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Effects of Location on Performance of Selected Tropical Maize Hybrids Developed in Malaysia

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ABSTRAK

Lapan belas hibrid terpilih jagung bijian tempatan yang terdiri daripada sepuluh kacukan tunggal, empat kacukan dua ganda dan empat kacukan tiga hala telah dinilaikan dengan dua varieti kawalan pendebungaan bebas (Metro dan Suwan 1), di tiga lokasi di Semenanjung Malaysia. Kajian ini bertujuan untuk membandingkan prestasi hibrid-hibrid tersebut pada lokasi-lokasi berkenaan, menilaikan interaksi genotip x lokasi yang ditunjukkan untuk hasil dan ciri penting yang lain, dan menganggarkan kebolehwarisan ciri-ciri tersebut. Banyak di antara hibrid-hibrid tersebut didapati memberikan hasil yang lebih tinggi dari varieti-varieti kawalan. Kesan lokasi bererti yang ditunjukkan untuk hasil bijian dan kebanyakan ciri lain memberikan gambaran bahawa faktor-faktor persekitaran dan tumbesaran yang terdapat di lokasi-lokasi berlainan telah mempengaruhi prestasi hibrid-hibrid tersebut. Interaksi genotip x lokasi didapati tidak bererti ke atas ciri-ciri penting, menunjukkan bahawa kedudukan kepentingan genotip-genotip dalam prestasinya adalah seragam pada setiap lokasi. Prestasi hibrid adalah terbaik di Terengganu, berbanding Selangor dan Perlis. Nilai kebolehwarisan lebih tinggi diperoleh di Terengganu untuk ciri-ciri yang diukur menekankan lagi keseragaman dalam faktor-faktor persekitaran yang mengawal tumbesaran jagung bijian di lokasi tersebut. Berdasarkan kepada prestasi keseluruhan, tiga kacukan tunggal (SC-1, SC-2 dan SC-8), satu kacukan dua ganda (DC-11) dan dua kacukan tiga hala (TWC-15 dan TWC-17) didapati sangat berpotensi untuk dilakukan penilaian seterusnya ke arah pengeluaran varieti baru.

ABSTRACT

Eighteen selected locally-developed maize hybrids involving ten single, four double and four three-way crosses were evaluated with two open-pollinated check varieties (Metro and Suwan 1) at three locations in Peninsular Malaysia. The study was aimed to compare performance among the hybrids at the locations separately and when combined, to evaluate the genotype x location interaction revealed for yield and other important traits, and to estimate the heritability of the traits. Many hybrids were found to have out-yielded the check varieties. Significant effects of location for grain yield and most other traits indicated that the environmental and growth factors characterising the locations considerably affected the performance of the hybrids. Genotype x location interactions were not significant for the important traits, indicating that the ranking in performance of the genotypes was consistent among locations. Performance of the hybrids was best in Terengganu as compared to Selangor and Perlis. Higher heritability estimates for characters when measured in Terengganu further revealed the uniformity of environmental factors governing maize growth in that location. Based on the overall performance, three single crosses (SC-1, SC-2 and SC-8), one double cross (DC-11) and two three-way crosses (TWC-15 and TWC-17) were found to be highly potential for further trials towards new variety release.

INTRODUCTION

Maize (*Zea mays* L.) is an important import commodity in Malaysia, as almost all maize grains utilised to support the local animal feed industry are imported. Local maize production is impaired by high production cost and low productivity from the use of low-yielding varieties (Leong 1987; Setefarzi 1990). To ensure profitability of local maize production, it is necessary to produce high yielding varieties, in particular, hybrids that are stable and adaptable to various environments in the country (Saleh *et al.* 1994).

In maize breeding, the response of genotypes to different environments on which evaluations are conducted is an important consideration. Neglecting the effects of genotype x environment interactions in variety development would reduce the effectiveness of selection programmes, thus producing varieties not readily suitable across varied environments (Oosterum *et al.* 1993). It is more meaningful to obtain genotypes that are stable across environments, or genotypes stable to any particular environment over a number of years. Genotype x environment interactions have been shown to contribute to yield variations (Sprague and Federer 1951). A stable genotype is one that shows minimum genotype x environment interaction, or low variation in performance in varied environments (Hanson 1970), while an unstable genotype is one which expresses high genotype x environment interaction, and responds to changes in the environment (Piepho 1994).

Weatherspoon (1970), in his evaluation on 36 maize single cross hybrids, 36 double crosses and 36 three-way crosses in highly varied locations, reported very high genotype x environment interaction effects. In contrast, the study by Ordas (1991) reported the absence of genotype x year and genotype x location interactions on the performance of two maize populations. With regards to the use of tropical maize germplasm, Subandi (1981), from his evaluation on 15 maize genotypes over 31 environments in Indonesia, reported that genotype x planting season and genotype x location within season interactions were very high, where component of variance for the latter was found to be higher than that of the former.

Selection of genotypes would only be effective if based on characters governed by genetic factors, i.e. based on characters with high heritability. Heritability estimates for characters on different maize populations, and using various methods of estimation were reported by many previous workers (Lee 1974, Daniel and Batjay 1975; Saleh *et al.* 1994), where estimates obtained varied with methods of estimation, genotypes used and environments of evaluation.

Realising the constraints in the local maize production, an extensive maize breeding programme was conducted at Universiti Putra Malaysia, aimed at developing superior hybrid varieties for grain yield (Saleh *et al.* 1995). The present study evaluated potential single, double and three-way cross hybrids developed and selected from this programme, in three separate locations in the country. The objectives were to identify those superior and stable for yield, at each location and locations combined, to evaluate the genotype x environment interactions revealed for yield and other important agronomic characters, and to estimate broad-sense heritability for important traits measured.

MATERIALS AND METHODS

Plant Materials

This study was an advanced stage of a long term tropical maize hybrid variety development programme conducted at Universiti Putra Malaysia, Serdang. Based on yield performance and general combining ability in previous evaluations, superior inbred lines were entered into a diallel crossing scheme to produce F_1 hybrids. Evaluations of performance of these hybrids were previously done in 1993 and 1994 (Sujiprihati 1996; Saleh and Sujiprihati 1997). Findings from these previous evaluations were based on the selection of hybrids for use in this present study. Ten best single cross (SC) hybrids involving various combinations among nine inbred lines, four double crosses (DC) and four three-way crosses (TWC) were evaluated in this study with two open-pollinated check varieties, Metro and Suwan 1, originating from Indonesia and Thailand respectively.

Location

Evaluations of all the genotypes were conducted at three locations in Peninsular Malaysia, *viz.* Serdang in the state of Selangor, Kuala Terengganu in Terengganu, and Kangar in Perlis. The locations represented different geographical zones and soil types. In Serdang, located in the middle of the southern part of the peninsula (with the bearing of 3° N, 101° E, at 31 m above sea level), the soil type was sandy loam of order Ultisol (Bungor series, Typic Kandiudult); in Kuala Terengganu, located on the east coast of the peninsula (with the bearing of 5° N, 105° E, at 15 m above sea level), the soil type was sandy, belonging to the order Spodosol (Rudua series, Typic Haplorthod); while in Kangar, located in the northern part of the peninsula (with the bearing of 7° N, 100° E, at 35 m above sea level), the soil type was loam of order Ultisol (Bukit Temiang series, Typic Hapludult).

Evaluation

At each location, the evaluation was carried out in a Randomised Complete Block Design, with three replications. Each replicate consisted of 20 plots, each represented by a genotype. Each plot measured 5.0m x 4.5m (22.5 m^2), with the planting density of 0.75m x 0.25m. Every plot consisted of six plant rows, each five metres in length, giving a total of 20 plants per row, and 120 plants per plot. Four middle rows of each plot measuring four metres long were used as the harvest area, giving an area of 12 m^2, with 64 plants. Among the plants in the harvest area, 16 plants were used as samples for the measurements of individual plant data. In cases where more than one ear were present on each plant, the largest ear was used.

Cultivation Practices

Before planting, the soil was ploughed twice to a depth of 15 to 30 cm, followed by rotovation. The soil pH was raised to 5.5 to 6.5 by applying Ground Magnesium Limestone before rotovation. Planting was done manually, at the rate of two seeds per point, and plants were later thinned to just one per point 10 days after planting. Fertilisers at the rate of 160 kg N ha^{-1}, 100 kg ha^{-1} P_2O_5 and 100 kg ha^{-1} K_2O were given in split applications, where a balanced compound fertiliser (15:15:15) was used seven days after planting, followed by Urea (46% N) 20 and 35 days after planting. Weeds were controlled manually using pre-emergence herbicide, 'Lasso' (2-chloro-2'-6'-diethyl-N-methoxymethyl) and post-emergence contact herbicide, 'Gramoxone' (1,1, dimethyl-dimethyl-4, 4'-bipyridinium). A sprinkler irrigation system was used to supply water to the plants when necessary.

Data Collection

Data collected involved pre-harvest data, including plant and ear heights at flowering, and days to tasseling and maturity, and post-harvest data, including yield and yield components, and ear and grain trait measurements taken at 15% grain moisture content.

Data Analysis

Data were subjected to the analysis of variance (ANOVA) carried out separately for each location, and also locations combined, to determine the effects of genotypes and also locations involved. Data from each location were however, first analysed for uniformity of the error mean squares using the test of homogeneity of error variances (Steel and Torrie 1980), following which, only data from locations that showed homogeneity were combined. Effects of location and genotype x location interaction for the characters measured on the combined data were analysed using ANOVA as proposed by McIntosh (1983). The ANOVA table key-outs with the expected mean squares (EMS) for each location, and locations combined are shown in Tables 1 and 2 respectively. For the combined analysis, to test the effects of location, replication/location mean squares ($MS_{R/L}$) were used as the error term (Table 1). For traits that did not show significant genotype x location interaction, however, the genotype x location mean squares were pooled into error mean squares (Table 2). The effects genotypes were considered fixed, while those of locations and replications were random. The Duncan's New Multiple Range Test was used to compare mean performances among the hybrids and also between them and the control varieties.

TABLE 1
Key-outs for ANOVA on characters measured on maize genotypes analysed at locations separately

Source of variation	d.f.	Mean squares	E(MS)
Replications (R)	r-1	MS_R	$\sigma^2_e + g\sigma^2_R$
Genotypes (G)	g-1	MS_G	$\sigma^2_e + r\sigma^2_G$
Error	(r-1)(g-1)	MS_e	σ^2_e

r = number of replications; g = number of genotypes;
σ^2_R = replication variance; σ^2_G = genotypic variance; σ^2_e = error variance.

TABLE 2
Key-outs for ANOVA on characters measured on maize genotypes at locations combined

Source of variation	d.f.	Mean squares	E(MS)
Locations (L)	l-1	MS_L	$\sigma^2_e + r\sigma^2_{GL} + g\sigma^2_{R/L} + gr\sigma^2_L$
Reps. within L (R/L)	l(r-1)	$MS_{R/L}$	$\sigma^2_e + g\sigma^2_{R/L}$
Genotypes (G)	g-1	MS_G	$\sigma^2_e + r\sigma^2_{GL} + rl\sigma^2_G$
G X L	(g-1)(l-1)	MS_{GXL}	$\sigma^2_e + r\sigma^2_{GL}$
Error	l(r-1)(g-1)	MS_e	σ^2_e

l = number of locations; r = number of replications; g = number of genotypes;
σ^2_L = locations variance; $\sigma^2_{R/L}$ = replications/location variance;
σ^2_G = genotypic variance; σ^2_{GL} = genotype x location variance; σ^2_e = error variance.

Broad-sense heritability (h^2_B) for traits in the hybrid populations were estimated separately for each location using the components of variance in the ANOVA table procedure (Table 1), as proposed by Baker (1984), as follows:

$$h^2_B = \frac{\sigma^2_G}{\sigma^2_P}$$

where:

$$\sigma^2_G = \frac{(r\sigma^2_G + \sigma^2_e) - \sigma^2_e}{r} = \frac{MS_G - MS_e}{r}$$

$$\sigma^2_P = \sigma^2_G + \sigma^2_e = \frac{MS_G - MS_e}{r} + MS_e$$

h^2_B : broad-sense heritability,
σ^2_G : genotypic variance,
σ^2_P : phenotypic variance,
σ^2_e : environmental variance,
MS_G : mean squares for genotypes in ANOVA,
MS_e : mean squares for error in ANOVA, and
r : number of replications.

For calculations of broad-sense heritability in the combined analysis, referring to Table 2, the equations for the variance components are as follows:

$$\sigma^2_G = \frac{(r\sigma^2_{GL} + rl\sigma^2_G + \sigma^2_e) - (r\sigma^2_{GL} + \sigma^2_e)}{rl} = \frac{MS_G - MS_{GL}}{rl}$$

$$\sigma^2_P = \sigma^2_G + \sigma^2_e = \frac{MS_G - MS_{GL}}{rl} + MS_e$$

where:

σ^2_{GL} : genotype x location variance,
MS_G : mean squares for genotypes in ANOVA,
MS_{GL} : mean squares for genotype x location interaction in ANOVA,
MS_e : mean square error in ANOVA,
l : number of locations, and
r : number of replications.

RESULTS AND DISCUSSION

Effects of Location, Genotype and Genotype x Location Interaction

From results of the test of homogeneity of error variances, for almost all traits measured, error variances were found to be homogeneous, and therefore, combined data from the three locations were also used in interpretations. The summary of the results of the combined analysis of variance is shown in Table 3. In the combined

TABLE 3
Mean squares in ANOVA for characters measured on 20 maize genotypes evaluated for combined location

Source of variation	d.f.	Mean Squares								
		Grain yield per ha.	Plant Height	Days to Tasseling	Days to Maturity	Shelling %	Ear weight	Ear length	Ear diameter	100-grain weight
Locations (L)	2	74133917**	1674**	105.43**	10.77*	195.8^{ns}	33554**	15604.5**	330.22**	61.31*
Replications within L (R/L)	19	3567375**	449*	11.43**	1.16^{ns}	40.8*	1855**	251.8**	28.03**	9.91**
Genotypes (G)	19	2599279**	1122**	6.58**	6.48**	18.3^{ns}	909**	318.4**	8.04**	6.99^{ns}
G X L	38	ne	ne	ne	ne	ne	322*	112.7**	ne	4.27*
Error	114	360934	175	0.78	0.92	13.7	191	61.2	1.95	2.52

ne : mean squares for G X L are negligible, and therefore pooled with error mean squares for analyses.
** : significant at p≤0.01; * : significant at p≤0.05; ns : non-significant.

analysis, grain yield and all other characters, except shelling percentage showed significant effects of location on the overall performance of the genotypes, indicating the presence of variations in the growth factors affecting the genotypes at different locations. With regards to variation among genotypes in the combined analysis, grain yield and all other characters except shelling percentage and 100-grain weight were highly significantly affected, indicating that the genotypes evaluated varied greatly in their performance across locations.

Genotype x location interactions were found significant only for ear weight, ear length and 100-grain weight, while the others, including grain yield did not exhibit significant interaction (Table 3). The absence of significant genotype x location interaction for grain yield and other important traits such as plant height and days to tasseling indicates that, for these characters, the 18 hybrids and the two check varieties evaluated in general, showed quite similar patterns of performance at the three different locations. The three locations selected, each representing the middle, eastern and northern part of Peninsular Malaysia, although showing significant location effects on the overall performance of the genotypes, however, did not reveal significant genotype x location interactions for the important traits measured. This is a good indication of the presence of generally good adaptability of the genotypes, but more evaluations at various environments are needed to explore this phenomenon.

Performance of Genotypes

Mean performances of the 18 hybrids in comparison with the check varieties at each location and locations combined, for all the nine characters are shown in Table 4.

Grain yields of the genotypes differed greatly with locations, where superior ones were identified specific to locations. The overall mean grain yield was 5612 kg/ha. Evaluation in Terengganu exhibited the best overall grain yields, with overall means of 6782 kg/ha, followed by Perlis (5483 kg/ha), and lastly, Selangor (4570 kg/ha). From evaluations in Selangor, four hybrids showed grain yields significantly higher than both the check varieties, *viz.* DC-11 (5708 kg/ha), TWC-15 (5389 kg/ha), SC-2 (5342 kg/ha) and SC-1 (5141 kg/ha). The two check varieties, Suwan 1 and Metro gave grain yields of 3772 kg/ha and 3914 kg/ha respectively. In Terengganu, only TWC-15 out-yielded both the check varieties, giving grain yield of 8041 kg/ha, compared to 6778 kg/ha from Metro, and 5989 kg/ha from Suwan 1. The grain yield obtained from this hybrid was also the highest recorded in this study. In Perlis, however, hybrid SC-8 was the only one giving higher yield than both the check varieties, with grain yield of 6473 kg/ha, compared to 5131 kg/ha from Metro and 4134 from Suwan 1. When data from all three locations were combined, four single crosses, one double, and two three-way crosses exhibited yields higher than both the checks, *viz.* SC-1 (5928 kg/ha), SC-2 (6219 kg/ha), SC-3 (5976 kg/ha), SC-8 (5932 kg/ha), DC-11 (6034 kg/ha), TWC-15 (6244 kg/ha) and TWC-17 (5970 kg/ha). Grain yields of Metro and Suwan 1 at locations com-

TABLE 4
Mean performance and coefficients of variation (c.v.) for characters measured on maize hybrids and check varieties at each location and locations combined

Genotype	Grain yield (kg/ha)				Plant height (cm)				Days to tasseling (days)			
	Selangor	*Terengganu*	*Perlis*	*Combined* (rank in brackets)	Selangor	Terengganu	*Perlis*[1]	*Combined* (rank in brackets)	*Selangor*[1]	*Terengganu*	*Perlis*	*Combined* (rank in brackets)
SC-1	5141 ab	6681 bcd	5961 ab	5928 ab *(7)*	179.4 cde	196.6 g	185.6	187.2 fg *(3)*	52.0	50.0 e	49.7 f	50.6 i *(1)*
SC-2	5342 ab	7484 ab	5829 ab	6219 a *(2)*	197.1 bcde	234.0 b	191.6	207.5 bcd *(14)*	53.0	52.0 bcd	51.7 bc	52.2 bcdef *(10)*
SC-3	4583 abcd	7654 ab	5690 ab	5976 ab *(4)*	195.7 bcde	234.0 b	196.6	208.8 bcd *(15)*	54.3	52.0 bcd	51.0 cde	52.4 bcd *(14)*
SC-4	4826 abcd	6711 bcd	5989 ab	5842 abcd *(9)*	196.8 bcde	222.8 bcde	193.6	204.4 bcde *(10)*	54.0	52.0 bcd	51.0 cde	52.3 bcde *(12)*
SC-5	4400 bcd	6640 bcd	5722 ab	5587 abcde *(14)*	188.4 bcde	222.6 bcde	195.1	201.9 cde *(8)*	53.7	52.0 bcd	51.0 cde	52.2 bcdef *(10)*
SC-6	4943 abcd	7170 abc	5402 ab	5839 abcd *(10)*	204.5 abc	223.8 bcd	187.6	205.3 bcde *(12)*	53.7	52.3 abc	52.0 bc	52.7 bc *(16)*
SC-7	4506 abcd	7179 abc	5936 ab	5880 abc *(8)*	198.6 bcde	223.6 bcd	206.2	209.5 bcd *(16)*	52.7	50.0 e	49.3 f	50.6 i *(1)*
SC-8	4472 abcd	6847 bcd	6474 a	5931 ab *(6)*	189.5 bcde	219.2 bcdef	203.1	203.9 bcde *(9)*	52.7	52.3 abc	50.0 ef	51.7 defg *(6)*
SC-9	2921 e	5251 e	4116 c	4096 g *(20)*	172.5 e	204.5 fg	168.0	181.7 g *(1)*	54.0	52.3 abc	51.3 cd	52.6 bcd *(15)*
SC-10	4238 bcd	6153 cde	5270 b	5220 de *(17)*	181.6 bcde	209.1 defg	188.2	193.0 efg *(4)*	54.0	52.7 ab	51.3 cd	52.7 bc *(16)*
DC-11	5708 a	6682 bcd	5712 ab	6034 ab *(3)*	208.8 ab	216.8 cdef1	91.3	205.6 bcde *(13)*	53.3	50.7 de	50.3 def	51.4 efgh *(5)*
DC-12	3706 de	6188 cde	5238 b	5053 ef *(18)*	181.8 bcde	213.7 def	201.2	199.0 def *(7)*	53.7	50.7 de	49.7 f	51.3 fghi *(4)*
DC-13	4228 bcd	6839 bcd	5871 ab	5646 abcde *(12)*	173.7 de	207.3 efg	179.8	186.9 fg *(2)*	54.7	50.3 abc	51.0 cde	51.7 defg *(6)*
DC-14	4633 abcd	6981 bcd	5244 b	5620 abcde *(13)*	200.6 bcde	232.0 bc	198.1	210.3 bcd *(17)*	53.3	50.7 de	51.3 cd	51.8 cdefg *(8)*
TWC-15	5389 ab	8041 a	5303 b	6244 a *(1)*	205.7 abc	216.4 cdef	192.5	204.7 bcde *(11)*	52.7	50.0 e	50.3 def	51.0 ghi *(3)*
TWC-16	5111 abc	6656 bcd	5638 ab	5802 abcd *(11)*	201.6 bcd	217.0 cdef	174.6	197.7 def *(5)*	52.7	53.0 ab	52.7 ab	52.8 b *(19)*
TWC-17	4883 abcd	7107 abc	5921 ab	5970 ab *(5)*	205.4 abc	233.5 b	203.5	214.2 bc *(18)*	54.7	52.3 abc	51.0 cde	52.7 bc *(16)*
TWC-18	4644 abcd	6616 bcd	5087 bc	5449 bcde *(15)*	200.7 bcde	216.0 def	179.6	198.8 def *(6)*	53.7	52.0 bcd	51.3 cd	52.3 bcde *(12)*
Metro	3914 cde	6778 bcd	5131 b	5274 cde *(16)*	198.4 bcde	249.0 a	207.0	218.1 ab *(19)*	53.3	51.0 cde	51.0 cde	51.8 cdefg *(8)*
Suwan 1	3772 de	5989 de	4134 c	4632 fg *(19)*	228.5 a	260.0 a	201.2	229.9 a *(20)*	55.7	53.7 a	53.3 a	54.2 a *(20)*
Mean	4570	6782	5483	5612	195.5	222.6	192.2	203.4	53.6	51.7	51.0	52.1
c.v. (%)	13.9	8.1	10.2	10.4	7.4	3.7	7.6	6.3	2.1	1.4	1.2	1.6

SC - single cross; DC - double cross; TWC - three-way cross.
Mean values followed by the same letter in the same column are not significantly different at p≤0.05, following DNMRT.
[1] DNMRT was not conducted because differences among genotypes were not significant.

TABLE 4 (continued).

Genotype	Days to maturity (days)				Shelling percentage (%)				Ear weight (g)			
	Selangor	*Terengganu*	*Perlis*	*Combined (rank in brackets)*	*Selangor*[1]	*Terengg-anu*[1]	*Perlis*	*Combined*[1]	*Selangor*	*Terengganu*	*Perlis*	*Combined (rank in brackets)*
SC-1	91.3 abc	90.7 ab	91.3 abc	91.1 bc *(18)*	80.8	81.8	85.4 a	82.6	123.1 ab	153.2 cd	140.9 b	139.0 abc *(8)*
SC-2	88.7 e	89.0 cd	90.3 bc	89.3 ef *(4)*	84.4	81.5	84.3 ab	83.4	133.9 a	172.2 abc	126.7 bc	144.3 a *(1)*
SC-3	90.0 bcde	89.7 bcd	89.3 c	89.7 def *(7)*	74.8	79.6	83.4 abc	79.3	122.8 ab	180.0 ab	122.9 bcd	141.9 ab *(3)*
SC-4	90.0 bcde	89.7 bcd	90.7 bc	90.1 cdef *(12)*	81.3	78.0	83.7 abc	81.0	113.4 abc	160.3 bcd	140.5 b	138.1 abcd *(9)*
SC-5	90.0 bcde	89.3 bcd	90.3 bc	89.9 def *(11)*	81.2	80.4	81.7 cd	81.1	117.4 ab	154.7 bcd	139.6 b	137.2 abcd *(10)*
SC-6	89.0 de	89.0 cd	90.0 bc	89.3 ef *(4)*	82.2	81.0	83.0 abcd	82.1	122.6 ab	166.1 abcd	134.8 b	141.2 ab *(5)*
SC-7	89.0 de	88.7 de	90.0 bc	89.2 ef *(2)*	79.4	81.2	83.2 abcd	81.3	102.6 abc	166.8 abcd	139.1 b	136.4 abcd *(11)*
SC-8	90.0 bcde	90.7 ab	90.0 bc	90.2 cde *(13)*	81.9	78.5	82.7 bcd	81.1	102.9 abc	164.1 abcd	163.3 a	143.4 a *(2)*
SC-9	92.3 a	90.7 ab	91.3 abc	91.4 ab (19)	69.4	78.5	82.9 abcd	77.0	86.0 c	125.8 e	104.9 cd	105.6 f *(19)*
SC-10	91.0 abcd	90.0 bcd	90.7 bc	90.6 bcd *(15)*	82.0	80.1	84.0 abc	82.0	103.7 abc	143.8 de	123.9 bcd	123.8 cde *(17)*
DC-11	89.0 de	89.3 bcd	90.7 bc	89.7 def *(7)*	80.3	79.9	84.2 ab	81.5	133.6 a	156.9 bcd	132.2 b	140.9 ab *(6)*
DC-12	92.3 a	90.3 bc	90.3 bc	91.0 bc *(17)*	76.5	80.4	84.4 ab	80.5	96.5 bc	144.2 de	127.3 bc	122.8 de *(18)*
DC-13	90.3 bcde	89.3 bcd	89.7 c	89.8 def *(10)*	81.6	79.4	82.9 abcd	81.3	101.7 bc	161.8 bcd	135.9 b	133.1 abcd *(14)*
DC-14	90.3 bcde	90.0 bcd	90.3 bc	90.2 cde *(13)*	82.4	79.9	82.0 bcd	81.4	118.8 ab	163.8 abc	137.6 b	140.1 ab *(7)*
TWC-15	89.7 cde	89.7 bcd	89.3 c	89.6 def *(6)*	80.0	80.4	83.7 abc	81.4	116.1 abc	187.6 a	121.8 bcd	141.8 ab *(4)*
TWC-16	89.7 cde	89.0 cd	90.3 bc	89.7 def *(7)*	83.5	81.1	83.6 abcd	82.7	126.7 ab	154.0 bcd	128.2 b	136.3 abcd *(12)*
TWC-17	89.0 de	89.0 cd	89.7 c	89.2 ef *(2)*	82.5	81.5	89.3 abc	82.7	110.1 abc	163.8 abcd	134.1 b	136.0 abcd *(!3)*
TWC-18	89.3 cde	87.7 e	90.3 bc	89.1 f *(1)*	83.6	79.4	83.3 abcd	82.1	106.0 abc	156.4 bcd	119.2 bcd	127.2 bcde *(16)*
Metro	91.0 abcd	89.7 bcd	92.0 ab	90.9 bc *(16)*	80.5	78.8	81.2 d	80.2	103.2 abc	161.7 bcd	124.1 bcd	129.7 abcde *(15)*
Suwan 1	92.0 ab	91.7 a	93.0 a	92.2 a *(20)*	80.3	77.2	82.3 bcd	80.0	102.5 abc	145.2 de	102.4 d	105.6 f *(19)*
Mean	90.2	89.6	90.5	90.1	80.4	79.9	83.3	81.2	112.3	159.1	129.9	133.8
c.v. (%)	1.2	0.7	1.2	1.0	7.4	3.2	1.5	4.6	14.2	8.3	9.2	10.3

SC - single cross; DC - double cross; TWC - three-way cross.

Mean values followed by the same letter in the same column are not significantly different at $p \leq 0.05$, following DNMRT.

[1] DNMRT was not conducted because differences among genotypes were not significant.

TABLE 4 (continued).

Genotype	Ear length (mm)				Ear diameter (mm)				100-grain weight (g)			
	Selangor	*Terengganu*	*Perlis*	*Combined (rank in brackets)*	*Selangor*[1]	*Terengganu*	*Perlis*	*Combined (rank in brackets)*	*Selangor*[1]	*Terengganu*	*Perlis*	*Combined*[1]
SC-1	121 abcdef	143 de	149 bcdef	138 def *(14)*	43.7	40.1 bcde	48.2 ab	46.0 abc *(3)*	22.7	24.0 abcd	25.0 ab	23.9
SC-2	128 abcde	153 abcd	145 cdef	142 abcde *(8)*	44.4	48.3 a	47.0 abcd	46.6 a *(1)*	21.3	24.3 abcd	21.2 cde	22.3
SC-3	135 ab	162 a	154 abcd	151 a *(1)*	42.6	48.4 a	46.1 bcd	45.7 abcd *(7)*	21.7	24.3 abcd	21.0 de	22.4
SC-4	125 abcdef	148 cd	153 abcde	142 abcde *(8)*	42.4	46.6 abcde	47.0 abcd	45.3 abcde *(8)*	23.5	22.3 bcd	25.1 ab	23.6
SC-5	127 abcde	153 abcd	163 ab	148 abc *(3)*	41.4	45.5 bcde	45.8 bcd	44.2 ef *(17)*	23.0	26.0 a	24.0 abc	24.3
SC-6	131 abc	158 abc	161 abc	150 ab *(2)*	43.1	46.5 abcde	45.9 bcd	45.2 abcde *(10)*	23.0	24.0 abcd	23.2 abcde	23.4
SC-7	114 bcdef	149 bcd	151 abcdef	138 def *(14)*	41.2	47.0 abc	47.0 abcd	45.1 abcde *(12)*	23.0	24.0 abcd	23.7 abcd	23.6
SC-8	108 f	151 bcd	167 a	142 bcde *(8)*	41.9	46.9 abcd	49.4 a	46.1 ab *(2)*	23.2	25.3 ab	25.0 ab	24.5
SC-9	108 f	136 e	137 ef	127 g *(20)*	40.7	42.9 f	44.9 d	42.8 g *(20)*	20.4	21.7 d	22.2 bcde	21.4
SC-10	127 abcde	144 de	145 cdef	139 def *(12)*	42.2	45.3 cde	46.1 bcd	44.6 cdef *(14)*	22.6	22.0 cd	24.5 ab	23.0
DC-11	137 a	146 de	148 bcdef	144 abcd *(5)*	44.4	45.6 bcde	45.9 bcd	45.3 abcde *(8)*	21.9	26.7 a	24.2 ab	24.2
DC-12	112 def	142 de	143 def	132 fg *(19)*	40.8	44.8 e	46.0 bcd	43.9 efg *(18)*	23.9	22.7 bcd	24.9 ab	23.8
DC-13	118 bcdef	149 bcd	151 abcdef	139 cdef *(12)*	42.4	46.8 abcde	48.1 abc	45.8 abcd *(6)*	21.9	26.0 a	23.0 abcde	23.4
DC-14	122 abcdef	160 ab	152 abcdef	141 cdef *(11)*	43.3	46.6 abcde	48.2 ab	46.0 abc *(3)*	22.5	24.7 abcd	23.3 abcd	23.5
TWC-15	129 abcd	160 ab	142 def	144 abcd *(5)*	41.5	47.6 ab	45.8 bcd	45.0 abcde *(13)*	22.4	24.3 abcd	22.6 abcde	23.1
TWC-16	129 abcd	151 abcd	157 abcd	146 abcd *(4)*	42.1	45.7 bcde	45.7 bcd	44.5 cdef *(15)*	24.1	26.3 a	23.7 abcd	24.7
TWC-17	123 abcdef	153 abcd	156 abcd	144 abcd *(5)*	42.6	46.2 bcde	46.8 abcd	45.2 abcde *(10)*	21.6	26.7 a	23.1 abcde	23.8
TWC-18	117 cdef	150 bcd	145 cdef	137 def *(16)*	42.2	45.9 bcde	45.2 cd	44.5 def *(15)*	22.4	23.7 abcd	22.5 abcde	22.9
Metro	115 cdef	147 cd	142 def	135 efg *(17)*	42.5	47.1 abc	48.3 ab	46.0 abc *(3)*	22.3	25.0 abcd	25.2 a	24.2
Suwan 1	111 f	152 abcd	137 f	133 fg *(18)*	41.5	44.9 de	44.4 d	43.6 fg *(19)*	20.6	24.7 abcd	20.4 e	21.9
Mean	122	3.9	150	141	42.4	46.2	46.6	45.1	22.4	24.4	23.4	23.4
c.v. (%)	7.5	150	5.5	5.6	3.3	2.2	3.2	3.0	7.6	6.5	6.3	6.8

SC - single cross; DC - double cross; TWC - three-way cross.

Mean values followed by the same letter in the same column are not significantly different at $p \leq 0.05$, following DNMRT.

[1] DNMRT was not conducted because differences among genotypes were not significant.

bined were 5274 kg/ha and 4632 kg/ha, respectively. These results on yield performances indicate that the hybrids revealed good adaptability to the specific locations concerned. In general, the hybrids evaluated in this study performed well, and were superior to the open-pollinated check varieties. A previous study by Subandi and Sudjana (1982) also indicated the superiority of the tropical maize hybrids over the open-pollinated ones.

Yield performance in Terengganu was encouraging although the soil type was sandy (order Spodosol, series Rudua, typic Haplorthod), and reported to have limitations such as coarse texture, poor structure and moderately imbalanced nutrient composition (Department of Agriculture 1993). The effects of these soil limitations might have been remedied through good management and cultural practices adopted in the farmer's plot where the evaluation was conducted. The performance in Terengganu was better than those in Perlis (soil with order Ultisol, series Bukit Temiang, typic Hapludult) and Selangor (soil with order Ultisol, series Bungor, typic Kandiudult).

Short plants are desirable, as they would have low incidence of lodging. For plant height, overall means for genotypes were highest in Terengganu (222.6 cm), followed by Selangor (195.5 cm), and lastly Perlis (192.2 cm). The hybrids were generally shorter than the open-pollinated check varieties. In Selangor, 14 out of the 18 hybrids evaluated had plants significantly shorter than Suwan 1 (228.5 cm), but none was shorter than Metro (198.4 cm). The shortest plants in Selangor were shown by the single cross hybrid SC-9 (172.5 cm). In Terengganu, all hybrids had plants shorter than those of the two check varieties. The shortest plants were shown by hybrid SC-1 (196.6 cm), followed by SC-9 (204.5 cm), DC-13 (207.3 cm) and SC-10 (209.1 cm). In contrast, in Perlis, there was no significant difference in plant height among the genotypes evaluated, with heights ranging from 168.0 and 207.0 cm. When locations were combined, eight hybrids (SC-1, SC-5, SC-9, SC-10, DC-12, DC-13, TWC-16 and TWC-18) had plants with average heights significantly lower than those of the two check varieties.

The hybrids also responded differently to locations for days to tasseling. On the average, genotypes were earliest tasseling in Perlis (51.0 days), and latest in Selangor (53.6 days). This might have been due to differences in weather conditions, where before the flowering stage of the plants, Perlis had higher temperatures than the other two locations, which are favourable factors to encourage early flowering. In Selangor, genotypes did not differ significantly for days to tasseling (ranged between 52.0 to 55.7 days). In Terengganu, although genotypes showed significant differences in days to tasseling, most hybrids tasselled only earlier than Suwan 1 (53.7 days), but not Metro (51.0 days). In Perlis however, three hybrids, SC-1 (49.7 days), SC-7 (49.3 days) and DC-12 (49.7 days) tasselled significantly earlier than both the check varieties, Suwan 1 (53.3 days) and Metro (51.0 days). When data from locations were combined, two hybrids, SC-1 and SC-7 were found to have tasselled earlier than most other hybrids as well as both the check varieties, indicating that they could be the choice hybrids for earliness. Both the hybrids tasselled at 50.6 days.

Genotypes, in general, had shown earlier maturity in Terengganu than they did in Selangor and Perlis. The overall genotype mean for maturity was 89.6 days in Terengganu, while those of Selangor and Perlis were not significantly different from each other, being 90.2 and 90.5 days respectively. Earlier maturity in Terengganu was probably due to the effects of high temperature modification contributed by the sandy soil at the stages of seed filling and drying of the genotypes. In Terengganu, TWC-18 was the earliest maturing hybrid (87.7 days), and was significantly earlier than both the check varieties. Evaluation in Selangor however, has shown that SC-2 was the earliest maturing among the hybrids (88.7 days), and significantly earlier than both the check varieties (92.0 days for Suwan 1, and 91.0 days for Metro). From evaluation in Perlis, four hybrids were found to have matured significantly earlier than both the check varieties. They were SC-3, DC-13, TWC-15 and TWC-17, with days to maturity ranging from 89.3 to 89.7 days. From locations combined, 11 out of the 18 hybrids showed maturity earlier than the two checks, with overall values ranging from 89.1 to 89.9 days.

There were no significant effects of location on shelling percentages of the genotypes evaluated (Table 3), with an overall mean of 81.2% across locations. From results of evaluations in Selangor and Terengganu (Table 4), all genotypes did not show significant differences for shelling percentage, with location means of 80.4% for Selangor, and 79.9% for Terengganu. Differences were however, observed from the evaluation in Perlis, where only hybrid SC-1 recorded higher shelling percentage (85.4%) than Metro (81.2%) and Suwan 1 (82.3%). Results of the analysis of combined locations also did not show significant differences in shelling percentages among the genotypes.

Significant effects of locations were observed on ear weights of the genotypes, where they produced heavier ears in Terengganu than they did in Selangor and Perlis (Table 4). The mean ear weight of the genotypes combined were 159.1 g in Terengganu, 129.9 g in Perlis and 112.3 g in Selangor. In Selangor, none of the hybrids produced ears heavier than those of the two check varieties; but in Terengganu, hybrid TWC-15 gave heavier ears (187.6 g) than those of the check varieties; while in Perlis, it was SC-8 (163.3 g). In addition, SC-8 was also found to produce ears heavier than any other hybrids evaluated. From results of the analysis on locations combined, no significant differences were shown for ear weight between the majority of the hybrids and the check variety, Suwan 1. Overall mean ear weight for all genotypes over locations was 133.8 g.

Ear lengths of the genotypes were significantly affected by locations, where with the mean ear length of 150 mm, genotypes in both Terengganu and Perlis did better than those in Selangor (122 mm) (Table 4). Evaluations in Selangor have shown that SC-3 and DC-11 had the longest ears (135 mm and 137 mm, respectively), and they were significantly longer than those of the two check varieties. In contrast, in Terengganu, all the 18 hybrids showed ear lengths lower than those of Metro and Suwan 1. In Perlis, two single crosses, SC-5 and SC-8 produced ears longer (163 mm and 167 mm, respectively) than those of the check varieties. From locations combined, six hybrids, SC-3, SC-5, SC-6, TWC-15, TWC-16 and TWC-17 were found to have ears longer than those of the check varieties, with values ranging from 144 mm to 151 mm.

Similar to ear length, ear diameter of the genotypes was significantly affected by locations, where in this case, genotypes produced ears with larger diameters in Perlis and Terengganu, compared to those in Selangor. Mean ear diameters were 46.6, 46.2 and 42.4 for Perlis, Terengganu and Selangor respectively. Differences among genotypes were only significant in Terengganu and Perlis, but not in Selangor. However, none of the hybrids had ear diameters larger than those of Metro, the check variety with ears having larger diameters between the two checks.

One hundred-grain weight of the genotypes differed significantly among locations, with Terengganu giving the highest (24.4 g), followed by Perlis (23.4 g), and lastly Selangor (22.4 g) (Table 4). Among genotypes, 100-grain weight differed only in Terengganu and Perlis, but not in Selangor. However, no hybrid had 100-grain weight higher than both the check varieties in Terengganu, and Metro in Perlis.

From the overall performance of the hybrids, this study has revealed that the selected hybrids have high genetic potential, and should be given the opportunity for further evaluation and selection purposes. Hybrids SC-1, SC-2, SC-8, DC-11, TWC-15 and TWC-17 were identified to be the highly potential ones, and should be given good consideration in further evaluations on a larger scale, before any could be released as a variety for commercial production.

Variance Components and Heritability

The genotypic and phenotypic variances, and broad-sense heritabilities for traits estimated from the population of hybrids, at each location and locations combined are shown in Table 5. Negative estimates of variances and heritability obtained for some traits are considered as zero, and could be attributed to high uncontrollable error variances in the experiment.

Broad-sense heritability estimates for grain yield were generally moderate, being 52.6%, 41.4%, 29.3% and 38.0%, from evaluations in Terengganu, Selangor, Perlis and the locations combined respectively. A similar trend was found for plant height, where estimates of heritability were 59.0%, 25.8%, 14.6% and 28.1% respectively, for the three locations and locations combined. This indicates that in the population of hybrids evaluated, the contribution of genetic factors on the expression of the phenotypes was moderate. Using the same method of estimation (variance components in ANOVA table), Saleh *et al.* (1994) also reported moderate estimates of heritability for yield traits.

With regard to days to tasseling, heritability estimates differed greatly with locations, where moderately high estimates were found from evalu-

TABLE 5
Genotypic variances (σ^2_G), phenotypic variances (σ^2_P) and broad-sense heritability estimates (h^2_B) for grain yield and other characters measured on maize hybrid populations studied, at each location, and locations combined

Character	*In Selangor*			*In Terengganu*			*In Perlis*			*Locations Combined*		
	σ^2_G	σ^2_P	h^2_B (%)	σ^2_G	σ^2_P	h^2_B (%)	σ^2_G	σ^2_P	h^2_B (%)	σ^2_G	σ^2_P	h^2_B (%)
Grain yield	284745	686991	41.4	291692	554062	52.6	142758	486481	29.3	205505	541368	38.0
Plant height	66.8	258.9	25.8	90.7	153.7	59.0	36.9	252.9	14.6	61.4	218.5	28.1
Tasseling	0.2	1.4	11.6	0.8	1.3	62.1	0.6	1.0	61.0	0.4	1.1	37.5
Maturity	0.9	1.8	48.6	0.4	1.0	47.4	-0.1	1.1	-4.7	0.4	1.2	30.3
Shelling percentage	0.5	38.5	1.4	-1.0	5.7	-17.8	0.3	1.7	16.4	0.6	16.0	3.9
Ear weight	88.2	332.8	26.5	140.0	294.0	47.6	95.8	251.6	38.1	55.9	240.3	23.3
Ear length	46.1	130.6	35.3	31.3	66.4	47.2	38.4	102.1	37.6	21.3	82.0	25.9
Ear diameter	0.5	2.5	19.7	1.3	2.3	55.8	0.6	3.1	19.7	0.5	2.4	22.8
100-grain weight	-0.2	3.0	-5.4	1.6	4.0	40.5	0.8	3.1	24.5	0.2	2.8	8.4

ations in Terengganu and Perlis (62.1% and 61.0%, respectively), while low estimates were obtained for Selangor (11.6%), and moderate from the locations combined (37.5%). Varied heritability estimates were also obtained for maturity in the population of hybrids, with moderate values in Selangor, Terengganu and the locations combined (48.6%, 47.4% and 30.3% respectively), but negative (considered zero) in Perlis.

Heritability estimates for shelling percentage were generally low in all evaluations, with values ranging from zero to 16.4%. With regards to the ear measurements, varied estimates of heritability were obtained. Heritabilities for ear weight were moderate in Terengganu and Perlis (47.6% and 38.1% respectively), but low in Selangor and the locations combined (26.5% and 23.3% respectively). Estimates of heritability for ear length were moderate from evaluations in Terengganu (47.2%), Perlis (37.6%) and Selangor (35.3%), but was low from the locations combined (25.9%). For ear diameter, only evaluation in Terengganu gave a moderate broad-sense heritability estimate (55.8%), while the others gave low estimates. Similarly, for 100-grain weight, only evaluation in Terengganu gave a moderate heritability (40.5%), while the rest were low.

In general, moderate to high heritability estimates were obtained for most of the characters from evaluation conducted in Terengganu, and they were generally higher than those obtained in Selangor and Perlis. This indicates that the genotypes from the evaluation conducted in Terengganu were less influenced by the environment, compared to those in Selangor and Perlis. This finding is in good agreement with the fact that performance of the genotypes was best in Terengganu. Hence, a more stable and uniform performance, with a better indication of the genetic merit of the genotypes, is possible.

CONCLUSION

Significant effects of location for most traits indicated that the different soil types and environmental factors characterising the locations considerably affected the performance of the genotypes. Significant genotype x location interaction observed only for ear weight, ear length and 100-grain weight, indicated that the genotypes were in general, ranked quite consistently among locations, although some variations existed. In general, for grain yield and all yield components, except plant height, days to maturity and shelling percentage, performance of genotypes was superior in Terengganu to those in the other two locations, where Selangor exhibited the lowest. Many hybrids were found to have out-yielded the check varieties at every location.

Higher estimates of heritability obtained in Terengganu gave an indication of uniformity of the environmental factors, as opposed to those in Selangor and Perlis. Single cross hybrids were found to have produced more consistent and stable grain yields across locations, compared to the three-way and double crosses.

Based on the overall performance at the three locations, the single crosses SC-1, SC-2, SC-8, the three-way crosses TWC-15 and TWC-17, and the double cross DC-11, were found to be most promising, and deserved to be short-listed for further trials on a larger scale in the future.

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