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STUDIES ON CARPELLODY OF STAMENS IN PAPAYA (*CARICA PAPAYA* L.)

Y.K. CHAN*

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RINGKASAN

Kajian mengenai stamen yang karpelod pada betik telah dijalankan dalam dua penanaman dalam tahun 1979 dan 1981 di dalam populasi pembiakan lima genotip di MARDI, Serdang. Data mengenai buah-buah karpelod yang dikutip hasil pada tiga peringkat berumur 6–12 bulan, 13–18 bulan dan 19–24 bulan telah dilakukan. Keputusan-keputusan telah menunjukkan bahawa perkembangan buah karpelod adalah nyata dipengaruhi oleh umur pokok, genotip dan interaksi kedua-dua kesan tersebut.

Kejadian karpelod di dalam kesemua lima genotip menurun dengan bertambahnya umur pokok. Ini adalah berkaitan dengan pertumbuhan tampang yang lebih lambat pada pokok tua. Satu perkaitan yang kuat telah didapati di antara kejadian buah karpelod dan panjang antara ruas di kalangan empat genotip tersebut (r = 0.68** kepada 0.86**).

Satu anggaran keturunan yang tinggi (h^2 = 82.34%) telah diperolehi untuk stamen yang ber-karpelod tetapi pemilihan fenotip yang berkesan mungkin berubah oleh jenis 'pertukaran dalam kadar' bagi interaksi di antara genotip dan umur pokok. Implikasi daripada penemuan yang ada di dalam usaha-usaha pembiakan dan pemilihan terhadap sifat yang tidak dikehendaki ini telah dibincangkan.

INTRODUCTION

Carpellody of stamens in papaya (*Carica papaya* L.) is a term used to describe the fusion of stamens to the ovary in the hermaphrodite flower. Fruits developed from such flowers have unsightly longitudinal scars indicating the area of adnation and fusion of the androecium to the ovary. Such fruits are generally misshapened or 'cat-faced' and are hardly marketable.

In Hawaii, where the papaya industry is traditionally based on cultivation of hermaphrodite populations, the fairly common occurrence of carpelloid fruits considerably reduces the marketability of fruits and profits of growers. This is a significant problem and is a major consideration in papaya breeding and selection programmes in Hawaii (NAKASONE, 1967). However, the success achieved hitherto in selection against this undesirable trait has been rather limited because the mercurial sex expressions of the hermaphrodite papaya are affected by environment. It has been reported that cool temperatures (AWADA, 1958) and high soil moisture regimes leading to rapid tree growth (AWADA, 1961) are favourable towards sex reversal of the hermaphrodite flower towards femaleness, resulting in the development of carpelloid fruits. NAKASONE (1975) suggested that although the incidence of carpellody has been reduced in major Hawaiian cultivars, there is a need to breed for cultivars adapted for specific growing areas in view of the sensitivity of sex expressions with changes in localities.

In Malaysia, locally recommended gynodioecious cultivars like Subang 6, Sitiawan and Taiping 3 have negligible or very low incidences of carpellody (CHAN, 1981). In fact, this undesirable trait has not been serious enough to be considered as a selection criterion in past breeding programmes. However, lately, an alarmingly high incidence was recorded on some advanced lines in the backcross breeding populations involving the Hawaiian Sunrise Solo at MARDI, Serdang. In view of this, it has become necessary to re-examine the performances of these lines before they are released to growers. The present study, using

*Fruit Research Division, MARDI, Serdang.

materials from this breeding population, is to determine the heritability of this trait and to examine its behaviour and relationship with vegetative growth over two crop years. This information will be of considerable value for selection efforts aimed at reducing the incidence of carpellody in subsequent generations of the backcross breeding programme.

MATERIALS AND METHODS

Five genotypes, namely, Sunrise Solo, Subang 6 and three advanced lines derived from the MARDI backcross breeding programme, were used for the experiment. Sunrise Solo (an inbred Hawaiian cultivar) and the four others, which have been inbred for at least five generations, were considered homozygous materials. The five genotypes were planted in a randomized complete block design with three replicates, each consisting of five plots of 20 plants each. The planting distance was 1.8 m within row and 2.7 m between rows.

The first crop was planted at the MARDI Research Station, Serdang, on the 19th October 1979 while the second crop was planted at the same location on the 18th February 1981. Both crops in the two years were irrigated with a drip system. A bi-monthly application of a 12:12:17:2 + TE fertilizer formulation was given at a rate of 2.7 kg/tree/year. Pest and disease management included monthly rounds of Dithane M-45 for protection against anthracnose, and Kelthane and Alboral against spider mites and scale insects, respectively.

Fruit harvests were recorded every two days during seasons of peak production and the number of carpelloid fruits were noted. Reports on the association of growth rates with the occurrence of carpellody (AWADA, 1961) make it necessary to divide the studies of each crop year into three plant age groups of harvest, that is 6–12 months, 13–18 months and 19–24 months. Internode lengths taken over these three plant ages were used as indices of vegetative growth. In recent studies, internode length was found to be related to other vegetative growth variables like plant height and stem diameter (CHAN and TOH, 1984).

For estimation of the heritability for carpellody, an analysis of variance components was carried out. In this analysis, crop year and plant age were treated as random effects and genotypes as fixed effects. The variance components as well as the expectations of mean square are presented in *Table 1.* The heritability estimate is derived from the mean square following ALLARD (1960), that is

$$h^2 = \frac{M_5 - M_4 - M_3 + M_2}{M_5}$$

All variance components that make up the mean square values were examined and negative variance components were assigned zero values. The corrected mean squares were used in the computation of heritability.

For derivation of the F ratios for testing the significance of the various effects, the two estimates of mean squares, which differ in their expected values by the term that involves the effect being tested, were used. The tests for years and genotypes were made by the approximate test presented by COCHRAN and COX (1955), that is for genotypes,

$$F^1 = \frac{M_5 + M_2}{M_4 + M_3}$$

The degrees of freedom for this F^1 test were derived from the method of SATTERTHWAITE (1946).

The relationship of internode length with incidence of fruit carpellody was computed for each genotype by correlation analyses.

RESULTS AND DISCUSSIONS

From the analysis of variance com-

Table 1. Analysis of variance components and expectation of mean square for fruit carpellody in papaya

Source	df	Mean square	Expectation of mean square
Years (Y)	$(n_y - 1)$		$\sigma^2 + n_g \sigma^2_{r(y)s} + n_g n_s \sigma^2_{r(y)} + n_r n_g \sigma^2_{ys} + n_r n_g n_s \sigma^2_y$
Plant age (S)	$(n_s - 1)$		$\sigma^2 + n_g \sigma^2_{r(y)s} + \quad + n_r n_g \sigma^2_{ys} + n_r n_g n_y \sigma^2_s$
Years x plant age (Y x S)	$(n_y - 1)(n_s - 1)$		$\sigma^2 + n_g \sigma^2_{r(y)s} + \quad + n_r n_g \sigma^2_{ys}$
Rep (year)	$n_y(n_r - 1)$		$\sigma^2 + n_g \sigma^2_{r(y)s} + n_g n_s \sigma^2_{r(y)}$
Rep (year) x plant age	$n_y(n_r - 1)(n_2 - 1)$		$\sigma^2 + n_g \sigma^2_{r(y)s}$
Genotypes (G)	$(n_g - 1)$	M_5	$\sigma^2 + n_r \sigma^2_{gys} + n_y n_r \sigma^2_{gs} + n_s n_r \sigma^2_{gy} + n_y n_s n_r (G)$
Genotypes x years (G x Y)	$(n_g - 1)(n_y - 1)$	M_4	$\sigma^2 + n_r \sigma^2_{gys} \quad + n_s n_r \sigma^2_{gy}$
Genotypes x plant age (G x S)	$(n_g - 1)(n_s - 1)$	M_3	$\sigma^2 + n_r \sigma^2_{gys} + n_y n_r \sigma^2_{gs}$
Genotypes x years x plant age (G x Y x S)	$(n_g - 1)(n_y - 1)(n_s - 1)$	M_2	$\sigma^2 + n_r \sigma^2_{gys}$
Pooled error	$(n_y n_s)(n_r - 1)(n_g - 1)$	M_1	σ^2
Total	$(n_y n_s n_g n_r - 1)$		

ponents for fruit carpellody *(Table 2)*, significance in the F test was detected for plant age and genotype as well as in the interaction between these two effects. Crop year and other interactions involving this effect were found to be not significant. The behaviour of the five genotypes in terms of carpelloid fruit development appears to be consistent over both crop years. However, with regards to plant age, this was not so. Significance in the interaction between genotype and plant age suggests that there is inconsistency in performance in fruit carpellody among genotypes over the three stages of plant development.

For derivation of the heritability for fruit carpellody, the variance components involving genotype and its interaction with other effects were computed *(Table 2)*. The contribution of the genotype component compared with the total phenotypic variance for fruit carpellody (h^2) was 82.34%. This high heritability estimate arose because with the exception of the fairly low genotype x plant age interaction (accounting for 13.29% of the total variation), other interaction effects with genotypes were not significant *(Table 2)*. It must be noted that the high h^2 estimate for fruit carpellody derived here may only be applicable to the population presently examined since genotypes were considered fixed effects. Although h^2 for this trait has not been reported elsewhere, there is sufficient evidence to indicate that h^2 in other papaya populations may not be as high as estimated in the present studies. NAKASONE (1967) in the review of the papaya breeding strategies in Hawaii reported that this trait was extremely sensitive to environmental influences and that it was not possible to eliminate it altogether. However, at least for the present backcross breeding population at MARDI, there is a good chance that carpellody can be substantially reduced through effective selection of desirable progenies because of the high heritability obtained for this population.

To examine further the relationship of fruit carpellody of the five genotypes with the various ages of plant development, the data from both crop years were combined for

Table 2. Variance component estimates for fruit carpellody

Source	df	MS	Variance component estimate	% of phenotypic expression
Years (Y)	1	142.9344 ns	1.7642	
Plant age (S)	2	674.5598*	20.0927	
Years x plant age (Y x S)	2	18.3458 ns	– 0.7034[a]	
Rep (year)	4	70.9632	2.7512	
Rep (year) x plant age	8	29.6945	3.2086	
Genotypes (G)	4	401.3853*	18.3982	82.34
Genotypes x years (G x Y)	4	16.7863 ns	0.4369	0.98
Genotypes x plant age (G x S)	8	66.2860*	8.9053	13.29
Genotypes x years x plant age (G x Y x S)	8	12.8542 ns	– 0.2658[a]	0.00
Pooled error	48	13.6516	13.6516	3.39
Total	89			

[a]Negative estimates for which the most reasonable value is zero.

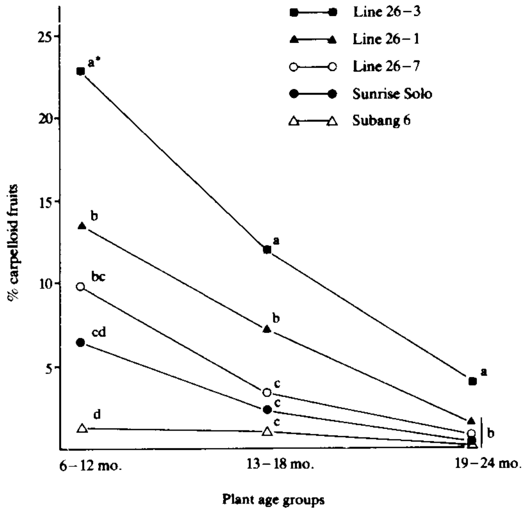
comparison of means between genotypes and plant age. This was done because no significant difference between the two crop years was found. The data are presented in *Table 3*. It becomes immediately evident that the incidence of fruit carpellody was highest during the early harvests. All the five genotypes showed a consistent, although disproportionate, decline in incidence of fruit carpellody in the later harvests. Fruits collected at the 19–24 month period were almost completely free of carpellody for all five genotypes *(Table 3)*. This is of interest to breeders particularly in derivation of early selection indices for this trait. Selection against carpellody of stamens may be initiated and completed within the first six months of harvests, since this was the period when incidence was highest. In contrast, selection based on data from older trees may be less effective.

To illustrate this point further, *Figure 1* summarizes the performance of the five genotypes in carpelloid fruit development over the three periods of plant age and it demonstrates very well the 'change-in-rate' type of interaction between genotype and plant age effects. Although a consistent drop in incidence of fruit carpellody over the various plant ages were observed, this decline was not proportional among the five genotypes. The implication of this in breeding programmes is that the genotype x

Table 3. Combined data of two crop years showing means of carpelloid % and internode lengths of five genotypes over three plant ages

Plant age	Line 26–7		Line 26–3		Line 26–1		Sunrise Solo		Subang 6	
	Carp. %	Internode length	Carp. %	Internode length	Carp. %	Internode length	Carp. %	Internode length	Carp. %	Internode length
6–12 month	9.84a	1.95a	22.90a	1.97a	13.52a	2.04a	6.53a	2.09a	1.26a	1.67a
13–18 month	3.34b	1.33b	12.00b	1.36b	7.43ab	1.41b	2.36b	1.40b	0.91a	1.21b
19–24 month	0.78b	0.85c	4.11c	0.84c	1.65b	0.83c	0.29b	0.84c	0.09a	0.85c

Column means with the same letter are not significantly different ($p < 0.05$) according to the Duncan's Multiple Range Test.



*Mean values of genotypes within the plant age group with the same letter are not significantly different ($p < 0.05$) according to the Duncan's Multiple Range Test.

Figure 1. Performance of five genotypes in carpelloid fruit development over three periods of harvest.

plant age interaction will interfere with selection of genotypes for low carpelloid incidence at the three periods of crop growth. For example, if selection had been carried out at the 19–24 month period, four genotypes, i.e., Line 26–1, Line 26–7, Sunrise Solo and Subang 6 would have been selected because they were not significantly different from each other in expression of fruit carpellody at this period. Had selection been exercised at the 13–18 month period, the latter three would have been selected while in the early stages (6–12 month), only Sunrise Solo and Subang 6 would have qualified for selection *(Figure 1)*. Selection based on early harvests at the 6–12 month period appears to have maximum precision because of the widest variability in expression of carpelloid fruit incidence among genotypes at this stage. As indicated earlier, the added advantage in selection at this stage is that the breeding programme against this undesirable trait may be initiated and completed early based on the first six months of harvest.

The explanation for high incidence of carpellody in the early harvests may be related to the differences in growth and development of the crop at various plant ages. From *Table 3*, a concomitant decrease in internode lengths with incidence of carpellody over the three plant ages was evident for the majority of genotypes. Correlation analysis indicates that the association between internode length and carpellody were significant among all genotypes *(Table 4)*. Fruits developed during periods of rapid vegetative growth appear to exhibit a higher tendency towards carpellody. In the present studies, fruit harvested at the 6–12 month period had higher carpellody percentage because these had developed from flowers initiated around the third to ninth month from planting and this stage coincided with the stage of rapid vegetative development (CHAN and TOH, 1984). Similar findings have also been reported by AWADA (1961) in his studies on the effects of moisture on sex expression of papaya. He noted that high incidence of carpellody was common among papaya plants grown under high moisture regimes and this was related, to a large extent, to the more rapid tree development under those conditions.

In summary, carpellody of stamens in the backcross breeding population studied presently, appears to be mainly governed by heritable effects (as indicated by the high h^2 estimate). However, because of the significant 'change-in-rate' type of interaction between genotype and plant age, efficiency in phenotypic selection may be masked if

Table 4. Correlation coefficients between incidence of fruit carpellody and internode lengths of five papaya genotypes

Genotype	r
Line 26–1	0.6759**
Line 26–3	0.8063**
Line 26–7	0.8581**
Sunrise Solo	0.7256**
Subang 6	0.4590*

selection is based on harvests over an extended period of time. Since incidence of fruit carpellody is related to rapid vegetative growth, it is recommended that selection against this undesirable character be done early to coincide with the period of rapid tree growth and development. The results obtained here indicated that selection based on early harvests at the 6–12 month period appears to have maximum precision because of the widest variability in expression of carpelloid fruit incidence among genotypes at this stage.

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SUMMARY

Studies on carpellody of stamens in papaya were conducted over two crops in 1979 and 1981 in a breeding population of five genotypes at MARDI, Serdang. Data on carpelloid fruits harvested over three plant ages, i.e. 6–12 months, 13–18 months and 19–24 months were monitored. The results showed that carpelloid fruit development was significantly influenced by plant age, genotype and the interaction of these two effects.

Incidence of carpellody in all five genotypes declined with increase in plant age. This was found to be related to a slow down in vegetative growth in older plants. A strong correlation was found between incidence of fruit carpellody and internode length among four of the genotypes ($r = 0.68^{**}$ to 0.86^{**}).

A high heritability estimate ($h^2 = 82.34\%$) was obtained for carpellody of stamens but effective phenotypic selection may be interfered by the 'change-in-rate' type of interaction between genotype and plant age. The implications of the present findings in breeding and selection efforts against this undesirable trait are discussed.

REFERENCES

ALLARD, R.W. (1960). *Principles of Plant Breeding*. London: John Wiley and Sons Inc.

AWADA, M. (1958). Relationship of minimum temperature and growth rate with sex expression of papaya plants (*Carica papaya* L.). *Hawaii Agr. Expt. Sta. Tech. Bull.* **38**, 16 pp.

AWADA, M. (1961). Soil moisture in relation to fruit types of papaya. *Hawaii Fm. Sci.* **10**, 7–8.

CHAN, Y.K. (1981). Monograph of Malaysian fruits [Papaya (*Carica papaya* L.)]. Fruit Research Branch, MARDI (mimeo).

CHAN, Y.K. and TOH, W.K. (1984). Growth studies on some vegetative characteristics of papaya (*Carica papaya* L.). *MARDI Res. Bull.* **12**, 46–54.

COCHRAN, W.G. and COX, G.M. (1955). *Experimental Designs*. New York, John Wiley. 611 pp.

NAKASONE, H.Y. (1967). Papaya breeding in Hawaii. *Agron. trop., Venezuela.* **17**, 391–399.

NAKASONE, H.Y. (1975). Papaya development in Hawaii. *Hortscience* **10**, 198.

SATTERTHWAITE, F.E. (1946). An approximate distribution of estimates of variance components. *Biometrics* **2**, 110–114.

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