4. RESULTS

4.1. SEED PRODUCTION USING FEMALE FLOWERS

4.1.1. ANOVA of seed characters

The ANOVA for seed count per fruit, percentage of pre-germinated seeds and percentage of floating seeds is shown in *Table 4.1*. The most striking result was that the 'rounds' of pollination affected all the three characters while inbred parents used as females was significant for seed number and percentage of germination. Surprisingly, the effect of inbred parents used as 'males' (or pollen source) was also significant for these two characters. This implies xenic effects in seed development of papaya. The interaction between female x male was not significant, suggesting that the combination of the best female with the best male would provide the best hybrid for the trait in question.

The total degrees of freedom in the ANOVA was 134 which was 9 short of the expected 143 derived from 6 males x 6 females x 4 rounds = 144 'plots'. This was because some of the plots did not set fruit at all inspite of pollination of 4-5 flowers in each 'plot'. For unbalanced data sets, the ANOVA was performed using the General Linear Model.

4.1.2. Effect of female (ovule) and male (pollen)

Examining the 'female' effect first, the means of the inbreds used as maternal parents in the seed production are shown in *Table 4.2*. Eksotika when used as the female parent for F_1 production appeared to be the most prolific seed producer, with an average of 1 137 seeds/fruit. Its sib, Line 19 which comes from the same breeding population, was also very seedy (1 053 seeds). Subang, Morib and Solo were moderately seedy (about 860-870 seeds) but Paris was the least seedy (690 seeds). For percentage of pre-germinated seeds, Line 19 and Paris seemed to have the highest. Pre-germinated seeds showed a break in the testa and sometimes the radicle has emerged. Such seeds when dried and stored, will not be viable. About 24% of the seeds of Line 19 and Paris germinated while still in the fruit. Because of this high rate of pre-germination, these two varieties will be expected to produce a lower percentage of good or 'sound' seeds compared with others. Subang and Eksotika, on the other hand, did not have this constraint in seed production (*Table 4.2*).

Table 4.1. Analysis of variance for number of seeds, % pre-germinated seeds and % floating seeds

		Mean square		
Source	df	No. seed/ fruit	% pre-germ. seed (x 10^5)	% floating seed (x 10^{-3})
Round	3	10.27 **	0.3105 **	8.1801 **
Maternal (M)	5	5.80 **	0.2882 **	0.6882 ns
Pollen (P)	5	0.58 *	0.2018 **	0.2189 ns
M*P	25	0.25 ns	0.0261 ns	0.4421 ns
Error	96	0.22	0.0252	0.3708
Total	134			

ns = not significant
* = significant at p>0.05
** = significant at p>0.01

Table 4.2. Hybrid seed production as influenced by maternal and pollen inbred parents

Inbred parent	No. seed/ fruit	% pre-germ. seed
Maternal		
Eksotika	1 137.0a	0.64d
Line 19	1 053.0a	24.74a
Subang	876.2b	0.83d
Morib	870.3b	14.05bc
Solo	861.7b	5.81cd
Paris	690.7c	23.46ab
Pollen		
Solo	975.8a	4.66c
Eksotika	961.3a	9.32bc
Paris	910.5ab	16.04b
Line 19	904.0ab	27.18a
Morib	897.8ab	11.50bc
Subang	845.3b	1.60c

Values within column followed by the same letter are not significantly different at $p = 0.01$ according to Duncan Multiple Range Test (DMRT).

The 'male' or pollen effects were significant for seed yield (number of seeds/fruit) and percentage of pre-germinated seeds, suggesting the occurrence of xenic effect of pollen source on these two seed production characters. Examining the mean of seed number arising from different pollen sources, it can be seen that Solo and Eksotika pollen significantly increased seed production compared with Subang (*Table 4.2*). The effects of pollen source were more pronounced on formation of pre-germinated seeds. About 27% of the seeds produced by fertilisation with Line 19 pollen germinated prematurely while still in the fruit. Paris also showed the same tendency although at a lower percentage (16%). Incidentally, these two varieties also developed high percentages of pre-germinated seeds when they were used as female parents in crosses.

4.1.3. Effect of age of tree

The significance of crossing 'rounds' for all the variables is of interest. The four rounds were carried out at three monthly intervals when the trees were 9, 12, 15 and 18 months old. The variation in seed production characteristics may not, of course, be due to the age of trees alone, but confounded with other factors such as environmental effects including weather. However, looking at the means of the four rounds, there appeared to be definite, predictive trends. Such trends are unlikely to have resulted from environmental effects as these tend to be random.

Seed yields seemed to increase with the age of the trees. The yield was 686 seeds/fruit in 9-month old trees increasing to 853 seeds/fruit in 12-month old trees and finally plateauing off at just over 1 000 seeds/fruit when trees were 15 to 18 months old (*Table 4.3*). The same trend was also true for occurrence of pre-germinated seeds where older trees seemed to have higher incidence. Nine and 12-month old trees showed negligible occurrences of 2 - 4%, but dramatically rose to 18% and 21% when trees were 15 to 18 months old respectively. The trend in occurrence of floating seeds (poorly developed embryo), however, was in the opposite direction. Seed and embryo development appeared to improve as trees got older (*Table 4.3*).

When the time taken for fruit development was examined at the various tree ages, it was found that the fruits took longer to ripen when trees were older. Fruits from younger trees (9-12 months old) took 151-156 days to mature while those from older trees (15-18 months old) took 159-163 days. There seemed to be a strong correlation between seed development, percentage pre-germination and time of fruit development which was logical. When fruits remained on trees longer, the seeds may have passed their stage of physiologic maturity and inhibitors in the fruit or sarcotesta may have lost their effectiveness, allowing seeds to germinate. On the other hand, the percentage of floating seeds may have decreased with age because a longer maturation period allows for better development of the embryos.

4.1.4. F_1 seed yield and estimated seed costs

Three factors need to be considered with regard to seed yield:

* the percentage of successful pollination and fruit set,
* the number of seeds developed in the fruit, and
* the percentage of seeds that are sound and viable i.e. excluding floaters and pre-germinated seeds

From the results shown in *Table 4.4*, the best fruit set came from Solo and its related lines, Eksotika and Line 19, where over 80% of the flowers successfully set fruits. Coupled with the high seed yield per fruit, these three genotypes topped in gross seed yield. On per 100 pollination basis, the seed yield for these three genotypes ranged from 75 795 to 94 746 seeds. Discounting for poor seeds (floaters and pre-germination), their seed yields were still very high, but Line 19 showed considerable reduction due to a high percentage of pre-germinated seeds (24%). The poorest seed yielder was Morib which had very poor fruit set (42.6%) as well as low seed yield/fruit (870 seeds). Paris had better fruit set (63%), but low seed yield/fruit (690 seeds) as well as high proportion of pre-germinated seeds (23%), pushed its seed yield down to almost the same level as Morib. Subang, despite quite poor fruit set (52%), made up for this weakness with a high percentage (97%) of sound seeds.

Eksotika appeared to be the best parent to use for hybrid seed production in so far as seed yield is concerned. In comparison, the others were far inferior, particularly Morib and Paris which yielded only 34-35% of Eksotika's production (*Table 4.4*). The capacity of an inbred to produce hybrid seeds must be given due consideration because it definitely affects the pricing of hybrid seeds. Eksotika hybrid seeds are now sold at RM 3 000/kg at MARDI. Using this as the yard-stick and assuming that all costs remain the same for the other inbreds, the cost of hybrid seeds using Subang will be about twice that of Eksotika because it produces only half the amount of seeds as Eksotika with the same inputs. For Paris and Morib, the seed cost may well be in excess of RM 8 000/kg. Whether or not this high seed cost can be justified by an increase in yield or returns to investment from these hybrids will be examined later.

Table 4.3. Hybrid seed production and time of fruit maturity as influenced by age of trees

Age (months)	Seed yield (no./fruit)	% pre-germ	% float seed	% good seed	Days to harvest
9	686.8c	4.27b	4.86a	90.85a	151.3c
12	853.8b	2.70b	2.39ab	94.86a	156.3b
15	1083.6a	18.07a	1.35b	80.58b	159.1b
18	1015.2a	21.63a	1.64b	76.72b	163.4a

Values within column followed by the same letter are not significantly different from one another at p = 0.01 according to DMRT.

Table 4.4. Seed yield and estimated seed costs of hybrids developed from six inbred parents

Inbred	Fruit set (%)	Seed yield		Good seed		Compare with Eksotika (%)	Cost RM/kg
		no./fruit	per 100 polln.	%	no.		
Eksotika	83.33	1 137.0	94 746	96.25	91 193	100.00	3000*
Solo	87.96	861.7	75 795	91.22	69 140	75.82	3957
Line 19	83.33	1 053.0	87 746	72.37	63 502	69.63	4308
Paris	63.88	690.7	44 121	74.30	32 782	35.95	8345
Subang	52.78	876.2	46 246	97.65	45 159	49.52	6058
Morib	42.59	870.3	37 066	83.77	31 050	34.05	8811

* MARDI's price of Eksotika II hybrid

4.2. SEED PRODUCTION USING HERMAPHRODITE FLOWERS

4.2.1. Combined ANOVA over environments

The results of the combined ANOVA are shown in *Table 4.5*. For the majority of characters, they show that there were significant differences between environments, maternal (seed) parent, pollen parent and sex types i.e. between hermaphrodite and female. Interaction between environment x maternal parent was usually highly significant and to a lesser extent between environment x pollen parent. Some characters also showed significance in interaction between sex and maternal parent while non-significance was shown in the interaction between sex and pollen parent.

4.2.2. Environmental effect

A comparison of means between the two environments for the six characters is shown in *Table 4.6*. The seed yield/100 pollinations at Serdang was 31 566 seeds and this was 25.8% higher than at Pontian. Total seed yield depended on the percentage of fruit set, the number of seeds developing in a fruit as well as the percentage of 'good' or sound seeds. Since no difference in fruit set between the two environments was detected (both 54%), the difference in seed yield arose largely because of the difference in the number of seeds developing in a fruit - 709 compared with 580 seeds/fruit between Serdang and Pontian respectively. To a lesser extent, the difference in the percentage of good seeds between the two environments (Serdang 81.3%, Pontian 74.8%) also contributed to the difference in total seed yield. The development of higher percentage of sound seeds at Serdang was due to lower occurrence of floaters which have under-developed embryos (*Table 4.6*).

4.2.3. Genotypic effect

The six seed parents also showed differences in production of seeds and they appeared to fall into two distinct groups as in the previous study (section 4.1). The first group, consisting of Sunrise Solo, Line 19 and Eksotika, has basically the Solo genetic background and they produced much more seeds than the second group which was made up of Paris, Subang and Morib. Seed production/100 pollinations was in the range of 42 021 - 54 550 for the first

Table 4.5. Analysis of variance of six characters for hybrid seed production over two environments

Source	df	MS fruit set ($x10^{-3}$)	seed/ fruit ($x10^3$)	% float seed	% pre-germ	% good seed	total seeds ($x10^3$)
Environment	1	5 ns	1461**	11709**	2228**	3721**	31855**
rep(env.)	4	221**	38 ns	91 ns	168 ns	179 ns	2018**
maternal	5	4356**	332**	1779**	7021**	9377**	9179**
pollen	5	126**	341**	316**	7101**	6049**	2182**
env*maternal	5	639**	133**	1157**	597 *	1995**	1985**
env*pollen	5	100 *	67 ns	153 *	587 *	708 *	412ns
sex	1	11863**	14076**	268 *	2104**	869 *	258565**
sex*maternal	5	476**	345**	230**	275 ns	250 ns	4359**
sex*pollen	5	110 *	52 ns	125 ns	53 ns	115 ns	839ns
error	313	40	37	63	232	247	515

Table 4.6. F_1 hybrid seed production at two environments

Environ.	% set	Seed/ fruit	Seed/ 100 polln	% pre-germ	% float seed	% good seed	Total good seed/ 100 polln
Serdang	54.7a	709.8a	38 826	15.8a	2.8b	81.3a	31 566
Pontian	54.0a	580.1b	31 325	10.8ab	14.4 a	74.8b	23 431

Means within column followed by the same letter are not significantly different at p=0.01 according to DMRT group, and this on average, was about double the production of the other inbreds which ranged from 19 925 to 23 552 (*Table 4.7*). This was due to the better fruit set of the three inbred parents in the first group. This yield, however, was much lower than the range of 75 795 - 94 746 that was obtained in an earlier trial using female flowers. This was because the present trial included hermaphrodites and as can be seen later, seed production from this source was considerably lower.

Quite a high percentage of this gross seed yield would not be viable because of pre-germination of the seeds in the fruit and under-developed embryos (floaters). As in the earlier trial, Subang and Eksotika again showed the highest percentage of sound seed while Paris, Morib and Line 19 have high percentages of poor quality seed mainly because of large amounts of pre-germinated seeds in the fruit.

With regard to effect of pollen parent on hybrid seed production, *Table 4.8* shows that Subang was the best pollen parent for fertilisation and development of the highest number of good seeds/100 pollinations (34 870 seeds). This was followed closely by Solo (32 503 seeds). Both of them were favourable as pollen parents because a high percentage of good seeds (87%) was developed. In contrast, Line 19 and Paris, as in the previous trial, were poor pollen parents because seeds formed as a result of fertilisation by their pollen have a high tendency (20 - 31%) to pre-germinate. Seed production (total good/100 pollinations) with Line 19 pollen was only 55 - 60% compared with Subang or Solo pollen parents (*Table 4.8*).

4.2.4. Genotype x environment effect

There was significant interaction between environment x maternal parent for all the six characters (*Table 4.5*). This means that while the genotypes generally differed in their capacity to yield seeds, this difference was not always in the same proportion over the two environments. *Table 4.9* shows the results of the six characters of the six genotypes at the two environments. It can be seen that production of seeds within genotypes between environments differed. The disproportionate difference in seed yield within the same genotype between environments was due to disproportionate differences in occurrence for fruit set, seed number per fruit and percentage of good seeds, all of which also showed significant environment x maternal parent interaction. Comparing the means of each inbred line at each environment, Serdang was a generally better environment in seed yield as indicated by the ratio between environments which was generally > 1. This was true for all genotypes with the exception of

Table 4.7. Means of six maternal parents in hybrid seed production

Maternal parent	% fruit set	No. seed/ fruit	No. seed/ 100 polln.	% pre-germ.	% float	% good seed	Total good seed/ 100 polln.
Solo	85.1	535.0d	45 529	7.7c	14.9a	77.3c	35 194
Line 19	75.7	721.0a	54 580	18.1b	10.7b	71.2d	38 861
Eksotika	67.7	620.7bc	42 021	3.5c	6.9c	89.6b	37 651
Paris	39.3	599.3dc	23 552	28.0a	14.2a	57.8e	13 613
Morib	30.6	682.7ab	20 891	24.2a	2.8d	73.1cd	15 271
Subang	28.4	701.6a	19 925	0.5d	2.7d	96.8a	19 287

Means within column followed by the same letter
are not significantly different at p=0.01 according to DMRT

Table 4.8. Means of six pollen parents in hybrid seed production

Pollen parent	% fruit set	No. seed/ fruit	No. seed/ 100 polln.	% pre-germ.	% float	% good seed	Total good seed/ 100 polln.
Solo	53.1	702.8a	37 318	5.6cd	7.3bc	87.1a	32 503
Line 19	52.2	603.4b	31 497	31.8a	6.4c	61.8d	19 465
Eksotika	51.0	696.1a	35 501	9.8c	9.6ab	80.6b	28 613
Paris	50.7	686.5a	34 805	20.4b	9.2bc	70.4c	24 502
Morib	57.3	513.3c	29 412	8.2c	12.5a	79.3b	23 323
Subang	61.8	645.6ab	39 898	2.8d	9.8ab	87.4a	34 870

Means within column followed by the same letter
are not significantly different at p=0.01 according to DMRT

Morib, where the seed yield at Pontian was almost twice that in Serdang, as indicated by the ratio between environment of 0.48. This happened because of the unusually high fruit set of Morib at Pontian.

4.2.5. Seed production: hermaphrodite v. female

The ANOVA in *Table 4.5* shows that there was significant differences in seed production between hermaphrodite and female seed parents. Comparison of means for total seed yield/100 pollinations between the two sexes indicated that females as seed parents were more efficient in production of hybrid seeds (*Table 4.10*). The total number of 'good' seeds obtained from pollination of 100 female flowers amounted to 45 687 seeds compared with 11 128 obtained for hermaphrodites. This difference in seed yield arose largely because fruit set in female trees was almost twice as high as hermaphrodites and female fruits also developed more than twice the amount of seeds per fruit. In addition, although to a lesser extent, female fruits bore slightly better quality seeds because of a lower percentage of pre-germination in the fruit. The advantage held by females in these three factors subsequently resulted in seed yield of females being just over four times that of hermaphrodites.

There was, however, significant interaction between sex and maternal parent for percentage fruit set, number of seed/fruit and total seed yield (*Table 4..5*). This means that while female was generally better than hermaphrodite in seed production, the difference between the two sexes was not demonstrated in the same relative proportion over all the six inbred parents. Therefore, the production of seeds by each sex type must be examined one genotype at a time in order to understand more clearly the nature of the interaction. *Table 4.11* shows the means between the two sexes of all the six maternal parents. Examining the total seed yield, it can be seen that the difference in seed production between female and hermaphrodite varied between 2.5 times for Line 19 to 16.7 times for Subang. Some trends were quite evident. For Line 19, Eksotika and Sunrise Solo which are quite similar in genetic background, the differences in production of seeds between female and hermaphrodite were considerably smaller than that of the others. The main reason for the smaller gap in seed production between the two sexes for these three inbred lines lies in the fact that hermaphrodite flowers have a high percentage of set despite emasculation injury. The fruit set ranged from 54.2% in Eksotika to 74.3% in Sunrise Solo. On the other hand, Morib, Paris and Subang hermaphrodite flowers have very low fruit set after emasculation, in the range of 5.6% to 17.4% only and this had resulted in a considerable decline in hermaphrodite seed production for these three inbred parents.

Table 4.9. Means of six genotypes at two environments for hybrid seed production

Genotype	Environ.	% fruit set	No. seed/ fruit	No. seed/ 100 polln.	% good seed	Total good seed/ 100 polln.	Ratio between environ.
Eksotika	Serdang	67.4	739.8	49 862	89.1	44 427	1.19
Eksotika	Pontian	68.1	602.6	41 037	90.8	37 261	
Line 19	Serdang	86.2	782.0	67 408	70.3	47 388	1.53
Line 19	Pontian	62.5	690.6	43 162	71.6	30 904	
Solo	Serdang	95.8	566.9	54 309	87.8	47 683	1.70
Solo	Pontian	74.3	571.3	42 447	66.0	28 015	
Paris	Serdang	30.9	673.6	20 814	74.7	15 548	1.06
Paris	Pontian	47.2	581.2	27 432	53.5	14 676	
Subang	Serdang	27.8	877.4	24 391	99.1	24 172	1.51
Subang	Pontian	29.9	567.8	16 977	94.1	15 975	
Morib	Serdang	19.4	755.4	14 654	69.5	10 185	0.48
Morib	Pontian	41.7	647.1	26 984	78.1	21 074	

Table 4.10. Seed production between females and hermaphrodites

Sex	% fruit set	No. seed/ fruit	No. seed/ 100 polln.	% pre-germ	% float	% good seed	Total good seed/ 100 polln.
Female	71.1a	810.3a	57 612	11.6b	9.1a	79.3a	45 687
Herma	37.9b	388.9b	14 739	15.3a	9.2a	75.5b	11 128

Means within column followed by the same letter
are not significantly different at p=0.01 according to DMRT

Table 4.11. Mean comparison between females and hermaphrodites of six genotypes in the production of hybrid seeds

Genotype	sex	% fruit set	No. seed/ fruit	No. seed/ 100 polln.	% good seed	Total good seed/ 100 polln	ratio between sexes
Eksotika	F	81.3	894.0	72 682	92.4	67 158	4.3
Eksotika	H	54.2	336.2	18 222	86.4	15 744	
Line 19	F	83.8	937.9	78 596	71.5	56 196	2.5
Line 19	H	65.5	497.9	32 612	70.2	22 893	
Solo	F	95.8	825.1	79 045	77.9	61 575	4.4
Solo	H	74.3	238.3	17 705	78.7	13 934	
Paris	F	69.4	633.4	43 958	62.7	27 562	11.4
Paris	H	9.3	490.7	4 563	52.9	2 414	
Subang	F	52.1	747.7	38 955	96.8	37 709	16.7
Subang	H	5.6	429.4	2 405	94.1	2 263	
Morib	F	43.8	784.2	34 348	81.2	27 891	6.2
Morib	H	17.4	422.7	7 355	60.7	4 464	

4.3. PERFORMANCE OF F_1 HYBRIDS IN GxE TRIAL

4.3.1. ANOVA examined by environments

The 14 characters were separated into vegetative, fruit and yield for more organised presentation. The ANOVA for the six environments is presented in *Table 4.12* for the four vegetative characters, in *Table 4.13* for the three fruit characters and resistance to malformed top disease (MTD) and finally in *Table 4.14* for the six yield characters.

The ANOVA for the vegetative characters (*Table 4.12*) indicated that genotypic effects were significantly different for trunk diameter and plant height at all the environments with the exception of Bukit Tangga. For petiole length, significance between genotypes was found at all environments except Kuala Kangsar and Bukit Tangga, while for lamina width, Kundang was found to show non significance in genotypic effects in addition to Kuala Kangsar and Bukit Tangga. The latter environment was the only one that did not show significant difference in genotypic effects for all four vegetative characters because the error M.S. were very high in that environment (*Table 4.12*).

The ANOVA on three fruit characters and incidence of malformed top disease (MTD) is presented in *Table 4.13*. Genotypic differences were highly significant at all the six locations for these four characters with the exception of carpellody % at Kuala Kangsar and Bukit Tangga and MTD incidence in Bukit Tangga.

The ANOVA for six yield characters (*Table 4.14*) showed that genotypic differences were mostly significant at all the environments with the exception of Bukit Tangga. Genotypes were not significantly different for yield 2 at Kundang and at Bukit Tangga, there was no difference between genotypes for five of the six yield characters. This appeared to arise again from the relatively large error M.S. at Bukit Tangga.

4.3.2. Genotypic means examined by environments

The genotypic means at each of the six locations for the 14 characters are presented in *Tables 4.15 - 4.28*. The genotypes in the rows were listed in an order such that the inbreds were placed on top of the table followed by the sibs and the wide cross hybrids occupied the lower half of the table. The environments in the columns were also ordered with the more favourable environments (in terms of vigour and yield) occupying the left-most column and the

Table 4.12. Summarised results of ANOVA at each environment for four vegetative characters

		Mean Squares			
Environment	Source	Trunk diameter	Plant height (x 10^2)	Petiole length (x 10^2)	Lamina width (x 10^2)
Pontian	R	96.88**	269.30**	35.33**	20.99**
	G	12.94**	73.60**	12.43**	9.33**
	E	4.69	15.66	2.87	1.86
Kundang	R	34.48**	125.41**	41.74**	18.26**
	G	9.77*	58.17**	8.64*	3.64
	E	4.28	7.27	4.80	2.02
Kluang	R	9.07**	26.75**	5.06	0.18
	G	5.67*	29.98**	13.93**	9.75**
	E	2.68	6.81	3.80	1.47
Serdang	R	2.09	2.80	1.59	1.10
	G	15.04**	28.50**	8.59**	3.67**
	E	2.62	3.51	1.21	0.72
KKangsar	R	5.37**	1.70	6.59*	8.95**
	G	7.31**	38.06**	4.85	2.52
	E	2.58	6.53	2.86	2.22
BTangga	R	2.57	9.43	22.36	12.33
	G	5.71	16.22	13.89	8.26
	E	7.00	16.89	17.70	7.90

R = replicate (df = 2)
G = genotype (df = 20)
E = error (df = 40)

Table 4.13. Summarised results of ANOVA at each environment for three fruit characters and resistance to malformed top disease (MTD)

		Mean Squares			
Environment	Source	Fruit weight (x 10^2)	Carpellody %	TSS %	MTD (x 10^2)
Pontian	R	21.58**	21.31	5.94**	1.44
	G	207.74**	45.07**	19.01**	3.54**
	E	4.72	8.32	0.96	1.06
Kundang	R	10.23	5.57	9.56**	1.28
	G	154.95**	159.98**	31.22**	15.77**
	E	6.05	15.91	2.62	0.78
Kluang	R	16.72	3.19	0.38	13.06**
	G	166.55**	18.35**	17.33**	11.25**
	E	8.56	4.08	0.71	1.28
Serdang	R	2.49	18.69	0.81	3.61
	G	102.85**	117.39**	25.27**	21.97**
	E	1.49	29.57	1.18	1.25
KKangsar	R	0.95	57.94	1.94	1.76
	G	68.05**	58.71	46.40**	29.65**
	E	3.05	31.84	2.74	2.82
BTangga	R	9.45	1364.50*	6.93**	0.19
	G	54.35**	347.47	19.86**	0.17
	E	4.83	470.27	1.38	0.19

R = replicate (df = 2)
G = genotype (df = 20)
E = error (df = 40)

Table 4.14. Summarised results of ANOVA at each environment for six yield characters

		Mean Squares					
Environ.	Source	Earliness	Height fruit	Fruit number	Yield 1 (harv. 1)	Yield 2 (harv. 2)	Yield (combined)
Pontian	R	7.51**	25.59**	94.22**	59.01**	28.35**	132.45**
	G	4.68*	16.96**	52.15**	29.38**	6.38*	43.43**
	E	2.48	1.78	5.22	4.77	2.68	7.75
Kundang	R	0.87**	0.90	2.88	0.86	7.17	6.69
	G	0.67**	23.22**	44.22**	7.70**	6.48	22.35*
	E	0.18	0.62	9.06	1.42	4.78	9.43
Kluang	R	0.72	11.22**	2.94	0.33	1.02	2.53
	G	7.89**	18.92**	21.75**	4.38**	5.20**	17.56**
	E	1.29	1.53	3.57	0.68	2.18	4.47
Serdang	R	36.97**	15.19**	19.42**	0.34	5.65**	7.28**
	G	129.89**	55.10**	21.17**	0.93**	8.19**	13.36**
	E	7.83	2.60	3.52	0.20	1.69	2.12
KKangsar	R	0.54**	5.09*	6.76**	0.90	1.98**	1.10
	G	0.09*	17.00**	6.78**	2.81**	0.51*	4.11**
	E	0.05	1.98	2.48	0.54	0.24	1.08
BTangga	R	35.96	9.95**	24.10	0.09	1.35	2.13
	G	55.44	13.75**	13.93	0.08	6.72	7.75
	E	40.91	1.74	16.34	0.06	7.13	8.32

R = replicate (df = 2)
G = genotype (df = 20)
E = error (df = 40)

least favourable to the right. This deliberate order was designed to let the matrix express the trends, if any, that may appear in the performance between inbreds and hybrids over the six environments.

For the four vegetative characters i.e. trunk diameter, plant height, lamina width and petiole length shown in *Tables 4.15 - 4.18*, a large declining gradient in values from the top left to the bottom right of the table was evident. This implied that inbreds under the best environments would be more vigorous than wide cross hybrids under poor environments. Within the most favourable environment (Pontian), there was little to separate the inbreds at the top from the wide cross hybrids at the bottom half, but the difference in vigour between these two groups became more prominent as less favourable environments were encountered. For trunk diameter, in particular, the superiority in vigour of wide cross hybrids became very obvious in less favourable environments like Serdang, Kuala Kangsar and Bukit Tangga (*Table 4.15*). With regard to CV, the variation of the genotypes at all the environments for the four characters were generally low, with the exception of Bukit Tangga which appeared to have the highest CV for the majority of characters.

For fruit characters (*Tables 4.19 - 4.21*), there appeared to be no distinct differences between the inbreds and hybrids for fruit weight and TSS %. These two characters appeared to be genotype dependent. The genotypes which have Solo genetic background such as So x So, Ek x Ek, 19 x 19 and their sibs have small fruits and high TSS % while the other inbreds Mo x Mo, Su x Su and Pa x Pa and their hybrids have large fruits and low TSS %.

It was interesting to note that for carpellody % *(Table 4.20*), there appeared to be no trends at all in the genotypes' performance over environments. Some genotypes such as So x So, 19 x 19 and Mo x So have negligible occurrence of carpellody over most environments but suffered an occasional setback of over 20% occurrence in one of the environments. Because of the unpredictability in genotypic performance (as reflected also in their extremely high CV), carpellody % was expected to show highly significant GxE interaction.

The incidence of MTD shown in *Table 4.22* indicated that genotypes with Solo genetic background such as So x So, 19 x 19 and Ek x Ek and the sibs between them were susceptible to the disease and more so at high disease environments such as Kundang, Kuala Kangsar and Serdang. On the other hand, Pa x Pa, Su x Su and Mo x Mo were resistant and incidence of disease were quite negligible even in disease prone areas. Hybrids between the resistant and susceptible groups gave rise to moderately tolerant genotypes.

For earliness (days to flower) (*Table 4.23*), there was a general increasing trend in maturity from the most favourable environment (Pontian) to the least favourable (Bukit Tangga). However, some genotypes, for example, Pa x Pa which flowered later in Pontian than Kundang and Kluang, did not follow this trend. This would lead to significant GxE interactions. Earliness and height of first fruit appeared to be genotype related and there was no distinction between inbreds and hybrids for these two characters. This was particularly true for height of fruit (*Table 4.24*) where inbreds at Pontian (best environment) at the top left of the table were not different in height of bearing compared to the wide cross hybrids at the worst environments (bottom right of table).

The genotypic means for fruit number over environments are shown in *Table 4.25*. Pontian produced the most number of fruits and a declining trend across environments to Bukit Tangga (least productive) was noted. However, some genotypes such as Su x Su, Pa x Pa, 19 x Pa, Ek x Su and Mo x Su did not follow this general trend and significant GxE may be expected.

For yield in harvest 1, harvest 2 and combined, shown in *Tables 4.26 - 4.28*, the superiority of hybrids over the inbreds and sibs was rather convincing. The hybrids were far better yielders at almost all environments for the three periods of harvest. There were only two occasions when the superiority in yield of the hybrids over the inbreds/sibs were not demonstrated. The first occasion was in the harvest 1 at Bukit Tangga and the second occasion was in the harvest 2 at Kuala Kangsar. On both occasions, the yield obtained was so low that no distinction between the two groups of genotypes was possible. It was also evident from the extremely large CV (142 % at Bukit Tangga, Yield 1 and 230 % at Kuala Kangsar, Yield 2), that the performances of the genotypes from both groups were extremely erratic on both these occasions.

4.3.3. Combined ANOVA over six environments

The results of the combined ANOVA over six environments for the 14 characters are shown in *Table 4.29*. For convenience of presentation and discussion, the 14 characters were divided into four groups i.e. vegetative, fruit, yield and disease resistance

Table 4.15. Genotypic means at six environments for trunk diameter (cm)

Genotypes	Environments Pontian	Kundang	Kluang	Serdang	KKangsar	BTangga
Ek x Ek	9.96	7.90	8.59	4.75	5.83	2.93
19 x19	9.65	8.89	8.87	5.46	6.19	3.35
So x So	9.62	7.92	8.15	5.58	5.99	3.40
Mo x Mo	7.76	7.57	7.66	6.89	5.33	3.56
Su x Su	7.97	8.91	8.07	6.66	5.79	4.98
Pa x Pa	8.00	9.49	7.48	7.18	6.17	4.35
Ek x 19	9.92	9.30	9.18	5.47	5.27	3.52
Ek x So	10.10	9.12	9.05	5.29	6.29	3.12
19 x So	9.97	8.73	8.43	5.28	7.12	3.73
Ek x Pa	10.34	10.71	9.80	7.17	7.26	4.01
Mo x Pa	8.87	9.23	8.96	7.39	6.40	4.53
19 x Pa	9.61	9.09	8.03	8.19	7.07	4.23
Su x Pa	8.42	9.52	8.04	7.54	7.57	4.64
So x Pa	10.45	11.20	9.58	7.55	7.39	3.73
Mo x So	11.28	10.05	9.24	7.47	7.40	4.85
Su x So	9.95	9.21	9.19	7.45	7.45	4.89
Ek x Su	9.17	9.65	8.93	6.95	6.27	4.41
Mo x Su	9.63	9.02	9.05	6.99	6.01	4.33
19 x Su	8.34	9.57	9.07	7.29	6.44	4.73
Mo x 19	8.97	9.37	8.47	7.63	6.85	3.81
Ek x Mo	10.15	8.89	8.64	7.64	6.67	4.58
Env. mean	9.43	9.21	8.69	6.75	6.51	4.08
C.V. %	8.22	10.04	9.42	8.63	13.56	17.11

Table 4.16. Genotypic means at six environments for plant height (cm)

Genotypes	Environments Pontian	Kundang	Kluang	Serdang	KKangsar	BTangga
Ek x Ek	168.6	130.0	139.9	103.2	117.8	74.5
19 x19	195.2	163.7	164.5	126.3	140.7	84.1
So x So	191.9	154.4	161.8	139.5	146.8	90.7
Mo x Mo	117.0	95.6	107.7	97.4	93.1	75.3
Su x Su	145.3	127.5	134.5	111.9	123.0	105.1
Pa x Pa	150.2	138.2	132.3	121.2	114.2	95.1
Ek x 19	180.9	152.7	154.5	124.2	118.9	84.7
Ek x So	191.3	167.6	161.5	126.7	139.3	82.8
19 x So	197.9	166.1	152.0	125.9	156.5	94.0
Ek x Pa	180.3	159.4	147.2	135.7	140.5	90.8
Mo x Pa	147.1	123.2	135.5	115.9	128.2	90.3
19 x Pa	175.7	149.3	141.3	156.4	142.7	102.2
Su x Pa	147.5	141.5	139.3	131.7	141.9	105.2
So x Pa	196.5	182.7	164.6	148.4	149.0	91.3
Mo x So	192.1	150.8	144.1	133.5	138.1	98.1
Su x So	191.3	155.1	154.8	137.4	152.4	115.7
Ek x Su	158.5	145.4	135.2	127.9	125.6	99.5
Mo x Su	170.8	124.3	143.1	113.3	114.9	88.5
19 x Su	161.7	144.1	161.1	133.4	135.4	108.5
Mo x 19	151.8	129.8	144.7	131.1	122.0	87.7
Ek x Mo	156.3	126.8	129.1	130.9	112.5	89.7
Env. mean	169.9	144.2	145.2	127.2	131.1	93.0
C.V. %	8.1	8.5	7.9	6.5	9.6	12.7

Table 4.17. Genotypic means at six environments for lamina width (cm)

Genotypes	Environments					
	Pontian	Kundang	Kluang	Serdang	KKangsar	BTangga
Ek x Ek	65.0	65.6	54.2	61.0	59.3	36.3
19 x19	60.5	69.8	55.8	63.1	52.6	48.0
So x So	53.8	60.0	41.8	49.7	48.1	30.7
Mo x Mo	57.0	57.8	59.3	52.7	48.8	47.7
Su x Su	67.8	62.0	62.0	54.4	51.0	55.5
Pa x Pa	76.2	68.0	62.9	62.8	56.2	52.3
Ek x 19	63.9	71.0	60.6	65.4	55.3	49.3
Ek x So	56.6	64.6	46.8	60.2	51.8	39.6
19 x So	52.8	57.9	47.2	59.8	53.1	44.1
Ek x Pa	81.3	78.6	70.6	69.2	57.0	58.4
Mo x Pa	72.9	67.1	71.0	61.0	61.1	56.5
19 x Pa	74.7	65.3	59.5	70.4	57.2	58.5
Su x Pa	73.8	64.2	69.8	63.0	60.4	55.9
So x Pa	76.4	70.5	66.9	63.7	61.6	46.1
Mo x So	56.9	67.2	58.2	59.3	53.8	56.2
Su x So	62.3	60.0	48.2	59.9	56.0	63.6
Ek x Su	64.2	70.8	61.2	57.3	50.9	56.2
Mo x Su	71.6	69.7	64.6	56.1	53.7	57.6
19 x Su	59.6	70.6	60.2	56.9	49.0	54.4
Mo x 19	67.2	65.2	59.5	61.3	56.0	44.4
Ek x Mo	68.2	65.4	65.4	61.9	49.8	57.3
Env. mean	66.0	66.4	59.4	60.5	54.4	50.9
C.V. %	21.2	13.6	14.6	10.1	16.8	17.8

Table 4.18. Genotypic means at six environments for petiole length (cm)

Genotypes	Environments Pontian	Kundang	Kluang	Serdang	KKangsar	BTangga
Ek x Ek	77.3	70.0	72.8	58.2	62.5	31.4
19 x19	85.4	83.6	87.1	76.2	60.5	47.3
So x So	68.0	78.3	63.6	56.8	53.2	38.7
Mo x Mo	64.1	61.7	69.6	45.0	48.3	47.4
Su x Su	80.2	69.6	77.2	54.4	54.2	59.8
Pa x Pa	88.6	77.6	82.2	60.1	57.7	56.6
Ek x 19	79.1	86.6	83.4	68.4	62.0	55.4
Ek x So	74.6	75.9	70.8	63.0	59.0	37.9
19 x So	77.1	74.6	72.1	67.7	66.0	51.7
Ek x Pa	98.0	93.4	97.3	71.2	68.0	60.9
Mo x Pa	90.8	77.7	96.6	63.2	61.0	63.3
19 x Pa	95.0	74.4	81.0	77.4	66.3	65.4
Su x Pa	89.6	75.4	90.6	62.2	65.1	61.2
So x Pa	97.9	85.0	93.1	68.9	73.0	48.7
Mo x So	76.8	86.4	86.3	68.6	64.4	66.9
Su x So	77.1	70.8	67.2	64.8	64.1	72.9
Ek x Su	80.1	85.0	78.2	58.0	57.6	54.0
Mo x Su	92.1	83.0	90.5	56.9	56.6	60.4
19 x Su	75.1	89.6	81.6	62.5	57.6	57.4
Mo x 19	89.9	78.9	87.0	70.0	66.4	45.2
Ek x Mo	85.3	75.6	86.3	66.0	58.7	31.4
Env. mean	83.0	78.8	81.7	63.8	61.1	54.5
C.V. %	21.2	15.4	11.3	11.8	18.1	23.6

Table 4.19. Genotypic means at six environments for fruit weight (kg)

Genotypes	Environments Pontian	Kundang	Kluang	Serdang	KKangsar	BTangga
Ek x Ek	0.67	0.46	0.39	0.48	0.46	0.40
19 x19	0.77	0.50	0.46	0.48	0.46	0.51
So x So	0.33	0.24	0.24	0.26	0.18	0.34
Mo x Mo	1.10	0.93	1.04	0.86	0.74	0.56
Su x Su	1.18	0.99	0.93	0.93	0.94	0.93
Pa x Pa	1.59	1.24	1.22	1.10	1.08	0.94
Ek x 19	0.94	0.62	0.75	0.56	0.66	0.63
Ek x So	0.51	0.44	0.41	0.41	0.40	0.29
19 x So	0.63	0.43	0.42	0.44	0.35	0.43
Ek x Pa	1.44	1.08	1.00	0.82	0.81	0.72
Mo x Pa	1.64	1.43	1.52	1.21	0.78	0.94
19 x Pa	1.47	0.98	0.99	0.82	0.91	0.84
Su x Pa	1.41	1.21	1.21	0.98	0.84	1.06
So x Pa	1.25	0.78	0.90	0.68	0.62	0.69
Mo x So	1.03	1.06	0.90	0.76	0.59	0.63
Su x So	0.87	0.66	0.64	0.68	0.56	0.61
Ek x Su	1.21	0.85	1.00	0.78	0.65	0.80
Mo x Su	1.39	1.22	1.19	1.23	0.81	1.01
19 x Su	1.19	0.99	0.99	0.87	0.63	0.68
Mo x 19	1.42	1.16	1.06	0.93	0.71	0.65
Ek x Mo	1.45	1.07	1.05	0.87	0.78	0.65
Env. mean	1.12	0.88	0.87	0.77	0.67	0.68
C.V. %	15.90	22.12	28.85	18.44	15.91	22.17

Table 4.20. Genotypic means at six environments for carpellody occurrence (%)

Genotypes	Environments Pontian	Kundang	Kluang	Serdang	KKangsar	BTangga
Ek x Ek	3.83	0.90	1.28	6.47	3.09	3.19
19 x19	1.83	4.04	0.68	39.00	2.09	5.57
So x So	0.00	0.00	0.00	28.56	0.53	4.08
Mo x Mo	1.69	2.48	0.53	15.06	0.00	0.60
Su x Su	0.00	0.00	0.00	11.31	0.21	1.53
Pa x Pa	5.90	2.21	0.00	3.60	3.76	3.57
Ek x 19	0.75	0.00	1.40	0.00	5.37	2.39
Ek x So	1.16	0.38	1.24	0.78	1.81	0.40
19 x So	17.83	1.31	0.70	1.47	2.03	1.77
Ek x Pa	1.66	6.78	0.00	17.60	6.67	5.26
Mo x Pa	3.78	4.05	2.36	15.21	6.65	10.98
19 x Pa	0.50	13.39	11.40	17.68	2.92	15.96
Su x Pa	0.59	2.08	0.00	10.79	1.52	0.86
So x Pa	18.03	4.26	24.14	5.67	7.43	3.09
Mo x So	21.33	2.48	1.73	0.18	0.95	1.01
Su x So	0.88	1.58	0.00	1.08	2.15	8.98
Ek x Su	1.26	2.25	0.76	0.81	1.28	15.57
Mo x Su	0.97	0.99	0.28	3.67	0.59	2.66
19 x Su	3.30	0.78	0.49	5.33	0.00	3.61
Mo x 19	5.79	5.39	1.66	4.92	2.22	20.82
Ek x Mo	0.40	0.00	0.91	0.00	16.48	0.00
Env. mean	4.36	2.64	2.36	9.01	3.22	5.33
C.V. %	112.60	92.41	200.33	126.15	351.24	77.37

Table 4.21. Genotypic means at six environments for total soluble solids %

Genotypes	Environments					
	Pontian	Kundang	Kluang	Serdang	KKangsar	BTangga
Ek x Ek	11.45	13.46	12.02	12.83	13.09	14.21
19 x19	12.12	13.69	13.48	13.95	13.18	15.20
So x So	12.69	14.57	13.50	13.99	14.31	14.82
Mo x Mo	9.41	10.40	10.63	10.59	7.05	10.93
Su x Su	9.31	10.81	10.62	9.53	8.44	11.29
Pa x Pa	10.57	10.95	10.43	11.58	8.98	11.80
Ek x 19	11.63	13.17	12.43	13.27	12.05	14.45
Ek x So	12.12	13.94	12.57	12.99	12.70	14.33
19 x So	12.23	14.70	12.90	13.78	13.30	14.75
Ek x Pa	11.05	10.95	11.51	12.98	9.86	13.18
Mo x Pa	9.69	10.73	10.19	11.11	9.96	11.57
19 x Pa	11.47	12.23	11.16	13.69	11.30	13.57
Su x Pa	9.86	10.40	9.87	11.35	11.64	11.67
So x Pa	11.84	12.24	11.41	13.79	12.24	13.21
Mo x So	9.65	10.73	10.96	12.02	10.93	12.90
Su x So	10.37	11.91	10.62	12.75	10.47	14.65
Ek x Su	9.51	11.72	10.57	11.68	10.01	13.67
Mo x Su	9.75	10.29	10.58	9.94	10.31	11.22
19 x Su	10.03	10.93	10.51	12.34	10.24	12.82
Mo x 19	10.00	10.44	11.26	12.29	11.21	12.90
Ek x Mo	9.33	11.60	10.72	12.28	10.58	12.44
Env. mean	10.67	11.90	11.33	12.32	11.04	13.12
C.V. %	9.33	10.65	9.60	9.07	4.12	6.03

Table 4.22. Genotypic means at six environments for Malformed Top Disease (MTD) incidence

Genotypes	Environments Pontian	Kundang	Kluang	Serdang	KKangsar	BTangga
Ek x Ek	36.7	100.0	70.0	80.0	100.0	0.0
19 x19	13.3	93.3	16.7	60.0.	56.6	3.3
So x So	20.0	90.0	36.7	50.0	90.0	0.0
Mo x Mo	3.3	33.3	0.0	6.7	40.0	0.0
Su x Su	0.0	43.3	0.0	0.0	20.0	0.0
Pa x Pa	0.0	36.7	0.0	0.0	3.3	0.0
Ek x 19	33.3	96.7	43.3	66.7	76.7	0.0
Ek x So	16.7	93.3	36.7	76.7	76.7	0.0
19 x So	3.3	93.3	23.3	70.0	36.7	0.0
Ek x Pa	0.0	70.0	0.0	43.3	66.6	0.0
Mo x Pa	0.0	30.0	0.0	0.0	3.3	0.0
19 x Pa	0.0	66.7	13.3	26.7	0.0	3.3
Su x Pa	0.0	40.0	0.0	3.3	3.3	0.0
So x Pa	0.0	66.7	0.0	50.0	23.3	10.0
Mo x So	0.0	60.0	3.3	36.7	43.3	3.3
Su x So	6.7	63.3	3.3	43.3	36.7	0.0
Ek x Su	10.0	73.3	0.0	33.3	23.3	0.0
Mo x Su	3.3	33.3	0.0	0.0	6.7	0.0
19 x Su	3.3	63.3	0.0	16.7	3.3	0.0
Mo x 19	3.3	66.7	0.0	16.7	23.3	0.0
Ek x Mo	13.3	66.7	20.0	30.0	6.7	0.0
Env. mean	7.9	65.7	12.7	33.8	35.2	0.9
C.V. %	129.8	13.5	89.1	33.1	47.7	458.3

Table 4.23. Genotypic means at six environments for earliness (days to flower)

Genotypes	Environments Pontian	Kundang	Kluang	Serdang	KKangsar	BTangga
Ek x Ek	142.7	141.7	158.0	226.3	151.3	270.2
19 x19	135.4	140.7	144.7	211.6	149.9	235.1
So x So	142.5	141.3	153.9	220.9	151.5	242.8
Mo x Mo	134.3	134.8	136.5	159.3	151.2	195.2
Su x Su	146.7	141.2	156.7	179.0	150.5	206.3
Pa x Pa	140.5	136.9	138.3	146.3	150.4	204.2
Ek x 19	138.1	137.9	152.4	216.3	152.5	202.6
Ek x So	136.1	140.7	152.5	222.6	150.5	241.0
19 x So	134.9	140.1	148.3	214.5	150.8	246.5
Ek x Pa	131.5	137.4	143.9	167.2	150.5	215.8
Mo x Pa	128.5	137.4	133.0	144.5	150.3	185.8
19 x Pa	130.5	135.3	137.0	148.1	150.6	222.0
Su x Pa	136.5	138.1	146.7	144.9	149.4	192.5
So x Pa	131.3	135.6	137.4	152.2	149.3	220.7
Mo x So	126.7	138.1	142.0	159.7	150.1	217.4
Su x So	138.9	140.7	155.3	167.6	151.5	204.6
Ek x Su	139.9	140.3	151.8	168.7	152.1	214.6
Mo x Su	134.1	138.9	144.7	166.0	150.8	193.8
19 x Su	144.9	140.5	150.8	164.0	151.5	204.4
Mo x 19	139.5	137.0	143.7	149.7	150.5	220.4
Ek x Mo	145.1	138.8	147.7	157.4	151.2	214.9
Env. mean	137.1	138.7	146.4	175.6	150.8	216.7
C.V. %	5.3	2.1	5.1	9.1	0.9	12.1

Table 4.24. Genotypic means at six environments for height of fruit (cm)

Genotypes	Environments Pontian	Kundang	Kluang	Serdang	KKangsar	BTangga
Ek x Ek	86.6	69.9	91.0	110.8	66.3	92.9
19 x19	87.7	92.1	97.9	122.9	83.3	88.9
So x So	90.8	95.8	103.0	141.1	93.1	79.3
Mo x Mo	55.9	52.0	60.9	73.1	51.7	56.2
Su x Su	79.0	71.4	86.5	92.9	68.9	84.0
Pa x Pa	69.7	69.5	72.9	86.7	55.1	78.9
Ek x 19	85.9	79.1	98.7	126.2	71.8	83.5
Ek x So	90.3	97.1	94.2	129.0	76.6	89.6
19 x So	98.2	97.7	94.3	123.5	80.0	94.0
Ek x Pa	82.7	79.6	91.2	98.7	80.2	81.1
Mo x Pa	61.8	60.8	70.5	77.1	73.9	71.3
19 x Pa	78.9	83.5	79.7	97.1	73.7	87.7
Su x Pa	71.7	74.8	82.2	77.5	68.0	81.8
So x Pa	84.3	88.8	93.6	95.5	79.5	82.3
Mo x So	78.7	79.3	83.6	90.7	68.3	78.6
Su x So	99.8	94.1	101.1	103.5	88.5	99.2
Ek x Su	81.2	83.9	89.7	95.2	74.3	91.5
Mo x Su	81.4	63.3	85.1	80.6	55.2	71.0
19 x Su	85.5	78.3	106.3	91.6	75.3	92.6
Mo x 19	74.7	69.4	88.7	82.4	63.5	83.4
Ek x Mo	76.6	77.8	81.2	92.6	63.0	76.5
Env. mean	81.0	79.0	88.2	99.5	71.9	83.1
C.V. %	11.8	9.4	9.4	13.1	10.3	12.5

Table 4.25. Genotypic means at six environments for fruit number

Genotypes	Environments Pontian	Kundang	Kluang	Serdang	KKangsar	BTangga
Ek x Ek	69.8	53.6	42.5	44.7	24.4	6.8
19 x19	73.5	75.4	53.8	35.7	22.1	13.7
So x So	117.7	91.3	69.6	67.1	18.4	15.0
Mo x Mo	47.9	30.6	22.3	25.8	16.5	22.1
Su x Su	35.4	36.9	21.0	25.6	13.9	20.6
Pa x Pa	34.9	36.3	29.4	15.3	17.1	11.0
Ek x 19	70.9	63.9	46.9	35.4	11.8	17.0
Ek x So	87.7	76.4	56.4	51.7	28.1	12.1
19 x So	78.3	65.4	46.3	47.6	22.1	20.2
Ek x Pa	63.6	64.2	47.2	40.9	26.2	23.5
Mo x Pa	51.2	35.9	26.4	28.1	15.9	11.4
19 x Pa	58.3	38.7	38.7	48.6	24.1	16.2
Su x Pa	47.9	37.9	30.6	31.9	25.6	24.3
So x Pa	72.0	67.9	47.5	51.5	28.8	12.1
Mo x So	95.5	47.7	52.9	52.3	41.7	42.2
Su x So	79.4	59.5	54.9	46.1	33.0	44.3
Ek x Su	62.4	67.7	44.4	42.6	21.2	28.0
Mo x Su	56.0	36.5	42.9	32.1	20.9	22.0
19 x Su	57.6	46.9	40.5	48.3	20.8	22.8
Mo x 19	56.3	54.3	41.1	49.9	23.1	17.8
Ek x Mo	53.6	52.5	36.6	41.0	20.1	35.6
Env. mean	65.2	54.3	42.5	41.1	22.7	20.9
C.V. %	26.5	36.6	25.6	31.8	53.2	70.2

Table 4.26. Genotypic means at six environments for yield of first harvest (kg)

Genotypes	Environments Pontian	Kundang	Kluang	Serdang	KKangsar	BTangga
Ek x Ek	14.6	5.9	5.1	0.0	7.4	0.0
19 x19	24.1	9.3	7.6	0.2	7.7	0.2
So x So	11.1	2.9	3.6	0.1	2.6	0.1
Mo x Mo	22.0	8.7	9.0	2.0	12.4	0.9
Su x Su	18.6	7.3	6.9	1.5	12.4	1.8
Pa x Pa	29.8	15.0	12.7	2.7	14.5	0.6
Ek x 19	24.9	12.2	11.5	0.1	7.9	0.2
Ek x So	18.1	8.7	7.0	0.2	7.4	0.2
19 x So	25.0	7.0	6.5	0.4	7.2	0.0
Ek x Pa	44.4	26.7	16.3	3.3	14.3	0.7
Mo x Pa	47.9	22.8	16.8	4.4	10.4	0.9
19 x Pa	40.3	14.7	15.6	7.6	16.9	0.5
Su x Pa	40.4	20.5	15.3	6.5	18.4	3.4
So x Pa	47.1	20.0	17.3	3.7	12.5	0.7
Mo x So	67.3	22.1	19.1	5.7	20.6	1.3
Su x So	32.8	13.0	9.9	3.9	14.4	0.9
Ek x Su	40.2	20.3	16.7	4.4	11.9	0.7
Mo x Su	43.9	20.2	22.4	5.2	15.8	2.0
19 x Su	32.2	20.2	17.6	5.4	12.0	1.6
Mo x 19	46.6	29.1	19.4	5.9	14.7	0.6
Ek x Mo	45.7	16.6	15.1	6.1	15.4	1.2
Env. mean	34.1	15.4	12.9	3.3	12.3	0.9
C.V. %	27.4	38.3	46.7	81.9	41.4	142.5

Table 4.27. Genotypic means at six environments for yield of second harvest (kg)

Genotypes	Environments Pontian	Kundang	Kluang	Serdang	KKangsar	BTangga
Ek x Ek	30.2	18.9	11.4	22.0	3.7	4.3
19 x19	32.5	29.4	16.8	16.6	1.9	8.1
So x So	28.2	18.9	12.8	17.0	0.6	5.5
Mo x Mo	29.3	19.7	13.2	17.2	0.2	11.8
Su x Su	23.0	28.2	13.1	22.3	1.3	20.5
Pa x Pa	26.5	28.7	23.3	14.2	4.0	9.7
Ek x 19	39.4	26.7	24.8	20.1	0.2	11.5
Ek x So	25.3	26.1	16.4	21.2	3.8	3.9
19 x So	23.6	21.7	12.9	20.4	0.9	9.0
Ek x Pa	45.3	40.6	30.7	30.4	6.6	17.6
Mo x Pa	35.9	28.1	22.3	29.6	1.6	10.2
19 x Pa	44.3	21.4	23.1	32.1	4.2	14.3
Su x Pa	26.4	25.6	20.4	24.7	2.9	23.2
So x Pa	42.2	31.9	25.3	31.6	5.4	10.8
Mo x So	30.3	26.3	29.1	35.2	3.8	27.1
Su x So	38.6	25.5	24.6	27.9	4.6	26.2
Ek x Su	35.5	38.5	27.2	29.5	2.1	21.5
Mo x Su	34.2	24.7	25.8	33.8	0.8	23.8
19 x Su	38.9	26.8	21.6	36.5	1.4	14.7
Mo x 19	37.5	33.1	25.5	40.4	1.1	11.2
Ek x Mo	32.5	42.4	23.9	28.6	1.0	22.0
Env. mean	33.3	27.8	21.2	26.3	2.5	14.6
C.V. %	50.1	58.1	49.8	41.4	230.1	58.8

Table 4.28. Genotypic means at six environments for total yield (kg)

Genotypes	Environments Pontian	Kundang	Kluang	Serdang	KKangsar	BTangga
Ek x Ek	44.1	24.8	16.5	22.1	11.3	4.3
19 x19	56.6	38.7	24.4	16.8	9.6	8.3
So x So	40.1	21.8	16.5	17.1	3.2	5.6
Mo x Mo	51.4	28.4	22.2	19.2	12.6	12.8
Su x Su	41.7	35.5	20.0	23.8	13.7	22.3
Pa x Pa	56.3	43.8	35.9	16.9	18.6	10.3
Ek x 19	64.4	38.9	36.3	20.2	8.1	11.6
Ek x So	42.2	34.2	23.4	21.4	11.2	4.2
19 x So	48.9	28.7	19.5	20.9	8.1	9.0
Ek x Pa	89.7	67.3	46.9	33.7	21.0	18.2
Mo x Pa	83.8	50.9	39.1	34.0	11.9	11.1
19 x Pa	84.6	36.2	38.7	39.7	21.2	14.8
Su x Pa	66.8	46.1	35.8	31.2	21.2	26.5
So x Pa	89.4	51.9	42.6	35.3	17.9	11.5
Mo x So	98.9	48.4	48.2	40.9	24.5	28.4
Su x So	71.3	38.5	34.6	31.8	19.1	27.2
Ek x Su	76.2	58.8	43.9	33.8	13.9	22.2
Mo x Su	74.4	44.9	48.2	39.0	16.6	25.8
19 x Su	69.9	47.1	39.2	41.9	13.4	16.1
Mo x 19	80.1	62.2	44.9	46.4	15.8	11.8
Ek x Mo	77.1	59.0	39.1	34.7	16.4	23.3
Env. mean	67.0	43.2	34.1	29.6	14.7	15.5
C.V. %	27.4	40.8	40.0	39.5	53.9	57.3

Environment and replicates within environment (Rep(Env)) effects were significant for all the characters. For genotype, all characters showed highly significant effects with the exception of carpellody % which was not significant. Genotype x environment (GxE) effects were not significant for petiole length, lamina width, yield (harvest 2) and yield (combined) and highly significant for the rest of the characters.

4.3.3.1. *Environment effect*

(i) Vegetative characters

The environment means for four vegetative characters are shown in *Table 4.30.* The order of the environments in this table as well as in the following two tables will be such that the best environment will be placed at the top and the poorest at the bottom, so that any trend in changes of the character over environments may be easily seen.

It was evident that plants in Pontian and to a certain extent, Kundang and Kluang were more vigorous in their vegetative growth, compared with the other environments. Serdang and Kuala Kangsar can be regarded as moderate for plant vigour while Bukit Tangga was definitely the poorest environment for plant growth. Trunk diameters at Pontian, Kundang and Kluang were more than twice compared with Bukit Tangga and other indications of vigour such as plant height, petiole length and lamina width were also considerably higher.

(ii) Fruit characters

For fruit characters such as fruit weight, carpellody % and TSS %, the environment means presented in *Table 4.31* showed some interesting trends. Environments such as Pontian, Kundang and Kluang which promoted better vegetative vigour also appeared to produce the largest fruits. Pontian produced fruits which weighed well over a kilogram while in environments such as Kuala Kangsar and Bukit Tangga which have poor vegetative vigour, fruits produced were smaller, in the range of 0.67 - 0.68 kg.

The reverse trend however, was true for total soluble solids % (TSS). Pontian produced fruits which were less sweet (TSS = 10.67%) while fruits from Bukit Tangga have the highest TSS (13.12%). The inverse relationship between fruit size and TSS % in papaya has been well documented (Storey, 1969; Chan, 1986).

For carpellody %, no definite trend between environments was observed. A significantly higher percentage of occurrence of carpellody was recorded at Serdang (9%) while at the other environments, carpellody was quite negligible in the range of 2.3% - 5.3%.

(iii) Malformed top disease

Malformed top disease which destroys the young terminal shoot of the trees was most severe in Kundang (65.7%), Kuala Kangsar (35.2%) and Serdang (33.8%) but was rather negligible in Kluang, Pontian and Bukit Tangga where disease incidence ranged from 0.9% - 12.7% only (*Table 4.31*).

(iv) Yield components and yield

The environment effects on the six yield characters are shown in *Table 4.32*. A definite trend existed between environments for earliness (time to flower), fruit number and yield. The environments which produced the best vegetative vigour such as Pontian, Kundang and Kluang also promoted earliest flowering, more fruits and higher yields

Trees in Pontian and Kundang which have the best vigour, flowered 137 - 138 days after seed sowing and were about 80 days earlier than Bukit Tangga (217 days). The number of fruits produced at Pontian, Kundang and Kluang was two to three times higher than Kuala Kangsar or Bukit Tangga.

The yield of the first harvest (6 - 12 months) was outstanding at Pontian (34 kg/tree). At Serdang and Bukit Tangga, trees hardly yielded any fruits in the first harvest while at the rest of the environments, an average of 12 - 15 kg/tree was recorded.

In the second harvest (12 - 18 months), Pontian maintained its outstanding yield (33 kg/tree), while at Kundang, Kluang and Serdang, somewhat high yields of 21 - 28 kg/tree were obtained. A sharp drop in yield in the second harvest was seen at Kuala Kangsar (2.5 kg/tree) and this was against a general increasing trend of yield from the first to the second harvest.

In the combined yield of the two harvests, Pontian with 67.4 kg was easily the most outstanding environment, followed by Kundang (43.2 kg), Kluang (34.1 kg), Serdang (29.6 kg), Bukit Tangga (15.5 kg) and Kuala Kangsar (14.7 kg). The poor combined yield of Kuala Kangsar was largely due to the low contribution of the second harvest.

For carpellody %, the genotypic means were presented in *Table 4.34*, but their differences were not statistically tested because the ANOVA did not show significant differences in the genotypic effect for this character. The occurrence of carpellody ranged from a low of 1% to just over 10%. The latter value is considered quite serious in the production of quality fruits.

For TSS %, a very definite trend was shown in the genotypic means. The top six genotypes were Solo (So x So), Line 19 (19 x 19), Eksotika (Ek x Ek) and the three sibs between them i.e. 19 x So, Ek x So and Ek x 19. The range of TSS % in this top group was from 12.8 - 13.9%. Another distinct group consisting of Morib (Mo x Mo), Subang (Su x Su), Paris (Pa x Pa) and their three hybrids i.e. Su x Pa, Mo x Pa and Mo x Su. These six genotypes have the lowest TSS % ranging from 9.8 - 10.8%. The intermediate group was made up of hybrids between the high TSS inbreds (So, 19 and Ek) and the low TSS inbreds (Su, Pa and Mo). The TSS % range of these nine intermediate genotypes was from 11.1 - 12.4%.

(iii) *Malformed top disease*

The genotypic means for incidence of malformed top disease (MTD) are shown in *Table 4.34*. It was immediately apparent that three of the closely related inbreds i.e. Solo (So x So), Line 19 (19 x 19), Eksotika (Ek x Ek) and the three sibs between them i.e. 19 x So, Ek x So and Ek x 19, were highly susceptible to MTD. The incidence of MTD among this group of genotypes ranged from 37.8 - 64.4%. On the other hand, the other three inbreds i.e. Pa x Pa, Su x Su and Mo x Mo and the three hybrids between them i.e. Mo x Pa, Mo x Su and Su x Pa, were highly tolerant with disease incidence ranging from 5.6 - 13.9%.

The third distinct group of genotypes in the resistance to MTD was the one intermediate between the susceptible and the highly tolerant groups. The nine genotypes in this group were made up of hybrids between the susceptible inbreds viz. So x So, 19 x 19 and Ek x Ek and the tolerant inbreds viz. Pa x Pa, Su x Su and Mo x Mo. The range of intermediate resistance of this group was from 14.4 - 30.0 % incidence.

(iv) *Yield components and yield*

The genotypic means of six yield characters viz. earliness (days to flower), height of fruit, fruit number, yield (harvest 1, harvest 2 and combined) are presented in *Table 4.35*.

Table 4.29. Combined ANOVA of 21 genotypes over six environments

Character	Mean squares				
	Environment (df=5)	Rep(Env) (df=12)	Genotype (df=20)	GxE (df=100)	Error (df=240)
Vegetative					
Trunk diameter	268.28**	5.25**	4.93**	1.30**	0.80
Plant height (x 10^2)	408.54**	14.86**	32.32**	3.25**	1.91
Petiole length (x 10^2)	93.03**	4.42**	6.93**	1.23	1.17
Lamina width (x 10^2)	23.51**	2.53**	4.49**	0.71	0.57
Fruit					
Fruit weight (x10^{-2})	176.18**	1.97**	137.44**	3.68**	1.00
Carpellody %	387.14*	118.33**	144.55	112.32**	56.52
TSS %	51.35**	0.82**	27.38**	1.21**	0.33
Yield (all values x 10^2)					
Earliness	592.17**	4.15*	15.28**	5.28**	2.10
Height of fruit	55.14**	2.37**	21.11**	1.59**	0.37
Fruit number	189.80**	4.97**	18.54**	2.83**	1.47
Yield (harvest 1)	87.56**	2.03**	5.01**	0.82**	0.25
Yield (harvest 2)	76.78**	1.83**	3.47**	0.70	0.69
Yield (combined)	240.52**	6.32**	15.48**	1.51	1.21
Disease resistance					
Malformed top	359.62**	3.56	51.88**	6.09	1.23

** = significant at p = 0.01
* = significant at p = 0.05

Table 4.30. Environment means for four vegetative characters

Environment	Trunk diameter (cm)	Plant height (cm)	Petiole length (cm)	Lamina width (cm)
Pontian	9.43 a	169.9 a	83.0 a	66.0 a
Kundang	9.21 a	144.2 b	78.8 a	66.4 a
Kluang	8.69 a	145.2 b	81.7 a	59.4 b
Serdang	6.75 b	127.2 c	63.8 b	60.5 ab
K. Kangsar	6.51 b	131.1 bc	61.1 bc	54.4 bc
B. Tangga	4.08 c	93.0 d	54.5 c	50.9 c

Values within columns with the same alphabet are
not significantly different at p=0.01 according to the DMRT

Table 4.31. Environment means for three fruit characters and incidence of malformed top disease (MTD)

Environment	Fruit weight (kg)	Carpellody %	TSS %	MTD %
Pontian	1.12 a	4.36 b	10.67 e	7.9 c
Kundang	0.88 b	2.64 b	11.90 c	65.7 a
Kluang	0.87 b	2.36 b	11.33 d	12.7 c
Serdang	0.77 c	9.01 a	12.32 b	33.8 b
K. Kangsar	0.67 d	3.22 b	11.04 d	35.2 b
B. Tangga	0.68 d	5.33 ab	13.12 a	0.9 d

Values within columns with the same alphabet are
not significantly different at p=0.01 according to the DMRT

Table 4.32. Environment means for six yield characters

Environment	Earliness (days)	Height fruit (cm)	Fruit number	Yield 1 (harvest 1)	Yield 2 (harvest 2)	Yield (combined)
Pontian	137.1 e	81.0 c	65.2 a	34.1 a	33.3 a	67.4 a
Kundang	138.7 de	79.0 c	54.3 b	15.4 b	27.8 b	43.2 b
Kluang	146.4 cd	88.2 b	42.5 c	12.9 b	21.2 c	34.1 c
Serdang	175.6 b	99.5 a	41.1 c	3.3 c	26.3 b	29.6 d
KKangsar	150.8 c	71.9 d	22.7 d	12.3 b	2.5 e	14.7 e
BTangga	216.7 a	83.1 bc	20.9 d	0.9 c	14.6 d	15.5 e

Values within columns with the same alphabet are not significantly different at p=0.01 according to DMRT

Table 4.33. Genotypic means for four vegetative characters

Genotype	Trunk diam. (cm)	Genotype	Plant height (cm)	Genotype	Petiole length (cm)	Genotype	Lamina width (cm)
Mo x So	8.38 a	So x Pa	155.4 a	Ek x Pa	81.5 a	Ek x Pa	69.2 a
So x Pa	8.32 a	Su x So	151.1 ab	So x Pa	77.8 ab	Mo x Pa	64.9 ab
Ek x Pa	8.22 a	19 x So	148.7 abc	19 x Pa	76.6 abc	Su x Pa	64.5 ab
Su x So	8.02 ab	So x So	147.3 abcd	Mo x Pa	75.4 abc	19 x Pa	64.3 ab
Ek x Mo	7.76 abc	19 x 19	145.7 abcde	Mo x So	74.9 abc	So x Pa	64.2 ab
19 x Pa	7.70 abc	Ek x So	144.8 abcde	Su x Pa	74.0 abcd	Pa x Pa	63.0 abc
Su x Pa	7.62 abcd	19 x Pa	144.6 abcde	19 x 19	73.3 abcd	Mo x Su	62.2 bc
19 x Su	7.57 abcd	Mo x So	142.8 abcde	Mo x Su	73.3 abcd	Ek x Mo	62.3 bc
Ek x Su	7.56 abcde	Ek x Pa	142.3 abcde	Mo x 19	72.9 bcd	Ek x 19	60.9 bc
Mo x Pa	7.56 abcde	19 x Su	140.7 bcdef	Ek x 19	72.5 bcd	Ek x Su	60.1 bcd
Mo x 19	7.52 abcde	Ek x 19	136.0 cdefg	Ek x Mo	72.2 bcd	Mo x 19	58.9 bcde
Mo x Su	7.50 abcde	Su x Pa	134.5 defg	19 x Su	70.6 bcde	Su x Su	58.8 bcde
19 x So	7.21 bcdef	Ek x Su	132.0 efg	Pa x Pa	70.5 bcdef	Mo x So	58.6 bcde
Ek x So	7.16 bcdef	Mo x 19	127.9 fg	Su x So	69.5 bcdef	19 x Su	58.4 bcde
Pa x Pa	7.11 cdef	Mo x Su	125.8 g	Ek x Su	68.8 cdef	Su x So	58.3 bcde
Ek x 19	7.11 cdef	Pa x Pa	125.2 g	19 x So	68.2 cdef	19 x 19	58.3 bcde
19 x 19	7.08 cdef	Su x Su	124.6 g	Su x Su	65.9 defg	Ek x Ek	56.9 cde
Su x Su	7.06 cdef	Ek x Mo	124.3 g	Ek x So	62.5 fgh	Mo x Mo	53.9 de
So x So	6.78 def	Mo x Pa	123.4 g	Ek x Ek	62.0 fgh	Ek x So	53.2 e
Ek x Ek	6.66 ef	Ek x Ek	122.3 g	So x So	59.8 gh	19 x So	52.5 ef
Mo x Mo	6.46 f	Mo x Mo	97.7 h	Mo x Mo	56.0 h	So x So	47.3 f

Values within columns with the same alphabet are not significantly different at p=0.01 according to DMRT

Table 4.34. Genotypic means for three fruit characters and incidence of malformed top disease (MTD)

Genotype	Fruit wt. (kg)	Genotype	Carpellody (%)	Genotype	TSS (%)	Genotype	MTD (%)
Mo x Pa	1.25 a	So x Pa	10.44 *	So x So	13.98 a	Ek x Ek	64.4 a
Pa x Pa	1.20 a	19 x Pa	10.31	19 x So	13.61 ab	Ek x 19	52.7 b
Mo x Su	1.14 a	19 x 19	8.87	19 x 19	13.60 ab	Ek x So	50.0 bc
Su x Pa	1.11 ab	Mo x Pa	7.17	Ek x So	13.11 bc	So x So	47.8 bcd
19 x Pa	1.00 bc	Mo x 19	6.80	Ek x Ek	12.84 bcd	19 x 19	40.6 cd
Mo x 19	0.99 bc	Ek x Pa	6.33	Ek x 19	12.83 bcd	19 x So	37.8 de
Su x Su	0.98 bc	So x So	5.53	So x Pa	12.45 cde	Ek x Pa	30.0 ef
Ek x Pa	0.98 bc	Mo x So	4.62	19 x Pa	12.33 def	Su x So	25.6 fg
Ek x Mo	0.98 bc	19 x So	4.18	Su x So	11.79 efg	So x Pa	25.0 fgh
19 x Su	0.89 cd	Ek x Su	3.66	Ek x Pa	11.59 fgh	Mo x So	25.0 fgh
Ek x Su	0.88 cd	Mo x Mo	3.40	Mo x 19	11.35 ghi	Ek x Su	23.3 fghi
Mo x Mo	0.87 cd	Pa x Pa	3.18	Mo x So	11.20 ghij	Ek x Mo	22.8 fghi
Mo x So	0.83 d	Ek x Ek	3.13	Ek x Su	11.19 ghij	19 x Pa	18.3 ghij
So x Pa	0.82 d	Ek x Mo	2.97	Ek x Mo	11.16 ghij	Mo x 19	18.3 ghij
Ek x 19	0.69 e	Su x Pa	2.64	19 x Su	11.14 ghij	19 x Su	14.4 hij
Su x So	0.67 e	Su x So	2.45	Su x Pa	10.80 hijk	Mo x Mo	13.9 ijk
19 x 19	0.53 f	19 x Su	2.25	Pa x Pa	10.72 ijk	Su x Su	10.6 jk
Ek x Ek	0.49 f	Su x Su	2.18	Mo x Pa	10.54 ijkl	Su x Pa	7.8 jk
19 x So	0.45 f	Ek x 19	1.65	Mo x Su	10.35 jkl	Pa x Pa	6.7 k
Ek x So	0.41 f	Mo x Su	1.53	Su x Su	10.00 kl	Mo x Su	6.7 k
So x So	0.26 g	Ek x So	0.96	Mo x Mo	9.80 l	Mo x Pa	5.6 k

Values within columns with the same alphabet are not significantly different at p=0.01 according to DMRT

* DMRT was not done because genotypic differences for carpellody % were not significant (Table 4.29)

Table 4.35. Genotypic means for six yield characters

Genotype	Earliness (days)	Genotype	Height fruit (cm)	Genotype	Fruit number
Ek x Ek	181.7 a	So x So	100.5 a	So x So	63.2 a
So x So	175.4 ab	19 x So	97.9 ab	Mo x So	55.4 ab
Ek x So	173.9 abc	Su x So	97.7 ab	Su x So	52.9 abc
19 x So	172.5 abcd	Ek x So	96.1 abc	Ek x So	52.1 abcd
19x 19	169.6 abcde	19 x 19	95.4 abcd	So x Pa	46.6 bcde
Ek x 19	166.6 abcde	Ek x 19	90.9 bcde	19 x So	46.6 bcde
Su x Su	163.4 bcdef	19 x Su	88.3 cdef	19 x 19	45.7 bcdef
Ek x Su	161.2 bcdef	So x Pa	87.3 cdefg	Ek x Su	44.4 bcdef
Su x So	159.7 bcdef	Ek x Ek	86.3 defgh	Ek x Pa	44.3 bcdef
19 x Su	159.3 bcdef	Ek x Su	85.9 efgh	Ek x 19	40.9 cdefg
Ek x Mo	159.1 bcdef	Ek x Pa	85.6 fgh	Mo x 19	40.4 cdefgh
Mo x Mo	158.5 bcdef	19 x Pa	83.4 efghi	Ek x Ek	40.3 cdefgh
Ek x Pa	157.7 bcdef	Su x Su	80.4 fghij	Ek x Mo	39.9 cdefgh
Mo x 19	156.7 cdef	Mo x So	79.9 fghij	19 x Su	39.5 defgh
Mo x So	155.6 cdef	Ek x Mo	77.9 ghijk	19 x Pa	37.4 efghi
Mo x Su	154.7 def	Mo x 19	77.0 hijk	Mo x Su	35.1 efghij
So x Pa	154.4 def	Su x Pa	75.9 ijk	Su x Pa	33.0 fghij
19 x Pa	153.9 ef	Mo x Su	72.8 jk	Mo x Pa	28.2 ghij
Pa x Pa	152.7 ef	Pa x Pa	72.1 jk	Mo x Mo	26.1 hij
Su x Pa	151.3 ef	Mo x Pa	69.2 k	Su x Su	25.6 ij
Mo x Pa	146.5 f	Mo x Mo	63.7 l	Pa x Pa	24.0 j

Values within columns with the same alphabet are not significantly different at p=0.01 according to DMRT

Table 4.35. (Contd.). Genotypic means for six yield characters

Genotype	Yield 1 (harvest 1)	% of combined yield	Genotype	Yield 2 (harvest 2)	Genotype	Yield (combined)
Mo x So	22.7 a	47.0	Ek x Pa	28.5 a	Mo x So	48.2 a
Mo x 19	19.4 ab	44.5	Ek x Su	25.7 ab	Ek x Pa	46.2 ab
Mo x Su	18.3 ab	44.1	Mo x So	25.3 ab	Mo x 19	43.6 ab
Ek x Pa	17.6 ab	38.1	Ek x Mo	25.1 ab	Ek x Mo	41.6 ab
Su x Pa	17.4 ab	45.9	Mo x 19	24.8 ab	Mo x Su	41.5 ab
Mo x Pa	17.2 ab	44.7	Su x So	24.6 abc	Ek x Su	41.5 ab
So x Pa	16.9 ab	40.8	So x Pa	24.6 abc	So x Pa	41.4 ab
Ek x Mo	16.7 ab	40.1	Mo x Su	23.9 abcd	19 x Pa	39.2 abc
19 x Pa	15.9 abc	40.6	19 x Su	23.3 abcd	Mo x Pa	38.5 bc
Ek x Su	15.7 abc	37.8	19 x Pa	23.2 abcd	Su x Pa	37.9 bc
19 x Su	14.8 bcd	39.0	Mo x Pa	21.3 bcde	19 x Su	37.9 bc
Pa x Pa	12.6 bcde	41.5	Su x Pa	20.5 bcde	Su x So	37.1 bc
Su x So	12.5 bcde	33.7	Ek x 19	20.5 bcde	Pa x Pa	30.3 cd
Ek x 19	9.5 cdef	31.8	Su x Su	18.1 cdef	Ek x 19	29.9 cd
Mo x Mo	9.2 cdef	37.6	Pa x Pa	17.7 def	Su x Su	26.2 de
19 x 19	8.2 def	31.9	19 x 19	17.5 def	19 x 19	25.7 de
Su x Su	8.1 def	30.9	Ek x So	16.1 ef	Mo x Mo	24.5 de
19 x So	7.7 ef	34.2	Mo x Mo	15.2 ef	Ek x So	22.8 de
Ek x So	6.8 ef	29.8	Ek x Ek	15.1 ef	19 x So	22.5 de
Ek x Ek	5.5 f	26.8	19 x So	14.8 ef	Ek x Ek	20.5 e
So x So	3.4 f	19.5	So x So	13.8 f	So x So	17.4 e

Values within columns with the same alphabet are
not significantly different at p=0.01 according to the DMRT

For earliness, a very distinct grouping of genotypes can be seen in So x So, Ek x Ek, 19 x 19 and their three sibs, Ek x So, 19 x So and Ek x 19. They made up a group of distinct late bearers which come into flowering after 166 - 181 days after seed sowing. The group of genotypes that showed early flowering and hence precocity in bearing, consisted of Paris (Pa x Pa) and four of its hybrids viz. So x Pa, 19 x Pa, Su x Pa and Mo x Pa. These genotypes flowered after 146 - 154 days after seed sowing.

There was no distinct trends or grouping of genotypes for height of fruit. However, Morib (Mo x Mo) which was very dwarf and compact in vegetative attributes, was also found to have the lowest fruit bearing height (63.7 cm) and Sunrise Solo had the highest (100.5 cm). Hybrids with Morib appeared to bear fruits generally lower to the ground (< 80 cm), but the opposite was true for hybrids with Solo which bore fruits from 79 - 97 cm from the ground (*Table 4.35*).

Three distinct groups of genotypic means were evident for fruit number . Solo and its hybrids showed very high fruit number ranging from 46 - 63/tree. An intermediate group which averaged between 37 - 45 fruits per tree, consisted of Ek x Ek, 19 x 19, Ek x 19 and their crosses with Mo, Su and Pa. The bottom liners for fruit number were six genotypes from the inbreds Pa x Pa, Su x Su, Mo x Mo and the hybrids between them viz. Mo x Su, Su x Pa and Mo x Pa. This group yielded between 24 to 35 fruits per tree.

With regard to yield (*Table 4.35*), a definite difference between the inbreds (including sibs) and hybrids can be found. In the combined yield over two harvests (18 month yield), the inbreds and the sibs were markedly poorer yielding than the wide cross hybrids. Pa x Pa, Su x Su, 19 x 19, Mo x Mo, Ek x Ek, So x So and the sibs Ek x 19, Ek x So and 19 x So, occupied the bottom nine positions in yield performance. The yield of this group ranged from a low of 17.4 kg in So x So to 30.3 kg in Pa x Pa. On the other hand, even the poorest wide cross hybrid Su x So yielded 37.9 kg while the best hybrid Mo x So yielded 48.2 kg which was 59% higher than the best yielding inbred (Pa x Pa) and an amazing 177% higher than the poorest inbred (So x So).

When the combined yield was partitioned into two separate harvests (harvest 1 = 6 - 12 months, harvest 2 = 13-18 months), it was found that, without exceptions, more yield was obtained in the second harvest than the first for every genotype. This was shown by the fact that none of the genotypes' first harvest contributed more than 50% of the combined yield

(*Table 4.35*). The rank order in yield performance of the genotypes in harvest 1, harvest 2, and combined harvest, did not change very much. The poorest yielders were made up of the group of inbreds and close sibs which appeared to consistently occupy the bottom positions of the table. The difference in yield of this poor yielding group compared with the high yielding wide cross hybrids was more apparent in harvest 1. With the exception of Pa x Pa, none of the other inbreds or sibs yielded more than 10 kg/tree in the first harvest. So x So was almost barren in the first year, yielding a meagre 3.4 kg. The difference in yield between the top hybrid, Mo x So (22.7 kg) and So x So was well over six-fold.

In the second harvest, most of the inbreds and sibs improved on their yield and the difference between this group and the wide cross hybrids were narrowed. Using the top and bottom genotypes i.e. Ek x Pa (28.5 kg) and So x So (13.8 kg), for comparison, the difference was two-fold as compared with a six-fold difference noted in the first harvest. The inbreds and sibs yielded between 13.8 - 20.5 kg compared with 20.5 - 28.5 kg recorded for the wide cross hybrids in the second harvest.

When the yield of the first harvest was expressed as a percentage of the combined yield for all the genotypes, some interesting conclusions may be made. The high yielding hybrids have a much higher contribution in the first harvest than the low yielding inbreds and sibs. In the majority of cases, the contribution in the first year towards the total yield was about 40% or more in the case of wide cross hybrids, while in the inbreds and sibs, the contribution tend to stay around 30% or lower. The poor overall yield performance of So x So, Ek x Ek and 19 x So was attributed directly to the poor harvest in the first year which accounted for only 19.5%, 26.8% and 29.8% respectively of the total yield.

The most promising hybrid for yield was Mo x So which showed almost the same high, uniform harvests in the first and second periods to accumulate a remarkable total yield of 48.2 kg/tree.

4.3.4. GxE analysis and stability in selection of genotypes

Of the 14 characters studied, only four i.e. petiole length, lamina width, yield in harvest 2 and combined yield, did not show significance in GxE interaction. This implies that only in these four characters can the mean of the genotype averaged over environments or mean of the environment averaged over genotypes be used for accurate interpretation of the performance of either the genotype or of the environment. In other characters where GxE existed, the performance of the genotype was environment dependent and the differences between genotypes were not in the same relative proportion from one environment to another. In such cases, the performance and selection of the genotypes has to be evaluated also in terms of its stability over the various environments. Three methods will be used in the analysis of GxE which will establish the relative stability of the genotypes. Coupled with the mean performance of the genotypes, indices will be developed as an aid for selection of promising genotypes.

The three methods were mean and CV distribution, non parametric ranking, and rank sum and rank product indices.

4.3.4.1. *Mean and CV distribution*

The mean and CV distribution of genotypes for eight characters that showed significant GxE interaction are shown in *Figures 4.1 - 4.8*. The figures showed that four quadrants were demarcated by the lines representing the genotypic mean and the CV mean i.e.

Quadrant I: area with above average mean and below average CV
Quadrant II: area with above average mean and above average CV
Quadrant III: area with below average mean and below average CV
Quadrant IV: area with below average mean and above average CV

(i) *Vegetative characters*

The mean and CV distribution for trunk diameter and plant height are shown in *Figures 4.1* and *4.2* respectively. For trunk diameter, two distinct groups can be demarcated based on the mean values. It was evident that wide cross hybrids were generally more vigorous in trunk size than the inbreds or sibs. All the wide cross hybrids had mean values higher than that demarcated by the average line while the reverse was true for inbreds and sibs (*Figure 4.1*). With regard to CV distribution, there was no indication that hybrids were more variable than inbreds or vice versa. There were inbreds with high CV such as Mo x Mo and Pa x Pa and some with low CV such as Ek x Ek and 19 x 19. The distribution of CV for hybrids appeared also to be rather random. The most desired genotypes (high vigour and low variability) found in Quadrant I were five wide cross hybrids i.e. Ek x Pa, Mo x So, Su x Pa, Su x So, Mo x Pa and 19 x Su. No inbreds or sibs were found in either Quadrant I or II.

For plant height (*Figure 4.2*), there were no particular pattern of distribution of the mean and CV between the inbreds/sibs and wide cross hybrids. However, it can be seen that Solo (So x So) and all its five hybrids have above average height while Mo x Mo was very dwarf and most of its hybrids with the exception of the cross with the tall Solo, have below average height. With regard distribution of CV, Solo and it hybrids have very low CV, and coupled with their tall height, were all placed in the most favoured Quadrant 1 (*Figure 4.2*). In addition, three other genotypes i.e. 19 x 19, 19 x Su and Ek x Pa were also found in this quadrant.

(ii) *Fruit characters*

The mean and CV distribution for fruit weight are presented in *Figure 4.3*. There was no distinct separation between inbreds/sibs and the wide cross hybrids for this character. However, it was evident that So x So, Ek x Ek and 19 x 19 and their three sibs bore small fruits which were below the line demarcating the genotypic mean. All the wide cross hybrids with the exception of those crosses made with Solo, have large fruits above the genotypic average line. With regard CV distribution, the group which bore small fruits i.e. So x So, Ek x Ek and 19 x 19 and two of their sibs i.e. Ek x So and 19 x So have below average CV. Pa x Pa and its five hybrids also showed below average CV and with the exception of So x Pa, were above average in mean fruit weight which placed them in the most preferred Quadrant 1 (*Figure 4.3*). Two other genotypes in this quadrant were Mo x Mo and Ek x Su.

For TSS % (*Figure 4.4*), three distinct groups based on their means can be seen. The group consisting of So x So, Ek x Ek, 19 x 19 and their three sibs have the highest TSS % while Su x Su, Mo x Mo, Pa x Pa and their three hybrids have the lowest. The crosses between the inbreds from these two extreme groups gave rise to genotypes which occupy the middle group with average TSS %. With regard to CV distribution, inbreds and sibs appeared to have less variability for this character. With the exception of Mo x Mo and Ek x 19, the other inbreds and sibs showed below average CV. The best quadrant consisted of So x So, Ek x Ek, 19 x 19 and two of their sibs, Ek x So and 19 x So and three other genotypes, 19 x Pa, So x Pa and marginally, Su x So.

(iii) *Yield components and yield*

The mean and CV distribution for earliness presented in *Figure 4.5* showed two distinct groups. The group of genotypes with late maturity was made up of So x So, Ek x Ek, 19 x 19 and their three sibs. All of them flowered later than the population mean. The other genotypes with the exception of Ek x Su and Su x Su, flowered earlier than the population mean. The best genotype was Mo x Pa which was the earliest and also the most uniform. The others in the Quadrant 1 were Ek x Pa, Mo x 19, 19 x Pa, Su x So and Mo x Su. There were no differences in CV between the inbreds and hybrids, although the group consisting of So x So, Ek x Ek, 19 x 19 and two of their sibs Ek x So and 19 x So have distinctly lower than average CV (*Figure 4.5*).

For height of fruit (*Figure 4.6*), again two distinct groups were evident. The first group which occupied Quadrants 1 and 2 were made up of genotypes with distinctly low bearing stature. The most prominent genotype in this group was Mo x Mo which bore fruits lowest from the ground. All its five hybrids were also below average in bearing height. The second group consisted of genotypes which have higher bearing height than the mean. These genotypes were So x So, Ek x Ek, 19 x 19 and all their sibs and hybrids (except those crossed with Mo x Mo). The best genotypes which have uniform, low bearing height demarcated by Quadrant 1 were Pa x Pa, Mo x 19, Mo x So and 19 x Pa.

Three groups based on mean values were evident for fruit number (*Figure 4.7*). The first group which had the largest number of fruit was made up of So x So and all its five hybrids. On the other extreme, the group with fruit number below average line was made up of Mo x Mo, Pa x Pa, Su x Su and their three hybrids. Ek x Ek, 19 x 19 and their crosses with Mo x Mo, Pa x Pa and Su x Su were mediocre in fruit number and constituted the third group. No distinct pattern of distribution was noted for CV. The top genotypes for this character were Ek x Pa, 19 x 19 and the five Solo hybrids.

For yield in harvest 1 (*Figure 4.8*), the distinction between the mean values of inbreds/sibs and wide cross hybrids was very well demonstrated. All wide cross hybrids with the exception of Su x So had higher than average yields while the reverse was true for inbreds and sibs. The distribution in CV between inbreds and hybrids, however, were more random. The best hybrids for this character were Mo x So, Ek x Pa, 19 x Pa, So x Pa, Mo x Su and Ek x Su. The poorest genotypes found in Quadrant 4 which had low, variable yield, were four inbreds So x So, 19 x 19, Mo x Mo and Pa x Pa.

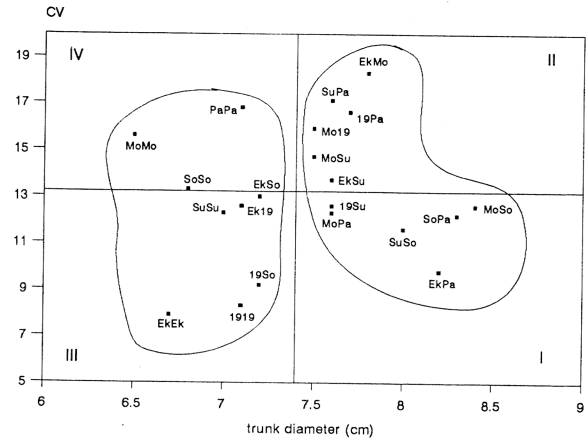

Figure 4.1. Mean and CV distribution of 21 genotypes for trunk diameter

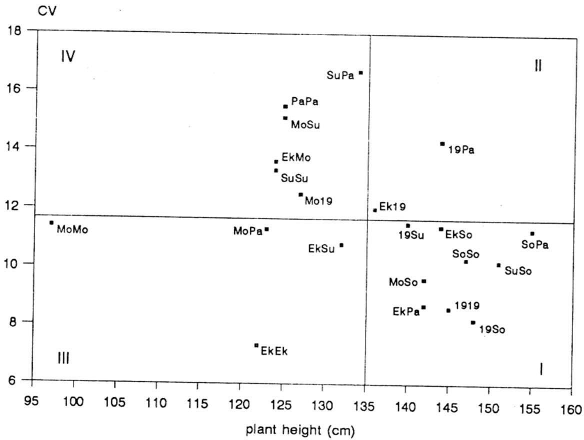

Figure 4.2. Mean and CV distribution of 21 genotypes for plant height

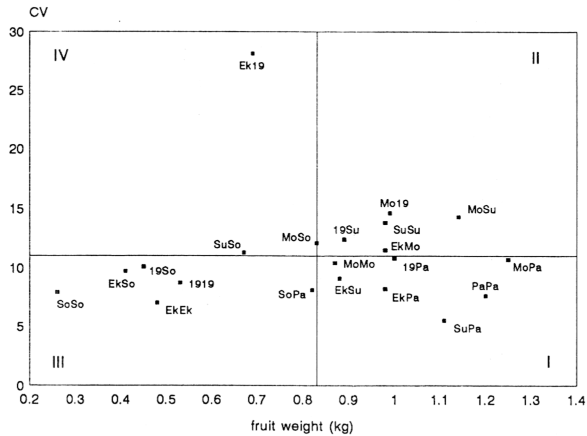

Figure 4.3. CV and mean distribution of 21 genotypes for fruit weight

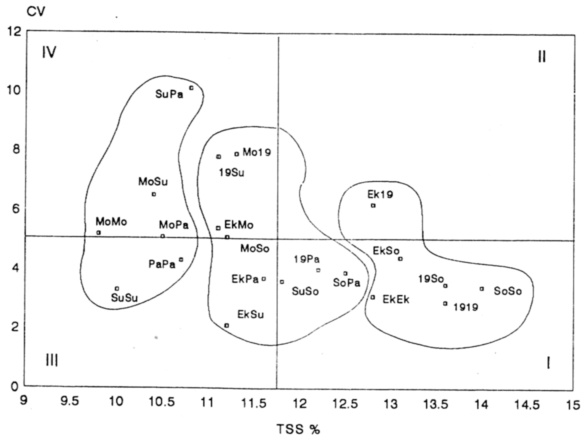

Figure 4.4. Mean and CV distribution of 21 genotypes for TSS %

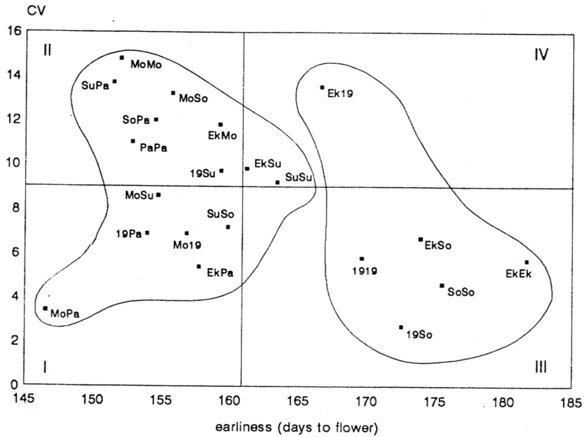

Figure 4.5. CV and mean distribution of 21 genotypes for earliness

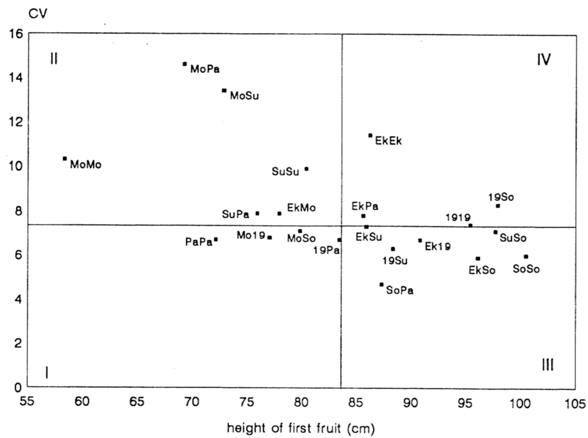

Figure 4.6. Mean and CV distribution of 21 genotypes for height of first fruit

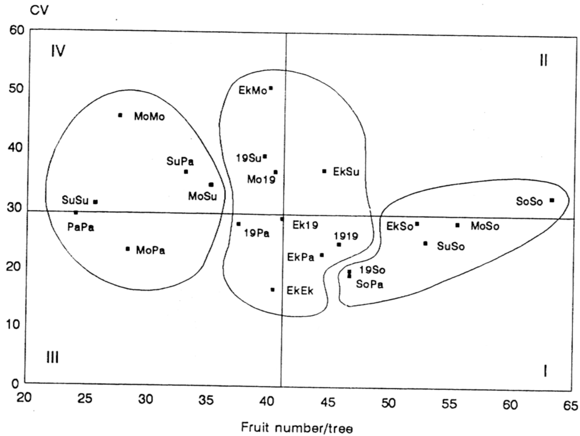

Figure 4.7. CV and mean distribution of 21 genotypes for fruit number

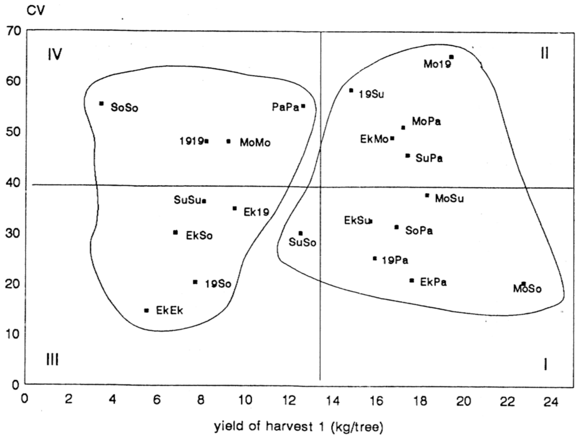

Figure 4.8. Mean and CV distribution of 21 genotypes for yield (harvest 1)

4.3.4.2. *Non parametric ranking*

Tables 4.36 - 4.43 show the non parametric ranking indices S_i^3 and S_i^6 for the nine characters that showed significance in GxE interaction. This analysis of GxE estimates the changes in rankings of a genotype over environments for a particular character. The greater the change, the higher is its instability or ranking index and vice versa.

(i) *Vegetative characters*

The non parametric ranking indices for trunk diameter for the 21 genotypes are shown in *Table 4.36*. It was clear that there was significant GxE interaction because of the large changes in ranking of all genotypes over the six environments. The most glaring was Su x Su which produced poor vigour, small trunk diameters in five environments but had the best rank at the poorest location in Bukit Tangga. This caused the highest S_i^3 index (32.93) for this genotype.

The lowest S_i^3 and S_i^6 indices were obtained for Mo x So (0.68 and 0.30 respectively). With the exception of Serdang where it was ranked 16, this genotype consistently held the 19th ranking at four environments and was the best ranked (21st) in Pontian.

In general, the S_i^3 and S_i^6 indices were very high for the group consisting of the inbreds and sibs. With the exception of 19 x 19 and So x So, all the others in this group had S_i^3 ranging from 13.01 to 32.92 and S_i^6 ranging from 2.93 to 5.00. On the other hand, the majority of wide cross hybrids had S_i^3 less than 10 and S_i^6 around 1 to 2 (*Table 4.36*).

The ranking indices for stability for plant height is shown in *Table 4.37*. Mo x Mo deserved special mention because it had the lowest plant height (denoted by ranking = 1) and this was consistently so over all the six environments. Since there were absolutely no changes in rank order, the S_i^3 and S_i^6 indices were given 0 values, indicating perfect stability. On the other hand, Su x Su again as in the case of trunk diameter, was the most inconsistent genotype. It was fairly short at most locations, but at Bukit Tangga, it ranked among the tallest genotypes. The S_i^3 (26.29) and S_i^6 (3.80) were the highest indices among the 21 genotypes.

In the comparison of ranking indices between the inbreds (including sibs) and the wide cross hybrids, a similar trend as in trunk diameter existed. With the exception of Mo x

Mo and So x So, the genotypes in the inbred group showed indices that were usually higher than those of the wide cross hybrids.

(ii) *Fruit characters*

The non parametric ranking indices for fruit weight and TSS % are presented in *Tables 4.38 and 4.39.* For fruit weight, the most striking result was that the S_i^3 (0.23 - 5.99) and S_i^6 (0.24 - 1.72) indices were relatively small in comparison with the vegetative characters. This would indicate that although changes in ranking occurred over environments to give significant GxE interaction, such changes were not as dramatic for fruit characters i.e. without any round-about turn of ranking as often observed in some genotypes for vegetative characters.

For the small-fruited genotypes such as So x So, Ek x Ek, 19 x 19 and two of their sibs Ek x So and 19 x So, their rankings were low and consistent over the six locations. Their S_i^3 were correspondingly low but their S_i^6 were high (with the exception of 19 x 19) because of their low mean fruit weight. The most consistent genotype for fruit weight was Pa x Pa ($S_i^3 = 0.27$ and $S_i^6 = 0.24$) (*Table 4.38*).

For TSS %, the most consistent genotype was So x So ($S_i^3 = 0.06$ and $S_i^6 = 0.13$). It had the highest TSS % at four environments and the second highest at the other two. Generally, genotypes related to the Solo variety such as Ek x Ek and 19 x 19 and their sibs showed consistent and good performance in this character over the various environments. Their S_i^3 and S_i^6 indices were never larger than 1.0.

Four genotypes i.e. Su x Pa, Mo x Mo, Su x Su and Ek x Su were poor, inconsistent performers over environments for TSS%. Their S_i^3 ranged from 10.25 to 17.33 and their S_i^6 from 2.50 to 4.40 (*Table 4.39*).

(iii) *Yield components and yield*

The non parametric ranking indices S_i^3 and S_i^6 for earliness (days to flower) were generally very high (*Table 4.40*) and this reflected the inability of the genotypes to hold on to a consistent ranking over environments. The best genotype for this character was Mo x Pa with $S_i^3 = 1.19$ and $S_i^6 = 0.56$. It was the earliest in flowering at Serdang and Kluang (rank 21) and the second earliest at Bukit Tangga and Pontian (rank 20). However, at Kundang and Kuala Kangsar, it was ranked 16 and 17 respectively. On the other hand, Su x Su was the most inconsistent in this character (S_i^3 = 28.86, S_i^6 = 4.29) because its ranking over environments fluctuated rather drastically (ranging from 17 to 1).

For height of fruit, Mo x Mo was the most consistent in its ranking over environments (*Table 4.41*). It had the lowest height of bearing over all the six environments (rank 21) and this resulted in the perfect stability indices of S_i^3 and S_i^6 = 0. With the exception of So x So, Ek x Ek and 19 x Su, the other genotypes have relatively small S_i^3 and S_i^6 values for this character indicating fairly consistent rankings over environments. So x So was a consistent tall bearer (rank 1-3 at five environments), but because of a drastic change in rank at Bukit Tangga (rank 14), the stability indices were pushed up.

The non parametric ranking indices for fruit number presented in *Table 4.42* showed that inbreds and sibs (with the exception of Pa x Pa and 19 x So) were generally less consistent over environments for this character as compared with the wide cross hybrids. The conspicuous examples were Mo x Mo and Su x Su which were not very fruitful at Kluang, Kuala Kangsar, Kundang, Pontian and Serdang where they were ranked a low 1 - 5, but at Bukit Tangga, their ranks improved dramatically to 12 and 10 respectively. So x So was also inconsistent in ranking (S_i^3 = 16.13 and S_i^6 = 2.29) because it had the highest number of fruits at Kluang, Kundang, Pontian and Serdang (rank 21) but failed dismally at Bukit Tangga (rank 8) and Kuala Kangsar (rank 6). The most stable genotype for fruit number was 19 x So (S_i^3 = 1.77 and S_i^6 = 0.74). All the wide cross hybrids appeared to have good stability with the exception of Su x Pa (S_i^3 = 18.84 and S_i^6 = 3.38) and Ek x Mo (S_i^3 = 12.60 and S_i^6 = 2.20).

For yield in harvest 1, the generally small S_i^3 and S_i^6 values indicated that most genotypes did not vary much in their rankings over the six environments. Only two genotypes i.e. 19 x Pa (S_i^3 = 10.18 and S_i^6 = 1.78) and Su x Su (S_i^3 = 21.75 and S_i^6 = 3.25) showed large discrepancies in rank order over environments. It was interesting to note that 19 x Pa had good yield ranking at five environments (rank 10 - 21) but dropped drastically at Bukit Tangga (rank = 7) while in the case of Su x Su, the opposite was observed — it was dismal at five locations but was the third best yielder (rank = 19) at Bukit Tangga.

The difference in performance of the inbreds and sibs compared with the wide cross hybrids were demonstrated very well in the first harvest (*Table 4.43)*. The first nine genotypes were the inbreds (including sibs) and in general, their ranks were single digits indicating low mean yields. On the other hand, the rest of the genotypes which consisted of wide cross hybrids in the bottom half of the table, mostly showed double digits in their ranks indicating high yields. The occasional double digit rank for Mo x Mo, Su x Su and Pa x Pa at the poorer environments of Kuala Kangsar and Bukit Tangga, raised their S_i^3 and S_i^6 indices substantially and caused the significant GxE interaction for yield in the first harvest.

Table 4.36. Non parametric ranking indices for selection of genotypes for trunk diameter

Genotype	Rank at environments BTA	KLG	KKR	KDG	PTN	SDG	mean of ranks	S_i^3	S_i^6
Ek x Ek	1	9	4	2	15	1	5.33	29.52	5.00
19 x 19	3	11	8	7	12	4	7.50	8.73	2.27
So x So	4	6	5	3	10	6	5.67	5.17	1.76
Mo x Mo	6	2	2	1	1	8	3.33	13.01	4.40
Su x Su	21	5	3	6	2	7	7.33	32.92	3.73
Pa x Pa	13	1	7	15	3	12	8.50	19.24	3.41
Ek x 19	5	17	1	13	13	5	9.00	21.33	3.56
Ek x So	2	14	10	10	17	3	9.33	18.79	2.93
19 x So	7	7	16	4	16	2	8.67	20.68	3.38
Ek x Pa	10	21	17	20	19	11	16.33	6.82	1.43
Mo x Pa	15	13	11	12	6	14	11.83	4.30	1.13
19 x Pa	11	3	15	9	9	21	11.33	16.53	2.35
Su x Pa	17	4	21	16	5	17	13.33	18.70	2.65
So x Pa	8	20	18	21	20	18	17.50	6.60	1.09
Mo x So	19	19	19	19	21	16	18.83	0.68	0.30
Su x So	20	18	20	11	14	15	16.33	4.00	1.10
Ek x Su	14	12	9	18	8	9	11.67	6.28	1.54
Mo x Su	12	15	6	8	11	10	10.33	4.78	1.36
19 x Su	18	16	12	17	4	13	13.33	9.85	1.65
Mo x 19	9	8	14	14	7	19	11.83	9.03	1.94
Ek x Mo	16	10	13	5	18	20	13.67	11.22	1.90

BTA = Bukit Tangga
KLG = Kluang
KKR = Kuala Kangsar
KDG = Kundang
PTN = Pontian
SDG = Serdang

Table 4.37. Non parametric ranking indices for selection of genotypes for plant height

Genotype	Rank at environments BTA	KLG	KKR	KDG	PTN	SDG	mean of ranks	S_i^3	S_i^6
Ek x Ek	2	8	5	7	10	2	5.67	9.41	2.82
19 x 19	4	20	15	18	19	9	14.17	14.31	2.16
So x So	10	19	18	15	17	19	16.33	3.63	0.94
Mo x Mo	1	1	1	1	1	1	1.00	0.00	0.00
Su x Su	18	4	8	5	2	3	6.67	26.29	3.80
Pa x Pa	14	3	3	8	5	6	6.50	13.15	2.77
Ek x 19	5	15	6	14	14	7	10.17	10.50	2.46
Ek x So	3	18	13	20	16	10	13.33	14.35	2.10
19 x So	13	14	21	19	21	8	16.00	8.50	1.62
Ek x Pa	11	13	14	17	13	17	14.17	2.03	0.80
Mo x Pa	9	6	10	2	3	5	5.83	8.72	2.57
19 x Pa	17	9	17	12	12	21	14.67	6.63	1.50
Su x Pa	19	7	16	9	4	14	11.50	14.39	2.52
So x Pa	12	21	19	21	20	20	18.83	3.12	0.73
Mo x So	15	11	12	13	18	15	14.00	2.29	0.86
Su x So	21	16	20	16	15	18	17.67	1.66	0.68
Ek x Su	16	5	9	11	8	11	10.00	6.80	1.60
Mo x Su	7	10	4	3	11	4	6.50	8.85	2.62
19 x Su	20	17	11	10	9	16	13.83	7.15	1.66
Mo x 19	6	12	7	6	6	13	8.33	6.40	2.00
Ek x Mo	8	2	2	4	7	12	5.83	13.18	3.26

BTA = Bukit Tangga
KLG = Kluang
KKR = Kuala Kangsar
KDG = Kundang
PTN = Pontian
SDG = Serdang

Table 4.38. Non parametric ranking indices for selection of genotypes for fruit weight

Genotype	Rank at environments BTA	KLG	KKR	KDG	PTN	SDG	mean of ranks	S_i^3	S_i^6
Ek x Ek	3	2	5	4	4	5	3.83	1.78	1.39
19 x 19	5	5	4	5	5	4	4.67	0.28	0.57
So x So	2	1	1	1	1	1	1.17	0.71	1.44
Mo x Mo	6	15	13	10	9	13	11.00	4.91	1.45
Su x Su	17	10	20	12	10	16	14.17	5.99	1.48
Pa x Pa	18	20	21	20	20	19	19.67	0.27	0.24
Ek x 19	8	7	11	6	7	6	7.50	2.33	1.07
Ek x So	1	3	3	3	2	2	2.33	1.43	1.72
19 x So	4	4	2	2	3	3	3.00	1.33	1.33
Ek x Pa	14	13	17	16	17	11	14.67	1.99	0.82
Mo x Pa	19	21	15	21	21	21	19.67	1.49	0.54
19 x Pa	16	12	19	11	19	12	14.83	4.51	1.28
Su x Pa	21	19	18	18	15	18	18.17	1.04	0.40
So x Pa	13	8	8	8	13	8	9.67	3.45	1.38
Mo x So	9	9	7	14	8	9	9.34	3.14	1.00
Su x So	7	6	6	7	6	7	6.50	0.23	0.46
Ek x Su	15	14	10	9	12	10	11.67	2.51	1.03
Mo x Su	20	18	16	19	14	20	17.83	1.62	0.64
19 x Su	12	11	9	13	11	14	11.67	1.31	0.69
Mo x 19	11	17	12	17	16	17	15.00	2.53	0.93
Ek x Mo	10	16	14	15	18	15	14.67	2.40	0.73

BTA = Bukit Tangga
KLG = Kluang
KKR = Kuala Kangsar
KDG = Kundang
PTN = Pontian
SDG = Serdang

Table 4.39. Non parametric ranking indices for selection of genotypes for total soluble solids %

Genotype	Rank at environments BTA	KLG	KKR	KDG	PTN	SDG	mean of ranks	S_i^3	S_i^6
Ek x Ek	15	16	18	17	15	13	15.67	0.98	0.51
19 x 19	21	20	19	18	18	20	19.33	0.38	0.31
So x So	20	21	21	20	21	21	20.66	0.06	0.13
Mo x Mo	1	9	1	2	3	3	3.17	14.14	3.68
Su x Su	2	7	2	7	1	1	3.33	12.41	4.40
Pa x Pa	6	3	3	9	12	6	6.50	9.46	2.46
Ek x 19	17	17	15	16	16	16	16.17	0.18	0.21
Ek x So	16	18	17	19	19	15	17.33	0.77	0.46
19 x So	19	19	20	21	20	18	19.50	0.28	0.26
Ek x Pa	11	15	4	10	13	14	11.17	7.06	1.52
Mo x Pa	4	2	5	5	6	4	4.33	2.15	1.38
19 x Pa	13	12	13	14	14	17	13.83	1.07	0.51
Su x Pa	5	1	14	3	8	5	6.00	17.33	3.33
So x Pa	12	14	16	15	17	19	15.50	1.90	0.71
Mo x So	10	11	11	6	5	8	8.50	3.94	1.53
Su x So	18	8	9	13	11	12	11.83	5.31	1.27
Ek x Su	14	5	6	12	4	7	8.00	10.25	2.50
Mo x Su	3	6	8	1	7	2	4.50	9.22	3.33
19 x Su	9	4	7	8	10	11	8.17	3.77	1.35
Mo x 19	8	13	12	4	9	10	9.33	5.50	1.50
Ek x Mo	7	10	10	11	2	9	8.17	6.71	1.79

BTA = Bukit Tangga
KLG = Kluang
KKR = Kuala Kangsar
KDG = Kundang
PTN = Pontian
SDG = Serdang

Table 4.40. Non parametric ranking indices for selection of genotypes for earliness (days to flower)

Genotype	Rank at environments BTA	KLG	KKR	KDG	PTN	SDG	mean of ranks	S_i^3	S_i^6
Ek x Ek	1	1	6	1	4	1	2.33	10.01	4.58
19 x 19	4	12	19	5	13	6	9.83	17.38	2.95
So x So	3	4	3	2	5	3	3.33	1.60	1.40
Mo x Mo	21	20	7	21	15	14	16.33	9.27	1.59
Su x Su	17	2	12	3	1	7	7.00	28.86	4.29
Pa x Pa	15	17	16	18	6	19	15.17	7.31	1.23
Ek x 19	9	6	1	14	10	4	7.33	14.64	3.00
Ek x So	5	5	14	6	12	2	7.33	14.64	3.09
19 x So	2	9	9	9	14	5	8.00	10.50	2.25
Ek x Pa	8	14	13	15	17	10	12.83	4.27	1.20
Mo x Pa	20	21	17	16	20	21	19.17	1.19	0.56
19 x Pa	6	19	11	20	19	18	15.50	10.42	1.81
Su x Pa	18	11	20	12	11	20	15.33	6.48	1.57
So x Pa	13	18	21	19	18	16	17.50	2.14	0.69
Mo x So	10	16	18	13	21	13	15.17	5.20	1.25
Su x So	14	3	4	4	9	9	7.17	12.67	2.93
Ek x Su	12	7	2	8	7	8	7.33	7.00	1.64
Mo x Su	19	13	10	10	16	11	13.17	5.07	1.32
19 x Su	16	8	5	7	3	12	8.50	13.35	2.59
Mo x 19	7	15	15	17	8	17	13.17	7.66	1.72
Ek x Mo	11	10	8	11	2	15	9.50	9.84	1.89

BTA = Bukit Tangga
KLG = Kluang
KKR = Kuala Kangsar
KDG = Kundang
PTN = Pontian
SDG = Serdang

Table 4.41. Non parametric ranking indices for selection of genotypes for height of first fruit

Genotype	Rank at environments BTA	KLG	KKR	KDG	PTN	SDG	mean of ranks	S_i^3	S_i^6
Ek x Ek	3	10	16	16	6	6	9.50	15.95	2.84
19 x 19	5	5	3	5	5	5	4.67	0.71	0.71
So x So	14	2	1	3	3	1	4.00	31.00	5.00
Mo x Mo	21	21	21	21	21	21	21.00	0.00	0.00
Su x Su	10	13	13	15	13	12	12.67	1.05	0.53
Pa x Pa	17	19	20	17	19	16	18.00	0.67	0.44
Ek x 19	9	4	12	11	7	3	7.67	8.78	2.35
Ek x So	7	7	7	2	4	2	4.83	6.38	2.69
19 x So	1	6	5	1	2	4	3.17	7.20	3.47
Ek x Pa	15	9	4	9	10	8	9.17	6.85	1.45
Mo x Pa	20	20	10	20	20	20	18.33	4.55	0.91
19 x Pa	8	18	11	8	14	9	11.33	7.00	1.65
Su x Pa	12	16	15	14	18	19	15.67	2.13	0.77
So x Pa	13	8	6	6	9	10	8.67	4.07	1.38
Mo x So	16	15	14	10	15	15	14.17	1.61	0.61
Su x So	2	3	2	4	1	7	3.17	7.20	2.95
Ek x Su	6	11	9	7	12	11	9.33	3.14	1.29
Mo x Su	19	14	19	19	11	18	16.67	3.44	1.00
19 x Su	4	1	8	12	8	14	7.83	14.92	2.73
Mo x 19	11	12	17	18	17	17	15.33	2.96	1.00
Ek x Mo	18	17	18	13	16	13	15.83	1.69	0.72

BTA = Bukit Tangga
KLG = Kluang
KKR = Kuala Kangsar
KDG = Kundang
PTN = Pontian
SDG = Serdang

Table 4.42. Non parametric ranking indices for selection of genotypes for fruit number

Genotype	Rank at environments BTA	KLG	KKR	KDG	PTN	SDG	mean of ranks	S_i^3	S_i^6
Ek x Ek	1	10	14	10	13	12	10.00	11.00	1.80
19 x 19	6	18	11	19	16	8	13.00	11.38	2.15
So x So	8	21	6	21	21	21	16.33	16.13	2.29
Mo x Mo	12	2	4	1	3	3	4.17	18.90	3.76
Su x Su	10	1	2	5	2	2	3.67	15.62	4.18
Pa x Pa	3	4	5	3	1	1	2.83	4.53	2.59
Ek x 19	17	14	1	14	14	7	11.17	16.01	2.57
Ek x So	2	20	18	20	19	19	16.33	15.27	1.76
19 x So	13	13	12	16	18	14	14.33	1.77	0.74
Ek x Pa	15	15	17	15	12	9	13.83	2.95	0.96
Mo x Pa	4	3	3	2	5	4	3.50	1.57	1.43
19 x Pa	7	7	15	7	9	16	10.17	8.73	2.10
Su x Pa	16	5	16	6	4	5	8.67	18.84	3.38
So x Pa	5	16	19	18	15	18	15.17	8.89	1.36
Mo x So	20	17	21	9	20	20	17.83	5.77	1.08
Su x So	21	19	20	13	17	13	17.17	3.54	0.99
Ek x Su	18	12	10	17	11	11	13.17	4.47	1.32
Mo x Su	14	11	9	4	7	6	8.50	7.71	2.00
19 x Su	11	8	8	8	10	15	10.00	3.80	1.20
Mo x 19	9	9	13	11	8	17	11.17	5.09	1.37
Ek x Mo	19	6	7	12	6	10	10.00	12.60	2.20

BTA = Bukit Tangga
KLG = Kluang
KKR = Kuala Kangsar
KDG = Kundang
PTN = Pontian
SDG = Serdang

Table 4.43 . Non parametric ranking indices for selection of genotypes for yield (harvest 1)

Genotype	Rank at environments BTA	KLG	KKR	KDG	PTN	SDG	mean of ranks	S_i^3	S_i^6
Ek x Ek	2	2	4	2	2	1	2.17	2.23	1.70
19 x 19	5	6	5	7	6	5	5.67	0.59	0.70
So x So	3	1	1	1	1	3	1.67	3.14	3.19
Mo x Mo	15	7	11	6	5	8	8.67	7.99	2.00
Su x Su	19	4	10	4	4	7	8.00	21.75	3.25
Pa x Pa	8	10	15	11	9	9	10.33	3.03	1.03
Ek x 19	4	9	6	8	7	2	6.00	5.67	2.00
Ek x So	6	5	3	5	3	4	4.33	1.70	1.40
19 x So	1	3	2	3	8	6	3.83	9.09	3.31
Ek x Pa	10	14	13	20	16	10	13.83	5.27	1.23
Mo x Pa	13	16	7	19	20	14	14.83	7.47	1.42
19 x Pa	7	13	19	10	13	21	13.83	10.18	1.78
Su x Pa	21	12	20	17	14	20	17.33	3.89	1.04
So x Pa	11	17	12	13	19	11	13.83	4.11	1.20
Mo x So	17	19	21	18	21	17	18.83	0.89	0.48
Su x So	14	8	14	9	11	12	11.33	2.77	1.06
Ek x Su	12	15	8	16	12	13	12.67	3.11	0.94
Mo x Su	20	21	18	14	15	15	17.16	2.49	0.87
19 x Su	18	18	9	15	10	16	14.33	5.40	1.36
Mo x 19	9	20	16	21	18	18	17.00	5.41	1.06
Ek x Mo	16	11	17	12	17	19	15.33	3.22	1.01

BTA = Bukit Tangga
KLG = Kluang
KKR = Kuala Kangsar
KDG = Kundang
PTN = Pontian
SDG = Serdang

4.3.4.3. *Rank sum and rank product*

(i) *Vegetative characters*

Table 4.44 shows the rank sum and rank product indices for trunk diameter. The stability variance σ_i^2 for all the inbreds and sibs (the first nine genotypes) with the exception of 19 x 19 and So x So, were large and significantly different from the error M.S. Coupled with the small mean values for this character, the rank sum and rank product indices for this group of genotypes were generally large and unfavourable. The general conclusion was that inbreds and sibs were usually less vigorous in trunk size and were also more variable from environment to environment compared with the more stable wide cross hybrids.

The most promising hybrid which showed excellent trunk vigour and consistently so over environments were Mo x So, Su x So, Ek x Su, Ek x Pa and Ek x Mo.

In the rank sum and rank product indices for plant height presented in *Table 4.45*, inbreds and sibs again showed their relative instability when five of the nine genotypes i.e. 19 x 19, Mo x Mo, Su x Su, Ek x So and 19 x So showed significantly large σ_i^2 as compared with only three of the wide cross hybrids (19 x Pa, Su x Pa and So x Pa) which showed significance. Inbreds like Mo x Mo and Su x Su which have large σ_i^2 and short plant stature, were rated the poorest. The most stable genotypes for plant height were Su x So (σ_i^2 = 145) and Ek x Pa (σ_i^2 = 141) and coupled with their tall height, were rated the lowest rank sum and rank product indices for this character.

(ii) *Fruit characters*

In general, the changes in fruit weight of the 21 genotypes over the various environments were not very dramatic as shown by the fact that only seven genotypes had significantly large stability variances (σ_i^2) (*Table 4.46*). Two inbreds that has the most uniform and large fruit was Pa x Pa (σ_i^2 = 12.8, mean = 1.20) and Su x Su (σ_i^2 = 7.9, mean = 0.98) which resulted in their low, favourable rank sum and rank product indices. Generally, the small-fruited genotypes such as So x So, Ek x Ek, 19 x 19 and their sibs, have large rank values because of the poor ranking of their means. This occurred in spite of the fact that some genotypes i.e. Ek x So and 19 x So have very low stability variance which ranked 1 and 3 respectively. Mo x Mo and three of its hybrids i.e. Mo x Pa, Mo x So and Mo x Su were poor genotypes in so far as uniformity of the fruit weight was concerned.

For TSS %, the group consisting of Ek x Ek, So x So 19 x 19 and their three sibs have low rank sum and rank product values because of their high mean values for TSS (*Table 4.47*). Further for Ek x 19, 19 x 19 and Ek x So, their rank indices were particularly low because their stability variances were also small and non significant. Three of the worst genotypes ranked by this method were inbreds Mo x Mo, Su x Su and Pa x Pa which had highly variable TSS over environments as shown by their high σ_i^2 ranging from 1.63 to 5.33. This was exacerbated by their low TSS means (9.8 - 10.7%), resulting in very large values for rank sum and rank product for these three inbreds.

In the comparison of inbreds with wide cross hybrids, no trends were shown to indicate the superiority in stability of either group for TSS%.

(iii) *Yield components and yield*

The rank indices for earliness (days to flower) presented in *Table 4.48*, showed that the inbred and sibs appeared to have greater variation in this character over the various environments. With the exception of Mo x Mo and Su x Su, the other inbreds and sibs have very large and significantly different stability variances (σ_i^2). In contrast, out of the 12 wide cross hybrids, only two i.e. Mo x Pa (σ_i^2 = 752) and Su x Pa (σ_i^2 =781) showed significantly large stability variances.

Pa x Pa and its five hybrids were the earliest to flower and where the stability variances were also low such as in Ek x Pa (σ_i^2 = 7), its rank sum and rank product indices were the lowest. Other genotypes which were early flowering and consistently so over environments were Mo x So and Ek x Su.

For height of fruit (*Table 4.49*), only three inbreds and four hybrids have low stability variances which did not show significance. The majority of genotypes may be considered rather unstable and showed large changes in height of fruit when grown over varied environments. Mo x Mo which had the smallest σ_i^2 and the shortest height of first fruit, was considered the most desirable genotype. The others which also featured well were Ek x Mo and Pa x Pa. The poorest genotypes for this character were So x So, Ek x Ek, 19 x 19 and their three sibs i.e. Ek x 19, Ek x So and 19 x So. These genotypes generally bore fruits high from the ground and were very variable from environment to environment.

With regard to fruit number, it was interesting to note that the stability variance for all genotypes with the exception of Mo x So, were not significantly larger than the error M.S.

(*Table 4.50*). This implied that only Mo x So showed very large fluctuations in the number of fruits over different environments. Although the stability variances for this genotype ranked last, its high mean yield which ranked second, appeared to off-set its instability to produce fairly acceptable rank sum (23) and rank product (42) indices. The best genotype which had uniform and high number of fruits over environments was So x So. Hybrids with So x So also performed creditably with regard this character.

For yield in the first harvest, the inbreds and sibs were not different in stability compared with the wide cross hybrids (*Table 4.51*). Many inbreds and sibs such as Ek x Ek, So x So, Mo x Mo, Su x Su and Ek x So and hybrids such as Ek x Pa, Mo x Pa, So x Pa, Mo x So, Mo x 19 and Ek x Mo showed high stability variances indicating the large yield fluctuations of these genotypes over the six environments. Mo x So deserved special mention because it was the most unstable yielder (σ_i^2 = 585, rank = 21) but compensated by having the best mean yield (22.7 kg, rank = 1). The rank sum index placed it as a mediocre performer, but the rank product index elevated Mo x So to be the second best genotype for this character.

The best performer for yield in the first harvest was Su x Pa which had the lowest stability variance (σ_i^2 = 7) and fairly good mean (17.4 kg, rank = 5). Other potential genotypes which have consistent, high yield in the first harvest were Mo x Su and Su x So.

In comparison of the performance between the inbred and hybrid groups for yield in harvest 1, although no apparent differences in stability between the two groups were found, the inbreds and sibs had much larger rank sum and rank product indices than the wide cross hybrids because of their lower mean yields. With the exception of Pa x Pa and Ek x 19, the rank sum and rank product indices of the other seven inbreds and sibs were so unfavourable that they placed these genotypes in the last seven positions (*Table 4.51*).

4.3.5. Overall performance of genotypes based on various ranking methods

Three methods were used to study the GxE interaction of genotypes over environments i.e. mean and CV distribution, non parametric ranking and rank sum/product indices. All the methods estimated the variance of the genotypes over environments for a certain character and made an assessment of the genotypic performance by considering simultaneously the stability estimates and the genotypic means. At times, discrepancies and disagreements in the results generated by these three methods will be expected to arise because of the differences in their computation. In order to draw some agreeable conclusions from these three methods, a summary table which awards points for each genotypes' performance in each character (with GxE interaction) was presented so that selection of genotypes may be permitted.

Table 4.44. Rank-sum and rank-product for selection of genotypes for trunk diameter

Genotype	Stability variance (σ_i^2)	σ_i^2 rank	Trunk diam. (cm)	Trunk diam. rank	Rank sum	Rank product	Rank sum rank	Rank product rank
Ek x Ek	3.30**	21	6.66	20	41	420	21	21
19 x19	1.28	10	7.08	17	27	170	14	14
So x So	1.08	8	6.78	19	27	152	13	13
Mo x Mo	1.91*	12	6.46	21	38	252	17	17
Su x Su	2.47*	16	7.06	18	34	288	19	19
Pa x Pa	2.64*	18	7.11	15	33	270	18	18
Ek x 19	2.65*	19	7.11	16	35	304	20	20
Ek x So	2.57*	17	7.16	14	31	238	16	16
19 x So	2.32*	15	7.21	13	28	195	15	15
Ek x Pa	1.16	9	8.22	3	12	27	5	4
Mo x Pa	0.68	4	7.56	10	14	40	6	8
19 x Pa	1.96*	13	7.70	7	20	91	11	11
Su x Pa	2.73**	20	7.76	6	26	120	12	12
So x Pa	2.20*	14	8.32	2	16	28	8	5
Mo x So	0.79	5	8.32	1	6	5	1	1
Su x So	0..36	2	8.02	4	6	8	2	2
Ek x Su	0.28	1	7.56	9	10	9	3	3
Mo x Su	0.37	3	7.50	12	15	36	7	7
19 x Su	1.64	11	7.57	8	19	88	10	10
Mo x 19	0.92	7	7.52	11	18	77	9	9
Ek x Mo	0.80	6	7.76	5	11	30	4	6

* = significantly different at $p = 0.05$
** = significantly different at $p = 0.01$

Table 4.45. Rank-sum and rank-product for selection of genotypes for plant height

Genotype	Stability variance (σ_i^2)	σ_i^2 rank	Plant height (cm)	Plant height rank	Rank sum	Rank product	Rank sum rank	Rank product rank
Ek x Ek	268	8	122.3	20	28	160	16	16
19 x19	711**	21	145.7	5	26	105	14	11
So x So	264	6	147.3	4	10	24	3	4
Mo x Mo	651**	16	97.7	21	37	336	21	21
Su x Su	618**	15	124.6	17	32	255	20	20
Pa x Pa	250	5	125.2	16	21	80	8	8
Ek x 19	395	13	136.0	11	24	143	13	15
Ek x So	701**	20	144.8	6	26	120	15	13
19 x So	675**	18	148.7	3	21	54	7	7
Ek x Pa	141	1	142.3	9	10	9	2	2
Mo x Pa	287	10	123.4	19	29	190	17	17
19 x Pa	479*	14	144.6	7	21	98	9	9
Su x Pa	662**	17	134.5	12	29	204	19	19
So x Pa	694**	19	155.4	1	20	19	6	3
Mo x So	226	4	142.8	8	12	32	4	5
Su x So	145	2	151.1	2	4	4	1	1
Ek x Su	182	3	132.0	13	16	39	5	6
Mo x Su	227	9	125.8	15	24	135	12	14
19 x Su	335	12	140.7	10	22	120	11	12
Mo x 19	266	7	127.9	14	21	98	10	10
Ek x Mo	313	11	124.3	18	29	198	18	18

* = significantly different at $p = 0.05$
** = significantly different at $p = 0.01$

Table 4.46. Rank-sum and rank-product for selection of genotypes for fruit weight

Genotype	Stability variance (σ_i^2) (x 10^3)	σ_i^2 rank	Fruit weight (kg)	Fruit weight rank	Rank sum	Rank product	Rank sum rank	Rank product rank
Ek x Ek	16.4	11	0.49	18	29	198	16	17
19 x19	18.2	14	0.53	17	31	238	21	21
So x So	12.8	9	0.26	21	30	189	17	16
Mo x Mo	40.4**	19	0.87	12	31	228	19	19
Su x Su	7.9	4	0.98	7	11	28	2	4
Pa x Pa	11.8	7	1.20	2	9	14	1	1
Ek x 19	24.1*	15	0.69	15	30	225	18	18
Ek x So	4.8	1	0.41	20	21	20	9	2
19 x So	5.8	3	0.45	19	22	57	11	7
Ek x Pa	11.8	8	0.98	8	16	64	5	10
Mo x Pa	80.1**	21	1.25	1	22	21	10	3
19 x Pa	34.5**	17	1.00	5	22	84	12	13
Su x Pa	24.5*	16	1.11	4	20	64	8	11
So x Pa	15.7	10	0.82	14	24	140	15	15
Mo x So	40.2**	18	0.83	13	31	234	20	20
Su x So	5.4	2	0.67	16	18	32	6	5
Ek x Su	16.9	12	0.88	11	23	132	14	14
Mo x Su	44.3**	20	1.14	3	23	60	13	9
19 x Su	11.0	6	0.89	10	16	60	4	8
Mo x 19	17.3	13	0.99	6	19	78	7	12
Ek x Mo	9.2	5	0.98	9	14	45	3	6

* = significantly different at p = 0.05

** = significantly different at p = 0.01

Table 4.47. Rank-sum and rank-product for selection of genotypes for total soluble solids %

Genotype	Stability variance (σ_i^2)	σ_i^2 rank	T.S.S (%)	T.S.S rank	Rank sum	Rank product	Rank sum rank	Rank product rank
Ek x Ek	1.33**	15	12.8	5	20	75	10	9
19 x19	0.28	4	13.6	3	7	12	1	1
So x So	1.08*	12	13.9	1	13	12	3	3
Mo x Mo	5.33**	21	9.8	21	42	441	21	21
Su x Su	2.67**	20	10.0	20	40	400	20	20
Pa x Pa	1.62**	17	10.7	17	34	289	19	19
Ek x 19	0.01	2	12.8	6	8	12	2	2
Ek x So	0.70	10	13.1	4	14	40	4	7
19 x So	1.11**	13	13.6	2	15	26	5	5
Ek x Pa	2.16**	19	11.5	10	29	190	17	17
Mo x Pa	0.00†	1	10.5	18	19	18	8	4
19 x Pa	1.02*	11	12.3	8	19	88	9	11
Su x Pa	1.94**	18	10.8	16	34	288	18	18
So x Pa	1.32**	14	12.4	7	21	98	12	12
Mo x So	0.68	9	11.2	12	21	108	14	14
Su x So	0.44	6	11.7	9	15	54	6	8
Ek x Su	0.21	3	11.1	13	16	39	7	6
Mo x Su	0.57	8	10.3	19	27	152	15	15
19 x Su	0.31	5	11.1	15	20	75	11	10
Mo x 19	1.41**	16	11.3	11	27	176	16	16
Ek x Mo	0.55	7	11.1	14	21	98	13	13

† = negative σ^2 assumed 0 value
* = significantly different at $p = 0.05$
** = significantly different at $p = 0.01$

Table 4.48. Rank-sum and rank-product for selection of genotypes for earliness (days to flowering)

Genotype	Stability variance (σ_i^2)	σ_i^2 rank	Days flower	Days flower rank	Rank sum	Rank product	Rank sum rank	Rank product rank
Ek x Ek	2462**	21	181	21	42	441	21	21
19 x19	955**	16	169	17	33	272	16	16
Mo x Mo	266	7	158	10	17	70	10	12
So x So	1249**	17	175	20	37	340	19	19
Su x Su	200	4	163	15	19	60	13	10
Pa x Pa	544*	13	152	3	16	39	7	6
Ek x 19	1377**	19	166	16	35	304	17	17
Ek x So	1480**	20	173	19	39	380	20	20
19 x So	1290**	18	172	18	36	324	18	18
Ek x Pa	7	1	157	9	10	9	1	1
Mo x Pa	752**	14	146	1	15	14	3	2
19 x Pa	489	12	153	4	16	48	8	7
Su x Pa	781**	15	151	2	17	30	9	5
So x Pa	328	10	154	5	15	50	4	8
Mo x So	145	3	155	7	10	21	2	3
Su x So	204	5	159	13	18	65	11	11
Ek x Su	40	2	161	14	16	28	6	4
Mo x Su	297	9	154	6	15	54	5	9
19 x Su	258	6	159	12	18	72	12	13
Mo x 19	460	11	156	8	19	88	14	14
Ek x Mo	282	8	159	11	19	88	15	15

* = significantly different at $p = 0.05$
** = significantly different at $p = 0.01$

Table 4.49. Rank-sum and rank-product for selection of genotypes for height of first fruit

Genotype	Stability variance (σ_i^2)	σ_i^2 rank	Height fruit (cm)	Height fruit rank	Rank sum	Rank product	Rank sum rank	Rank product rank
Ek x Ek	272**	16	86	13	29	208	16	16
19 x 19	157**	11	95	17	28	187	14	14
So x So	909**	21	100	21	42	441	21	21
Mo x Mo	19	1	63	1	2	1	1	1
Su x Su	31	4	80	9	13	36	5	6
Pa x Pa	74	7	72	3	10	21	3	3
Ek x 19	442**	20	90	16	36	320	19	19
Ek x So	380**	19	96	18	37	342	20	20
19 x So	189**	13	97	20	33	260	17	17
Ek x Pa	43	5	85	11	16	55	6	7
Mo x Pa	309**	17	69	2	19	34	10	5
19 x Pa	94*	8	83	10	18	80	9	12
Su x Pa	221**	14	75	5	19	70	12	9
So x Pa	100**	9	87	14	23	126	13	13
Mo x So	26	3	79	8	11	24	4	4
Su x So	101**	10	97	19	29	190	15	15
Ek x Su	66	6	85	12	18	72	7	10
Mo x Su	246**	15	72	4	19	60	11	8
19 x Su	313**	18	88	15	33	270	18	18
Mo x 19	173**	12	77	6	18	72	8	11
Ek x Mo	20	2	77	7	9	14	2	2

* = significantly different at $p = 0.05$
** = significantly different at $p = 0.01$

Table 4.50. Rank-sum and rank-product for selection of genotypes for fruit number

Genotype	Stability variance (σ_i^2)	σ_i^2 rank	Fruit number	Fruit number rank	Rank sum	Rank product	Rank sum rank	Rank product rank
Ek x Ek	116	14	40	12	26	168	16	17
19 x 19	255	20	45	7	27	140	17	14
So x So	26	4	63	1	5	4	1	1
Mo x Mo	108	11	26	19	30	209	19	19
Su x Su	63	6	25	20	26	120	14	12
Pa x Pa	111	12	24	21	33	252	20	20
Ek x 19	83	8	40	10	18	80	5	9
Ek x So	86	9	52	4	13	36	3	4
19 x So	0†	1	46	6	7	6	2	2
Ek x Pa	61	5	44	9	14	45	4	6
Mo x Pa	23	3	28	18	21	54	8	8
19 x Pa	193	19	37	15	34	285	21	21
Su x Pa	14	2	33	17	19	34	6	3
So x Pa	145	16	46	5	21	80	9	10
Mo x So	635**	21	55	2	23	42	11	5
Su x So	154	18	52	3	21	54	7	7
Ek x Su	145	17	44	8	25	136	13	13
Mo x Su	104	10	35	16	26	160	15	16
19 x Su	80	7	39	14	21	98	10	11
Mo x 19	116	13	40	11	24	143	12	15
Ek x Mo	141	15	39	13	28	195	18	18

† = negative σ_i^2 assumed 0 value
* = significantly different at p = 0.05
** = significantly different at p = 0.01

Table 4.51. Rank-sum and rank-product for selection of genotypes for yield 1 (harvest 1)

Genotype	Stability variance (σ_i^2)	σ_i^2 rank	Yield 1 (kg)	Yield 1 rank	Rank sum	Rank product	Rank sum rank	Rank product rank
Ek x Ek	174**	19	5.5	20	39	380	20	20
19 x 19	35	8	8.2	16	24	128	15	15
So x So	250**	20	3.4	21	41	420	21	21
Mo x Mo	89**	12	9.2	15	27	180	17	17
Su x Su	155**	18	8.1	17	35	306	19	19
Pa x Pa	13	3	12.6	12	15	36	6	6
Ek x 19	32	7	9.5	14	21	98	12	13
Ek x So	110**	15	6.8	19	34	285	18	18
19 x So	36	9	7.7	18	27	162	16	16
Ek x Pa	101**	14	17.6	4	18	56	9	10
Mo x Pa	130**	17	17.2	6	23	102	14	14
19 x Pa	27	6	15.9	9	15	54	5	8
Su x Pa	7	1	17.4	5	6	5	1	1
So x Pa	98**	13	16.9	7	20	91	11	12
Mo x So	585**	21	22.7	1	22	21	13	2
Su x So	10	2	12.5	13	15	26	4	3
Ek x Su	25	4	15.7	10	14	40	3	7
Mo x Su	51	10	18.3	3	13	30	2	4
19 x Su	26	5	14.8	11	16	55	7	9
Mo x 19	129**	16	19.4	2	18	32	8	5
Ek x Mo	63	11	16.7	8	19	88	10	11

* = significantly different at $p = 0.05$
** = significantly different at $p = 0.01$

4.3.5.1. *Method of scoring*

For mean and CV distribution (*Figures 4.1 - 4.8*), four quadrants were demarcated by the lines for genotypic mean and CV mean. No points will be awarded for genotypes in quadrant 1 which had below average CV and above average mean. Five points were given to quadrant 2 (above average CV and above average mean), 10 points to quadrant 3 (below average CV and below average mean) and 15 points to the poorest quadrant 4 (above average CV and below average mean). Up to 15 points were awarded for this method of selection because sufficient weight must be given as other ranking methods have awarded up to 21 points.

For earliness (days to flower) and height of fruit, smaller mean values denote higher preference, therefore the positions of the quadrants for these characters will be shifted as compared with the normal situations where high mean values were desired. The points awarded for non parametric ranking and rank sum/product indices followed the position of ranking of these estimates for the genotype. For example, if a genotype had the poorest estimate, it will have 21 points while the best would have one. The sum of the points from the five columns (mean/CV, S_i^3, S_i^6, rank sum and rank product) will provide the yardstick in the overall performance of the genotypes. Evidently, the genotype with the lowest points will be the most desired.

4.3.5.2. *Performance in vegetative characters*

For trunk diameter (*Table 4.52*), there was little dispute among the different methods in pinpointing the best performers. All six genotypes in the most favourable quadrant 1 (0 points) were also placed favourably by the non parametric ranking and the rank sum and rank product analyses. The top five genotypes that emerged as having the most consistent trunk vigour were Mo x So, Su x So, Mo x Pa, So x Pa and Ek x Pa. There was also general consensus of opinion among the methods that the group of inbreds and sibs were unstable and weak in trunk vigour. All these genotypes fell into quadrants 3 or 4 and were also poorly placed by the other rank indices. With the exception of 19 x 19 and So x So, the rest of the seven genotypes in the inbred group were placed in the bottom positions in the overall ranking for trunk diameter (*Table 4.52*).

There was debate over the selection of consistent, tall genotypes using the three methods (*Table 4.53*). While quadrant 1 picked out genotypes like Su x So, Ek x Pa, So x Pa, Mo x So and So x So which were also favoured by the non parametric ranking and rank sum/product, others in the quadrant 1 like 19 x 19, Ek x So 19 x So and 19 x Su failed to get the consensus of the other indices over their performance. At the other extreme, some genotypes like 19 x Pa and Ek x Su that were written off in quadrants 2 and 3, received favourable assessment from the other ranking methods. Mo x Mo deserved special mention because there was total disagreement in the points awarded by non parametric ranking which placed it at the top (rank = 1) and the rank sum/product which placed it last (rank = 21). The reason for this gross discrepancy will be discussed later.

4.3.5.3. *Performance in fruit characters*

For fruit weight (*Table 4.54*), the scoring of the three methods for establishing the performance of genotypes also showed wide discrepancies. Only in the case of Pa x Pa and to a certain extent Su x Pa and Mo x Pa were there agreement among the three methods in the selection of consistent, large-fruited genotypes. In the cases of Mo x Mo (quadrant 1) and Su x So (quadrant 4), the points awarded by the other ranking methods showed total disagreement with the mean/CV distribution analysis. Even within the ranking methods, there were discrepancies as seen in the case of Su x Su where non parametric ranking awarded poor 20 - 21 scores while rank sum and rank product ranked this genotype very high (2 - 4).

There were no trends to suggest that inbreds and sibs were any better or worse in stability and mean performance for fruit weight. The best was an inbred Pa x Pa, followed by Su x Pa and Mo x Pa while the worst were Mo x Mo and Ek x 19.

For TSS % (*Table 4.55*), there was no question that the three closely related inbreds So x So, Ek x Ek and 19 x 19 and their three sibs Ek x Su, 19 x So and Ek x 19 were outstanding both in terms of stability of the trait over environments as well as their superior means. These six genotypes were favourably scored by all the three methods and were placed in the top six positions in the overall standings. The poorest genotypes were the three inbreds Mo x Mo, Su x Su and Pa x Pa and the three hybrids between them. All of them have variable and low TSS %.

4.3.5.4. *Performance in yield and yield components*

There was fairly good agreement in the selection of earliness by the mean/CV distribution and ranking methods (*Table 4.56*). They concurred strongly in the selection of the top two performers i.e. Mo x Pa and Ek x Pa and were also in general agreement for the next five i.e. Mo x So, So x Pa, Mo x Su, Pa x Pa, and Su x Pa with the exception that four of them were placed in quadrant 2. In the overall ranking, it appeared that inbreds and sibs (with the exception of Pa x Pa) were less stable and flowered later than wide cross hybrids.

For height of fruit, there was also concurrence from the three methods of analysis. The top five genotypes i.e. Mo x Mo, Pa x Pa, Mo x So, Ek x Mo and Su x Su were in quadrants 1 and 2 and all their rank scores were under 10 points (*Table 4.57*). There were no particular trends to indicate the superiority of either the inbred group or the wide cross hybrid group. In the inbred group, Mo x Mo and Pa x Pa consistently bore fruits low to the ground while So x So was very variable and generally fruited high on the trunk. It was evident, however that all hybrids with Mo x Mo showed the ability to bear low to the ground.

For fruit number (*Table 4.58*), the best three genotypes i.e. 19 x So, Ek x Pa and Su x So were favourably scored by all the three methods. There was also agreement in the selection of the worst genotypes Su x Su and Mo x Mo. Other than that, there seemed to be fairly wide discrepancies either between mean/CV distribution and ranking analyses or between non parametric and sum/product with the ranking methods.

In the overall ranking, three inbreds Mo x Mo, Su x Su and Pa x Pa and their hybrids performed poorly with low, variable fruit number over the six environments. On the other hand, hybrids that involved So x So i.e. 19 x So, Su x So, Mo x So, Ek x So and So x Pa were particularly stable and fruitful. These hybrids were placed seventh or better in the overall ranking for fruit number.

For yield in the first harvest, the top three genotypes i.e. Mo x Su, Mo x So and Ek x Su were rated highly by all the three methods with the exception of rank sum for Mo x So (*Table 4.59*). At the bottom end, the three methods concurred in establishing the dismal performance of Su x Su, So x So, Mo x Mo and 19 x So.

In the overall assessment of genotypes for yield in harvest 1, it was very clear that inbreds and sibs with the exception of Pa x Pa were the poorer performers compared with the wide cross hybrids. The worst six genotypes in terms of stability and mean yield were from the inbred/sib group (*Table 4.59*).

4.3.6. Selection of inbreds v. hybrids

The results presented earlier have covered, amongst other things, the genotypic means over the six environments. In many of the cases, the genotypic means cannot be used directly to indicate the performance of those genotypes because of significance in GxE interaction. Some methods of selection that gave consideration to the relative changes of the genotypes' performance (stability) over environments coupled with their mean values were employed to identify performers which not only have superior means but were consistently so over environments..

In this part, the selection of the top five and the worst five genotypes based on the scores from the mean/CV distribution and ranking indices were presented. For those characters that did not show significance in GxE interaction, the genotypic means were used directly for selection of genotypes. The selections were partitioned into two groups i.e. inbreds/ sibs and the wide cross hybrids, to give an indication of the representation and superiority of each group for the character concerned. This will be important for papaya breeders who will have to decide whether to use hybrids or inbreds (pure lines) for improvement of a particular trait.

Table 4.60 shows the representations of inbreds/sibs and wide cross hybrids when the top five and worst five genotypes were selected for each character.

For vegetative characters, it was very clear that wide cross hybrids were more vigorous than inbreds/sibs. For trunk diameter, petiole length and lamina width, the top five genotypes were all hybrids while the bottom five were consistently all inbreds or sibs. The vigour of hybrids expressed in plant height, however was not as unanimous, although four of the five top selections were from wide cross hybrids.

In malformed top disease (MTD) resistance, two inbreds Pa x Pa and Su x Su were very resistant, resulting in their selection in the top five, but inbreds/sibs generally appeared to succumb more to the disease as shown by the fact that five most susceptible genotypes were inbreds/sibs.

For fruit characters, including fruit weight and TSS%, there were probably no differences between inbreds/sibs and hybrids in the composition of the worst five genotypes but inbreds, thanks to the presence of So x So and its derivatives, were clearly better in TSS%. The results showed that the top five performers all came from this group. For fruit weight, hybrids were slightly better with four of the five top selections coming from the hybrid group. With regard to carpellody %, selection would probably not be effective because the genotypic means over environments were not significantly different.

In consideration of yield characters, hybrids were definitely more promising than inbreds and sibs. While there were probably not much to separate between the two groups for height of fruit and fruit number, hybrids were clearly more outstanding than inbreds or sibs in earliness (days to flower) and yield over harvest 1, harvest 2 and combined harvest. For these four characters, the best five genotypes were consistently wide cross hybrids while the worst five were all inbreds or sibs.

Table 4.52. Overall rank of genotypes in selection for trunk diameter

Genotype	Scores from various methods						
	Mean CV	S_i^3	S_i^6	Rank sum	Rank prod.	Total score	Overall rank
Ek x Ek	10	20	21	21	21	93	21
19 x19	10	9	12	14	14	59	12
So x So	15	5	9	13	13	55	11
Mo x Mo	15	13	20	17	17	82	17
Su x Su	10	21	19	19	19	88	20
Pa x Pa	15	17	17	18	18	85	18
Ek x 19	10	19	18	20	20	87	19
Ek x So	10	16	15	16	16	73	15
19 x So	10	18	16	15	15	74	16
Ek x Pa	0	8	6	5	4	23	5
Mo x Pa	0	3	4	6	8	21	3
19 x Pa	10	14	13	11	11	59	13
Su x Pa	10	13	14	12	12	61	14
So x Pa	0	7	2	8	5	22	4
Mo x So	0	1	1	1	1	4	1
Su x So	0	2	3	2	2	9	2
Ek x Su	5	6	7	3	3	24	6
Mo x Su	5	4	5	7	7	28	7
19 x Su	0	11	8	10	10	39	9
Mo x 19	5	10	11	9	9	44	10
Ek x Mo	5	12	10	4	6	37	8

Table 4.53. Overall rank of genotypes in selection for plant height

Genotype	Scores from various methods						
	Mean CV	S_i^3	S_i^6	Rank sum	Rank prod.	Total score	Overall rank
Ek x Ek	10	14	19	16	16	75	18
19 x19	0	18	13	14	11	56	12
So x So	0	6	6	3	4	19	5
Mo x Mo	10	1	1	21	21	54	11
Su x Su	15	21	21	20	20	97	21
Pa x Pa	15	16	18	8	8	65	15
Ek x 19	5	15	14	13	15	62	14
Ek x So	0	19	12	15	13	59	13
19 x So	0	11	9	7	7	34	6
Ek x Pa	0	3	4	2	2	11	2
Mo x Pa	10	12	16	17	17	72	17
19 x Pa	5	8	7	9	9	38	8
Su x Pa	15	20	15	19	19	88	20
So x Pa	0	5	3	6	3	17	3
Mo x So	0	4	5	4	5	18	4
Su x So	0	2	2	1	1	6	1
Ek x Su	10	9	8	5	6	38	7
Mo x Su	15	13	17	12	14	71	16
19 x Su	0	10	10	11	12	43	9
Mo x 19	15	7	11	10	10	53	10
Ek x Mo	15	17	20	18	18	88	19

Table 4.54. Overall rank of genotypes in selection for fruit weight

Genotype	Scores from various methods						
	Mean CV	S_i^3	S_i^6	Rank sum	Rank prod.	Total score	Overall rank
Ek x Ek	10	11	17	16	17	71	17
19 x19	10	3	5	21	21	60	15
So x So	10	4	18	17	16	65	16
Mo x Mo	0	20	19	19	19	77	20
Su x Su	5	21	20	2	4	52	12
Pa x Pa	0	2	1	1	1	5	1
Ek x 19	15	13	13	18	18	77	21
Ek x So	10	8	21	9	2	50	10
19 x So	10	7	15	11	7	50	11
Ek x Pa	0	12	9	5	10	36	7
Mo x Pa	0	9	4	10	3	26	3
19 x Pa	0	19	14	12	13	58	14
Su x Pa	0	5	2	8	11	26	2
So x Pa	10	18	16	15	15	74	19
Mo x So	5	17	11	20	20	73	18
Su x So	15	1	3	6	5	30	4
Ek x Su	0	15	12	14	14	55	13
Mo x Su	5	10	6	13	9	43	8
19 x Su	5	6	7	4	8	30	5
Mo x 19	5	16	10	7	12	50	9
Ek x Mo	5	14	8	3	6	36	6

Table 4.55. Overall rank of genotypes in selection for total soluble solids % (TSS)

Genotype	Scores from various methods						
	Mean CV	S_i^3	S_i^6	Rank sum	Rank prod.	Total score	Overall rank
Ek x Ek	0	6	6	10	9	31	6
19 x19	0	4	4	1	1	10	2
So x So	0	1	1	3	3	8	1
Mo x Mo	15	20	20	21	21	97	21
Su x Su	10	19	21	20	20	90	19
Pa x Pa	10	17	16	19	19	81	18
Ek x 19	5	2	2	2	2	13	3
Ek x So	0	5	5	4	7	21	5
19 x So	0	3	3	5	5	16	4
Ek x Pa	10	15	13	17	17	72	16
Mo x Pa	15	9	11	8	4	47	10
19 x Pa	0	7	7	9	11	34	7
Su x Pa	15	21	19	18	18	91	20
So x Pa	0	8	8	12	12	40	9
Mo x So	10	11	14	14	14	63	13
Su x So	0	12	9	6	8	35	8
Ek x Su	10	18	17	7	6	58	12
Mo x Su	15	16	18	15	15	79	17
19 x Su	15	10	10	11	10	56	11
Mo x 19	15	13	12	16	16	72	15
Ek x Mo	15	14	15	13	13	70	14

Table 4.56. Overall rank of genotypes in selection for earliness (days to flower)

Genotype	Scores from various methods						
	Mean CV	S_i^3	S_i^6	Rank sum	Rank prod.	Total score	Overall rank
Ek x Ek	10	13	21	21	21	86	20
19 x19	10	20	17	16	16	79	17
So x So	10	2	7	19	19	57	13
Mo x Mo	5	11	9	10	12	47	10
Su x Su	15	21	20	13	10	79	18
Pa x Pa	5	9	4	7	6	31	6
Ek x 19	15	18	18	17	17	85	19
Ek x So	10	19	19	20	20	88	21
19 x So	10	15	14	18	18	75	16
Ek x Pa	0	4	3	1	1	9	2
Mo x Pa	0	1	1	3	2	7	1
19 x Pa	0	14	12	8	7	41	8
Su x Pa	5	7	8	9	5	34	7
So x Pa	5	3	2	4	8	22	4
Mo x So	5	6	5	2	3	21	3
Su x So	0	16	16	11	11	54	12
Ek x Su	15	8	10	6	4	43	9
Mo x Su	0	5	6	5	9	25	5
19 x Su	5	17	15	12	13	62	15
Mo x 19	0	10	11	14	14	49	11
Ek x Mo	5	12	13	15	15	60	14

Table 4.57. Overall rank of genotypes in selection for height of fruit

Genotype	Scores from various methods						
	Mean CV	S_i^3	S_i^6	Rank sum	Rank prod.	Total score	Overall rank
Ek x Ek	15	20	18	16	16	85	19
19 x19	10	3	5	14	14	46	10
So x So	10	21	21	21	21	94	21
Mo x Mo	5	1	1	1	1	9	1
Su x Su	5	4	3	5	6	23	5
Pa x Pa	0	2	2	3	3	10	2
Ek x 19	10	18	15	19	19	81	17
Ek x So	10	13	16	20	20	79	16
19 x So	15	17	20	17	17	86	20
Ek x Pa	15	14	13	6	7	55	13
Mo x Pa	5	12	8	10	5	40	7
19 x Pa	0	15	14	9	12	50	12
Su x Pa	5	7	7	12	9	40	8
So x Pa	10	11	12	13	13	59	14
Mo x So	0	5	4	4	4	17	3
Su x So	10	16	19	15	15	75	15
Ek x Su	10	9	11	7	10	47	11
Mo x Su	5	10	10	11	8	44	9
19 x Su	10	19	17	18	18	82	18
Mo x 19	0	8	9	8	11	36	6
Ek x Mo	5	6	6	2	2	21	4

Table 4.58. Overall rank of genotypes in selection for fruit number

Genotype	Scores from various methods						
	Mean CV	S_i^3	S_i^6	Rank sum	Rank prod.	Total score	Overall rank
Ek x Ek	10	13	11	16	17	67	15
19 x19	0	14	14	17	14	59	13
So x So	5	19	16	1	1	42	8
Mo x Mo	15	21	20	19	19	94	21
Su x Su	15	17	21	14	12	79	20
Pa x Pa	10	7	18	20	20	75	18
Ek x 19	0	18	17	5	9	49	11
Ek x So	0	16	10	3	4	33	5
19 x So	0	2	1	2	2	7	1
Ek x Pa	0	3	2	4	6	15	2
Mo x Pa	10	1	9	8	8	36	6
19 x Pa	10	11	13	21	21	76	19
Su x Pa	15	20	19	6	3	63	14
So x Pa	0	12	7	9	10	38	7
Mo x So	0	9	4	11	5	29	4
Su x So	0	4	3	7	7	21	3
Ek x Su	5	6	6	13	13	43	9
Mo x Su	15	10	12	15	16	68	16
19 x Su	15	5	5	10	11	46	10
Mo x 19	15	8	8	12	15	58	12
Ek x Mo	15	15	5	18	18	71	17

Table 4.59. Overall rank of genotypes in selection for yield (harvest 1)

Genotype	Scores from various methods						
	Mean CV	S_i^3	S_i^6	Rank sum	Rank prod.	Total score	Overall rank
Ek x Ek	10	4	15	20	20	69	17
19 x19	15	1	2	15	15	48	12
So x So	15	9	19	21	21	85	20
Mo x Mo	15	18	18	17	17	85	19
Su x Su	10	21	20	19	19	89	21
Pa x Pa	15	7	6	6	6	40	6
Ek x 19	10	16	17	12	13	68	16
Ek x So	10	3	13	18	18	62	14
19 x So	10	19	21	16	16	82	18
Ek x Pa	0	13	11	9	10	43	9
Mo x Pa	5	17	14	14	14	64	15
19 x Pa	0	20	16	5	8	49	13
Su x Pa	5	11	7	1	1	25	4
So x Pa	0	12	10	11	12	45	10
Mo x So	0	2	1	13	2	18	2
Su x So	10	6	8	4	3	31	5
Ek x Su	0	8	4	3	7	22	3
Mo x Su	0	5	3	2	4	14	1
19 x Su	5	14	12	7	9	47	11
Mo x 19	5	15	9	8	5	42	8
Ek x Mo	5	10	5	10	11	41	7

Table 4.60. Composition of inbred (including sibs) and hybrid in the best and worst five selections for 14 characters

Character	Selection method	Best 5 selections		Worst 5 selections	
		Inbred	Hybrid	Inbred	Hybrid
Vegetative					
Trunk diameter	GxE ranking	0	5	5	0
Plant height	GxE ranking	1	4	2	3
Petiole length	Genotypic means	0	5	5	0
Lamina width	Genotypic means	0	5	5	0
Fruit					
Fruit weight	GxE ranking	1	4	3	2
TSS %	GxE ranking	5	0	3	2
Carpellody %	No selection *				
Yield					
Earliness	GxE ranking	0	5	5	0
Height of fruit	GxE ranking	3	2	4	1
Fruit number	GxE ranking	2	3	3	2
Yield (harvest 1)	GxE ranking	0	5	5	0
Yield (harvest 2)	Genotypic means	0	5	5	0
Yield (combined)	Genotypic means	0	5	5	0
Disease resistance					
Malformed top	GxE ranking	2	3	5	0

* No significant difference between genotypes

4.4. HETEROSIS

Heterosis estimates were computed based on the relative performance of the hybrids compared with the mid-parent and the better parent. The definition of 'better parent' would mean the 'more desired' and therefore, it may not necessarily be the one that had the larger mean value. In the cases of earliness (number of days to first flower) and height of fruiting, smaller means are obviously desired, and the better parent would be the one with shorter maturation period or lower height of fruiting. For these two cases, negative estimates of heterosis would reflect better performance of hybrids over the parents.

4.4.1. Heterosis in vegetative characters

The heterosis estimates for the four vegetative characters i.e. trunk diameter, plant height, petiole length and lamina width are shown in *Table 4.61*. In general, vegetative vigour of hybrids over mid-parent (MP) was evident, ranging from 9.0% for lamina width to 14.8% for petiole length. With regard to heterosis over the better parent (BP), significant heterosis was still obtained for trunk diameter and petiole length. However, for plant height and lamina width, the majority of hybrids were not as vigorous as the better parent. In the case of plant height, this was because Solo and Line 19 were genetically tall varieties and most crosses with them would be expected to show negative heterosis.

Hybrids generally showed fairly high heterosis for trunk diameter (12.9% over MP and 3.7% over BP) and petiole length (14.8% over MP and 3.7% over BP). However, not all of them showed positive heterosis. Four hybrids in trunk diameter and six in petiole length performed poorer than their better parent. The most vigorous hybrids appeared to be Mo x So, Ek x Mo, Ek x Pa and So x Pa. All of them showed marked heterosis exceeding the overall mean for all the four vegetative characters (*Table 4.61*).

Crosses between Line 19, Eksotika and Solo, as mentioned earlier, were considered sibs because of their similar genetic background. For these three sib crosses, they showed negative heterosis over BP for all the four vegetative characters. When the heterosis was computed without the sibs, the estimates for the other hybrids were increased and all showed positive estimates ranging from 10.4% - 16.9% over MP and 0.6% - 5.5% over BP. (*Table 4.61*).

4.4.2. Heterosis in fruit and fruiting characters

Fruit carpellody was not included for the heterosis evaluation because the ANOVA carried out earlier did not indicate genotypic differences for this character. Heterosis for fruit weight, TSS%, earliness in flowering and height of first fruit are shown in *Table 4.62*. With regard to fruit weight and TSS%, it was very clear that hybrid means were, more often than not, poorer than their better parents. This was indicated by the majority of hybrids having negative heterosis estimates for these two characters. Of the 15 hybrids, only five of them for fruit weight and two for TSS% showed positive heterosis. As discussed earlier, these two characters were likely to be controlled largely by additive genes and hybrids have a tendency to have intermediate values between the parents.

When sib crosses were considered by themselves, there appeared to be heterotic effects over BP for fruit weight (1.3%) mainly because of the contribution from Ek x 19 which had 31.1% heterosis for this character.

For earliness and height of first fruit, positive estimates for these two characters were undesirable because hybrids with earlier maturation and lower bearing height were sought after. For height of fruiting which showed heterosis over MP and BP of 3.8% and 20.0% respectively, it is reasonable to conclude that there is no useful heterosis for this character. With regard to earliness, the heterosis was marginal (-3.5% over MP and 2.2% over BP) because all hybrids flowered earlier than MP but only four were earlier than the earlier-flowering parent (*Table 4.62*). Hybrids that have high positive estimates for earliness invariably have Morib (Mo) as one of its parents. Morib, as mentioned earlier, is an early maturing, genetic dwarf and hybridisation with it is unlikely to yield an earlier-maturing hybrid.

4.4.3. Heterosis in yield components and yield

Heterosis estimates for fruit number and yield over two harvests as well as combined yield are presented in *Table 4.63*. For fruit number, heterosis over MP, in general, was quite marked for hybrids but not for the sibs. Heterosis over BP was less evident and only 53% of the crosses showed a higher fruit number than the better parent.

In contrast, there is no argument that considerable heterosis for yield exist. All hybrids (excluding sibs) showed higher yields compared with MP or BP over the two harvests as well as in the combined yield. The mean heterosis of hybrids for the combined yield was 51%. It was also evident that greater heterosis was shown by hybrids in the first harvest (175.2% over

Table 4.61. Heterosis estimates over mid and better parents of 15 hybrids for vegetative characters

Genotype	Trunk diameter		Plant height		Petiole length		Lamina width	
	MP	BP	MP	BP	MP	BP	MP	BP
Ek x 19	3.8	-2.4	2.0	-6.9*	9.7	-1.1	6.6	-0.7
Ek x So	5.8	-0.4	6.9*	-3.0	5.2	-2.9	4.0	-5.3
19 x So	4.9	-1.0	2.1	-2.3	4.1	-6.3	0.7	-9.7**
Sib mean	4.8	-1.3	3.7	-4.1	6.3	-3.4	3.8	-5.2
Ek x Pa	18.8**	6.4*	15.2*	7.9**	24.0**	13.0**	16.3**	8.1*
Mo x Pa	12.2**	1.6	11.0**	-1.3	20.5**	6.5*	11.7**	1.7
19 x Pa	10.1*	-0.7	8.2	-1.2	7.8	-2.3	6.1	-1.1
Su x Pa	7.9*	1.0	8.4*	2.9	9.0	0.6	6.5	-1.2
So x Pa	18.4**	8.3	13.6**	4.1	20.1**	9.7	16.9**	2.4
Mo x So	29.2**	19.1**	17.0**	2.7	33.6**	20.6*	18.6*	9.1
Su x So	17.5**	7.4	11.9**	0.9	14.5*	3.9	12.7*	-0.2
Ek x Su	11.8*	1.7	8.2*	2.5	10.9	2.8	6.2	-2.4
Mo x Su	10.7*	1.8	12.2**	-0.4	20.6**	7.6	10.8*	2.4
19 x Su	9.7	1.4	6.0	-3.2	4.5	-5.1	1.3	-5.0
Mo x 19	12.4**	1.6	6.1*	-10.8**	12.5*	-3.4	5.1	-2.8
Ek x Mo	21.4**	10.4*	14.1**	3.5	24.9**	11.9*	12.0**	3.4
Hybrid mean	15.0	5.0	11.0	0.6	16.9	5.5	10.4	1.2
Overall mean	12.9	3.7	9.5	-0.3	14.8	3.7	9.0	-0.1
% heterotic hybrids	100	73	100	47	100	60	100	40

* significantly different from MP or BP values at $p \leq 0.05$

** significantly different from MP or BP values at $p \leq 0.01$

Table 4.62. Heterosis estimates over mid and better parents of 15 hybrids for fruit characters

Genotype	Fruit wt.		TSS%		Earliness †		Height frt. †	
	MP	BP	MP	BP	MP	BP	MP	BP
Ek x 19	38.7**	31.1**	-3.0*	-6.1**	-3.6	-0.7	-0.5	9.2**
Ek x So	12.5*	-12.9**	-2.2*	-6.2**	-2.4	-0.1	3.2	17.0**
19 x So	14.0**	14.4**	-1.3	-3.4**	-0.2	1.9	0.7	5.4
Sib mean	21.7	1.3	-2.2	-3.1	-2.1	0.4	1.1	10.5
Ek x Pa	16.1**	-18.8**	-1.7	-9.5**	-5.1**	4.5*	9.7**	21.2**
Mo x Pa	20.4**	4.5	3.6	-1.6	-3.2	0.9	7.4	20.1**
19 x Pa	15.8**	-16.4**	0.6	-10.0**	-4.3	2.3	0.4	17.0**
Su x Pa	3.4	-7.0*	5.2	1.1	-3.9	2.3	0.4	7.6*
So x Pa	11.2**	-31.8**	0.9	-10.7**	-5.7*	2.1	2.6	23.2**
Mo x So	46.4**	-3.3	-5.9**	-19.9**	-4.3	3.7	2.1	38.7**
Su x So	8.3*	-30.7**	-1.8	-15.7**	-4.7*	-0.2	9.6**	25.1**
Ek x Su	21.9**	-9.0	-2.2	-13.0**	-5.5*	-0.2	4.4	10.7**
Mo x Su	23.8**	13.9**	5.7	1.3	-1.4	5.1	4.9	25.5**
19 x Su	18.7**	-8.4	-5.5*	-18.2**	-3.2	1.3	1.2	11.2**
Mo x 19	39.6**	13.1*	-2.9	-16.6**	-1.7	4.1	1.3	33.5**
Ek x Mo	43.5**	12.2*	-1.6	-13.1**	-3.3	5.4	9.1**	34.7**
Hybrid mean	22.4	-6.8	-0.5	-10.5	-3.9	2.6	4.4	22.4
Overall mean	22.3	-5.2	-0.8	-9.4	-3.5	2.2	3.8	20.0
% heterotic hybrids	100	40	33	13	100	27	7	0

† negative heterosis desired

* significantly different from MP or BP values at p = 0.05
** significantly different from MP or BP values at p = 0.01

Table 4.63. Heterosis estimates over mid and better parents of 15 hybrids for fruit number and yield

Genotype	Fruit number		Yield 1		Yield 2		Yield (combined)	
	MP	BP	MP	BP	MP	BP	MP	BP
Ek x 19	-2.3	-18.7*	41.3	10.5	16.4	-4.0	30.5	6.1
Ek x So	17.2	-9.1	102.2*	36.6	46.9	6.8	34.4	6.7
19 x So	-4.6	-21.4*	28.6	-6.3	11.9	-12.3	18.1	-5.3
Sib mean	3.4	-16.4	57.4	13.6	25.1	-3.2	27.7	2.5
Ek x Pa	107.6	13.2	117.4**	41.9**	184.2*	120.0	143.7	103.4
Mo x Pa	25.4	5.0	53.4**	16.5	31.9*	4.3	41.3**	11.3
19 x Pa	16.2	-11.5	130.0	59.3	29.2	10.7	47.4**	23.6
Su x Pa	38.0**	14.8	115.1**	59.7*	39.4	2.0	37.5**	12.2
So x Pa	24.1	-14.7	165.9*	59.0	80.2**	34.8**	85.2**	36.4**
Mo x So	69.8	14.1	348.9*	199.6*	229.7*	118.3*	195.0**	129.1**
Su x So	49.4	3.4	162.4**	68.2*	123.1**	64.0*	88.4**	46.5**
Ek x Su	44.1*	9.2	167.6**	95.1**	55.1*	30.0	78.1**	51.3**
Mo x Su	50.9**	22.8	146.0**	92.4**	57.1*	25.5	82.8**	48.7**
19 x Su	24.0	-7.5	152.7*	81.5*	27.2	5.4	50.2**	25.9
Mo x 19	16.2	-8.7	225.3*	146.2*	44.1	20.9	76.6**	48.3*
Ek x Mo	95.7	63.4	317.7	161.2	94.2*	62.4*	112.3**	75.1*
Hybrid mean	46.8	8.6	175.2	90.0	83.0	41.5	86.5	51.0
Overall mean	38.1	3.6	151.6	74.8	71.4	32.6	74.8	41.3
% heterotic hybrids	87	53	100	93	100	87	100	93

* significantly different from MP or BP values at p = 0.05
** significantly different from MP or BP values at p = 0.01

MP; 90% over BP) than the second harvest (83% over MP and 41.5% over BP). This trend was true for all the hybrids with the exception of Ek x Pa (*Table 4.63*).

Closely related sib crosses showed positive heterosis for yield (57.4% over MP and 13.6% over BP) in the first harvest but negative heterosis over BP (-3.2%) in the second harvest. However, the extent of heterosis, 13.6% over BP in the first harvest and 2.7% over BP in the combined harvest, appeared minuscule compared with the wide-cross hybrids (90% and 51% respectively). Mo x So which was the highest yielding hybrid was also one that showed the highest heterosis over the two harvests. It was particularly impressive in the first harvest, when it recorded a dramatic 348.9% yield increase over MP and 199.6% over BP. In the second harvest, the estimated dropped, but still maintained an impressive 229.7% over MP and 118.3% over BP (*Table 4.63*).

In summary, useful heterosis were obtained for characters related to vegetative vigour, yield and to a certain extent, earliness. As discussed earlier, other characters like fruit weight, TSS%, height of fruit and fruit number which appeared to be controlled by additive genes, expressed little or no heterosis.

4.4.4. Heterotic response over environments

Heterosis in trunk diameter, yield of first harvest and earliness will be further examined over environments because the ANOVA carried out earlier (*Table 4.29*) indicated that there was significant GxE interaction and as such, heterotic responses expressed by hybrids may not be in the same relative proportion from environment to environment.

Table 4.64. shows the heterotic responses of 15 hybrids over six environments for trunk diameter. There were obvious deviations from the overall results presented in *Table 4.61* where the majority of hybrids exhibited heterosis for stem vigour. When examined over the six environments, only two hybrids i.e. Mo x So and Ek x Mo were consistently more vigorous than their better parent over all the environments.

When the environment means for heterosis of trunk diameter were examined, there appeared to be an interesting trend. At both the best environment (Pontian) and the worst environment (Bukit Tangga), the extent of heterosis over BP was lower than the medium-ranked environments (*Table 4.64*). Bukit Tangga had the lowest (-1.1%) and Pontian (-0.6%) the second lowest, compared with 4.2% to 9.2% for the rest of the environments. There were also lower percentages of heterotic hybrids at Pontian (40%) and Bukit Tangga (46%) for this character compared with 60% - 93% in other environments.

Heterotic responses for earliness over six environments are shown in *Table 4.65*. The general trend of hybrids at each environment for earliness was more or less the same as the overall results over environments (*Table 4.62)*. Most of the hybrids were earlier flowering compared with MP, but were not quite so when comparison was made with BP. However, it may be noted that in more favourable environments such as Pontian, Kundang, Kluang, and Serdang, the percentage of heterotic hybrids for earliness (compared with BP) appeared to be higher, ranging from 26% - 40% (*Table 4.65*). At the other less favourable environments, it can be concluded that hybrids were not earlier in flowering compared with the better parent.

For yield at first harvest, the heterotic response of the 15 hybrids over environments are shown in *Table 4.66.* At Bukit Tangga and Kuala Kangsar, the two poorest environments, low heterosis over BP of -7.1% and 13.7% respectively were obtained. Further, ten of the 15 hybrids did not fare better than the better parent at Bukit Tangga. In contrast, very high heterosis for yield at first harvest ranging from 64.3% - 199.6% were obtained at other more favourable environments. Only four hybrids i.e. Ek x So, Su x Pa, Mo x So and Mo x Su showed consistent, positive heterosis (over BP) over all the six environments. Hybrids generally maintained positive heterosis over most environments but failed to do so at the poorest environment i.e. Bukit Tangga (*Table 4.66*).

Figures 4.9 and *4.10* present the relationship of heterosis in yield of first harvest with the environment index, which is the indicator of the suitability of the environment. In *Figure 4.9,* the environment index used the trunk diameter as the indicator while in *Figure 4.10*, it used the combined yield. The mean yields of environments were commonly used as environment indices in many GxE trials (Finlay and Wilkinson, 1963; Eberhart and Russel, 1966). A low environment mean for trunk diameter or combined yield would classify the environment as poor and vice versa.

The results showed that regardless of the different environment indices used, the patterns of the relationship in heterosis of yield 1 and environment index were more or less the same. It was evident that heterosis was the lowest at the two poorest environments i.e. Bukit Tangga and Kuala Kangsar. (*Figures 4.9* and *4.10*) It was raised to the highest level (about 200%) at the medium environment at Serdang and stabilised around 60% - 80% at the three favourable environments.

Table 4.64. Heterosis estimates over mid and better parents for trunk diameter over six environments

Genotype	Pontian		Kundang		Kluang		Serdang		KKangsar		BTangga	
	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP
Ek x 19	1.2	-2.5	10.0	3.4	5.3	1.8	7.2	0.2	-12.3	-18.3*	11.4	1.0
Ek x So	3.0	-2.7	15.2*	7.1	8.9	5.8	2.8	-4.2	6.7	4.8	-1.6	-13.2
19 x So	3.4	-0.4	3.7	-2.9	-0.8	-6.3	-4.3**	-6.3*	17.5	8.5	10.2	1.6
Ek x Pa	16.7	3.7	23.1*	13.0	22.1*	14.3	20.1**	0.2	21.1*	15.1	9.8	-7.9
Mo x Pa	12.2	-0.1	8.4	-2.8	18.7*	12.9	5.2	-5.3	11.6	3.1	17.3	1.5
19 x Pa	10.7	-3.5	-1.8	-4.2	-1.6	-9.3	29.8	15.1	14.5	5.2	9.2	-7.3
Su x Pa	5.2	-1.5	3.3	-2.1	3.5*	-0.4	8.9	5.3	26.4	21.1	-0.1	-16.4
So x Pa	19.2	7.1	29.1*	18.1	23.1	14.9	17.9	4.8	21.6	17.6	-0.6	-12.9
Mo x So	29.8**	17.3*	30.2*	25.0*	17.8	14.1	20.9	10.6	31.2	24.1	45.3	23.4
Su x So	13.1	3.8	10.6	-0.1	12.9	7.5	21.8*	12.0	26.5	21.4	20.3	0.2
Ek x Su	2.2	-8.1	15.8	9.8	7.2	2.4	21.9	4.6	8.0	4.1	15.9	-2.3
Mo x Su	22.2*	15.7	9.8	-1.4	14.8	8.7	3.5	-4.9	8.3	3.9	5.7	-11.4
19 x Su	-5.7	-13.7	7.6	3.2	7.1	2.4	20.3	9.6	7.3	1.9	21.7	5.4
Mo x 19	2.7	-7.5	13.9	4.6	3.1	-5.6	24.0*	12.6	19.7	10.7	11.2	-4.9
Ek x Mo	13.9	1.0	14.5	7.1	6.7	0.5	32.1	12.9	19.9	14.5	41.0	26.6
Env. mean	10.0	-0.6	12.9	5.2	9.9	4.2	15.5	4.5	15.2	9.2	24.4	-1.1
% heterotic hybrids	93	40	93	60	87	73	93	73	93	93	80	47

* significantly different from MP or BP values at p = 0.05
** significantly different from MP or BP values at p = 0.01

Table 4.65. Heterosis estimates over mid and better parents for earliness over six environments

Genotype	Pontian		Kundang		Kluang		Serdang		KKangsar		BTangga	
	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP	B
Ek x 19	-0.6	2.1	-2.3	-1.8	0.7	5.4	-1.3	2.7*	1.3*	2.0**	-19.6	-14
Ek x So	-4.5	-1.3	-0.6	-0.3	-2.3	-0.9	-0.3	2.5	-0.6	0.2	-6.0	-0
19 x So	-2.8	-0.3	-0.6	-0.2	-0.7	2.9	-0.6	1.6	0.1	0.6	3.2	6
Ek x Pa	-6.9	0.9	-1.3	0.4	-2.8	4.4	-10.2	14.5	-0.2	0.4	-9.0	6
Mo x Pa	-6.5**	0.4	1.2	1.9*	-3.1	-0.3	-5.2	2.9	-0.4	0.1	-5.0	0
19 x Pa	-4.9	0.9	-2.5	-1.1	-3.2	1.6	-17.3**	1.2	0.3	0.3	1.8	10
Su x Pa	-4.8	2.0	-0.6	0.9	-0.5	6.3	-10.8*	-0.6	-0.7	-0.6	-6.2	5
So x Pa	-7.0	1.0	-2.5	-0.9	-5.8	-0.3	-17.0	4.4	-1.1	-0.7	-0.9	9.
Mo x So	-8.3	-5.6*	0.1	2.5	-2.2	4.0*	-15.9*	2.1	-0.9	-0.4	1.5	19.
Su x So	-3.8	-0.8	-0.4	0.3	-0.1	1.3	-16.0	6.4	0.3	0.6	-8.3	3.
Ek x Su	-3.3	-0.5	-0.8	0.1	-3.5	-2.2	-16.9	-5.8	0.8*	1.3*	-9.3	6.
Mo x Su	-4.4	0.1	0.6	3.0	-1.2	6.2	-1.6	7.5	-0.1	0.4	-1.5	13.
19 x Su	2.7	7.0	-0.3	-0.1	0.1	4.3	-15.9	-8.4	0.8	1.4	-6.6	3.
Mo x 19	3.6	4.7	-0.5	1.6	2.3	5.4	-19.2*	-5.0	-0.1	0.5	4.0	17.
Ek x Mo	5.0	8.3	0.5	3.0	0.3	8.3	-18.3*	-0.1	-0.1	0.5	-7.3	12.
Env. mean	-3.1	1.3	-0.7	0.6	-1.5	3.1	-11.1	0.9	-0.1	0.4	-4.6	6.
% heterotic hybrids	80	33	73	40	73	26	100	33	60	20	73	13

* significantly different from MP or BP values at p = 0.05
** significantly different from MP or BP values at p = 0.01

Table 4.66. Heterosis estimates over mid and better parents for yield 1 (first harvest) over six environments

Genotype	Pontian		Kundang		Kluang		Serdang		KKangsar		BTangga	
	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP
Ek x 19	34.9	14.0	59.9**	30.7	89.5	58.5	78.4	-10.8	3.4	-10.1	-100.0	-100.0
Ek x So	40.4*	23.6	81.4	34.6	67.7	37.6	286.4	93.2	49.1	0.9	245.0	72.5
19 x So	57.9	15.6	14.9	-25.6	20.5	-8.3	122.1	74.6	44.2	1.8	-100.0	-100.0
Ek x Pa	112.0	65.5	154.4**	77.9*	84.5	32.5	213.9	56.9	34.0	4.4	100.0	-0.1
Mo x Pa	81.2	31.0	96.3	56.4	55.3*	36.3	83.5	23.9	-13.6	-36.3	-0.6	-26.3
19 x Pa	59.0	21.4	19.0	-4.2	55.4*	26.7	563.0	308.6	51.4*	22.3	-16.7	-58.3
Su x Pa	71.6	44.9	83.2*	38.1	59.7	20.8	241.3	181.0	40.7	20.3	193.9	53.4
So x Pa	145.7	93.5	127.4	33.3	114.6	41.7	172.2	45.4	45.5	-13.4	501.7	200.9
Mo x So	341.8	238.1	280.1*	165.3	203.5**	111.3**	933.2	513.9	237.7	138.3	184.9	42.4
Su x So	122.7**	79.5*	158.0*	85.4	88.0	55.3	328.9	129.2	91.8*	17.5	-28.9	-54.0
Ek x Su	140.6**	115.4**	210.9	178.5	181.1*	132.2	427.0	163.5	20.1	-2.1	-45.2	-72.6
Mo x Su	118.7	90.1	152.4	134.5	184.0*	129.8	225.0*	153.5*	44.8	20.8	151.4	25.7
19 x Su	45.6	26.3	142.0	115.8	142.4*	103.9**	558.0	266.3*	18.4	1.0	-61.3	-77.2
Mo x 19	114.8	79.6	220.8	198.7	135.9	119.6	700.0	423.9	54.0	13.8	76.4	-11.1
Ek x Mo	170.4	139.6	145.6	110.9	111.6	66.3	1242.1	571.1	66.2	26.8	96.3	-1.8
Env. mean	110.5	71.9	129.8	82.0	106.2	64.3	411.7	199.6	52.5	13.7	79.8	-7.1
% heterotic hybrids	100	100	100	87	100	93	100	93	93	73	53	33

* significantly different from MP or BP values at p = 0.05
** significantly different from MP or BP values at p = 0.01

4.4.5. Heterotic effects of parents

The heterotic effects of parents will be examined in some characters which showed significant heterosis i.e. trunk diameter and yield 1, yield 2 and combined yield. The total heterotic effect of each parent was calculated by summation of heterosis (over BP) of all the F_1's which involved the parent in the cross. The mean heterotic effects of the six parents for the four characters are given in *Table 4.67.*

The results showed that all the inbred parents, on the average, contributed positive heterotic effects to their hybrids, with the exception of Line 19 which showed a negative estimate (-0.2%) for trunk diameter. Morib appeared to be the best parent for producing hybrids with high heterosis in stem vigour and yield. On the average, it was found to produce hybrids which were 6.9% larger in trunk diameter than the best parent and the hybrid yield improvement with Morib were very impressive i.e. 123%, 46% and 62% for yield 1, yield 2 and combined yield respectively (*Table 4.67*).

Solo and Eksotika were also good parents for promoting stem vigour and yield heterosis and Subang and Paris appeared to follow next. All of these four produced hybrids with significant heterosis of 2.7% - 6.7% for trunk diameter and 36.9% - 48.5% for combined yield. The parent that was least effective in production of heterotic hybrids was Line 19. Its hybrids, on the average, did not exhibit stronger stem vigour than the better parent and their yields, while heterotic, were not in the same magnitude of increase as hybrids produced by the other parents (*Table 4.67*).

Table 4.67. Heterotic effects (% over BP) of parents for trunk diameter and yield

Parents	Trunk diameter	Yield 1	Yield 2	Yield (combined)
Line 19	-0.2	58.2	4.1	19.7
Eksotika	3.1	69.1	43.0	48.5
Solo	6.7	71.4	42.3	42.7
Paris	3.3	47.3	34.3	37.4
Morib	6.9	123.2	46.3	62.5
Subang	2.7	79.4	25.4	36.9

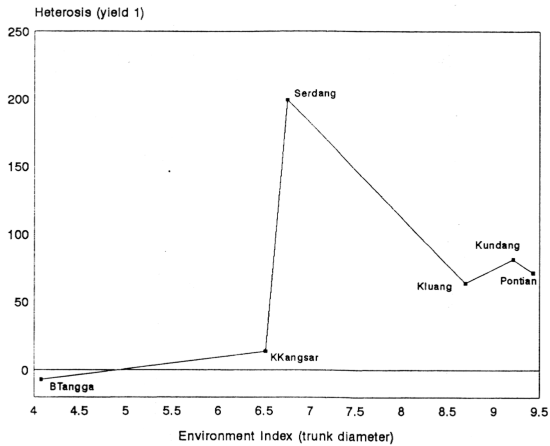

Figure 4.9. Relationship of heterosis (Yield 1) with environment index (trunk diameter)

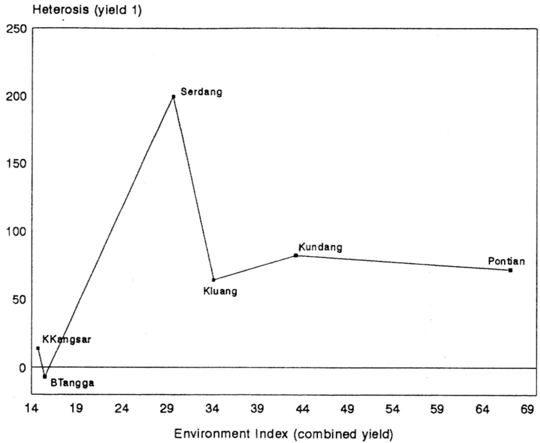

Figure 4.10. Relationship of heterosis (Yield 1) with environment index (combined yield)