybrids, such as 10A3WH20 and 10A3WH10 were found to be suitable to all sites. However, 10A3WH10 and SC 727 performed better in high potential areas like Harare. Most of the hybrids including 10A3WH03 and 10A3WH06 were all found to be concentrated close to Matopos and Kadoma, which are low potential areas (Figure 1). Some experimental hybrids, including some checks (ZS 259 and SC 403) were not specific to any environment. The environments were also grouped into one mega-environment (Figure 1).

Discriminating and culling environments

Since there was one mega-environment, the better testing environments had to be found. The genotype + genotype x environment (GGE) scatter plot showed the most discriminating and suitable culling environments to be Harare, Gwebi and any one of either Kadoma, Shamva or Matopos (Figure 3).

Decision on the number of testing sites and number of replications per site

Agriseeds requires detecting critical differences of 0.8, 1.0 and 1.5 tha^{-1} among the varieties under testing. Based on the equation by Bernardo (2002), the number of environments required are 8, 5 and 2 when there are three replications, respectively. However, when there are two replications the number of sites will increase to 14, 8 and 3, respectively, based on the same critical distances to be detected.

DISCUSSION

Existence of genetic variability among the hybrids for grain yield, anthesis-silking interval ASI and days to maturity raises possibilities of identifying high yielding hybrids with desirable physiological maturity periods and suitable pollen-silk synchronization under diverse environments. Grain yield has been singled out as the most important trait in cereals. Late maturing varieties are needed to achieve high yield in high potential environments, where there is a low risk of occurrence of drought. However, early maturing varieties are desirable in low potential drought prone areas, since they have the capacity to escape late season drought (Banziger et al., 2004). The significant ASI and its high broad sense coefficient of genetic variation (fixed parent equivalent to broad sense heritability calculated from individuals selected from a random mating population) suggest genetic differences in synchronization and therefore selection of hybrids that exhibit good pollen-silk synchronization under drought is possible. A ASI and/or negative ASI is desirable for hybrids to be grown in drought prone areas such as Kadoma and Matopos. Shorter ASI improves the pollen-silk synchronization, a major trait that is affected under drought. The need for a shorter ASI to achieve high grain yield has been observed by Bassetti and Westigate (1993) and Anderson et al. (2004), where the potential number of florets that could become grains was limited by the receptivity of the silks. Asychrony is correlated with reduced number of grains per plant and grain yield in maize (Edmeades et al., 1993). Bolanos and Edmeades (1993) noted a yield decline by 90% as ASI increases from -0.4 to 10 days. To this regard, ASI has been widely

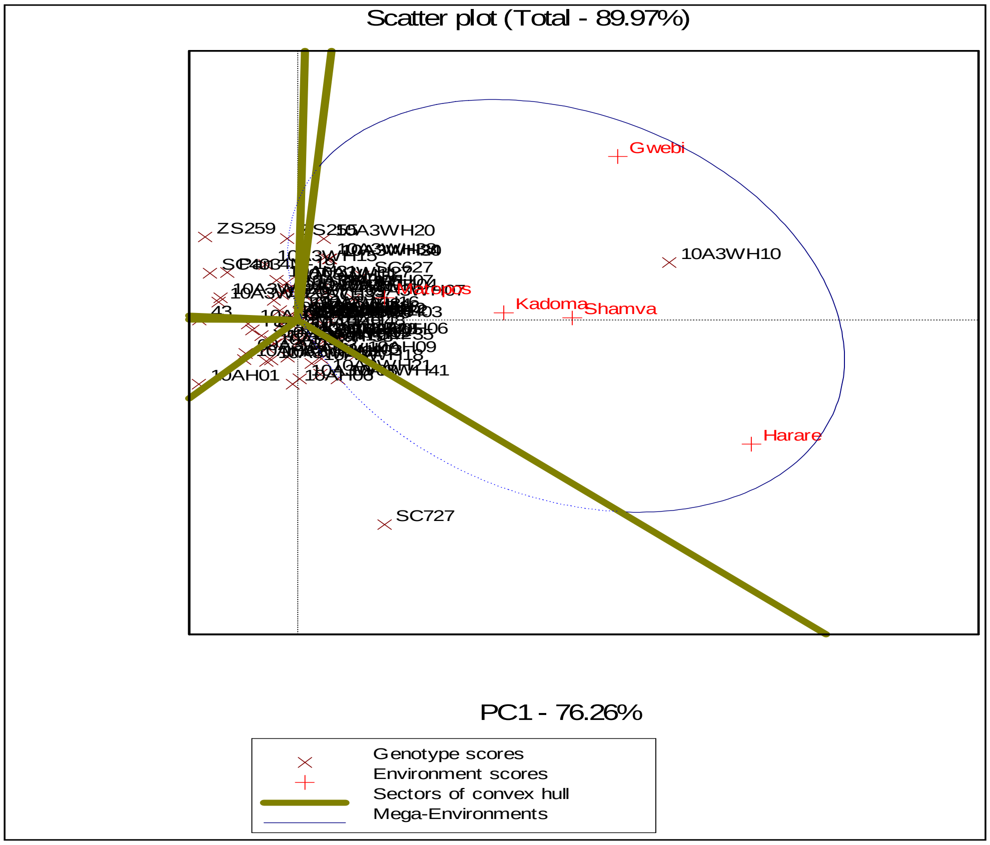

Figure 1. The GGE scatter plot showing all sites to be in one mega-environment.

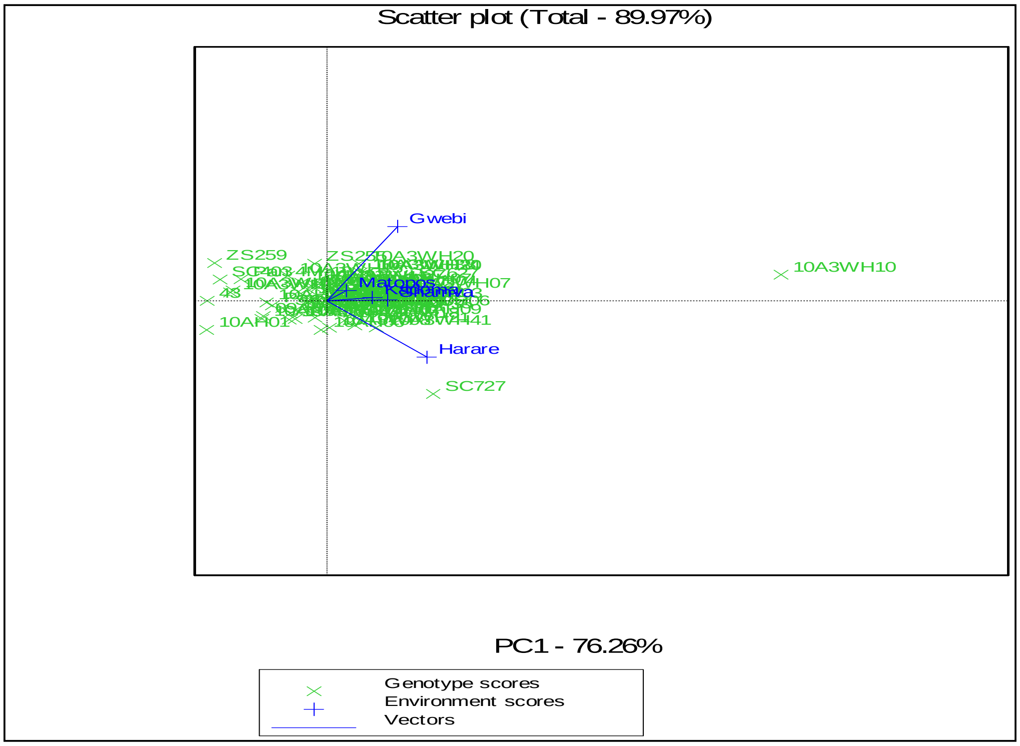

Figure 2. Three groups of discriminating and culling sites of Agriseeds hybrid trials.

Table 4. Genotypes stability parameters for grain yield across sites based on the Finlay and Wilkinson (1963) stability model.

Hybrid name	Yield (tha^{-1})	b-value	p-value	Hybrid name	Yield (tha^{-1})	b-value	p-value
10A3WH29	4.76	0.53	0.003	Pan 53	6.44	1.00	0.006
SC403	4.57	0.55	0.006	10A3WH25	6.08	1.00	0.001
ZS259	4.48	0.59	0.077	10A3WH40	5.78	1.01	0.002
10A3WH15	5.62	0.68	0.016	10A3WH18	6.26	1.01	0.012
Pan 4M-21	4.79	0.72	0.009	10A3WH08	6.05	1.02	0.011
10A3WH28	4.52	0.84	0.004	10A3WH19	5.49	1.02	0.001
10AH01	4.09	0.84	0.024	SC533	6.34	1.02	0.001
10A3WH33	5.69	0.84	0.001	10AH12	5.26	1.03	0.013
10AH31	5.71	0.84	0.003	10AH49	6.05	1.04	0.001
SC411	5.37	0.85	0.001	Pan 7M-97	5.71	1.05	0.002
10AH37	5.01	0.87	0.005	10AH48	6.53	1.07	0.001
09A3WH05	5.93	0.88	0.001	10A3WH06	6.77	1.09	0.001
ZS255	5.95	0.88	0.026	10AH02	5.32	1.09	0.006
10A3WH11	5.88	0.89	0.002	09A3WH07	7.11	1.09	0.003
10A3WH34	6.18	0.90	0.001	Pan 4M-19	4.94	1.09	0.001
10A3WH20	6.64	0.90	0.024	10A3WH42	6.25	1.09	0.001
10A3WH27	0.03	0.90	0.004	10A3WH14	5.24	1.11	0.002
10A3WH37	5.78	0.91	0.001	10A3WH30	6.59	1.11	0.008
10A3WH35	5.80	0.91	0.004	10A3WH26	6.15	1.12	0.001
10A3WH38	6.64	0.92	0.015	10A3WH05	5.74	1.12	0.003
10A3WH23	6.27	0.93	0.002	10A3WH10	7.03	1.12	0.001
10A3WH32	5.48	0.93	0.005	10AH06	5.80	1.13	0.005
09A3WH10	5.99	0.93	0.005	10A3WH39	5.99	1.13	0.004
10A3WH17	6.16	0.94	0.001	10A3WH16	6.01	1.14	0.003
10A3WH12	6.15	0.94	0.002	10AH05	6.82	1.14	0.001
10A3WH31	5.52	0.94	0.001	10AH03	6.38	1.15	0.002
10A3WH22	6.47	0.95	0.001	10A3WH02	5.87	1.16	0.001
10A3WH36	5.86	0.96	1.163	SC637	7.21	1.18	0.004
10A3WH09	6.13	0.96	0.001	Pan 5M-35	6.43	1.20	0.001
10AH34	5.00	0.96	0.001	10A3WH07	6.26	1.22	0.005
10A3WH24	6.74	0.96	0.007	10A3WH03	6.50	1.23	0.001
10AH42	5.67	0.97	0.001	10A3WH21	6.19	1.27	0.002
09A3WH11	5.74	0.97	0.002	10A3WH41	6.58	1.31	0.003
10A3WH13	4.94	0.99	0.008	10AH09	6.96	1.31	0.001
10A3WH04	6.67	1.00	0.001	SC727	7.24	1.55	0.058

used in indirect selection of higher grain yield under drought conditions (Banziger et al., 2004). The yield differences that were observed across sites also confirm the site potential as evidenced by their natural regions (NR) (Rukuni et al., 2006).

The best site was Harare (NR2a) followed by Gwebi (NR2a), Shamva (NR2b), Kadoma (NR3) and Matopos (NR4). Natural region 2a (Harare and Gwebi) is associated with highest rainfall followed by NR2b (Shamwa).

Although Gwebi and Harare are in the same natural region, Gwebi has the least yield because this site is associated with high incidences of diseases such as maize streak virus (MSV) and leaf blight. Although NR3 is better than NR4, these areas are prone to drought, with the highest frequencies of the occurrences of the mid-season and late season drought spells that greatly impact on maize yield.

The NR4 is not good for maize production although farmers insist to grow this crop. Harare and Gwebi are rich sites (yielded above the mean), Shamva is an average site (yielded about the mean) while Kadoma and Matopos are poor sites (yielded below the mean).

This classification of sites is also backed up by their geographical classification into various natural regions (Nyamapfene, 1991; Rukuni et al., 2006).

Significance of the genotype x environment interaction, variance components and broad sense coefficient of genetic determination of the traits studied

Genotype x environment interaction (GEI) has been widely reported to impede the speed at which desirable cultivars are made (Caliskan et al., 2007). In this study, the cross-over interactions were common and the GEI variance components for grain yield were larger than the error and the genotype variance components. The large contribution of GEI to grain yield makes is difficult for breeding and selection of better maize varieties. For example, it reduces the heritability and gain in selection and it confuses early generation selection. The high broad sense coefficient of genetic determination across environments raises the possibility of identifying the suitable genotypes across environments. To increase heritability, more number of sites and replications will be required as evidenced by lower heritability estimates at single plot basis but higher estimates as the number of replications and sites are increased. In other studies, broad sense heritability for maize was also found to be low at single plot basis but high at across site basis (Hallauer and Miranda, 1988). Heritability can be improved by increasing the number of sites and replications per site but this has the consequences of increasing the cost of research and this is detrimental to a small company like Agriseeds. To this regard, logical decisions must be made to attempt to reduce the number of sites and replications per site. Fehr (1987) recommended the use of few replications and then increase the number of sites. Based on Bernardo (2002), if the number of replications are three and two, then the number of sites required to achieve a critical distance of 1.0 tha^{-}1 were found to be five (5) and eight (8), respectively. Hence, for Agriseeds to reduce their cost of research, they have to use more replications per site and reduce the number of sites which are in the same mega-environment, in order to detect the same difference in yield.

Changes in the genotype ranks across environments suggest the existence of cross-over genotype by environment interactions. Cross-over interactions has been reported to be the major worry for breeders as it results in changes of cultivars ranks across environments. Changes in cultivar ranks across environments make it difficult to recommend a single best genotype for all environments based on evaluations from a single site (Fehr, 1987).

Causes of genotype x environment interactions (GEI)

Grain yield, a quantitative trait, has been widely reported to be due to the interaction of many genes with small effects. The effect of the environment on quantitative traits has been widely reported to be significant. Grain yield formation is influenced by the duration and rate of grain filling (Lee and Tollennaar, 2007). Furthermore, the variability for 1000 kernel weight and kernel number per ear are predictive of the genotype’s sink capacity, hence grain yield (Lee and Tollenaar, 2007; Wang et al., 1999). Grain filling follows three stages, that is, lag phase (rapid cell division and differentiation), linear phase (rapid dry matter accumulation) and the final phase (Lee and Tollenaar, 2007). Extremes in temperature and low amounts of rainfall affects these critical stages, thereby resulting in GEI across the five sites used in the study, since they differ in rainfall distribution and temperature (Rukuni et al., 2006). In deed in this study, the natural regions of Zimbabwe were observed to experience different rainfall amount and pattern. This makes it critical to select genotypes that have stable ASI in order to achieve some levels of drought tolerance.

Grain yield stability

Grain yield is the most important trait because it is the one that gives an economic benefit to the consumers. Hence, good hybrids should give high yield and should be stable across different environments in which they are grown as alluded by Finlay and Wilkinson (1963). Fan et al. (2007) pointed genotype by environment interactions (GEI) as the basic cause of differences between genotypes in their yield stability. Hybrids such as 10A3WH04 (6.67 tha^{-1}) and 10A3WH24 (6.70 tha^{-1}) were high yielding and they showed above average stability and can be taken for further evaluations to estimate the genotype x years interactions and genotypes x environments x years interactions. Although some varieties showed high yielding capabilities, their stability was poor. On the other hand, some hybrids like 10A3WH29 (4.80 tha^{-1}) and 10AH37 (5.0 tha^{-1}) gave above average stability but low yield. This is the scenario exhibited by most of the hybrids, that is, they tend to be stable, yet they produce uneconomic yields. These varieties are generally undesirable to the farmer who wants higher yields in order to get higher returns per each dollar invested. Hence, breeders select higher yielding hybrids and discard low yielding ones, regardless of their stability performance abilities across different environments. Furthermore, hybrids like 10A3WH14 (5.20 tha^{-1}) showed that low yields and below average stability are considered as poor performing cultivars and they have to be discarded as they are of little benefit to the farmers.

Genotypes for specific environments, discriminating and culling environments

Generally, crop varieties show wide fluctuations in their yielding abilities when grown over varied environments or agro-climatic zones (Fan et al., 2007). Based on the genotype + genotype x environment (GGE) scatter plot, hybrids such as 10A3WH20 and 10A3WH10 were found to be suitable to all the sites. This means that these varieties have above average stability. The scatter plot also demonstrated that the most yielding varieties like SC 727 and 10A3WH10 favors the highest potential environments, that is, Harare and Gwebi. Surprisingly, most hybrids, for example 10A3WH06 were found to favor low potential environments. These genotypes are highly stable under adverse environmental conditions, hence can be recommended for low potential areas like natural regions 3 and 4 of Zimbabwe. The existence of one mega-environment suggest that there is no need to initiate separate breeding programmes for Agriseeds, however, discriminating and culling environments are needed. These proved to be Harare, Gwebi and any one among Shamva, Kadoma and Matopos. Although, sites fell in one mega-environment, the site means and the natural region classification system show that it will be critical to evaluate in all these sites. The existence of one mega-environment is not supported by CIMMYT where Southern Africa was partitioned into various mega-environments (Setimela et al., 2005). However, the existence of one mega-environment shows that it is not essential to have separate breeding programmes for various environments for Agriseeds. The existence of one mega-environment also shows that cross-over interactions could be occurring within a few varieties and thus, selection of stable genotypes is needed. The genotype + genotype x environment interaction (GGE) scatter plot showed the most discriminating and suitable culling environments to be Harare, Gwebi and any one of Kadoma, Shamva and Matopos. These environments are the most discriminating and are good as the testing environments for both early generation testing and advanced testing.

CONCLUSIONS AND RECOMMENDATIONS

Genotypes x environment interaction (GEI) effects are huge in grain yield abilities of Agriseeds materials, thus necessitating the need to do multi-locational trials. Although our data showed the testing sites in Zimbabwe to represent one mega-environment for maize, evaluation of maize in all these sites is critical since the sites represent various natural regions of Zimbabwe. Furthermore, the data was based on one year that might need further investigations. Further increasing the number of testing sites will not improve the breeding and selection efficiency, but would rather increase the cost of the breeding programmes. Gwebi and Harare are good culling sites and could be used in early generation evaluation of the breeding materials. The better hybrids for various sites are 10A3WH04 (6.7 tha^{-1}) and 10A3WH24 (6.7 tha^{-1}), since they are high yielding and have above average stability. The hybrid 10A3WH10 (7 tha^{-1}) is suited for the high potential areas such as (Gwebi and Harare) while hybrids such as 10A3WH03 (6.5 tha^{-1}) and 10A3WH06 (6.8 tha^{-1}) are suited for low potential areas (Kadoma and Matopos). Further evaluation of stable and specific genotypes is required before release of the hybrids, in order to determine their genotype x years and genotype x environments x years interactions. However, an increase in the number of locations will reduce the number of testing years in attempting to derive desirable cultivars. Based on this study we recommend Agriseeds to do early generation testing at Gwebi and Harare, and then test in two sites per each natural region in order to reduce the time of releasing a cultivar due to the effects of GEI.

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