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STABILITY OF GRAIN MAIZE GENOTYPES AS AFFECTED BY LOCATIONS AND YEARS

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ABSTRACT

In plant breeding programs, potential genotypes are usually evaluated in different environments (locations and years) before desirable ones are selected. Genotype x environment (G x E) interaction is associated with the differential performance of materials tested at different locations and in different years, and influences selection and recommendation of cultivars. Highly stable genotypes are desirable. Performance and stability of grain maize (*Zea mays* L.) genotypes were evaluated at four locations in Peninsular Malaysia *viz*. Padang Rengas (Perak), Rhu Tapai (Terengganu), Sungai Udang (Melaka) and UPM, Serdang (Selangor), in two years. The objectives of this study were to evaluate the G x E interactions effects, and to identify high yielding genotypes at each location and their stability by using different stability parameters. The experiments at the locations were arranged in a randomized complete block design (RCBD) with four replications. Recommended agronomic practices were used at each location. Evaluations were conducted from June 2000 to March 2002. Genotype and G x E interaction effects were highly significant indicating high variability among genotypes, and genotypes responded differently to the changing environments. Among the 14 genotypes evaluated, GxA, Selected GxA, SC-2, Putra J-58 and TWC-4 revealed high performance and have good potential to be used as source populations for future breeding programs. Comparing performance of genotypes for grain yield and yield components, Selected GxA was found to have the highest grain yield (5726 kg ha^{-1}), shelling percentage (84.9 %), 100-grain weight (25.5 g) and ear weight per plant (149.5 g), earliest in flowering (50.6 days to tasseling, and 53.2 to silking) and longest ears (15.5 cm). TWC-2 was found to be earliest to mature. SC-3 revealed the shortest plants, while Suwan 1 was the tallest and was late in maturity. The highest ear diameter was observed on SC-1. Terengganu in 2000 was found to be the most favourable environment, as shown by its highest environmental index. The stability analyses indicate that Selected GxA and DC-1 were identified as having the highest grain yields and the most stable. Some genotypes showed specific adaptability to specific locations, such as GxA in Perak, Putra J-58 in Terengganu and Selected GxA in Melaka and Selangor. This study has led to the identification and possible release of a new, high yielding and stable grain maize synthetic variety, Selected GxA, and a promising hybrid variety, DC-1.

Keywords: Breeding programs, environmental index, genotype x environment interaction, performance of genotypes, stability analyses, *Zea mays* L.

INTRODUCTION

In Malaysia, grain maize (*Zea mays* L.) is grown as a minor crop produced for livestock feed. Grain maize and sweet corn are grown on 21,000 hectares on land, with a total production of 65,000 metric tons in 2000-2001 (USDA-FAS, 2002). Due to lack of local supplies, the local animal feed industry is still dependant on imported grain maize as the main source. In 2000, 2.1 million metric tons of maize valued at US$ 190.6 million was imported (USDA-FAS, 2001). It is therefore, important for the country to develop high yielding varieties in allowing profitability of the locally grown crops. Realizing this fact, a maize breeding program has been started in 1987 at Universiti Putra Malaysia (UPM), directed towards the development of hybrid varieties (Saleh *et al*., 1994).

Soil nutrients, particularly potassium, phosphorus, and nitrogen, the latter in the form of either nitrate or ammonium are needed for maize growth and development. The nutritional requirements of maize tend to be higher when expressed on per-hectare basis, than those for other grain species (MAFF, 1994). The recommended application rates for nitrogen, phosphorus and potassium fertilizers are 160 kg N ha^{-1}, 44 kg P ha^{-1} and 83 kg K ha^{-1} (Saleh *et al*., 2002).

Maize is a well-known cereal throughout the world. It is an annual, monoecious grass, grown mainly for food, feed and industrial raw materials. It is also an important source of raw materials for extraction of oil, sugar, syrups, starch and other products (Dowswell *et al*., 1996). The choice of genotypes as potential cultivars in a plant breeding program is generally based on their superior performance in a wide range of environments. The method widely used in measuring and comparing genotypic stability in

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Table 1. Fourteen grain maize genotypes evaluated, and their pedigrees.

Genotype	Pedigree
Single Cross (SC):	
SC-1	UPM SM 5-4 x IPB 14
SC-2	UPM SM 5-4 x UPM SW 2
SC-3	UPM SM 5-4 x UPM MT 13
SC-4	UPM SM 5-4 x UPM SW 2
Three Way Cross (TWC):	
TWC-1	UPM SM 5-4 x UPM SW 9) x IPB 14
TWC-2	(UPM SM 5-4 x UPM SW 9) x UPM MT 13
TWC-3	(UPM SM 5-4 x IPB 8-2) x UPM MT 13
TWC-4	(UPM SM 5-4 x IPB 15) x UPM SW 2
TWC-5	(UPM SM 5-4 x IPB 15) x UPM SM 7-6
Double Cross (DC):	
DC-1	(UPM SM 5-4 x UPM SW 9) x UPM SM 7-6
Synthetic:	
GxA	Synthetic Population
Selected GxA	Selected Synthetic Population
Check Variety:	
Putra J-58	Hybrid Variety
Suwan 1	Composite Variety

different environments involves the regression across environments of an average yield of a genotype on mean yield of all genotypes in each environment (Finlay and Wilkinson, 1963; Eberhart and Russell, 1966).

Genotypes that produce above average yields and have minimal variation from expected yields across environments are considered stable and desirable. Yield stability is an important characteristic for commercial hybrids with a wide range of adaptation. G x E interaction is important in plant breeding programs and germplasm evaluation trials, and it is often desirable to find genotypes that show little interaction with environments (Lin *et al*., 1986; Westcott, 1986; Becker and Leon, 1988; Crossa, 1990). Plant breeders use yield trials to identify promising genotypes and agronomists use them to make recommendations to farmers. The objectives of this study were to evaluate genotype x environment interaction effects, and to identify high yielding genotypes at each location and their stability using different stability parameters.

MATERIALS AND METHODS

Locations

Experiments were conducted from June 2000 to March 2002, at four different locations over two years (eight environments) in Peninsular Malaysia, *viz.* Padang Rengas, Perak, in the northern part of the Peninsular (100^o 51' E, 4^o 48' N), Rhu Tapai, Terengganu, in the east coast of the Peninsular (103^o 09' E, 5^o 09' N), Sungai Udang, Melaka, in the southern part of the Peninsular (102^o 11' E, 2^o 19' N), and UPM Serdang, Selangor, in the middle part of the Peninsular (101^o 42' E, 2^o 12' N). The soil types of the locations were of the Order Ultisols (Bukit Temiang series Typic Hapludult), Spodosols (Rudua Series, Typic Haplorthod), Ultisols (Gajah Mati series Typic Paleudult), and Ultisols (Bungor series, Typic Kandiudult), respectively (FAO/UNESCO, 1988; Soil Survey Staff, 1998).

Plant Materials

A total of 14 grain maize genotypes were subjected to evaluation at these locations. These genotypes include four singles crosses (SC), five three-way crosses (TWC), one double cross (DC), two synthetics and two check varieties (Table 1).

Experimental Layout and Cultural Practices

The recommended cultural practices were employed at each location. Plantings were established on 20 June 2000 in Perak, 16 July 2000 in Terengganu, 1 November 2000 in Melaka, and 30 November 2000 in Selangor. Second year plantings commenced on 23 April 2001 in Melaka, 6 June 2001 in Terengganu, 26 August 2001 in Selangor, and 5 December in Perak. At each location, experiments were carried out in a randomized complete block design (RCBD) with four replications. The size of each experimental plot was 18.75 m^2 (5m x 3.75m), consisting of five 5-m long rows. The planting density was 0.75 m between rows and 0.25 m between plants within rows.

The soil pH was determined prior to planting. Ground Magnesium Limestone (GLM) was applied to raise pH to 5.5-6.5 for favourable grain maize growth. In Terengganu, Melaka and Selangor, chicken dung at the rate of 2 tons per hectare was applied ten days before planting. Experimental fields were ploughed once and harrowed

Table 2. Mean squares in combined ANOVA for characters measured on 14 grain maize genotypes evaluated at four locations in two years.

Source of variation	d.f.	Mean squares					
		Grain yield	Shelling percentage	Ear wt/plant	Grain wt/plant	Ear length	No. kernel rows/ear
Locations (L)	3	65958207**	235.93**	8683.89**	10234.12**	7.53**	4.49**
Years(Y)	1	38012203**	3.91	15752.21**	7037.40**	0.84	0.69
L x Y	3	3076743**	79.25**	1171.18**	368.73	19.82**	5.01**
Genotypes (G)	13	5412590**	57.01**	1870.14**	1568.32**	16.24**	9.60**
G x L	39	846004**	7.36	487.66**	381.32	1.90**	0.31
G x Y	13	625926	6.90	492.21	322.44	4.06**	0.78
G x L x Y	39	552647	9.49	380.62	270.32	1.39	0.46
Pooled error	312	450698	6.38	285.30	222.24	1.20	0.36

*,** Significant at $p \leq 0.05$ and 0.01, respectively.

Table 3. Mean squares in combined ANOVA with regression analysis for characters measured on 14 grain maize genotypes evaluated in eight environments (four locations in two years, 2000 and 2001).

Source of variation	d.f.	Mean squares					
		Grain yield	Shelling percentage	Ear wt/plant	Grain wt/plant	Ear length	No. of kernel rows/ear
Genotypes	13	5412590**	57.01**	1870.14**	1568.32**	16.24**	9.60**
Reps/Env(R/E)	24	1611905**	12.00**	878.87**	615.87**	4.62**	0.33
Env(E) + (GxE)	98	3140747**	17.30**	873.25**	698.49**	2.69**	0.71**
E (Linear)	1	245117053**	949.44**	45317.43**	38845.94**	82.89**	29.21**
G x E (Linear)	13	3941139**	46.92**	2416.75**	1782.73**	10.82**	2.44**
Pooled Deviations	84	136207	1.63	105.28	76.55	0.48	0.10
Pooled error	312	518608	6.38	285.30	222.24	1.20	0.36

*,** Significant at $p \leq 0.05$ and 0.01, respectively.

twice to a depth of 0.20-0.25 m, followed by basal application of chemical fertilizers at rates equivalent to 100 kg N ha^{-1}, 44 kg P ha^{-1} and 117 kg K ha^{-1}, of Nitrophoska Blue compound fertilizers (N, P_2O_5, K_2O, MgO, 12:12:17:2).

Two seeds were sown per hill and then thinned to one vigorous plant at the three-leaf stage, to reach a planting density of approximately 53,333 plants ha^{-1}. Urea (46% N) side dressing was applied at the rate of 30 kg ha^{-1} of N, each at the two weeks and four weeks after sowing. Muriate of Potash (MOP) at the rate of 19 kg K ha^{-1} was applied three weeks after planting. In Terengganu, however, due to its sandy soil condition, side dressing of Nitrophoska Green compound fertilizer (N, P_2O_5, K_2O, 15:15:15) was applied at the rate of 40 kg N ha^{-1}, 18 kg P ha-1 and 33 kg K ha-1, at two weeks after planting, each at the rate of 30 kg N ha^{-1}. Six weeks after planting, MOP at the rate of 20 kg K ha-1 was also applied.

Ten days before tasseling, foliar fertilizer (NR) at the rate of 10 ml L^{-1} was applied. Sprinkler irrigation was used throughout the growing season to supply sufficient water. Weeds were controlled using pre-emergence herbicide, Lasso (2-chloro-2'-6'-diethyl-N-(methoxymethyl)-acetanilide) immediately after planting, at the rate of 2 ml L^{-1}, and as post-emergence herbicide, Gramoxone (1,1' dimethyl-4, 4'-bipyridylium) at the concentration of 3 ml L^{-1} was applied one month after planting. Weeds were also controlled manually.

Data Collection and Sampling

Data on grain yield components were collected on the genotypes at all four locations in the two year experimental period. Plants were hand harvested on 20 September 2000 in Perak, 15 October 2000 in Terengganu, 1 February 2001 in Melaka and 2 March 2001 in Selangor for the first year plantings, and 25 July 2001 in Melaka, 8 September 2001 in Terengganu, 28 November 2001 in Selangor and 10 March 2002 in Perak for the second year plantings. The centre three rows of each plot, measuring three meters in length were harvested. The ears were then oven dried for about one week, until constant grain moisture content of 15 % was achieved where grain yield was determined.

Table 4. Stability parameters for grain maize genotypes evaluated at four locations in two years.

Genotype	Mean ($kgha^{-1}$)	b_i	s^2_d	R^2	s^2	W_i	σ^2_i	CV (%)
SC–1	4855	0.81	330039	0.59	60594	127796	47635	11.8
SC–2	5184	0.77	248407	0.64	68131	183193	69178	9.6
SC–3	4200	1.14	50501	0.95	3612	23108	6923	5.4
SC–4	4621	1.07	168394	0.83	34178	67750	24283	8.9
TWC–1	4797	0.93	163807	0.79	35532	68605	24616	8.4
TWC–2	4574	1.24	70840	0.94	4254	15105	3810	5.9
TWC–3	4724	0.72	145277	0.72	14359	31484	10180	8.1
TWC–4	5130	0.87	168616	0.77	41962	75811	27418	8.0
TWC–5	4612	1.47	95925	0.94	37399	133848	49988	6.7
DC–1	4937	1.05	33381	0.96	1472	8518	1249	3.7
GxA	5535	0.68	293773	0.54	41307	87812	32015	9.8
Selected GxA	5726	0.95	24473	0.96	90	8178	1116	2.7
Putra J-58	5277	1.56	79355	0.96	29988	102654	37857	5.3
Suwan 1	4747	0.74	34120	0.92	7021	32054	10401	3.9
L.S.D. (0.05)	429							

b_i= regression coefficient, s^2_d= mean square of deviations, R^2= coefficient of determination,
s^2= environmental variance, W_i= Wricke's ecovalance, σ^2_i= Shukla's stability variance,
CV= coefficient of variation.

Harvest index (HI) was calculated from the oven dried ears and vegetative parts of three randomly selected plants from the middle three rows of each plot at harvest. The HI is the ratio of economic yield (dry grain weight) to biological yield (dry total plant weight). Data collection for HI was only done in the second year plantings.

Data were taken on the following agronomic characters:

Pre-harvest data:

1. Days to tasseling (days), measured as the number of days from planting until the day pollen was shed,
2. Days to silking (days), measured as the number of days from planting until the day silk was formed,
3. Ear height (cm), measured as the height from the soil surface to the base of the first ear on the plant, at flowering, and
4. Plant height (cm), measured as the height from the soil surface to the point of attachment of the lowest lateral tassel branch of the plant at flowering.

Post-harvest data:

1. Days to maturity (days), measured as the number of days from planting until the day when the husks were totally dry,
2. Harvest index (%), measured as yield of biomass divided by aerial biomass, taken after samples were oven dried at 70°C at least for five days,
3. Grain yield (kg ha^{-1}), measured as grain weight from the harvested area converted to kilogram per hectare,
4. Ear weight per plant (g), measured as dehusked ear weight per plant,
5. Ear length (mm), measured as the distance from the base to the tip of ear,
6. Ear diameter (mm), measured as the average of three diameter readings using a vernier caliper, at the middle and the two ends of the dehusked ear,
7. Number of kernel rows/ear, counted as number of kernel rows on each ear,
8. Number of kernels per row, counted as number of kernels per row at random on three rows of each ear,
9. Grain weight per plant (g), measured as shelled grain weight per plant,
10. 100-grain weight (g), measured as the average weight of three samples of 100 grains taken randomly from the shelled grains from each plot, and
11. Shelling percentage (%), measured as the percentage of shelled grain weight over ear weight.

RESULTS AND DISCUSSION

Stability of Grain Maize Genotypes over Locations and Years

Combined Analysis of Variance and Regression

Results of the detailed combined analysis of variance involving four locations and two years (eight environments) for grain yield, shelling percentage, ear weight per plant, grain weight per plant, ear length and number of kernel rows per ear are shown in Table 2.

Locations (L) effect was significant (at $p \leq 0.01$) for all characters. Highly significant location x year (L x Y) interactions ($p \leq 0.01$) were found for grain yield and all yield components, indicating that performance of the genotypes varied with locations and years for yield and the yield components. The location effect was more pronounced than the year effect, as initially hypothesized. The pronounced effect was also indicated by genotypes (Table 2). Genotype x location (G x L) interaction effect was significant (at $p \leq 0.01$) for grain yield, ear weight per plant and ear length (at $p \leq 0.05$). Genotype x year (G x Y) and genotype x location x year (G x L x Y) interaction effects were not significant for all characters.

Results of the combined ANOVA with regression analysis (Table 3) showed that there were significant effects of genotypes (G). Further partitioning of the genotype x environment (G x E) interaction effects into linear and deviation from linear showed that, effects of environments (E) (linear) and G x E (linear) were significant when tested against pooled error mean squares and pooled deviations for grain yield, shelling percentage, ear weight per plant, grain weight per plant and number of kernel rows per ear, indicating that the linear portion of G x E was the important contributor to the interaction obtained in the analyses.

Genotype x environment interaction (linear) component was significant (at $p \leq 0.01$) when tested against pooled deviations from regression and pooled error. Effects of pooled deviations were found not significant for all characters.

Stability of Grain Maize Genotypes

Stability measurements of the genotypes, using the different methods of determination *viz*. comparison of mean values, regression coefficient (b_i), deviation from regression mean squares (s^2_d), coefficient of determination (R^2), environmental variance (s^2), Wricke's ecovalance (W_i), Shukla's stability variance (σ^2_i) and genotype grouping involving coefficient of variation (CV), for grain yield, are shown in Table 4. The mean values of the genotypes for grain yield ranged from 4200 to 5726 kg ha^{-1} (Table 4).

Grain Yield

Results of the stability analysis on genotypes for grain yield at the four locations over two years, determined using the different methods, are shown in Table 4.

Based on comparison of mean values and the linear regression, the most stable genotypes for grain yield were found to be Selected GxA and DC-1, as they showed high mean grain yields (5726 and 4937 kg ha^{-1}, respectively), regression coefficients close to unity (b_i= 0.95 and 1.05, respectively), and the least deviation from regression mean squares (s^2_d=24473 and 33381, respectively). In contrast, the least stable genotypes were SC-1, SC-2 and GxA, showing regression coefficients far from unity (b_i=0.81, 0.77 and 0.68, respectively) and high deviation from regression mean squares (s^2_d= 330039, 248707 and 293773, respectively). High coefficients of determination (R^2), indicating high stability were observed on Selected GxA (0.96), DC-1 (0.96), Putra J-58 (0.96) and SC-3 (0.95), while low R^2 values indicating low stability were shown by GxA (0.54), SC-1(0.59) and SC-2 (0.64).

Using the other stability determination methods, low values of environmental variances (s^2), Wricke's ecovalance (W_i) and Shukla's stability variance (σ^2_i) were observed for grain yield, indicating high stability of Selected GxA (s^2=90, W_i=8178 and σ^2_i=1116), DC-1 (s^2=1472, W_i=15105, σ^2_i=1249), SC-3(s^2=3612, W_i=23108, σ^2_i=6923) and TWC-2 (s^2=4254, W_i=15105, σ^2_i= 3810). In contrast, the least stable genotypes for grain yield were SC-2 (s^2=68131, W_i=183193 and σ^2_i=69178) and SC-1 (s^2=60594, W_i=127796, σ^2_i=47635).

Based on the genotype grouping method, the most highly stable genotype for grain yield was found to be Selected GxA, as it had the highest mean grain yield (5726 kg ha^{-1}) and low CV value (2.7%), followed by DC-1, as it had high mean grain yield (4937 kg ha^{-1}), although lower than that of Selected GxA, and low CV value (3.7%). Putra J-58 was also considered quite stable, due to its high mean grain yield (5277 kg ha^{-1}) and moderate CV (5.4%). In contrast, GxA and SC-2 were considered unstable due to their high CVs (9.8% and 9.6%, respectively), although they had higher grain yields (5535 and 5184 kg ha^{-1}, respectively). The highly unstable genotypes were SC-1 and TWC-1, as shown by their low mean grain yield (4855 and 4200 kg ha^{-1}, respectively) and high CV values (11.8% and 8.4%, respectively).

CONCLUSION

The significant effects of locations (L) and years (Y) revealed in this study indicate that there were fluctuations in the environmental conditions throughout the experiments. Variability among locations and years was mainly the result of differences in soil type, temperature, and soil moisture concentration during the growing seasons. The significant effects of genotypes (G) showed that the genotype differed in their grain yield. The significance of G x L effects demonstrated that genotypes revealed inconsistencies in performance across locations. This variation was attributed to different growth and edaphic factors at the different locations. The significant location and year interaction (LxY) effect indicates that there were fluctuations in the environmental conditions throughout the experiments.

A genotype is said to be stable if the deviation from the regression is low and regression coefficient (b_i) remains close to unity. From the present study, based on this method of determination, Selected GxA and DC-1 were considered stable, and their responses to the changes in environmental conditions were small, as indicated by high mean grain yield at all locations. SC-1, SC-2 and GxA were found to be unstable, because of their b_i values far from unity and having high deviations from the regression.

Genotypes having regression coefficient (b_i) values less than one (<1), shows a constant expression of the traits under a range of environments and better adaptation to poor environments. The SC-1, SC-2, TWC-1, TWC-3, TWC-4 and Suwan 1 were found to have adapted better to poor environments. In contrast, SC-3, SC-4, TWC-2, TWC-5 and Putra J-58 had b_i values more than one (>1), indicating their responsiveness to changes in the environmental conditions and specific adaptation to favourable ones.

By genotype grouping method, Selected GxA was found to be the most stable genotype, due to its high mean yield and low CV value, whereas genotypes SC-1, SC-4, TWC-1, TWC-3 and TWC-5 were highly unstable.

Hence, based on the different stability parameters, it could be concluded that, Selected GxA and DC-1 were the highest yielding genotypes and showed the highest stability, as revealed by their consistency in performance across environments and low responses to environmental changes. Therefore, Selected GxA and DC-1 could be considered for recommendation of planting over a wide range of environments. In contrast, the unstable genotypes were SC-1, SC-2, TWC-1, TWC-3 and TWC-5, because their yield responses to environmental changes were very high.

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