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CYTOGENETICS AND BREEDING

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The breeding system of arecanut palm (*Areca catechu* L.), its perennial habit and the long juvenile phase constitute the chief barriers in undertaking cytogenetic and breeding investigations in this crop. The role of cytogenetic investigation in determining the phylogenetic relationship in the family Palmae was first suggested by Sharma and Sarkar (1956). Since then, detailed cytological information, such as chromosome number, meiotic behaviour, chromosome size and morphology, have been reported atleast in the *Areca* spp. through a series of papers (Bavappa and Raman, 1965; Bavappa, Nair and Ratnambal, 1975; Bavappa and Nair, 1978). In recent years newer and sophisticated biometrical techniques have been employed in crop improvement and phylogenetic studies. These methods have been extensively used in improvement of arecanut crop also (Bavappa and Ramachander, 1967a, 1967b, 1968a, 1968b). The usefulness of multivariate analysis to classify *Areca* species and cultivars based on genetic divergence has also been indicated by Bavappa (1974) in an extensive study.

I. Cytogenetics

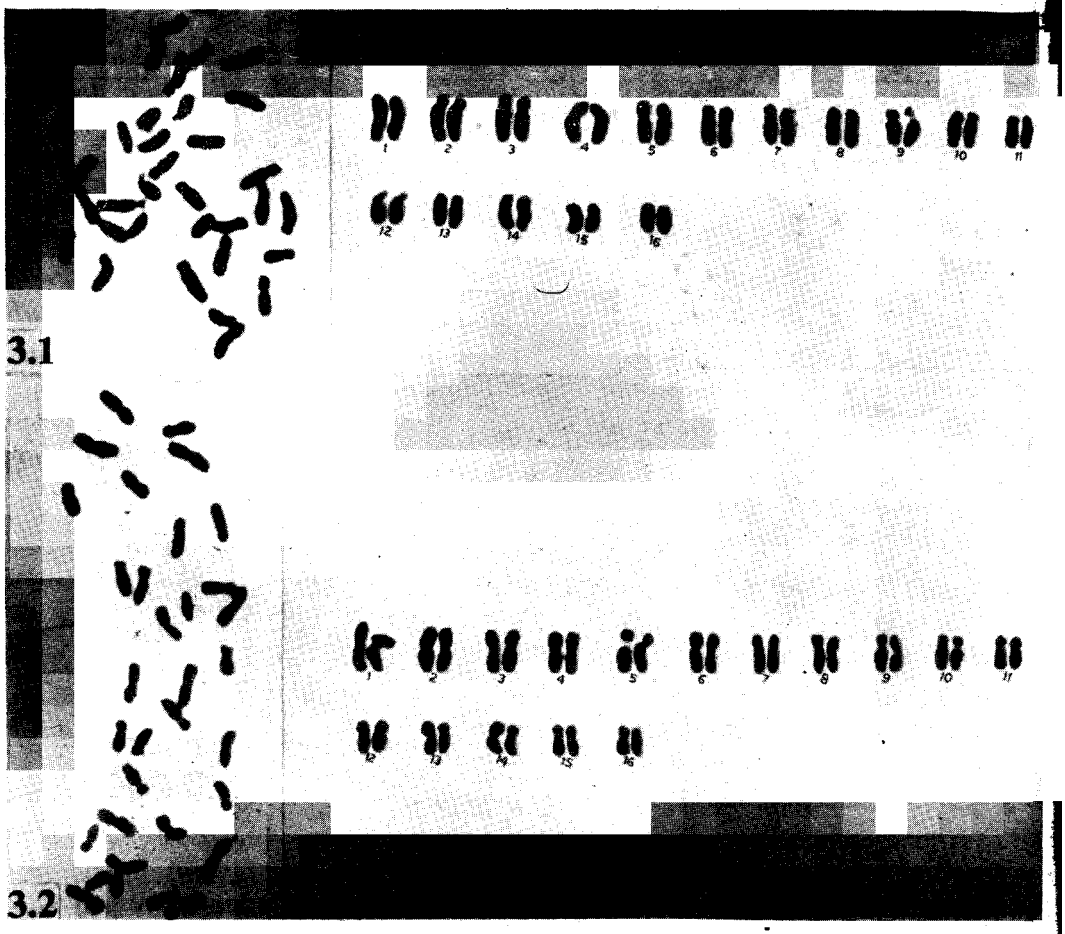
1. Chromosome number

The chromosome number of *Areca catechu* L. was first determined and reported by Venkatasubban (1945) as 2n=32 (Fig. 3.1). The chromosome number of the species was later confirmed by Sharma and Sarkar (1956), Raghavan and Baruah (1958), Abraham, Mathew and Ninan (1961) and Bavappa and Raman (1965).

A chromosome number of 2n=32 reported by Darlington and Janaki Ammal (1945) for *A. triandra* Roxb. was later confirmed by Sharma and Sarkar (1956) and Bavappa and Raman (1965) (Fig. 3.2). Nair and Ratnambal (1978) determined the meiotic chromosome number of *A. macrocalyx* Becc. as n=16 (Fig. 3.3).

2. Meiosis

Meiotic abnormalities such as non-disjunction, lagging chromosomes, univalents and pentads were reported in *A. catechu* by Sharma and Sarkar (1956).



Figs. 3.1—3.2 Somatic chromosomes in *Areca* spp.
Fig. 3.1 A. catechu *2n=32; Fig. 3.2* A. triandra *2n=32.*

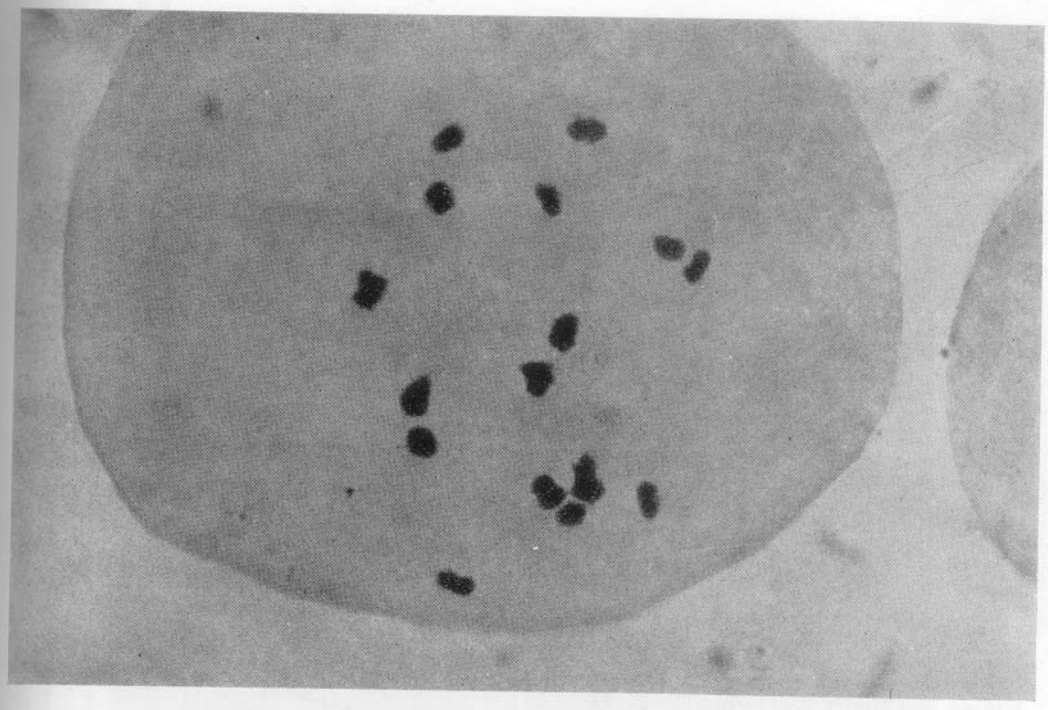
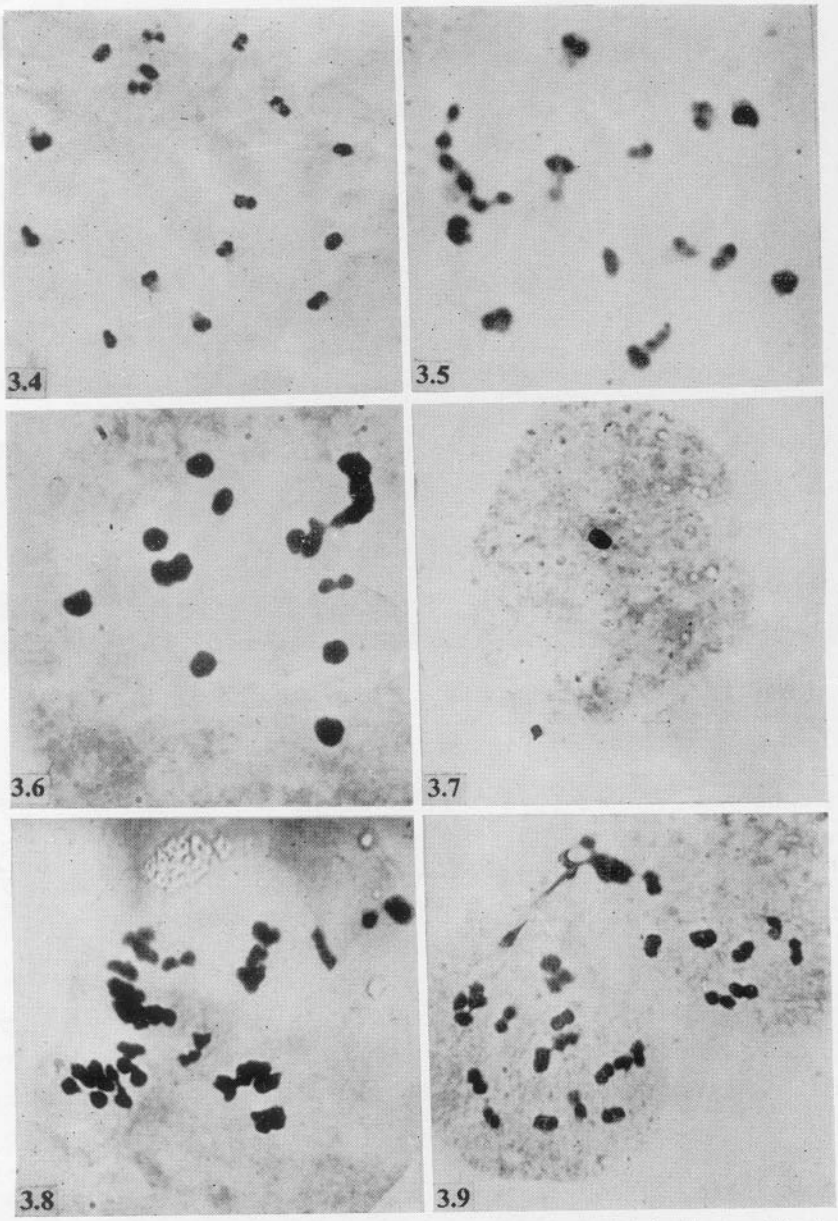


Fig. 3.3 Meiotic chromosomes in *A. macrocalyx* n=16 (1 IV+14 II)

Bavappa and Raman (1965) observed in the meiosis of four ecotypes of *A. catechu,* abnormalities like univalents at diakinesis and metaphase I, non-synchronisation of orientation, clumping, delayed disjunction, chromosome bridges and laggards at anaphase I and II, chromosome mosaics and supernumerary spores.

Sharma and Sarkar (1956) found the meiotic division quite normal in *A. triandra* except for the presence of 14 and 18 chromosomes occasionally at metaphase II. Bavappa and Raman (1965) also reported regular meiotic division in the types of *A. triandra* studied by them.

Intra-cultivar variation in meiotic behaviour of *A. catechu* was reported by Bavappa (1974) and Bavappa and Nair (1978). While normal bivalent formation was observed in some palms (Fig.3.4), others had maximum association of hexavalents (Fig. 3.5) octovalent and even decavalent (Fig. 3.6; Table 3.1). Abnormalities like bridges and laggards, disorientation of chromosomes at anaphase I and anaphase II were also reported in this species (Table 3.2).



Figs. 3.4—3.9 Microsporogenesis in *A. catechu* and *A. triandra*. *Fig. 3.4* A. catechu *Local (717), early M I, 16 II; Fig. 3.5* A. catechu *China (111), diakinesis, I VI+13 II; Fig. 3.6* A. catechu *Local (471), diakinesis, I X+ I IV+ 9 II; Fig. 3.7* A. triandra *Ceylon-3 (55) 1 II+1 I; Fig. 3.8* A. triandra *Ceylon-3 (55), 27 II+1 I; Fig. 3.9* A. triandra *Ceylon-3 (87), Cytomixis.*

Species/hybrids	Diakinesis						Metaphase I						
	No. of PMCs observed	Above quadrivalent (Mean)	IV Range (Mean)	III Range (Mean)	II Range (Mean)	I Range (Mean)	No. of PMCs observed	Above hexavalent (Mean)	VI Range (Mean)	IV Range (Mean)	III Range (Mean)	II Range (Mean)	I Range (Mean)
A. catechu													
Local (471)	82		0–2 (0.67)		12–16 (14.66)		53	0.02 X+ 0.08 VIII	0–2 (0.17)	0–5 (0.60)	0–2 (0.16)	4–16 (13.59)	0–2 (0.08)
Local (717)	100				11–16 (15.64)	0–10 (0.72)	87					15–16 (15.96)	0–2 (0.08)
China (111)	82	0.01 VI	0–2 (0.15)		12–16 (15.55)	0–4 (0.24)	63		0–1 (0.02)	0–2 (0.16)		9–16 (15.62)	
China (175)	80		0–2 (0.24)	0–1 (0.01)	12–16 (15.45)	0–2 (0.11)	43		0–1 (0.02)	0–2 (0.21)		13–15 (15.52)	
A. triandra													
Ceylon-3 (55)	55				8–16 (12.68)	0–14 (6.64)	84				0–1 (0.01)	14–16 (15.73)	0–2 (0.51)
Ceylon-3 (70)	80				6–16 (13.74)	0–20 (4.52)	76					13–16 (15.71)	0–6 (0.58)
Ceylon-3 (87)	96		0–1 (0.03)		7–16 (12.85)	0–18 (6.18)	66					8–16 (14.65)	0–16 (2.70)
Mauritius (109)	49			0–1 (0.06)	5–16 (12.12)	0–22 (7.58)	71				0–2 (0.10)	4–16 (13.46)	0–24 (4.78)
Indonesia-2 (154)	38				4–15 (11.05)	1–24 (9.90)	36			0–1 (0.03)	0–1 (0.03)	8–16 (14.59)	0–16 (2.41)
A. catechu × *A. triandra*													
Palm No. 248	107	0.31VIII+ 0.01VI+ 0.01IV	0–2 (0.10)	0–3 (0.40)	2–14 (8.92)	0–28 (12.37)	61		0–1 (0.02)	0–1 (0.02)	0–2 (0.12)	5–16 (14.07)	0–10 (3.30)
Palm No. 287	90			0–1 (0.08)	0–16 (11.24)	0–32 (9.28)	114				0–1 (0.06)	10–16 (14.83)	0–9 (2.16)
Palm No. 288	82		0–1 (0.13)	0–1 (0.05)	8–16 (14.34)	0–14 (2.65)	81			0–1 (0.09)	0–1 (0.06)	11–16 (15.33)	0–6 (0.90)
Palm No. 307	65				1–16 (10.34)	0–30 (11.32)	97				0–1 (0.01)	13–16 (15.73)	0–6 (0.51)
Spontaneous hybrid	57		0–1 (0.04)	0–1 (0.09)	4–16 (9.90)	5–24 (11.77)	39				0–1 (0.05)	11–16 (14.33)	0–10 (3.19)

Table 3.2. *Abnormalities at later stages of meiosis, pollen fertility and nut set in* A. catechu, A. triandra *and their hybrids*

Species/hybrids	Anaphase I		Anaphase II		Tetrads						Pollen fertility (%)	Nut set (%)
	No. of cells observed	Cells with bridges, laggards and disorientation %	No. of cells observed	Cells with bridges, laggards and disorientation %	No. of cells observed	Micronuclei (%)	Monads (%)	Diads (%)	Triads (%)	Supernumerary spores (%)		
A. catechu												
Local (471)	121	9.1	84	10.7	171	0.0	0.0	0.0	12.3	0.0	95.4	26.4
Local (717)	123	11.4	67	1.5	144	0.8	0.0	1.4	2.0	0.0	82.7	36.9
China (111)	163	0.6	70	0.0	67	0.0	0.0	0.0	3.0	0.0	98.2	42.2
China (175)	95	6.3	63	4.8	106	0.0	0.0	2.8	10.4	0.0	95.7	12.0
A. triandra												
Ceylon-3 (55)	148	26.4	81	11.1	178	1.7	0.5	1.7	2.8	0.0	75.5	36.4
Ceylon-3 (70)	110	8.2	67	1.5	140	0.0	0.0	0.7	12.9	0.7	65.4	42.1
Ceylon-3 (87)	106	17.9	77	15.6	147	4.1	0.0	0.7	13.6	2.7	63.3	28.1
Mauritius (109)	44	29.5	41	26.8	175	14.9	1.7	4.6	6.8	0.0	33.1	33.8
Indonesia-2 (154)	80	18.8	57	24.6	164	1.8	1.2	0.0	4.3	0.0	45.2	41.3
A. catechu × *A. triandra*												
Palm No. 248	89	69.7	44	52.3	137	22.6	0.0	2.2	16.1	2.9	3.7	0.5
Palm No. 287	109	14.7	117	16.2	148	4.7	0.0	0.7	8.8	0.0	0.5	0.3
Palm No. 288	87	29.9	93	26.9	185	4.6	0.0	3.2	11.8	4.8	8.3	0.0
Palm No. 307	46	71.7	80	37.5	133	10.9	0.7	0.4	2.3	0.4	6.1	0.0
Spontaneous hybrid	71	46.5	66	31.8	143	12.6	6.3	9.8	15.4	0.0	0.1	0.0

Intra-palm variation in chromosome numbers in the pollen mother cells of *A. catechu, A. triandra* and their hybrids was reported by Bavappa and Nair (1978) (Fig. 3.7 and 3.8; Table 3.3) and cytomixis to an extent of 39% seemed to have contributed to this abnormality (Fig. 3.9). In spite of high degree of multivalents in *A. catechu,* pollen fertility was very high. The possibility of the frequency of multivalent formation and disjunction being under genotypic control and being subjected to selection was suggested by Bavappa and Nair (1978).

Table 3.3. *Intra-palm variation in chromosome number at meiosis in* A. catechu, A. triandra *and their interspecific hybrids*

Species/hybrids	Meiotic stage	Number of PMCs observed	Number of PMCs with chromosome mosaic	Percentage	Range of chromosome association
A. catechu					
Local (471)	Diak.	82	–	–	
	MI	53	–	–	
Local (717)	Diak.	102	2	2.0	15II
	MI	87	–	–	–
China (111)	Diak.	88	6	6.8	6II to 1IV+13II
	MI	66	3	4.5	6II to 15II
China (175)	Diak.	80	–	–	–
	MI	43	–	–	–
A. triandra					
Ceylon-3 (55)	Diak.	72	17	23.6	5II+1I to 17II
	MI	98	14	14.3	1II+1I to 27II+1I
Ceylon-3 (70)	Diak.	87	7	8.0	8II+3I to 15II
	MI	81	5	6.2	12II to 19II
Ceylon-3 (87)	Diak.	103	7	6.8	5II+5I to 15II
	MI	73	7	9.6	2II to 18II+1Fr
Mauritius (109)	Diak.	56	7	12.5	4II+3I to 1IV+1III+7II+13I
	MI	79	8	10.1	7II to 1III+9II+13I
Indonesia-2 (154)	Diak.	38	–	–	–
	MI	37	1	2.7	15II+1Fr
A. catechu × *A. triandra*					
Palm No. 248	Diak.	119	12	1.0	1II+3I to 1VI+8II+4I
	MI	64	3	4.6	12II+6I to 1III+10II+3I
Palm No. 287	Diak.	97	7	7.2	4II+3I to 1III+2II+8I
	MI	117	3	2.6	8II to 1III+13II+1I
Palm No. 288	Diak.	87	5	5.7	2II+2I to 1III+14II+3I
	MI	85	4	4.7	14II to 1III+13II+2I
Palm No. 307	Diak.	72	7	9.7	6II to 27II+2I
	MI	105	8	7.6	11II to 1III+13II+2I
Spontaneous hybrid	Diak.	60	3	5.0	13II+15I to 1III+9II+9I
	MI	44	4	9.1	15II+1I to 9II to 12I

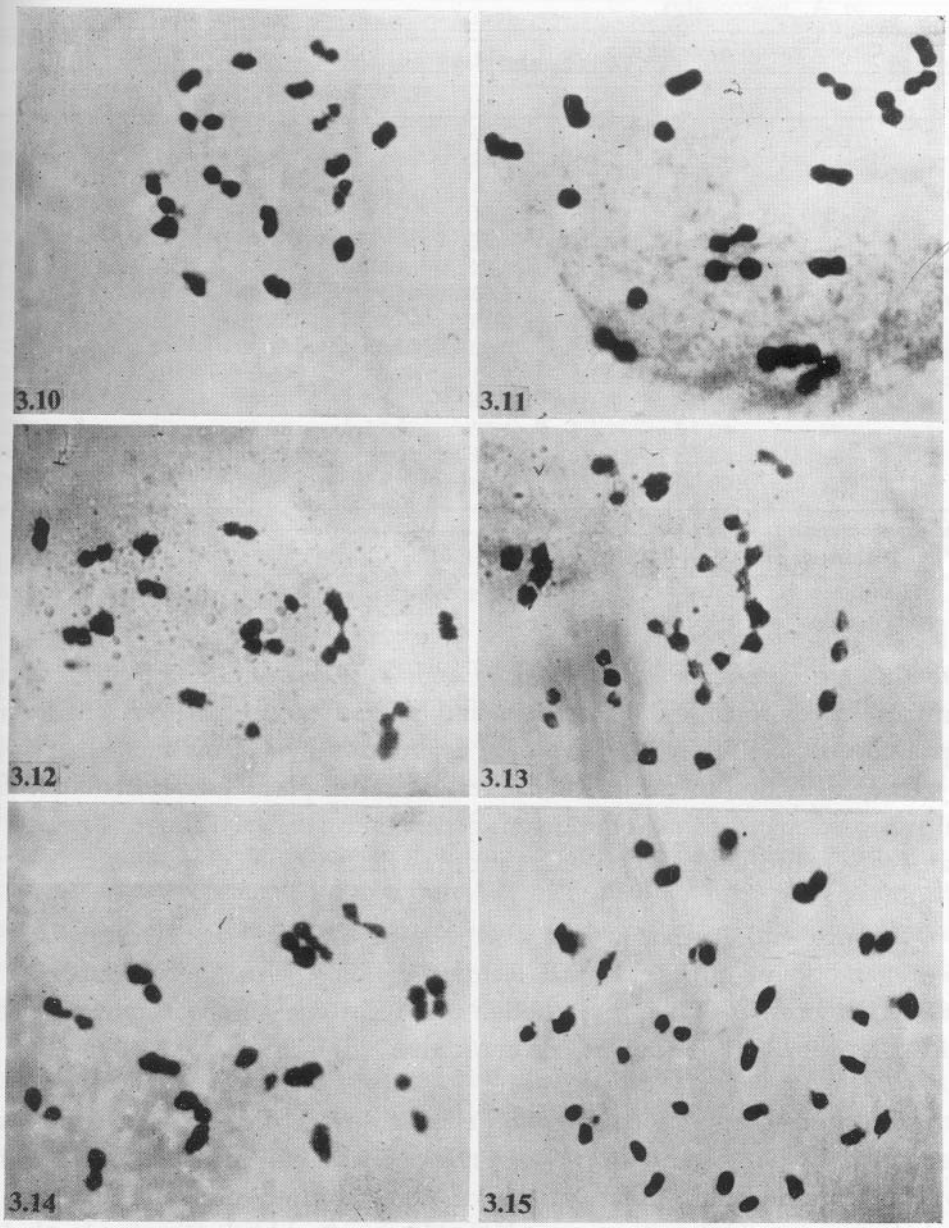
Meiotic observation in five palms belonging to *A. triandra* showed that maximum association of only bivalents occurs in palm No. 70 (Fig. 3.10), and trivalents (Fig. 3.11) and quadrivalents (Fig. 3.12) in the others (Table 3.1). The chromosome pairing in *A. catechu* × *A. triandra* hybrids showed a maximum association of one octovalent in hybrid No. 248 (Fig. 3.13), quadrivalent in hybrid No. 288 and spontaneous hybrid (Fig. 3.14) and trivalents in others (Table 3.1).

Partial desynapsis of chromosomes at diakinesis was reported by Bavappa (1974) and Bavappa and Nair (1978) in *A. triandra* and *A. catechu* × *A. triandra* hybrids. Desynapsis observed at diakinesis was followed by an increase in pairing at metaphase I as reflected by the frequency of bivalents (Table 3.1) in *A. triandra* and *A. catechu* × *A. triandra* hybrids and this was attributed to distributive pairing, a mechanism that has been possibly adopted for ensuring their regular segregation (Bavappa and Nair, 1978). The extent of desynapsis was higher in the F_1 hybrids of *A. catechu* and *A. triandra* (Fig. 3.15) as compared to *A. triandra,* suggesting that the gene controlling this character may be dominant. The large number of univalents observed in the hybrid as compared to *A. triandra* parent (Table 3.1) has been attributed to reduced homology of the parental chromosomes (Bavappa and Nair, 1978).

Nair and Ratnambal (1978) reported chromosome association in *A. macrocalyx* during microsporogenesis. While 16 bivalents were of the highest frequency at diakinesis and metaphase I, the maximum configuration observed was one hexavalent at both the stages of division (Table 3.4). The chromosome association in *A. macrocalyx* indicated the probability of autopolyploid origin with restricted multivalent formation as in the case of *A. catechu* and *A. triandra.*

3. Karyotype

Venkatasubban (1945) observed two pairs of short satellite chromosomes in the somatic chromosome complement of *A. catechu.* Three pairs of long chromosomes, six pairs of medium sized chromosomes and seven pairs of short chromosomes were observed by Sharma and Sarkar (1956) in *A. catechu.* They categorised the chromosomes into seven groups based on their morphology and relative length. Two pairs of long chromosomes next to the longest was found to have secondary constrictions. They also observed that the chromosomes of *A. triandra* were longer than those of *A. catechu.* Bavappa and Raman (1965)



Figs. 3.10—3.15 Microsporogenesis in *A. triandra* and *A. catechu* × *A. triandra* hybrids. *Fig. 3.10* A. triandra *Ceylon–3 (70), diakinesis 16 II; Fig. 3.11* A. triandra *Mauritius (109), M I, 1 III+13 II+ 3 I; Fig. 3.12* A. triandra *Ceylon–3 (87), diakinesis I IV + 13 II + 2 I; Fig. 3.13* A. catechu × A. triandra *(248), diakinesis I VIII + I V + I III + 5 II + 6 I; Fig. 3.14 Spontaneous hybrid, M1, 1 IV + 11 II + 6 I; Fig. 3.15* A. catechu × A. triandra *(287), diakinesis, 1 II + 30 I.*

Table 3.4. *Chromosome associations and their frequencies at diakinesis and metaphase in* A. macrocalyx

Chromosome associations				Frequencies at	
VI	IV	II	I	Diakinesis	Metaphase I
1	—	13		5	3
	4	8		2	4
	3	10		2	3
	2	12		7	5
	1	14		17	9
		16		50	17
		15	2	6	8
		14	4	2	2
		13	6	1	6
				92	57

Average association :

Diakinesis : $0.05_{VI} + 0.49_{IV} + 14.73_{II} + 0.28_{I}$

Metaphase I : $0.05_{VI} + 0.77_{IV} + 13.83_{II} + 1.06_{I}$

found the chromosomes of *A. catechu* and *A. triandra* differing in size, total chromatin length, position of primary and secondary constrictions and number and position of satellites. Based on the assumption of Sharma and Sarkar (1956) that gradual reduction in chromatin matter had taken place in the evolution from primitive to advanced forms of different genera and tribe of Palmae, Bavappa and Raman (1965) considered *A. catechu* as more advanced than *A. triandra.*

Bavappa and Raman (1965) also studied the pachytene chromosomes in *A. catechu* and found morphological features in fairly close agreement with the somatic chromosomes (Table 3.5), though the pachytene chromosomes were about ten times longer than the somatic chromosomes.

The chromosome morphology of a few cultivars of *A. catechu* from Assam was reported by Raghavan (1957). Minor variation in structure and length of individual chromosomes, total length of the complement and position of constrictions among the types was noted by him. On the basis of morphology, he recognised nine groups in the somatic chromosomes of the cultivars.

Studies on the karyotypes of eight cultivars of *A. catechu* and four ecotypes of *A. triandra* (Bavappa, 1974; Bavappa, Nair and Ratnambal, 1975) revealed

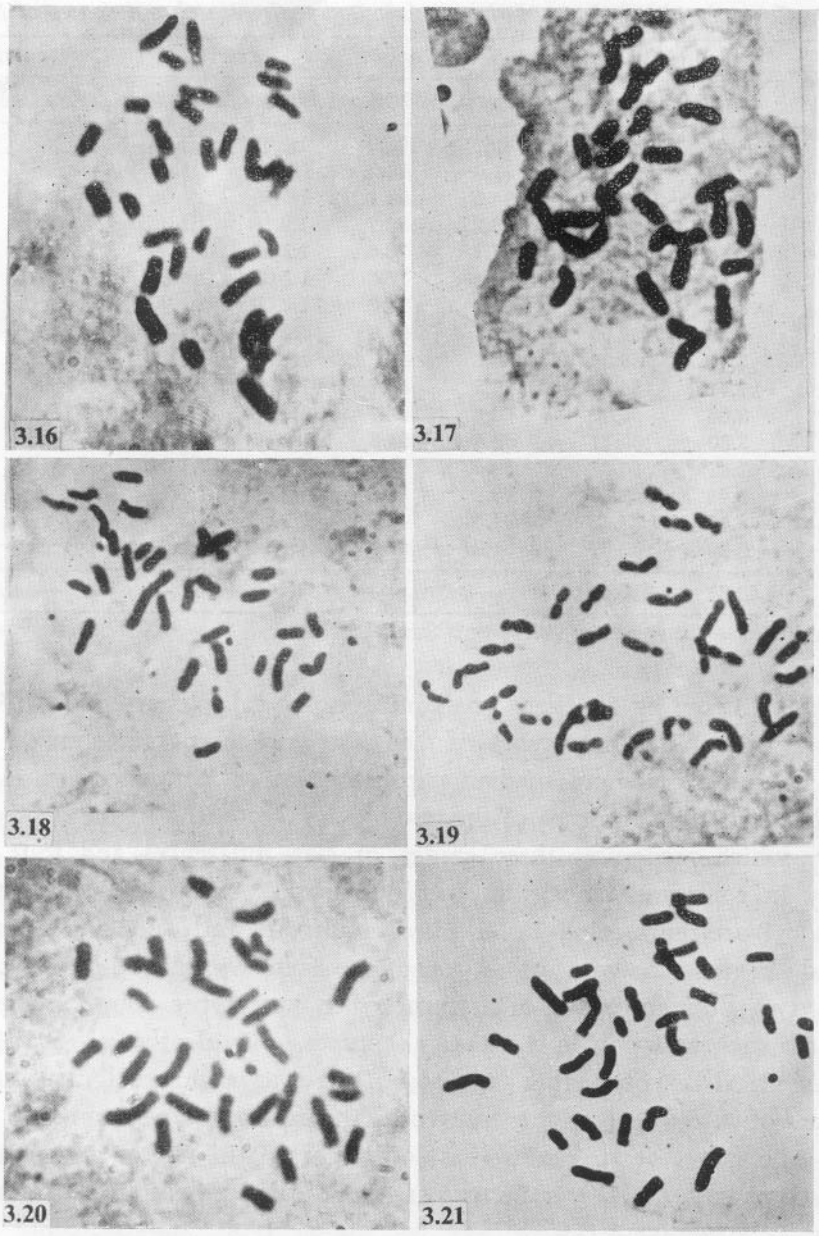
Table 3.5. *Comparative analysis of the somatic and pachytene chromosomes of* A. catechu

Chromosome	Length in μ		Relative length		Arm ratio		Centromere position	
	Somatic	Pachytene	Somatic	Pachytene	Somatic	Pachytene	Somatic	Pachytene
I	4.41	56.63	100.0	100.0	1:1.20	1:1.33	M	Sm
II	4.28	53.89	97.0	95.2	1:1.46	1:1.40	Sm	Sm
III	4.17	49.91	94.5	88.1	1:1.45	1:1.09	Sm	M
IV	3.89	46.86	88.2	82.7	1:2.19	1:1.35	St	Sm
V	3.78	46.00	85.7	75.9	1:1.29	1:1.54	Sm	Sm
VI	3.41	42.63	77.3	75.5	1:2.09	1:4.26	St	St
VII	3.31	42.04	75.1	74.2	1:2.09	1:1.79	St	Sm
VIII	3.28	39.00	74.4	68.9	1:1.88	1:1.45	Sm	Sm
IX	3.21	36.36	72.7	64.2	1:1.83	1:1.25	Sm	M
X	3.11	34.31	70.5	60.2	1:1.83	1:2.21	Sm	St
XI	3.06	30.99	69.3	54.7	1:1.78	1:1.45	Sm	Sm
XII	2.80	30.77	63.5	54.3	1:1.62	1:2.76	Sm	St
XIII	2.47	30.22	56.0	53.4	1:1.11	1:1.04	M	M
XIV	2.44	28.49	56.3	50.3	1:1.87	1:1.14	Sm	M
XV	2.40	25.63	54.4	45.3	1:3.00	1:3.50	St	St
XVI	2.29	22.67	51.9	40.0	1:1.31	1:3.02	Sm	St
Total :	52.31	616.40	—	—	—	—	—	—

M = Median; Sm = Sub-median; St = Sub-terminal

considerable differences in their gross morphological characteristics (Figs.3.16–3.42; Table 3.6). The karyotypes of the *A. triandra* ecotypes showed a higher frequency of submedian and median chromosomes as compared to *A. catechu.* A classification of the karyotype of the two species according to the degree of their asymmetry which recognises three grades of size differences and four grades of asymmetry in centromere position (Stebbins, 1958), showed that karyotypes, 1B, 2A, 2B and 3B are represented in *A. catechu* cultivars and only 1A, 2A and 2B are represented in the ecotypes of *A. triandra.* Even within the same cultivar of *A. catechu,* two different types of asymmetry in karyotypes were observed, while there was no such variation in *A. triandra* ecotypes. Evidently *A. triandra* has a more symmetrical karyotype than *A. catechu.* It was concluded that delineating the cultivars of *A. catechu* on the basis of standard karyotype seemed to be rather difficult. The fact that *A. catechu* has lesser chromatin matter and asymmetrical karyotype compared to *A. triandra* shows that the latter is more primitive.

In *A. catechu* and *A. triandra* the relative length of chromosomes ranged from 4.12 to 8.59 whereas in the *A. catechu* × *A. triandra* hybrids the variation was from 3.45 to 10.72 (Table 3.7). This indicated that compensation effect due to differential dimensions of the parental chromosomes has brought about a reduction in the length of the shortest chromosome and an increase in that of the longest



Figs. 3.16—3.21 Somatic chromosomes in *Areca* spp. and hybrids. *Fig. 3.16* A. catechu *Local (717), 2n=32; Fig. 3.17* A. catechu *China (111), 2n=32; Fig. 3.18* A. triandra *Indonesia-2 (154), 2n=32; Fig. 3.19* A. triandra *Ceylon-3 (87), 2n=32; Fig. 3.20* A. catechu × A. triandra *(248), 2n=32; Fig. 3.21* A. catechu × A. triandra *(307), 2n=32.*

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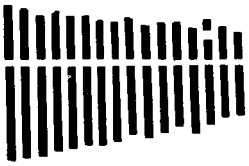

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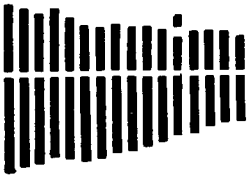

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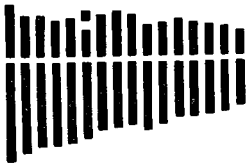

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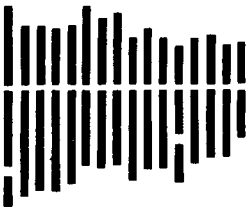
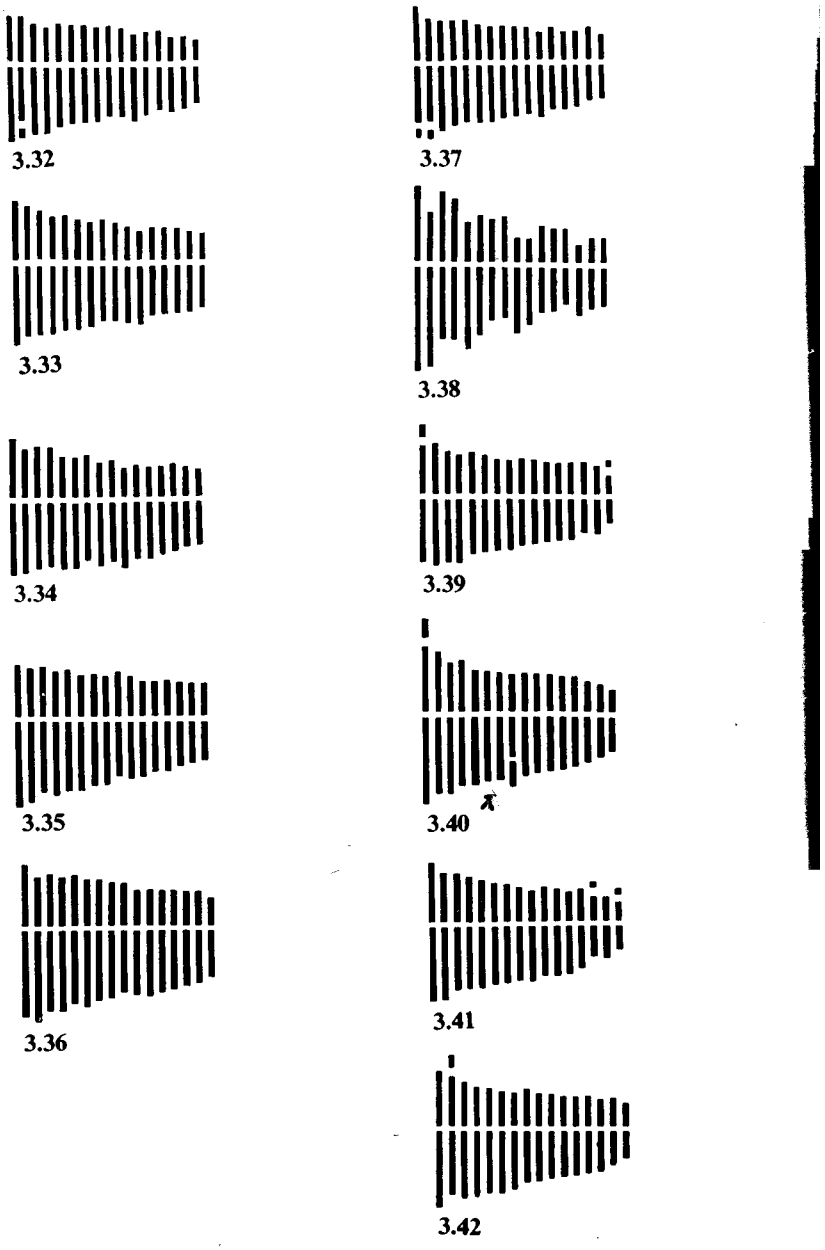


3.31

Fig. 3.22—3.31 Idiograms of *A. catechu* and *A. triandra*. *Fig. 3.22* A. catechu *Local (471); Fig. 3.23* A. catechu *Local (717); Fig. 3.24* A. catechu *China (111); Fig. 3.25* A. catechu *Ceylon-1 (191); Fig. 3.26* A. catechu *Indonesia (6); Fig 3.27* A. catechu *Saigon-1 (176); Fig. 3.28* A. catechu *Saigon-2 (180); Fig. 2.29* A. catechu *Ceylon-2 (192); Fig. 3.30* A. catechu *Singapore (163); Fig. 3.31* A. triandra *Mauritius (109).*



Figs. 3.32—3.42 Idiograms of *A. triandra* and *A. catechu* × *A. triandra* hybrids. *Fig. 3.32* A. triandra *Indonesia-1 (125); Fig. 3.33* A. triandra *Indonesia-2 (74); Fig. 3.34* A. triandra *Indonesia-2 (154); Fig. 3.35* A. triandra *Ceylon-3 (55); Fig. 3.36* A. triandra *Ceylon-3 (70); Fig. 3.37* A. triandra *Ceylon-3 (87); Fig. 3.38* A. catechu × A. triandra *(248); Fig. 3.39* A. catechu × A. triandra *(287); Fig. 3.40* A. catechu × A. triandra *(288); Fig. 3.41* A. catechu × A. triandra *(307); Fig. 3.42* A. catechu × A. triandra *Spontaneous hybrid.*

Table 3.6. *Karyotype differences in* A. catechu, A. triandra *and their hybrids*

Species/hybrids	2n	Total chromatin length (μ)	Range of chromosome length (μ)	Chromosome types			Satellite chromosome	Symmetry (Stebbins, 1958)
				Median	Sub-median	Sub-terminal		
A. catechu								
Local (471)	32	49.42	4.13–2.18	–	6	10	3	2A
Local (717)	32	43.97	3.78–1.83	5	11	–	–	1B
China (111)	32	41.64	3.59–1.72	–	1	15	1	3B
Ceylon-1 (191)	32	51.79	4.41–2.14	5	9	2	1	1B
Indonesia-6 (61)	32	46.81	4.12–1.93	–	3	13	1	2B
Saigon-1 (176)	32	44·48	3.67–1.92	–	9	7	1	2A
Saigon-2 (180)	32	50.78	4.15–2.13	–	3	13	1	2A
Ceylon-2 (192)	32	47.60	4.43–1.88	–	3	13	1	3B
Singapore (163)	32	44.52	3.62–2.11	–	6	10	2	2A
A. triandra								
Mauritius (109)	32	61.21	5.24–2.52	4	3	9	2	2B
Indonesia-1 (125)	32	48.04	4.04–2.02	–	9	7	1	2B
Indonesia-2 (74)	32	53.73	4.68–2.40	2	8	6	–	2A
Indonesia-2 (154)	32	54.14	4.41–2.44	3	7	6	–	2A
Ceylon-3 (55)	32	56.32	4.72–2.46	1	10	5	–	1A
Ceylon-3 (70)	32	59.77	4.89–2.62	–	11	5	–	1A
Ceylon-3 (87)	32	50.59	4.20–2.14	3	12	1	2	1A
A. catechu × *A. triandra*								
Palm No. (248)	32	56.80	6.19–2.21	6	4	6	–	2B
Palm No. (287)	32	47.35	4.20–1.68	9	7	–	2	1B
Palm No. (288)	32	55.88	5.77–1.99	2	11	3	2	2B
Palm No. (307)	32	48.69	4.51–1.68	5	10	1	2	1B
Spontaneous hybrid	32	48.19	4.43–1.83	2	12	2	1	1B

Table 3.7. *Chromosome frequencies of* A. catechu, A. triandra *and interspecific hybrids in different relative length classes*

Species/hybrids	10.9	10.4	9.9	9.4	8.9	8.4	7.9	7.4	6.9	6.4	5.9	5.4	4.9	4.4	3.9	3.4
A. catechu																
Local (471)	–	–	–	–	–	1	1	3	2	3	2	2	2	–	–	
Local (717)	–	–	–	–	1	–	2	2	2	2	2	2	2	1	–	
China (111)	–	–	–	–	1	–	2	2	1	4	2	2	1	1	–	
Ceylon-1 (191)	–	–	–	–	1	1	2	1	3	1	2	2	2	1	–	
Indonesia-6 (61)	–	–	–	–	1	–	2	2	2	2	3	2	1	1	–	
Saigon-1 (176)	–	–	–	–	–	1	2	1	3	3	2	2	1	1	–	
Saigon-2 (180)	–	–	–	–	–	1	2	2	2	3	2	2	1	1	–	
Ceylon-2 (192)	–	–	–	2	1	1	1	1	1	1	1	3	2	2	–	
Singapore (163)	–	–	–	–	–	1	1	2	3	3	3	2	1	–	–	
A. triandra																
Mauritius (109)	–	–	–	–	–	1	1	2	4	2	4	–	1	1	–	
Indonesia-1 (125)	–	–	–	–	1	–	2	2	2	3	2	2	1	1	–	
Indonesia-2 (74)	–	–	–	–	1	–	2	2	1	3	3	2	2	–	–	
Indonesia-2 (154)	–	–	–	–	–	1	2	2	2	3	2	2	1	1	–	
Ceylon-3 (55)	–	–	–	–	–	1	2	2	2	2	3	3	–	1	–	
Ceylon-3 (70)	–	–	–	–	–	1	2	2	2	2	3	3	–	1	–	
Ceylon-3 (87)	–	–	–	–	–	1	1	1	2	3	4	2	1	1	–	
A. catechu×*A. triandra*																
Palm No. (248)	1	–	–	1	1	1	–	1	1	2	2	1	2	2	1	
Palm No. (287)	–	–	–	2	–	–	2	1	1	2	3	2	2	–	1	
Palm No. (288)	–	1	–	–	1	–	1	1	2	3	2	2	1	1	1	
Palm No. (307)	–	–	–	1	1	1	1	1	2	1	4	1	–	2	1	
Spontaneous hybrid	–	–	–	1	1	–	1	2	2	2	2	2	2	–	1	

chromosome. No consistency in the presence/absence, the number and position of satellites could be observed either in the parents or hybrids. It was inferred that in the classification of the karyotypes in *Areca* species, satellite may have only limited role.

4. Basic number

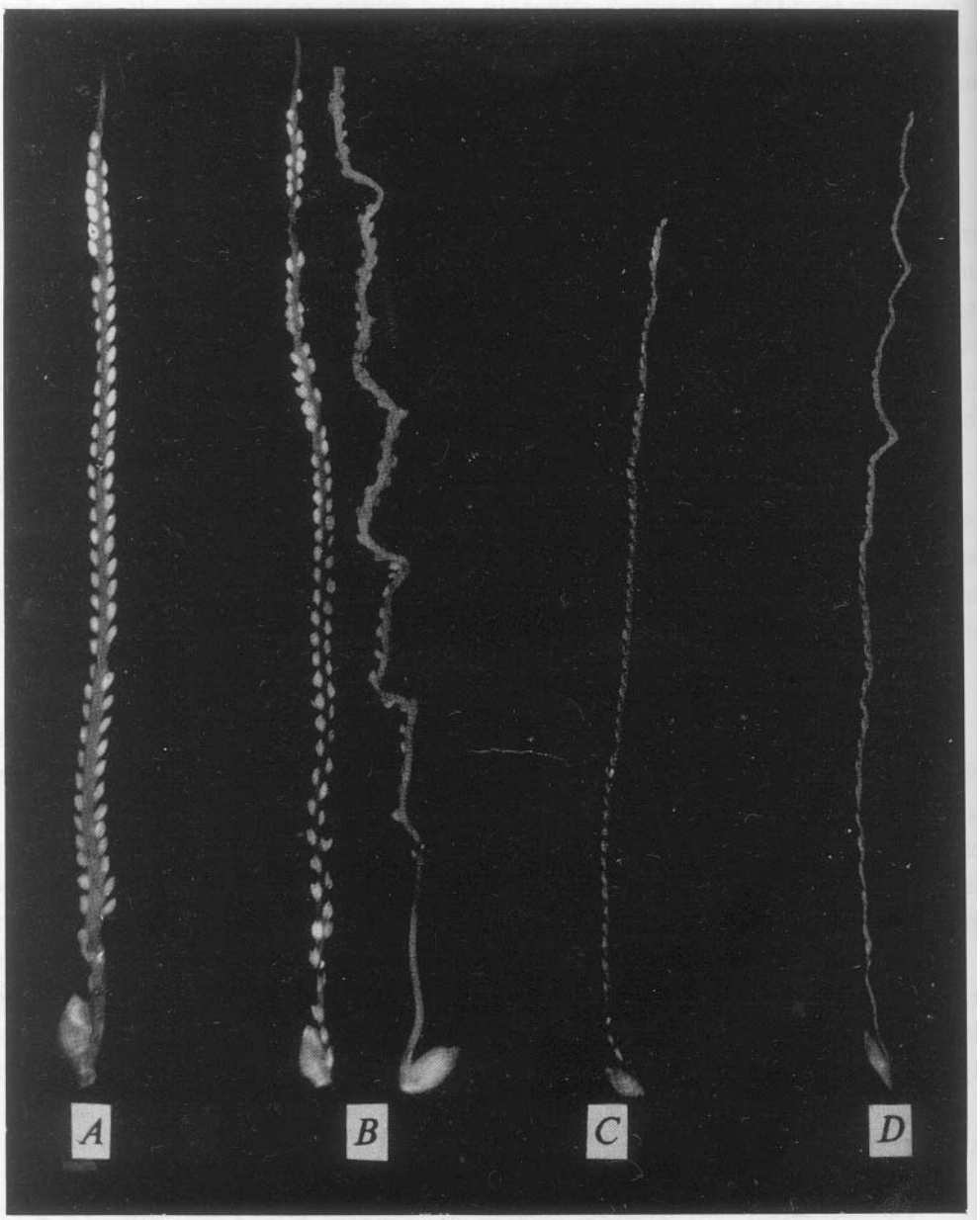
Based on the cytogenetical studies on different genera of Palmae, Venkatasubban (1945) suggested a basic number of x=8 and secondary basic numbers of x=7 and 9, derived from x=8 by fusion and fragmentation respectively. Darlington and Janaki Ammal (1945) proposed x=16 as the basic number for *Areca*. Sharma and Sarkar (1956) stressed the role of amphidiploidy in the initial stages of evolution of the tribe *Areceae* and deduced a basic number of x=8 for the tribe.

A basic number of x=7 was assumed for *Areca* by Bavappa and Raman (1965) based on the secondary association and karyomorphological data. They could recognise seven groups in the chromosome complement of *A. catechu* as distinguished by the length and morphology of somatic as well as pachytene chromosomes and concluded that *A. catechu* is a secondary allotetraploid.

5. Apomixis

Bavappa and Nair (1975) reported morphological differences in reciprocal hybrids between *A. catechu* and *A. triandra*. All the *A. triandra* × *A. catechu* plants showed considerable morphological similarities with the female parent for stem number, internodal distance, stem girth at fixed mark, leaf number per clump, female flower size, number and size of male flowers, male flower arrangements (Figs. 3.43 A-D) and maturity period of fruits (Table 3.8). While F_1 of *A. catechu* × *A. triandra* showed clear evidences for heterosis and dominance for certain characters, the reciprocal hybrids did not show such genetic effect. These, along with the differences in F_0 nuts observed in the reciprocal crosses (Fig. 3.44; Table 3.9), and failure of *A. catechu* pollen to germinate on the stigma of *A. triandra* indicated that *A. triandra* × *A. catechu* nuts (F_0) might not be of sexual origin.

Apomictic reproduction in *A. triandra* was indicated by the limited degree of meiotic irregularities, reduced pollen fertility, low quantity of pollen, and low chiasma frequency in the species(Bavappa, 1974), together with morphological and genetical evidences obtained from the reciprocal crosses. The observation that *A. catechu* pollen failed to germinate on the stigma of *A. triandra* and fruit set



Figs. 3.43A—D Arrangements of male flowers on the rachis. *A.* A. catechu—*single biseriate and alternate;* *B.* A. catechu × A. triandra—*pairs, biseriate and alternate;* *C.* A. triandra × A. catechu—*pairs, uniseriate;* *D.* A. triandra—*pairs, uniseriate.*

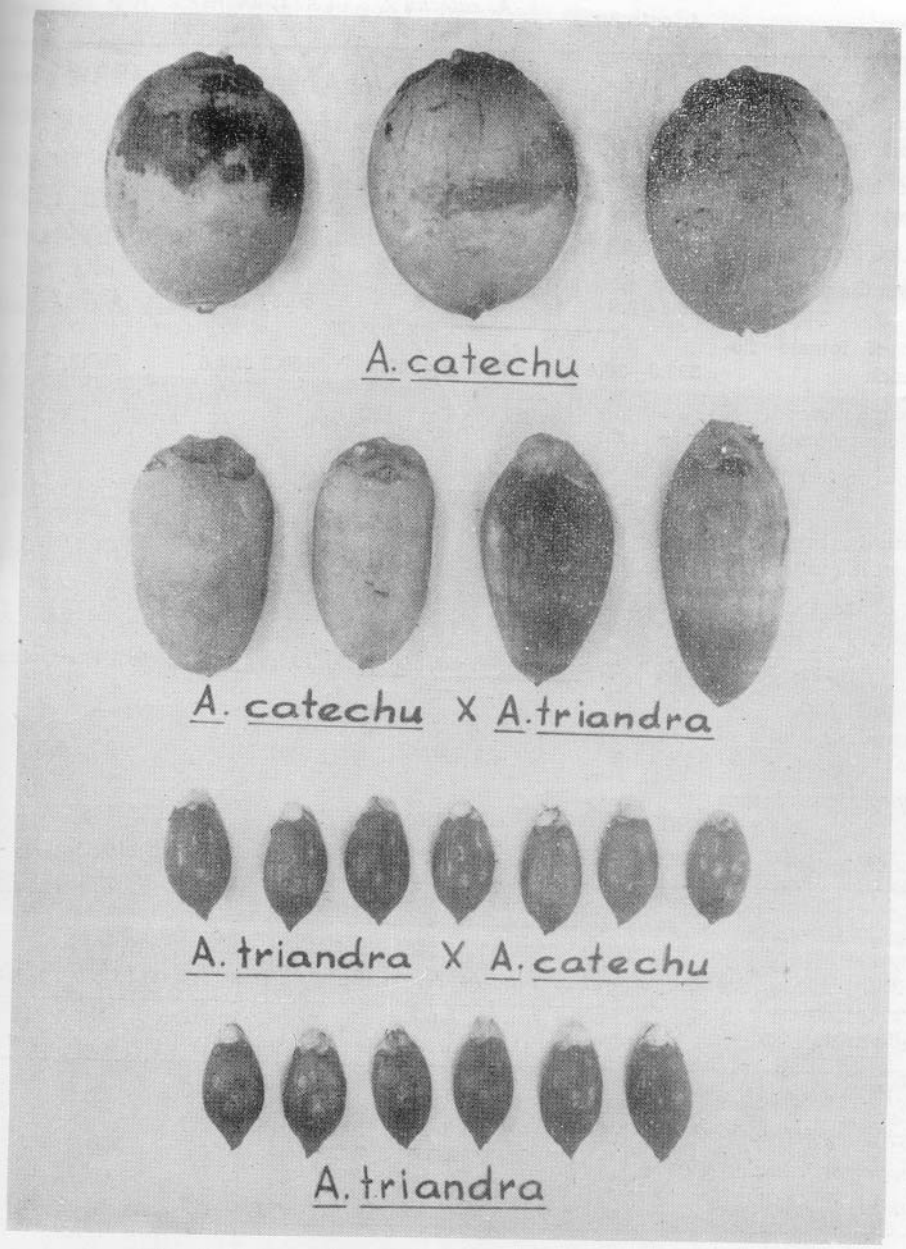


Fig. 3.44 Ripe nuts in *A. catechu*, *A. catechu* × *A. triandra* F_0, *A. triandra* × *A. catechu* F_0 and *A. triandra*

Table 3.8. *Morphological characteristics of* A. catechu, A. triandra *and their hybrids*

Characters	*A. catechu*	*A. catechu* × *A. triandra*	*A. triandra* × *A. catechu*	*A. triandra*
Number of stems	1	1	9.5±3.1	9.8±2.9
Internodal distance at fixed mark (cm)	11.4±3.3	19.8±2.4	16.0±1.7	13.6±3.6
Girth of stem at fixed mark (cm)	45.3±4.4	39.0±0.70	24.1±0.4	18.2±1.2
Number of leaves/clump	9.5±0.3	9.5±0.3	35.0±3.4	51.4±14.4
Mean length of spadix (cm)	56.3±2.9	87.8±2.6	50.3±1.2	43.0±2.3
Number of female flowers/bunch	386.3±36.4	2856.8±340.3	409.8±64.6	588.2±133.4
Mean length × breadth of female flowers (cm)	1.76×1.02	1.13×0.52	0.83×0.05	0.84×0.46
Number of male flowers/bunch	33521±5080	48856±3868	29682±4027	27083±3191
Mean length × breadth of male flowers (cm)	0.44×0.23	0.26×0.12	0.24×0.10	0.22×0.10
Number of stamens	6, occasionally 5	3–5	3	3
Arrangement of male flowers	Single, biseriate, alternate	Paired, biseriate, alternate	Paired, uniseriate	Paired, uniseriate
Mean length × breadth of fruit (cm)	5.3×4.2	4.2×2.1	2.9×1.44	2.7×1.5
Maturity period of nuts (days)	287±16	298±19	162±1	163±8
Pollen stainability	93.0±3.5	4.7±1.7	67.0±6.4	56.5±7.6

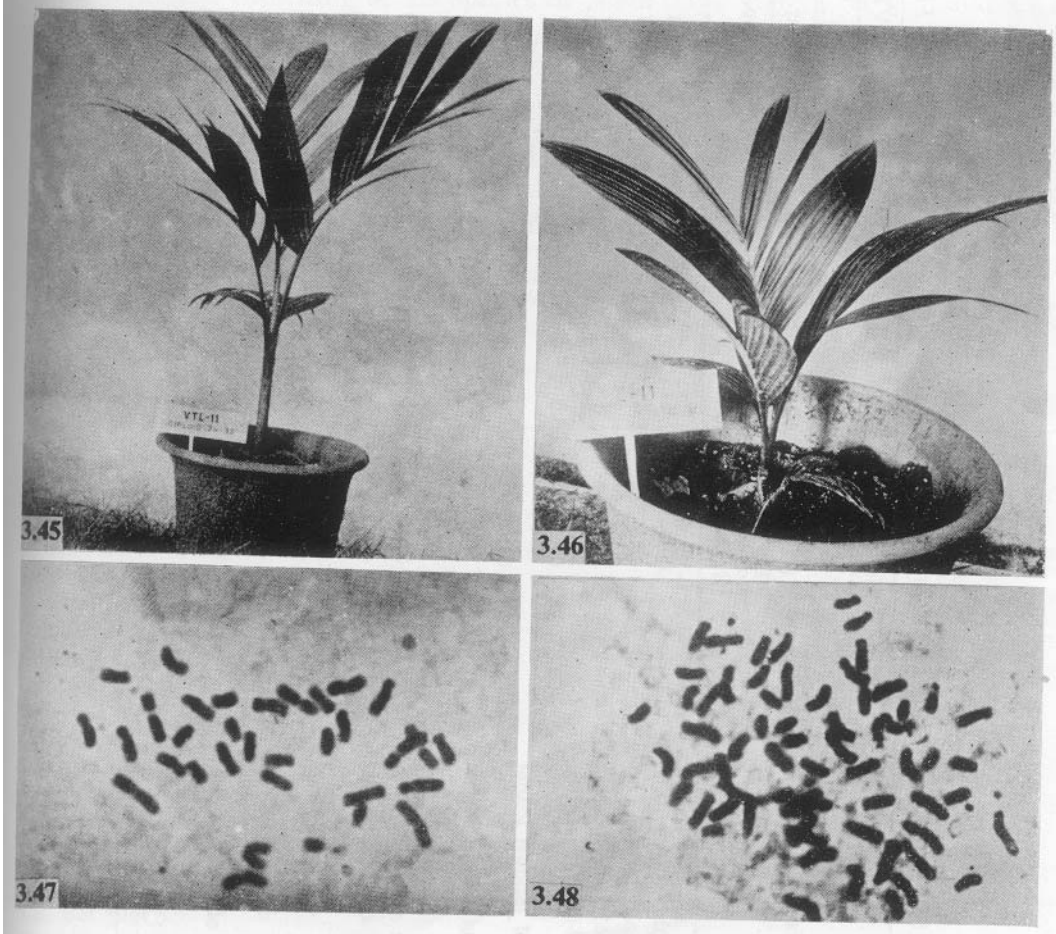
Table 3.9. *Mean size and weight of nuts of* A. catechu, A. triandra *and their hybrids* (F_0

Parents/hybrids	Length (cm)	Breadth (cm)	Weigh (gm)
A. catechu	5.3	4.2	43.6
A. catechu × *A. triandra* (F_0)	5.5	3.3	34.2
A. triandra × *A. catechu* (F_0)	2.7	1.5	3.9
A. triandra	2.7	1.5	3.9

obtained without pollination in *A. triandra* and *A. triandra* × *A. catechu* showed that apomixis in *A. triandra* is autonomous (Bavappa, 1974; Bavappa and Nair, 1975).

6. Induced polyploidy

Nair and Ratnambal (1974) induced tetraploids in two cultivars of *A. catechu*, *Mangala* and VTL–11 (Indonesia) by treating the emerging sprouts with aqueous colchicine. Two tetraploids in *Mangala* and five in VTL–11 were isolated based on chromosome counts in somatic cells; the most successful treatment being the dipping of sprouts in 0.1% aqueous colchicine for 24 hr. The tetraploid seedlings were stunted in growth compared to the diploids, and had reduced plant height and number, length and breadth of leaves (Figs. 3.45, 3.46, 3.47 and 3.48; Table 3.10). The tetraploids had fewer epidermal cells and stomata per unit area.



Figs. 3.45—3.48 Diploids and tetraploids in *A. catechu*. *Fig. 3.45* A. catechu *(VTL–11) diploid plant; Fig. 3.46* A. catechu *(VTL–11) tetraploid plant; Fig. 3.47 Somatic chromosomes in diploid plant (VTL–11) 2n=32; Fig. 3.48 Somatic chromosomes in tetraploid plant (VTL–11) 4n=64.*

Table 3.10. *Morphological and anatomical characters of diploids and tetraploids in* A. catechu *(Nine months old seedlings)*

Characters	*Mangala*			VTL – 11					
		Tetraploids			Tetraploids				
	Diploid	0.1% aqueous colchicine 24 hr.	0.5% aqueous colchicine 72 hr.	Diploid	0.1% aqueous 24 hr.		0.1% aqueous colchicine 72 hr.	0.2% aqueous colchicine 48 hr.	0.5% aqueous colchicine 72 hr.
					Plant No.1	Plant No.2			
Plant height (cm)	116.5	80.0	65.5	28.5	28.5	92.5	61.0	65.0	61.5
Girth at collar (cm)	1.6	1.8	1.4	1.8	0.7	1.7	1.3	2.1	1.6
Number of leaves	6	4	4	6	3	4	4	6	5
Length of longest leaf (cm)	69.5	61.5	53.0	76.5	25.5	75.0	51.0	45.0	27.0
Length of longest leaflet (cm)	36.5	31.0	27.0	37.0	–	38.0	30.5	26.5	26.5
Breadth of middle leaflet (cm)	4.1	5.4	3.3	6.4	–	5.4	5.0	3.1	7.4
Number of epidermal cells/unit area	43.0	32.4	37.2	43.0	–	43.2	26.3	39.4	39.9
Length of epidermal cells (μ)	46.9	57.0	56.6	45.8	–	47.2	69.7	59.6	58.1
Breadth of epidermal cells (μ)	21.1	22.9	23.1	18.6	–	21.6	20.5	22.7	21.3
Number of stomata/unit area	3.5	2.6	2.7	3.3	–	3.3	2.3	2.6	2.3
Length of guard cells (μ)	29.9	35.3	31.0	28.3	–	34.5	35.6	27.4	27.8
Breadth of guard cells (μ)	10.5	13.0	12.8	10.3	–	13.1	12.9	13.9	10.6

II. Breeding

Crop improvement work in arecanut has been mainly through introductions of exotic and indigenous types and refinements of selection procedures in mother palms, seednuts and seedlings, though hybridisation has also been undertaken in recent years.

1. Introduction

A collection of the cultivars of *A. catechu* and related species from within the country as well as from Sri Lanka, the Philippines, Indonesia, Singapore, Malaysia, Thailand, South China, Fiji, Solomon Islands and Mauritius are being maintained at the Regional Station, Vittal of the Central Plantation Crops Research Institute. The exotic collection consisting of six species of *Areca* (Figs. 3.49, 3.50, 3.51 and 3.52) and 34 *A. catechu* cultivars were introduced in various stages, starting from 1957. The comparative yield evaluation of 16 types among these for a period of nine years (1964–'65 to 1972–'73) indicated that five introductions *viz.*, VTL–3 (China), VTL–11 (Indonesia), VTL–12 and VTL–13 (Thailand), and VTL–17 (Singapore) have high yield potential and the increase in yield (weight of nuts) was 6–50% more than the local cultivar (Table 3.11) (Anonymous, 1974).

Table 3.11. *Yield (weight of nuts) of 16 exotic introductions of* A. catechu

Name of the type	Accession number	1964–1965 to 1972–1973 (Average for 9 years)	Percentage of increase (+) or decrease (—) over Local
		Wet weight of nuts per tree in kg.	
Fiji	VTL–1	3.1	—68.0
Mauritius	VTL–2	6.1	—37.1
China	VTL–3	10.3	+ 6.2
Ceylon	VTL–5	6.9	—28.9
Indonesia–1	VTL–6	1.4	—85.6
Indonesia–2	VTL–7	8.2	—15.5
Ceylon–2	VTL–15	6.7	—30.9
Indonesia–6	VTL–11	14.5	+49.5
Saigon–1	VTL–12	12.9	+33.0
Saigon–2	VTL–13	11.7	+20.6
Saigon–3	VTL–14	9.0	— 7.2
Singapore	VTL–17	14.6	+50.5
Solomon Islands–1	VTL–18a	2.7	—72.2
Solomon Islands–2	VTL–18b	5.1	—47.4
Solomon Islands–3	VTL–18c	3.2	—67.0
Ceylon–3	VTL–21	2.6	—73.2
South Kanara (control)	—	9.7	—
S.E. per plot		3.9	
Overall mean		7.6	
C. V. (%)		52.0	
C. D. (P=0.05)		4.5	

Fig. 3.49—3 52 *Areca* species and related genus. *Fig. 3.49* A. triandra; *Fig. 3.50* A. normanbyii; *Fig. 3.51* A. macrocalyx; *Fig. 3.52* Actinorhytis calapparia.

Fig. 3.53 *Mangala*

Among these accessions, VTL–3 obtained from Peking (China) was found to have a number of desirable characters such as earliness in bearing, more number of female flowers per inflorescence, higher nut set, initial and cumulative higher yields, quicker stabilisation of production and lower height, in comparison with the Local ('South Kanara') cultivar (Table 3.12).

Table 3.12. *Comparative yield of* Mangala *(1967 planting)*

	Wet weight of nuts/palm/year						
Cultivars	1970–'71	1971–'72	1972–'73	1973–'74	1974–'75	1975–'76	Total
Mangala	–	4.73	16.75	12.36	16.04	14.15	64.03
South Kanara	–	1 57	4.80	5.11	6.62	8.89	26.99

The cultivar has since been released under the name *Mangala* (Fig. 3.53). This semi–tall variety is characterised by partially drooping crown with well-spread leaves and having more number of leaflets than the local type. The leaflets are dark green in colour with crinkling at the tip. The fruits are dark green with good chewing and marketing quality of the nut (Bavappa, 1977).

The indigenous collections of *A. catechu* maintained at Vittal include 3 cultivars from Thirthahalli, Chickamagalur, Hirehalli, Peechi, Mohitnagar, Assam, South Kanara and Gujarat planted in 1964, and four more types from Sreevardhan, Bapoli, Thirthahalli and Assam planted during 1966. In addition, four progenies of a dwarf palm from Thirthahalli are also being maintained (Fig. 3.54).

Yield evaluation of the seven cultivars among these (introduced in 1964) for a period of ten years (1967–'76) showed continued high yield of 'Thirthahalli' over others. There was no significant difference in yield in the case of other cultivars in comparison with the 'South Kanara' type (Table 3.13).

2. Selection

i. *Seedling selection*

Studies on selection of arecanut seedlings showed that considerable increase in yield of the plantation could be obtained by judicious selection of seedling at the time of planting, as well as in subsequent stages (Bavappa and Ramachander, 1967a, Bavappa, 1970).

It has been established that in the case of seedlings, number of leaves at the time of planting, girth at collar one year after planting and number of nodes two years after planting have high heritability and have positive genotypic and

Fig. 3.54 Dwarf mutants of *A. catechu*

Table 3.13. *Yield (weight of nuts) of seven indigenous cultivars of* A. catechu

Cultivar	Wet weight of nuts/tree/year in kg										Mean yield	Percentage increase (+) or decrease (—) over local
	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976		
Thirthahalli	4.9	17.4	13.1	17.9	19.7	18.9	15.3	15.3	15.5	20.5	15.85	+49.1
Chickamagalur	3.8	8.3	8.0	9.2	5.4	8.5	4.5	6.1	7.6	8.3	6.97	—34.4
Hirehalli	2.9	13.9	9.2	13.9	17.1	10.8	16.9	12.7	9.4	13.7	12.10	+13.8
Peechi	3.5	8.8	7.6	10.7	15.6	10.2	9.6	13.1	13.3	6.7	9.91	— 6.8
Mettupalayam	2.6	8.9	10.0	10.1	12.9	5.0	12.1	5.1	6.2	7.4	8.03	—24.5
Mohitnagar	3.0	16.4	13.5	18.9	17.2	10.5	10.5	10.7	7.9	10.2	11.88	+11.6
Assam	3.1	14.6	4.9	9.6	-	6.3	-	6.3	6.3	5.9	7.12	—33.0
South Kanara (Control)	1.2	7.3	6.4	10.9	8.7	11.3	11.5	16.0	18.1	14.9	10.63	— -

phenotypic correlations with the yield. The yield behaviour of the palms selected under different groups for the above mentioned three characters showed that the best seedlings are those which have more than four leaves at the time of planting, and a girth of more than 20 cm after one year, and four nodes or more after two years of growth in the field after transplanting. Further, the negative correlation established for these three characters with age at first bearing indicated that excercising selection of seedlings for the above mentioned characters would aid in bringing down the age at first bearing of the population (Bavappa and Ramachander, 1967a, 1967c).

In view of the significant positive genotypic correlation of number of leaves and negative correlation of the height at the time of transplanting with subsequent yield, Bavappa (1970) suggested selection of seedlings having maximum number of leaves and minimum height. To simplify the procedure of selection, he suggested that the number of leaves present at the time of planting is to be multiplied by 40 and the height of the concerned plant substracted from this figure. Seedlings which have a high value for this alone should be selected (*e.g.*, No. of leaves=5, height of the plant=90 cm, no. of leaves $\times$ 40—height= $5 \times 40 - 90 = 110$. Suppose the value of the seedlings vary from 50 to 150 seedlings having higher values may be selected to the extent practically feasible).

ii. *Mother palm selection*

Bavappa and Ramachander (1967c) tested the validity of the earlier method of selection of seed material as a means of genetic improvement which consisted of collection of seeds from phenotypically high yielding mother palms located in gardens reputed for their average yield (Bavappa, Patel and Mohiyuddin 1958). The progeny performance as judged from the yield of 41 such mother palms (Table 3.14) showed that though the mother palms had been selected for

Table 3.14. *Frequency distribution of mother palms based on progeny performance*

Range in mean yield of progency (gm)	No. of mother palms	
	1963–'64	1964–'65
2000–3000	3	0
3000–4000	5	2
4000–5000	7	7
5000–6000	11	11
6000–7000	7	11
7000–8000	6	6
8000–9000	2	3
9000–10000	0	1

high yield, there was wide variability in the performance of their progenies. It was also observed that the mother palms having high progeny performance were present in all the gardens more or less uniformly and there was no advantage in selection of mother palms giving stress to the garden in which they are located. They also observed that the progeny performance had no relation with the regularity in the yielding behaviour of mother palms (Bavappa and Ramachander, 1967b; Anonymous, 1969a).

An examination of the yield pattern of palms of different bearing ages by Bavappa and Ramachander (1967c) showed that palms which came to bearing early are consistantly better yielders (Fig. 3.55; Table 3.15). Based on the data, they suggested that confining selection of seednuts to 62 per cent palms which come to bearing at fifth year, an increase in yield of 8–15 per cent could be expected depending upon the extent of selfing or nature of crossing taking place.

Table 3.15. *Yield pattern of palms having different age at first bearing*

Age at first bearing in years	Percentage of palms in the population	Yield (number of nuts) in different years				Mean
		I	II	III	IV	
5	62	109	211	255	305	220
6	32	–	139	148	208	165
7	4	–	–	58	95	76
8	1	–	–	–	34	34
9	1	–	–	–	–	0

Further, it was observed that selection of seedlings for number of leaves, girth at collar and number of nodes at the appropriate stage totally eliminated the late bearing palms and accordingly the yield of the population was increased (Table 3.16).

Table 3.16. *Effect of selection of seedlings on age at first bearing*

Age at first bearing in years	Percentage of palms in different age groups	
	Before selection	After selection
5	62	74
6	32	25
7	4	1
8	1	0
9	1	0

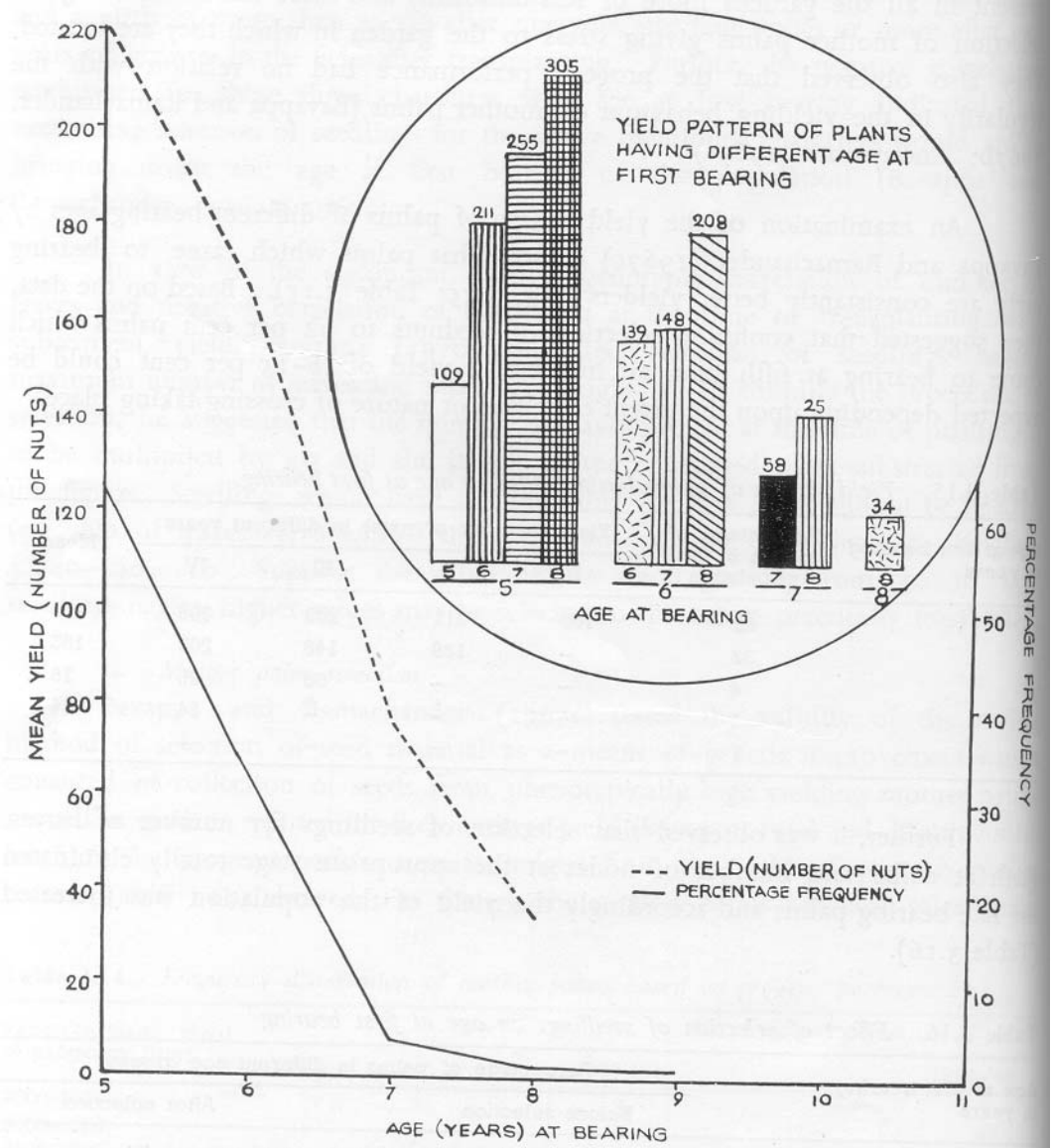


Fig. 3.55 Relationship between age at bearing and yield

A field trial was initiated at Vittal during 1963 to critically evaluate the possible beneficial effects of the existing practice of selection of seednuts from healthy and regularly high yielding palms and to fix selection standards for mother palms, seednuts, and seedlings. The treatments were unselected bulk nuts; selected bulk nuts; unselected nuts from mother palms; selected nuts from mother palms; selected nuts from non-prepotent mother palms and selected nuts from prepotent mother palms. The data on seed weight, number of days taken for germination, seedling girth, seedling height and number of leaves (at the time of transplanting) and number of nuts and weight of nuts (average over four years, 1972–'76) from two treatments *viz.*, unselected nuts and selected nuts from selected mother palms were subjected to half-sib analysis for working out genotypic and phenotypic correlations and heritabilities. Significant correlations of seed weight, seedling girth and age at first flowering with number of nuts and weight of nuts were noticed in the case of treatments with selected seednuts. It was also observed that selection of seed nuts has resulted in an improvement in heritability values for all the characters except for height and number of leaves (Table 3.17). However, heritability values for number of nuts and weight of nuts were low thereby suggesting that selection based on yield alone may not be worth practising (Bhagavan et al., 1981).

Table 3.17. *Heritability estimates for various characters*

Characters	Heritability	
	Unselected nuts	Selected nuts
Seed weight	0.14	0.33
Germination	0.53	0.65
Girth	0.08	0.25
Height	0.59	0.58
Number of leaves	0.23	0.23
Age at flowering	0.15	0.26
Number of nuts	0.06	0.25
Weight of nuts	0.08	0.29

iii. *Mass pedigree selection*

With the primary objective of the attainment of increase in yield, besides the seedlings and mother palm selection standards worked out, a modified mass pedigree selection programme was initiated in arecanut (Bavappa and Ramachander, 1967c; 1968a; 1968b). Mother palms were selected from the farmers' gardens of the Dakshina Kannada region and 41 families with 2,966 plants were raised at

Vittal. Bulk norm and individual norm tests were applied to screen the famili and individuals within the selected families. Ten palms belonging to thre families were selected and the seedlings raised from the individual plants thu selected, were grown in replicated progeny rows alongwith proper controls. The process of screening the families based on the bulk norm test was repeated an plants of selected families which yielded less than the garden family mean wer eliminated. Thirty–eight palms belonging to six treatments and two familie passed the test. However, it was found that in all these families, the observed an expected genetic gains for wet weight of nuts were very low; the expected gain fo number of nuts was also found to be low; falling below the population mean. The result in effect showed that selection as practised in this experiment was ineffectiv in improving the yield (Anonymous, 1981).

A further refinement of the above selection programme was also suggested by Bavappa and Ramachander (1967b). They presumed that screening individual plants based on characters of high heritability and correlation with yield, prepotency, selection index, desirable characters such as resistance to pests and diseases and effecting controlled pollination between selected palms in addition to the bulk norm test and single norm test are likely to be more advantageous than simple mass pedigree selection.

3. Hybridisation

Choice of parents possessing desirable characteristics is a pre-requisite fo any effective breeding programme. The CPCRI Regional Station, Vittal has a live herbarium of *Areca* species and cultivars mainly from South East Asia and South Asian countries, possessing large number of desirable characters and offer choice o selection of parents depending on the breeding objectives. Distribution of such desirable characters in different accessions of *Areca* is listed in Table 3.18.

Taking into consideration the available variability, hybridisation work i *Areca* was initiated with the following specific objectives:

1) To evolve varieties with high yield and regular bearing, 2) to combin large sized fruit with more number of nuts per bunch, 3) to combine semi-tal early bearing and high yielding characteristics of *Mangala* with quality o 'Sreevardhan', 4) to evolve varieties tolerant to yellow leaf disease, 5) to transfe the suckering habit, more number of female flowers and high percentage of se from *A. triandra* to *A. catechu* 6) to study the genetics of dwarfness, suckerin habit etc. and 7) to study the combining ability for exploitation of hybrid vigou

Table 3.18. *Distribution of characters in different accessions*

Characters	Probable donors
High yield	*A. catechu* 'Singapore'
	A. catechu Mangala
Early bearing	*A. catechu Mangala*
Greater number of fruits/bunch	*A. catechu* 'Thirthahalli'
Better quality	*A. catechu* 'Sreevardhan'
Fruit size (large)	*A. catechu* 'South Kanara'
Regular bearing	*A. catechu* 'South Kanara'
Dwarfness	*A. catechu* Dwarf mutant
Tolerance to yellow leaf disease	*A. catechu* Dwarf mutant
More number of female flowers per bunch	*A. triandra*
High percentage of fruit set	*A. triandra*
Suckering habit	*A. triandra*

i. *Hybrid performance*

An inter-varietal crossing programme was initiated at Vittal during 1965 with *Mangala,* a semi-dwarf high yielding type as female parent and 'Sreevardhan', 'Local' and 'Thirthahalli' as male parents. Other inter-varietal hybrids available are involving 'Local' and 'Indonesia 1,' 'Indonesia 2' and 'Andamans' and hybrids derived from *Mangala* and four selected exotic types (VTL–11, VTL–12, VTL–13 and VTL–17) and two indigenous types ('Mohitnagar' and 'Thirthahalli' and Dwarf mutant).

Hybrids derived from crosses 'Local' × 'Indonesia' 1 (VTL–47), 'Local' × 'Andamans' (VTL–45), 'Local' × 'Indonesia' (VTL–48) and 'Nicobar' (VTL–46) × 'Local' showed earliness in bearing, large sized inflorescence, large number of female flowers and heavier crown habits (Anonymous, 1970). Hybrid vigour for leaf length, number of leaves, number of leaflets, length of leaflet, breadth of leaf sheath and girth at crown has also been observed for these characters (Anonymous, 1971).

Among the hybrids from *Mangala* × 'Local' and *Mangala* × 'Sreevardhan', the latter group was vigorous as observed from increased height and girth of stem and number of leaves (Anonymous, 1971).

Inter-varietal crosses were carried out at Vittal among *Mangala,* VTL 11, 13 and 17, 'Mohitnagar', 'Thirthahalli' and Dwarf mutant during 1975. The seedlings raised from these crosses were planted in a field trial at Palode, South Kerala during 1976 with a view to studying the disease reaction to the yellow leaf disease of arecanut. Observations recorded till 1981 indicated that hybrid seedlings derived from crosses involving Dwarf mutant have some degree of tolerance. (Table 3.19).

Table 3.19. *Disease reaction of hybrids derived from crosses involving Dwarf mutant*

Crosses	No. of palms available out of 48 in all the replications	No. of diseased palms	% of palms affected
Mangala × Dwarf	36	1	2.8
VTL 13 × Dwarf	39	5	12.8
Mohitnagar × Dwarf	43	0	0.0
Thirthahalli × Dwarf	35	2	5.7
Dwarf × VTL 11	17	0	0.0
Mangala	30	3	10.0
Dwarf	41	2	4.9

ii. *Interspecific hybrids*

Reciprocal crosses between *A. catechu* and *A. triandra* were made at Vittal during 1965–'66 and detailed morphological and cytological investigation on these hybrids were reported by Bavappa (1974).

The F_1 hybrids of *A. catechu* × *A. triandra* had only one stem as in *A. catechu* indicating the dominance of single stem (Fig. 3.56). As discussed elsewhere (Table 3.8) the reciprocal hybrids are soboliferous like *A. triandra* parent and based on this, as well as other supporting evidences *A. triandra* is considered to be apomictic (Bavappa, 1974; Bavappa and Nair, 1975). The *A. catechu* × *A. triandra* hybrids mostly equalled the parents in respect of internodal distance at fixed mark and leaf length and it was suggested that a dosage effect of gene for these characters are operative in *Areca*. The similarity of the hybrids to their respective female parents in respect of leaves per clump indicated that this character might be maternal in inheritance.

A. catechu × *A. triandra* hybrids exhibited hybrid vigour for number of male flowers per bunch, number of female flowers, length of spadix and girth of stem at fixed mark, the maximum hybrid vigour being for the number of female flowers (Table 3.8). However variation in hybrid vigour expression in hybrids derived from different cultivars of *A. catechu* and ecotypes of *A. triandra* was observed.

The number of stamens in *A. catechu* parent is mostly six (with some variability) while as the very name indicates *A. triandra* has three anthers. The number of stamens in *A. catechu* × *A. triandra* hybrids vary from 3 to 6 indicating probable quantitative inheritance. Since all the hybrids of *A. catechu* × *A. triandra* have paired and biseriate arrangement of male flowers on the rachilla, in contrast

Fig. 3.56 *A. catechu* × *A. triandra* hybrid

to single and alternate arrangement in *A. catechu* and in pairs and uniseriate in *A. triandra,* Bavappa (1974) concluded that biseriate is dominant over uniseriate and paired condition over singleness.

The inheritance of fruit size in *Areca* is presumed to be quantitative sinc the fruit size in all the *A. catechu* × *A. triandra* hybrids were intermediat (Table 3.9) (Bavappa, 1974).

The interspecific hybrids between *A. catechu* and *A. triandra* showed high sterility and also hybrid vigour for many characters. This is to be expected in an interspecific cross involving genetically divergent parents. The studies on intercluster divergence showed that the genetic distance between *A. catechu* and *A. triandra* is wide (Bavappa, 1974). Since it has been possible to backcross the F1 hybrids of *A. catechu* × *A. triandra* to *A. catechu,* the possibilities of transferring high fruit set reported in *A. triandra* (Bavappa, 1966a, 1966b) to *A. catechu* are bright. As the sterility observed in the hybrids appears to be due to disharmonious interaction between the cytoplasm of *A. catechu* and genotype of *A. triandra,* restoration of fertility through repeated backcrosses to *A. catechu* may be feasible and it may be possible to evolve better varieties combining qualities of both the species.

4. Biometrical studies

i. *Correlation and heritability*

In an attempt to establish relationship between vigour of the seedlings and subsequent yield of arecanut palm, Bavappa and Ramachander (1967b) worked out phenotypic and genotypic correlation between some of the morphological characters of the seedlings at the time of planting as well as one and two years after, with the yield in the first four years of bearing. From the phenotypic correlation it is observed that morphological characters like number of leaves, girth at collar and height at the time of planting are correlated with the yield during the first year of bearing only. Characters recorded, one and two years after planting have significant positive correlation with yield in all the four years except for the girth at last exposed node for the second year (Table 3.20).

Genotypic correlation worked out with yield during the first four years of bearing showed that the number of leaves at the time of planting, girth at collar one year after planting and number of nodes two years after planting have significant positive correlation with yield during all the four years (Table 3.20).

Table 3.20. *Phenotypic and genotypic correlations between morphological characters of seedlings and their yield*

Morphological characters	Phenotypic correlation with yield during				Genotypic correlation with yield during				Heritability
	First year	Second year	Third year	Fourth year	First year	Second year	Third year	Fourth year	
I year (at the time of planting)									
Number of leaves	0.21**	0.04	0.04	0.04	0.32*	0.12	0.21	0.39**	0.92
Girth at collar	0.12*	0.04	0.03	0.05	0.12	−0.35*	−0.40**	−0.16	0.96
Height	0.19*	0.06	0.06	0.06	0.36*	−0.18	−0.18	−0.15	0.80
II Year (one year after planting)									
Number of leaves	0.26**	0.17*	0.12*	0.09*	0.98**	−0.32*	−0.08	−0.01	0.32
Girth at collar	0.21**	0.27**	0.16*	0.23**	0.46**	0.10	0.16	0.28*	0.80
Height	0.22**	0.27**	0.22*	0.19**	0.31*	−0.25	−0.41**	−0.27	0.32
III Year (two years after planting)									
Number of leaves	0.24**	0.13*	0.15*	0.26*	0.19	−0.08	−0.09	0.14	0.32
Girth at permanent mark	0.16*	0.17*	0.14*	0.16*	0.34*	−0.15	0.68**	0.45**	0.36
Girth at last exposed node	0.19*	0.09	0.23**	0.13**	0.33*	−0.03	0.21	0.25	0.64
Number of nodes	0.20**	0.26**	0.13*	0.17*	0.39**	0.28*	0.03	0.12	0.96

* Above P 0.05 level of significance: 0.10
** Above P 0.01 level of significance: 0.20

* Above P 0.05 level of significance: 0.28
** Above P 0.01 level of significance: 0.38

Bavappa and Ramachander (1967c) observed that heritability for yie in arecanut is very low (0.20) and hence practically no improvement in yie could be achieved by direct selection for this character. To achieve improveme in yield by selection, they tried to identify characters having high heritability as well as correlation with yield. Values in respect of phenotypic, genotypic an environmental correlations of these characters with yield and heritability are give in Table 3.21.

Table 3.21. *Correlation of different characters with yield (number of nuts) and thei heritability*

Characters	Correlations			h^2
	Phenotypic	Genotypic	Environmental	
Age at first bearing	-0.45	-0.55	-0.65	0.72
Number of leaves shed	0.19	0.53	0.35	0.32
Number of inflorescences produced	0.41	0.02	0.59	0.46
Number of bunches harvested	0.72	0.27	0.77	0.10
Number of female flowers produced	0.55	-0.44	0.65	0.08
Number of nuts set	0.97	1.08	0.97	0.03
Percentage of nut set	0.78	0.88	0.75	0.33
Mean weight	-0.28	-0.58	-0.24	0.07
Number of nuts per bunch	0.84	0.86	0.82	0.22
Percentage of bunches to inflorescences	0.60	0.42	0.63	0.16
Percentage of inflorescence to leaves shed	0.42	0.04	0.69	0.60

Among the 11 characters considered, age at first bearing alone has high heritability and correlation with yield. The percentage of inflorescence to leave shed and number of inflorescences produced also have high heritability. But i view of low genotypic correlation of these characters with yield, selectio based on these two characters would not help in improvement of yield. Percen tage of nut set is highly correlated with yield, but the heritability is relatively low Eventhough the mean weight of nut is negatively correlated with yield, in the absence of a threshold value, the total weight of nuts produced increased with the number of nuts and this negative correlation did not set a limit to the possible yield improvement (Bavappa and Ramachander, 1967c; Anonymous, 1969b).

ii. *Selection index*

Due to the limited variability in age at first bearing, selection based on this character (which has got high heritability and highly significant correlation with yield) may not lead to a very significant improvement in yield. Under such

a situation, Ramachander and Bavappa (1972) attempted to refine the selection method adopting selection index technique. They pointed out that standardisation of such selection procedures is particularly useful in perennial crops where once the genetically potential parents are identified, planting material could be continuously collected for a number of years. They standardised the selection technique by working out selection indices and set up the selection differential to select the palms which passed the limit. For this study, 17 growth measurements taken at various stages of growth, 12 yield components as well as cumulative yield for first four years in respect of 220 palms belonging to 10 families of 'Vittal' type of arecanut were used. From the different indices and genetic advance (G.A.) presented (Table 3.22) it was observed that the selection index based on 17 growth measurements gave an efficiency of 476% over straight selection, while all the 29 characters gave an efficiency of 498%. However, it was pointed out that from the point of view of practical breeding, inspite of slightly higher efficiency from selection utilising all the 29 characters, an index based on growth measurements would be preferred because of the ease of calculation as well as possibility of raising seed gardens with such selected seed donors. From the selection index presented by them, it was observed that as against, an expected genetic advance of 57.11 due to straight selection, a simpler index using two characters at the time of transplanting *viz.*, the number of leaves and height gives genetic advance of 190% and relative improvement of 332%. A simplified formula utilising these two characters for selection of seedlings has been suggested by Bavappa (1970) as explained earlier.

iii. *Genetic divergence*

Bavappa (1974) recorded morphological, anatomical and yield characters of 13 cultivars of *A. catechu* and four ecotypes of *A. triandra* for the years 1963, 1966 and 1972. The analysis of variance of the results obtained in 1963 showed that the differences between cultivars are highly significant for all the six morphological characters (Table 3.23). A combined analysis of the data for two years for 14 common characters recorded during 1967 and 1972 also revealed significant difference between cultivars for all characters (Table 3.24). A significant interaction between years and cultivars was seen in the case of height, girth, internodal distance, number of bunches and inflorescences on the palm, length and breadth of leaf sheath, length and volume of nut and length, breadth, weight and volume of kernel.

Bavappa (1974) also worked out 136 D^2 values between cultivars, the number of characters being unequal in different years. The magnitude of D^2 values

Table 3.22. *Constants of different characters for calculating selection indices, genetic advance (GA) and relative improvement (RI)*

Characters		Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8
					GROWTH MEASUREMENTS				
At the time of planting									
X_1	Number of leaves	180.623	187.865		193.133	206.618			
X_2	Girth at collar (cm)	46.043	50.933		114.644				
X_3	Height (cm)	-6.299	-6.302		-6.551	-4.966			
After one year growth in the field									
X_4	Number of leaves	2.041	3.517				3.233		
X_5	Girth at collar (cm)	12.407	13.640				18.245		
X_6	Height (cm)	-2.367	-2.285				-0.621		
X_7	Number of nodes	-60.421	-68.296				-75.460		
After two years growth in the field									
X_8	Number of leaves	-49.358	-54.352					-47.532	
X_9	Girth at permanent mark (cm)	12.126	11.435					11.480	
X_{10}	Girth at last exposed node (cm)	-13.341	-12.089					-14.859	
X_{11}	Number of nodes	49.347	61.061					20.804	
After six years of growth in the main field									
X_{12}	Number of leaves	-19.161	-33.384						9.066
X_{13}	Girth at collar (cm)	0.871	2.757						3.388
X_{14}	Girth at permanent mark (cm)	-13.245	-15.140						-9.532
X_{15}	Girth at last exposed node (cm)	-8.203	-3.564						-7.622
X_{16}	Total height (cm)	1.152	0.909						0.744
X_{17}	Number of nodes	-5.121	-12.667						-4.415
					YIELD COMPONENTS				
X_{18}	Number of leaves shed	-60.308		-32.811					
X_{19}	Number of inflorescence produced	84.710		23.316					
X_{20}	Number of bunches harvested	-67.710		-107.216					
X_{21}	Total number of female flowers	-0.238		-0.031					
X_{22}	Total number of fruits	0.678		1.036					
X_{23}	Percentage of fruit set	-5.378		2.128					
X_{24}	Mean weight per nut (gm)	-1.878		1.202					
X_{25}	Mean number of nuts/bunch	0.509		-3.401					
X_{26}	Percentage of bunches harvested	1.529		0.881					
X_{27}	Inflorescence to leaves (%)	-3.706		-1.997					
X_{28}	Nuts harvested to set (%)	0.968		6.339					
X_{29}	Kernel to wet weight (%)	-0.632		-1.427					
	GA	284.694K	271.854K	116.274K	200.884K	190.020K	96.050K	126.705K	80.450K
	R.I(%)	498.484	476.011	203.589	351.749	332.726	168.180	221.863	140.860

Table 3.23. *ANOVA of means for six characters in arecanut (1963)*

Characters	Replications (3 d.f.)	Cultivars (16 d.f.)	Error (48 d.f.)
		Mean sum of squares	
Total number of suckers	1.02	8.51**	1.14
Height	531.33	5165.12**	422.83
Girth at collar	38.43	879.78**	53.13
Girth below crown	4.23	322.06**	11.65
Number of leaves	0.33	7.22**	0.85
Number of nodes	1.06	54.82**	3.98

**Significant at P = 0.01

indicated that considerable divergence exists between many of the cultivars in all the years. He grouped 13 cultivars and four ecotypes from nine countries into six clusters for the independent years 1963, 1966 and 1972 and found that though the number of clusters were the same, constituents in the different clusters were slightly different in different years (Table 3.25). The number of clusters and pattern of clustering were more or less similar for the years 1966 and 1972. In the pooled analysis, the number of clusters got reduced from six to five. However, the pattern of clustering was more or less in conformity with the groups obtained for the individual years. The spatial diagram showing the distribution of clusters in 1966 and 1972 (pooled) is given in Fig. 3.57.

All the four ecotypes of *A. triandra* were in one cluster in the pooled analysis and this cluster continued to show maximum divergence from the rest. The divergence between clusters IV and V were due to the differences in nut and kernel characters, breadth of leaf sheath, breadth of leaflets and number of leaflets. Bavappa (1974) based on the analysis concluded that detection of the genetic divergence in the early years of productive phase is of considerable advantage in formulating breeding programme in a perennial crop like arecanut.

The rankings obtained by the different characters during 1966 for their contribution towards overall genetic divergence showed that the mean volume of nut and breadth of kernel were the characters of primary importance. For divergence between *A. triandra* and *A. catechu*, mean length of fruit was found to be second in importance, next only to volume of nut. The results of characters for 1972 and the pooled data also revealed the importance of nut and kernel characters in differentiation within *A. catechu* cultivars and between *A. catechu* and *A. triandra* types. The results obtained from canonical analysis were also in broad agreement

similarity between the cultivars from different countries has also been observed. The cultivar from Singapore got grouped with the three cultivars from Saigon in one cluster. A similar affinity between the two geographically distant cultivars was shown by 'Ceylon–1' and 'Indonesia–6,' both always coming within the same cluster. The local cultivar has been found to be invariably associated with the cultivar from Singapore in forming the cluster. Of the two cultivars of *A. catechu* from Ceylon, 'Ceylon–2' was always forming a separate cluster indicating its distinct nature of divergence. The clustering pattern of cultivars and ecotypes revealed that geographic diversity need not always be related to genetic diversity (Bavappa, 1974).

III. Evolutionary significance

Based on the clustering pattern of certain cultivars of *A. catechu* from countries such as India, Sri Lanka, Singapore, Indonesia and Saigon, Bavappa (1974) deduced that probably both *A. catechu* and *A. triandra* had their origin in group of islands in Indonesia as concluded earlier (Bavappa 1963; Corner, 1966). He presumed that probably these species moved to west through Malaysia to India, Sri Lanka and as far west as Mauritius, all-through maintaining their specific identity, while *A. catechu* found its way to north (Saigon) as well.

Bavappa (1974) also deduced the evolutionary course of *A. catechu*, *A. triandra* and *A. concinna* on the evidences of their distribution, similarities of synthetic hybrid between *A. catechu* and *A. triandra* to *A. concinna* and also the natural occurrence of *A. catechu* × *A. triandra* hybrids. Based on the available information, he concluded that probably *A. catechu* and *A. triandra* were the putative parents of *A. concinna*.

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