

BREEDING AND GENETICS OF ARECANUT, *ARECA CATECHU* L.—A REVIEW

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ABSTRACT

Work done so far on the range of variation, floral biology, improvement, and cytogenetics of arecanut is reviewed. The review discusses the need for making intensive collection of cultivars for their evaluation to isolate high yielding lines, locating additional characters correlated with yield and having high heritability, and repeating the selection for a number of generations and assessing the actual gains over an extended period of time against the estimates of the different selection parameters that have been identified so far. The possibility of exploiting hybrid vigour for yield by crossing genetically divergent cultivars and inbred lines has been indicated. It has been suggested that a close study of the related species and genera for useful characters may be taken up with a view to transferring them to the background of *A. catechu*.

INTRODUCTION

Of the varying number of species recognised in the genus *Areca* by different authors (Bentham and Hooker, 1882; Ridley, 1925; Blatter, 1926; Murthy and Bavappa, 1962) arecanut or betelnut palm (*Areca catechu* L.) is the only commercially exploited species. Though this palm is reported to be growing in 16 countries of the tropics (Bavappa, 1963), organised research work on the crop has been attempted only in India. The breeding system of the palm, the perennial habit, and the long juvenile phase constitute the barriers in undertaking breeding and genetical investigations in arecanut. This paper reviews the breeding and genetic research work done so far on arecanut and suggests future lines to be pursued.

CULTIVARS OF ARECANUT

Rau (1915), based on the sweet kernel of mature fruit, described a variety from Mysore

(India) as *A. catechu* var. *deleciosa*. On the basis of fruit size and shape, Beccari (1919) identified four varieties of arecanut in the Philippines, viz., *A. catechu* var. *communis*, *A. catechu* var. *silvatica*, *A. catechu* var. *batanensis* and *A. catechu* var. *longicarpa*. Sands (1926), Grist (1926), Molegode (1944), Iyer (1950), and Nambiar (1954) have designated the varieties occurring in Malaya, Sri Lanka, and South India by local names. On the basis of a number of fruit and inflorescence characteristics, Raghavan and Baruah (1956b) described the variations of arecanut occurring in Assam. Murthy and Bavappa (1962) identified 64 cultivars based on fruit size from the Indian States of Kerala, Karnataka, and Bombay. They have also discussed the pattern of variation in fruit size in relation to elevation of the tract. Significant variations between the different cultivars and ecotypes of *A. catechu* and *A. triandra* for various characters were observed in the study of the yield components in a

germplasm collection of arecanut (Bavappa and Pillai, 1974). The possibility of distinguishing different cultivars of *A. catechu* and the related species, *A. triandra*, on the basis of growth characters and epidermal pattern of leaf has been brought out by Bavappa (1966a). He observed that the varieties of *A. catechu* could be identified by the number of stomata per unit area and that climatic factors influenced stomatal frequency.

FLORAL BIOLOGY AND FRUIT SET

Murthy (1977) had reviewed this aspect recently. Bavappa and Annaji Rao (1970) studied the mode of initiation of inflorescence, male and female flowers and their course of development and observed that one inflorescence is initiated in every leaf axil and that the differentiation of the inflorescence primordia commences in the axil of the fourth unopened leaf. Initiation of male and female flowers takes place when the inflorescence is in the axil of the spindle leaf and the first opened leaf, respectively. They also found that age of palms, management conditions, and season influenced the abortion of inflorescences and that abortion took place at the stage when the inflorescence started developing rapidly. Inflorescence located in the sixth leaf axil in February to May aborted to a great extent. Shama Bhat, Balakrishna, and Adyanathaya (1956) reported seasonal variation in the percentage of inflorescence to the leaf fall for middle-aged palms. Raghavan (1957), Murthy and Bavappa (1960a), Shama Bhat (1961) and Shama Bhat, Krishna Murthy, and Madhava Rao (1962) studied the floral biology of arecanut cultivars of south India and Assam. They found that the male phase began on an average about four days after the spadix freed itself of the spathe and the phase lasted about 26 days, while the female phase, which lasted for about three days commenced in 84% of the cases after the completion of

the male phase. They also observed that though the stigma remained receptive upto 6 days, the maximum receptivity was between second and fourth day of opening. From the study of large scale data, Bavappa and Ramachander (1967b) confirmed the report of Murthy and Bavappa (1960a) that on an average upto 13% inter-spadix overlapping and 4% intra-spadix overlapping take place. In the light of these observations, they suggested that arecanut may be considered to be a largely cross pollinated species.

Several studies have been made on pollen grains and their germination and factors influencing fruit set and sterility (Marudarajan, 1950; Raghavan and Baruah, 1956a, b, c, d; Baruah and Raghavan, 1957 a, b; Raghavan and Baruah 1959; Nair 1965). Pollen stored at a humidity level of 15-20% maintains high viability upto 35 days of storage. A medium consisting of 0.5% sucrose and 0.1% agar is ideal for pollen germination (Anonymous, 1967). Shama Bhat, Krishna Murthy, and Madhava Rao (1961) reported the overlapping of male and female phases and the role of thrips as pollinating agents in arecanut. Method of artificial pollination were standardised by Murthy and Bavappa (1960b) and Shama Bhat (1965). Increasing fruit set by spraying pollen was reported by Shama Bhat (1963). A 10% increase in fruit set was obtained when gibberellic acid at 1000 ppm was sprayed (Anonymous, 1967). Murthy and Bavappa (1960b) showed that fruit set was not improved by assisted pollination. Female flower production and weight of nuts were influenced by season (Bavappa and Abraham, 1961b). Nuts maturing in November are heavier both in total weight and weight of kernel than those maturing later.

Bavappa (1974) studied pollen fertility and fruit set in the two species, *A. catechu* and *A. triandra*, and their interspecific hybrid. He also worked out the possible extent of crossing and selfing in 13 cultivars

of *A. catechu* and four ecotypes of *A. triandra*. Murthy and Bavappa (1961) found that areca pollen was carried by wind up to a distance of about one kilometer and that the concentration of pollen in the atmosphere was related to the time of flower opening and weather conditions. Apomictic development of fruits in *A. triandra* was reported by Bavappa and Nair (1975). Murthy (1977), while reviewing the work done on floral and pollination biology of arecanut, indicated that the available information on these aspects was very inadequate especially on factors relating to reduced fruit set and immature nut fall.

SELECTION AND BREEDING

The scope of arecanut improvement by breeding was discussed by Patel (1957). Negative significant correlations have been found between time of germination of seed arecanuts and different morphological characters of seedlings (Bavappa et al., 1964). In a study on the quality of nuts and the influence of seed quality and weight on the performance of seedlings, about 25% of the harvested nuts were found to be light nuts; further heavier seeds not only germinated earlier, but also gave significantly higher germination and produced more vigorous seedlings (Bavappa et al., 1957; Bavappa and Abraham, 1961a). Methods for selection of mother palms and seed nuts and seedlings have been described by Bavappa et al. (1958), and Bhatkal (1965). They suggested the marking of vigorous, regular, and high yielding palms for collection of seed nuts and sowing of only heavy nuts for raising seedlings. They recommended also to eliminate mother palms whose nuts germinated late, gave low germination percentage, and lower percentage of quality seedlings. A negative correlation between the weight of individual nuts and their number in the bunch has also been

observed (Bavappa and Abraham, 1961b).

A number of biometrical methods have been used in the improvement of arecanut crop. Bavappa and Ramachander (1967b) found that mother palms of uniform standards had differential transmitting ability with regard to yield. They also observed that high transmitters were distributed randomly in different plantations and that no relationship existed between the regular yielding habit of mother palms and their progeny performance. They worked out the phenotypic and genotypic correlations of various growth characters of seedlings recorded at the time of transplanting to the main field and after one and two years with nut yield during the first, second, third, and fourth years of bearing and cumulative yield for these four years. Among the various growth characters studied by them, number of leaves at the time of planting and girth at collar, and number of nodes one and two years after planting, showed high heritability as well as positive significant phenotypic and genotypic correlations with yield. From a study of the yielding behaviour of the plants selected on the basis of the above standards, Bavappa and Ramachander (1967a) showed that if selection was confined to seedlings having five or more leaves, the overall yield could be increased by 11%. They also indicated that plants which had less than 20 cm girth after one year growth and plants which produced less than four nodes after two years' growth constituting about 8% of the population, if replaced could increase the overall yield by 9%. They showed further that half of the 40% plants, which are either regularly low yielders or low yielders for three years' out of the four years studied would get eliminated if these three selection standards were applied at the appropriate stages.

As the heritability of yield in arecanut was low (Bavappa and Ramachander, 1967b) a search for characters having high herita-

bility and correlation with yield was made. Among the various characters examined, age at first bearing alone showed high heritability and correlation with yield (Bavappa and Ramachander, 1967c, 1968b). By selection of plants for number of leaves, girth at collar, and number of nodes, late bearing plants could be totally eliminated. By confining selection of seed nuts to palms coming to harvest in the fifth year after transplanting it was possible to get an yield increase of 8-15% (Bavappa and Ramachander, 1968b). Percentage of nut set showed high correlation with yield, but only medium heritability (Bavappa and Ramachander, 1967c).

The possibility of exploiting prepotency for higher yields has been discussed by Bavappa and Ramachander (1967b, c, 1968a, b). They indicated that even though such palms were present, it was doubtful whether sufficiently large number of these plants could be identified through progeny testing so as to make available enough seed material for direct use. In the absence of known self-fertilised varieties, easy methods of identification of prepotents on lines suggested for coconut by Harland (1957) is not possible in arecanut. As such, these authors suggested that along with distribution of open pollinated nuts from these mother palms, large scale crossing of phenotypically high yielders with pollen collected from the prepotent palms might be taken up for utilising the limited number of prepotent palms available. They also suggested the study of second generation progenies of prepotent mother palms with a view to finding out if the high yielding first generation progenies of prepotent mother palms were similar transmitters as their mother so that larger supply of good planting material could be obtained. Isolated seed gardens could be established with seedlings raised from crossed seeds involving prepotent parents in all possible combinations (Bavappa and Ramachander, loc. cit.). Bavappa and Ramachander (1967c) further proposed a

modified mass pedigree selection programme for arecanut consisting of selection of mother palms in farmer's fields growing their progenies and screening the seedlings for all characters having high heritability and high correlation with yield, further selection of progenies and individual plants on the basis of bulk and single norm tests, comprising the selected plants in adequately replicated progeny rows, and repeating the screening procedure for a second generation before seed distribution.

Using 17 growth characters and 12 yield components Ramachander and Bavappa (1972) worked out selection indices for different groups of characters following the Smith's method of discriminant function (Smith, 1936). An index based on all the 29 characters was five times more efficient than the straight selection based on yield alone. The major contribution to this efficiency was 17 growth characters of which those having high heritability at the time of planting were most important. An index based on only two characters, viz., number of leaves and height, was three times more efficient than straight selection (Bavappa, 1970).

Using the D^2 statistics of Mahalanobis (1936), Bavappa (1974) studied the genetic distance in 13 cultivars of *A. catechu* and four ecotypes of *A. triandra* during different years of productive phase and concluded that detection of genetic divergence was possible even in the early years of productive phase. He obtained more or less consistent results from a study of 24 characters recorded in the productive phase for two years and the pooled data for both these years. The cultivars could be grouped into six clusters in both the years and into five with the pooled data. The four ecotypes of *A. triandra* came in one cluster and it diverged maximum from the rest. Of the cultivars of *A. catechu*, Ceylon-2 was distinct from the rest. The rankings obtained by the different characters for their contribution towards genetic

divergence revealed the importance of nut and kernel characters in differentiation within *A. catechu* group and between *A. catechu* and *A. triandra* types. When the analysis was carried out with 40 characters, there was not only an overall increase in D^2 values, but also an increase in the number of clusters from six to seven. Out of the characters added, interval between successive leaf fall, breadth of guard cells and number of stomata per unit area were important. The clustering patterns obtained in this study also revealed that geographic diversity was not always related to genetic diversity (Bavappa, 1974).

Based on genetic divergence, Bavappa (1974) pointed out the advantage of crossing the cultivar Ceylon-2 with Ceylon-1, Indonesia 6, China, and Fiji. He also observed hybrid vigour for different characters in a natural hybrid of Ceylon-2 and China. Bavappa and Nair (1975) reported hybrid vigour in the interspecific hybrid *A. catechu-A. triandra* for internodal distance at fixed mark, mean length of spadix, and number of male and female flowers per bunch. The pollen fertility of this hybrid was low (4.7%). However, the possibilities of transferring the mite tolerance and high fruit set reported in *A. triandra* (Bavappa, 1966a, b) to *A. catechu* have been pointed out by Bavappa and Nair (1978) since backcrossing the hybrid to *A. catechu* has been possible. A superior arecanut variety, Mangala which yield on an average about 75% more ripe nuts than the local and which is precocious by one year has been reported by Bavappa (1977).

CYTOGENETICS

Venkatasubban (1945) first determined the chromosome number of the species as $2n=32$. This was confirmed by several others (Sharma and Sarkar, 1956; Raghavan and Baruah, 1958; Abraham, Mathew, and Ninan 1961; Bavappa and Raman, 1965).

Sharma and Sarkar (1956) recorded certain meiotic irregularities such as non-disjunction and lagging of bivalents, univalents, and pentads. Sarkar (1956) found that 15.8% of the pollen grains were inviable. Bavappa and Raman (1965) observed mostly bivalents with a rare quadrivalent in *A. catechu* and bivalents only in *A. triandra*.

Chromosome morphology of few cultivars of *A. catechu* from Assam was studied by Raghavan (1957). He found minor variations in structure and length of individual chromosomes. On the basis of morphology, the individual chromosomes in these types could be demarcated into nine groups. Based on chromosome morphology, Bavappa (1963) and Bavappa and Raman (1965) classified the 16 chromosomes of *A. catechu* (cultivar South Kanara) into seven groups. They also studied its pachytene chromosomes and compared them with somatic chromosomes. Based on karyomorphological features, secondary association, nucleolar chromosomes, and the seven groups into which the chromosomes could be classified on the basis of morphology, they proposed that *A. catechu* was a secondary allotetraploid with a basic number of seven.

A detailed study of microsporogenesis in two cultivars of *A. catechu*, three ecotypes of *A. triandra*, and four interspecific and one natural hybrids of these two species showed frequent multivalent pairing (Bavappa and Nair, 1978). The highest configurations observed were decavalent in *A. catechu*, quadrivalent in *A. triandra*, and octavalent in *A. catechu-A. triandra* hybrids. On the basis of these evidences they indicated the probability of an autopolyploid origin for the two species with restricted multivalent pairing. They also observed that pollen fertility in *A. catechu* was high in spite of the high degree of multivalent associations observed. They indicated the possibility of the frequency of multivalent formation being under genotypic control and being

subjected to selection. Chromosome pairing in *A. triandra* and *A. catechu*-*A. triandra* hybrids studied by them revealed that partial desynapsis occurred to varying degrees in both. They inferred that the higher number of univalents in the hybrids was due to nonhomology of some of the parental chromosomes. They attributed the increase in pairing at Metaphase I in *A. triandra* and *A. catechu* × *A. triandra* to 'distributive pairing' (Bavappa and Nair, 1978).

Bavappa, Nair, and Ratnambal (1975), in their study of the karyotypes of eight cultivars of *A. catechu*, four ecotypes of *A. triandra*, and their hybrids observed considerable differences in their gross morphological characteristics. In most cases, *A. catechu* had subterminal or submedian chromosomes. However, in one plant there were only median and submedian chromosomes. The karyotype of *A. triandra* ecotypes showed a higher frequency of submedian and median chromosomes as compared to *A. catechu*. A classification of the karyotypes of the two species, according to the degree of their asymmetry (cf., Stebbins, 1958) showed that karyotypes 1B, 2A, 2B, and 3B were represented in *A. catechu* cultivars and only 1A, 2A, and 2B in the ecotypes of *A. triandra*. They observed that *A. triandra* has a more symmetrical karyotype than *A. catechu* (Bavappa and Raman, 1965). Bavappa et al. (1975) concluded that *A. triandra* was primitive as it has a more symmetrical karyotype and also possessed more chromatin matter. The karyotypes of *A. catechu*-*A. triandra* hybrids showed wider variability in chromosome size than both the parents. The relative length of chromosomes of these two parents ranged from 4.12 μ to 8.59 μ whereas in the hybrids the variation was from 3.45 μ to 10.72 μ . They felt that these data indicated a compensation effect, as had brought about a reduction in the length of the shortest chromosome and an increase in that of the longest one. No consistency

in the presence/absence, number and position of the satellite was observed either in the parents or hybrids and they inferred that the usefulness of this character in the classification of *Areca* karyotype was very limited (Bavappa et al., 1975).

Occurrence of five chlorophyll deficient forms in arecanut was reported by Bavappa and Murthy (1959). They indicated the advantages of eliminating them in breeding programmes. Naidu, Kumar, and Sannamarappa (1963) observed a dwarf arecanut palm in a natural population. on the basis of the morphological study of the hybrids between *A. catechu* and *A. triandra*, Bavappa (1974) proposed that internodal distance and leaf length showed dosage effect of genes. He inferred also that stem thickness, number of stamens and fruit size were quantitative in inheritance. He has also reported the dominance of paired nature of male flowers over singleness and biseriate arrangement over uniseriate.

DISCUSSION

The immediate objective of breeding programmes in arecanut will have to be higher yield and resistance to yellow leaf disease, though resistance to other pests and diseases are also important. Studies made so far on the variability in *A. catechu* and the related species *A. triandra* show that they possess wide diversity. Bavappa (1963) has discussed the possibility of the subspecies and varieties of arecanut acquiring distinct varietal characteristics. A comprehensive survey of arecanut within India and outside, evaluating their yield and studying the genetic distance among them will enable identification of high yielding cultivars for direct cultivation and genetically divergent ones for hybridization. The higher yields of the cultivars Saigon 1, 2 and 3, Indonesia 6, Singapore, and Andaman (Anonymous, 1974, 1976, 1977) indicate the

potential for isolating superior varieties through such a programme.

A number of selection parameters that are likely to affect the yield of arecanut favourably has been identified, and the theoretical estimates have been made of the gains that could be obtained. However, these have a limitation that these estimates relate to specific populations and of studies carried out for limited periods of time. Being a cross fertilized perennial crop, variation in the genetic make up of different plants and populations and their interaction with environment during growth periods are factors that can affect the above estimates to varying degrees. Bavappa and Ramachander (1967c, 1968b) had reported a low heritability (20%) for yield (number and total weight of nuts). Using data from the same population for a different set of years, Ravindran (personal communication) estimated again heritability for yield and found that the results, though different slightly from the earlier estimates, were still low. Almost similar results were obtained in the study of the divergence in 13 cultivars of *A. catechu* and four ecotypes of *A. triandra* (Bavappa, 1974). The pattern of clustering was stable in respect of widely divergent groups for different years. It, therefore, appears that for a given population at least some of the estimates may be valid irrespective of its age. All the same, the need to check the stability of all the parameters period of years and for different populations is very much apparent.

Of the various methods that have been suggested for the improvement of arecanut, selection based on characters of high heritability and high genotypic and phenotypic correlation with yield, selection based on selection index, yield improvement through mass pedigree system and use of prepotency, are the major approaches attempted so far. However, it appears that one or more of these selection methods, while being effective under specific conditions of their application,

may not be additive or may even become inoperative when another method is applied. Selection of seedlings for number of leaves, girth at collar, and number of nodes at the appropriate stages totally eliminate the late bearing plants (Bavappa and Ramachander 1967c). Thus, when selection pressure is applied for these characters, no advantage can be expected by selection for earliness in bearing. There are also limitations in achieving significant improvement in methods of selections based on a single character with narrow variability (Ramachander and Bavappa, 1972). In spite of this, a simple selection index technique worked out by them using number of leaves and height of the plant at the time of transplanting gave an estimated relative improvement of 332%. The advantage of mass pedigree selection method in a cross fertilized crop like arecanut irrespective of the estimates of heritability for any character, has also been pointed out by Bavappa and Ramachander (1967c).

The existing method of identifying prepotent palms is only by progeny testing. This requires considerable time and resources. Information is lacking on the genetics of prepotency and the yield improvement that could be obtained if selection is exercised for this character. Bavappa and Ramachander (1967c) have indicated the possible association of percentage of fruit set with prepotency. Large scale progeny testing and search for characters associated with prepotency should also be taken up.

Preliminary results on the evaluation of these methods showed that as far as earliness in flowering is concerned, plants selected on the basis of selection index alone (index value 110) were significantly superior to control. Significant yield differences were observed among the progenies selected by the mass pedigree method (Anonymous, 1977). It has also been estimated that the genetic gain for number of nuts in the mass pedigree method was over 35% (Ravindran,

personal communication). No significant difference has so far been observed between progenies of prepotent and non-prepotent mother palms (Bhagavan, personal communication). It appears that a selection system based on average effects of genes and not the genotype might be more efficient.

Improvement in the genetic potential of a population can be achieved by repeated selection based on characters having high heritability and correlation with yield. There are a number of measurable characters such as seed weight, time taken for germination, seedling characters at various stages of growth, chemical characteristics such as C/N ratio (Heslop-Harrison, 1967), etc. for which correlation and heritability estimates are yet to be worked out. These information, coupled with selection index technique, if appropriately used in different generations, should prove useful. In cotton, a yield increase of the order of 4% per generation has been achieved over eight generations without any evidence of a decline in the rate of advance (Hutchinson, 1959). Since yield improvement through selection methods is likely to be slow, efforts will have to be continued for a number of generations.

Planned efforts for exploiting heterosis for yield have not been made though earliness in bearing and high yields in the inter-varietal hybrids of local and exotic accessions have been reported (Anonymous, 1970, 1971). One of the methods of enhancing hybrid vigour expression is to use inbred lines for hybridization (Anonymous, 1969, 1970). Since evolving homozygous lines in each cultivar is time consuming, crossing of the cultivars in every generation of selfing and studying the hybrids may be useful. Crossing highly divergent cultivars is yet another method for the efficient use of heterosis. Based on genetic divergence, the advantage of crossing Ceylon-1, Indonesia 6, China, and Fiji with Ceylon-2 has been indicated by Bavappa (1974). Though no information

is available on the genetics of dwarfness in arecanut, crossing different palms of the dwarf variety with different palms of various cultivars may give useful hybrids. Proper choice of palms even among dwarf and tall varieties of coconut has been suggested for the efficient exploitation of these hybrids (Bavappa et al., 1972).

Hybrid vigour for important economic characters such as length of spadix, girth of stem at fixed mark, number of male and female flowers per bunch, and length and breadth of female flowers has been observed in the interspecific hybrid of *A. catechu* and *A. triandra* (Bavappa and Nair, 1975). Other interspecific crosses of *A. catechu* with *A. normanbyii* and *A. macrocalyx* and an intergeneric cross with *Actinorhysis calaparia* have been also reported (Anonymous, 1973, 1974). In the absence of crossability barrier, a careful search of related species and genera for economic characters, particularly for resistance to yellow leaf disease, and producing hybrids using such species may be worth trying. Though these hybrids may be sterile to varying degrees, it may be possible to restore fertility and transfer desirable characters by repeated backcrossing with *A. catechu*.

The studies initiated so far and the results obtained from them are far too inadequate to draw any conclusions about the effectiveness of different crop improvement programmes and their relative merits. Collection of data should be continued systematically for a number of years and the same analysed statistically following different methods. As and when indications become available from these studies, further experiments should be laid out so that over a period of time, adequate results of both basic and applied nature are available. Since these results are likely to have bearing on the crop improvement procedures that could be followed in other seed propagated, out-crossed perennial crops, sustained efforts are called for in

continuing these investigations in all their aspects.

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