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GENOTYPE – ENVIRONMENT INTERACTION AND STABILITY ANALYSIS FOR BUNCH YIELD AND ITS COMPONENTS, VEGETATIVE GROWTH AND BUNCH CHARACTERS IN THE OIL PALM (*ELAEIS GUINEENSIS* JACQ)

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ABSTRACT

The development of oil palm planting material ('Dura' × 'Pisifera') with a high level of performance over a wide range of environments is an important objective for most breeding programs. In Malaysia, four companies cooperated and evaluated seven Nifor hybrids (Nigerian Institute for Oil Palm Research) and four Malaysian hybrids for five years at four locations in Malaysia. There were significant differences among the hybrids for all the bunch yield and its components (bunch number and bunch weight), some vegetative growth and bunch characters analyzed. Significant G × E interactions were observed for the bunch yield and its components, some vegetative growth characters (height, petiole cross section and leaf area) and some of the bunch characters (kernel to fruit, wet mesocarp to fruit and oil to bunch). The significance of these G × E interactions was discussed. In the regression analysis for the yield and the vegetative growth characters, the growth response and stability indices of these traits were also examined.

Breeding for stable genotypes in different environments has received much attention in recent years. For quantitative traits in many crop plants, the relative performance of different genotypes often changes from one environment to another, i.e. the presence of a genotype × environment (G × E) interaction.

Several methods have been used to estimate the differential responses of genotypes to environments (Spraque & Federer 1951, Comstock & Robinson 1952, Hanson *et al.* 1956, Comstock & Moll 1963). These methods provide only information on the existence and magnitude of G × E interactions but no measurements on the response of individual genotype.

The method to quantify stability of individual genotypes using a regression analysis was first raised by Yates and Cochran (1938), and was later developed by Finlay and Wilkinson (1963), and Eberhart and Russell (1966). Subsequently there were further modifications of the regression technique for estimating stability parameters (Perkins & Jinks 1968, Breese 1969, Freeman & Perkins 1971).

This approach on stability analysis has been widely used to compare the relative performance of genotypes in various environments of different annual crops but little information is available on perennial tree crops (Nguyen *et. al.* 1980, Gray 1982, Obisesan and Fatunla 1983).

In the oil palm, there are limited information available on genotype-environment interactions. Rosenquist (1982) concluded that there were no evidence of G × E interaction based on ranking of the progenies evaluated on two sites. Obisesan and Fatunla (1983) reported significant genotype × year interaction for bunch yield and its components on 49 D × P hybrids based on a single location trial. Rajanaidu *et al.* (1985) also reported no G × E interaction in a study involving oil palm D × P hybrids derived from 7 origins and evaluated at 3 locations.

The objectives of this paper are:

(i) To determine whether G × E interactions exist in oil palm for bunch yield and its components (bunch number and bunch weight), vegetative growth and bunch characters, and

(ii) To estimate the stability indices of these characters using Eberhart & Russel model.

In the Eberhart-Russell model, an environmental index is expressed by the mean performance of all genotypes grown in an environment. The regression of individual genotype's performance on the environmental index provides two stability indices, viz, the regression coefficients (b-values) and the mean square deviations from regression, S^2d (a measure of departure of individual genotype from its linear response to the environment).

MATERIALS AND METHODS

Seven Nifor and four Malaysian 'dura × pisifera' hybrid families of oil palm *(Elaeis guineensis)* planted at four locations in Malaysia were used for this study. The trial in HMPB was planted on coastal soil with a fairly high water table for most part of the year while the trials in Guthrie and Dunlop were planted on inland soils with a low water table and seasonal variation in rainfall. The fourth trial was planted by Pamol in Sabah (East Malaysia) and located near a river bank with a fluctuating water table. The locations and experimental details are shown in Appendix I.

The 'dura' and 'pisifera' are different fruit forms of shell thickness controlled by a single gene (Beirnaert & Vanderweyen 1941) The 'dura' palms produce thick-shelled fruits while the fruit form of the 'pisifera' palms is shell-less. The hybrid is referred to as 'tenera' or D × P and the fruit form of this hybrid has thin shell with a fibre ring. The 'pisifera' palms are female sterile and therefore used as male parents.

The data for bunch yield and its components (total of 5 years), vegetative growth and bunch characters were analyzed for genotype-environment (G × E) interaction according to Cochran and Cox (1959).

Stability indices proposed by Eberhart and Russell (1966) were calculated for bunch yield and its components and vegetative growth characters. Growth response index of each hybrid was expressed by the linear regression (b-value) of its average yield on the average yield of all hybrids in each environment (environmental index). The deviation from regression mean square (S^2d) can be used as a stability index. Pinthus (1973) proposed the use of the coefficient of determination, r^2 as a stability index and this was calculated between average yield of individual hybrids and the environmental index of each trait. The r^2 measures the proportion of a hybrid's production variation that is attributable to linear regression, as an index of production stability over environments. Another stability index, the Ecovalence, w, developed by Wricke (1962) was also calculated. This Ecovalence, w assigns an index to a hybrid on the basis of its deviation from a regression line of unity.

RESULTS AND DISCUSSION

Differences among D × P hybrids for the bunch yield and its components (bunch number and bunch weight) and some vegetative growth characters (height, petiole cross-section and leaf area) were highly significant ($P < 0.01$) as shown in Table 1 and 2.

Table 1. Analysis of variance for bunch yield, bunch number and bunch weight of DxP oil palm hybrids (Total of 5 years).

Source	d.f.	Mean Squares Bunch yield (kg/palm)	Bunch No. (No./palm)	Bunch Wt. (kg)
Locations (E)	3	660168.0	3729.50	53.8438
Families (G)	10	275918.0 ***	1800.88 ***	48.4290 ***
GxE	21	10419.1 ***	221.27 ***	1.6830 ***
Pooled Error	101	3316.2	31.33	0.2463
for Homogeneity of variance	3	9.1 ***	1.89 NS	8.2 **

NS : Not Significant.
** : Significantly different at 1% level.
*** : Significantly different at 0.1% level.

Table 2. Analysis of variance for some vegetative growth characters (Height, petiole cross-section and leaf area) of DxP oil palm hybrids

Source	d.f.	Mean Squares Height (cm)	 Petiole cross-section (sq cm)	 Leaf Area (sq m)
Locations (E)	3	90443.4	651.884	25.2681
Families (G)	10	17711.1 XXX	469.858 XXX	14.5998 XXX
GxE	21	1753.1 XXX	25.149 XXX	0.7255 XX
Pooled Error	101	541.4	6.722	0.3198
for homogeneity of variance	3	3.85 NS	14.31 XX	4.45 NS

NS : Not Significant.
XX : Significantly different at 1% level.
XXX : Significantly different at 0.1% level.

Significant G × E interactions were observed for the bunch yield and its components and vegetative growth characters. Although the individual error variances for bunch yield ($P < 0.001$), bunch weight ($P < 0.01$) and petiole cross-section ($P < 0.01$) were not homogenous (Bartlett's test), the G × E interactions for these three characters as measured from their respective pooled variances were found to be significant. However, previous studies indicated no significant G × E interactions in oil palm (Rosenquist 1982, Rajanaidu *et al.* 1985).

The mean values of the characters (×) and the stability indices, b, S^2d, r^2 and w values are presented in Appendix IIa and IIb. For average bunch yield, bunch number and bunch weight, the b-values ranged from 0.7533 to 1.4375, 0.5194 to 1.6903 and 0.5896 to 1.7485 respectively. In the vegetative growth characters of leaf area, petiole cross-section and height, the b-values ranged from 0.4206 to 1.5134, 0.3872 to 1.4714 and 0.5584 to 1.3624 respectively. A b-value of unity indicates the genotype's ability to respond to increment in an improved environment. T-tests showed that bunch weight in M 17 and leaf area in M 25 differed significantly from unity ($b = 1$). However, the wide range of b-values obtained showed that there were considerable variations for the growth response index in all characters tested.

The deviation mean square (S^2d) for each hybrid was not significantly different for all the characters tested except S^2d for bunch number in NF 10 ($P < 0.001$). According to Langer *et al.* (1979), S^2d is a measure of response to varying environments and concluded that S^2d is a true measure of production stability, i.e. a stable genotype has S^2d not significantly different from zero. As the number of locations and hybrids tested is small in this analysis, statistical interpretation on S^2d will not be drawn but rather used as a guide on the relative stability of the hybrid families, i.e. the smaller the S^2d, the more stable will be the hybrid as compared to others.

The coefficients of determination (r^2) were highly variable in bunch number, petiole cross-section and height. The w index of stability varied greatly among the hybrids for each trait. Nguyen *et al.* (1980) and Gray (1982) reported that the stability of a genotype is inversely proportional to the w index and therefore showing stability differences among the genotypes over the environments. Similarly, the w index obtained were found to be highly variable in most of the characters studied.

An attempt was also made to study the G × E interaction of some bunch characters at 2 locations viz, Guthrie and HMPB. No significant family differences were observed for wet mesocarp to fruit ratio (WP/F %) and oil to bunch ratio (O/B %) as presented in Table 3. Significant G × E interactions were found in kernel to fruit ratio (K/F %), wet mesocarp to fruit ratio (WP/F %) and oil to bunch ratio (O/B %). Rajanaidu *et al.* (1985) again reported no significant G × E interaction on bunch characters for oil to bunch ratio (O/B %) and oil to wet mesocarp (O/WP %) at three locations. As data for bunch characters were available only at two locations, regression analysis could not be carried out.

Table 3. Analysis of Variance for some bunch characters of DxP oil palm hybrids.

Source	d.f.	Mean Squares				
		F/B(%)	K/F (%)	S/F (%)	WP/F (%)	O/B (%)
Locations (E)	1	1.165	8.820	1.576	32.397	7.415
Families (G)	6	20.287 *	7.296 *	11.956 **	14.589 NS	8.835 NS
GXE	6	2.608 NS	1.564 **	0.813 NS	5.420 *	4.882 ***
Pooled error	42	1.897	0.341	0.715	1.716	0.491
for homogeneity of variance	3	1.95 NS	0.77 NS	1.52 NS	2.84 NS	0.25 NS

F/B : Fruit to bunch ratio (%).
K/F : Kernel to fruit ratio (%).
S/F : Shell to fruit ratio (%).
WP/F : Wet mesocarp to fruit ratio (%).
O/B : Oil to bunch ratio (%).

NS : Not significant.
* : Significantly different at 5% level.
** : Significantly different at 1% level.
*** : Significantly different at 0.1% level.

The stability indices and mean bunch yield over all the environments are important parameters in the identification for a stable genotype. An ideal genotype is one with high bunch yield, a regression coefficient of one (b = 1) and a low deviation mean square ($S^2d = 0$). Of the various hybrids studied, M 22 appears to be desirable with the highest bunch yield of 194.2 kg/palm/yr, a regression coefficient not significantly different from one, a low S^2d (4.07) and a high r^2 (0.97). Conversely, NF 5 and NF 7 though having b values closed to one and low S^2d, they are not so desirable because of their poor yields.

CONCLUSION

In the development and evaluation of new planting materials, the breeders are often confronted by the large space requirement and long generation time that preclude standard exploratory experimentation. Progeny testing of new planting materials at different locations is therefore seldom carried out. From the commercial viewpoint, it may be desirable to produce oil palm planting material adaptable to different environments. Alternatively, it can be developed to suit a specific environment.

In the present study, though significant genotype-environment interactions were observed in all the yield components, some of the vegetative growth and the bunch characters, the inclusion of the regression analysis had provided further explanation on the variable growth response and stability of each genotype. The results from the regression analysis further indicate that oil palm hybrids of Nigerian and Malaysia sources exhibit some differential response to the locations tested. To ensure success in the production of better planting materials, it is, therefore, possible to select high yielding genotypes with wide adaptability. Thus, evaluation trials for new planting materials should be tested at different locations.

With the advent of tissue culture techniques for clonal propagation of oil palm, utilization of the response and stability indices could further enhance the effectiveness of clonal comparisons and selection for clones with high adaptability.

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Appendix I. Experimental details on DxP hybrids planted at locations in Malaysia.

	Locations			
	Dunlop	Guthrie	HMPB	Pamol
Experiment No.	0/5-1/G	GB 31 (Phase II)	PT 29	PT 2/69
Estate	Gomali	Bukit Badak	Sungei Sedu	Tungud
Location	Batu Anam, Gemas, Johore	Layang Layang Johore	Banting Selangor	Sandakan Sabah
Date of Planting	May 1967	Jan 1968	Nov 1967	Dec 1968
Soil type	Batu Anam Durian (Inland soil)	Rengam series (Inland soil)	Selangor series (Coastal clay)	Inanam series (Riverine alluvium)
Plot size	20	16	12	16
Density (palms/ha)	148	148	148	148
Replicates	4	4	5	4
Design	RCBD	RCBD	RCBD	RCBD
Yield records	Jan 1971- Dec 1975	Jan 1972- Dec 1976	Jan 1971- Dec 1975	Jan 1973- Dec 1977
Vegetative measurements	June 1978	June 1978	June 1978	June 1978
Bunch analysis	-	Jan 1973- Feb 1977	Jan 1971- Dec 1973	-

Appendix IIa. **Estimates of stability indices for bunch field and it components (Bunch number & Bunch weight) based on four environments.**

Hybrid Family No.	Bunch Yield (kg/palm/yr)					Bunch No. (No./palm/yr)					Bunch Weight (kg)				
	$\bar{X}$	b	S^2d	r^2	w	$\bar{X}$	b	S^2d	r^2	w	$\bar{X}$	b	S^2d	r^2	w
NF 5	138.72	1.1005	0	0.9927	32.963	17.426	1.1216	1.717	0.7357	4.1948	7.9480	0.7680	0.244	0.8295	0.8873
NF 6	122.57	0.8572	1.118	0.9489	103.970	12.269	0.7414	0.196	0.8290	1.6110	10.3310	1.1982	0.188	0.9356	0.6920
NF 7	128.04	1.0508	0	0.9729	57.795	17.073	1.6903	0.095	0.9692	5.0972	7.5110	0.7625	0.175	0.8610	0.7643
NF 8	140.33	1.0381	13.055	0.9528	94.975	18.272	1.3450	0.176	0.9433	2.0502	7.6000	0.9677	0.044	0.9572	0.2241
NF 9	123.19	0.7980	29.227	0.8984	195.560	14.936	1.0670	0	0.9959	0.0788	8.3470	0.8155	0.446	0.7674	1.1904
NF 10	148.21	1.4375	77.614	0.9417	553.270	18.309	1.2500	8.002***	0.4577	17.1940	8.0950	0.5896	0.144	0.8103	1.2624
NF 12	182.39	1.0325	141.606	0.8409	351.280	18.200	0.9408	0	0.9717	0.2671	10.1640	0.7688	0.324	0.7940	1.0379
M 17	157.72	0.9116	0	0.9878	31.366	13.524	0.6361	1.350	0.5221	4.5110	12.142	1.7485*	0	0.9953	2.8795
M 18	171.00	0.7533	126.810	0.7545	425.360	15.255	0.5194	2.871	0.2757	8.4406	11.750	1.1168	0.133	0.9416	0.4493
M 22	194.16	1.1358	4.065	0.9678	106.300	17.296	0.8895	0	0.9340	0.6142	11.473	1.0985	0.036	0.9692	0.2347
M 25	177.90	0.8847	94.935	0.8411	279.150	16.011	0.8015	0.128	0.8668	1.2398	11.347	1.1671	0.249	0.9170	0.7541

$\bar{X}$: Mean values of the character.
* : Significantly different at 5% level.
*** : Significantly different at 0.1% level.

Appendix IIb. **Estimates of stability parameters for vegetative growth characters based on four environments**

Hybrid Family No.	Leaf Area (m^2)					Petiole Cross Section (cm^2)					Height (cm)				
	$\bar{X}$	b	S^2d	r^2	w	$\bar{X}$	b	S^2d	r^2	w	$\bar{X}$	b	S^2d	r^2	w
NF 5	8.463	1.0343	0	0.9519	0.0977	28.448	0.9928	0	0.9530	2.2499	284.95	1.0882	0	0.9894	116.76
NF 6	10.490	0.8219	0	0.8996	0.1851	36.730	1.0292	5.432	0.7659	14.2100	388.17	0.5584	290.743	6.752	1906.20
NF 7	8.888	1.2698	0.041	0.9205	0.3707	28.720	1.1514	0	0.9575	3.6980	342.51	1.1625	0	0.9789	315.39
NF 8	7.988	1.1872	0	0.9710	0.1367	26.920	0.7073	4.154	0.6533	15.5760	318.44	1.2729	0	0.9842	571.09
NF 9	8.808	0.9500	0.287	0.6823	0.7382	30.378	0.3872	4.119	0.3619	28.1910	306.08	0.8359	0	0.9729	263.72
NF 10	9.078	0.8725	0.007	0.8838	0.2034	31.213	1.1017	0	0.9451	3.6114	338.94	0.9441	0	0.9671	190.26
NF 12	9.155	1.1119	0	0.9454	0.1468	33.478	1.2076	2.813	0.8770	10.8940	341.27	1.1698	255.395	0.9087	945.16
M 17	9.773	0.6413	0	0.8485	0.3518	40.213	1.4714	1.916	0.9297	16.8360	374.92	0.9807	918.821	0.7216	2110.30
M 18	9.798	1.5134	0.113	0.9112	0.8454	39.270	1.3832	7.107	0.8271	23.9240	385.21	1.3624	366.500	0.9131	1749.50
M 22	11.250	1.355*	0	0.9753	0.0859	37.743	0.7182	0.179	0.8590	7.1364	353.67	0.9587	0	0.9835	97.34
M 25	9.435	0.4206	0	0.8532	0.6385	41,935	0.8499	1,856	0.8178	7.9073	360.33	0.6671	151.910	0.8149	1204.10

$\bar{X}$: Mean values of the character

* : Significantly different at 5% level.