# 5. DISCUSSION

## 5.1. $F_1$ SEED PRODUCTION

### 5.1.1. Factors affecting seed production and quality

Results from the two trials on seed production using female or hermaphrodite flowers of six inbred papaya lines indicated that seed production was abundant and may not pose a problem in hybrid development even if high costs in hand emasculation and pollination were involved. However, several factors which can drastically affect seed production and quality and the economic feasibility of hybrid seed production must be noted.

#### 5.1.1.1. *Environment effect*

Adverse environments such as high temperatures and water stress generally bring about sterility skips (formation of barren Type IV+ flowers) (Awada, 1958; Awada, 1961). This leads to a decrease in fruit production and concomitantly, a decline in seed yield. On the other extreme, very cool temperatures and excessive moisture coupled with high nitrogen fertilisers will result in formation of carpelloid fruits which are also unsuitable for seed production.

Seed production at the two environments in the trial differed by as much as 25.8%, although the mean fruit set at the two environments (54%) were similar. This was because of the difference in the seed number/fruit at the two environments. It is presently not clear how environmental factors influenced seed set in papaya fruits.

Quality of papaya seeds may also be influenced by environmental factors. Under stress conditions, seed development may be restricted and smaller sized seeds may be formed. Sage (1973) reported that the performance and degree of heterosis of wheat hybrids was positively correlated to seed size. Difference in heterosis between large and small seeds could be as much as 12%. Chan *et al.* (1991) reported that dry periods also appear to delay fruit ripening on the tree and this may result in higher percentage of pre-germinated seeds and a decline in viability and quality.

It is important in seed production, therefore, to have good agronomic practices, particularly in water management, to ensure high productivity and quality of seeds.

5.1.1.2. *Genotypic effect*

From the results of the two trials, the quantity and quality of $F_1$ seeds clearly depended on the maternal and paternal (pollen) genotypes. Eksotika, Line 19 and Solo which have more or less the same genetic background, were generally more seedy and have the advantage as maternal parents for hybridisation. Wasee *et al.*, (1980) also found differential seed set among four varieties ranging from no seed (parthenocarpic) to 278 seed per fruit. In terms of seed quality, Line 19 was clearly not a very good parent because it appeared to have some problems with pre-germinated seeds. One way to overcome this problem is to pick the fruits at mature green and not to wait for full yellow.

With regards to pollen effects, Line 19, Paris and to a certain extent Morib, appeared to be poor parents because a very high percentage of seeds that developed after fertilisation with these pollen showed pre-germination. The results of the differential influences of maternal and paternal parents in seed production are useful in determining the direction of cross that is most efficient. As an example, assuming that there is no reciprocal difference in performance between Eksotika and Paris hybrids (Ek x Pa), the breeder would most certainly use Eksotika as the female parent and Paris as the pollen donor. Not only would seed yield be doubled, but the amount of good seeds would also be high because of the negligible percentage of pre-germinated seeds in Eksotika. Direction of cross for maximising seed yield was also important in chilli and pineapple breeding. In the hybridisation of *Capsicum anuum* var *fasciculatum* (pungent chilli) and *Capsicum anuum* var *grossum* (bell pepper), the latter was recommended as the seed carrier (maternal parent) because more seeds were developed (Anand and Deshpande, 1985). In pineapple, hybrid seeds were formed easily between the Johor (maternal) and Sarawak (pollen) parents but the reciprocal was almost incompatible (Chan, 1993c).

5.1.1.3. *Age of tree*

Seed production appeared to increase with increasing age of trees. The results indicated that seed yields of fruits harvested from 15 - 18-month old trees were 30 - 40% higher than those from 9 - 12-month old trees. However, there appeared also a decline in seed quality because of high pre-germination incidence in fruits from older trees. This was related to the longer time taken for fruit maturation in older trees.

Although seed yields from older trees were higher, it is unlikely that seed production can extend much longer than two years. This is because the trees would have become too tall and hybridisation work would be very inconvenient and hazardous.

5.1.1.4. *Sex of flowers*

Seed production from female flowers which obviated emasculation, was about four times higher than hermaphrodite flowers. The main reason for this large difference was that fruit set in female trees was almost twice as high as hermaphrodites which appeared to be affected by the emasculation injuries. Further, female fruits also develop twice as much seeds compared with the hermaphrodites. Ram and Majumder (1990) also found that dioecious cultivars of papaya produced more seeds at lower costs than gynodioecious cultivars. However, Wasee *et al.*, (1980) reported that under natural conditions (without hand pollination), hermaphrodite fruits produced more seeds than females. This may have arisen because of poor pollination and there was evidence that some female fruits were parthenocarpic..

5.1.2. Cost benefits in using hermaphrodites for $F_1$ seed production

The question to be asked now is whether the lower seed yield and therefore, higher production costs in using hermaphrodite flowers for production of hybrid seeds can be amply compensated by the increase in production of hermaphrodite fruits and higher returns from this seed source. Two examples i.e. Line 19 and Subang will be presented. The reason for the choice of these two varieties is because of the considerable variation in the gap in seed yield between the two sexes. In Line 19, female outyielded hermaphrodite 2.5 times only while in Subang, female trees were 16.7 times higher in seed yield. This would give the widest range for consideration of the economics and feasibility in seed production from hermaphrodite and female flowers. Another reason for the choice is that there is a big difference in price between hermaphrodite and female fruits for Line 19 hybrids as compared with Subang.

*Table 5.1* shows the cost benefits in production of $F_1$ seeds of Line 19 and Subang. In order to scale down to a common standard for comparison, all estimates were based on per hectare basis. Therefore, it was assumed that costs in seed production were for the production of 3 000 seeds which was sufficient for cultivation of 1 ha of papaya. (One hectare of papaya has 2 000 points and 66% germination was assumed). This was then compared with the returns from sale of fruits from a one hectare orchard which has been planted with seeds from hermaphrodite or female sources.

In the production of seeds, two major costs were involved i.e. labour costs required for hybridization and the management costs of trees that would produce the hybrid seeds. Labour costs in production of hybrid seeds from hermaphrodite flowers were generally much higher compared with females ( *Table 5.1*) The first and rather obvious reason is that additional costs were required in emasculation of hermaphrodite flowers before hybridization. It generally took about 3 minutes to remove all the anthers of one hermaphrodite flower. The second reason was that less seeds per pollination were obtained for hermaphrodites because as seen earlier, hermaphrodites have higher flower abortion due to injury during emasculation, lower number of seeds per fruit as well as lower percentage of sound seeds (*Table 4.11*). It was particularly poor in the case of Subang which showed extremely high flower abortion after emasculation (only 5.6% set) and subsequently only 22.6 seeds/pollination was obtained. Because of such low seed yield in Subang hermaphrodites, its production cost in terms of labour, was about 10 times more than Line 19 hermaphrodites. In contrast, seeds produced from female flowers incurred minimal labour costs.

To compute for the management costs such as fertilizers, pest and disease control, labour for maintenance etc. for production of 3 000 seeds from hermaphrodite or female sources of the two varieties, a standard maintenance cost of RM 10 per tree (worked out from RM 20 000/ha/crop) had been reported (Chan *et al.*, 1991). The cost of production of a single fruit was then computed. The number of fruits on a tree varied between sexes as well as between varieties. It varied from 2.8 fruits for hermaphrodite Subang because of its high abortion and 26.0 fruits for its female to 32.8 fruits and 41.9 fruits for Line 19 hermaphrodite and female respectively. The cost per fruit was computed accordingly and it turned out to be rather low for Line 19 - only 30 sen and 24 sen for hermaphrodite and female fruits respectively, but rather astronomical (RM 3.57) for a Subang hermaphrodite fruit. This of course is not the normal cost in production of a Subang fruit, but has escalated because of severe fruit abortion due to emasculation injury. The number of fruits required to produce 3 000 seeds ranged from 3.2-4.0 for females to 6.0-7.0 for hermaphrodites. The management costs involved ranged from a low of 77 sen for the Line 19 female to RM 24.99 for the unproductive Subang hermaphrodite. Adding the labour costs with the management cost for the two sexes and the two varieties, Subang hermaphrodite required a whopping RM 201.92 for production of 3 000 seeds compared with a mere RM 19.27 for Line 19 hermaphrodites

(*Table 5.1*). Female seeds of both varieties were comparatively very cheap to produce ranging from RM 5.18 - RM 8.19 only. In other words, the production cost for 1 kg of Subang hermaphrodite will be over RM 4 000 (assuming 60 seeds/g).

We will now examine the returns from a one hectare orchard that was planted with seeds from the two sexes for Line 19 and Subang. It was well established (Storey, 1941) that hermaphrodite seeds will segregate 2 hermaphrodite : 1 female while female seeds will give a 1:1 ratio. The yields of Line 19 hybrid and Subang were 50 tons and 44 tons/ha/crop respectively (Chan, 1985) and the prices of fruits followed those quoted by growers in 1993 for Eksotika and Subang. The returns between Line 19 and Subang hybrids differed greatly because of the much higher prices paid for the former fruits. In the market today, Eksotika II, a hybrid of Line 19, is sought after by both growers and consumers because of the good quality and yield. The returns from the conventional varieties like Subang is only about half that of Line 19 hybrids. However, consumers were not as fastidious in the choice of hermaphrodite or female fruits in the conventional varieties but for Eksotika or Eksotika II, female fruits are often discarded or sold at much reduced price. Because of this and the larger proportion of females in female derived hybrid seeds, the returns of Line 19 hybrids from hermaphrodite seeds (RM 24 155) was 12% higher than that from female seeds (RM 21 250). On the other hand, the difference was only 1% between the returns of Subang hybrids grown from hermaphrodite and female seed sources. In order to justify the use of hermaphrodite seeds, the following ratio must be much greater than unity:

$$\frac{\text{Returns from Herma - Returns from Female}}{\text{Cost of Herma - Cost of Female}} \gg 1$$

For the Line 19 hybrids (Eksotika II), this worked out to be:

$$\frac{24155 - 21250}{19.27 - 5.18} = 206.2$$

For Subang hybrids the ratio is:

$$\frac{13786 - 13640}{201.92 - 8.19} = 0.75$$

Table 5.1. Cost benefits of using hermaphrodites compared with females for hybrid seed production of Line 19 and Subang

| Costs | Line 19 | | Subang | |
|---|---|---|---|---|
| | Herma | Female | Herma | Female |
| No. seeds/pollination | 228.9 | 561.9 | 22.6 | 377.1 |
| No. pollinations to produce 3000 seeds (1 ha) | 13.1 | 5.3 | 132.7 | 8.0 |
| Time/pollination (min) | 8.0 | 5.0 | 8.0 | 5.0 |
| Total time (min) to produce 3000 seeds (1 ha) | 104.8 | 26.5 | 1061.6 | 40.0 |
| Labour costs (@ RM10/h) | 17.47 | 4.41 | 176.93 | 6.67 |
| Fruit set (%) | 65.5 | 83.8 | 5.6 | 52.1 |
| Fruit no./tree | 32.8 | 41.9 | 2.8 | 26.0 |
| Prod. cost/tree (RM) | 10.0 | 10.0 | 10.0 | 10.0 |
| Prod. cost/fruit (RM) | 0.30 | 0.24 | 3.57 | 0.38 |
| No. seed/fruit | 497.9 | 937.9 | 429.4 | 747.7 |
| No. fruits required to produce 3000 seeds (1 ha) | 6.0 | 3.2 | 7.0 | 4.0 |
| Cost of fruits to produce 3000 seeds (1 ha) | 1.80 | 0.77 | 24.99 | 1.52 |
| TOTAL COSTS | 19.27 | 5.18 | 201.92 | 8.19 |
| Additional costs of herma seeds (RM) | 14.09 | | 193.73 | |

Table 5.1. (Continued)

| Returns | Line 19 Herma | Line 19 Female | Subang Herma | Subang Female |
|---|---|---|---|---|
| % herma fruits | 66.6 | 50.0 | 66.6 | 50.0 |
| % female fruits | 33.4 | 50.0 | 33.4 | 50.0 |
| Yield herma (tons) | 33.3 | 25.0 | 29.3 | 22.0 |
| Yield female (tons) | 16.7 | 25.0 | 14.7 | 22.0 |
| Price/ton (RM) | 600.0 | 250.0 | 320.0 | 300.0 |
| Returns herma (RM) | 19980.0 | 15000.0 | 9376.0 | 7040.0 |
| Returns female (RM) | 4175.0 | 6250.0 | 4410.0 | 6600.0 |
| GROSS RETURNS | 24155.0 | 21250.0 | 13786.0 | 13640.0 |
| Additional returns from herma seeds (RM) | 2905.00 | | 146.00 | |
| Cost benefits of herma seeds over female seeds | 2890.91 | | -47.73 | |

It is evident that there is strong economic justification to use hermaphrodite as seed parents in the case of Line 19, but not so for Subang. The additional costs in emasculation and lower seed yields appeared to be only minor shortcomings and were well compensated by the much higher returns arising from a higher hermaphrodite population in the orchard. The same will also be true for Sunrise Solo and Eksotika which behaved very similar to Line 19 in seed production characteristics. However, for Subang, Paris and Morib which have low successes in fruit set and seed production using hermaphrodite flowers, hybrid seeds should be produced using female flowers. This obviates emasculation and injuries which evidently caused high fruit abortions. Further, the non-discrimination in price of hermaphrodite and female fruits of the conventional varieties does not provide incentives in getting higher proportions of hermaphrodites in the orchards.

5.1.3. Commercial production of $F_1$ papaya seeds

The results from the trial on seed production will be used to develop a scheme for commercial production of $F_1$ papaya seeds. The hybrid that is used as an example is Morib x Solo (Mo x So) because as will be seen later, this hybrid was by far the highest yielding and the best adapted. Hermaphrodite flowers which produce seeds that give better economic returns, will be used for hybridisation.

5.1.3.1. *Scale and layout*

The scale of operation is one hectare with a regular planting density of 2 000 trees. For the Morib x Solo hybrid, it is obvious that Solo should be the maternal (seed) parent because Solo hermaphrodite trees produced three times more seeds than hermaphrodite Morib (*Table 4.11*). With regard to layout, one paternal (pollen) row (Morib) to every four maternal (seed) rows (Solo) will be sufficient for pollen supply for hybridisation.

5.1.3.2. *Production volume*

Seeds of the inbred parents Morib and Solo will segregate 2:1 hermaphrodite to female in the seed plot. Since females will not be used, they are culled as soon as the sex of trees can be determined. Out of the 1 600 trees of Solo in the seed plot therefore, only 1 066 hermaphrodite trees can serve as seed parents. Similarly, only 266 hermaphrodite trees of Morib will be left to supply pollen after removal of the females.

In the later GE trial, it was shown that fruit production of Solo was about 63 fruits/tree over 18 months. However, with emasculation, a lower fruit set of 74% was obtained for Solo hermaphrodite flowers (*Table 4.11*). The successfully-set fruits from each Solo hermaphrodite tree over 18 months of production is expected to be 46. Each hermaphrodite Solo fruit was found, on the average to bear 238 seeds. The seed yield for one tree would be 238 x 46 = 10 948 seeds. Solo seeds weigh the same as Eksotika i.e. 14.5 g/1 000 dry seeds (Chan, 1994). Therefore, the weight of seeds produced per tree would be 10 948/1 000 x 14.5 = 158g. The production volume for the one hectare plot consisting of 1 066 hermaphrodite Solo trees would work out to be 1 066 x 158/1 000 kg = 168 kg. Based on the differences in production due to the physiological age of the trees (*Table 4..3*), the output over time will be 44 kg (9-12 months), 54 kg (12-15 months) and 70 kg (15-18 months).

5.1.3.3. *Economics of $F_1$ seed production*

The average cost for maintenance of a papaya tree over 18 months is about RM 10 (Chan *et al.*, 1991). Therefore, the total cost for maintenance of 1 332 trees (1 066 Solo and 266 Morib) in the seed plot will be RM 13 320.00 This cost will be inflated to be about RM 15 000 if the costs of maintenance of female trees till flowering and culling them later are included.

The labour cost in hybridisation will be based on crossing 63 hermaphrodite Solo flowers per tree over 18 months. The time estimated to complete hybridisation of each flower is about 8 minutes. The wage of the semi-skilled workers would be RM 10 per hour. The total hybridisation costs for the one hectare seed plot were worked out as follows:

(i) Total pollinations = 63 flowers x 1 066 trees = 67 158
(ii) Total time = 67 158 x 8 min/pollination / 60 = 8 954 h
(iii) Total hybridisation costs = 8 954 x RM10/h = RM89 540

Added to the maintenance costs of trees (RM 15 000) the total costs of production of a one hectare seed plot would be RM 104 540.

The price of hybrid seeds of Eksotika II is RM 3 000/kg. Based on this price, a return of 168 kg x RM 3 000 = RM 504 000 can be realised. This would give a profit of RM 399 460. This seemed to be a lucrative business because a return to investment ratio of RM 4.8 to every Ringgit investment is obtained in 18 months.

The price of hybrid seeds at RM 3 000/kg is not considered high and will be quite acceptable for growers because of the low seeding rates for papaya. Usually only 50 - 100 g/ha are required (Chan, 1994). The seed cost works out to be RM 150 - RM 300/ha and this is only a meagre 0.75% to 1.5% of the total production costs. This is extremely low compared with other high seeding crops such as carrots where the seed cost may be as much as 7% of the production costs (Dorsman, 1976).

5.1.4. Improving efficiency in $F_1$ seed production

The labour cost in hybridisation estimated for the production of one hectare of papaya hybrid seeds over 18 months was about 85% of the total seed production costs. For hybrid seed production in tomato, costs in manual emasculation and hybridisation were estimated to be about 40% (Yordanov, 1983). Research into screening of suitable gametocides which will destroy pollen viability in seed parents will drastically reduce costs of emasculation. Male sterility in papaya, presently not found, would probably not be widely used even if it is discovered. Like the Solanaceous crops which bear a lot of seeds, hand pollination will still be economical and favoured. There is more confidence in the seed purity from hand pollination than from those produced with male steriles because the latter method may produce off-types due to reversions to male fertility.

Labour in transfer of pollen can also be effectively reduced by spraying pollen suspended in a liquid media (Indu Bala, *pers. comm..*, Fruit Research Division, MARDI, Serdang). The pollen can be collected prior to the day of pollination and mixed in a solution of sucrose and Boron which will help in pollen tube germination. There is also the possibility of long-term storage of pollen using cryogenic preservation (Ganeshan, 1986). Pollen remained viable and effected normal fertilisation even after storage for 300 days. In subtropical areas, pollen storage for pollination in winter months during which little or no viable pollen is formed is essential for good fruit set (Cohen *et al.*, 1989). Likewise for seed production, stored pollen may be important during periods in which viable pollen production is low.

The present scheme for production of hybrid seeds of papaya uses inbred line seeds which segregate to a 2:1 ratio of hermaphrodite to female. This is rather wasteful as the females are not used in the seed production. In order to increase the proportion of useful hermaphrodites in the seed production plot, double-point or triple-point planting with subsequent culling of female trees, may be adopted. With this method, the increase in hermaphrodite trees and therefore seed yields over the conventional planting is estimated to be at least 20%. There are also very good prospects of using in vitro propagated inbred parents. The seed plot in this case will be a pure stand of hermaphrodite trees.

## 5.2. PERFORMANCE OF $F_1$ HYBRIDS IN GxE TRIAL

### 5.2.1. Environment: Suitability for papaya

#### 5.2.1.1. *Delineating suitable regions for papaya*

In the last decade, two reports on delineating suitable regions for papaya cultivation in Peninsular Malaysia have been prepared. The first was based on agro-ecological requirements and the second was based on agro-socioeconomic factors.

In the first report by Nieuwolt *et al.* (1982), twenty six agro-ecological regions in Peninsular Malaysia were demarcated based on characteristics of soil type and climate. The regional suitability of 16 perennial lowland crops including papaya were identified by matching the crop requirements with the characteristics of agro-ecology of the region. For papaya, the edaphic requirements for high yields were flat to slightly undulating terrain, soil depth at least 50 cm, well drained sandy loam and pH around 6.0. The major climatic limitations to crop performance were prolonged drought, surplus rainfall (including flash floods) and high winds.

Edaphic factors are very difficult to generalise in the demarcation of regions because there are usually large variations with the area. Therefore, they do not serve much purpose in the discussion of these trials which were held in small areas and as can be seen later, these have unique soil properties quite unlike those characteristic of that region as a whole. If the edaphic factors were disregarded for the time being, the 26 agro-ecological regions can be summarised into three fairly distinct climatic zones based on annual rainfall patterns. Zone 1 represents a region which have a distinct annual dry season ranging from 2 - 3 months, Zone 2 has 1 - 2 months of regular annual drought while Zone 3 has fairly equable rainfall distribution without a distinct period of drought. (Nieuwolt *et al.*, 1982).

Using the climatic requirements mentioned above will immediately preclude certain regions for papaya cultivation. The east coast states like Kelantan, Trengganu and eastern parts of Pahang and Johor will be unsuitable because of the devastating north-east monsoon which causes flooding and wind damage to the crop. The northern states like Perlis, Kedah and northern Perak which experience regular, prolonged drought would also not be suitable unless added inputs like irrigation are considered. The most suitable agro-ecological regions for papaya are those in Zone 3 which have equable rainfall distribution. They are found predominantly in southern Johor, parts of Selangor and central Pahang around Lipis. Under this classification, the environments in the present trials like Pontian, Kluang, Kundang and

Serdang were the best environments, Kuala Kangsar was second, and Bukit Tangga with the prolonged drought, the worst.

In the second report on the delineation of suitable regions for papaya, Chan and Tay (1982) used an additional factor i.e. socio-economics to demarcate the region. They reasoned that more often than not, socio-economics play a more important role in influencing the suitability of an area for development of a crop than the biological factors. Crops have been known to be planted in areas ill-suited for it, but the environmental deficiencies can be economically rectified by agronomic manipulations because of prevailing, favourable socio-economic factors (e.g. profitability, market demands, infrastructures, technological support etc.) in that area. Chan and Tay (1982) concurred with the previous delineation based on agro-ecological factors in that Pontian was regarded as the most suitable for papaya cultivation. Kluang, Kuala Kangsar, Kundang and Serdang were regarded as 'conditional' because papaya was not widely cultivated there and large inputs may be necessary to promote and develop the crop in those areas. Both reports also concurred that Bukit Tangga should not be recommended for papaya cultivation because neither the biological nor the socio-economical factors favoured the crop there.

*5.2.1.2. Suitability of environments in GxE trial*

In this section, more of the edaphic factors of the environments in the trial can be elaborated because they are no longer regional (and variable) but local and specific to the test site.

The trial site at Pontian was placed by both delineation reports to be the best suited for papaya cultivation, but this was without consideration of the fact that the experimental plot was situated on peat soil. This soil was generally regarded as marginal for crop production (Mohd. Tamin *et al.*, 1982). Three other trial sites at Kluang, Kundang and Serdang were in Zone 3 which were considered ideal, but in Kundang, it may not be favourable because it was situated on another marginal soil i.e. tin-tailings. With regard to the remaining two environments, both on mineral soils, Kuala Kangsar was regarded as marginal while Bukit Tangga was decidedly unsuitable for papaya cultivation.

When the classification and recommendations of the delineation of suitable regions were cross-checked with the results of the yield of papaya over these six environments, it can be seen that there was remarkable agreement between the postulated and the actual ground data. Pontian, Kundang and Kluang were the top environments for production of papaya in this trial, in full agreement with Nieuwolt *et al.'s* (1982) agro-ecological classification and to a large extent with Chan and Tay's (1982) agro-socioeconomic delineation. All the variables related to vigour, precocity and yield were outstanding at these three environments. The poor showing both at Kuala Kangsar and Bukit Tangga too were accurately postulated in those two delineation reports.

Some caution, however, must be exercised in the interpretation because while the delineation of suitability was regional, the yield results from the trials were local and may be locality specific. While there may be close agreement (or coincidence) between the two, certainly the specific factors that may account for the unusually high yields in environments normally considered marginal such as Pontian (peat) and Kundang (tin-tailings) deserve further investigation. The argument is that not every site in Pontian district (regional) or around Kundang should be expected to yield like the experimental peat or tin-tailing sites. This is because the high yields may be related to the peat properties *per se* or the soil amelioration that was done at the tin-tailing site. This will be considered in the next section which discusses cultivation of papaya on marginal soils.

The delineation of suitable regions for papaya considered crop performance in terms of yield. For fruit cultivation in general, a second factor i.e. fruit quality is also of paramount importance. This was glaringly missing in the delineation of papaya regions. The results of the present trials showed that while Pontian had the best yields, the TSS % was the lowest and the fruits may be too large in that environment. Therefore, for cultivation of papaya there, the growers must be prepared to harvest slightly poorer quality fruits in terms of lower sugars. The larger fruit size will also affect grading and quality of varieties like Solo, Eksotika and Eksotika II (Ek x 19) because these are traditionally grown for their petite size for export. Excessively large fruits may be ill-fitted for the standard carton packing. On the other hand, one of the worst environments at Bukit Tangga produced fruits with very high TSS %, probably because of the long dry season that favoured sugar accumulation. However, this increase in fruit quality was unlikely to compensate for the extremely low, uneconomic yields caused by the harsh dry season at Bukit Tangga.

It is interesting to note that the incidence of malformed top disease (MTD) was probably unrelated to agro-ecological factors of the six environments. It was rampant at Kundang, Kuala Kangsar and Serdang but rather negligible at Pontian, Kluang and Bukit

Tangga. The most likely reason was that the former three sites have been previously cropped with papaya and there may be a build-up of *Cladosporium* inoculum and the predisposing thrips population which could lead to the heavy infection. On the contrary, those sites with negligible disease incidence were those which did not have a papaya crop history. This relationship of cropping cycle with disease was also noted by Eksotika growers who find that more inputs for MTD control were necessary after the first plant crop. The same *Cladosporium* pathogen which causes fruit freckles of papaya was found to cause more severe infection during wet seasons or in damp environments (Chan and Toh, 1988)

Another disorder in this trial which surprisingly cannot be related to agro-ecological factors was carpellody %. Previous reports have indicated that this disorder may be related to high moisture (Awada, 1961), high nitrogen (Awada and Ikeda 1957; Ghosh and Sen 1975) and cool temperatures (Awada, 1958). The above mentioned influences which promoted high vegetative vigour would also cause high occurrences of carpellody. In this study however, there was no support for this conclusion. At Pontian, Kundang and Kluang, all in Zone 3 with high rainfall (particularly in Pontian with high water table) and high vegetative vigour, were found to be rather negligible in carpellody % in the range of 2.3 - 4.3 % only. However, the occurrence at Bukit Tangga and Serdang where vegetative vigour was markedly poorer, the occurrence was significantly higher (5.3 - 9.0 %).

*5.2.1.3. Marginal soils for papaya*

The soils that were classified as marginal for agriculture totalled about 7 million hectares in Peninsular Malaysia (Mohd. Tamin *et al.* 1982). Of this, 8.5 % or about 600 000 ha was peat and 1.7 % or 120 000 ha was tin tailings. In addition, significant areas of Bris (162 000 ha) and acid sulphate soils (352 000 ha) were also considered marginal. Stony and steepland (79%) formed the majority of non-arable land. There is tremendous competition from the traditional plantation crops for premium agriculture soils, and quite often what remains for minor crops including vegetables and fruits are those of marginal status.

One of the surprises that sprung out from this GxE trial on papaya was the fact that the top two environments for yield belonged to the marginal soils. Pontian, situated on peat, produced the most vigorous and precocious plants and the highest yields, followed closely by Kundang which was on tin tailing soils. The yield at Pontian (67 kg/tree) and Kundang (43 kg/tree) worked out to 134 t/ha and 86 t/ha per crop cycle respectively. The national average for Eksotika papaya was quoted at 50 t/ha/crop cycle (Chan *et al.*, 1991). In an earlier GxE trial, Chan (1985) had reported that the peat site at Jalan Kebun also outyielded three other locations on mineral soils by as much as 78 %. The advantage in yield was masked however, by the lower TSS %, excessively large fruits and susceptibility to lodging due to the poor anchorage of roots in the loose peat.

There are little similarities between peat and tin tailing soils, yet both could influence papayas to perform so creditably. Peats are extremely acidic and formed from decomposed forest debris while tin tailings are slightly acidic and made up predominantly of sand, after the silt and tin ore were washed out during the mining operation. The cation exchange capacity (C.E.C.), which is a measure of the capability of the soil to hold nutrients, is very high for peat (100 mg/100 g) compared with tin tailings which is usually less than 1.0 mg/100 g).

With certain ameliorations to these soils, as was done in this trial, a transition from marginal to premium status for papaya cultivation was possible. In the case of Pontian, initial liming to improve pH to about 4 - 6 helped to unlock many of the nutrients which, in the natural acidic state, would have remained fixed and unavailable to the plants. Micronutrient deficiencies were also widespread on peat and this in part was resolved by liming and also supplementing with micronutrient fertilisers from time to time. In the case of Kundang, addition of Palm Oil Mill Effluent (POME) to improve soil structure and C.E.C. together with an efficient irrigation system, were crucial for the success of papaya in that environment.

One of the most likely reasons for the high yields at these two marginal soils was the friable nature of the soil media. The soils did not become compacted with time and 'cake' up and therefore root development was not hindered. In other environments which have high clay content like Kuala Kangsar, the fine clay was compacted and had a hard cement-like surface one year after planting. This affected root development and resulted in extremely poor yield in the second year of harvest.

As for the other marginal soils viz. acid sulphate and Bris, there were also reports to indicate that papaya was not fastidious about these soils as well, provided proper soil amendments were made. Basri (1991) reported that by liming acid sulphate soils to pH 4 - 5 using 3-15 t/ha of ground magnesium limestone and proper management of water table, papaya may be profitable on acid sulphate. As for Bris, a starkly infertile coastal sandy soil, application of layered composts made of oil palm empty fruit bunches (OPEFB) and palm oil mill effluent (POME) can ameliorate the soil for production of high papaya yields (Wahab Nafis, *pers.*

*comm.*, Basic Research Division, MARDI, Serdang).

In terms of environment suitability for papaya, this GxE trial which included two marginal soils, added credence to the growing opinion that in so far as papaya is concerned, there is hardly any marginal soils, so long as proper amelioration to redress the deficiencies are made.

5.2.2. Genotype: Inbred v. Hybrid

The essence of the GxE trial was to determine whether $F_1$ hybrids would be consistently more superior compared with the inbreds over diverse environments. This was important because production of hybrids requires more efforts and inputs and therefore costs, and the superiority of the hybrids over the inbreds must be to such an extent that it would justify the additional costs involved in their production.

*5.2.2.1. Vegetative characters*

Vegetative vigour is important in fruit cultivation because it is often linked to precocity and high yields. In pear and apple, Visser and DeVries (1970) reported that earliness in bearing was related to the trees achieving a minimum size of the trunk. In papaya, trunk circumference and petiole weights have been used as measures of vegetative growth and response to fertiliser (Awada and Long, 1971) and irrigation treatments (Awada *et al.*, 1979). Both measurements were found to be highly correlated with total yield.

In the present studies, the hybrids were generally much better in vigour than the inbreds or sibs in all the four measurements of vegetative growth. However, it appeared that trunk diameter would be the best indicator of vegetative vigour. This was because there was strong genetic influence in the other three characters i.e. plant height, lamina width and petiole length. In the case of the latter two characters which also did not show significance in GxE interaction, Pa x Pa had a dominant influence as most of its hybrids showed high mean values for lamina width and petiole length. Likewise for plant height, So x So dominated because it was genetically tall and most of its crosses were also very tall. When characters are strongly influenced by genes, environmental influences would be expected to play a relatively minor role. Therefore, when these characters are used as indicators for measuring response to environmental changes (fertiliser treatment for example), such responses will be minimal and highly masked by the genetic influences.

In this trial, tall plants were interpreted to be vigorous and desirable and this was quite acceptable in the discussion of hybrid vigour. However, in many instances, this may not be an accurate assessment of a papaya ideotype. For the single-stemmed papaya, vigour in height may be a nuisance, particularly in fruit harvesting. When trees grow too fast in height, their economic crop cycle may be shortened because the fruits may soon be too high from the ground and out of reach of the harvester. The slowest growing and shortest was Mo x Mo and it was a genetic dwarf with compressed internodes (Chan, 1980). Its hybrids were also quite short. The potential of using Morib genes to reduce tree height and extend the economic cropping period of papaya should be investigated further.

*5.2.2.2. Fruit characters*

For fruit size and TSS %, there was no justification for comparison of performance between inbreds and hybrids because these characters were strongly influenced by additive genes. Certain genotypes or groups of genotypes like So x So, Ek x Ek and 19 x 19 have genes for high TSS % and small fruit size and at the other end, Su x Su, Mo x Mo and Pa x Pa have low TSS % and large fruits. Because of the additive gene action for size and TSS % (Chan, 1987), the hybrids between these two groups tend to be intermediate between the parents and no heterosis may be expected.

The variability in fruit size and TSS % of some well known dessert varieties deserves special mention. The Solo and the Eksotika were bred for their distinctive petite size for the convenience in packing, transport and export. They were also selected for high fruit quality (TSS % and flavour) and were highly regarded as dessert papaya cultivars. It was therefore not surprising to find that their CV for fruit size and TSS % were very low. However, in the case of the new Eksotika II (Ek x 19) released by MARDI (Chan, 1993a), the CVs for both fruit weight and TSS % were high. There were feedbacks from growers of Eksotika II that in favourable environments, fruit size may exceed a kilogram with a concomitant drop in TSS %. This was also the case in Pontian where fruit weight of this genotype was 0.94 kg and the TSS was a low 11.6 %. In most other environments, however, the weights hovered around the expected range of 0.6 - 0.7 kg and TSS was 12.0 - 14.4 %. The recommendation of Eksotika II therefore, requires some caution and adjustments. Excessive inputs of fertiliser and irrigation which would encourage development of large, poor quality fruits should be avoided to reduce the risk of fruit rejection due to overly large size.

All of the wide cross hybrids were found to be lower in TSS % than the genotypes in the Solo and Eksotika groups. Under such circumstances, the question to ask is whether these hybrids with much higher yields but mediocre TSS %, can be accepted as dessert varieties. This may be highly unlikely, because the Eksotika had been around the market for eight years and consumers may already be used to, and prepared to pay for, its high quality. In this case, fruits from such hybrids can only find acceptance in less fastidious markets in the downstream industries like juice and other canned products.

A future step in breeding for dessert papaya would be to use these high-yielding hybrids with fair TSS % (Mo x So and Ek x Pa) and make a further cross with 19 x 19 to enhance the fruit quality and retain most of the heterosis.

The other fruit character, carpellody %, is an important assessment of fruit quality and was compulsory in field testing of new varieties in Hawaii (Nakasone *et al.*, 1972; Nakasone *et al.*, 1974) and in Malaysia (Chan, 1992). This was because carpellody can be very mercurial in expression and crop losses due to its occurrence may be devastating. This was exemplified by Higgins and Wilder, two varieties which have less than 10 % carpellody under Hawaiian conditions (Nakasone *et al.*, 1974). However, when they were evaluated under Malaysian conditions, they recorded devastating 40 % and 75 % respectively (Chan, 1980). Culling of carpellody-proned genotypes should also be done early in the breeding programme. Chan (1984) estimated that some of the advanced lines in the backcross breeding programme have as high as 23 % carpellody which would effectively rule them out as potential commercial varieties. This character was also found to be highly heritable.

The results obtained in this trial for carpellody were very surprising. The genotypes in general, did not show any differences from each other in the combined analysis. However, the significant GxE effects indicated that if the environments were analysed one at a time, there will be significant genotypic effects. When this was done, there were no comprehensible trends to pinpoint either the susceptibility or immunity of genotypes to occurrence of carpellody. For some unexplained reasons, some genotypes were glaringly susceptible in one environment but remained negligible in occurrence in others. One example worth noting was 19 x 19 which was reported to be highly susceptible to carpellody (Chan, 1992). However, in this trial, 19 x 19 had the highest occurrence only at Serdang (39 %) and negligible elsewhere. Previous studies which reported high occurrence of carpellody in 19 x 19 were also carried out at Serdang

(Chan 1992). There are perhaps some hitherto unknown factors at Serdang that might have caused this excessive expression in 19 x 19.

### *5.2.2.3. Incidence of malformed top disease*

Malformed top disease appeared to be controlled by genes with partial dominance. The Solo group of genotypes i.e. So x So, Ek x Ek and 19 x 19 including their sibs were highly susceptible. In contrast, another group made up of Su x Su, Mo x Mo and Pa x Pa were highly resistant. Hybrids between these two groups showed intermediate tolerance (*Table 4.34*). Breeding for malformed top resistance is urgently required for the Eksotika cultivar because the fruit is popular for export with an annual export value of about RM 20 million. Its high susceptibility to malformed top disease had caused great concern and high added costs in its management.

For immediate solutions, it is recommended that Eksotika be planted in areas which have no previous history of papaya cultivation because the present study had indicated that disease incidence will be low to negligible in such areas. In high infestation areas, some of the tolerant hybrids like 19 x Su may be recommended. As a long term measure, tolerant hybrids which have good fruit qualities may be selfed to generate a segregating $F_2$ population. Promising progenies from this population that have the qualities of the Eksotika and resistance to malformed top may be selected and further inbred for several generatins to obtain pure lines. These may be recommended for cultivation or they may be crossed with each other to provide $F_1$ hybrids with better vigour. Such varieties are expected to be similar to Eksotika in most respects but will have resistance to the disease.

### *5.2.2.4. Yield components and yield*

Height of fruiting and earliness (time to flower) are important considerations in papaya cultivation in view of the short economic life-span of the orchard (normally 18 months). When trees come into flowering early and bear fruits low to the ground, the harvesting period may be extended and more yield can be expected in the cropping cycle. Earliness in bearing was reported by Nakasone and Storey (1955) to be influenced by the number of nodes produced to the first flowering node and the height of bearing was influenced by the added effect of internode length. In their studies, they found that earliness and height of bearing were governed by additive genes and hybrids were intermediate between the two parents. This appeared to be also the case in the present studies.

For height of fruiting, So x So was the tallest with Mo x Mo the lowest. Most hybrids appeared to be intermediate between parents, indicating the lack of heterosis for this character. For earliness, Ek x Ek was the latest to flower, and another inbred, Pa x Pa was very early. However, two other Paris hybrids (Su x Pa and Mo x Pa) were even earlier than this parent and some heterotic effects for earliness may be expected.

For fruit number, again no comparison should be made between inbreds and hybrids because this character was strongly influenced by genetic effects. Within the inbreds, the So x So had the highest fruit number and Pa x Pa the lowest. Hybrids with So x So appeared to congregate in the high end of the means for fruit number. This was an indication of the partial dominance of Solo genes for high fruit number.

With regards to yield, there was no question about the superiority of the wide-cross hybrids over the inbreds and sibs. In the combined yield over two harvests, the hybrids were 39.7 % higher yielding than the inbred group. Even the sibs, which was actually a narrow-cross hybrid, were about 7 % better yielding than the inbreds. The bulk in difference of yield appeared to arise from the first harvest where hybrids outyielded the inbreds by 57.8 %. In the second harvest, however, while there was still a significant difference between hybrids and inbreds (31.1 %), the gap was considerably reduced compared with the first harvest.

The reason for the dramatic heterosis in yield appeared to stem from the fact that hybrids were more vigorous and precocious and these factors translated to very high early harvests for hybrids. This seemed to be the contributing factor for the large margin in combined yield between hybrids and inbreds. In tomato, Yordanov (1983) also reported that most of the difference in yield between hybrids and inbreds was accounted for by the early maturation of hybrids which resulted in high, early yields in the first harvest.

Examining the most precocious Mo x Pa which flowered 35 days earlier than the latest maturing Ek x Ek, it can be appreciated that the disadvantage in yield of the latter genotype can be considerable. Chan and Toh (1984) estimated that papaya under local conditions developed an average of three leaves per week and the disadvantage of Ek x Ek can be translated to a lag of 15 leaves (nodes) or potential fruiting sites. On the assumption of 50 % fruit set and taking the mean of 1.25 kg as the fruit weight of Mo x Pa, a difference in yield of about 10 kg/tree would be anticipated. This estimate was very close to the actual difference in yield (11.7 kg/tree) between the two genotypes in the first harvest.

In summary, examination of the genotypic means indicated that only in several characters such as stem diameter, earliness and yield were the hybrids unquestionably superior to the inbreds or sibs. For other characters, they appeared to be strongly influenced by additive gene action with hybrids usually having mean values intermediate between the parents. The dramatic margin in combined yield between hybrids and inbreds/sibs appeared to be linked with the other characters which exhibited heterosis, particularly vegetative vigour (stem diameter) and precocity (earliness).

5.2.3. Genotype x environment

The earlier two sections dealt with the environment and the genotype *per se* and in this section, the interplay of these two effects is discussed. This is a very important area of study, indeed it generally forms the main topic for discussion in the current fields of biometrical genetics.

The occurrence of GxE masks the superiority of genotypes and complicates the selection process because the genotypes do not show the same relative performance or rank order when tested over a range of environments. In other words, the performance of genotypes are environment dependent i.e. if genotype 'A' was said to be the best, the attendant environment in which the performance was produced must also be mentioned. This places great difficulty on a breeder to make appropriate recommendations of varieties. Faced with this daunting task, the breeder may make the recommendations based on:

(i) the most repeatable performances of genotypes over environment (stability *per se*)
(ii) a combination of stability and good mean performance (simultaneous selection of mean and stability
(iii) the general and specific adaptability of the selections

Since the objective of the trial-was to distinguish the performance between inbreds and hybrids, the discussion will focus on these two groups rather than on the performances of individual genotypes.

*5.2.3.1. Stability in performance*

Lin *et al.* (1986) summarised nine methods for estimating stability and two of these i.e. CV and stability variance ($\sigma_i^2$) were used in the present studies. The CV uses the conventional coefficient of variance derived for each genotype as a stability measure and it represents the Type 1 stability described by Lin *et al.* (1986). This means that a genotype is considered stable if its among-environment variance is small. In the second method proposed by Shukla (1972), the variance of a genotype across environment ($\sigma_i^2$), is the stability measure. This is the Type 2 stability of Lin *et al.* (1986), i.e. a genotype is considered stable if its response to environments is parallel to the mean response of all the genotypes in the trial.

*Table 5.2* was derived from *Figures 4.1 - 4.8* (for CV) and from *Tables 4.44 - 4.51* (for $\sigma_i^2$). The table listed the eight characters which showed significant GxE interaction and the percentage of inbred or hybrid which have below average CV or which did not show significance in the stability variance ($\sigma_i^2$). In either case a high percentage would indicate better stability.

The most striking feature in the overall presentation was that inbreds seemed to have better stability than hybrids when CV was used as the measure of stability but the reverse was generally true when stability variance ($\sigma_i^2$) was the estimator (*Table 5.2*). The main reason was that the Type 1 stability that was derived from CV was related to the biological concept of stability while the Type 2, derived from stability variance ($\sigma_i^2$) was related to the agronomic concept of stability (Becker, 1981). Inbreds seemed to have higher biological stability and did not vary much in genotypic values over environments as compared with the hybrids. Another way of putting it is that inbreds will not be expected to respond very much to added inputs (such as fertiliser) to the environment. Kang (1990) called this type of stability 'static'. If a regression of the means to the environment index is made, very small or negligible changes of genotypic mean will be found in response to a unit change of environment index. In the perfect Type 1 stability, the regression obtained is $b = 0$ (Finlay and Wilkinson, 1963), suggesting that there will be absolutely no changes in genotypic values regardless of the changes to the environment.

Type 1 stability, frequent among inbreds in this study is obviously not very useful for the breeders. This is because genotypes with Type 1 stability are usually poor performers and are indifferent to favourable changes in environment which would raise yields in other more responsive genotypes. It may be argued however, that genotypes with Type 1 stability coupled with high mean yield would be perfect, but while such situations are most desirable, they have not been achieved in practice (Lin *et al.*, 1986).

Shukla's (1972) stability variance estimated each genotype's variation over environments. The genotypes were considered not stable if their stability variance ($\sigma_i^2$) were significantly different when tested against the within environmental variance ($\sigma_o^2$) (*Tables 4.44 - 4.51*). The percentages of genotypes having non significant $\sigma_i^2$ (stable) are given in *Table 5.2*. Hybrids in general, have higher percentages (better stability) than inbreds in this case. This type of stability (Type 2) in which the genotypes were responsive to the variation in the environments, falls under the agronomic concept of stability (Becker, 1981) and is also known as 'dynamic' stability (Kang, 1990). In this case, the genotypes respond with a unit of yield (or other characters) to a unit improvement of environment. It has a regression slope of b = 1 and represents average stability as defined by Finlay and Wilkinson (1963). That more hybrids than inbreds were found to have Type 2 stability in this study is testimony that hybrids were better overall performers because of their capability to respond favourably to added inputs in the environments. Therefore hybrid papayas will be more useful and readily accepted by breeders, agronomists and growers. However, it must be cautioned that the interpretation of this type of stability should be confined to the test set of genotypes (Lin *et al.*, 1986). The hybrids that were stable by this definition were only so with respect to the inbreds in the present test set, without assurance that it will appear stable if assessed with another set of genotypes.

For the Type 2 (agronomic stability) the hybrids were clearly more stable for characters related to vigour, precocity and yield. However inbreds were more stable for fruit weight. This was because many of the inbreds like Su x Su, So x So and Ek x Ek were selected based on stringent standards of uniform size fruits for the local and export markets.

In summary, with regard to stability *per se*, the hybrids have a better advantage with the Type 2 stability compared with the inbreds which were more inclined towards Type 1 stability. While inbreds may enjoy the uniformity in characters with the genotypes, they will lose out in overall performance because of their failure to respond to added inputs or favourable changes to the environments.

*5.2.3.2. Simultaneous selection of mean and stability*

There is general consensus of opinion that stability *per se* would not be of value because genotypic mean and stability are often antagonistic in relationship. Negative correlation of yield with stability have been reported for several horticultural crops including cassava (Tan, 1984), papaya (Chan, 1985) and tomato (Poysa *et al.*, 1986). In all these three cases, the authors suggested that high genotypic means should take priority over stability parameters.

Table 5.2. Percentage of stable inbreds and hybrids derived from CV and stability variance ($\sigma_i^2$) methods

| | CV (Type 1 stability) | | $\sigma_i^2$ (Type 2 stability) | |
|---|---|---|---|---|
| | Inbred | Hybrid | Inbred | Hybrid |
| Trunk diam. | 66 | 50 | 22 | 75 |
| Plant height | 66 | 58 | 44 | 75 |
| Fruit weight | 78 | 50 | 78 | 58 |
| TSS % | 78 | 58 | 33 | 58 |
| Earliness | 55 | 50 | 22 | 83 |
| Height fruit | 44 | 58 | 33 | 33 |
| Fruit no. | 66 | 50 | 100 | 92 |
| Yield 1 | 55 | 58 | 44 | 58 |

There are, however methods which could take both yield and stability into consideration during selection. Three methods were used in this trial to simultaneously select for both high means and stability. The first was Francis and Kannenberg's (1978) distribution of means and CV, Hühn's (1979) non parametric ranking and Kang's (1988) and Schuster and Zschoeche's (1981) rank sum and rank product indices.

The results showed that there was general agreement between these three methods in selection of genotypes on basis of mean and stability. There were, however some areas where there were gross discrepancies which need to be discussed. In selection for plant height, there was total disagreement between Hühn's non parametric ranking which rated Mo x Mo as the best but the rank sum/product rated it the worst. This arose because Mo x Mo was a genetic dwarf and although environment effects have some influence on its height expression, they were insufficient to overcome its strong genetic expression and cause any change in rank over the six environments. Since Mo x Mo was shortest at all environments, its ranking was perfectly consistent with $S_i^3$ and $S_i^6$ having zero values and this gave the genotype the best rank under Hühn's method. However, in the rank sum and rank product method, the mean height of Mo x Mo was used as part of the sum or product in the estimate. Since the height was the shortest, the rank sum and product were also not favourable and this placed Mo x Mo as the worst selection in this character.

The caution to exercise in Hühn's non parametric method is that this method may place too strong an emphasis on stability with disregard for mean values in situations where genotypes did not vary their rankings over environments. The importance of the rank means ($\bar{r}_{i.}$) in the denominator will only be felt when the numerator ($r_{ij} - \bar{r}_{i.}$) has some value other than zero.

As reported by Leon (1986) and Kang and Pham (1991), the $S_i^3$ was more inclined to select for stability while the $S_i^6$ favoured selection of high mean values. This was also generally the case in the present studies. In yield of first harvest for example (*Table 4.43*), Mo x So was rated the best by $S_i^6$ index favoured its very high yield while with the $S_i^3$, it lost out to 19 x 19 because this genotype varied less in ranking over environments.

Between the two ranking methods of Hühn (1979) and Kang (1988) therefore, the rank sum and rank product appeared to give less biasness and a better basis for selection of mean and stability. A strong point was that Shukla's stability variance which measured Type 2 (dynamic) stability was used to derive the rank sum and product indices.

With regard to CV and mean distribution proposed by Francis and Kannenberg (1978), the computation was easy and the scatter diagram presented a good visual on the performance of a large number of genotypes with regards these two parameters. However, the use of CV which measures the within genotype variation as the stability indicator has its limitations. Being an estimate for Type 1 or static stability, it does not tell how the genotypes' behaviour is going to be under different environments. However, Type 1 stability has a broad inferential base and not dependent on genotypes in the test and may have usefulness if the geographical range for the experiment was restricted (Lin *et al.* 1986).

Having examined the strengths and weaknesses of these methods, we will now look at genotypes that were selected using these three methods. As before, the main objective was to distinguish the hybrids from the inbreds, therefore, discussion on specific selection of genotypes will only be occasionally done.

*Tables 4.52 - 4.59* show the total scores for the various characters grossed from the combination of the three methods for all the genotypes. The selection of genotypes based on simultaneous consideration of mean and stability in general did not differ very much from selection based on genotypic mean alone (discussed under section 5.2.2.). Hybrids formed the top rung in rankings for characters related to vegetative vigour (trunk diameter) precocity (earliness) and yield of first harvest. The separation of hybrids from the inbreds was less clear for characters which were more influenced by additive genetic effects i.e. plant height, fruit weight, TSS %, height of fruit and fruit number.

The superiority of hybrids was underlined when the top five selections for vigour (trunk diameter, petiole length, lamina width), precocity (earliness) and yield (yield 1, yield 2 and combined) were from hybrids (*Table 4.60*). Conversely, the worst five selections for all these characters were from inbreds.

*5.2.3.3. General and specific adaptability*

When genotypes do not show the same relative performance over different environments i.e. when there is significant GxE interaction, a third option exists for breeders in the recommendation of selections. One can either recommend those which are generally good performers over all environments (general adaptability) or those which are excellent at certain environments and recommend them for these specific areas only (specific adaptability).

There are, of course, pros and cons to either recommendation. For generally adapted varieties, they are 'safe', prudent and less likely to face failure. However, they would not be able to exploit favourable environments because they are incapable of very outstanding performance, nor could they thrive on adverse environments and give reasonable yields. Finlay and Wilkinson (1963) described generally adapted varieties as those having average stability with a regression slope $b = 1$. This is analogous to the Type 2 stability concept. Generally adapted varieties are often useful for environments in which the characteristics and influences are not fully known. In such circumstances, it would be wise to be conservative and prudent.

On the other hand, the choice of specifically adapted varieties can really give handsome returns if they are grown in the right environments. Finlay and Wilkinson (1963), indicated that these specifically adapted genotypes have below average stability with regression slope $b > 1.0$ if they are adapted to favourable environments. They have above average stability ($b < 1.0$) if they are adapted specifically to unfavourable environments.

There is of course a certain amount of risk involved in recommendation of specific adapted varieties. Recommending varieties with $b < 1.0$ specifically adapted for poor environments would be wasteful if the environment had been able to support better performance and conversely, subjecting specifically adapted varieties ($b > 1.0$) to adverse environments may bring about complete crop loss. The risk in using specifically adapted varieties can be considerably reduced by understanding the environmental influences on crop yield. Eisemann *et al.* (1990) proposed that in assessment of biological performance, a concomitant definition of the nature and extent of environmental challenges or constraints that influence differential genotypic adaptation should be made. They recommended varietal trials under 'structured stress' environments and the use of genotypic probes with established behavioural patterns to develop this understanding. When the crop-environment relationship is better understood, recommendation of specifically adapted varieties will be risk-free and the occurrence of GxE can be exploited rather than avoided.

In the present trial, the recommendation of general and specific adapted genotypes from the hybrid and inbred groups for yield in the first harvest will be considered. The mean scores for yield (y-axis) at the six environments were obtained from the ranking of the genotypes for harvest 1 (*Table 4.43*). The environment index (x-axis) consisted of the six environments arranged in ascending order of performance judged from two characters, trunk diameter and combined yield.

Three of the top yielders for hybrids (Mo x So, Mo x 19, Su x Pa) and for inbreds (Pa x Pa, Mo x Mo, Su x Su) were used for illustration (*Figure 5.1*). It was evident that at the poorest environment i.e. Bukit Tangga, hybrids were not permitted to express their superiority because of the harsh environment. Some inbreds were in fact better yielding than the hybrids at Bukit Tangga. However, the difference between inbreds and hybrids were more apparent under better environments.

For the inbreds, it was clear that Pa x Pa had general adaptability, having fairly good yield over most environments except at Bukit Tangga. Mo x Mo and Su x Su appeared to be specifically adapted for poorer environments particularly at Bukit Tangga where they outyielded Pa x Pa and even one or two hybrids as well (*Figure 5.1*).

For the hybrids, three different responses can be found. Mo x So (*Plate 5.1*), can be regarded as the generally adapted genotype because it had above average yields at all environments. It was the best yielder at Kuala Kangsar and Kundang and its ranking did not dip below 17 at any environments. Su x Pa (*Plate 5.2*), was specifically adapted for poor environments as it was better ranked than the generally adapted Mo x So at two of the poorer environments at Bukit Tangga and Serdang. Under good environments, however Su x Pa's performance was rather dismal. In contrast, Mo x 19 (*Plate 5.3*), was specifically adapted to good environments, but was extremely disappointing at poor environments, losing out even to some inbreds (*Figure 5.1*).

In recommending hybrid varieties for yield in harvest 1, it was rather 'safe' to recommend Mo x So for planting at all diverse environments because of its general adaptibility. With the present understanding of environmental influences on papaya production, it is not yet possible to establish and characterise good and poor environments. Hence it is better to make recommendations based on general rather than specific adaptibility for the time being. Alternatively, it may be wise to recommend a mixture of Su x Pa and Mo x 19 to exploit the high yields of Mo x 19 under favourable environments and to reduce crop loss with Su x Pa in the case when environments turned adverse.

There is little justification to use inbreds, because the yield disadvantage compared with hybrids was too great. In the case when there are still reasons for using inbreds, Pa x Pa appeared to be a generally adapted variety that can be confidently recommended for a wide range of environments.

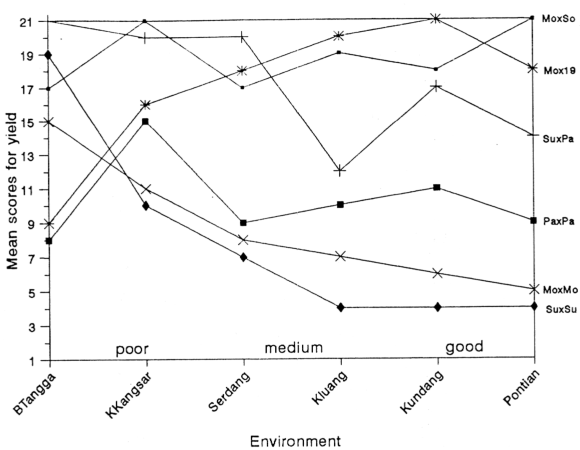


Figure 5.1. Adaptability of hybrids and inbreds


Plate 5.1 Mo x So hybrid with general adaptability at mediocre environments (Kluang) compared with the two parents (Mo - top left and So - top right)

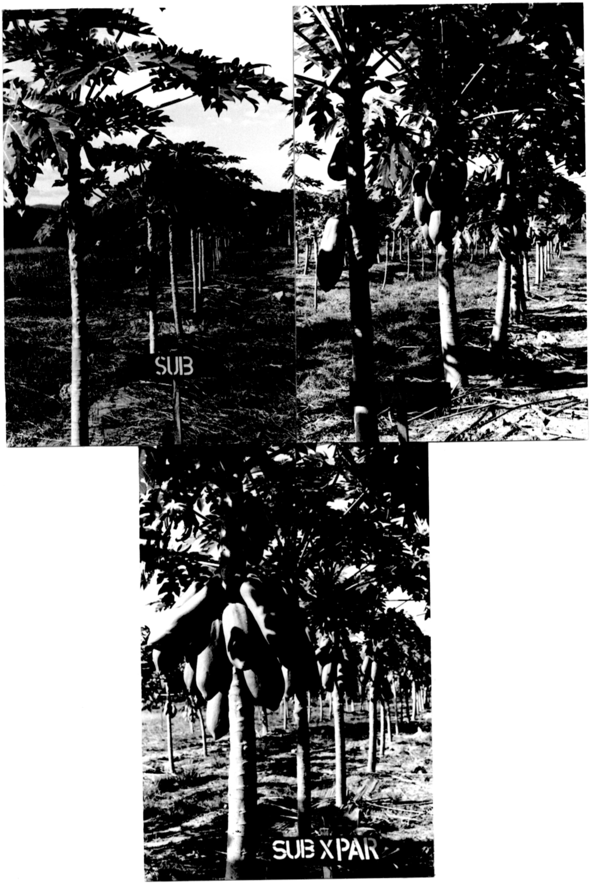


Plate 5.2 Su x Pa hybrid adapted to poor environments (Bukit Tangga) compared with the parents (Su - top left and Pa - top right)

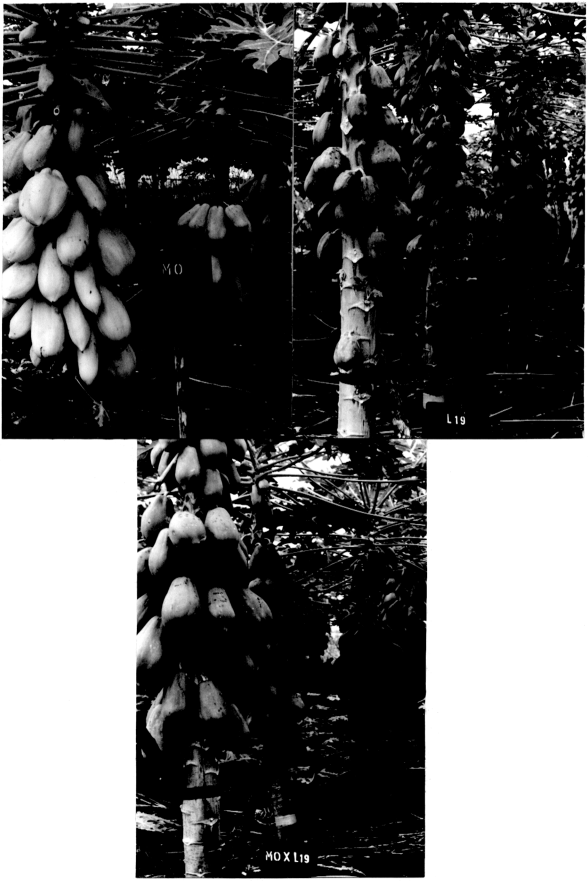


Plate 5.3 Mo x 19 hybrid adapted to good environments (Pontian) compared with the parents (Mo - top left and 19 - top right)

## 5.3. HETEROSIS

### 5.3.1. Exploitation of heterosis in papaya

There is recent encouraging evidence to show that there is potential in exploitation of heterosis in papaya. Subramanyam and Iyer (1984) improved papaya yields by more than 100% in some hybrid combinations while Giacometti (1987) reported that Tainung no. 2, a hybrid from Taiwan yielded 80 t/ha which was almost twice as much as the inbred Eksotika. More recently, Chan (1992) reported a yield increase of 2% - 22% in hybrids developed from closely related sib crosses.

In this study, it was important to indicate in what characters was heterosis most pronounced, the heterotic differences between close and divergent crosses and the variation in heterotic response over environments. This information is crucial to the formulation and implementation of strategies in exploitation of heterosis in papaya. In the following discussion, heterosis estimates over the better parent ($H_{bp)}$ will be used because this is more meaningful in terms of genetic gain and economic value.

#### 5.3.1.1. *Differential heterosis in characters*

The results presented in *Tables 4.61* and *4.62* indicated that the most pronounced heterosis was found in characters related to vegetative vigour and yield. Of the four indicators of vegetative vigour i.e. trunk diameter, plant height, petiole length and lamina width, heterosis in trunk diameter was the most evident. This was also supported by the earlier work of Subramanyam and Iyer (1984) in which substantial heterosis was obtained for stem girth (4.6%), plant height (2.6%) and leaf area (2.2%). Trunk diameter or stem girth appears to be the best yardstick for measurement of papaya vigour because it appeared to be a true manifestation of response to environmental changes. Other related characters like plant height, petiole length and lamina width were, to some extent, governed by genes and these may somewhat mask environmental influences on these characters.

Heterosis in yield was very clear cut in this study (*Table 4.63*). The more pronounced heterosis in the first harvest (74.8%) compared with the second harvest (32.6%), was expected because the reason in high yielding capacity of hybrids lies usually in the fact that they are earlier bearers than the inbred parents. This was also the case in hybrid tomatoes where the heterosis in the first harvest was more marked than later harvests because of the earliness in fruiting of hybrids (Yordanov, 1983). Consistent yield heterosis among papaya hybrids was also obtained by Subramanyam and Iyer (1984). Nine of their ten hybrids showed significant heterosis ranging from 9.6% - 111.4% with a mean of 60.0%.

With regards to earliness (*Table 4.62*), a positive, although very low mean heterosis of 2.6% was obtained which meant that, by and large, hybrids were nearly as early as the earlier parent. About 27% of the hybrids in fact showed negative heterosis (i.e. earlier than the earlier parent). Similar findings were also obtained by Subramanyam and Iyer (1984) in which 30% of the hybrids were found to mature earlier than the better parent.

For the other characters such as fruit weight, height of fruit and total soluble solids %, there appeared to be no heterotic responses. In the study on the inheritance of fruiting height in papaya, Nakasone and Storey (1955) reported that the mean of $F_1$ deviated significantly from the mid-parent value, but there was no evidence of heterosis or complete dominance. According to them, height of fruiting was governed by the number of nodes to first flower and internode length, with the former playing a greater role because internode length was more susceptible to environmental changes. For fruit weight and TSS%, the $F_1$'s derived from the initial cross between Subang and Sunrise Solo varieties and in later crosses of the backcross programme, were found to have intermediate mean values between parents for these two characters (Chan, 1987). This suggests that fruit weight and TSS% were governed by additive genes. In the study by Valicek and Obeidat (1987) on tomato, no heterosis was also reported for TSS% in the hybrids.

Contrary to the present findings, Subramanyam and Iyer (1984) reported fairly high, consistent heterosis for fruit weight (7.9%) and together with heterosis in fruit number (16.3%), concluded that high heterosis in these two yield components was responsible for the striking heterosis in yield. This means that yield heterosis was due to accumulation of favourable dominant genes governing fruit weight and fruit number. In the present studies, however, heterosis in fruit number was weak (3.6%) and there was no positive contribution from the other component i.e. fruit weight, which showed a negative estimate of -5.2% (*Table 4.63*), yet heterosis in yield was just as striking. The mechanism for expression of heterosis in yield in this case was more inclined towards the non-allelic gene interaction theory in which the two parents differed reciprocally for the interacting yield components i.e. fruit weight and fruit number. Although the $F_1$ levels were moderate, they appeared to compensate one another in such a way that their products were greater than the parents (Williams, 1959).

5.3.1.2. *Differential heterosis between sibs and wide crosses*

Three of the hybrids i.e. Ek x 19, Ek x So and 19 x So were considered sib crosses because of their closely related genetic background. Heterosis in sib crosses was evident only for yield, but the extent of heterosis was clearly diminished compared with the wide crosses. This is to be expected because widely divergent, phenotypically different inbred lines give maximum heterosis (Pearson, 1983). Further, Williams (1959) reported that high heterosis will result only if two parents differed reciprocally for the interacting yield components (fruit weight and fruit number). Eksotika, Line 19 and Sunrise Solo all bear small fruits but a large number of them, and thus do not satisfy the conditions for maximum heterosis. On the contrary, any of these three genotypes combined extremely well with the phenotypically different, large-fruited parents such as Morib, Paris or Subang to produce high heterosis for yield.

Although yield heterosis in the first harvest was meagre in sib crosses (13.6%) compared with the hybrids (90.0%), the decline in TSS% was not very drastic compared with the wide cross hybrids. Heterosis in TSS% in sibs, on the average was about -3.1% compared with -10.5% for wide cross hybrids. Sib crosses may be the compromise for improvement of yield of $F_1$ hybrids of papaya for table fruit. While the gain in yield may be small, the TSS% did not diminish to a considerable extent compared with the high quality parent. This was the case in the development of Eksotika II (Ek x 19)which was a sib. The yield increase was 2% - 22% but it retained most of the fruit qualities of Eksotika and the cosmetic appeal of Line 19 (Chan, 1992).

5.3.1.3. *Differential heterosis over environments*

Three important characters which expressed heterosis i.e. earliness, trunk diameter and yield (harvest 1) and which also showed significant GxE interaction, were examined over each of the six environments to establish the variation of heterosis over environments.

The results of the heterotic response for trunk diameter, earliness and yield 1 over six environments are shown in Tables *4.64 - 4.66*. For earliness, the favourable factors at Pontian and Kluang appeared to encourage many hybrids to flower earlier than their inbred parents. At the other environments, the general trend was that hybrids were not significantly earlier in flowering than their earlier parent, although some specific crosses at certain environments indicated considerable heterosis. Subramanyam and Iyer (1984) have also indicated that heterosis for earliness in papaya was not very evident. However, the present studies indicate that heterosis for earliness can be very significant under specific environments favourable for its expression.

For trunk diameter (vegetative vigour) and yield 1, the general conclusion was that maximum heterosis was not obtained at high yielding environments i.e. Pontian, Kundang and Kluang. The patterns of yield heterosis over environments in *Figures 4.9* and *4.10* showed that the level of heterosis stabilised around 60% - 80% at the three favourable environments. It was most heterotic in the medium environment at Serdang (about 200%) and diminished rapidly at the poor environments. At the favourable environments, the lower heterotic responses can be explained by the diminishing returns of hybrids with increasing favourable factors added to the environment. It appeared that environmental influences for example at Pontian, may be so conducive for expression of vigour and yield that even inbreds were responsive enough to narrow the gap with hybrids at this environment.

Expression of heterosis appeared to be maximum under poor to mediocre environments. Serdang, a mediocre environment, showed the highest yield 1 heterosis (199.6%) while Kuala Kangsar, a poor environment showed the highest heterosis (9.2%) for trunk diameter. However, at the poorest environment i.e. Bukit Tangga, the heterotic response was the lowest for trunk diameter (-1.1%) and yield (-7.1%). This appears to contradict the findings of Yordanov (1983), Narula (1984) and Conti *et al.* (1990) who reported that hybrids were better adapted to least favourable conditions and have the capacity to set fruits or seeds better than inbreds under adverse conditions. It may be possible, however, that conditions of drought and high temperature at Bukit Tangga may be so severe that the critical point in tolerance of even the most adaptive had been passed. All genotypes subsequently were similarly and adversely affected in growth and yield at this environment.

The heterosis estimates over the six environments for three high yielding hybrids i.e. Mo x So, Mo x 19 and Su x Pa supported the earlier findings on their adaptability characteristics. Su x Pa described as specifically adapted for low yielding environments showed the high heterosis at Bukit Tangga (54.3%) while Mo x 19, specifically adapted to high yielding environments, had very high heterosis ranging from 79.6% - 198.7% at the three most favourable environments but showed a dismal -11.1% at Bukit Tangga. Mo x So had high consistent heterosis over all environments, justifying its description as a generally adapted variety.

5.3.1.4. *Strategies for exploitation of heterosis*

Variations in the expression of heterosis related to different characters, parents and environments were found. As a result of such variations, certain strategies must be adopted regarding exploitation of heterosis in papaya.

Heterosis breeding for papaya may only be applicable to certain characters which expressed sufficient heterosis to justify usage of this methodology. In this study, there is certainly agreement that if yield was the prime consideration for papaya improvement, heterosis breeding should be strongly recommended. There will also be other attendant benefits such as better vigour and in many cases, early maturation and harvests. However, it must be cautioned that for certain characters such as TSS% and to a certain extent, fruit weight and fruit number, heterosis will not be expected to result in much genetic gains. As discussed later (section 5.4), this may be the greatest limitation to the use of $F_1$ hybrids for papaya.

In so far as the choice of the six inbred parents for hybridisation is concerned, there appeared to be a check-and-balance situation between using very divergent lines for maximum yield heterosis but poor fruit quality or using closely related lines with high fruit quality which would result in not so dramatic yield increases but with retention of good fruit qualities. Quite obviously, divergent lines for maximum yield heterosis should be recommended for breeding of varieties that are targeted for the less quality-fastidious processing industry. Closely related sibs i.e. Eksotika, Line 19 and Sunrise Solo which have high fruit quality, should be used for breeding of dessert varieties. Sib crosses between them usually result in small yield gains in the $F_1$ but the decline in TSS% was minimal.

In the long term breeding programme, it may be possible to develop inbred lines with divergent genetic background but with genes for high fruit quality, so that maximum yield heterosis may be exploited with little loss of fruit quality in the hybrids.

With regards to the environments in which $F_1$ hybrids would be suited, it can be concluded that in so far as yield is concerned, hybrids can be recommended for all environments because of their generally better performance compared with inbreds. However, it must be realised that the extent of heterosis appeared to diminish as the environments become very favourable as well as when environments become very adverse. Extremely favourable environments are conducive to the full expression of the capabilities of inbreds, thus narrowing the gap in performance compared with hybrids. In extremely adverse environments, neither hybrids nor inbreds were given any opportunity to perform well and heterosis was negligible. Maximum heterosis in vigour and yield appeared to be expressed in slightly marginal to mediocre environments.

Hybrids also showed significant GxE interactions for yield in the first harvest and this can be exploited for fine-tuning recommendations of hybrids for general or specific environments. Mo x So had high consistent heterosis over all environments and may be recommended as a generally adapted variety. Su x Pa and Mo x 19 were specifically adapted for low and high yielding environments respectively. Separate recommendations of Su x Pa for adverse environments and Mo x 19 for favourable environments may be made. Another strategy is to bulk equal amounts of seeds of these two hybrids and recommend it as a generally adapted composite variety.

5.3.2. Towards ceiling yield

Several of the inbred parents used in this study, for example, Eksotika, Sunrise Solo and Subang, were established cultivars bred, amongst other characters, for high yield. Yet, compared with the hybrids, they lost out in yield on almost all occasions. In many instances, the deficits were more than three-digit percentages. How much more can hybrids, or for that matter, any papaya tree yield, is the topic of discussion here.

The yields of papaya reported in various parts of the world varied tremendously. This can be expected because of differences in climates and varieties. The Eksotika papaya in Malaysia yields a national average of 50 t/ha over an 18-month crop (Chan *et al.*, 1991). This converts to a yield of 66 t/ha/harvested year, discounting the 9-month barren gestation period. In Brazil, the hybrid Tainung no. 2 was reported to yield 80 t/ha/year (Giacometti, 1987). Still higher yields were reported by Nakasone *et al.* (1972) for Waimanalo variety in Hawaii (100 t/ha/year). Later, Nakasone *et al.* (1974) reported a range of 79 - 126 t/ha/year when the same variety was tested over a range of environments. The question to ask is 'what is the limit or ceiling of papaya yield and can this be approached with the present hybrids which exhibited extremely high heterosis over what appeared to be already high yielding, selected inbreds?

The capacity of the papaya to increase in yield depend on the following factors:

(i) the rate of appearance of new leaves or nodes which are the fruiting sites

(ii) the physical space around the trunk for accommodating the fruits without over-packing which leads to fruit malformation

(iii) the gestation period or earliness in bearing

In computation of the ceiling yield for papaya, the best yielding or the most heterotic hybrid i.e. Mo x So in the best environment (Pontian), will be used for illustration. Mo x So was the earliest to flower at Pontian (126 days) and was the best yielder (98.9 kg/tree) with a total of 95.5 fruits/tree at that environment. Since Mo x So flowered after 126 days and its fruit maturation was 140 days, a total of 266 days or about 9 months were required before the harvest of the first fruit from seed sowing. Therefore, over a period of 18 months of the crop cycle as in this study, there would be 9 months of harvest.

Chan and Toh (1984) estimated that under Malaysian conditions, papayas would consistently develop about three leaves per week over a one year period. If this was the case, Mo x So would have theoretically developed, in the 9 months (or 36 weeks) of harvest, 36 weeks x 3 leaves/week = 108 potential fruiting sites. Assuming that only a single fruit developed in each node, the fruit set of Mo x So in Pontian is estimated to be:

95.5 fruits / 108 potential fruiting nodes = 88.4 %

Therefore, had conditions been perfect, a 100% fruit set for Mo x So would have arrived at a ceiling yield of:

98.9 kg/tree x (100/88.4) = 112 kg/tree or 224 t / ha (for 2 000 trees/ha density)

This figure was only for a 9-month harvest. Since most figures reported in literature were based on a full year of harvesting, the conversion of the ceiling yield over a year of harvest would be:

224 x (12/9) = 298 t/ha/harvested year.

In comparison to the ideal situation therefore, Eksotika was only 22% of the ceiling yield while other high yields reported elsewhere in the world would still be a distant 27% - 32% of the ceiling estimate. The highest yielding hybrid, Mo x So at the best environment (Pontian) was just 12% away from the theoretical maximum.

This ceiling yield for papaya may, perhaps be specific to local environments or neighbouring tropical countries where environmental factors favour rapid growth and development. For papaya-growing countries in the sub-tropics like Australia and Taiwan, the gestation period is expected to be longer and coupled with the slower rate of leaf development, the ceiling yields from these countries will be expected to be considerably lower than those in the tropics. Allan *et al.* (1987) reported that papaya planted under cool temperatures of $10^0$ C to $20^0$ C developed only 4 - 5 leaves in a month. Under such conditions, therefore, the ceiling yield would probably be about 30% of that in the tropics.

### 5.4. PROSPECTS AND LIMITATIONS OF $F_1$ PAPAYA HYBRIDS

$F_1$ hybrids of papaya have been shown to be more outstanding than inbreds in vigour, precocity and yield. However, the added costs in production of $F_1$ hybrids in terms of emasculation during seed production, higher inputs in fertilisers and harvesting efforts etc. must be weighed against this increase in yield. Further, $F_1$ hybrids in this trial at least, did not have the fruit quality compared with the contemporary dessert varieties like Solo and Eksotika. Would they be accepted at a lower price and if so, would there still be economic justifications in using $F_1$ hybrids? To answer these questions, the economics of production using $F_1$ hybrids, first for production of table fruits and in the second case, for production of processing fruits will be examined.

#### 5.4.1. Economics of $F_1$ hybrids for production of table fruit

The $F_1$ hybrids were generally poor to mediocre in fruit quality, especially in TSS % compared with the Solo, Eksotika and Line 19 and their sibs. The most likely candidate from the hybrids which may be used for table fruit appeared to be Mo x So because it had the highest yield and its TSS % was fairly high (11.2%). However, it must be anticipated that fruits from this genotype will be sold at lower prices because of the mediocre quality, but this may be compensated by its high yield.

*Table 5.3* shows the economics of production between two well-known dessert cultivars i.e. Eksotika and Eksotika II (Ek x 19) compared with the high-yielding hybrid Mo x So. The yields of the three genotypes, converted to t/ha, were 41.0, 59.8 and 96.4 respectively. The seed costs computed earlier (*Table 4.4.*) was the lowest for the Eksotika (RM 1 000/kg) and three times as much for Eksotika II (RM 3 000/kg) and Mo x So (RM 3 957/kg). The higher costs for the latter hybrid was because of lower seed yield when Solo was used as the maternal parent. About 75 g of seeds/ha were required, and the seed cost/ha worked out to be RM 75, RM 225 and RM 297 for Eksotika, Eksotika II and Mo x So respectively.

The production cost (30 sen/kg) and the price of Eksotika (60 sen/kg) followed that quoted by a commercial papaya orchard (Lim, 1987). Mo x So had the highest production cost (RM 28 920) because of its much higher yields compared with the other two. The price of Eksotika II followed Eksotika but for Mo x So, it was quoted arbitrarily lower at 40 sen/kg because of its poorer quality.

From the costs and returns analysis, it was found that Mo x So had the poorest net returns (RM 9 343/ha) compared with RM 17 715 for Eksotika II and RM 12 225 for Eksotika. The high yields of Mo x So apparently cannot compensate for the 20 sen/kg price disadvantage due to the poorer fruit quality.

To compute for the break even price of Mo x So compared with Eksotika, the increase to break even price of Mo x So should be:

$$\frac{\text{Net returns (Ek) - Net returns (MoxSo)}}{\text{Yield (Mo x So)}} = (12\,225 - 9\,343) / 96\,400 = 2.99 \text{ sen/kg}$$

The increase to break even price of Mo x So compared with Eksotika II should be:

$$\frac{\text{Net returns (Ek II) - Net returns (MoxSo)}}{\text{Yield (Mo x So)}} = (17\,715 - 9\,343) / 96\,400 = 8.68 \text{ sen/kg}$$

Fruits of Mo x So therefore, should be priced at 40 + 2.99 sen or 42.99 sen/kg to break even with Eksotika and at 48.68 sen/kg to break even with Eksotika II. Since Eksotika and Eksotika II were priced at 60 sen/kg, it is highly unlikely that consumers will switch to a poorer quality hybrid fruit with such a meagre price differential of 12 - 17 sen/kg. The prospects of these high-yielding papaya hybrids as table fruit cultivars, at least for the time being, do not appear very bright.

5.4.2. Economics of $F_1$ hybrids for production of processing fruit

The quality standards in the downstream market for papaya are not as fastidious as those for dessert fruit. Basic requirements for processing are good colour, firm texture and high recovery. Other aspects like TSS %, acidity and so on can be adjusted accordingly during the canning process. This appears to be the best market that the high yielding hybrids can aim for. In Malaysia, there is good potential for production of papaya purée and also in canning in syrups and dehydrated papaya for powder and fruit leather (Nordin and Adinan, 1989)

A comparison in economics of production between the highest yielding hybrid (Mo x So) and the best inbred (Pa x Pa) is presented in *Table 5.4* Pa x Pa or Paris Semangka was also selected for downstream processing (papain production) in Indonesia (Daryono and Muhidin, 1974). The seed costs of inbreds and hybrids followed that computed earlier and worked out to be RM 75 for Pa x Pa and RM 297 for Mo x So. The production costs for processing fruits were estimated to be about half that of fresh fruit production i.e. 15 sen/kg. This was because less inputs (e.g. pest & disease control) were required in the production of fruits with less fastidious quality standards. Concomitantly, the price of fruits was also much lower - at 25 sen/kg which was less than half the price of Eksotika.

Table 5.3. Economics of production of Mo x So compared with Eksotika and Eksotika II for table fruit

| | Eksotika | Eksotika II | Mo x So |
|---|---|---|---|
| Genotype | inbred | sib | hybrid |
| TSS% | 12.8 | 12.8 | 11.6 |
| Yield/tree (kg) | 20.5 | 29.2 | 48.2 |
| Yield/ha (m.t.) | 41.0 | 59.8 | 96.4 |
| Seed cost/kg (RM) | 1 000 | 3 000 | 3 957 |
| Seed cost/ha (RM) | 75 | 225 | 297 |
| Production cost (@ 30 sen/kg) | 12 300 | 17 940 | 28 920 |
| Price/kg (sen) | 60 | 60 | 40 |
| Gross returns | 24 600 | 35 880 | 38 560 |
| Total costs | 12 375 | 18 165 | 29 217 |
| Net returns | 12 225 | 17 715 | 9 343 |

Table 5.4. Economics of production of Mo x So compared with Pa x Pa for processing fruit

| | Pa x Pa | Mo x So |
|---|---|---|
| Genotype | inbred | hybrid |
| Yield/tree (kg) | 30.3 | 48.2 |
| Yield/ha (m.t.) | 60.6 | 96.4 |
| Seed cost/kg (RM) | 1 000 | 3 957 |
| Seed cost/ha (RM) | 75 | 297 |
| Production cost (@ 15 sen/kg) | 9 090 | 14 460 |
| Price/kg (sen) | 25 | 25 |
| Gross returns | 15 150 | 24 100 |
| Total costs | 9 165 | 14 685 |
| Net returns | 5 985 | 9 415 |

The net returns of Mo x So was RM 9 415/ha compared with only RM 5 985/ha for Pa x Pa. This represented a gain of 57%. Similar figures would be arrived at, had Eksotika II been used instead of Pa x Pa because their yields were about similar and no advantage in price would be envisaged if Eksotika II was sold for processing. Therefore, it appeared that it is more profitable and there is good scope for using high yielding hybrids like Mo x So for the less fastidious downstream markets.

5.4.3. $F_1$ hybrids for annual cropping: beating the PRSV

The papaya ringspot virus disease (PRSV), is the single most devastating disease of papaya. It was first reported in Malaysia in June 1991 (Noriah, 1991) but its spread apparently was confined, for the time being, to the southern state of Johor (Yakob, *pers. comm.*, Fruit Research Division, MARDI, Serdang). The experience in many countries was that the spread of the disease was very rapid and eradication measures were deemed ineffective once the disease entered the country.

In Taiwan for example, the PRSV was reported in 1975 and in four years had destroyed most of the commercial orchards in the west coast (Wang *et al.*, 1978). The current feasible method to cultivate papaya in Taiwan is to use mild strains of PRSV for cross protection and to grow the crop on an annual basis (Yeh *et al.*, 1988). The mild PRSV strains were symptomless on papaya seedlings and appeared to have the ability to protect inoculated seedlings from the severe strains long enough to obtain an economic crop. The inoculated seedlings are usually planted during fall, overwinter and then flower in spring the following year. The crop is harvested in summer through fall. Usually by the arrival of the following winter, most of the crop would have been harvested or the trees would be too debilitated with the disease to be of any further use. This annual cropping method coupled with cross protection measures have been reported to yield 17.9 kg/tree (spring planting) and 7.2 - 29.3 kg/tree (fall planting) under infected field conditions (Yeh *et al.*, 1988).

The PRSV situation in Malaysia will likely to worsen in future to a point when papaya can only be grown as an annual crop as in Taiwan. If this is the case, the high yielding hybrids in this study appear to be valuable assets. The results of the trial indicated that for most hybrids, about 40% of their yield was produced in the first year of cultivation. With the removal of nine months of gestation, this represents only three full months of harvesting. The genotypic means for these three months of harvest for the majority of hybrids ranged from 15 - 22 kg/tree. This was rather comparable to 7.2 - 29.2 kg/tree obtained from the six-month yield (June - November) of cross-protected papayas in Taiwan.

It should be noted that the above yields were quoted from the combined means over six environments. There is even greater prospects and justification for annual cropping using hybrids if the choice of environments is judiciously made. At Pontian, the highest yielding environment for example, the first year harvest of the best hybrid Mo x So was a tremendous 67.3 kg/tree and most of the other hybrids were well over 40 kg/tree. Under such favourable conditions, the trees grew rapidly and produced a very high, precocious crop, especially for the hybrids.

This may well be the interim answer to combat the PRSV problem. Cultivation of hybrid papaya varieties in Pontian-like environments and preferably with cross-protection measures appear to be very feasible. With cross protection, it was reported by Yeh *et al.* (1988) that disease incidence can be kept down to 31% - 68% compared with total losses of the unprotected. Using these figures on Mo x So, a first year harvest of 21.5 - 46.6 kg/tree may be obtained after correction for mortality due to PRSV. These figures are equivalent to 43 - 92 t/ha depending on the extent of PRSV destruction. Even at the highest end of devastation, a 43 t/ha yield is considered satisfactory, comparable to that of Eksotika cropped over a period of 18 months. If disease incidence was less severe, the yield could easily be doubled.

There appears to be good scope in the use of high yielding hybrids in the fight against PRSV. They have the capability to produce very high, early yields especially at favourable environments and appear to be able to wrap up a good economic harvest in the first year before the devastating disease sets in.

5.4.4. Limitations of $F_1$ hybrids

*5.4.4.1. Acceptance of variety*

The Solo is acknowledged as the premier variety because of its petite fruit size, pyriform shape and excellent eating qualities. The Eksotika, released in 1985, took great efforts in market promotion, consumer education and publicity before it established a 'brand name' for itself in the export markets. The major challenge facing the $F_1$ hybrids and indeed any new varieties is gaining acceptance by the growers, consumers and exporters and this process takes time and money. There was a further setback in that the quality of the new hybrids did not measure up to the well-established Solo and Eksotika and the prospects of them breaking into the fresh fruit market appear remote. However, as mentioned earlier, this limitation may seem secondary in situations where other high quality varieties are uneconomic to cultivate, for example, under high infection of PRSV. Under such circumstances, there may be a forced acceptance of the new hybrids.

*5.4.4.2. Transition woes*

Concomitant to the release of a new technology, in this case a new hybrid, transition woes are to be expected. These are more acute in the case of production of $F_1$ hybrid seeds, where, because of security reasons, only certain agencies are appointed to produce them. There must be adequate training to ensure that proper procedures are followed to obtain the necessary seed purity, certification, and processing, packing and storage to ensure good viability. Such a process involves much extension work, and delays in the availability of hybrid seeds may be envisaged.

Other areas in which transition woes may arise are in aspects of supportive research for the new variety. Requirements in agronomy, pest and disease management and postharvest may be different and perhaps need fine-tuning. These areas of work will require quite substantial research and development funding.

## 5.5. CONCLUDING REMARKS

The present studies indicate that there is very good potential in the development of $F_1$ hybrids for papaya. Hybrid seed production for this fruit is not a constraint and appear economical to produce even when carried out by hand.

The strengths of the hybrids lie in their vigour, earliness and extremely high yields which was close to the ceiling at the best environment. Indeed, the yields of some of the best hybrids seemed to break into new frontiers and will inject fresh expectations and future goals in papaya breeding. It is unlikely, however, that the present hybrids can be accepted for the fresh fruit market because of their low total soluble solids % and poor eating qualities.

Their immediate prospects lie with the less fastidious processing industry. Their characteristic high, early yields would also provide an 'escape' mechanism to beat the dreaded papaya ringspot virus disease. In the long term plan for development of papaya hybrids suitable for dessert varieties, selection of inbred lines that are genetically diverse and have good eating qualities is necessary. Hybridisation between these inbreds will result in marked heterosis for earliness, vigour and yield, while retaining the high eating qualities necessary for fresh fruits.