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Coconut Breeding in Sri Lanka : A Review

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ABSTRACT

Work done by Coconut Research Institute, Sri Lanka, on the genetics and breeding of the coconut palm from 1930 to 1980 is described.

It involves studies on: mass selection methods, selection differential, progeny trials, inbreeding depression, estimation of genetic parameters, construction of selection indices and varietal hybridization.

Two improved varieties CRIC 60 and CRIC 65 have been produced. An isolated seed garden was established for the large scale production of seed of the improved varieties.

INTRODUCTION

The Coconut Research Scheme in Sri Lanka was established in 1929, under the Coconut Research Ordinance, No. 29 of 1928. There were three divisions then: technology, genetics and soil chemistry. There was only one scientific officer attached to each division. The genetics division functioned from 1930. Subsequently, the Coconut Research Scheme was upgraded and enlarged into the Coconut Research Institute (CRI) in 1951 with more divisions and scientific staff.

The present report covers the work done by CRI on coconut breeding from 1930 to 1980. Those who were in charge of the Division during this period are indicated below. The emphasis on the nature of breeding work varied with the Heads of Division: Pieris concentrated on mass selection, Raghavan on a progeny trial; Liyanage on genetic parameters, controlled pollination and production of improved varieties; Manthriratne on assessment of performance of hybrids.

W. V. D. Pieris	from 1930 to 1946
T. S. Raghavan	from 1947 to 1949
D. V. Liyanage	from 1949 to 1966
M. A. P. Manthriratne	from 1970 to 1979

In this paper, * indicates statistical significance at P= 0.05 ** at P= 0.01 and *** at 0.001.

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COCONUT VARIETIES IN SRI LANKA

A critical examination of data pertaining to the morphological characters and breeding systems of coconut palms grown in Sri Lanka indicated that three varieties could be distinguished (Liyanage, 1958),

Variety *typica* Nar.

The popular Sri Lanka Tall (SLT) palm grown on a plantation scale, late flowering, 5 to 6 years after planting, flower production continuous and predominantly outbreeding; hardy palms tolerating a wide range of environmental conditions.

Variety *nana* (Griff) Nar.

Early flowering, 3-4 years after planting, flower production seasonal, inbreeding; grows in a restricted environment; suffers adversely from drought; susceptible to pests and diseases.

Variety *aurantiaca* Liy.

Late flowering in 5 to 6 years, flower production seasonal, inbreeding; epicarp of nut orange in colour; nut water sweet; grows in a restricted environment; suffers from drought; susceptible to pests and diseases.

All three varieties have a chromosome number $2n = 32$.

Within each variety, a number of forms could be recognized, each having its own distinctive characters. Their local names are listed below (Liyanage, 1958).

Forms of the variety *typica*:

Typica, *Navasi*, *Gon-thembili*, *Ran-thembili*, *Pora-pol*, *Bodiri*, *Kamandala* and *Dikiri-pol*.

The form *typica* (SLT) is grown on a commercial scale for the production of endosperm and fibre products. The other forms are found scattered about plantations with a low frequency. They are of little economic value, but useful for breeding.

Forms of the variety *nana:*

pumila, *eburnea* and *regia*

They are not grown on a plantation scale, but have been used extensively in breeding work, because of low stature and large number of nuts as well as early flowering.

Forms of the variety *aurantiaca*:

King coconut (*thembili*) and *navasi-thembili*

King coconut has nut water with a higher sucrose content. Hence grown on a large scale for drinking purposes.

Table 1. *Some quantitative characters of coconut forms growing in Sri Lanka*

	Weight (g)			*Nuts per ton of copra*	*Oil content dry basis %*
	Husked nut	*Shell*	*Copra/nut*		
Forms of variety *typica*					
typica ...	692	157	211	4,750	68.95
navasi ...	606	169	178	5,675	69.54
gon-thembili ...	692	197	229	4,400	69.20
ran-thembili ...	827	197	219	4,600	68.46
pora-pol ...	533	225	141	7,150	69.73
bodiri ...	194	51	51	19,900	69.58
kamandala ...	1,600	320	375	2,700	67.65
dikiri-pol ...		(not recorded)			
Forms of variety *nana*					
pumila ...	285	70	112	8,950	69.65
eburnea ...	429	87	111	9,050	65.49
regia ...	276	56	86	11,675	65.23
Forms of variety *aurantiaca*					
King coconut ...	398	168	141	7,150	65.62
navasi-thembili ...	461	98	139	7,250	68.10

(*Source:* Liyanage, 1958)

Variations between the forms in quantitative characters are given in Table 1, and in shape and size in Fig. 1. The *typica* forms have more copra per nut and heavier shells than the others except for the *bodiri*. Oil content of two *nana* forms and King coconut is less than that of the *typica*.

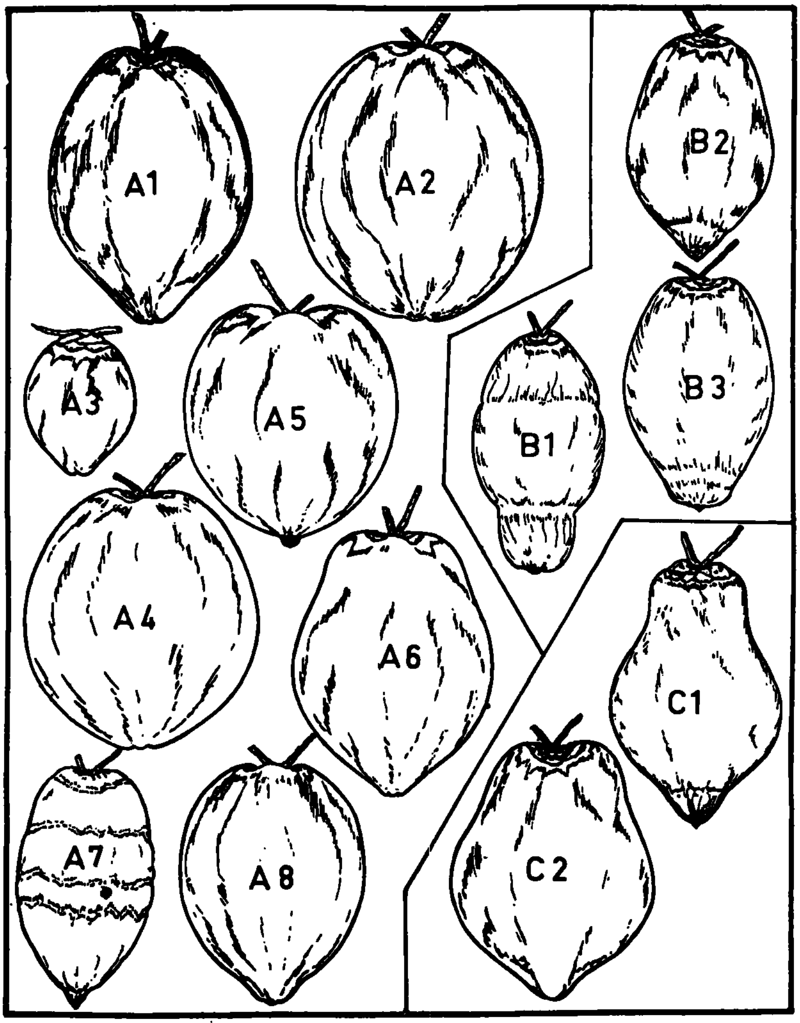

Fig. 1. Shape and size (approximate) of forms of coconut found in Sri Lanka Forms of variety *typica:* Al–typica, A2-kamandala, A3-bodiri, A4-navasi. A5-ran-thembili, A6-gon-thembili, A7-pora-pol, A8-dikiri-pol Forms of variety *nana:* Bl-pumila, B2-eburnea, B3-regia. Forms of variety *aurantiaca:* Cl-thembili (King Coconut) C2-navasi thembili.

Forms that are useful for breeding are *typica* (low out-turn, high oil content) *kamandala* (high copra/nut), *pumila* (early bearing, short habit, high oil content)*pora-pol* (high shell weight). The early bearing character of *nana* appears to be partially dominant and the short habit is recessive. The F_1 palms of *typica x pumila* exhibit heterosis in growth.

The chances of inter-spadix pollination are remote in the forms *thembili, pumila, regia* and *bodiri*, slight in *navasi-thembili* and *gon-thembili;* greater in *eburnea* and *navasi;* extremely high in *typica, kamandala* and *ran-thembili*, particularly when the palms are young and vigorous. The potential for self-pollination depends on the length of male and female phases and the chances of overlap within and between spadices (Fernando, 1976).

The stomatal density is a varietal character. Variations due to environment were negligible. All three forms of the self-pollinating *nana* variety had more stomata (31) per mm^2 when compared with the varieties *typica* (24) and *aurantiaca* (25). Stomatal density may prove to be a useful marker for the identification of *typica* x *nana* hybrids, for they have an average of 27 stomata per unit area, which is the mid-parental value for this character (Manthriratne and Sambasivam, 1974).

By chromatography techniques, it was observed that the green and brown forms of *typica* have similar carotenoids. The three colour forms of *nana* have carotenoids which have similar Rf. values, which differ from Rf. value for *typica*. In the hybrids between *typica* and *nana* (3 colour forms) carotenoid characteristics of dwarf appear to be greater (Jayasekara, 1979).

An attempt has been made to separate pollen proteins of coconut by electrophoresis for varietal identification. The method is reported, but not the results (Manthriratne, 1977).

The abbreviations used for coconut varieties/forms in the following pages are:

SLT : Sri Lanka Tall palms (form *typica*)
GD : Green Dwarf palm (*pumila*)
YD : Yellow Dwarf palm (*eburnea*)
RD : Red Dwarf palm (*regia*)
KC : King Coconut palm (*aurantiaca*)

SRI LANKA TALL (SLT) PALMS

The SLT palms are the mainstay of the coconut industry in Sri Lanka, providing a variety of food and industrial goods. They are hardy, tolerating a wide range of environmental conditions, ranging from the marginal lands in the dry zone to the more favourable areas in the intermediate and wet zones. Consequently production varies considerably between locations.

The SLT palms are monoecious. They are largely cross-fertilized with a timing mechanism. The male phase precedes the female phase on the same inflorescence, and when the next inflorescence opens the receptivity of the female flowers of the previous one has lapsed. Sometimes, vigorously growing young palms produce inflorescences more frequently, allowing inter-spadix pollination within the same palm.

It is predominantly insect pollinated, honey bees (*Apis indica*) and mites playing a major role. Wind pollination is negligible. The stem is visible about the fourth year after transplanting seedlings. Its growth is continuous depending on the environment, and a 50-year old palm could attain a height of 20 meters.

The first visible inflorescence appears (flowering-period) in an axil of a leaf when the palms are 54 to 72 months old. Thereafter flower production is continuous, with occasional flowering.

A SLT coconut fruit

The weight of fruit components after studying 1,000 cooonuts from Bandirippuwa Estate, withered for one month, is given below. The same study also showed that 30 coconuts was a reasonable optimum sample size (Nathanael, 1958).

Character		*Weight per fruit component(g)* *Wet*	*Dry*
Whole fruit	...	1,053 ± 9.64	673 ± 6.09
Husked-nut	...	640 ± 4.50	343 ± 4.83
Husk	...	413 ± 7.10	330 ± 3.47
Shell	...	177 ± 0.88	155 ± 0.68
Endosperm	...	339 ± 3.15	182 ± 4.52
Nut Water	...	124 ± 4.22	6 ± 0.09
Copra (6% moisture)	...		182 ± 4.52

(Source: Nathanael, 1958)

The respective weights of the fruits could vary with the environment, season the nuts are picked and the age of palms. These samples have been taken from palms over 50 years old. At that age the weight of fruits and their components decrease, *eg.* weight of copra per fruit averages 194 g. Hence these figures may be lower, compared to those of younger palms.

Yield potential

The SLT palm grown on a plantation scale remains productive for over 60 years depending on soil, climate and crop husbandry. After initial bearing, the yield of nuts increases progressively every year, until an optimum is attained, which is maintained thereafter depending on the environmental conditions.

The yield curves of two SLT populations are given in Fig. 2. Curves A and B cover 5 and 2 ha. plantations with lateritic gravel and clayey soil types respectively. The yearly fluctuations in yield of B are largely related to poor rainfall regime combined with a less favourable soil for coconuts (Liyanage and Abeywardane, 1958).

The SLT palms give a yield of about 6200 nuts ha/yr when they are 10 to 12 years old, reaching an optimum at 16 to 18 years. The average yield varies between 7400 to 9880 nuts per ha/yr, variations attributed to differences in environmental factors and management practices.

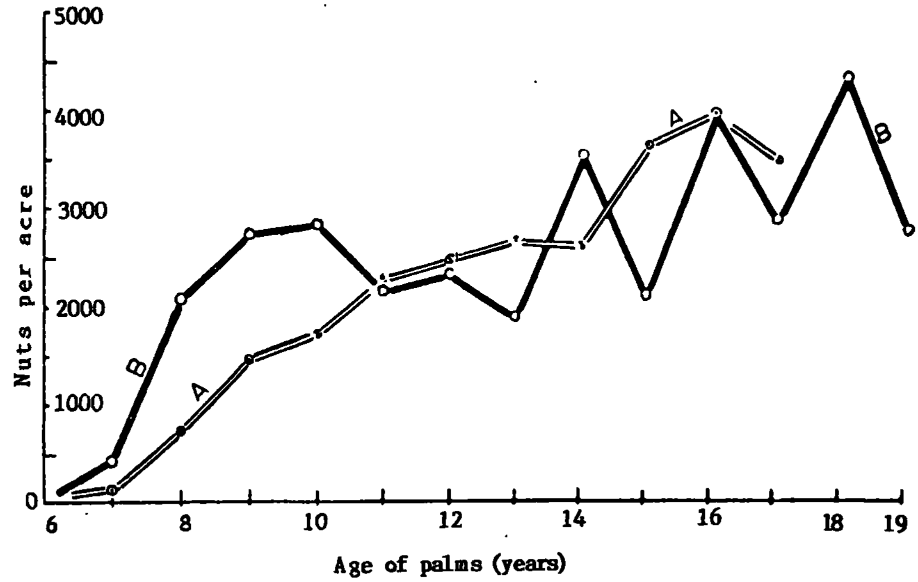

Fig. 2. The yield curves of two populations of coconut palms.

Variation between harvests

The SLT palms are harvested once every two months. The variations between these harvests with respect to some characters that contribute to production were studied on 972 palms over a 10-year period (Table 2).

Table 2. *Variations between harvests of SLT palms*

Component	*Jan./ Feb.*	*March/ April*	*May/ June*	*July/ August*	*Sept./ Oct.*	*Nov./ Dec.*	*Repeatability Value*
No. of bunches/palm ...	1.82	2.01	2.06	1.99	2.05	1.99	*
No. of female flowers/bunch ...	14.77	15.47	15.59	16.33	13.85	13.41	ns
Setting of female flowers into fruits (%) ...	25.77	35.05	41.81	38.17	31.60	27.36	***
Wt. of copra/nut(g) ...	217	211	206	193	183	198	***
Wt. of copra/palm(kg) ...	1.39	2.16	2.69	2.29	1.52	1.30	***

(*Source:* Adapted from Abeywardane and Fernando, 1963)

Generally, more copra per palm/year is derived from the three harvests gathered from March to August (7.14 kg.), than from September to February (4.19 kg.); 63% and 37% respectively of the total crop. May/June harvest alone contributes nearly 25% of the total for the year.

The components listed in Table 2 have given repeatability values as follows:

Number of bunches,	x^2	=	11.86*
Number of female flowers/ bunch,	x^2	=	9.31
Setting of female flowers,	x^2	=	22.10***
Weight of copra per nut (based on wt. of husked-nut)	x^2	=	19.31*
Weight of copra per palm/ Year (based on wt. of husked nuts)	x^2	=	25.50***

(*Sources*: Abeywardane and Fernando, 1963)

Biennial bearing

Most tree crops are to some extent biennial in growth and cropping. Those that exhibit a biennial rhythm, carry a heavy crop in one year and less in the following year.

Production of nuts of 300 SLT palms for a period of 10 years was examined to determine biennial bearing tendency. There is a biennial rhythm in coconut production, but the intensity of biennial fluctuations is low and of no significance in economic terms (Abeywardane, 1962).

Correlation studies

The data of 144 SLT palms whose female parents are known were used in the study. Correlations between and within families of the characters listed in column one in Table 3 were worked out. The adult palm components represent yield data collected from palms 16 to 17 years old. The more important findings are illustrated in Figures 3 and 4 (Liyanage, 1957).

Table 3. *Correlation of some characters between and within families of SLT palms*

	Between r	*Within r*
Seednut volume x number of nuts per palm ...	—0.5598***	—0.1117
,, ,, x weight of copra per palm ...	—0.3597	—0.0974
,, weight x number of nuts per palm ...	—0.5351**	—0.0581
,, weight x weight of copra per palm ...	—0.0422	—0.0374
Sprouting period x flowering period of palm ...	+0.5468***	—0.0271
Flowering period x weight per nut of palm ...	—0.5375**	—0.4268***
,, ,, x number of nuts per palm ...	—0.4957**	—0.6348***
,, ,, x weight of copra per palm ...	—0.6236***	—0.5525***
Initial yield of nuts x number of nuts of the adult palm ...	+0.8861***	+0.7369***
,, ,, ,, x weight of copra of the adult palm ...	+0.9216***	+0.7389***
Partial correlation coefficient keeping flowering-period constant		
Initial yield of nuts x number of nuts of the adult palm ...	+0.8699***	+0.6856***
,, ,, ,, x weight of copra of the adult palm ...	+0.9299**	+0.7119**

(*Source:* Liyanage and Abeywardane, 1958)

The seed parents that gave nuts above the average size have progenies with fewer nuts. The same relationship holds even if flowering is kept constant.

Early sprouting promotes seedling height, leaf and root number, presumably due to the higher physiological age.

A palm that flowers early will give a higher yield both of nuts and copra than those that flower late.

If a palm during the second and third years of bearing gives a high-yield, then it will continue to be very productive subsequently.

Seednuts that sprout early, give palms that have a shorter flowering-period, leading to a higher production of nuts and copra in the adult palms. These correlations are indeed very useful in the selection of seedlings and roguing poor bearing palms, leading to a uniformly high-yielding plantation. The ideal would be to plant about 20% more palms than the recommended number per unit area. so that after thinning out is completed, the required density of palms is maintained.

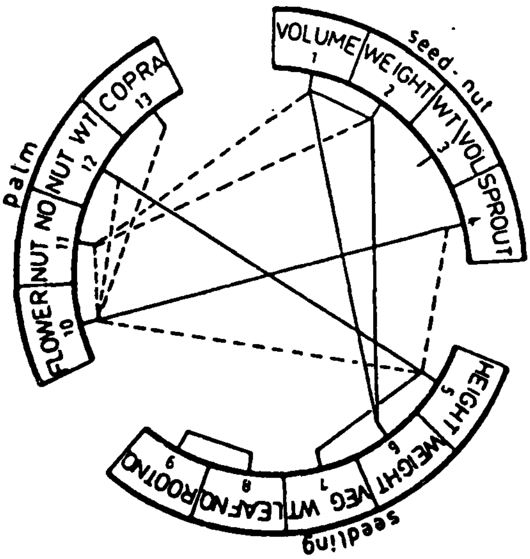

Fig. 3. The significant correlations between parents.

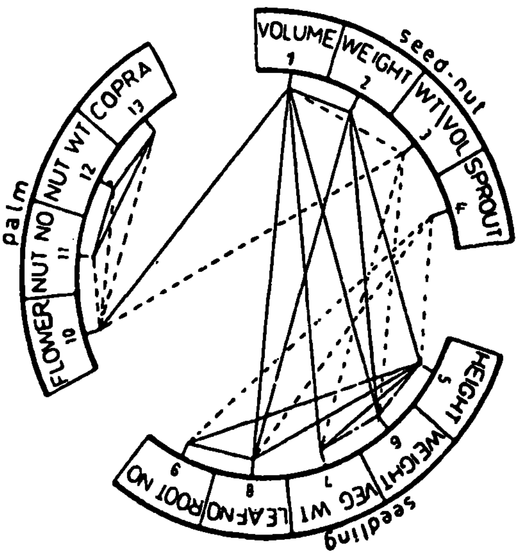

Fig. 4. The significant correlation within parents.

(All correlations are significant at least at 5 per cent level. A continuous line joining two characters indicates a positive correlation and a discontinuous line a negative correlation.)

Other correlation coefficients calculated from data collected from 122 SLT palms are given in Table 4. Yearly leaf production from the 2nd to the 6th year is negatively correlated with the flowering period. Thus, in a programme of selective thinning of transplanted material, it is possible to use an index of leaf production for roguing purposes, with a view to promote early flowering of palms in the population. Leaf production and yield of 9 to 12 year old palms, both nuts and copra, are positively and significantly correlated (Liyanaae, 1962).

Table 4. *Phenotypic correlation coefficients between leaf production, flowering-period and yield of SLT palms*

	Correlation coefficient r		
	x *flowering period*	x *yield of nuts*	x *yield of copra*
No. of leaves produced in 2 yr old palms ...	—0.5076*	0.1269**	0.1809*
,, ,, 3 yr ,, ...	—0.6836*	0.3956*	0.3912*
,, ,, 4 yr ,, ...	—0.8046*	0.4903*	0.5001*
,, ,, 5 yr ,, ...	—0.7556*	0.5618*	0.5982*
,, ,, 6 yr ,, ...	—0.7698*	0.6277*	0.6443*
Total number of leaves produced from the 2nd to 6th year ...	—0.8560*	0.5773*	0.6029*
Total number of leaves borne on the palm at the end of the 5th year ...	—0.8092*	0.5438*	0.5894*
Flowering-period ...	—	—0.5442*	—0.5521*

(*Source:* Liyanage, 1962)

Since the SLT palms are highly heterozygous, roguing undesirable types in the nursery stage and at flowering will result in a highly productive population. Important characters to be considered for that purpose are: early sprouting of seednuts, high production of leaves upto the age of 3 years or more, early flowering of palms and initial high yield of copra.

MASS SELECTION

The initial studies at CRI were directed to identify suitable criteria for the selection of SLT palms for the collection of seed. Standards for the selection of these palms were outlined. They should have a short, straight stem; closely set leaf scars; short, well orientated fronds; short bunch stalks; a fair number of female flowers on the inflorescences a large number of inflorescences carried evenly round the crown; a large number of nuts, the size of nut being of no importance as long as the number is large and weight of husked nut high (Pieris, 1934). Field studies indicated below were undertaken to study the efficiency of mass selection methods.

300 palm block

A block of 300 SLT palms, already in bearing was taken for yield recording in 1931. At each pick, the number of bunches harvested, fruits gathered and the weight of a sample of husked-nuts were recorded (Pieris, 1932).

This study, apparently, was to relate selection standards to actual yield data. A very useful correlation has been established: the ratio of copra to the weight of husked-nuts is 32% (Pieris, 1935). Subsequently, this ratio has been used widely to estimate copra weight of palms in field trials.

Ratmalagara Estate Field Trial (REFT)

The field trial started in 1939 was to compare progenies derived from high-yielding palms, low-yielding palms and from mixed heaps with or without selection of seedlings (Pieris, 1939).

Early attempts at analyses of data indicated that the selection of seed parents was ineffective, as there were no significant differences in yield of nuts and copra of the progenies between the three sources of seed. However, there was a significant response to seedling selection (Liyanage, 1953).

A subsequent more critical evaluation of the results revealed that the planting material used had been from two distinct populations. Consequently, there has been a masking of the true results of this trial. More evidence in favour of selection of parent palms for seed collection has been obtained from other progeny trials (Liyanage and Sakai, 1960:)

Progeny trials of SLT palms

The first trial was planted at Marandawila Estate (MEPT) in 1934, for testing 292 open-pollinated progenies of nine selected high-yielding SLT palms growing on the same estate. The progenies were planted without selection on a fully randomized design (Pieris, 1934; 1943).

The second progeny trial was planted at Walpita Estate (WEPT) in 1948, to test the open-pollinated progenies of 232 palms from MEPT. Thus WEPT is second generation progeny testing. The seed parents, seed and seedlings were taken at random without selection. The design is a cubic lattice (Raghavan, 1948).

The third progeny trial was at Bandirippuwa Estate (BEPT), planted in 1959. It is composed of open-pollinated progenies of 125 selected high-yielding palms growing at Bandiruppuwa, Ratmalagara, Letchemy, Archchitotam and Marandawila Estates. The main purpose of this trial is to isolate prepotent palms. The design is a cubic lattice (Harland, 1957; Liyanage, 1959).

It is unfortunate that the data collected from BEPT have not been processed and analysed yet.

The data of MEPT and WEPT have been used extensively for genetic studies such as estimation of genetic and environmental correlations, heritability values, genetic progress due to selection and the construction of a selection index (see section 6).

There was no genetic information, when the mass selection programme was initiated in 1930. Hence, desirable palms for seed collection were identified, based on the seven characters indicated earlier. Out of them, the weight per husked-nut and yield of copra per palm have high heritability values, indicating efficiency of selection of seed parents on that basis (see section 6).

Selection differential

Further, MEPT and WEPT have given very useful information on the effect of selection of seed parents on the performance of their progenies. That effect, when the seed parents are selected from the two extreme ranges (the best 15% and the worst 15% of the palms in the population) based on weight of husked-nuts is indicated in Table 5.

Table 5. *The performance of progeny when the seed parents are selected on weight of husked-nuts*

Proportion selected		*Selection differential*	*Increase/decrease over population mean (%)*
UPWARDS			
The best 5% of the palms	...	55.5	14.4
,, 10% ,,	...	45.7	10.1
,, 15% ,,	...	39.6	7.1
DOWNWARDS			
The worst 5% of the palm	...	−49.5	−15.7
,, 10% ,,	...	−41.4	− 9.3
,, 15% ,,	...	−37.1	− 4.6

(*Source:* Liyanage, 1967)

When the selection differential is increased on an upward basis, with respect to the weight of husked-nuts, the response of the progeny increases. The best 5% of the palms has given progenies with a yield of 14% higher than the population mean. With selection on a downward basis, the worst 5% of the palms gave progenies whose phenotypic value was much inferior to those of the worst 15%. This indicates that there is a response to the selection of SLT palms, when selection is based on weight of husked-nuts (Liyanage, 1967).

Table 6. *Data of the best* 10% *of the parents on the basis of their breeding values*

Parent Number	*Phenotypic value (lb)*	*Breeding value*	*CV of progenies (Un-adjusted yield) (%)*
55	174.3	59.6	19.1
141	111.3	57.6	36.1
179	150.5	48.5	31.6
248	76.1	48.2	19.3
183	113.3	42.9	46.4
237	124.7	41.6	17.1
13	89.5	36.7	25.7
62	147.9	36.5	22.0
284	99.5	35.5	21.0
26	125.3	34.8	32.1

(*Source:* Liyanage, 1967)

Thus, there is definite evidence to prove that selection of SLT palms on certain criteria is an efficient method to collect seed. Selection of palms should be based on the following criteria (see section 6).

— Short internode length.
— high setting of female flowers into fruits,
— high weight of endorsperm per nut,
— high yield of copra per palm/year and
— desirable agronomic characters.

6. GENETIC PARAMETERS OF SLT PALMS

Breeding value

The breeding value of a palm is determined by the average effects of the genes. In this study using WEPT data, the breeding value of a palm has been taken as twice the deviation of the mean of its progenies from the mean of the entire progeny population, in respect of the weight of husked-nuts.

The breeding value of the 104 SLT palms tested has varied between +59.6 and-62.1. These variations are to be expected, as the parents are heterozygous and have been taken at random.The best 10% of the parents on the basis of breeding value are listed in Table 6. The phenotypic value is the weight of husked-nuts (Liyanage, 1967).

Table 7. *The mean weight of endosperm and of the embryos of 8 high-yielding palms*

Seed parent				*Endosperm weight per nut(g)*			*Embryo weight (mg)*		
No.	*Pheno-typical value (lb)*	*Breeding value*	*No. of nuts (Sample)*	*Mean*	*Percent*	*C.V %*	*Mean*	*Percent*	*C.V %*
55	56	59.6 (*a*)	34	362.8	100	6.3	126	100	15.5
		(*b*)	20	362.8	100	10.4	122	96.8	13.0
179	48	48.5 (*a*)	24	354.1	100	7·8	131	100	16.1
		(*b*)	19	353.0	99.7	11.7	135	103.1	12.1
85	56	31.5 (*a*)	18	319.0	100	14.2	118	100	11.5
		(*b*)	36	325.3	102.0	16.9	115	97.5	13.3
62	47	36.5 (*a*)	8	407.3	100	8.4	96	100	16.2
		(*b*)	5	394.0	96.7	12.1	87	90.6	12.4
105	47	18.0 (*a*)	27	325.0	100	9.0	107	100	15.5
		(*b*)	22	317.9	97.8	3.8	106	99.1	13.2
222	51	—9.3 (*a*)	14	329.6	100	8.0	119	100	15.8
		(*b*)	8	287.8	87.3	13.4	105	88.2	13.7
145	48	—15.6 (*a*)	21	285.6	100	3.2	116	100	9.8
		(*b*)	15	285.4	99.9	12.1	115	99.1	8.0
37	45	—28.5 (*a*)	8	398.3	100	11.6	135	100	11.7
		(*b*)	5	340.0	85.4	2.7	117	86.7	2.7

(*Source:* Liyanage, 1969)   (*a*) open-pollinated
(*b*) selfed

The breeding values of palms 55, 141, 179 and 248 were similar, the differences being statistically insignificant; yet there was a high variation in the performance of the progenies, as reflected in their coefficicnts of variation (Table 7). In family 55, none of the progenies gave a mean yield less than the population mean (36.11 kg), whereas in family 248 one out of eight, in 141 two out of eight and in 179 three out of nine palms have given yields less than the population mean. The high progeny means of families 55 and 248 were probably due to the additive effects of genes of the parents rather than to non-additive effects (Liyanage, 1967).

Certain palms are able to transmit the high-yielding character to their offspring inspite of open-pollination, and these have been described as *prepotent palms* (Harland, 1957). Apparently palm No. 55 is such a case; both its phenotypic and breeding values are high, its open-pollinated progenies are consistently high yielding with a low coefficient of, variation (Table 6), and its agronomic characters are of a high standard. Only one percent of the palms tested could be classified as prepotent.

Heritability values

The data collected from the MEPT have been used to calculate the heritability values of a number of characters of the SLT palms.

The method used was to partition the mean squares and mean products of the characters measured into within and between family components and to estimate the genetic, non-genetic variances and covariances. The following heritability values were obtained (Liyanage and Sakai, 1960; Liyanage, 1959; 1961).

Character		*Heritability* (h^2)
Girth of stem	...	0.45
Internode length	...	0.63
Flowering-period	...	0.23
Number of bunches per palm/year	...	0.47
Number of female flowers per bunch	...	0.52
Setting of female flowers into fruits	...	0.81
Number of nuts per bunch	...	0.50
Weight per husked-nut	...	0.95
Number of nuts per palm/year	...	0.48
Yield of copra per palm/year	...	0.67

Selection of seed parents on a basis of yield of copra per palm/year, weight per husked-nut and setting of female flowers will be highly effective. The selection for number of nuts per palm/year, number of bunches per palm/year, number of female flowers per bunch and number of nuts per bunch may be effective, while selection for early flowering will not be effective.

Genetic correlations

In a selection programme, the genetic correlations between the different productive traits of SLT as estimated below would be of considerable importance. Since yield of nuts and yield of copra are highly correlated positively, and the flowering-period and yield of copra are highly correlated negatively, selection of seed parents for early flowering and number of nuts tends to increase the yield of the progeny population with respect to copra production (Liyanage and Sakai, 1960).

Characters		*Genetic correlation* (r_g)
Flowering-period of a palm x weight per husked nut	...	—0.25
Flowering-period of a palm x yield of nuts per palm/year	...	—0.72
Flowering-period of a palm x yield of copra per palm/year	...	—0.81
Weight per husked-nut x yield of copra per palm/year	...	+0.43
Weight per husked-nut x yield of nuts per palm/year	...	—0.22
Yield of nuts per palm/year x yield of copra per palm/year	...	+0.79

These findings suggest that a number of characters should be considered in the selection of seed palms. It is necessary to ascertain which trait would be most useful for this purpose in relation to genetic gain due to selection.

The relative importance of the characters listed above was in the following order of merit: (i) yield of copra, (ii) yield of nuts, (iii) weight per husked-nut and (iv) flowering-period, as indicated below (Liyanage and Sakai, 1960):

Selection criteria of seed parent		*Expected genetic gain in yield of copra*
Yield of copra (lb)	...	31.4 lb
Yield of nuts (no.)	...	21.1 lb
Weight per husked-nut (lb)	...	15.8 lb
Flowering-period (mths)	...	14.9 lb

6.4 Selection index

Heritabilities of, and genetic correlations between various productive traits of the coconut palm have been worked out using data from MEPT. They are of considerable importance in a selection programme. Since the yield of nuts and copra are highly correlated positively (r_0 = 0.79), and the flowering-period and yield of copra are highly correlated negatively (r_g = —0.81), selection of seed parents on early flowering and number of nuts will tend to increase the yield of the progeny with respect to copra production. As a number of characters have to be considered in the selection of seed palms, it would be generally useful to construct selection indices. An index I using three characters has been computed as follows (Liyanage, 1961).

$$1 = X_1 - 14.70\ X_2 - 4.47\ X_3$$

Where X_1 = number of nuts per palm/year
X_2 = weight per husked-nut (lb)
X_3 = flowering-period of palm(mth)

Another selection index applicable to a particular palm as given below, has been calculated based on four characters of a palm (Abeywardena and Mathes, 1980).

$$I = \left(\frac{x_1 - \bar{x}_1}{\sigma_{x_1}}\right) 0.5593 + \left(\frac{x_2 - \bar{x}_2}{\sigma_{x_2}}\right) 0.4743 + \left(\frac{x_3 - \bar{x}_3}{\sigma_{x_3}}\right) 0.3553 + \left(\frac{x_4 - \bar{x}_4}{\sigma_{x_4}}\right) 0.5796$$

Where X_1 : girth of the stem just below the crown (mean of two measurements taken 30 cm apart)

X_2 : number of opened inflorescences and bunches bearing fruits.

X_3 : number of nuts per bunch (averaged over X_2 records)

X_4 : number of green fronds present at a given time.

The four characters listed above could be scored at any time. They lead to the vigour of the palm, but the heritability of those characters has not been reported.

Inbreeding of SLT palms

Eight high-yielding SLT palms whose breeding values are known (Section 6.1) were self-pollinated and open-pollinated nuts were also taken from the same palms. Nuts were harvested during the 52nd week after pollination. The wet weight of the endosperm and the embryo were recorded giving the results presented in Table 7 and Fig. 5. The phenotypic value is the yield of copra per palm/year given in pounds (Liyanage, 1969).

There is considerable variation between palms with respect to the weight of endorsperm from 286 to 407 g and embryo weight from 96 to 136 mg of open-pollinated nuts. These variations are to be expected due to the natural out-crossing habit of the variety of palms under consideration. If the weight of either of these characters is under genic control one could expect different behaviour between genotypes when selfed, depending on the nature of the genes involved. If it is largely due to the additive effects of genes, then the in-breeding depression may be less marked or even negligible than when it is controlled by dominance and epistasis.

Table 8. *Mean yield of SLT* x *SLT* and *SLT* x *GD palms*

	SLT x *SLT*				*SLT* x *GD*			
Year after	*Per palm*		*Per* h_1^+		*Per palm*		*Per* ha^+	
planting	*Nuts*	*Copra (kg)*	*Nuts*	*Copra (kg)*	*nuts*	*Copra (kg)*	*Nuts*	*Copra (kg)*
5th	—	—	—	—	23	5.18	3,630	818
6th	22	5.16	3,480	815	68	15.28	10,740	2,414
7th	52	10.08	8,220	1,592	86	17.70	13,590	2,797
8th	65	14.72	10,270	232,6	65	15.91	10.270	2,514
Total (A)	**139**	**29.96**	**21,970**	**4,733**	**242**	**54.07**	**38,230**	**8,543**
9th	84	18.24	13.270	2,882	103	21.17	16,270	3,345
10th	88	19.11	13,900	3,019	108	27.04	17,060	4.272
11th	121	30.57	19,220	4,830	129	32.49	20,380	5,133
12th	161	41.31	25,440	6.527	146	40.91	23,070	6.464
Total (B)	**454**	**109.83**	**71,830**	**17,258**	**486**	**121.61**	**76,780**	**19,214**
Total (A+B)	**593**	**139.79**	**93,800**	**21,991**	**728**	**175.68**	**115,010**	**27,757**

(*Source:* Liyanage, 1963) +based on 158 palms/ha.

Table 9. *The performance of four types of progenies*

		Mean yield palms 9 to 12 years old			
	Flowering-	*Per palm*		*Per ha*+	
Progeny type	*period (mth)*	*Nuts*	*Copra (kg)*	*Nuts*	*Copra (kg)*
SLT x GD	34.8	64	11.47	10,110	1,810
SLT x YD	37.1	67	11.61	10,590	1,830
SLT x RD	38.9	55	9.58	8.690	1,510
SLT x SLT	52.9	39	7.55	6,160	1,190

(*Source:* Manthriratne, 1971). +based on 158 palms/ha.

Five of the eight palms taken for this experiment (Nos. 55, 179, 85, 62 and 105) were of good breeding value and the remaining three (Nos. 222, 145 and 37) were of low value (Table 9). The loss in weight of endosperm and of embryo of selfed nuts in the former group of palms has been low in relation to those of open-pollinated nuts: in each case the selfed weight being less than 5 percent, except embryro weight of palm 62 which has shown a difference of 9.4 percent. On the other hand, two of the palms of low breeding value have shown a marked decrease in weight of endorsperm and embryo on selfing—over 12 percent in each case.

The behaviour of palm 145 is quite inconsistent: the two characters have shown no in-breeding depression, although the palm is of low breeding value. It is likely that the high phenotypic values of palms 55, 179, 85 and 105 are mainly due to the additive effects of genes rather than to other causes.

The correlation coefficient between gain/loss in endorsperm weight and the breeding value of the palm is high ($r = 0.6935$). Thus, there is an indication that palms of high breeding value could be isolated from phenotypically superior palms (copra production), by selfing and studying the depression on endorsperm and embryo weights relative to the open-pollinated nuts. In this study, 5 palms (55, 179, 65, 105 and 145) would have been picked out as desirable genotypes on the above basis: 4 of them have turned out to be of good breeding value and the other (palm 145) of low value as judged from progency trials. This method takes only 12 months to test the relative breeding value of a palm.

The coconut endosperm is composed mostly of triploid tissue (Abraham and Mathew' 1963) and the embryo diploid. The genic balance may be unlike in the two tissues owing to the double contribution of the female parent to the endosperm. Yet, the percentage loss in weight of endosperm and embryo has been practically the same on selfing, but the coefficient of variation of endorsperm weight has increased with selfing.

In palm No. 55, the weight of 33 embryos (other being aborted) of open-pollinated nuts ranged from 63 to 152 mg with a mean weight of 126 mg, and similar variations were common for the other palms. It was was suggested in 1969 that an interesting study of immense practical value would be to ascertain any useful correlations between weight of embryo, and vigour and yield of the resulting palm within families using embryo culture techniques. Are the heavier embryos within a family an expression of specific combining ability?

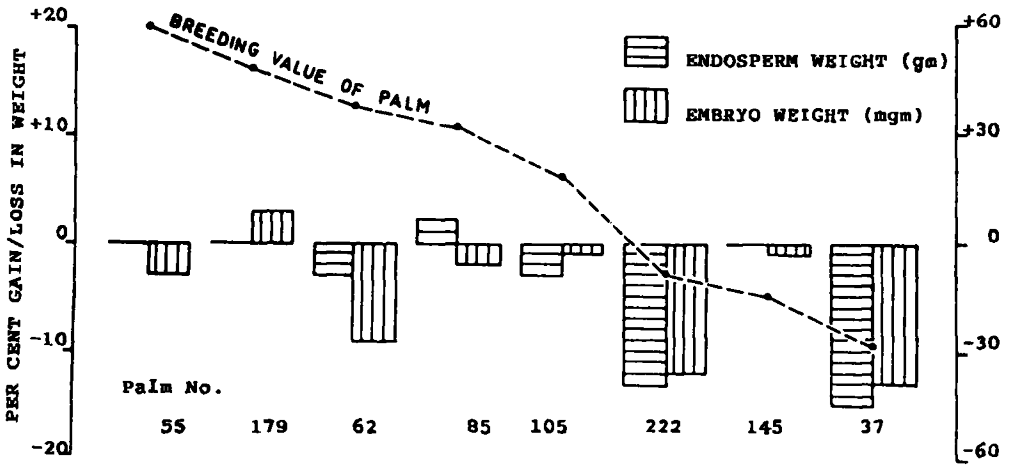

Fig. 5. Percent gain/loss in weight of the wet endosperm and of the embryo due to selfing in relation to the breeding value of the palm.

CONTROLLED POLLINATION

Controlled pollination work on coconut palms was initiated in 1947, with a view to produce improved cultivars through hybridization, Initially the floral biology of SLT and other varieties growing in Sri Lanka had to be studied. Thereafter, pollen collection and processing and techniques of pollination had to be developed.

In SLT, green Dwarf and King Coconut the male phase lasted 18 to 20 days from opening of spathe. The male flowers borne on the upper half of each spikelet open earlier than those on the lower half. They open in early hours of the day and are shed the same evening. In SLT the female phase lasts 5 to 7 days and in Dwarf and King Coconut 10 to 16 days. In the former the male phase precedes the female phase and in the latter they overlap. Thus, SLT is generally cross-pollinated and the other varieties self-pollinated (Liyanage, 1949; 1956).

Spikelets with male flowers about to open were cut from the infloresoences and kept in boxes with the spikelets dipped in test tubes containing water. They were placed in test tube racks over blackpaper. Pollen shed on paper were collected the following morning. Pollen (SLT) germinated in 10% sugar and 2% gelatine medium amounted to 74%. Pollen (SLT) stored in a desiccator with an inside relative humidity of 50% (*ie.* desiccator containing 43.4% H_2SO_4) remained viable for 19 days. Dwarf pollen was more short-lived; on the 8th day of storage, viability was less than 40% (Liyanage, 1949).

Pollen storage techniques were improved subsequently. Vials containing pollen were sealed in an atmosphere about 50% relative humidity and stored at a low temperature (0° C). Pollen remained viable for over 12 months.

Coconut pollen grains are monocolpate. Those of SLT measure 0.065 to 0.069 mm in length and 0.028 to 0.030 mm in diameter. There were no significant inter-varietal differences observed in relation to the size and shape of pollen grains. Pollen production per anther has been estimated at between 110,000 and 221,000 grains (Manthriratne, 1965). A good SLT palm could give about 5 g pollen per inflorescence. Lycopodium powder is a good diluent for pollen, as it mixes well with no tendency for clumping. Mixtures containing pollen/lycopodium in the ratio 1:10 have maintained viability for long periods.

The private sector initiated their own controlled pollination programme with the assistance of CRI who trained the necessary staff and provided pollen. In order to meet the increasing demand for pollen, a Pollen Bank was developed in 1959. Nearly 5,000 samples were distributed to them each year.

In SLT palms, the inflorescences are emasculated, spikelets cut short and covered with a cloth bag on the 17th day after the opening of the spathe. Pollination was done with an insufflator 2 to 3 times per inflorescence when the female flowers were receptive (Liyanage, 1954; Manthriratne and Liyanage, 1960). Since then, these techniques have been further updated.

PRODUCTION OF IMPROVED COCONUT VARIETIES

After the completion of studies on pollen processing and crossability between varieties, a programme to produce intra-and inter-varietal hybrids was introduced in 1949. The main objective was to develop improved varieties.

The first series of crosses

These were restricted to crosses between selected SLT (female parent) and GD palms. The seedlings were planted in 1949 in a block with a fertile loamy soil, situated in the semi-wet intermediate climatic zone. The performance of the F_1 palms are outlined in Tables 8 and 9

Table 10. *Yield of nuts of the seed garden*

Year	1982	1983	1984	1985	1986	*Mean*
Nuts per ha. (based on 165 palms/ha) ...	18,200	17,500	11,100	25,100	17,800	17,900
Total rainfall (mm) ...	1,236	1,209	2,389	1,305	1,014	1,431
No. of wet days ...	110	105	134	110	90	113

(*Source:* Wickramaratne, 1987)

The F_1 palms SLT x GD are early flowering and exhibit hybrid vigour in leaf production and stem formation as indicated below. GD has narrow stems, SLT and F_1 progenies broad stems: the difference between GD and the latter are highly significant ($P = 0.01$). Leaf production was highest in the F_1 progenies, significantly more than the parental types. GD is early flowering. SLT late and the hybrid less than the mid-parental value. Sixty four percent of the hybrids flowered in less than 42 months (Liyanage, 1956).

Character		*SLT* x *SLT*	*GD*	*SLT* x *GD*
No. of leaves produced during the 4th year	...	11.7 ± 2.21	13.4 ± 1.49	15.8 ± 0.83
Girth of stem (in cm) measured 13 cm above ground	...	146.4 ± 15.25	85.4 ± 10.68	164.7 ± 7.63
Flowering-period (mth)	...	74.3	38.0	48.6
No. of plants	...	16	17	22

(*Source:* Liyanage, 1957)

The SLT palms are out-breeding, GD inbreeding and the hybrid between them out-breeding.

The F_1 palms of SLT x GD started bearing fruits in the 5th year after planting and most of them were in production the following year. The SLT x SLT progenies commenced flowering only in the 6th year. The yield data are presented in Table 8 (Liyanage, 1963).

The hybrids (SLT x GD) are more productive than the other variety during the early years of bearing. When the palms are 12 years old, the hybrids have given a cumulative yield of 115,000 nuts/28 tons copra per ha. against 94,000 nuts/22 tons copra from SLT x SLT, *ie.* increase of 22% nuts and 27% copra.

The hybrid starts producing more than 100 nuts/palm/year from the 9th year, whereas SLT x SLT achieved that level of production in the 11th year. When the palms are 11 to 12 years old, the yield differences between the two varieties disappear, each aggregating about 23,500 nuts/6,100 kg. copra per ha/year. During the second four-year period, copra per nut was practically the same (242 to 250 g.)

It is clear that the F_1 of SLT x GD shows precocity in bearing and high production capability in the early years of bearing, compared to SLT x SLT. The latter progenies have also given a very high yield of 140 nuts/36 kg. copra per palm/year, when the palms were 11 to 12 years old. Thus, the possibility exists for the development of two high-yielding varieties F_1 of SLT x GD and SLT x SLT using selected SLT parents.

The second series of crosses

In this programme, progenies of SLT x SLT, SLT x GD, SLT x YD (yellow dwarf, form *eburnea*) and SLT x RD (red dwarf, form *regia*) were studied. They were planted in 1958; 235 plants of the three hybrids and 90 of SLT x SLT. Their performance is summarised in Table 9.

The SLT crossed to the three colour forms of dwarf shows precocity in bearing and are superior to the SLT x SLT. The differences in production between the three types of hybrids are negligible (Manthriratne, 1971).

The copra content per nut of these crosses is given below. The difference between reciprocals is negligible. Conversion ratio is weight of copra: weight of husked-nuts.

Copra	*No. of nuts sampled*	*Copra per nut* (g)	*Conversion ratio* (%)
SLT x GD	952	193	32
GD x SLT	1224	180	32
SLT x RD	575	204	31
RD x SLT	1628	198	31

(*Source:* Manthriratne, 1971)

These results confirm the early flowering character of the SLT x Dwarf progenies.

When the SLT x GD palms were 9 to 12 years, the cumulative production of the first series hybrids was 77,000 nuts/19 tons copra per ha, where as those of the second series recorded only 40,000 nuts/7 tons copra—a decrease of 63% in weight of copra. The drop in yield of copra of the SLT progenies amounted to 75%.

The drastic drop in yield of the second series of plants could be traced to soil factors. Palms of both series were planted in two separate blocks on the same estate. The plants of the first series were planted in a loamy, fertile soil; whereas the other plants were in a heavy clayey soil, subject to cracking in dry weather.

A comparison of the fruit components of CRIC 60 and CRIC 65 is given below. The latter gives a lower weight of husk and shell when compared to the former.

	CRIC 60 (*SLT* x *SLT*)	*CRIC 65* (*Dwarf* x *SLT*)
Mean weight of fruit (g)	1517	1327
Percent ...	100	87
,, of husk (g)	748	640
Percent	100	86
,, of husked-nut (g)	769	687
Percent ...	100	89
,, of shell (g)	204	173
Percent	100	85
,, of kernel (g)	378	348
Percent ...	100	92

(*Source:* Wickramaratne, 1987)

Other crosses

King coconut (KC) x Green Dwarf (GD): The KC female parent has orange red nuts and GD green nuts. Their F_1 palms have reddish brown nuts. The nuts of the hybrid are small in size, giving about 100 nuts per palm/year with 160 g copra per nut.

They are less hardier than SLT palms and are more susceptible to pest damage. They are unsuitable for cultivation on commercial scale (Liyanage, 1957).

San Ramon x GD: 34 progenies gave a mean flowering-period of 50.6 months, yielding 68 nuts in the 9th year with 250 g copra per nut.

This is a cross that should be studied further, the high copra content per nut is a useful character.

Improved varieties

Based on the progeny trials outlined above, two improved coconut varieties were released to the industry: CRIC 60 and CRIC 65.

CRIC 60: Derived by crossing selected SLT x SLT palms. Late flowering (55 to 70 months), out-breeding. hardy palms tolerating a wide range of environmental conditions, capable of producing over 110 nuts per palm/year with about 225 g copra per nut, under rainfed conditions with a satisfactory environment combined with good management (Fig. 6). Released to the industry in 1960. Recommend for planting in all the coconut growing areas in Sri Lanka, where conditions are suitable for coconut cultivation.

CRIC 65: Derived by crossing selected GD x SLT palms. Early flowering (36 to 45 months), out-breeding, tolerates only a restricted environment, capable of producing over 120 nuts per palm/year with about 210 g copra per nut. Released to the industry in 1965. Recommend for planting in the home gardens only or under irrigated conditions.

Thus, the coconut breeding programme has been very successful, culminating in the production of two improved varieties that will help the industry to at least double the coconut production in the country, provided the technology could be passed on to the growers.

Fig. 6. A CRIC 60 Palm 6½ Yrs Old

Germplasm

The importance of having a coconut germplasm collection introduced from other countries has been recognized since 1950. But unfortunately, it could not be implemented, due to the fear that new pests and diseases may be introduced inadvertently. Such fears may be justified, when one considers the large number of diseases of unknown etiology prevalent in many coconut growing countries. Yet an effort should be made to introduce foreign coconut germplasm.

MASS PRODUCTION OF CRIC 60 AND CRIC 65 SEED

It was realised from a study of the characters of juvenile progenies of SLT x SLT and SLT x GD, that they will be highly productive surpassing the yield of SLT palms. Sri Lanka requires two to three million seednuts per year for planting. It will be quite impossible to raise this quantity of seed through artificial pollination. Hence the concept of isolated seed gardens was developed for large scale production of seed (Liyanage 1953, 1960; 1962).

A seed garden is a special coconut plantation, carrying palms of known identity and protected to prevent pollination of palms within the garden by those outside it. The first coconut seed garden in Sri Lanka was initiated in 1955. eventually covering 125 ha. for the production of CRIC 60 seed and subsequently provision made to produce CRIC 65 seed. It is situated in the Puttalam district in the semi-dry intermediate zone.

SLT palms are largely cross-pollinated. The principal agent of pollination is the honey bee (*Apis indica*). Wind pollination is negligible. Based on these factors, it was considered that a forest barrier 800 m deep all round the garden, would prevent pollen contamination between the palms within and outside.

The seed garden was largely planted with seed derived by crossing selected SLT x SLT, except for two blocks where GD open-pollinated seed was planted. The GD is emasculated regularly and is crossed with SLT pollen under natural conditions to produce CRIC 65 seed. The SLT palms will cross naturally between them to give CRIC 60 seed.

Nut production for 5 years of 5,700 SLT x SLT palms growing in the seed garden under rainfed conditions and good management is given in Table 10. The year 1982 is the 27th year after planting seedlings. In the year 1985, production exceeded 25,000 nuts per ha as the rainfall and its distribution were satisfactory in the previous year. In 1984 yield dropped to 11,000 nuts per ha. due to adverse climatic conditions prevalent in 1983..

It could be expected that the plantations raised from the seed of the seed garden may give atleast 18,000 nuts per ha/year under rain-fed conditions and over 25,000 with irrigation. The existing plantations in Sri Lanka that are well managed give about 9,000 nuts ha/year. That means, production could be doubled when CRIC 60 seed is used for planting.

SUMMARY

The coconut palms grown in Sri Lanka have been classified into three varieties with 13 forms amongst them. Only one form *typica* (SLT) is grown on a plantation scale. Besides morphological characters, stomatal density and carotenoids are useful in the classification. All the three varieties have a chromosome number, $2n = 32$.

The SLT are monoecious, generally cross-pollinated and therefore, highly heterozygous. Insects are the major agents of pollination.

The SLT palms flower intially in 54 to 72 months after planting. Optimum yield is obtained when the palms are 16 to 17 years old with a crop of about 7,400 to 9,800 nuts/1400 to 1,960 kg. copra per ha/year with a density of 158 palms. That level is maintained with fluctuations related to environmental factors, until the palms are 50 to 60 years old.

Out of the total crop (copra) for a year, about 63% is harvested between March and August and 37% in the other months.

The components of yield exhibit different levels of repeatability with high values for setting of female flowers into fruits, copra per nut and copra per palm/year.

The heritability (h^2) values for copra weight per nut and per palm are high, for yield of nuts intermediate, and for the flowering-period low. The genetic correlation between yield of nuts and copra is high positive, between yield of copra and the flowering-period is high and negative, Genetic progress in the progenies is likely to be more, if the seed parent is selcted on high yield of copra and nuts rather than on the weight per husked-nut and flowering period.

When the selection differential with respect to yield of copra is increased, the response of progeny increases. The best 5% of the SLT palms in a population have given progenies with a yield of 14.4% higher than the mean for the entire population. Thus, selection of parents, on the lines advocated above, would assist in upgrading progenies in the first generation.

The breeding value of 104 SLT palms in relation to yield of copra has varied between +59.6 and —62.1. Number of leaves produced during the first three years of young palms on a family basis, is related to the breeding value of the parent, giving a quick method of identifying the latter.

Inbred coconut palms have shown a depression on leaf production, flowering-period endosperm weight and embryo weight; the intensity varying between families. Perhaps palms of high-breeding value could be isolated from phenotypically superior palms (copra production) by assessing the inbreeding depression on endosperm and embryo weights. Selection indices have been calculated based on economic characters of production.

Coconut varieties have been developed: CRIC 60 and CRIC 65, both giving very high production of nuts. A seed garden was developed for mass production of seed.

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