BIOMETRICAL STUDIES IN CASHEW (*Anacardium occidentale* L.) HYBRIDS

By

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THESIS

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DECLARATION

I hereby declare that the thesis entitled "Biometrical studies in cashew (*Anacardium occidentale* L.) hybrids" is a bonafide record of research work done by me during the course of research and this thesis has not previously formed the basis for award of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

Vellanikkara,
27th October, 1992.

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We, the undersigned, members of the Advisory Committee of **Mr. Manoj, P.S.,** a candidate for the degree of Master of Science in Horticulture agree that the thesis entitled **"Biometrical studies in cashew (*Anacardium occidentale* L.) hybrids"** may be submitted by Mr. Manoj, P.S. in partial fulfilment of the requirement for the degree.

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Introduction

INTRODUCTION

From its humble beginning as a crop intended to check soil erosion cashew (*Anacardium occidentale* L.) has emerged as one of the most important dollar earning crops of the country. Cashew is traditionally grown in Kerala, Karnataka, Goa and Maharashtra in the Western plains and ghats and Tamil Nadu, Andhra Pradesh and Orissa in the east coast plains and hill region. It has spread to other non-traditional areas of West Bengal in the lower Gangetic plains and Tripura in the eastern Himalayas in recent years.

In India cashew occupies an area of 5.32 lakh hectares with a production of 2.95 lakh tonnes, of which Kerala has 1.55 lakh hectares area and 1.42 lakh tonnes production. The average cashew nut yield on all India basis is 634 kg/ha whereas in Kerala it is about 978 kg/ha (Balasubramaniam, 1991).

Export of cashew kernels from India in 1990-91 touched a new height of Rs.443.5 crores showing a growth of 23 per cent over the previous year. In terms of quantity, the export registered a growth of 12 per cent amounting to 50,080 tonnes. However, our country is not self sufficient as far as availability of raw nuts is concerned. While the total installed capacity of processing factories in India is around six lakh tonnes per annum, the availability of raw nuts is only 2.95 lakh tonnes. This necessitates import of raw cashew nuts from other cashew growing countries. During 1990-91, 0.67 lakh tonnes of raw cashew nuts worth 40 million dollars were imported to meet the requirement of processing factories. This drain of foreign exchange can be effectively checked by enhancing the level of cashew production in the country.

The productivity of cashew plantations in India is abysmally low. One major reason for this low productivity is the fact that the existing plantations have been established from seedling progenies of poor genetic stock. By using clonal planting material of improved genotypes productivity of cashew can be increased manifold. Hence the breeding programme for cashew is formulated with the objectives of effecting crosses involving as many parental combinations as possible having the desired characters, making a rigorous screening in the F_1 and multiplying the selected superior progenies by vegetative means (Damodaran *et al.*, 1979).

Proper evaluation of F_1 hybrids is as important as the production of hybrids. It is in this context that the present investigation was undertaken. This will help to identify superior F_1 hybrids of cashew with increased production potential and desirable horticultural attributes. The information on variability and association of characters obtained through this study will be useful in rendering the selection of hybrids more effective.

Review of Literature

REVIEW OF LITERATURE

Cashew is one of the most important foreign exchange earning crops of the country. It is a highly cross pollinated crop. Due to continued seed propagation for over several centuries, the existing trees are highly heterozygous and exhibit enormous variability in their performance. For a systematically planned crop improvement programme, a precise knowledge of the extent of variability present among the genotypes and the association which exists between yield and different biometrical characters is important. However such studies carried out in cashew so far are only limited and consequently the information available is rather meagre (Nawale and Salvi, 1990).

Literature pertaining to the aspects investigated in this study is reviewed here under the following heads.

2.1 Growth parameters

2.2 Floral traits

2.3 Yield attributes

2.4 Apple characters

2.5 Crop improvement through hybridization

2.6 Genetic variability and correlation of characters

2.1 Growth parameters

Rao and Hassan (1957) noted two main active growth phases, one beginning in October and lasting until January prior to the flowering stage and the other between March and May. Shoot growth during the active phase beginning in October varied from 2.5 to 21.5 cm per shoot, with a mean of 10.7 cm. The extension growth ceased with the flowering of the shoots. The subsequent growth of these shoots at the beginning of March comprised only the lateral shoots arising from buds below inflorescence.

Dasarathy (1958) after conducting a study of growth features and blossom biology of cashew observed two types of branching in cashew namely extensive and intensive. The intensive shoot grew to a length of about 25 to 30 cm and terminated in a panicle. Simultaneously seven to eight lateral branches also arose within 10 to 15 cm of the apex of the main branch. Some of these lateral shoots also terminated in panicles in the same flowering season, repeating the same growth pattern and giving a bushy appearance to the tree. In the extensive type, the shoots grew to a length of 20 to 30 cm and became dormant for some time. This kind of growth pattern resulted in a spreading canopy. In high yielding trees, more than sixty per cent of the shoots constituted the intensive type of branching as against twenty per cent only in the low yielders.

Bigger (1960) studying young trees in southern Tanzania observed that maximum growth took place during the rains from January to April, while there was evidence of two lesser periods of increased growth in August in the middle of dry season and in November at the beginning of the rainy season following fruiting.

Maity (1960) observed three growth flushes in a year and the rainy season flush was reported to be less vigorous than the winter or spring season growths. Argles (1969) noticed a similar growth pattern in cashew. He observed two or three peak periods of growth in a bearing cashew tree. According to Morton (1970), maximum flowering was seen in trees with erect growing habits.

Chakraborty et al. (1980). in their studies on growth and flowering in cashew observed that the terminal shoots which emerged in spring showed continuous and steady linear extension and diametric thickening upto six months after emergence and thereafter the rate of growth slowed down considerably. Emergence of laterals took place mainly during summer rains. Although lateral branches developed on recent growths as well as in one or two years old terminal shoots, maximum branching usually occurred on one year old shoots. Both vegetative and flowering shoots produced laterals, but maximum number of laterals appeared from the latter category of shoots.

2.2 Floral traits

2.2.1 Flowering habit and season

Bigger (1960) in Tanzania observed a considerable variation in the date at which the trees reached their flowering peak. On the average, this peak was about two-and-a half months after appearance of the first flowers.

According to Damodaran et al. (1965) who conducted a detailed study on flowering behaviour in cashew, flowers were borne on the past season's growth either terminally or laterally. Both vegetative and floral parts emerged from the same bud. The initial growth that emerged from the growing bud gave rise to normal vegetative leaves which became smaller as the extension growth developed into the floral panicle. They also reported that the emergence of flower bud extended over a period of nearly five and a half months. In some trees, the emergence period was continuous while in some others there were distinct flushes. The period of flower opening varied from a minimum of 25 days to a maximum of 168 days. The peak period of flowering in most trees was from December to the middle of February.

According to Northwood (1966) who conducted recordings of a number of inflorescences over several years in Jamaica, there was no consistency in early, mid-season or late flowering of any individual tree. Three distinct phases in flowering were observed by Pavithran and Ravindranathan (1974). These were first the male phase during which only staminate flowers opened, second the mixed phase during which both staminate and hermaphrodite flowers opened and third the male phase during which few male flowers only opened. The trees showed considerable variation in the duration of different phases. Trees having short male phase and longer mixed phase with abundant flowering produced more hemaphrodite flowers.

Nambiar (1975) reported that the duration and season of flowering varied from one region to another depending on altitude, temperature, humidity and rainfall. Hanamashetti et al. (1986) observed that duration of flowering extended for about four months from last week of November to the last week of March. The duration ranged from 51 to 111 days.

2.2.2 Morphology of flower

Rao and Hassan (1957) studied the floral biology in cashew and reported that nearly 96 per cent of the flowers were found to be staminate and only 4 per cent were hermaphrodite. Most of the latter appeared between 45 and 105 days from the commencement of flowering. The need for selecting trees producing high proportion of perfect flowers for getting high yields was emphasized.

Aiyadurai and Koyamu (1957) studied the branching, flowering and fruiting habits of a population of one thousand cashew trees raised from seed and observed wide variation in the above characters. Mutter and Bigger (1962) in Tanzania reported a ratio of 1.0 to 6.5 between perfect and staminate flowers in cashew and they observed that perfect flowers reached their maximum by the third week of flowering and disappeared finally by the sixth week, whereas the male flowers were at their maximum by the sixth week and continued until the tenth.

A comprehensive study of the morphology and biology of cashew flower was made by Damodaran et al. (1965). They reported that panicles which emerged earlier in the season had a higher proportion of staminate flowers than those produced later in the season. The proportion of perfect flowers was found to vary considerably even between panicles on the same tree. It varied from as low as 0.45 per cent to 24.90 per cent in different trees.

Northwood (1966), in Tanzania, found that most of the perfect flowers were produced within the first three weeks. Ascenso and Mota (1972) who studied the morphology of cashew flower described the andromonoecious nature of cashew trees. The number of sepals varied between four and seven and the number of petals between four and nine. Each flower had one ovary, rudimentary in the case of male flowers. The flowers usually had one or sometimes two large extended stamens and eight or nine short stamens.

Hanamashetti et al. (1986) reported that the total number of flowers per panicle varied from 165 to 837 and the number of perfect flowers per panicle varied from 2.5 to 61.1. The ratio of male to bisexual flowers ranged from 4:1 to 61:1. Ghosh (1988) reported that under Jhargram (West Bengal) conditions, percentage of staminate flowers per panicle ranged from 34.80 to 95.03.

Krishnappa et al. (1991 a) in one study reported that varieties significantly differed in the number of panicles per one square metre area in the different directions. This ranged from 9.57 to 23.25. In another study they reported that the total number of flowers per panicle varied from 231.4 to 835.8 in different varieties. The number of staminate flowers per panicle ranged from 69.0 to 628.8, while number of hermaphrodite flowers ranged from 115.4 to 302.0. Regarding the number of fruits per panicle, it varied from 4.5 to 8.0 (Krishnappa et al., 1991 b). In a recent study, Krishnappa et al. (1992) found that the total number of flowers per panicle ranged from 380.4 to 742.6 while the number of staminate and hermaphrodite flowers per panicle ranged from

103.4 to 511.8 and 89.0 to 354.6 respectively. Thimmaraju et al. (1980), Patnaik et al. (1985), Elsy et al. (1987), Khan and Kumar (1988) and Reddy et al. (1989) also reported the range of variation of the floral traits in cashew in different populations.

2.2.3 Fruit set and development

Rao (1956) observed only 3 per cent fruit set in cashew. Damodaran et al. (1966) stated that the mean number of fruits set per panicle was slightly higher in the case of the tree with a higher sex ratio as compared to the tree with a low sex ratio. But the difference was not fully reflected in the ultimate number of fruits per panicle carried to maturity. Only 4-6 per cent of the perfect flowers carried fruits to maturity. The intensity of drop was heaviest before the fruit attained a length of 5 cm. He also reported that about fifty four days were needed for full ripening of the fruit.

Pillai and Pillai (1975) conducted a study on the shedding of immature fruits in cashew. According to them nearly 85 per cent of the fruits shed were fertilized and at different stages of development while the remaining 15 per cent were unfertilized. Out of the 85 per cent of fertilized fruits, only 4 per cent reached maturity, the remaining

81 per cent being shed away at various stages of development. Of this 20 per cent was caused by insect attack and the remaining 61 per cent could be attributed to any factor ranging from nutritional imbalance to defective metabolism.

Nawale et al. (1984) reported 7.97 to 26.59 per cent fruit set under Konkan conditions. They had also reported 25.40 to 82.50 per cent fruit drop at mustard stage and 1.67 to 26.09 per cent fruit drop at the later stages. In another study Patnaik et al. (1985) observed 11.92 to 54.50 per cent fruit set under Orissa conditions. About 45.50 to 88.08 per cent of the hermaphrodite flowers dropped off without setting any fruits. The total fruits drop varied from 50.61 to 100 per cent in different cashew types. On an average only about 23.26 per cent of the flowers that had set fruit reached maturity.

Krishnappa et al. (1991 b) reported that the number of fruits per panicle varied from 4.5 to 8.0 while Nalini and Santhakumari (1991) reported number of nuts per panicle as high as 16.0 and 13.5. In another study Krishnappa et al. (1992) could observe only 4.6 to 6.6 fruits per panicle.

2.3 Yield attributes

Variations in the nut characters were observed by Mukherjee (1956) who recognized six types based on apple and nut characters. Rao and Hassan (1956) studied seed characters of cashew and found considerable variation in weight and shelling percentage of 100 samples, collected from India and other countries. Peixoto (1960) mentioned nuts of 30 g in Brazil. Correia (1963) estimated the average weight of a nut in Mozambique to be about 5 g. Lefebvre (1963) in Madagascar, found average weight for samples of 100 nuts from different regions ranging from 395 to 467 g. Rocchetti and Moselle (1967), studying Tanzanian nuts, reported an average weight of 4.8 g per nut.

Mohapatra et al. (1972) found great differences in protein contents, ranging from 13.13 to 25.03 per cent. They concluded that protein content should be considered as one of the most important factors in future breeding and selection programmes of cashew nut.

Giuliano and Agnoloni (1975) investigated samples of cashew nuts from different countries and found the individual nut weight varying from 3.6 to 5.4 g. Nandini and James (1984), in an yield trial reported that nut size of sixteen promising types varied from 5.21 to 9.40 g, and the shelling percentage from 22.37 to 28.71. In another study, nut size and shelling percentage ranged from 4.25 to 6.73 g and 18.0 to 34.7 respectively (Ghosh and Chatterjee, 1987).

Chemical characterization of a few high yielding varieties of cashew was made by Nagaraj and Nampoothiri (1986). Kernels without testae from sixteen high yielding varieties of cashew contained protein as high as 32.1 to 43.8 per cent.

Reddy <u>et al</u>. (1989) studied six varieties released from Andhra Pradesh Agricultural University. These varieties showed a variation in nut size from 4.0 to 6.0 g, shelling percentage from 23.0 to 28.1 and protein content of kernel from 18.06 to 21.30 per cent.

A study on the performance of ten selected types at Cashew Research Station, Anakkayam showed that nut size ranged from 5.1 to 8.9 g and shelling percentage from 25.80 to 27.99 (Nalini and Santhakumari, 1991).

2.4 Apple characters

Jain <u>et al</u>. (1954) noted that the astringent and acrid taste of cashew apples was mainly due to the presence of tannins (0.36 per cent) and other substances present in the juice. In a population of thousand bearing cashew trees, Aiyadurai and Koyamu (1957) found considerable differences in growth habit, size, colour and shape of cashew apples. Uthaman and Koyamu (1957) also noticed similar variations. Albuquerque <u>et al</u>. (1960) studied the apple characters of cashew and found that yellow apples tended to be heavier, softer and less astringent than red apples. They also noticed wide variation in weight and size of cashew apple. Aiyadurai (1966) also reported the existence of cashew apples in varying intensities of yellow, red and mixed shades of these two characters.

Pereira (1966) studied the physico-chemical characters of cashew apples from Portugese Guinea, and had reported wide variation in the important characteristics, viz. flavour, aroma, density, dry matter content, acidity, sugars, tannins, total nitrogen and vitamin C.

Lopes (1972) analysed red and yellow apples from various parts of Mozambique. Although there was a considerable variability between apples from different regions and between individual apples, there was no significant difference as to red and yellow ones. The greatest variability was found in the tannin content, the lowest being 0.06 and the highest 0.22 g per 100 g. The pH of the apples varied between 4.1 and 4.7, and total sugars from 6.7 to 10.5 per cent, the vitamin C content ranged from 234 to 371 mg per 100 g.

Damodaran (1977) reported that along with other economic characters, considerable variation existed in mean weight, size, shape and colour of apples of the F_1 progenies of four cross combination.

Study of 16 high yielding varieties of cashew showed variation in total sugar (5.5-7.7 per cent), reducing sugar (5.5-7.5 per cent), ascorbic acid (144-269 mg/100 g) and tannin content (0.027-0.153 per cent) of cashew apples (Nagaraja and Nampoothiri, 1986).

Reddy et al. (1989) observed wide variation in the juice content of cashew apples from as low as 10 per cent to 61 per cent. Ghosh (1990) reported that the apple of the best variety TN-16 of West Bengal was medium in size, yellow in colour and the juice recovery was 63.5 per cent. In another study, on the performance of five high yielding varieties of cashew, Antarker et al. (1991) observed variation in T.S.S. (14-16 per cent), reducing sugars (9.23-10.10 per cent), total sugars (10.76-12.25 per cent), acidity (0.192-0.272 per cent), pH (4.5-5.1), ascorbic acid (212.5-375.0 mg/100 g) and tannins (0.25-0.36 per cent) of cashew apples.

In a recent study, Sapkal et al. (1992) reported wide variation in the juice content (47.13 to 63.89 per cent), total soluble solids (12.83 to 17.92 per cent), acidity (1.82 to 3.38 mg/100 g), phenolic content (0.93 to 1.33 mg/g) and pH (3.61 to 4.26) of cashew apples.

2.5 Crop improvement through hybridization

Genetic improvement in cashew through hybridization was initiated in the country during early sixties. Work on this line is in progress in different research stations and several superior hybrids suitable for cultivation in different agro-climatic zones have been identified and released for large scale cultivation in the respective zones.

Damodaran (1975) observed hybrid vigour in cashew. According to him, hybrids displayed increased girth, earlier bearing and higher yields as compared to selfed and open pollinated progenies.

Hybridization work undertaken at the Cashew Research Stations at Kottarakkara and Anakkayam in Kerala during the period from 1963 to 1973 had resulted in the development of 216 hybrid progenies from 28 parental combinations. Among these, hybrids H-3-17 and H-4-7 were selected as promising for large scale cultivation under Kerala conditions (Damodaran *et al*., 1978).

Damodaran *et al*. (1979) observed that whenever an exotic parent was involved in the hybridization programme, the progeny showed better performance than cross between local types. This was in conformity with the established concept that hybrid vigour is best manifested in crosses involving parents with greater genetic diversity.

The studies conducted at Cashew Research Station, Anakkayam and Cashew Research Station, Madakkathara resulted in the standardization of hybridization technique in cashew (Nair, 1981).

The hybridization programmes of cashew in the country during the last three decades have so far resulted in the release of five hybrids BPP-1 and BPP-2 from Cashew Research Station, Bapatla and Vengurla-3, Vengurla-4 and Vengurla-5 from Fruit Research Station, Vengurla (Rao, 1989).

Evaluation of 163 F_1 hybrids developed during 1973-1979 conducted at Cashew Research Station, Madakkathara resulted in the identification of 14 superior hybrids (Veeraraghavan, 1990). The highest mean yield per tree for 12 years (1977-1988) of 12.83 kg was recorded by H-1598 followed by H-1608, H-1610 and H-1602. H-1591 had the boldest nut followed by H-1602 and H-1608. H-1602 had the highest kernel weight followed by H-1596 and H-856.

Nawale and Salvi (1990) studied the inheritance of certain characters in the F_1 hybrid progenies of cashew. The results of these studies indicated that improvement of cashew in respect of yield of nuts, size of nuts, shelling percentage and other desirable tree growth, flowering and fruiting characters is possible through hybridization by proper selection of the parental combination. Besides high yield of nuts, intensive branching behaviour, large number of lateral shoots and panicles per unit area, compact canopy, high percentage of perfect flowers, high fruit set per panicle, better medium nut size and good shelling percentage were found to be the desirable characters of cashew parents and these characters could be transmitted to the F_1 hybrid progenies of cashew.

2.6 Genetic variability and correlation of characters

According to Rao (1974) percentage of hermaphrodite flowers had a strong positive correlation with yield in cashew. The variability in the F_1 population of cashew was studied by Damodaran (1977) and he observed considerable variation for mean yield, weight of 100 nuts, mean weight of apple, shelling percentage, size, colour and shape of apples. It was also noted that a large number of productive hybrid progenies were derived from the crosses in which one of the parents was an exotic type. Among the three characters studied, Nayar et al. (1981) reported that canopy spread has maximum positive correlation with yield followed by trunk girth and height of the tree.

Varietal differences in tree size and yield of cashew were studied by Falade (1981) in Nigeria. Cashew trees in two selected plots of comparable ages were grouped into varieties on the basis of colours and shapes of their apples. The variation in the size of the trees was found to be comparatively narrower than that in the yield. Varieties also greatly differed, in their yield potentials which in turn depended on the location.

Devi (1981) studied the variability in F_1 population of cashew and found that the variability was maximum for nut weight followed by shelling percentage, percentage of hermaphrodite flowers and mean nut yield.

Ramdas and Thatham (1982) studied the variability and correlation of yield and seven nut and kernel traits in cashew and found that yield was the most and shell weight the least variable trait. They also concluded that individual tree yield offered the best scope for selection for improved yield.

It is reported by Nawale (1983) that spread of plant, a large number of lateral shoots and panicles per unit area, and high fruit set per panicle are correlated with higher yield of cashew and he further pointed out that these characters need to be considered in cashew breeding for its improvement. Besides high yield and desirable tree characters, size of nuts, kernel size and shelling percentage are also important in view point of processing of cashew nuts for kernels in trade.

A study conducted by George *et al*. (1984) for three years to standardise a technique for forecasting cashew yield based on seven biometrical characters recorded at weekly intervals revealed that yield could be forecasted with reasonable precision (R^2 = 0.64) by a single spot observation made during the peak flowering period (February-March). The number of variables could be brought down to three viz., the number of nuts on the tree, condition of flowering (graded 0 to 5), and canopy area, without substantially affecting the accuracy of the estimate (R^2 = 0.61).

Factors influencing yield in cashew were studied by Parameswaran *et al*. (1984 a). A strong corrleation was observed between tree yield and the percentage of flowering shoots per unit area of tree canopy followed by total canopy area. No significant correlation was noted between yield and tree height. A weak positive correlation was found between yield and the percentage of open hermaphrodite flowers. A significant inverse relationship was observed between yield and the percentage of fruit drop.

Parameswaran *et al*. (1984 b) investigated the relationship between yield and duration of different phases in flower opening in cashew. The mean duration of flowering in trees above medium yield was 83.7 days and in those below medium yield, it was 102.7 days. The proportion of male phase in the total duration of flowering was significantly lower in trees above medium yield.

Mohan _et_ _al_. (1987) had developed an index score method using yield components for classifying cashew types. Individual trees with high scores and high yield were identified and treated as elites. These were characterized by medium sized nuts, and more number of nuts per panicle.

Genetic variability among nut yield traits was studied by Faluyi (1987). Among the eight characters studied, variation was greatest for nuts per tree and nut weight per tree. For all characters, genotypic variance was over 50 per cent of the phenotypic variance. Kernel weight per nut and shell weight per nut were closely correlated and were in a ratio of about 1:2. Broad sense heritability estimates ranged from 51.1 per cent for nut weight per tree to 60.5 per cent for shell weight per tree. Only nut weight per tree and its components had values for expected genetic advance of over 20 per cent. Study of correlation coefficients suggested that selection should be based on nut weight per tree.

George _et_ _al_. (1989) developed and field tested a method to forecast the cashew yield from large plantations based on biometrical characters and yield attributes. The yield estimates arrived at were found to be reasonably precise with an average deviation of 6.7 to 17.9 per cent with the actual yield at different locations.

In an effort to promote a national network of cashew genetic resources by establishing "Clonal Gene Banks", a total collection of 292 accessions obtained from different Cashew Research Stations in the country in addition to primary collections made from southern region were systematically evaluated and characterized using IBPGR germplasm descriptor list (Swamy and Thimmappaiah 1990). Considerable variation was noticed among the collections for some economic characters, viz., the season of flowering and its duration, apple colour, shape and weight, nut weight and kernel to whole nut ratio.

The step-wise regression analysis of ten seed/seedling characters on the nut yield of cashew made by Bhagavan and Kumaran (1990) has highlighted the prominence of six characters namely seed length, days taken for germination, seedling height, length and breadth of first leaf and number of opened leaves. Further study on direct and indirect effect of these characters suggested that the selection of long sized nuts for raising seedlings resulted in higher yield and the seedling which germinated early had better yield potential.

Correlation and regression studies of eleven yield contributing characters were made by Anitha *et al.* (1991). The nut yield had a positive and highly significant correlation with number of nuts per panicle that reached maturity (0.961) and mean number of perfect flowers per panicle (0.564). Mean nut weight had negative correlation with the number of nuts per panicle that reached maturity. The maximum regression coefficient of the yield was observed in number of nuts reached maturity.

Materials and Methods

MATERIALS AND METHODS

The present investigation envisaged to determine the extent of variability and degree of association of quantitative characters in cashew and to evaluate F_1 hybrids of cashew for growth parameters, floral traits, yield attributes and apple characters were carried out at the Department of Pomology and Floriculture, College of Horticulture, Vellanikkara during 1990-1992. The experimental field is located at an altitude of 23 m above MSL and is between 10° 32' N latitude and 70° 16' E longitude.

The experimental material comprised of fifty six F_1 hybrids of cashew developed under the erstwhile Kerala Agricultural Development Project of Kerala Agricultural University which have been planted at the Instructional Farm of College of Horticulture, Vellanikkara during the year 1980. These ten year old F_1 hybrids belonged to tweleve parental combinations, the parents being high yielding trees identified at the Cashew Research Station, Madakkathara. The cross combinations and the number of F_1 hybrids belonging to each parental combination are furnished in Table 1.

The hybrids and parents were observed for four growth parameters, five floral traits, six yield attributes and seven

Table 1. Cross combinations and number of F_1 hybrids

Sl. No.	Cross combination	F_1 hybrids of each combination	Number of F_1 hybrids
1.	T.1589 x T.730 *	H-338, H-339, H-340, H-341, H-342, H-345, H-346, H-347, H-348, H-349, H-350 **	11
2.	T.1599 x T.745	H-351, H-352, H-353, H-354, H-355, H-357, H-363, H-364	8
3.	T.1098 x T.1589	H-358, H-359, H-360	3
4.	T.1140 x T.855	H-365, H-367, H-368, H-370	4
5.	T.1672 x T.1589	H-373, H-374, H-375, H-376, H-377	5
6.	T.855 x T.662	H-381, H-382	2
7.	T.1602 x T.885	H-390, H-392	2
8.	T.1733 x T.1673	H-394, H-395, H-396	3
9.	T.514 x T.1588	H-397, H-398	2
10.	T.730 x T.1589	H-402, H-403, H-405, H-407, H-408	5
11.	T.745 x T.657	H-419, H-420, H-421, H-422, H-423, H-424	6
12.	T.1663 x T.1589	H-425, H-426, H-427, H-428, H-429	5

* T stands for tree number of the parent as entered in the Tree Register Vol.I of Cashew Research Station, Madakkathara.

** H stands for tree number of the hybrid.

apple characters for two seasons, 1990-1991 and 1991-1992. The characters observed were as follows:

3.1 Growth parameters

3.1.1 Height of the tree (cm)

3.1.2 Girth of the tree (cm)

3.1.3 Mean canopy spread (cm)

3.1.4 Leaf area (sq cm)

3.2 Floral traits

3.2.1 Season and duration of flowering

3.2.2 Number of panicles per $(\frac{1}{2}\ m)^2$ canopy area

3.2.3 Number of flowers per panicle

3.2.4 Per cent hermaphrodite flowers

3.2.5 Per cent fruit set

3.3 Yield attributes

3.3.1 Number of nuts per panicle

3.3.2 Individual nut weight (g)

3.3.3 Nut yield per tree (kg)

3.3.4 Weight of kernel (g)

3.3.5 Shelling percentage

3.3.6 Protein content of kernel (%)

3.4 Apple characters

3.4.1 Weight of apple (g)

3.4.2 Juice per cent of apple

3.4.3 Reducing sugars in apple (%)

3.4.4 Total sugars in apple (%)

3.4.5 Total soluble solids (%)

3.4.6 Titrable acidity (%)

3.4.7 Tannin content (%)

The methodology adopted to study these characters is as follows:

3.1 Growth parameters

3.1.1 Height of the tree

The distance between base and top most point of the tree was measured using a long graduated pole.

3.1.2 Girth of the tree

Girth of the tree was measured at 50 cm from the ground level.

3.1.3 Mean canopy spread

Mean spread of the tree canopy was worked out by measuring the spread in North-South and East-West direction and averaging these two.

3.1.4 Leaf area

Five fully matured leaves were collected randomly from each tree and the leaf area was measured using a Leaf Area Meter and their average was worked out.

3.2 Floral traits

3.2.1 Season and duration of flowering

The trees were grouped into early, mid-season and late based on the time of fifty per cent flowering. The hybrids which recorded fifty per cent flowering during November were classified as early, while those in December and January as mid-season and late respectively. The period between the initiation of flowering and completion of flowering represented the duration of flowering.

3.2.2 Number of panicles per $(\frac{1}{2}\ m)^2$ canopy area

During peak flowering period wooden frame of $(\frac{1}{2}\ m)^2$ area was placed at ten randomly selected locations of tree canopy and the number of panicles covered by square at each location was counted and the average worked out.

3.2.3 Number of flowers per panicle

Before the commencement of flower bud opening, ten panicles were selected at random and tagged on each tree. The number of hermaphrodite flowers and male flowers that opened on each day was recorded separately during the entire flowering period. The total number of flowers was worked out for each panicle and the average worked out.

3.2.4 Per cent hermaphrodite flowers

Percentage of hermaphrodite flowers produced on each tree was calculated on the basis of the number of hermaphrodite flowers and total number of flowers produced in the tagged ten panicles.

3.2.5 Per cent fruit set

Observations regarding fruit set were made on the same panicles chosen for floral studies. The hermaphrodite flowers which showed marked swelling of the ovary were treated as set. Such flowers were counted and totalled and on that basis per cent fruit set worked out.

3.3 Yield attributes

3.3.1 Number of nuts per panicle

The nuts that were retained on the ten panicles selected for floral studies were counted and the average worked out.

3.3.2 Individual nut weight

Weight of 100 nuts were taken and the average worked out.

3.3.3 Nut yield per tree

Tree-wise yield was recorded at each harvest and totalled.

3.3.4 Weight of kernel

Weight of 100 whole kernels were taken and the average worked out. This observation was also used for working out export grades of kernels of selected hybrids. Export grades of cashew kernels were calculated on the basis of the number of kernels per pound as notified by the Government of India.

3.3.5 Shelling percentage

One kg of sundried, roasted nuts were shelled and weight of whole kernels obtained was found out. Then the shelling percentage was worked out using the following formula.

$$\text{Shelling percentage} = \frac{\text{Average kernel weight}}{\text{Average nut weight}} \times 100$$

3.3.6 Protein content of kernel

Kernels were scooped out from nut samples after sundrying and they were dried in the oven and testa was removed. The nitrogen content of these kernels was estimated using the Microkjeldahl method (A.O.A.C., 1980). The nitrogen content was multiplied by 5.30 to obtain the protein content and expressed as percentage.

3.4 Apple characters

3.4.1 Weight of apple

Weight of ten apples were taken and mean worked out.

3.4.2 Juice per cent of apple

Juice was extracted from apples of known weight and the percentage calculated.

3.4.3 Reducing sugars in apple

Reducing sugar in cashew apple juice was estimated by Lane and Eynon method (1923) described by Ranganna (1977) and the reducing sugars were recorded as grams of glucose per 100 g of the original juice.

3.4.4 Total sugars in apple

Total sugar which includes the reducing and non-reducing sugars was estimated by Lane and Eynon method (1923) described by Ranganna (1977) and the total sugars were recorded as grams of glucose per 100 g of the original juice.

3.4.5 Total soluble solids

Total soluble solids were determined by a hand refractometer at room temperature and the value expressed as percentage.

3.4.6 Titrable acidity

Titrable acidity was determined as per the analytical procedures given by Ranganna (1977) and expressed as percentage of anhydrous citric acid.

3.4.7 Tannin content

Total tannins were determined after developing colour with Folin-Denis reagent (A.O.A.C., 1980) in water extract. The absorbance of the developed colour was recorded using spectrophotometer at 760 nm and total tannins were expressed as percentage.

3.5 Statistical analysis

The details of the statistical analysis followed in the present study are as follows. The mean of the data of the years 1990-91 and 1991-92 was used for all statistical analyses.

3.5.1 Estimation of variability

Variability existing in different characters was estimated as suggested by Burton (1952). The formula used in the estimation of variability is given below.

$$\text{Coefficient of variation} \quad \frac{\text{Standard deviation}}{\text{Mean of the character under study}} \times 100$$

3.5.2 Estimation of correlation

Correlation coefficient is used to measure the association between the variables. Correlations between yield and 18 characters were calculated by the method advocated by Searle (1961).

Correlation between characters x and y: $r_{xy} = \frac{\text{Cov}\ (x,y)}{\sqrt{V\ (x)\ V\ (y)}}$

where,

r_{xy} = Correlation coefficient between x and y

Cov (x,y) = Covariance between x and y

V (x) = Variance of x, and

V (y) = Variance of y

3.5.3 Path coefficient analysis

If the cause and effect relationship is well defined, it is possible to represent the whole system of variables in the form of a diagram known as path-diagram. With the help of the path diagram, a set of simultaneous equations can be written directly and a solution of these equations provide information on the direct and indirect contribution of these causal factors to the effect. Thus path coefficient analysis was used to partition the correlation coefficients into direct and indirect effects (Wright, 1921; Li, 1956).

The following set of simultaneous equations were formed and solved for estimating the various direct and indirect effects.

$$r_{1y} = P_{1y} + r_{12}P_{2y} + r_{13}P_{4y} + r_{14}P_{4y} + \ldots\ldots\ldots + r_{1k}P_{ky}$$

$$r_{2y} = P_{2y} + r_{21}P_{1y} + r_{23}P_{3y} + r_{24}P_{4y} + \ldots\ldots\ldots + r_{2k}P_{ky}$$

$$r_{3y} = P_{3y} + r_{31}P_{1y} + r_{32}P2y + r_{34}P_{4y} + \ldots\ldots\ldots + r_{3k}P_{ky}$$

$$r_{4y} = P_{4y} + r_{41}P_{1y} + r_{42}P_{2y} + r_{43}P_{3y} + \ldots\ldots\ldots + r_{4k}P_{ky}$$

$$r_{ky} = P_{ky} + r_{k1}P_{1y} + r_{k2}P_{2y} + r_{k3}P_{3y} + \ldots\ldots + r_{k(k-1)}P_{(k-1)y}$$

where,

r_{1y} to r_{ky} denote coefficient of correlation between independent characters 1 to k and dependent character y,

r_{12} to $r_{k(k-1)}$ denote coefficient of correlation between all possible combinations of independent characters, and P_{1y} to P_{ky} denote direct effects of characters 1 to k on character y.

3.5.4 Principal component analysis

Altogether there were observation on 19 characters including yield with 56 observations under each. The volume of the data had to be reduced first for the sake of simplicity. Principal component analysis is one of the variable directed techniques which aims at the reduction in dimensionality of the problem and which finds new variables that make the data easier to understand (Chatfield and Collins, 1980).

The procedure involved in the calculation of principal components included the following steps.

$X^T = (X_1, \ldots\ldots X_p)$ was considered as a p - dimensional random variable with mean μ and covariance matrix Σ. To find a new set of variables; Y_1, Y_2, ... Y_p, which were uncorrelated and whose variances decreasedfrom first to last, each Y_j was taken to be a linear combination of the X's, so that

$$
\begin{aligned}
Y_j &= a_{1j}X'_1 + a_{2j}X_2 + \ldots\ldots\ldots\ldots + a_{pj}X_p \\
&= a_j^T X
\end{aligned}
$$

where,

$$a_j^T = (a_{ij}, \ldots\ldots a_{pj})$$ was a vector of constants.

The first principal component, Y_1, was found by choosing a_1 so that Y_1 has the largest possible variance. The second principal component was found by choosing a_2 so that Y_2 has the largest possible variance for all combinations which were uncorrelated with Y_1. Similarly, we derived $Y_3, \ldots\ldots, Y_p$, so as to be uncorrelated with each other and to have decreasing variance.

3.5.5 Step-wise regression

It would be appropriate if a prediction of yield could also be made by reducing the number of variables and hence the step-wise regression procedure to predict yield based on 21 characters was performed (Draper and Smith, 1966). It could be used to reduce the incidence of multicollinearity among the independent variables and to arrive at the best subset of variables.

3.5.6 Discriminant function analysis

For effective selection of stable genotypes, the discriminant function was fitted as

$$Z = b_1x_1 + b_2x_2 + \ldots\ldots\ldots\ldots + b_nx_n$$

where,

x_1, x_2, ... x_n were the variables measured and
b_1, b_2, ... b_n were the weighing coefficients.

The b_i values are estimated such that based on Z values, the ratio of variance between populations to that of within the populations would be maximised. The maximization of this ratio leads to a set of simultaneous equations which after solution provide the desired b_i values (Fisher, 1936).

3.5.7 Heterosis

Heterosis over mid-parent (relative heterosis), better parent (heterobeltiosis) and standard variety (standard heterosis) was worked out for characters nut yield per tree, individual nut weight and weight of kernel in selected hybrids using the formulae suggested by Briggle (1963) and Hayes et al. (1965).

$$\text{Relative heterosis} = \frac{F_1 - MP}{MP} \times 100$$

$$\text{Heterobeltiosis} = \frac{F_1 - BP}{BP} \times 100$$

$$\text{Standard heterosis} = \frac{F_1 - CV}{CV} \times 100$$

where, F_1, BP and CV denote average performance of F_1, better parent and check/standard variety respectively and MP denotes mid-parental value.

Results

RESULTS

The experimental results obtained in the current investigation are presented under the following heads.

4.1 Estimation of variability

4.2 Estimation of correlation among characters

4.3 Path coefficient analysis

4.4 Principal component analysis

4.5 Step-wise regression of yield on different characters

4.6 Discriminant function analysis

4.7 Performance of superior hybrids

4.1 Estimation of variability

4.1.1 Growth parameters

The range, mean and coefficient of variation of growth parameters of both hybrids and parents were worked out and are presented in Table 2.

It can be seen from the above table that height of the hybrids ranged from 475.00 to 987.50 cm while that of the parents varied from 395.00 to 1000.00 cm. Among the hybrids, H-349 had the maximum height (987.50 cm) followed by H-350 (952.50 cm) and H-346 (865.00 cm). Parents had a higher mean

Table 2. Variation in growth parameters of hybrids and parents

Sl. No.	Character	Range		Mean		Coefficient of variation	
		Hybrids	Parents	Hybrids	Parents	Hybrids	Parents
1.	Height of the tree (cm)	475.00-987.50	395.00-1000.00	728.67	749.00	12.14	24.66
2.	Girth of the tree (cm)	64.75-177.00	84.50-183.00	111.86	129.15	22.43	22.62
3.	Mean canopy spread (cm)	706.25-1507.50	867.50-1437.50	1042.39	1046.50	16.58	16.36
4.	Leaf area (cm^2)	55.77-126.41	81.21-161.32	94.58	104.09	15.97	24.16

and coefficient of variation than the hybrids for this character.

Hybrids had a wider range in the girth of the tree (64.75 to 177.00 cm) than the parents (84.50 to 183.00 cm), but the mean and coefficient of variation were found to be higher in parents. Among the hybrids the maximum girth of the tree was noticed in H-360 (177.00 cm) followed by H-402 (172.75 cm) and H-346 (154.50 cm).

In the case of mean canopy spread, both the hybrids and parents showed a similar mean and coefficient of variation, while the hybrids had a wider range in this character. The highest mean canopy spread was in H-402 (1507.50 cm) followed by H-350 (1362.50 cm) and H-338 (1343.75 cm) among the hybrids studied.

The data showed that parents had a wider range and a higher mean and coefficient of variation than the hybrids as far as the leaf area was concerned. The highest leaf area of 126.41 cm^2 was noticed in the hybrid H-427 followed by H-428 (121.31 cm^2) and H-374 (118.17 cm^2).

4.1.2 Floral traits

The range of variation in duration of flowering, number of panicles per $(\frac{1}{2}\ m)^2$ canopy area, number of flowers per panicle, per cent hermaphrodite flowers and per cent fruit set and their means and coefficients of variation are presented in Table 3.

The hybrids were classified into three based on the time of fifty per cent flowering into early, mid-season and late. The hybrids coming under each of the above groups are listed in Table 4. It can be seen from the above table that there were altogether 13 early, 38 mid-season and 5 late flowering types.

The hybrids varied widely in duration of flowering than the parents and they also had a higher mean and coefficient of variation. The highest duration of flowering was found in H-338 (170 days) followed by H-402 (165 days) and H-368 (161 days) among the hybrids studied.

The number of panicles per $(\frac{1}{2}\ m)^2$ canopy area varied from 2.80 to 5.50 in hybrids and from 3.10 to 4.40 in the parents with a mean of 4.05 and 3.72, respectively. H-402 had the highest number of panicles per $(\frac{1}{2}\ m)^2$ canopy area among the hybrids (5.50) followed by H-382 (5.20) and H-381 and H-357 both with the same number of panicles per $(\frac{1}{2}\ m)^2$ canopy area (5.00).

The range of variation and coefficient of variation

Table 3. Variation in floral traits of hybrids and parents

Sl. No.	Character	Range		Mean		Coefficient of variation	
		Hybrids	Parents	Hybrids	Parents	Hybrids	Parents
1.	Duration of flowering (days)	92.00-170.00	103.00-153.00	128.34	123.20	13.72	12.18
2.	Number of panicles per $(\frac{1}{2}\ m)^2$ canopy area	2.80-5.50	3.10-4.40	4.05	3.72	13.19	9.03
3.	Number of flowers per panicle	132.05-444.25	298.70-361.00	221.48	332.89	24.15	6.14
4.	Per cent hermaphrodite flowers	7.38-37.36	19.36-28.67	18.66	23.36	37.46	14.28
5.	Per cent fruit set	17.28-50.46	23.70-58.56	31.25	36.35	18.64	26.11

Table 4. Classification of hybrids based on the season of flowering

Season	Hybrids
Early (November)	H-338, H-350, H-353, H-354, H-367, H-370, H-374, H-375, H-381, H-382, H-396, H-424, H-425
Mid-season (December)	H-340, H-342, H-346, H-347, H-349, H-351, H-352, H-355, H-357, H-358, H-359, H-360, H-363, H-364, H-365, H-368, H-373, H-376, H-377, H-390, H-392, H-394, H-395, H-397, H-398, H-402, H-403, H-405, H-408, H-419, H-420, H-421, H-422, H-423, H-426, H-427, H-428, H-429
Late (January)	H-339, H-341, H-345, H-348, H-407

with respect to number of flowers per panicle were more in hybrids than parents. But the parents showed a higher mean. The number of flowers per panicle among the hybrids was highest for H-402 (444.25) followed by H-342 (369.00) and H-370 (313.60).

Percentage of hermaphrodite flowers had a wider range and a higher coefficient of variation in hybrids while parents showed a higher mean for this character. The highest percentage of hermaphrodite flowers was observed in the hybrid H-381 (37.36%) followed by H-382 (33.76%) and H-419 (32.59%).

Percentage of fruit set varied widely in the hybrids and parents while a higher mean and coefficient of variation were noticed in the parents. More than fifty per cent of hermaphrodite flowers set fruits in the hybrid H-342 which had the highest fruit set (50.46%) followed by H-341 (41.89%) and H-407 (41.49%).

4.1.3 Yield attributes

The range, mean and coefficient of variation for the main yield attributes like number of nuts per panicle, individual nut weight, nut yield per tree, weight of kernel, shelling percentage and protein content of kernel were worked out and are presented in Table 5. Variability with respect to size and shape of nut is displayed in Plate 1.

Table 5. Variation in yield attributes of hybrids and parents

Sl. No.	Character	Range		Mean		Coefficient of variation	
		Hybrids	Parents	Hybrids	Parents	Hybrids	Parents
1.	Number of nuts per panicle	2.20-6.50	3.80-4.80	3.23	4.32	27.56	6.97
2.	Individual nut weight (g)	4.76-10.45	4.81-13.00	7.33	6.80	19.16	40.56
3.	Nut yield per tree (kg)	0.60-23.48	7.20-14.90	10.03	10.91	60.95	24.66
4.	Weight of kernel (g)	1.37-3.19	1.42-3.08	2.18	2.01	19.56	26.78
5.	Shelling percentage	23.58-37.03	23.69-37.55	29.85	30.73	7.63	14.67
6.	Protein content of kernel (%)	18.55-38.58	20.03-28.94	24.13	23.89	24.13	11.60

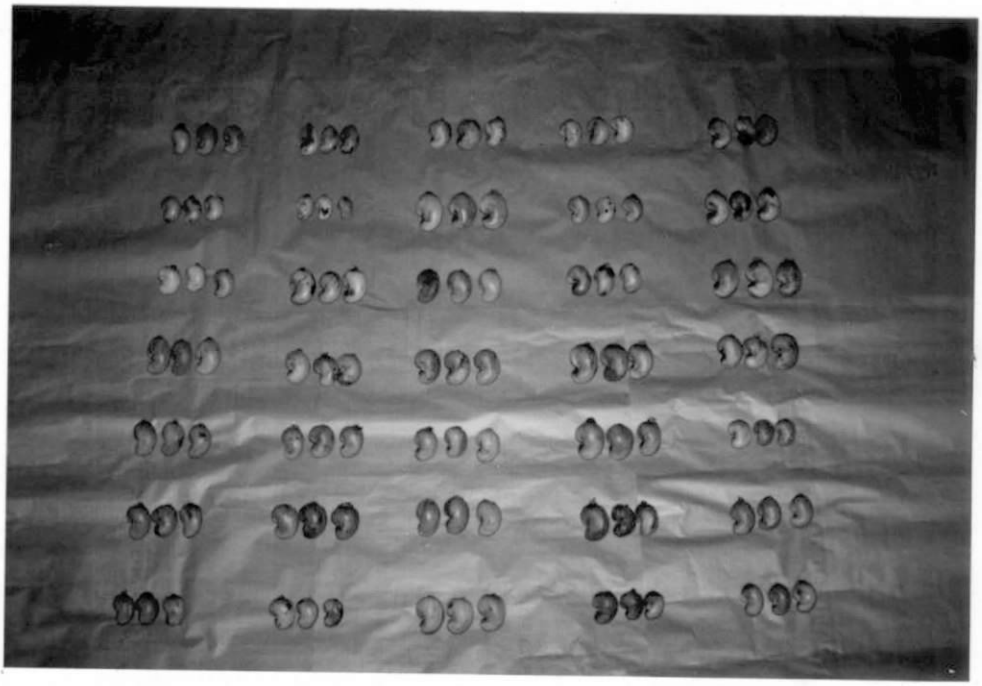


Plate 1 Variability with respect to size and shape of nuts

The hybrids had a wider variation in number of nuts per panicle and a higher coefficient of variation than the parents, but the mean was found to be higher in parents. When the hybrids showed a wider range of 2.20 to 6.50 nuts per panicle, in parents it was only 3.80 to 4.80. The number of nuts ultimately retained per panicle was highest in the hybrid H-376 (6.50) followed by H-364 (5.70) and H-355 (5.50).

Individual nut weight showed a wide variation among parents (4.81 to 13.00 g) while the hybrids had a slightly narrower range (4.76 to 10.45 g). However a higher mean was found in the hybrids, but the coefficient of variation was much higher in the parents. The heaviest nut was noticed in the hybrid H-349 (10.45 g) followed by H-375 (10.26 g) and H-419 (9.60 g) while the lightest nut was found in H-396 (4.76 g).

Nut yield per tree had a very wide range in the hybrids from as low as 0.60 kg per tree to as high as 23.48 kg per tree and this accounted for the highest coefficient of variation among all the characters studied (60.95%). Eventhough the parents had only a narrow range, and their highest yield was far below the highest observed in hybrids, the mean for this character was similar in both the hybrids and parents. The highest nut yield per tree was observed in the hybrid H-342 (23.48 kg) followed by H-402 (23.13 kg) and

H-419 (21.43 kg) while this was maximum in the parent T.1663 (14.90 kg) followed by T.1098 (13.35 kg) and T.657 and T.1672 both with 13.10 kg of nut yield per tree.

It can be seen from the Table 5 that weight of kernel had a wider range and a higher mean in hybrids while parents had a higher coefficient of variation. The highest kernel weight of 3.19 g was noticed in the hybrid H-349 followed by H-419 (3.03 g) and H-375 (2.95 g). Among the parents T.1589 had the heaviest kernel (3.08 g) followed by T.855 (2.88 g) and T.1140 (1.98 g).

Shelling percentage showed similar range and mean in hybrids and parents while the coefficient of variation was nearly double in parents compared to hybrids. The highest shelling percentage of 37.03 was found in the hybrid H-359 followed by the hybrids H-421 (33.60%) and H-347 (33.44%). The lowest shelling percentage of 23.58 was found in the hybrid H-381.

In the case of protein content of kernel, the hybrids showed a much wider range and a higher mean and coefficient of variation than parents. A very high protein content of 38.58 per cent was noticed in the hybrid H-390 followed by H-402 (35.62%) and H-354 and H-365 both with 31.16 per cent protein.

4.1.4 Apple characters

Variation in different apple characters of hybrids and parents namely weight of apple, juice per cent, reducing sugars, total sugars, total soluble solids, titrable acidity and tannin content were worked out and are presented in Table 6. Variability with respect to size, shape and colour of apple is depicted in Plate 2.

Both the hybrids and the parents had a similar range in the weight of the apple. While a higher mean was noticed in hybrids, the parents exhibited a higher coefficient of variation. The hybrid H-349 had the heaviest apple (126.00 g) among the hybrids studied followed by H-370 (105.00 g) and H-341 (98.00 g).

The range of variation for juice per cent was more in hybrids compared to parents. While they had a similar mean, the parents had a slightly higher coefficient of variation. The juice content was as high as 89.36 per cent in the hybrid H-395 followed by H-403 (83.75%) and H-397 (81.40%).

The reducing sugar and total sugar showed almost similar range, mean and coefficient of variation, the values being slightly higher for the total sugar content, the exception being in the case of coefficient of variation, where the reducing sugar content exhibited a higher variation.

Table 6. Variation in apple characters of hybrids and parents

Sl. No.	Character	Range		Mean		Coefficient of variation	
		Hybrids	Parents	Hybrids	Parents	Hybrids	Parents
1.	Weight of apple (g)	32.00-126.00	32.33-126.00	72.80	61.62	23.54	44.58
2.	Juice per cent	51.19-89.36	51.92-75.81	66.90	66.47	12.92	13.32
3.	Reducing sugars (%)	4.24-12.50	8.33-12.50	9.02	9.67	22.80	14.65
4.	Total sugars (%)	4.30-13.16	8.62-12.82	9.74	10.41	22.25	14.42
5.	Total soluble solids (%)	7.00-13.60	10.80-12.40	11.01	11.80	11.95	4.45
6.	Titrable acidity (%)	0.10-0.80	0.16-0.38	0.30	0.25	47.04	28.05
7.	Tannin content (%)	0.09-0.20	0.12-0.24	0.15	0.16	13.01	21.95

Plate 2. Variability with respect to size, shape and colour of apples

The highest reducing sugar content of 12.5 per cent was noticed in two hybrids namely H-360 and H-426 followed by H-368, H-382, H-420 and H-428 all with 11.91 per cent reducing sugar content. The hybrids H-426 and H-428 showed the maximum total sugar content (13.16%) followed by H-370, H-420 and H-421 all with 12.82 per cent total sugar content.

In respect of total soluble solids, hybrids had a wider range and a higher coefficient of variation, while the mean was almost similar. The highest total soluble solids content of 13.60 per cent was found in the hybrid H-382 and this was followed by H-397 (13.20%) and H-394, H-395 and H-396 all the three with 12.80 per cent total soluble solids.

Titrable acidity had a wider range, higher mean and coefficient of variation in hybrids compared to parents. A high titrable acidity of 0.80 per cent was noticed in the hybrid H-349 followed by H-345 and H-382 both with 0.54 per cent.

Parents showed a higher mean and coefficient of variation for tannin content than hybrids. The range had no much variation in both the groups. H-358 was having the highest tannin content (0.20%) among hybrids followed by H-423 (0.19%) and H-421 (0.17%).

4.2 Estimation of correlation among characters

Correlation studies were undertaken using 18 selected characters and nut yield to determine the degree of association between yield and different characters (Table 7). Mean canopy spread showed the maximum positive correlation with yield (0.57). Yield was also found to possess statistically significant positive correlation with girth of the tree (0.54), number of nuts per panicle (0.36), weight of kernel (0.35), duration of flowering (0.30), leaf area (0.27), height of the tree (0.26) and individual nut weight (0.24). Total soluble solid content had the maximum negative association with yield (-0.50) followed by tannin content (-0.17). Another important finding of this study was a weak negative correlation of percentage of hermaphrodite flowers with yield. Besides the factors mentioned earlier, number of panicles per $(\frac{1}{2}\ m)^2$ canopy area, number of flowers per panicle, percentage of fruit set, shelling percentage, protein content, weight of apple and juice per cent had a weak positive association with yield.

It was also observed that height of the tree was positively correlated with girth and mean canopy spread while mean canopy spread which had the highest positive correlation with yield in turn was highly associated with girth of the tree (0.74). The studies also revealed that leaf area was positively correlated with all these characters.

Table 7. Correlation coefficients between yield and different characters

	Y	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}	x_{16}	x_{17}	x_{18}
Y	1.00	0.26*	0.54**	0.57*	0.30*	0.27*	0.03	0.22	-0.12	0.20	0.36**	0.24*	0.35**	0.15	0.03	0.11	0.01	-0.50**	-0.17
x_1		1.00	0.48**	0.50**	0.25*	0.17	-0.32**	0.19	-0.16	0.15	0.09	0.09	0.11	0.01	-0.13	0.08	-0.11	-0.21	-0.17
x_2			1.00	0.74**	0.28*	0.16	0.02	0.38**	-0.07	0.14	0.21	0.14	0.14	-0.01	0.10	0.09	-0.11	-0.19	-0.27*
x_3				1.00	0.42**	0.05	0.03	0.22	-0.06	0.00	0.14	0.29*	0.31*	-0.04	0.16	0.16	-0.05	-0.27*	-0.38**
x_4					1.00	-0.10	0.12	0.11	0.08	-0.18	0.07	0.10	0.13	0.00	0.14	0.18	-0.12	-0.15	-0.08
x_5						1.00	-0.13	0.10	-0.09	0.26*	0.16	0.51**	0.45**	-0.18	-0.20	0.15	-0.18	-0.23	-0.09
x_6							1.00	-0.02	-0.01	0.09	-0.22	0.01	-0.06	-0.15	0.32**	-0.12	0.13	-0.02	-0.17
x_7								1.00	0.24*	0.21	0.39**	-0.08	-0.16	-0.05	0.05	-0.16	0.15	0.05	0.03
x_8									1.00	-0.35**	-0.09	-0.17	-0.22	-0.01	0.04	-0.31*	0.23	0.33**	0.21
x_9										1.00	0.18	0.16	0.09	-0.07	0.04	-0.08	-0.03	-0.09	-0.09
x_{10}											1.00	-0.09	-0.11	0.03	0.13	-0.06	-0.06	-0.15	0.00
x_{11}												1.00	0.91**	-0.39**	-0.24*	0.49**	-0.11	-0.40**	-0.29*
x_{12}													1.00	0.01	-0.26*	0.48**	-0.19	-0.44**	-0.23
x_{13}														1.00	0.03	-0.16	-0.16	0.04	0.28*
x_{14}															1.00	-0.22	-0.08	0.03	-0.04
x_{15}																1.00	-0.16	-0.26*	-0.37**
x_{16}																	1.00	0.04	-0.04
x_{17}																		1.00	0.38**
x_{18}																			1.00

Y = Nut yield per tree
x_1 = Height of the tree
x_2 = Girth of the tree
x_3 = Mean canopy spread
x_4 = Duration of flowering
x_5 = Leaf area
x_6 = Number of panicles per $(\frac{1}{4}\ m)^2$ canopy area
x_7 = Number of flowers per panicle
x_8 = Per cent hermaphrodite flowers
x_9 = Per cent fruit set
x_{10} = Number of nuts per panicle
x_{11} = Individual nut weight
x_{12} = Weight of kernel
x_{13} = Shelling percentage
x_{14} = Protein content of kernel
x_{15} = Weight of apple
x_{16} = Juice per cent of apple
x_{17} = Total soluble solids of apple
x_{18} = Tannin content of apple

The studies also disclosed that duration of flowering had a slight positive correlation with number of panicles per $(\frac{1}{2}\ m)^2$ canopy area, number of flowers per panicle, percentage of hermaphrodite flowers, number of nuts per panicle, individual nut weight, weight of kernel, protein content of kernel and weight of apple.

Number of panicles per $(\frac{1}{2}\ m)^2$ canopy area had a weak positive correlation with percentage fruit set while it was negatively associated with number of flowers per panicle, percentage of hermaphrodite flowers and number of nuts per panicle.

Number of flowers per panicle had a slight positive association with percentage of hermaphrodite flowers, per cent fruit set and number of nuts per panicle.

The studies made it clear that percentage of hermaphrodite flowers had a negative association with percentage fruit set and number of nuts per panicle, while percentage of fruit set is positively correlated with number of nuts per panicle. Individual nut weight, weight of kernel, and weight of apple recorded only negative correlation with number of nuts per panicle.

Another notable observation of this study was a strong positive correlation (0.91) of individual nut weight with kernel weight, but the former showed a negative correlation (-0.39) with shelling percentage, while the latter had a weak positive correlation (0.01) with shelling percentage. However both the individual nut weight and weight of kernel had positive correlations with weight of apple (0.49 and 0.48 respectively).

Protein content was found to be negatively associated with individual nut weight (-0.24) and weight of kernel (-0.26). Weight of apple had only negative correlation with juice per cent, total soluble solids and tannin content while total soluble solids was found to be positively correlated with juice per cent. At the same time, tannin content had a negative correlation with juice per cent and a positive correlation with total soluble solids.

4.3 Path coefficient analysis

In this study, eight parameters showing positive correlation with yield were selected based on their importance as causal factors. The values of the direct effects and indirect effects with yield are presented in Table 8. Figure 1 illustrates the direct effect of each parameter on yield and correlation coefficients between these parameters. The residual effect in this study was found to be 0.45.

Table 8. Direct effects, indirect effects and correlation coefficients of different characters on yield

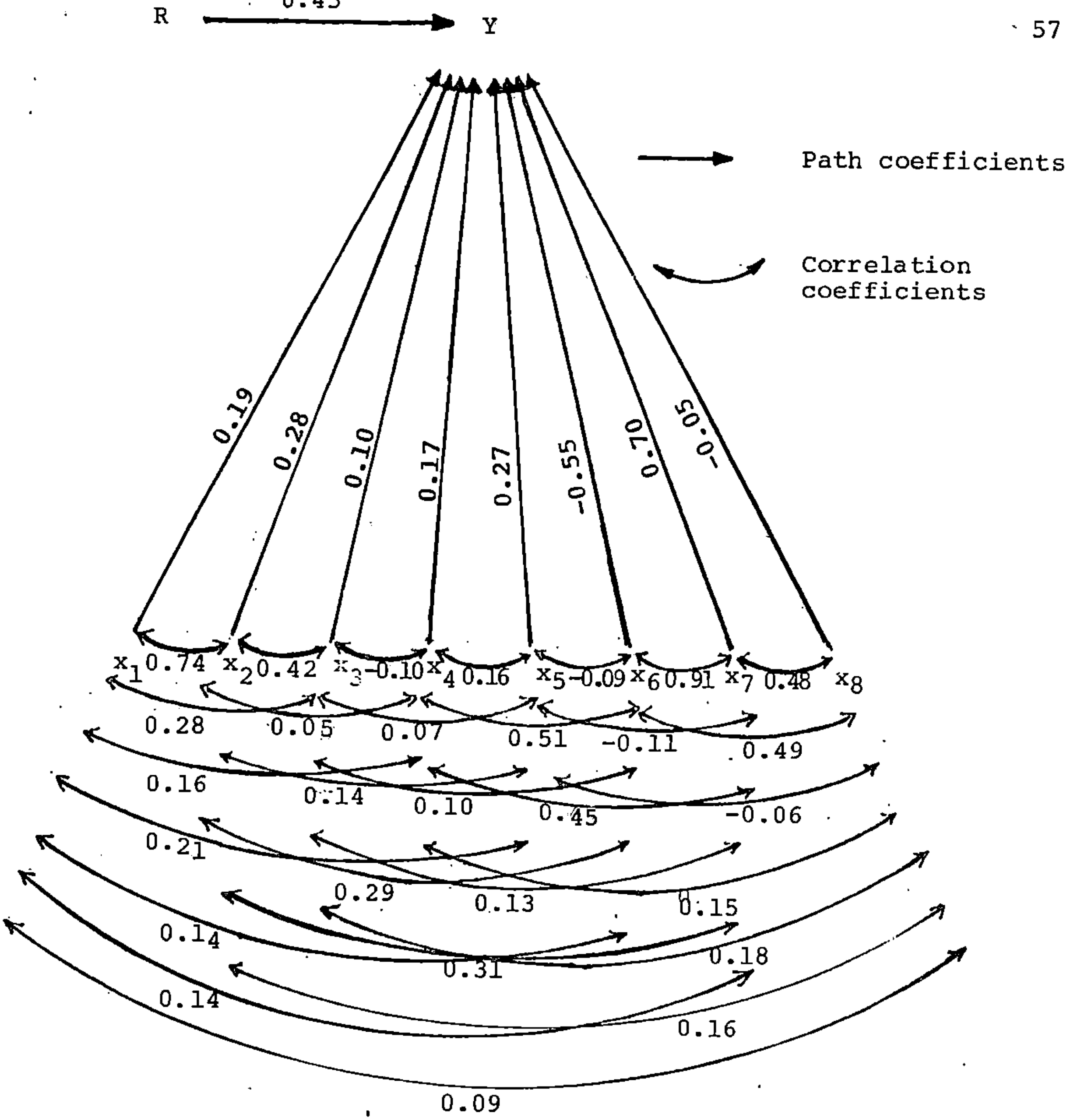
Character	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	Y(r)*
x_1	0.19	0.21	0.03	0.03	0.06	-0.08	0.10	0.00	0.54
x_2	0.14	0.28	0.04	0.01	0.04	-0.16	0.22	-0.01	0.57
x_3	0.05	0.12	0.10	-0.02	0.02	-0.06	0.09	-0.01	0.30
x_4	0.03	0.01	-0.01	0.17	0.04	-0.28	0.31	-0.01	0.27
x_5	0.04	0.04	0.01	0.03	0.27	0.05	-0.08	0.00	0.36
x_6	0.03	0.08	0.01	0.09	-0.02	-0.55	0.64	-0.02	0.24
x_7	0.03	0.09	0.01	0.08	-0.03	-0.50	0.70	-0.02	0.35
x_8	0.02	0.05	0.02	0.02	-0.02	-0.27	0.33	-0.05	0.11

Note: The diagonal values (underlined) show the direct effect and the off-diagonal values indicate the indirect effects

* Coefficient of correlation of each parameter with yield

Y - Nut yield per tree

x_1 - Girth of the tree
x_2 - Mean canopy spread
x_3 - Duration of flowering
x_4 - Leaf area
x_5 - Number of nuts per panicle
x_6 - Individual nut weight
x_7 - Weight of kernel
x_8 - Weight of apple



Y = nut yield per tree

x_1 = girth of the tree

x_2 = mean canopy spread

x_3 = duration of flowering

x_4 = leaf area

R = Residual effect

x_5 = number of nut per panicle

x_6 = individual nut weight

x_7 = weight of kernel

x_8 = weight of apple

FIG.1 PATH DIAGRAM INDICATING DIRECT AND INDIRECT EFFECTS OF THE POSSIBLE COMPONENTS OF NUT YIELD PER TREE.

Among the eight characters studied, weight of kernel showed maximum positive direct effect on yield (0.70) followed by mean canopy spread (0.28). Individual nut weight and weight of apple exhibited negative direct effects with yield (-0.55 and -0.05 respectively), but the former had a slightly high positive indirect effect on yield (0.64) through weight of kernel.

Eventhough weight of apple had a weak positive correlation with yield (0.11), its direct effect on yield was negative, but found to contribute positively mainly through the indirect effect of kernel weight (0.33).

The study also revealed that girth of the tree has a direct positive effect on yield (0.19), but it had a slightly higher indirect effect on yield (0.21) through mean canopy spread. The results also indicated that mean canopy spread which showed the highest positive correlation (0.57) among the characters studied, contributed towards yield mainly through its direct effect (0.28) followed by the indirect effect (0.22) through weight of kernel.

Number of nuts per panicle also exerted a positive direct effect on yield (0.27), but it had a negative indirect effect on yield (-0.08) through weight of kernel. Other notable observations made during this study were the positive direct effects of leaf area (0.17) and duration of flowering (0.10) on yield. Leaf area also had a slightly higher positive indirect effect on yield through weight of kernel (0.31).

4.4 Principal component analysis

The principal component analysis was performed using the deviation squares and products matrix of the 18 variables. The first two principal components which accounted for the cumulative variance of 88.71 per cent are given in Table 9. The yield was predicted using the regression equation with the first two principal components as the explanatory variables. The predictor equation was found to be

$$Y = 0.0175\ P_1 - 0.0087\ P_2 - 9.3137 \text{ with an } R^2 \text{ of } 0.329$$

where, P_1 and P_2 are the first and second principal components respectively.

The principal component analysis reduces only the dimensionality, but not the number of variables involved. Hence to reduce the number of variables, step-wise regression was performed.

4.5 Step-wise regression of yield on different characters

Step-wise regression of yield on the 21 characters was

Table 9. Principal component vectors

Sl. No.	Character	Principal component 1	Principal component 2
1.	Mean canopy spread	0.919	-0.374
2.	Height of the tree	0.365	0.923
3.	Girth of the tree	0.110	0.000
4.	Number of flowers per panicle	0.093	0.081
5.	Duration of flowering	0.040	-0.007
6.	Weight of apple	0.016	-0.010
7.	Leaf area	0.008	0.034
8.	Individual nut weight	0.002	-0.002
9.	Protein content of kernel	0.002	-0.011
10.	Per cent fruit set	0.001	0.015
11.	Number of nuts per panicle	0.001	0.000
12.	Weight of kernel	0.001	-0.001
13.	Tannin content	0.000	0.000
14.	Number of panicles per $(\frac{1}{2} m)^2$ canopy area	0.000	-0.002
15.	Shelling percentage	0.000	0.001
16.	Total soluble solids	-0.002	0.000
17.	Per cent hermaphrodite flowers	-0.003	-0.010
18.	Juice per cent	-0.003	-0.008

done which finally gave the following regression equation with an R^2 of 0.5735.

$$Y = 0.0152\ x_3 + 0.0622\ x_5 + 1.3579\ x_{10} + 0.4436\ x_{13} - 1.4043\ x_{19} - 13.9381$$

where,

x_3 = mean canopy spread

x_5 = leaf area

x_{10} = number of nuts per panicle

x_{13} = shelling percentage, and

x_{19} = total soluble solid content

4.6 Discriminant function analysis

The graphic representation of the first two principal components which accounted for 88.71 per cent of cumulative variance are given in Fig.2. From this figure a cluster was selected which could be described as a sample from the population which had atleast above average traits with respect to all the characters included in the principal component analysis. The residual points were clubbed as another cluster and discriminant function was fitted for these two populations which gave the function as

$$Z = 2.8181\ x_1 + 0.2178\ x_2 - 0.0637\ x_3 + 0.1604\ x_4 + 0.4207\ x_5 + 0.0771\ x_6 - 0.1327\ x_7 + 0.5757\ x_8 + 0.0547\ x_9$$

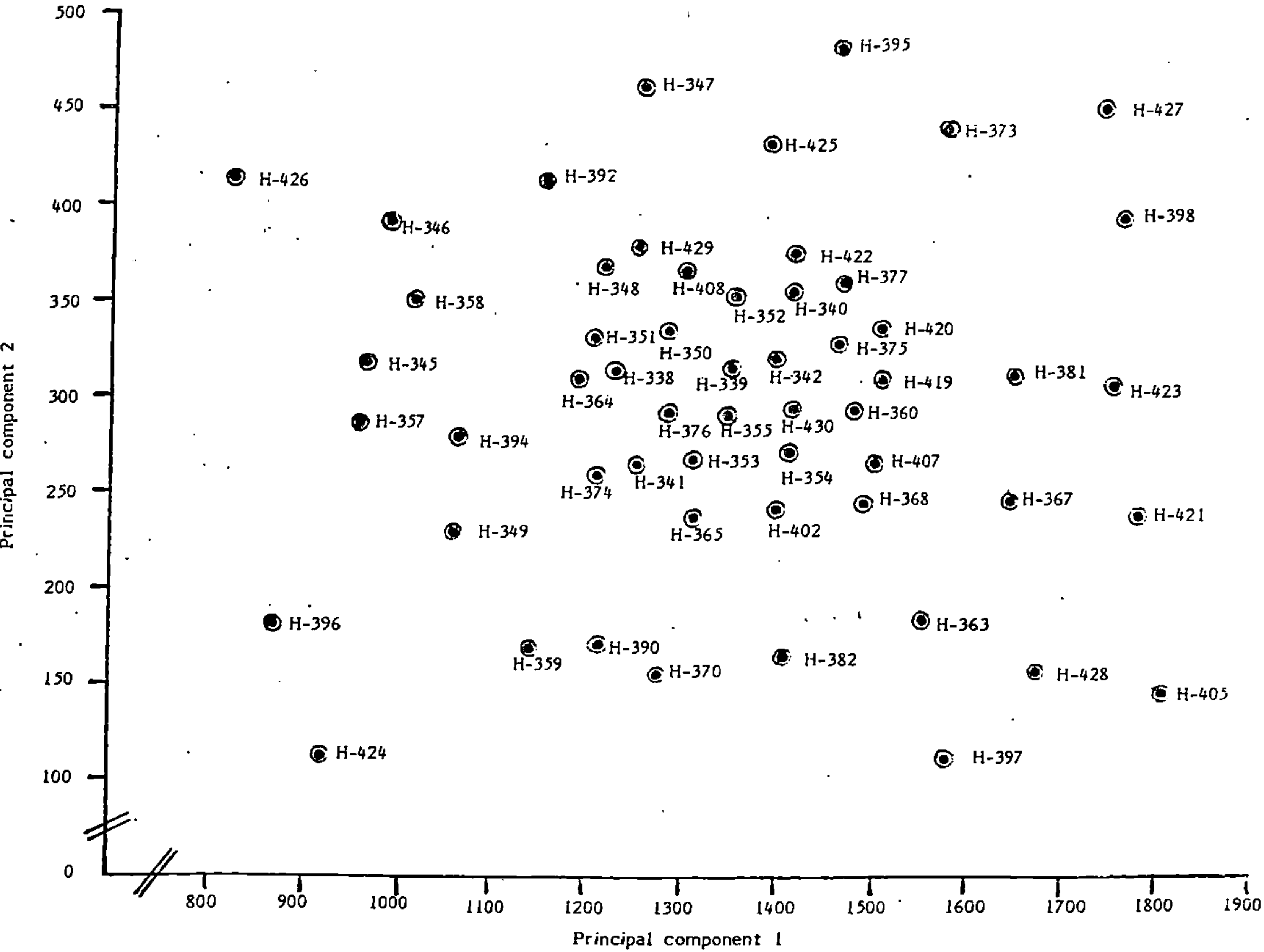


FIG.2 GRAPHIC REPRESENTATION OF THE FIRST AND SECOND PRINCIPAL COMPONENTS

where the explanatory variables x_1 to x_9 represented respectively nut yield per tree, girth of the tree, mean canopy spread, duration of flowering, leaf area, number of nuts per panicle, individual nut weight, weight of kernel and weight of apple. The D^2 value was found to be 4.13 and was significant at 1 per cent level.

Using this function, selection index value for each of the hybrids in the cluster giving better performance was determined (Table 10). These hybrids were arranged in the order of merit on the basis of selection index values and best 20 per cent which in effect is 10 per cent of the whole population was selected as superior.

4.7 Performance of superior hybrids

The performance of hybrids selected on the basis of selection index values with respect to major economic characters is presented in Fig.3 and 4.

Among the six hybrids thus selected H-342 (Plate 3) had the highest nut yield per tree (23.48 kg) followed closely by H-402 (23.13 kg) which showed the highest protein content (35.62%). The highest individual nut weight (9.60 g), kernel weight (3.03 g) and shelling percentage (31.56 per cent) were observed in the hybrid H-419 having a nut yield per tree of

Table 10. Selection index values of hybrids

Sl. No.	Hybrid	Selection index value
1.	H-342	95.83
2.	H-402	91.15
3.	H-419	82.05
4.	H-354	81.15
5.	H-376	78.28
6.	H-340	75.18
7.	H-374	72.58
8.	H-364	71.99
9.	H-353	70.75
10.	H-420	68.37
11.	H-377	67.48
12.	H-368	66.50
13.	H-338	62.94
14.	H-360	62.30
15.	H-352	61.85
16.	H-341	61.18
17.	H-350	60.15
18.	H-422	58.68
19.	H-429	58.46
20.	H-403	57.01
21.	H-351	56.82
22.	H-348	55.74
23.	H-375	55.50
24.	H-355	51.92
25.	H-365	50.24
26.	H-407	49.99
27.	H-408	48.79
28.	H-339	43.91

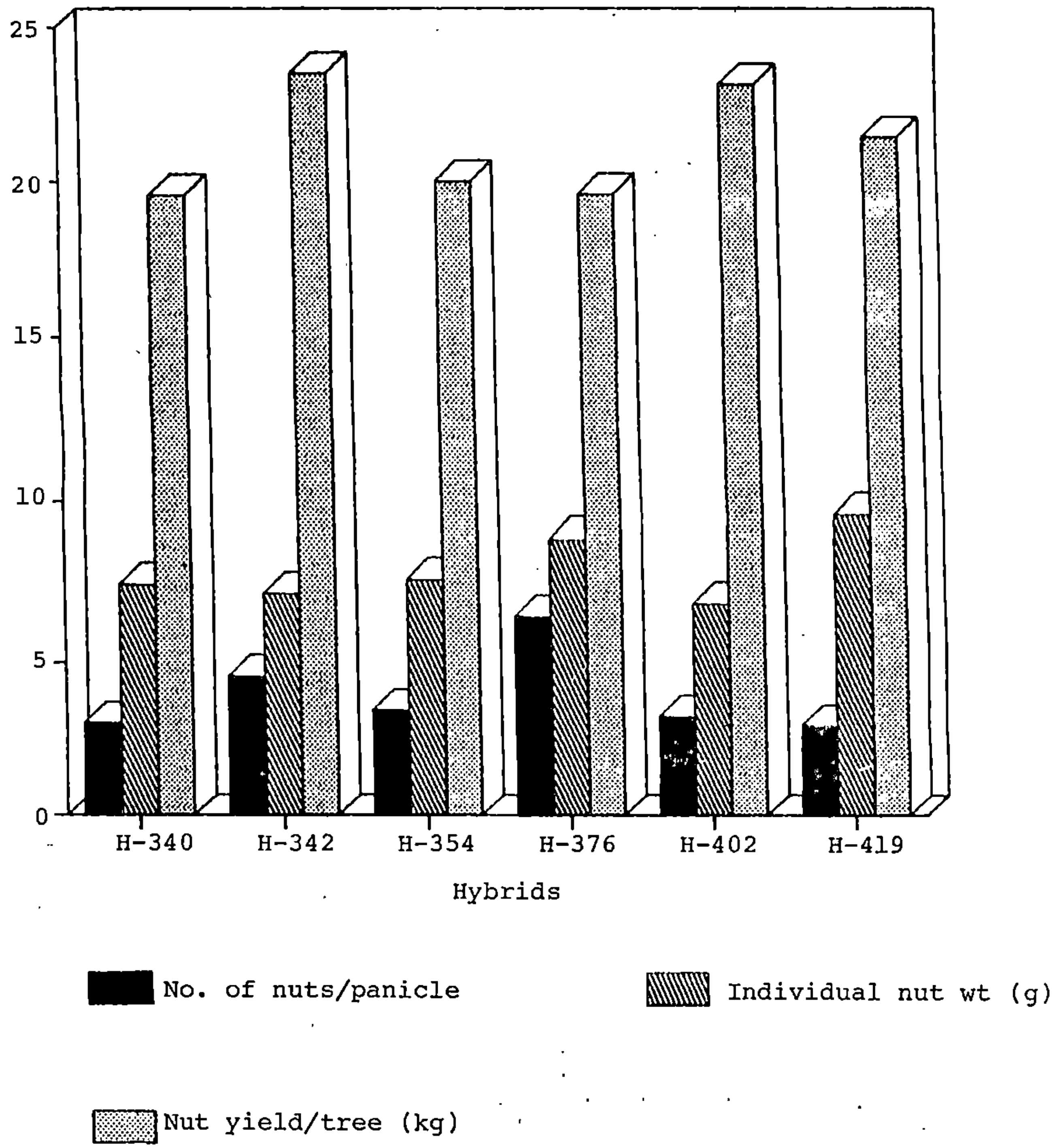


FIG.3 NUMBER OF NUTS PER PANICLE, INDIVIDUAL NUT WEIGHT AND NUT YIELD PER TREE OF SIX SUPERIOR HYBRIDS

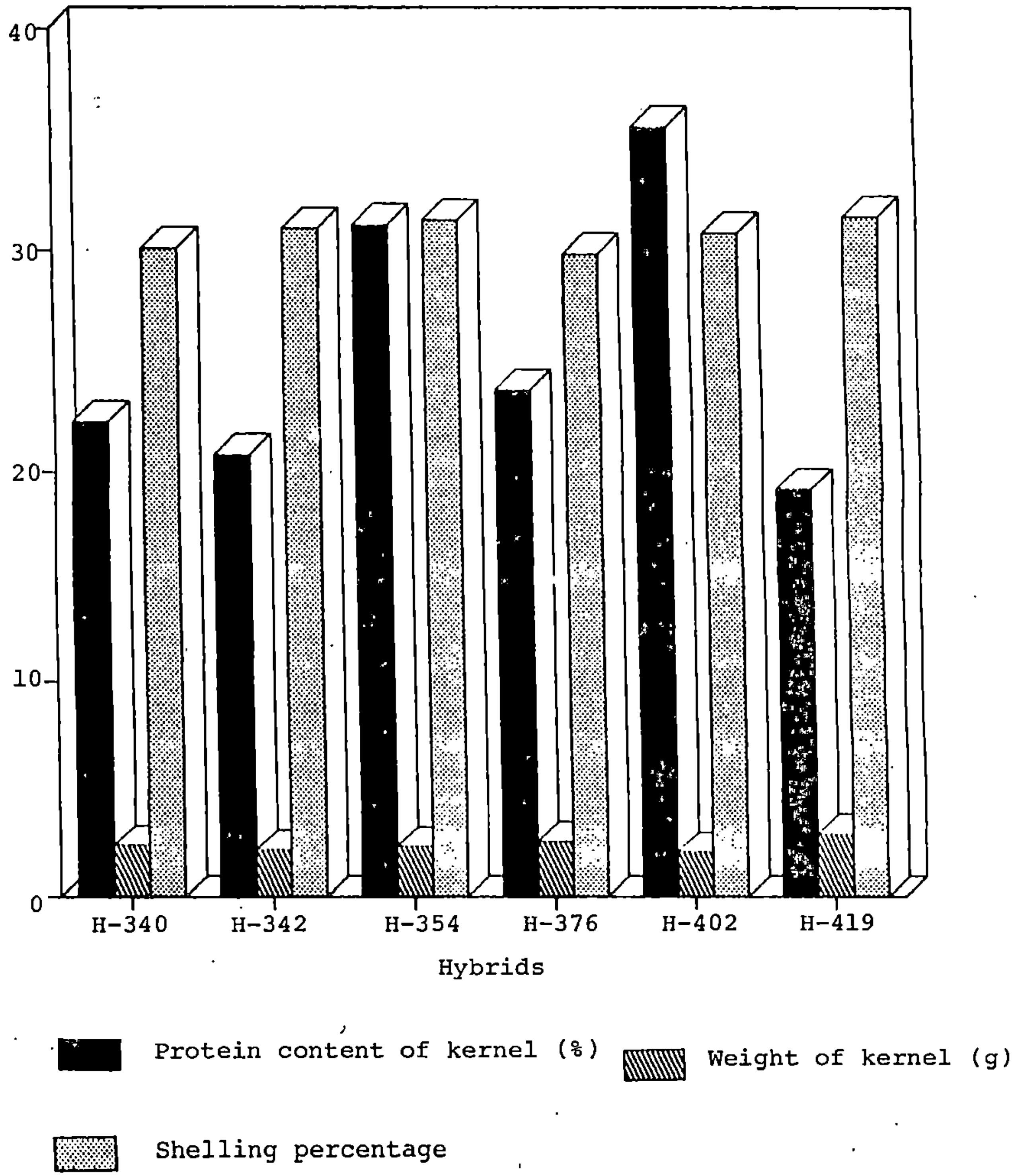


FIG.4 PROTEIN CONTENT, WEIGHT OF KERNEL AND SHELLING PERCENTAGE OF SIX SUPERIOR HYBRIDS

Plate 3. H-342

21.43 kg. Eventhough the number of nuts per panicle was medium ranging from 3.0 to 6.5 in these hybrids, these had a comparatively high nut yield ranging from 19.55 to 23.48 kg per tree. Though the nut size was found to be medium, almost all the hybrids had large sized kernel weighing above 2.0 g, the highest being 3.03 g in H-419. The shelling percentage was also found to be higher averaging about 30.00 per cent in all these hybrids.

One of the main nutritive components of the kernel - the protein content - was found to be medium in most of the hybrids. H-402 and H-354 had a very high protein content of 35.62 and 31.16 per cent respectively.

Magnitude of heterosis was calculated for nut yield per tree, individual nut weight and weight of kernel in all these selected hybrids. Relative heterosis, heterobeltiosis and standard heterosis were worked out and are presented in Tables 11 to 13.

It can be seen from the above tables that all these hybrids showed relative heterosis for nut yield per tree and this ranged from 62.87 (H-354) to 175.26 (H-342) per cent. Altogether three hybrids namely H-340, H-342 and H-402 showed a relative heterosis over 100 per cent for nut yield. All

Table 11. Heterosis for nut yield per tree

Sl. No.	Hybrid	Nut yield per tree (kg)					Relative heterosis (%)	Hetero-beltiosis (%)	Standard heterosis (%)
		Hybrid	Parent 1	Parent 2	Mid-parent	Standard variety			
1.	H-340	19.55	7.20	9.85	8.53	17.60	129.19	98.48	11.08
2.	H-342	23.48	7.20	9.85	8.53	17.60	175.26	138.38	33.41
3.	H-354	20.00	12.15	12.40	12.28	17.60	62.87	61.29	13.64
4.	H-376	19.58	13.10	7.20	10.15	17.60	92.91	49.47	11.25
5.	H-402	23.13	9.85	7.20	8.53	17.60	171.16	134.82	31.42
6.	H-419	21.43	12.40	13.10	12.75	17.60	68.08	63.59	21.76

these hybrids exhibited heterosis over better parent for nut yield, the magnitude ranging from 49.47 (H-376) to 138.38 (H-342) per cent. Two hybrids viz., H-342 and H-402 displayed above 100 per cent heterosis for nut yield over their respective better parents.

All these six selected hybrids also showed heterosis for nut yield over Madakkathara-1 which was taken as the standard variety. Here the range of magnitude of heterosis was from 11.08 (H-340) to 33.41 (H-342) per cent.

Regarding heterosis for individual nut weight among the six hybrids studied two hybrids namely H-419 (45.02%) and H-354 (30.72%) showed relative heterosis. Heterosis over better parents for the same character was also shown by only these two hybrids the values being 43.07 and 14.16 per cent respectively for H-419 and H-354. At the same time all these hybrids exhibited heterosis over the standard variety for the same character with a range of 11.45 (H-402) to 54.84 (H-419) per cent.

With respect to heterosis for weight of kernel three hybrids namely H-419 (67.40 per cent), H-354 (34.08 per cent) and H-376 (7.72 per cent) showed heterosis over mid parent, while two among these namely H-419 (56.19 per cent) and H-354 (23.71 per cent) displayed heterosis over their respective

Table 12. Heterosis for individual nut weight

Sl. No.	Hybrid	Individual nut weight (g)					Relative heterosis (%)	Hetero-beltiosis (%)	Standard heterosis (%)
		Hybrid	Parent 1	Parent 2	Mid-parent	Standard variety			
1.	H-340	7.49	13.00	7.20	10.10	6.20	--	--	20.81
2.	H-342	7.23	13.00	7.20	10.10	6.20	--	--	16.61
3.	H-354	7.66	5.00	6.71	5.86	6.20	30.72	14.16	23.55
4.	H-376	8.87	4.90	13.00	8.95	6.20	--	--	43.06
5.	H-402	6.91	7.20	13.00	10.10	6.20	--	--	11.45
6.	H-419	9.60	6.72	6.52	6.62	6.20	45.02	43.07	54.84

Table 13. Heterosis for weight of kernel

Sl. No.	Hybrid	Weight of kernel (g)					Relative heterosis (%)	Hetero-beltiosis (%)	Standard heterosis (%)
		Hybrid	Parent 1	Parent 2	Mid-parent	Standard variety			
1.	H-340	2.46	3.08	2.17	2.63	1.64	--	--	50.00
2.	H-342	2.24	3.08	2.17	2.63	1.64	--	--	36.59
3.	H-354	2.40	1.63	1.94	1.79	1.64	34.08	23.71	46.34
4.	H-376	2.65	1.84	3.08	2.46	1.64	7.72	--	61.59
5.	H-402	2.13	2.17	3.08	2.63	1.64	--	--	29.88
6.	H-419	3.03	1.94	1.67	1.81	1.64	67.40	56.19	84.76

better parents also. However all the six hybrids exhibited heterosis over the standard variety with values ranging from 29.88 (H-402) to 84.76 (H-419) per cent.

The export grades in terms of the number of whole kernels per pound of all these selected hybrids were worked out and are presented in Table 14. It can be seen from the above table that all the six selected hybrids had superior export grades with H-340, H-354, H-376 and H-419 having the best grade of W 180 and H-342 and H-402 with the next best grade of W 210.

Table 14. Export grade of superior hybrids

Sl. No.	Hybrid	Weight of kernel (g)	Number of kernels per pound	Export grade
1.	H-340	2.46	184.38	W 180
2.	H-342	2.24	202.50	W 210
3.	H-354	2.40	189.00	W 180
4.	H-376	2.65	171.17	W 180
5.	H-402	2.13	212.95	W 210
6.	H-419	3.03	149.70	W 180

Discussion

DISCUSSION

Crop improvement in cashew was attempted only recently and its potentialities are now well recognised by the research workers in this field (Devi, 1981). Most of the existing cashew plantations have been raised from seedling progenies of non-descript, genetically inferior seed material. This is one of the obvious reasons for the present low level of productivity of cashew. Developing genotypes with increased production potential without sacrificing the desirable horticultural attributes is the challenge faced by the breeder. A planned programme of hybridization between selected types possessing one or more of the desirable characters and a comprehensive evaluation of F_1 hybrids will result in the identification of superior hybrids. As cashew can be successfully propagated by vegetative methods, the superior genotypes thus developed can easily be multiplied and maintained.

Information on variability of quantitative characters and on the association among yield and its component characters are of vital importance in any plant breeding programme. This is more so in a crop like cashew where a little work has only been done to improve the genetic potential.

The present investigation was basically envisaged to determine the extent of variability and degree of association of quantitative characters in cashew and to evaluate the F_1 hybrids with respect to different biometric characters. The results obtained are discussed in the ensuing pages.

5.1 Variability

Wide variability in terms of range and coefficient of variation existed in the population under study which involved fifty six cashew hybrids and their sixteen parents for all the four growth parameters. Maximum extent of variation was observed for the character girth of the tree followed by mean canopy spread and leaf area. Damodaran et al. (1978), Falade (1981) and Devi (1981) also reported the presence of high variability for growth parameters in cashew.

Hybrids displayed a slightly higher degree of variation than parents in the case of mean canopy spread, which had the highest positive correlation with yield among the eighteen characters studied. This finding shows that the spectrum of variability has been broadened as a result of hybridization in case of this particular character. But in all other growth parameters, hybridization could not result in enhanced variability indicating that the extent of variability available in the parental population was itself high.

Most of the floral traits also exhibited high degree of variability in the population under study. Per cent hermaphrodite flowers possessed maximum extent of variation followed by number of flowers per panicle and per cent fruit set. Wide variation in season of flowering and its duration was noticed by Swamy and Thimmappaiah (1990) while Krishnappa *et al*. (1992) observed high variability in total number of flowers, staminate and hermaphrodite flowers and fruit set per panicle. Number of flowers per panicle and per cent hermaphrodite flowers had a higher degree of variation in hybrids than the parents. This increase in the variability as a result of hybridization could be properly utilized during the selection process.

The low variability observed for the number of panicle per $(\frac{1}{2}\ m)^2$ canopy area is a matter of concern as this is an important character. In a study utilizing seventeen varieties Krishnappa *et al*. (1991 a) could observe high variability for the number of flowers per m^2 area. This emphasized the need for further exploration and collection of genotypes if an improvement for this particular character is to be achieved.

Almost all the yield attributes had a high degree of variability in the population studied. Nut yield per tree which is the most important economic character exhibited the highest degree of variation followed by number of nuts per panicle and protein content of kernel. A high variability in nut yield per tree has been reported by Aiyadurai and Koyamu (1957), Damodaran *et al*. (1978), Falade (1981), Ramdas and Thatham (1982) and Nalini and Santhakumari (1991), while Damodaran (1977) and Swamy and Thimmappaiah (1990) also observed wide variation in other yield attributes like nut weight and shelling percentage. Presence of such variability underscores the scope for improving the population for yield and its components. The degree of variation was higher in hybrids than the parents in case of three yield attributes namely nut yield per tree, protein content of kernel and number of nuts per panicle.

The variability observed in the case of number of nuts per panicle was not quite high and since it is an important character; further exploration and collection of superior genotypes seems necessary. The existence of genotypes with number of nuts per panicle as high as 16.0 as reported by Nalini and Santhakumari (1991) accentuates this fact.

Wide diversity existed in the population under study with respect to apple characters. Titrable acidity showed the highest variation followed by weight of apple and reducing sugar content. This is in conformity with the findings of Aiyadurai and Koyamu (1957), Uthaman and Koyamu (1957), Damodaran (1977), Damodaran *et al*. (1978), Swamy and Thimmappaiah (1990) and Sapkal *et al*. (1992) who reported the presence of high variability in different apple characters.

A higher degree of variation was noticed in hybrids than the parents in case of four apple characters namely percentage of reducing sugar and total sugar, total soluble solid content and titrable acidity, while in the three other characters, hybridization did not broaden the spectrum of variability. Eventhough the variability existing for the tannin content was high, hybrids with tannin content as low as 0.09 per cent could be identified in this study. Since the tannin utilized in the leather industry is extracted mainly from the bark and testa of nuts of cashew, low tannin content in the cashew apples is advantageous as it lessens the acrid taste of cashew apple juice.

5.2 Correlation and direct effects

Selection of yield *per se* may not be effective since implicitely or explicitely "there may not be genes for yield *per se* but rather for the various components, the multiplicative interaction of which results in the artifact of yield" (Grafius, 1956). This necessitates identification of appropriate component character(s) whose selection would result in the selection for complex character like yield.

Nut yield per tree was found to possess significant positive correlation with mean canopy spread (0.57), girth of the tree (0.54), number of nuts per panicle (0.36), weight of kernel (0.35), duration of flowering (0.30), leaf area (0.27), height of the tree (0.26) and individual nut weight (0.24). The characters number of panicles per ($\frac{1}{2}$ m)^2 canopy area, number of flowers per panicle, percentage of fruit set, shelling percentage, protein content of kernel, weight of apple and juice content also exhibited positive association with nut yield per tree, though not in a significant manner. The characters total soluble solid content, tannin content and percentage of hermaphrodite flowers displayed negative correlation with nut yield. The positive association between nut yield and spread, girth and height of the plant was reported by Nayar et al. (1981), while Anitha et al. (1991) observed high positive association between nut yield and number of nuts per panicle that reached maturity. The results are also in agreement with Parameswaran et al. (1984 a) who reported a strong correlation between tree yield and percentage of flowering shoots per unit area of tree canopy and total canopy area.

The significant positive correlation observed between mean canopy area and nut yield is of great importance since yield per tree is influenced by the shape of the canopy. Cashew trees bear fruits at the periphery and fruit production becomes almost nil on branches of trees that intermingle with branches of neighbouring trees thus limiting the availability of sun light. So higher yields can be expected from trees with higher canopy area at the same time having an intensive branching habit.

It was also found that there is a significant positive correlation between yield and duration of flowering. But this association between duration of flowering and yield is not of much practical significance as longer duration of flowering results in protracted harvest which in turn causes heavy harvesting cost. Moreover nuts produced on late flowers may ripen in the next rainy season and become spoiled due to prevailing humid conditions. However in areas where labour availability is limited during peak harvesting time, staggering of the flowering period may become beneficial.

It was also noted that number of panicles per $(\frac{1}{2}\ m)^2$ canopy area, number of flowers per panicle, per cent fruit set, number of nuts per panicle, individual nut weight and weight of kernel contributed positively to increase the nut yield per tree. This highlights the usefulness of these characters in a selection programme and these characters can be considered as the important yield components in cashew. These results are in conformity with Anitha et al. (1991).

The results indicated that number of panicles per

(½ m)^2 canopy area had a weak positive correlation with percentage fruit set but it was negatively associated with number of nuts per panicle. The high density of panicles per unit canopy area might have enhanced the chances of pollination and resulted in a high fruit set, but the possible existence of competition among developing nuts present per unit canopy area for nutrients and assimilates might have kept a check on the ultimate number of nuts retained per panicle. The same reason holds good for the positive association between number of flowers per panicle and per cent fruit set. But the positive association between fruit set and number of nuts per panicle clearly indicates that the number of nuts reaching maturity is decided not by the competition for assimilates between nuts within a panicle but the competition between nuts of different panicles located at a closer proximity in the plant canopy area.

But the results further points to the fact that individual nut weight, weight of kernel and weight of apple had only negative association with number of nuts per panicle. So it must be presumed that competition may arise even between nuts within a panicle as weight of aforesaid characters crosses an apparently existing threshold level.

Eventhough number of flowers per panicle which consisted of both male and hermaphrodite flowers had a weak positive correlation with percentage of fruit set, percentage of hermaphrodite flowers as such had only negative correlation with fruit set. This indicates that number of male flowers is a major factor deciding pollination and fruit set and proportion of male flowers below a particular level in a panicle may adversely affect fruit set. Ohler (1979) also reported that higher setting was obtained when number of perfect flowers was lower.

Another important observation of this study was a strong positive correlation of individual nut weight with kernel weight. This shows that heavier nuts contain heavier kernels. But the results also indicate that individual nut weight had only negative correlation with shelling percentage while the kernel weight had a weak positive correlation with shelling percentage. Though larger nuts tend to contain heavier kernels, with regard to kernel percentage, smaller nuts seems to contribute more. This may be possible due to the presence of cavities between kernel and shell and between two cotyledons of large nuts. The results are in consonance with Ohler (1979) and Ramdas and Thatham (1982) who could also observe a positive correlation between nut weight and per cent whole kernel recovery and a negative correlation with testa weight and weight of broken kernel. Thus a higher nut weight implies less of testa component of the kernel and also a lesser percentage of broken kernels. Moreover large sized kernels command premium price in the market. Since cashew is mainly an export oriented crop, selection based on large sized nut would not only lead to high grade quality kernels, but also a higher percentage recovery of whole kernels. Further, there was a positive association between nut yield per tree and individual nut weight.

However, Ohler (1979) and Damodaran et al. (1979) recommended selection of trees producing medium sized nuts as they were reported to be more productive. The outcome of the present study do not exactly corroborate with their findings. The existence of the positive correlation between individual nut weight and nut yield per tree and strong positive association between individual nut weight and kernel weight indicate the significance attached to selection for trees with medium sized nuts uncalled for.

The existence of positive association of individual nut weight and kernel weight with the weight of the apple is an interesting piece of information. This clearly indicates that the development of apple in no way hampers the development of nut. The report of Damodaran et al. (1966) that the enlargement of cashew apple takes place when the development of nut ceases substantiates the above finding.

Weight of apple had only negative association with juice per cent. This may be due to the fact that, as the weight of apple increases, the proportionate increase in the juice content may be less to the proportionate increase in the fibre and other solid constituents of apple.

The path coefficient analysis indicated that weight of kernel had the maximum positive direct effect followed by mean canopy spread and number of nuts per panicle, while individual nut weight and weight of apple had negative direct effects.

The high positive direct effect of kernel weight on yield and its significant positive correlation with yield project out kernel weight as the single most character to be considered for selection of superior plants for nut yield. Though individual nut weight had only a negative direct effect on nut yield per tree, it had a high positive indirect effect on yield through kernel weight. In a similar fashion, weight of apple which had only negative direct effect on yield had positive indirect effect on yield through kernel weight.

Both the girth and mean canopy spread had positive direct effects on yield and positive association with yield with the former having a slightly higher indirect effect on yield through mean canopy spread than its direct effect on yield. Moreover mean canopy spread contributed towards yield mainly through its direct effect and also by its indirect effect through girth of the tree. Therefore mean canopy spread and girth of the tree could also be considered as characters for direct selection.

Number of nuts per panicle also had a positive direct effect on yield and a positive association with yield, but had a slight negative indirect effect on yield through kernel weight. Eventhough leaf area had a positive direct effect and positive association with yield, it had a slightly higher positive indirect effect and a negative indirect effect on yield through weight of kernel and individual nut weight respectively.

Thus the correlation studies and path coefficient analysis revealed the important biometric characters which contribute towards nut yield in cashew as weight of kernel, mean canopy spread, number of nuts per panicle, girth of the tree, leaf area, duration of flowering and height of the tree.

5.3 Principal component analysis and discriminant function analysis

The principal component analysis reduced the dimensionality from eighteen variables to two. As such a plot of the points was elucidated in the two dimensional plane. Since the cumulative variance accounted for 88.71 per cent it could be deemed that the first two principal components was well effective in total description of the whole set up. Hence the yield was predicted using the first two principal components as explanatory variables. Though a very significant R^2 was not obtained, the simplicity of the regression equation serves as a ready reckoner in most of the situations where an initial approximate prediction is called for.

The solution of the problem through a biometric angle can also be thought of in terms of the reduction of number of variables involved instead of the reduction of dimensionality. The step-wise regression is a procedure where a second thought is made before finally eliminating the same from the vector of explanatory variables rather basing the decision merely on the low profile of correlations involved. In the usual set up where only variables which are highly correlated with yield are taken into the hold of the vector of explanatory variables the inherent curvilinear relationship is never thought of from any angle. The step-wise regression is really a well defined set up which serves as a remedy for the above lapse.

The step-wise regression on yield reduced the number of explanatory variables from twenty one to five. The predictor equation obtained had a highly significant R^2. So the yield could be more precisely estimated at a later stage if necessary using the regression equation obtained. The predictor equation based on principal component analysis and the equation obtained by way of step-wise elimination of the explanatory variables predict the yield with a reasonable degree of precision.

In addition to the above advantages; the plot of the principal components in a plane as a two dimensional set up can pick up the hybrids that can be considered superior with respect to the characters under study. A cluster of hybrids thus obtained can be considered as a sample of better yielders of the population as against the outlayers that can be regarded as poor yielders. The characterization of the clusters based on the principal components could be regarded as a right step in the screening of hybrids in terms of superiority for yield and its component characters.

Application of discriminant function as a basis for making selection for several characters simultaneously is aimed at discriminating the desirable genotypes from undesirable ones on the basis of their phenotypic performance. The discriminant function fitted in this study gave a good fit to the data as the D^2 value was found to be significant at one per cent level. Using this function, selection index values could be computed for the hybrids which made it possible to arrange them in order of merit with respect to nine economic characters and to identify the most promising hybrids.

5.4 Performance of superior hybrids

The principal component analysis and discriminant function analysis resulted in the identification of six hybrids as the most promising out of fifty six hybrids evaluated. The performance of these hybrids with respect to six important economic characters are shown in Fig.5.

The hybrid H-342 with the highest nut yield per tree (23.48 kg) medium nut size (7.23 g), medium kernel size (2.24 g), high shelling percentage (30.98), medium protein content (20.78%) and medium number of nuts per panicle (4.6) is the best among the group. This showed a heterosis for yield of 175.26 per cent over the mid-parent, 138.38 per cent over the better parent and 33.41 per cent over the standard variety. This hybrid also had a superior export grade of W 210.

The hybrid H-402 with a mean nut yield per tree of 23.13 kg had the highest protein content (35.62%) other characters being medium to high. This hybrid which displayed

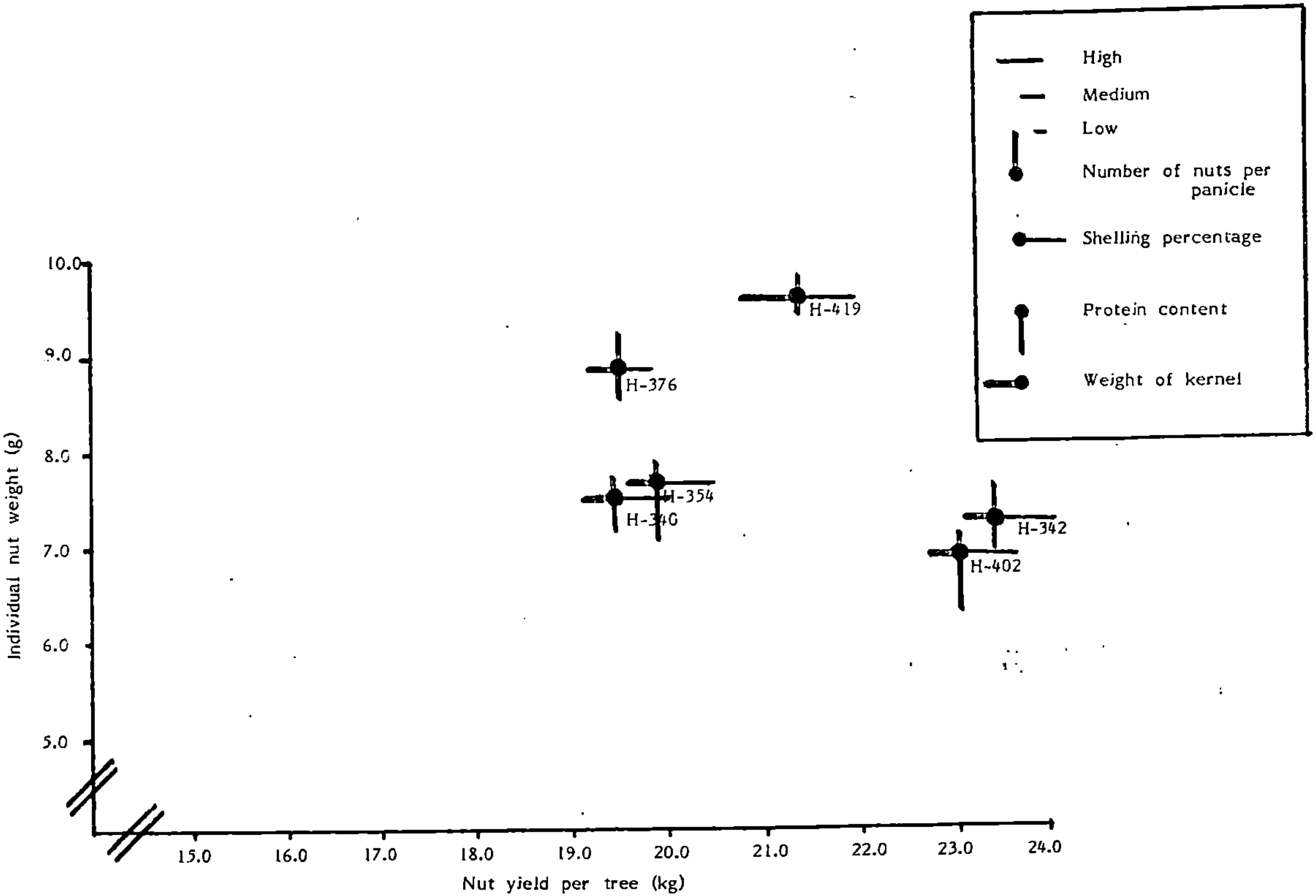


FIG. 5 CONSTELLATION OF SIX SUPERIOR HYBRIDS THROUGH METROGLYPH

a heterosis for nut yield per tree over mid-parent, better parent and standard variety possessed the best export grade of W 180.

The highest individual nut weight (9.60 g), kernel weight (3.03 g) and shelling percentage (31.56) were observed in the hybrid H-419 having an yield of 21.43 kg per tree. It also had the best export grade of W 180.

Among these six superior hybrids identified, H-354 was found to be early with respect to season of flowering, the fifty per cent flowering being observed in the month of November itself. The flowering of rest of the hybrids can be considered mid-season as fifty per cent flowering took place in the month of December.

The factor that all these six selected hybrids exhibited heterosis for nut yield per tree over their respective mid-parents, better parents and the standard variety Madakkathara-1 underscores the effectiveness of hybridization in crop improvement of cashew. The results are in conformity with Damodaran (1975) who reported hybrid vigour for nut yield in cashew after evaluating a different set of hybrids. All these selected hybrids exhibited standard heterosis for individual nut weight and kernel weight in addition to nut yield per tree indicating their superiority

Summary

over the recently released cultivar Madakkathara-1 which was taken as the standard variety.

The findings of the present investigation thus point towards the superiority of six hybrids viz., H-342, H-402, H-419, H-354, H-376 and H-340 with respect to important economic characters over the rest of the hybrids studied, parents involved and the standard variety Madakkathara-1. After testing these six hybrids in replicated multilocation experiments, if they prove their superiority and stability, they can be recommended for large-scale cultivation.

SUMMARY

The present study was carried out at the Department of Pomology and Floriculture, College of Horticulture, Vellanikkara during 1990-1992 to determine the extent of variability and degree of association of quantitative characters in cashew and to evaluate F_1 hybrids of cashew for growth parameters, floral traits, yield attributes and apple characters. The experimental material comprised of ten year old fifty six F_1 hybrids of cashew belonging to twelve parental combinations, the parents being high yielding trees identified at the Cashew Research Station, Madakkathara.

The hybrids and parents were observed for four growth parameters, five floral traits, six yield attributes and seven apple characters for two seasons, 1990-91 and 1991-92. The salient findings of this study are listed below.

1. Variability studies of different growth parameters showed that wide variability in terms of range and coefficient of variation existed in the hybrids as well as parents. Maximum extent of variation was observed for the character girth of the tree followed by mean canopy spread and leaf area in the hybrids.

2. Most of the floral traits also exhibited high degree of variability in the population under study. Per cent hermaphrodite flowers possessed maximum extent of variation followed by number of flowers per panicle and per cent fruit set in the hybrids.

3. Hybrids were classified into early, mid-season and late based on the time of fifty per cent flowering. There were altogether 13 early, 38 mid-season and 5 late flowering types.

4. Almost all the yield attributes had a high degree of variability in the population studied. Nut yield per tree which ranged from as low as 0.60 to 23.48 kg in the hybrids exhibited the highest degree of variation followed by number of nuts per panicle and protein content of kernel.

5. Wide diversity existed in the population under study with respect to apple characters. Titrable acidity showed the highest variation followed by weight of apple and reducing sugar content in the hybrids.

6. Correlation studies were undertaken using nineteen selected characters to determine the degree of association between yield and different characters. Nut yield per

tree was found to possess significant positive correlation with mean canopy spread (0.57), girth of the tree (0.54), number of nuts per panicle (0.36), weight of kernel (0.35), duration of flowering (0.30), leaf area (0.27), height of the tree (0.26) and individual nut weight (0.24). Total soluble solid content had the maximum negative association with yield (-0.50) followed by tannin content (-0.17). A strong positive correlation (0.91) was also noted between individual nut weight and weight of kernel.

7. The path coefficient analysis using eight selected parameters showing positive correlation with nut yield per tree indicated that weight of kernel had the maximum positive direct effect followed by mean canopy spread and number of nuts per panicle, while individual nut weight and weight of apple had negative direct effects.

8. The correlation studies and path coefficient analysis revealed the important biometric characters which contribute towards nut yield in cashew as weight of kernel, mean canopy spread, number of nuts per panicle, girth of the tree, leaf area, duration of flowering and height of the tree in that order of priority.

9. The principal component analysis was performed using eighteen selected variables. Based on the first two principal components which accounted for 88.71 per cent of the cumulative variance, an yield prediction model was fitted which had an R^2 of 0.329 the prediction model being

$$Y = 0.0175\ P_1 - 0.0087\ P_2 - 9.3137$$

where P_1 and P_2 are the first and second principal components respectively.

10. To reduce the number of variables involved in the yield prediction model, the step-wise regression of yield on 21 characters was performed which gave the regression equation

$$Y = 0.0152\ x_3 + 0.0622\ x_5 + 1.3579\ x_{10} + 0.4436\ x_{13} - 1.4043\ x_{19} - 13.9381$$

with an R^2 of 0.5735 where the explanatory variables x_3, x_5, x_{10}, x_{13} and x_{19} represented respectively mean canopy spread, leaf area, number of nuts per panicle, shelling percentage and total soluble solid content.

11. Based on the discriminant function fitted, selection index values were calculated for hybrids and they were arranged in the order of merit and best 10 per cent of the whole population which came to six was selected as

superior. These hybrids were H-342, H-402, H-419, H-354, H-376 and H-340.

12. Among the six selected hybrids H-342 had the highest nut yield per tree (23.48 kg) while H-402 with a mean nut yield per tree of 23.13 kg had the highest protein content (35.62 per cent). The highest individual nut weight (9.60 g), kernel weight (3.03 g) and shelling percentage (31.56 per cent) were observed in the hybrid H-419 having a nut yield per tree of 21.43 kg.

13. Magnitude of heterosis was calculated in terms of nut yield per tree, individual nut weight and weight of kernel for all the six selected hybrids over mid-parent (relative heterosis), better parent (heterobeltiosis) and standard variety, (standard heterosis). All these hybrids exhibited heterosis for nut yield per tree over their respective mid-parents, better parents and standard variety Madakkathara-1. They showed standard heterosis for individual nut weight and weight of kernel also.

14. Hybrids H-340, H-354, H-376 and H-419 had the best export grade of W 180 while hybrids H-342 and H-402 had the next best export grade of W 210.

15. The six superior cashew hybrids were pictorially represented through metroglyph.

16. Thus the findings of the present investigation point towards the superiority of six hybrids viz., H-342, H-402, H-419, H-354, H-376 and H-340 with respect to important economic characters over the rest of the hybrids studied, parents involved and the standard variety Madakkathara-1.

The results obtained in the present study are adequately discussed and its implications elucidated.

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BIOMETRICAL STUDIES IN CASHEW (*Anacardium occidentale* L.) HYBRIDS

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ABSTRACT OF A THESIS

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ABSTRACT

An investigation to determine the extent of variability and degree of association of quantitative characters in cashew and to evaluate F_1 hybrids of cashew for growth parameters, floral traits, yield attributes and apple characters was carried out with ten year old fifty six F_1 hybrids of cashew belonging to twelve parental combinations at the Department of Pomology and Floriculture, College of Horticulture, Vellanikkara during 1990-92. The hybrids and parents were evaluated for four growth parameters, five floral traits, six yield attributes and seven apple characters for two seasons.

Variability studies showed that wide variability in terms of range and coefficient of variation existed in the hybrids as well as parents for all the characters studied. Hybrids showed the highest degree of variation for the character nut yield per tree followed by titrable acidity and per cent hermaphrodite flowers.

Nut yield per tree exhibited maximum significant positive correlation with mean canopy spread followed by girth of the tree, number of nuts per panicle, weight of kernel, duration of flowering, leaf area, height of the tree and individual nut weight.

Weight of the kernel displayed the highest positive direct effect on nut yield per tree followed by mean canopy spread and number of nuts per panicle while individual nut weight and weight of apple had negative direct effects.

The correlation studies and path coefficient analysis identified the important biometric characters which contribute towards nut yield per tree in cashew as weight of kernel, mean canopy spread, number of nuts per panicle, girth of the tree, leaf area, duration of flowering and height of the tree in that order of priority.

The principal component analysis and step-wise regression procedure gave two yield prediction models for cashew with the latter having a higher R^2 value.

Based on the discriminant function analysis, and selection index values, six hybrids viz., H-342, H-402, H-419, H-354, H-376 and H-340 were identified as superior to the rest of the hybrids studied. All these selected hybrids exhibited heterosis for nut yield per tree over their respective mid-parents, better parents and standard variety Madakkathara-1. They also showed standard heterosis for individual nut weight and weight of kernel and had superior export grades.