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Phenotypic Stability of Selected Tropical Maize Genotypes at Four Locations

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Abstract: The analysis of genotypes by environmental interactions in essential in plant breeding programme because it indicates the stability of genotypes before release. Highly stable genotypes are desirable. In the present study, the stability of performance of selected 14 grain maize genotypes were evaluated at four different locations in Malaysia for grain yield, number of kernels per ear row and 100-grain weight. For average main yield, number of kernels per ear rows and 100-grain weight ranged from 4541 to 6110 kg ha^{-1}, 32.6 to 38.0, 23.1 to 26.4 g respectively. The different methods of stability analyses were in close agreement with each other in revealing the stability of the genotypes evaluated. Selected G×A was identified as the genotypes with highest grain yield and most stable performance. TWC-5 was the lowest yielding and the most unstable. For number of kernels per ear row, SC-2, TWC-2 and Selected G×A were the most stable. For 100-grain weight, Suwan 1 was the best performer, revealing average stability. The high stability of Selected G×A was probably due to its nature of having a broader genetic base, being a synthetic population, as opposed to its hybrid counterparts.

Key words: Maize genotypes, *Zea mays* L., stability analysis, genotypes x environment interaction

Introduction

The aim of a plant breeding programme is to improved genotypes for some predefined target population of environments. Population genotypes are usually evaluated in different environments before the desired ones are selected. Genotypes x environment (G x E) interaction, which is associated with the differential performance of materials tested at differential performance of materials tested at different locations and in different years and its influence on the selection and recommendation of cultivars has long been recognized (Lin *et al.,* 1986; Geletu and Tsegayeaand, 1995; Annicchiarico, 1997a). Selection of genotypes is based on the assessment of their phenotypic performance at a number of locations provides useful information to determine their adaptability and stability (Crossa, 1990). Measuring G × E interactions helps to determine an optimum breeding strategy of either to breed for specific or wide adaption, which depends on the expression of stability under a limited or wide range of environments (Romagosa and Fox, 1993; Annicchiarico, 1997b; Yue *et al.,* 1997) Moreover, genotype x location interaction allows the grouping of relatively similar sites in relation to genotypic performance (Eberhart and Russell, 1966 Romagossa and Fox 1993; Annicchiarrico, 1997b)

Stability refers to non-erratic performance with respect to agronomic traits and stable cultivars shows minimal or low interactions (Allard and Bradshaw, 1964). Stability also denotes consistency in rank relative to other cultivars in a given set of environments (Yue *et al.,* 1997). Yield stability is the ability of a genotype to avoid substantial fluctuations in yield over a range of environments (Heinrich *et al.,* 1983). Varieties with high and stable performance are desirable (Becker and Leon, 1988). Instability is caused by the different expression of traits across environments or G × E interactions, which decrease progress from selection, since they reduce the association between genotypic overcome the problem of interment very complicated (Romagosa and Fox, 1993).

The maize breeding programme conducted at Universiti Putra Malaysia since 1987 is directed towards the development of hybrid varieties (Saleh, 1998). The objectives of the present study were to investigate the G × E interment on selected grain maize genotypes with reference to grain yield, number of kernels per ear row and 100-grain weight and to determine the stability of the of the genotypes in plantings at four locations in Malaysia.

Materials and Methods

Fourteen selected grain maize genotypes were grown and evaluated for performance at four locations, viz. Pandang Rengas (Peark), Rhu Tapai (Terengganu), Sungai Udang (Melaka) and Serdang (Selangor). This study was conducted from March, 2000 to December, 2001. The genotypes used in this study were single cross, three way cross and double cross hybrid as well as synthetic populations developed from maize breeding programme previously conducted at Universiti Putra Malaysia (Saleh

Table 1: Fourteen genotypes evaluated in the study and their pedigrees

Genotypes	Pedigree
Single Cross Hybrids (SC):	
SC-1	SM 5-4×IPB 14-2
SC-2	SM 5-4×SW2
SC-3	SM 5-4×MT13
SC-4	SW2×MT13
Three way cross hybrids (TWC):	
TWC-1	(SM 5-4×SW9)×IBP 14-2
TWC-2	(SM 5-4×SW9)×MT13
TWC-3	(SM 5-4×IPB 8-2)×MT13
TWC-4	(SM 5-4×IPB 15-2)×SW2
TWC-5	(SM 5-4×IPB 8-2)×SM7-6
Double cross hybrids (DC):	
DC-1	(SM 5-4×SW9)×(MT13×IPB15-2)
Synthetics:	
G×A	Synthetic population
Selected G×A	Selected synthetic population
Check varieties:	
Putra J-58	Hybrid variety
Suwan 1	Composite variety

and Sujiprihati, 1997), evaluated together with two check cultivars (Table 1).

At each location, the experiment was conducted in a randomized complete block design (RCBD) with four replications. Similar agronomic practices were applied at each location. The middle three rows of 3m long were used as the harvest area of each plot. Ten plants from each plot were chosen randomly as samples for measurements of number of kernels per ear row and 100-grain weight.

Data for grain yield, number of kernels per ear row and 100-grain wight were subjected to combined analyses of variance. Location effects were considered as random variables while the genotype effects were treated as fixed. Different stability parameters were used and compared. The method of Eberhart and Russell (1996) employs the regression of individual means on the environmental index which is defined as the mean of all genotypes grown in that environment. The regression coefficient, b and the deviation from the regression s^2d are the parameters of stability. Both b and s^2d have been used widely in previous studies (Langer *et al.*, 1979; Yue *et al.*, 1997). Ecovalance (W_i) developed by Wricke (1962) and stability variance statistics) (θ^2_i) developed by Shukla (1972) and then other commonly used parameters of stability like coefficient of determination, r^2; environmental variance, s^2 (Becker and Leon, 1988; Nissila, 1992) and the grouping technique of mean against coefficient of variation (c.v.), were also considered.

Results and Discussion

The genotypes evaluated revealed inconsistent performance for grain yield, as was reflected by their

Table 2: Mean grain yields (kg ha^{-1}) of the grain maize genotypes evaluated and their ranks (in parantheses), at four locations

Genotype	Grain yield (kg ha^{-1}) Perak	Terengganu	Melaka	Serdang	Genotype mean
SC-1	3677(11)	6533(4)	5062(9)	4397(14)	4917(9)
SC-2	3725(10)	5252(14)	5478(6)	5021(11)	4871(13)
SC-3	4687(3)	5343(13)	6128(2)	5465(5)	5405(4)
SC-4	3071(13)	5567(12)	4649(12)	4875(12)	4541(14)
TWC-1	4080(9)	5801(11)	4355(13)	5339(8)	4894(12)
TWC-2	3632(12)	5902(9)	4804(10)	5282(9)	4905(11)
TWC-3	4136(7)	6084(6)	4744(11)	5925(3)	5222(6)
TWC-4	3061(14)	6224(5)	5586(4)	5128(10)	5000(8)
TWC-5	4211(6)	6002(8)	5393(7)	4860(13)	5117(7)
C-1	4291(4)	6049(7)	5558(5)	5363(7)	5315(5)
G×A	5182(1)	6669(3)	5239(8)	6201(2)	5848(2)
Selected G×A	5159(2)	6807(2)	6136(1)	6337(1)	6110(1)
Putura J-58	4288(5)	7427(1)	5991(3)	5653(4)	5840(3)
Suwan 1	4081(8)	5802(10)	4355(13)	5399(6)	4909(10)
Location mean	4103	6091	5287	5368	5212
S.E. (d.f.=39)	560	678	633	603	449

Table 3: Mean number of kernels per ear row of the grain maize genotypes evaluated and their ranks (in paranthesis), at four locations

Genotype	Number of kernels per ear row Perak	Terengganu	Melaka	Serdang	Genotype mean
SC-1	25.7(14)	32.4(14)	32.6(14)	35.2(11)	35.4(11)
SC-2	34.3(5)	38.0(2)	38.0(1)	39.3(2)	38.1(2)
SC-3	28.6(13)	35.1(9)	34.4(11)	36.3(9)	37.7(4)
SC-4	36.8(1)	36.7(4)	35.3(7)	39.0(3)	37.1(6)
TWC-1	30.0(12)	34.6(11)	34.0(12)	34.6(13)	36.7(8)
TWC-2	33.7(6)	35.2(8)	35.7(5)	38.2(7)	35.8(10)
TWC-3	34.6(3)	36.2(6)	35.4(6)	38.9(4)	36.2(9)
TWC-4	33.7(6)	38.4(1)	35.3(7)	35.2(12)	33.9(14)
TWC-5	30.2(11)	35.9(7)	35.0(10)	36.0(10)	37.8(3)
C-1	35.1(2)	36.4(5)	38.0(1)	41.1(1)	39.5(1)
G×A	34.4(4)	33.4(13)	35.1(9)	38.3(6)	34.3(12)
Selected G×A	34.0(8)	34.9(10)	35.9(4)	37.1(8)	37.4(7)
Putura J-58	31.5(9)	37.4(3)	36.3(3)	38.5(5)	37.7(4)
Suwan 1	30.7(10)	33.6(12)	32.7(13)	32.2(14)	34.1(13)
Location mean	32.4	35.6	35.3	37.2	36.4
S.E. (d.f.=39)	2.3	3.7	1.8	2.9	2.3

different rankings at the different locations. This showed the varied performance of the genotypes and their superiority was dependent on environment. The highest yield was given by Selected G×A with mean over locations of 6110 kg ha^{-1} followed by G×A (location mean of 5848 kg ha^{-1}) (Table 2). The lowest yield was observed on SC-4 (4541 kg ha^{-1}). The check varieties. The check varieties, Putra J-58 and Suwan 1 produced mean over locations grain yields of 5840 and 4909 kg ha^{-1}, respectively.

For number of kernels per ear row, DC-1 and SC-2 gave the highest mean values (39.5 and 38.1, respectively), while TWC-4 gave the lowest (33.9) (Table 3). These were comparable to that of hybrid check, Putra J-58 (37.7), but much higher than that of the open-pollinated check, Suwan 1 (34.1).

For 100-grain weight, Suwan 1 had the highest mean value

Table 4: Mean 100-grain weight (g) of the grain maize genotypes evaluated and their ranks (in parantheses), at four locations

	100-grain weight (g)				
Genotype	Perak	Terengganu	Melaka	Serdang	Genotypemean
SC-1	21.0(10)	27.4(3)	24.4(13)	24.6(6)	24.6(6)
SC-2	22.5(3)	24.7(5)	26.4(5)	24.1(7)	24.1(7)
SC-3	21.5(5)	24.2(12)	24.6(12)	24.0(11)	24.0(11)
SC-4	22.8(1)	22.7(2)	27.7(2)	24.1(7)	24.1(7)
TWC-1	21.4(9)	26.3(14)	24.2(14)	24.1(7)	24.1(7)
TWC-2	20.9(11)	22.4(4)	26.5(4)	23.1(14)	23.1(14)
TWC-3	19.8(13)	25.1(9)	25.4(9)	23.5(13)	23.5(13)
TWC-4	22.4(4)	25.8(7)	25.9(7)	25.2(4)	25.2(4)
TWC-5	19.8(13)	26.7(10)	25.2(10)	23.9(12)	23.9(12)
C-1	20.6(12)	25.9(1)	28.2(1)	25.5(3)	25.5(3)
G×A	21.5(5)	27.5(6)	26.3(6)	25.6(2)	25.6(2)
Selected G×A	21.2(7)	25.2(3)	26.6(3)	24.9(5)	24.9(5)
Putura J-58	21.2(7)	25.5(11)	24.8(11)	24.1(7)	24.1(7)
Suwan 1	22.8(1)	28.2(8)	25.6(8)	26.4(1)	26.4(1)
Location mean	21.6	25.5	25.8	24.5	24.5
S.E. (d.f.=39)	1.9	2.0	2.4	1.3	1.3

Table 5: Results of the combined analysis of variance for performance of grain genotypes at four locations

		Mean squares		
Source of variation	d.f.	Grain yield (kg ha^{-1})	No. of kernels per ear row	100-grain weight (g)
Genotypes (g)	13	3160082**	41.20**	12.82**
Reps/locations (R/L)	12	1825943**	26.04**	9.89**
Locations (L)+(G×L)	42	38702290**	321.12	250.18**
L (Linear)	1	113729846**	308.85**	217.80**
G×L (Linear)	13	2020428**	32.91**	653.39**
Pooled deviations	28	165911	1.80	2.09
Pooled error	156	541048	1568.00	3.88

*,** significant at p≤0.05 and 0.01, respectively

(26.4 g), while TWC-2 had the lowest (23.1 g) (Table 4). No genotype had average 100-grain weight over locations higher than Suwan 1.

Results of the combined analysis of variance for grain yield, number of kernels per ear row and 100-weight indicate that the genotype x location (G×L) interaction effects were statistically significant (Table 5). This demonstrates the presence of genotype and environmental differences governing the expression of these traits and the significant contribution of G×L interactions in influencing genotype performance. Partitioning of interaction effects using Eberhart and Russell's (1966) regeneration method showed that Location (Linear) and G×L (Linear) effects were significant for all traits. This represents the heterogeneity of the regression coefficients.

Results of the different analyses of stability and adaption on the genotypes are shown in Table 6 for grain yield, Table 7 for number of kernels per ear row and Table 8 ranged from 0.40 to 1.62 (Table 6), while those for 100-grain weight ranged from 0.52 to 1.57 (Table 8). The deviations were low for all traits, showing the good fit of the regression model.

Eberhart and Russell (1966) proposed that an ideal population of genotype is one which has the highest yield over a broad range of environments, a regression coefficient (b) value of 1.0 and deviation mean square of zero. Based on result of the joint regression analysis, Selected G×A was classified as highly stable over environments because its regression coffined was close to unity (b=1), having lowest deviation from regression (s^2d) and the highest grain yield (Table 6). Although TWC-4 showed b value of 1.0 s^2d value was very high and therefore considered to be unstable. Generally, regression coefficient value of more than one (b>1) indicates that the genotype tested is of low stability, while value close to one indicates that the genotype is more stable and consistent in the performance across environments, DC-1 and Suwan 1 had regression coefficients significantly less than 1, which indicate their above-average adaptability and lack of response to environmental changes for grain yield, with relatively small fluctuation in performance between poor and good environments. This trend was also reported in sorghum (Heinrich *et al.,* 1983) and tetraploid wheat landraces (Tesemma *et al.*, 1998) to indicate their abilities to adopt to environmental changes.

Genotypes indicating low environmental variances (s^2) and low coefficients of variation (c.v.) are considered stable (Lin *et al.,* 1986). Low c.v. values and environmental variances for grain yield were shown by Selected G×A, DC-1 and Suwan 1, confirming their high stability. The unstable cultivars, TWC-5 and DC-1 had the highest s^2 values and high c.v.s. for grain yield. Generally, genotypes with high b values tended to have high s^2 and c.v.s. and vice versa. The r^2 values f or grain yield were mostly high, indicating environmental effects as the main determinants of phenotypic performance. Ecovalance (W_i) measures the genotype environment effects for each environment sum of squares also increases. Lower values are indicators of genotype stability (Wricke, 1962). For grain yield, the lowest W_i was found on Selected G×A. The lowest θ^2_i value for grain yield was also revealed by Selected G×A (Table 6), thus further confirming that Selected G×A was the most stable and adaptable genotype.

For number of kernels per ear row, SC-2, TWC-2 and Selected G×A were the stable genotypes, with b<1 and s^2d (Table 7). The b value for TWC-5 was significantly lower than 1, showing its lack of response to changes in environment and above average adaptability. Lower c.v.s. and low s^2 were shown by SC-2, Selected G×A and Suwan 1, indicating their stability. The lowest W_i was found on TWC-5.

For 100-grain weight, SC-3 was the most stable genotype, with b<1 and low s_2 (Table 8). TWC-4 and Putra J-58 had

Table 6: Stability parameters for grain yield of grain maize genotypes evaluated at four locations

Genotype	Mean (kg ha^{-1})	b	s^2	r^2	s^2d	W_i	θ_i^2	c.v. (%)
SC-1	4917	1.34	3655352	0.82	392694	392694	110814	12.7
SC-2	4871	0.40	319624	0.31	363199	363199	102211	11.1
SC-3	5405	1.28**	3304174	0.99	15346	46217	754	2.7
SC-4	4541	0.82	1380912	0.74	23960	135501	66208	10.1
TWC-1	4894	0.85	147053	0.75	251850	137211	69734	10.3
TWC-2	4905	1.15*	2692488	0.97	37139	30211	7110	3.9
TWC-3	5222	0.87	1530078	0.88	108241	64969	27849	6.4
TWC-4	5000	1.00	203927	0.77	303238	151621	84722	10.5
TWC-5	5117	1.62*	5324442	0.95	146087	267695	38887	7.6
C-1	5315	0.89*	1604679	0.97	21539	17037	2560	2.8
G×A	5848	0.72	1063291	0.66	273660	175625	76095	9.0
Selected G×A	6110	0.84**	1429343	0.99	6367	16356	-1865	1.3
Putura J-58	5840	1.53*	4723814	0.95	130606	205307	34371	6.2
Suwan 1	4909	0.69*	976617	0.94	32795	64107	5843	3.6
S.E. (d.f.=39)	449							

Table 7: Stability parameters for number of kernels per ear row of grain maize genotypes evaluated at four locations

Genotype	Mean (kg ha^{-1})	b	s^2	r^2	s^2d	W_i	θ_i^2	c.v. (%)
SC-1	32.6	1.63*	43.70	0.97	0.76	0.18	0.18	2.68
SC-2	38.0	0.42	2.86	0.85	0.25	0.03	0.03	1.32
SC-3	34.4	1.66*	45.55	0.93	1.67	0.45	0.45	3.75
SC-4	35.3	2.06**	70.47	0.99	0.33	0.06	0.06	1.64
TWC-1	34.0	1.10	19.90	0.82	2.23	0.61	0.61	4.39
TWC-2	35.7	0.71	8.25	0.76	1.29	0.34	0.34	3.18
TWC-3	35.4	1.53	38.90	0.96	0.78	0.19	0.19	2.49
TWC-4	35.3	0.27	1.21	0.09	6.27	0.25	0.25	7.09
TWC-5	35.0	0.75*	9.20	0.94	0.31	0.05	0.05	1.58
C-1	38.0	1.01	16.80	0.75	2.74	0.76	0.76	4.35
G×A	35.1	0.41	2.84	0.20	5.66	1.61	1.61	6.78
Selected G×A	35.9	0.62	6.40	0.76	0.99	0.25	0.25	2.77
Putura J-58	36.3	1.37	30.87	0.96	0.30	0.05	0.05	1.50
Suwan 1	32.7	0.47	3.72	0.52	1.72	0.46	0.46	4.01
S.E. (d.f.=39)	2.3							

Table 8: Stability parameters for 100-grain weight of grain maize gernotypes evaluated at four locations

Genotype	Mean (kg ha^{-1})	b	s^2	r^2	s^2d	W_i	θ_i^2	c.v. (%)
SC-1	24.6	1.11	16.00	0.74	2.87	1.48	0.80	7.0
SC-2	24.1	0.60	4.63	0.48	2.51	1.07	0.68	6.8
SC-3	24.0	0.77	7.62	0.80	0.93	0.21	0.24	3.9
SC-4	24.1	0.52	3.58	0.21	6.84	1.57	2.00	10.7
TWC-1	24.1	0.86	9.56	0.78	1.34	0.25	0.33	2.1
TWC-2	23.1	0.79	8.14	0.48	4.33	0.86	1.24	9.2
TWC-3	23.5	1.22	9.24	0.96	0.41	0.10	0.08	3.3
TWC-4	25.2	0.84**	9.13	0.98	0.11	0.02	-0.01	1.7
TWC-5	23.9	1.33	8.27	0.89	1.47	0.38	0.41	5.2
C-1	25.5	1.57*	31.99	0.94	1.05	0.57	0.22	5.4
G×A	25.6	1.28*	21.19	0.92	0.92	0.24	0.23	4.2
Selected G×A	24.9	1.17*	17.71	0.91	0.84	0.16	0.19	3.4
Putura J-58	24.1	0.91*	10.70	0.95	0.25	0.02	0.03	2.4
Suwan 1	26.4	1.06	14.70	0.63	4.28	0.80	1.20	8.4
S.E. (d.f.=39)	1.9							

b= regression coefficient s^2=environmental variance r^2=coefficient of determination
s^2d=deviation from regression W_i=Ecovalance θ_i^2=stability variance
c.v=coefficient of variation *,** significant at $p \leq 0.05$ and 0.01, respectively

b values significantly less than 1, indicating the constant expression of the traits under the range of environments and better adaption to poor environments. SC-1, TWC3, TWC-5, DC-1, G×A, Selected G×A and Suwan 1 had b values > 1, which indicate their responsiveness to changes in environmental conditions and specific adaption to favourable ones. TWC-4 had the lowest c.v. value, while SC-4 the highest. The highest r^2 and lowest W_i values were found on TWC-4. This indicates that environmental effects were mainly responsible for the expression of the traits and similar patterns of adaption and stability were reflected for all traits.

Selected G×A was found to be a highly stable genotype, while SC-3 and TWC-2 should also be noted as stable genotypes that have importance towards efforts in choosing suitable cultivars.

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