STUDIES ON GENETIC PARAMETERS AND ASSOCIATION OF YIELD AND ITS COMPONENTS IN SHORT DURATION TAPIOCA VARIETIES (*Manihot esculenta* Crantz.)

BY

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DECLARATION

I hereby declare that this thesis entitled "Studies on genetic parameters and association of yield and its components in short duration tapioca varieties (Manihot esculenta Crantz)" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other university or Society.

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7-8-1987

CERTIFICATE

Certified that this thesis entitled " Studies on genetic parameters and association of yield and its components in short duration tapioca varieties (Manihot esculenta Crantz) is a record of research work done indpendently by Kumari Rekha V.R. under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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INTRODUCTION

1. INTRODUCTION

Tapioca otherwise known as Cassava (<u>Manihot esculenta</u> Crantz) a member of Euphorbiaceae family and native of South America (Rogers, 1963) is widely cultivated in tropics. The crop was introduced to India in Seventeenth century by portuguese travellers. The starch rich thickened roots or tubers are the parts used as food. The bulk of the cassava growing areas of the country is located in two southern States namely Kerala and Tamil-Nadu of which Kerala accounts for ninety per cent of the total acreage producing 36.94 lakh tonnes from about 2.16 lakh ha. Tapioca is the fifth important staple food in World (Philips, 1973) and in Kerala it occupies a paramount position next to rice. It is the cheapest source of calories both for human nutrition and animal feeding.

Inspite of the economic importance of this crop, yield of tapioca in this part of the country is diplorably low, probably due to the routine practice of using inherently inferior varieties with low production potential. Hence in recent years considerable efforts are underway to improve the situation. This consists of evolution of high yielding cultivars, development of suitable agronomic practices and evolution of suitable plant protection measures.

Evolution of high yielding cultivars require a good knowledge of the various genetic components of yield and their inheritance.

Cassava is normally considered to be a long term root crop which can be harvested between eight and twelve months after planting. It may be possible to improve the efficiency of the crop in terms of root yield per unit time, one method being by shortening the growth period through the identification of early maturing cultivars. If early elite types are identified they can be successfully used for planting in wet land after the harvest of second crop paddy from January to June.

A proper evaluation of the variability available for yield and yield attributes would go a long way in formulating sound breeding programme. Selection which is as old as cultivation is an important part of all crop improvement programmes. For selection programme to be effective a sound knowledge of the variability present in the breeding population is necessary. The variability available in a population could be partitioned into heritable and nonheritable components with the aid of genetic parameters.

Yield in tapioca as in other crops is a complex characters. Besides being polygenic in nature yield is greatly influenced by environmental factors. Further, the character is governed by several other equally complex polygenically controlled component characters as well. Hence in variety improvement programmes it is necessary to know the relationship of these yield components among themselves and also with tuber yield. Correlations measure only mutual associations and they do not provide information on direct and indirect effects. Path coefficient analysis devised by Wright (1921) is a partial regression coefficient and as such measures the direct influence of one variable upon another and permits the separation of correlation coefficients into components of direct and indirect effects (Dewey and Lu 1959).

It was in this background the present investigation was undertaken in tapioca with the following objectives.

(i) to assess the extent of variability present in the population by estimating genetic parameters like genotypic coefficient of variation, heritability, genetic advance and genetic gain.

(2) to identify early maturing superior genotypes for yield and other attributes

(3) to find out the association of different characters with yield and also among themselves and

(4) to determine the direct and indirect influences of different component characters on yield using path coefficient analysis.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

An attempt has been made in this review to summarise the important works carried out on the biometrical aspects of yield and its components, reaction to pests and diseases and chemical assay of two important tuber yielding crops. They are being reviewed under the following headings.

1. Studies on variability
2. Correlation studies
3. Earliness
4. Pests and disease resistance and
5. Chemical assay

2.1 Studies on variability

For any crop improvement programme aimed at achieving maximum productivity, a detailed knowledge of genetic variability of various quantitative characters and their contribution to yield is an essential pre-requisite. The variability available in a population could be partitioned into heritable and nonheritable components with the aid of genetic parameters such as phenotypic and genotypic coefficients of variation, heritability, genetic advance and genetic gain which serve as a basis for selection. The extent of variability in tuber crops have been studied by many workers by estimating genetic parameters.

Lush (1949) and Johnson et al.(1955) devised an accurate procedure for calculation of genetic advance under specified intensities of selection.

Burton (1952) introduced a convenient procedure for the calculation of the phenotypic and genotypic coefficients of variation.

The methodology for partitioning the total variance into that due to phenotype, genotype and error in the analysis of variance was introduced by Johnson et al.(1955). Error denotes the genotype environmental interaction. They further, substantiated the advantage of computing genetic gain under selection and its usefulness in relative comparison of variables.

Hanson et al.(1956) proposed the mathematical relationship of various estimates on computation of heritability. This estimate is generally expressed as percentage and in broad sense it refers to the relative proportion of variance due to genotype over the variance due to phenotype.

In asexually reproducing plants like cassava, any combination of genetic factors that yields a superior genotype can be used through clonal propagation. In such circumstances, all genetic variability can be used and heritability estimates have meaning (Hanson, 1963).

According to Li (1975) in sweet potato additive component of genetic variance was relatively more important than nonadditive for total root weight, average weight per root and number of roots. For total weight of leaves and stem the main components of genetic variance were non-additive type. Total weight, average weight and number of roots showed comparatively high heritabilities of 44.5 per cent, 50 per cent and 43.5 per cent respectively. Weight of leaves and stem showed a heritability of 10.04 per cent. With a selection intensity of 10 per cent the predicted and observed genetic advance closely coincided.

Genetic variability was studied in fortyone varieties of sweet potato by Singh and Mishra (1975) for 6 characters viz. length of vine per plant, number of branches per plant, number of leaves per plant, total leaf area per plant, number of tubers per plant and yield of tubers per plant. A wide range of variability was observed in all the quantitative characters. Differences among the varieties were highly significant. Phenotypic, genotypic and environmental variances were of higher value for all the characters studied except number of branches per plant. Total leaf area gave the highest genotypic coefficient of variation followed by length of vine, number of leaves and yield of tubers. Estimates of heritability percentage in broad sense were of high magnitude for total leaf area (92.25 per cent) length of vine (88.10 per cent), number of leaves (74.48 per cent) and yield of tuber (56.78 per cent). Estimates of genetic advance expressed in percentage of mean were high for total leaf area, length of vine and yield of tubers. Total leaf area per plant, length of vine per plant and yield of tuber per plant had high values for genotypic coefficient of variation, heritability percentage and genetic advance indicating thereby the scope for selection of these characters on the basis of their phenotype.

Investigation carried out by Thamburaj and Muthukrishnan (1976) indicated that in general genotypic coefficient of variation was lower than phenotypic coefficient of variation indicating larger measure of environmental influence. The weight of tuber per vine, number of leaves per vine and the weight of foliage exhibited a high degree of both phenotypic and genotypic coefficients of variation, while girth of stem had the least coefficient of variation. High heritability estimates were obtained for length of petiole and number of leaves per vine. High heritability and low genetic advance were observed for all the characters except girth of tuber and number of tubers per vine in which the genetic advance was very high.

In a study conducted with ten varieties of sweet potato genotypic coefficient of variation was found to be lower than phenotypic coefficient of variation for all the characters studied. Length of vine and number of tubers showed very high degree of phenotypic and genotypic coefficients of variation associated with high heritability estimates and genetic advance (Kamalam et al. 1977)

Biradar et al. (1978) conducted detailed investigation with 12 varieties of cassava to estimate genetic variability for seven quantitative characters. In general, phenotypic coefficients of variation was higher than that for the genotypic coefficients of variation for all characters studied. Phenotypic and genotypic coefficient of variation, heritability and genetic advance estimates were high for number of nodes and tuber yield per plant indicating considerable scope for the improvement of economic trait like tuber yield.

Kawano <u>et al</u>.(1978) had reported that there was enormous genetic variation for harvest index in seedling populations of cassava and by virtue of its high heritability could be effectively used as an indicator for seedling selection.

In cassava heritability of harvest index was much higher than that of root yield and total plant weight under both very high yielding and low yielding environments. This indicated that harvest index was a highly stable character over a wide range of environments while yield and total plant weight were not as stable (Anon., 1979).

Six diverse cassava populations grown during 1979-80 and 1980-81 at IITA were investigated to estimate genetic parameters for twenty two traits of cassava. The data on analysis revealed that considerable variation existed both within and between populations for most of the characters, the coefficients of variation for phenotype and genotype were largest for root yield (85 per cent and 62 per cent respectively), quite large for the roots per plant and root size (60 per cent and 40 per cent) moderate for harvest index and total number of branches (45 per cent and 30 per cent respectively) and low ($\angle$ 30 & 15 per cent) for stem girth, canopy width and plant height at harvest. Heritability estimates as well as expected genetic gain also varied considerably. On an average root yield and number of roots showed moderately high heritability (50 per cent) and high expected response to selection (88 per cent and 64 per cent respectively). Relatively high heritability estimates were obtained for harvest index (49 per cent), dry matter content (52 per cent), but they were associated with expected genetic gains of only 50 per cent and 29 per cent respectively. Agronomic traits such as stem girth, canopy width and plant height at harvest showed moderate to low heritability values (32-42 per cent) associated with low expected genetic advance (15-18 per cent) (Mahungu et al. 1983)

Maluf et al.(1983) observed high heritability values in sweet potato for number of marketable roots and vine length.

When eleven characters were evaluated in fifteen cultivars of sweet potato, weight of dry matter, length of main stem, stem/tuber weight, internode length and yield showed high heritability values (> 65 per cent). Stem/tuber weight and number of large tubers had the high genotypic coefficient of variation and greatest genetic advance followed by yield per plant, length of main stem and branch number (Lin, 1983).

2.2 Correlation studies

One of the important objectives in a breeding programme is the incorporation of genetic potential for high yield in a variety. Since yield is a complex character it is worthwhile to estimate the influence of the association existing between less variable characters and yield. Correlation studies are conducted to determine the inter-relationship among various traits, which are useful in making selection. Information on the association of plant characters with yield and also on the intercorrelations are available in tuber crops.

Galton (1989) conceived the idea of correlation of variables for the first instance.

Williams and Gazali (1969) had stated that harvest index of high yielding cassava was very high and that high yields were not necessarily due to the production of large total biomass. They also suggested that difference in yield might be associated with an improved canopy structure with narrow leaves that become more vertically oriented at midday.

The main components of yield in tuber crops were the number and mean weight of tubers which were directly related to the process of tuber initiation and tuber growth (Wilson, 1970).

According to Sinha and Nair (1971) in cassava only those cultivars which had larger leaf area duration and high leaf area index were high yielders.

Enyi (1972) reported negative relationship between leaf area and tuber yield in multishoot plants of tapioca. Bulking rate increased with increase in Leaf area index reaching a maximum at a leaf area index of 3.5. Increase in leaf area index above this value led to decrease in bulking rate.

In tapioca, varieties with high root yield had a low fresh weight in the aerial parts, although an occurrence in the contrary need not be necessarily overlooked (Estevao et al. 1972).

Number of tubers per plant was significantly and positively correlated with tuber yield per plant in tapioca. Further, the yield was significantly and directly correlated with tuber length, tuber circumference, plant height and rind thickness. Length of tuber was, however, positively associated with girth (Magoon, 1972).

According to Enyi (1973) in tapioca high yields could be achieved with a low leaf production cultivar, provided that high harvest indices were realised.

An investigation in M_4 variety of tapioca revealed that the yield of tubers had a positive correlation with length of tuber, girth of tuber, number of nodes per plant and height of plants. Leaf area and tuber yield were negatively correlated while the leaf length and breadth were positively correlated. The node number had a positive correlation with characters other than leaf area. The height of the plants recorded a positive relationship with length, girth and yield of tubers while leaf area exhibited negative relationship (Muthukrishnan et al.1973).

Magoon and Krishnan (1973) reported that in tapioca tuber length, tuber circumference and tuber number per plant were positively correlated with tuber yield, but tuber number per plant was negatively correlated with tuber length and circumference. High leaf number was positively correlated with high yield. The traits such as starch, dry matter, crude protein and cyanide contents were independently inherited.

In cassava yield had significant positive correlation with spreading-branching plant type. Because of the positive correlation between yield and undesirable plant type, which reduced the population per unit area, sèlection of erect types with high yield became difficult (Anon., 1973).

Hunt (1974) observed that tapioca cultivars producing leaves rapidly were better as they were able to replace damaged leaves and no significant reduction in yield was realised.

Holmes and Wilson (1974) recommended that harvest indices could be made use of as a measure of assessing the yield potential in a collection of cultivars grown under similar conditions. They reported the existance of significant association between leaf production parameters (node number, leaf number and leaf area) and total dry weight of the plant. Correlations between these parameters and tuber yield indicated that leaf production and leaf abscission were important determinants of total dry matter production and tuber yield. The values for correlation coefficients were however, higher with total dry matter production than with tuber yield. There was significant negative correlation between tuber number and mean tuber weight in high yielding and also in low yielding cultivars.

Works at IITA, Nigeria indicated significant positive correlation between number and size of tuber with yield in tapioca (Anon., 1974b).

Root measurement on three Malayan varieties of tapioca (high, medium and low yielding clones) showed that the onset of tuberization brings about a slowing down or cessation of growth in root length, but no changes in stem growth rate were associated with the onset of tuber growth. High yield was associated with high tuber weight rather than with tuber number, which could be related to the size of storage tissue cells formed by the root cambium. Diameter of the tuber was the main yield component rather than its length (Williams, 1974).

Total yield and yield components (tuber number and mean tuber weight) of six local sweet potato cultivars were compared by Lowe and Wilson (1975) in wet and dry seasons. There were significant negative correlation between tuber number and mean tuber weight in five out of the six cultivars and positive correlation between these yield components and total yield, suggesting that cultivars may be grouped into tuber number-tuber weight and tuber weight types, as well as random types in which yield was related to neither components. Marketable yield tended to be directly related to both components, and cultivars with lower tuber numbers, usually produced a higher percentage of marketable yields.

In a study conducted by Pushkaran <u>et al</u>.(1976) with seventeen varieties of sweet potato highly significant positive association with yield was exhibited by girth of tuber, length of tuber and number of tubers. The association of leaf area and length of vine to yield were significant, but in the case of the former it indicated a negative trend. Leaf area exhibited a more intense association with girth of tuber than towards yield and in both cases the relationship was negative.

Experiments conducted at CIAT revealed that the optimum leaf area index for cassava was about three and that when this was maintained yield was found to be maximum. With a rapid increase in leaf area index the root growth was found to be reduced even though leaf area index was optimum (Anon., 1976).

According to Cock (1976) high yielding varieties should have a large leaf area index and a high harvest index but the distribution of dry matter to the roots should not be so great that leaf production was curtailed.

Harvest index in single row and population trials was very highly correlated whereas yield was not. So harvest index was a better character for selection than root yield (Kawano et al. 1976).

An investigation with 65 clones of sweet potato indicated that number of tubers per vine, girth of tuber, weight of foliage, number of branches per vine, number of leaves per vine, length of tuber and length of petiole had a high degree of positive association with tuber yield both at genotypic and phenotypic levels, while the characters girth of stem and length of vine had negative association (Thamburaj and Muthukrishnan, 1976).

Kawano *et al.* (1977) stated that varietal variation in yield and harvest index were sufficient for making efficient visual selection in cassava. Harvest index was highly associated with root yield and the correlation was significant.

An investigation with ten varieties of sweet potato revealed that in general, phenotypic correlations were higher than genotypic correlations. Number of tubers had significant positive correlation with yield (Kamalam *et al.* 1977)

Mani *et al.* (1977) reported that the morphological characters like average height of plant, average number of tubers per plant and average tuber weight had no correlation with the maturity of cassava crop.

In Sweet potato yield was positively correlated with average tuber weight and contents of carotene, total sugar and water (Stino *et al.* 1977)

In a study conducted by Biradar *et al.* (1978) with twelve varieties of cassava genotypic correlation coefficients were found to be higher in magnitude than phenotypic correlation coefficients. Harvest index, number of tubers per plant and mean tuber weight showed strong positive correlation with tuber yield, while number of nodes per plant had significant negative correlation. They suggested that for the identification of high yielding genotypes more emphasis had to be laid on characters like harvest index and number of tubers per plant.

In seventy one selfed progeny lines of cassava correlation coefficients were studied by Kamalam *et al.* (1978) for tuber yield and its five components viz. harvest index, number of tubers, number of nodes, weight of vegetative part and plant height. The tuber yield was positively and significantly associated with all the above characters. Harvest index showed significant negative correlation with number of nodes, weight of vegetative part and plant height though it had a non-significant positive correlation with number of tubers. Tuber yield was mainly dependent on harvest index, number of tubers and to a certain extent on weight of vegetative part.

Kawano (1978) reported significant positive correlation between harvest index and yield based on population studies in cassava.

According to Kawano et al.(1978) in cassava there was no significant correlation between root yield of a given genotype in single row trial and that in population trial. However, the correlation of harvest index between the single row trial and population trial was highly significant and the correlation between harvest index and root yield was very high in population trial. As a consequence the correlation of harvest index in single row trial with root yield in population trial was significant. They concluded that in single row trial harvest index was a better indicator of true yielding ability than root yield itself.

Selection for higher harvest index had been the major tool for obtaining high yielding genotypes in tapioca. Under both very high and very low yielding environments, harvest index was highly correlated to root yield (Anon., 1979).

Leaf area was found to be a limiting factor of productivity in cassava under rainfed conditions. Leaf area index of 2.5 - 3.5 was found to be optimum to realise highest yield. Specific leaf weight, petiole length, net assimilation rate, crop growth rate, harvest index and biomass production could be considered as suitable selection indices while evaluating genetic material for yield potentials (Anon., 1982).

Sushama *et al.* (1982) reported significant positive correlation between leaf area and tuber yield in cassava.

In a study with forty lines of sweet potato a high positive correlation occurred between dry matter percentage and starch content of tuber, while a negative correlation occurred between tuber yield and starch content (Mao, 1982).

Significant positive correlations were noticed between the total biomass yield at fourth and sixth month stage and the final tuber yield. Thus repliminary screening of the genetic stocks of cassava for the productivity may be possible even at fourth and sixth month stage (Anon., 1983a).

Ramanujam and Indira (1983) conducted two years trial with ten varieties of tapioca which displayed a wide range of branching habits, height and leaf shapes under rainfed conditions. In general the harvest index was highest in most productive varieties. High yields depended on the maintenance of a leaf area index around 2.5 for much of the growing season and did not depend on height, number of nodes or stem thickness. The three highest yielding varieties all had broad lobed leaves, two were of non-branching habit and one was semibranching.

In sweet potato high yield was associated with high harvest index (Ashokan and Nair, 1984).

Radhakrishnan and Gopakumar (1984) suggested harvest index as the best reliable criterion for effecting selection in favour of desirable genotype from among others in a genetically heterogeneous base population of tapioca. Yield bore significant positive association with harvest index, number of tubers, mean tuber weight and girth of tuber and negative association with length of stem.

Yoshida (1985) suggested that in sweet potato selection at early stages should emphasize dry matter percentage or resistance to Partylenchus sp. and Meloidogyne rather than root yield, as the mean correlation coefficients for these characters were higher than that for yield and in the case of nematode resistance, were also stable from year to year.

A correlation study between stability parameters in twenty eight genotypes of sweet potato indicated positive significant correlation for characters top weight, length of vine, number of branches, number of tubers and tuber yield and negative significant correlation for drying percentage of tubers. There was no significant association for the characters length of tuber, girth of tuber and harvest index (Ibrahim and Mary, 1985).

According to Acosta (1986) the best prediction of root yield could be done by combining weight of aerial parts and harvest index. Weight of aerial parts and canopy diameter were the aerial characters most correlated with root yield.

Path coefficient analysis devised by Wright (1921) is a standardized partial regression coefficient and as such measures the direct influence of one variable upon another and permits the separation of correlation coefficients into components of direct and indirect effects (Dewey and Lu, 1959). Working on Crested wheat grass, Dewey and Lu (1959) demonstrated the application of the method of 'Path coefficients' in the analysis of correlation, in a system of correlated variables, which was widely employed by animal breeders but only rarely by plant breeders, till that time. After the pioneering work of Dewey and Lu (1959) the path coefficient analysis was extensively undertaken by many research workers in many crop plants including tuber crops.

Analysis of seventeen varieties of sweet potato showed that yield was influenced by the first order components, girth of tuber, number of tubers and length of tuber, the direct effects of the last two being more pronounced. An increase in the second order component length of vine caused a significant increase in tuber yield but was associated with an increase in leaf area which had a negative correlation with yield. It is concluded that attempt to increase vine length should be coupled with selection for reduced leaf area (Pushkaran et al. 1976).

In an investigation with sixty five clones of sweet potato, the path analysis indicated that the weight of foliage, girth of tuber and number of tubers per vine contributed maximum direct effects on tuber yield indicating the importance of these three characters as selection indices for sweet potato and the number of leaves, length of petiole and length of tuber had negative direct effects on tuber yield (Thamburaj and Muthukrishnan, 1976).

Kamalam et al. (1977) conducted a study with ten varieties of sweet potato. The results of path analysis indicated that number of tubers contributed the maximum positive direct effect to the tuber yield followed by length of vine, length of petiole and weight of individual tubers. The high direct influence of number of tubers was intensified further by the positive indirect effects through length of petiole and weight of vine. It was concluded that number of tubers per plant, the length of petiole and to a lesser extent the weight of vine were the three factors exerting the greatest influence directly and indirectly upon the tuber yield in sweet potato.

Taking into consideration the readily readable characters, it was suggested that in tapioca genotypes with potentially high tuber yield could be identified among those having relatively high values for harvest index and that are inherently short statured with profuse foliage consisting of relatively large sized leaves which have become developed completely at a relatively earlier period of the life span, a majority of which eventually get themselves abscissed fairly late, preferably towards the time of harvest (Radhakrishnan and Gopakumar, 1984).

2.3 Earliness

Cassava is normally considered to be a long term root crop, which can be harvested between eight and twelve months after planting, depending on whether the roots are to be consumed as a fresh vegetable or processed for flour or starch. Too early harvest of the crop often leads to reduced tuber yield, while delayed harvest cause development of woody and fibrous tubers and reduction in starch content. It may be possible to improve the efficiency of the crop in terms of root yield per unit time, one method being by shortening the growth period through the identification of early yielding cultivars. If early elite types are identified they can be successfully used for planting in wet land after the harvest of second crop paddy from January to June. Some works in this line are reviewed here.

Data presented by Corus (1951) showed that root bulking began about three months after planting, although he mentioned that rapid starch deposition did not occur until six months or after.

Doku (1969) stated that root bulking began during the second month and that many Ghanian cultivars produced reasonable yield of roots only after six months of growth.

Tuber differentiation in cassava starts within six weeks of planting and the onset of root bulking was associated with the initiation of secondary thickening, thickened roots being characterised by the accumulation of starch grains in parenchyma (Indira and Sinha, 1970).

Results of an experiment conducted using three promising cassava hybrids to find out the effect of varying stages of harvest on tuber yield and starch content showed that with increase in age of the plant the tuber yield as well as starch yield increased progressively upto ten month stage and tended to show a significant decrease beyond that period. However, there was not much variation in tuber and starch yields from seven to nine month stage. They suggested that for consumption purpose harvesting can be started from seventh month onwards (Singh et al. 1970)

Douglas et al. (1974) conducted an experiment to find out the onset and rate of root bulking in cassava. Results showed that three out of the four highest yielding cultivars at third month were also the heaviest yielders after fifth and seventh months. They suggested that it may be possible in selection trials to make preliminary selection for early yielding cultivars, early in their growth cycle.

The stage at which the starch content in the tuber started decreasing can be taken as a criterion of maturity in cassava, as yield did not decrease at any stage of crop growth (Maini et al. 1977)

Ramanujam (1981) conducted a detailed investigation with three varieties of cassava - H-2304, H-165 and M4 to determine the optimum time of harvest for getting best yields with good quality tubers. The variety H-165 recorded high yield by eighth month stage and beyond which there was no appreciable increase in tuber yields. In M-4 and H-2304 the tuber yield increased upto twelfth and eleventh months respectively. The tuber number did not show any difference while, mean tuber weight increased during crop growth. The starch content decreased after tenth month stage in H-165, while it was not affected in M-4 and H-2304 upto twelfth month stage. Highest bulking rates were noticed during seventh and eighth months in H-165, sixth and eleventh months in M-4 and sixth and eighth months in H-2304.

Preliminary evaluation of the clones CI-129, CI-206 and CI-856 at sixth month growth had shown that they were early maturing and high yielding like H-165. Out of the above clones CI-856 showed twenty per cent increase in tuber yield with good culinary quality compared to H-165, the plants were sparse braching and field tolerant to cassava mosaic disease and mites (Nair and Rajendran, 1982).

An experiment was undertaken at CRS, Nileswar using M-4 variety to find out the optimum stage of harvest. The results indicated that the number of tubers per plant and tuber yield obtained at different stages of harvests such as seventh, eighth, ninth and tenth months after planting were not significantly different. Similarly the specific gravity of the tubers recorded at the four stages of harvest were on par and it was concluded that good yield of quality tubers could be obtained in cassava variety M-4 even at the very early stage, seven month after planting and it was an ideal variety for growing in single cropped paddy fyields (Ashokan et al., 1983).

To assess the nature and extent of earliness and to identify the early types with reasonable tuber bulking at sixth month stage, two hundred entries were evaluated at CTCRI, Trivandrum. The ratio of the yield recorded at sixth and tenth month was taken as an index for earliness. About 20 per cent of the entries examined had shown 80-100 per cent yield even at sixth month stage indicating the presence of earliness (Anon., 1983b).

2.4 Pests and disease resistance

Since cassava is a low value crop chemical control of pests and diseases are often prohibitive in cost. Therefore, crop resistance offers an economic alternative. So it is a must to identify resistant varieties to ensure guaranteed yield in tapioca. Many workers had studied the effect of pests and diseases on tuber yield, other morphological characters and quality aspects of tapioca.

Muller (1931) stated that cassava mosaic in the Cameroons depressed the tuber yield to 15 quintals per ha as against 70-80 quintals per ha from a healthy crop.

Golding (1936) observed a loss of 30 per cent in the tuber yield of plants infected by mosaic disease when compared to healthy plants.

An yield reduction of upto 95 per cent due to cassava mosaic was demonstrated by Tidbury (1937).

While compiling data on the losses caused by plant diseases in Colonies a loss of yield between 15 and 20 per cent was observed owing to cassava mosaic disease (Padwick, 1956).

Plants infected by mosaic viruses showed reduction of chlorophyll content which eventually reflected on the carbohydrate synthesis. A reduction of 26.09 per cent starch and 25.99 per cent total carbohydrate was noted in diseased tubers. The amylose activity in the diseased tubers was 67 per cent higher than in healthy tubers and this would lead to high sucrose accumulation (Alagianagalingam and Ramakrishnan, 1970).

Although several fungicides have been reported to give effective control of brown leaf spot disease practicability was limited due to economic consideration. The most effective and practical means of controlling this disease was through the use of resistant varieties (Arene 1974, Lozano and Booth, 1974).

Both bitter and sweet cassavas which were known to differ in their HCN content had been found to be equally susceptible to Cercospora leaf disease (Anon., 1974a).

No relationship between HCN content and susceptibility to *Cercospora hennigsii* was found in the works at CIAT (Anon., 1975)

In an experiment conducted at CIAT to find out the effect of brown leaf psot and Cercospora leaf blight on the yield of cassava, the two diseases were found to reduce the yield by 14 per cent (Anon., 1976).

An estimation on the loss of yield due to brown leaf spot disease of tapioca showed almost 40 per cent reduction in fresh tuber yield from a susceptible variety (Thankappan, 1976).

Studies on the effect of cassava mosaic using five varieties viz. M-4, H-43, H-86, H-97 and H-165 indicated that infection by cassava mosaic disease significantly reduced stem girth, plant height petiole length, middle leaflet length and width of the middle leaflet of all the varieties tested. Virus infection also reduced the yield of tubers in all the five varieties. The mean per cent reduction of tuber yield for the five varieties was 21.2. The mean per cent reduction of individual characters for all the five varieties were 19.1 for stem girth, 16.4 for plant height, 13.3 for petiole length, 15.3 for middle leaflet length and 18.2 for width of the middle leaflet (Thankappan and Chacko, 1976).

Teri (1978) carried out experiments at two locations in Colombia to determine the separate effects of brown leaf spot and leaf blight on yield using five varieties and four hybrids, ranging from highly resistant to susceptible. The increase in fresh root yield of susceptible cultivars resulting from disease control ranged from 10-23 per cent for leaf spot and 12-30 per cent for blight. There were also apparent increase in root starch content and yield.

In a study at CTCRI thirty varieties of cassava were scored for their resistance under field condition to brown leaf spot disease. None of the thirty varieties tested was found to be immune or completely field resistant. However, variation was noticed in their relative degree of susceptibility. Based on their reaction to disease the varieties could be grouped into three categories viz. highly susceptible (index value above 4), tolerant (index value between 1 and 2) and field resistant (index value below 1). Two hybrids H-1843 and H-2351 were identified as field resistant to the disease (Thankappan and Govindaswamy, 1979).

Brown leaf spot significantly reduced fresh yield of cultivars as well as hybrids. Root dry matter content, number of roots per plant and harvest index were not significantly affected by the disease (Teri et al.1980).

Nair and Malathi (1981) investigated the yield loss due to cassava mosaic disease in five varieties of cassava viz. H-97, H-226, H-1687, H-2304 and M-4.

The effect of Cassava mosaic disease in general was not significant for the characters - number of leaves produced, number retained and plant height. The disease reduced yield significantly in all the varieties tested except in M-4 when harvested after eight months. Significant reduction was found to occur in all varieties including M-4 when harvested after 10 months. Maximum reduction occurred in H-97 and H-1687. Disease severity calculated showed that in all varieties where significant yield reduction occurred had a severity grade of more than 2.5.

The spidermites were the most serious pests of cassava causing (17-33 per cent) yield reduction. The exotic genotypes Ce-4, Cel-4, Ce-38, Ce-81 were field tolerant to spidermites. The mite population per leaf in these genotypes were 30-40 while the susceptible genotypes showed a high population of 139-350 per leaf (Anon., 1982).

Field experiments adopting varieties H-2304, H-1687 and M-4 were conducted for four years in two planting seasons coinciding Southwest and Northeast monsoons to find out the yield loss due to mite infestation. In the first planting season (July planting) the yield loss in unprotected fields ranged from 17-23 per cent in different varieties and in the second season (November planting) the yield loss was invariably higher in all varieties ranging from 20-33 per cent recording highest in M-4. Yield loss to the range of 17-33 per cent under natural infestation on different varieties in two planting seasons indicated that spider mites were the potential enemies of cassava plants (Pillai and Palani swami, 1982).

Teri <u>et al</u>.(1983) studied the progress of cassava brown leaf spot and its effect on yield of five cassava cultivars. Disease intensity was found to be highest between third and sixth month after planting. Results of the study showed a significant yield loss of 21-32 per cent during 1981-82. The variety tanga showed resistance with a yield reduction of 15.6 per cent and 15.2 per cent during 1981-82 and 1982-83 respectively which were not significant.

Preliminary field evaluations of fifty one cassava germplasm lines revealed the existance of wide variability against mite infestation. No cultivar showed complete resistance to mite infestation but a few viz. CE-140, CE-171, CE-191, CI-175 and CI-574 were found to be least susceptible and least preferred by both tetranychid and Eutetranychid mites. The remaining cultivars harboured higher mite population ie. twenty two cultivars in the range of 10-50 mites, twelve cultivars in the range of 51-100 mites, eight cultivars in the range of 101-200 mites and four cultivars in the range of 201-450 mites per leaf (Lal and Hrishi, 1983).

2.5 Chemical Assay

Quality evaluation should form an important criterion in tapioca breeding, since major part of tapioca production goes for human consumption. Improvement in quality of tapioca includes, evolution of varieties with high starch and low HCN and high sugar content with good adaptability for consumption purposes. The need to detoxify the cassava tuber before it can be consumed is a major constraint on its utilization. The solution to the hydrocyanic acid problem lies in the breeding and selection of cultivars which contain little or no HCN.

The hydrocyanic acid content of tubers was a very much variable characteristic which was subjected to environmental influence. With cyanide titration it had been found to vary within tuber and within the variety (Jones, 1959).

It was reported that in cassava the bitter types contained 0.077 per cent (770 ppm) HCN while sweet types contained less than 0.016 per cent (160 ppm) on fresh weight basis (Anon., 1962).

Cultivars of cassava differ considerably in cyanogenic glucoside content and starch content. The starch content ranged from 30-35 per cent in the edible portion of the tubers (Rogers, 1963).

According to Sinha and Nair (1968) in cassava the HCN content may vary in tubers of same plant and the tuber obtained from wet land contained the highest amount of HCN in the edible portion. The amount of HCN was reduced in the tubers as they mature. They further, stated that the amount of HCN alone, did not seem to be the deciding factor for bitterness but the bitterness was possibly determined by the quantity of sugars and the amount of HCN present. If a strain lacked sugars it was likely to taste bitter even if it had relatively low quantity of HCN. Similarly a large amount of sugar might reduce the bitterness caused by the presence of cyanogenic glucosides. The amount of HCN in the rind was usually more than the amount in flesh. However, there was no relationship between the cyanogenic glucoside content in the rind and the flesh.

Mahendranathan (1971) observed that in tapioca the flesh of the sweet types contained 70 ppm, while the bitter types about 200-300 ppm of HCN.

Munoz and Casas (1973) recorded 262-772 ppm of HCN on dry weight basis in the bitter cassava roots.

In an analysis made with tubers of variety Malavella at seven to eleven month age, the peel was found to contain higher levels of HCN (260 mg per kg at eighth month) than pulp. In the pulp the HCN content increased from seventh month reaching maximum value at ninth month (45 mg per kg) and thereafter it decreased (Gopal and Sadasivan, 1973).

The average HCN content in the tubers from thirty varieties of tapioca on fresh weight bais was 41.21 ppm and the varietal differences ranged from 5-125 ppm and all the types studied were classified as sweet since maximum HCN content recorded was 125 ppm (Muthuswamy *et al* 1973).

Twenty four cassava varieties from the germplasm were evaluated for their starch, hydrocyanic acid and sugar contents. Based on the variation in starch the varieties could be arbitarily grouped as high (25-35 per cent) medium (20-25 per cent) and low starch (< 20 per cent) varieties. Based on the variation of HCN in the pulp and the rind the varieties could be arbitarily grouped as high (35-55 microgram per gram) Medium (20-30 microgram per gram) and low (< 20 microgram per gram) toxic. HCN content in flesh had no direct relationship with that of the rind in the varieties studied. Sweetness of varieties depended primarly on their sugar content rather than the hydrocyanic acid content (Dharmalingam *et al.* 1973).

Guillermo and Mauricio (1983) reported that variety and age of plants are two important factors affecting both the yield and quality of cassava tubers. The cyanide in root peels diminished with age of the plant. Concentration of cyanide in the parenchyma was the most stable parameter and was practically not affected by plant age.

Analysis of roots harvested at various dates showed that the content of cyanogenic glucoside depended on the variety and plant age at harvest. Starch percentage tended to rise with increasing age of the plant. Flavour showed no direct dependence on the content of cyanogenic glucosides (Santamaria and Guillen, 1984).

The starch content, its distribution, swelling properties and sugar content in tubers were found to govern the cooking quality of cassava tubers. High starch content leds to soft and mealy nature of cooked tubers. Cassava varieties with low starch and high sugar content did not cook well owing to the increased solubility of starch in the presence of sucrose, thereby reducing the swelling power (Anon., 1985).

MATERIALS AND METHODS

3. MATERIALS AND METHODS

3.1 Materials.

Eight varieties of tapioca, which exhibited identifiable diversity in morphology and performance constituted the material of the present experiment. The varieties were collected from different agro-climatic zones of Kerala where tapioca is being cultivated in rice fields. The plant characters and place of collection of eight varieties are given in Table 1.

3.1.1 Table 1. Plant characters and place of collection of chosen tapioca varieties

Variety	Plant characters	Place of collection
1. Mankozhanthan	Stem profusely branching at top with light brown colour, tender leaves reddish brown, petiole purplish, internodal length medium and early flowering.	Venpakal
2. Karukannan	Moderately branching type. Stem blackish green in colour, petiole light red, tender leaves reddish brown, leaves dark green, internodal length medium.	Kuttichal

Variety	Plant characters	Place of collection
3. Pravu vella	Moderately branching type, stem light brown at the base and light green at the top portion, petiole light yellow, tender leave light brown in colour, internodes shorter.	Venganoor
4. 4/84	Shy branching type, stem light brown in colour, petiole purplish and internodal length medium.	R.A.R.S. Kumarakom
5. 6/84	Moderately branching type, stem light brown in colour, petiole light yellow, internodal length medium, tender leaves light green in colour.	R.A.R.S. Kumarakom.
6. 2/84	Shy branching type, stem light brown in colour, petiole light yellow, internodal length higher and tender leaves light green in colour.	R.A.R.S. Kumarakom.
7. Padinjattinkara vella	Highly branching and early flowering type, stem blackish green with brown markings, petiole light yellow, tender leaves reddish brown, internodal length medium.	Padinjattinkara of Kottarakkara.
8. Chavaravella	Stem non-branching whitish to light green in colour, petiole light green with purplish tinge at the tip, tender leaves light green, internodes shorter.	Mannady of Adoor village.

3.2 Methods

The investigation was conducted at the Department of Plant Breeding, College of Agriculture, Vellayani during January - June 1986 in paddy fields.

The experiment with eight treatments was laid out in a randomised block design with four replications. Each plot had a size of 4.5 x 4.5 m with 22 plants in 90 x 90 cm spacing. The management practices were done as per package of practices recommendations of Kerala Agricultural University (1984).

3.3 Observations recorded

From among twentytwo plants in each replication ten plants were selected at random for recording biometrical observations.

3.3.1 Biometrical observations

1. Number of leaves per plant

Total number of leaves at harvest were recorded by counting the number of fully opened leaves as well as the leaf scars from the base to the tip of the stem.

2. Number of leaves retained at harvest

The number of green leaves retained in the plant at the time of harvest were recorded.

3. Plant height

The total length of the stem from the basal node to the tip was measured at the time of harvest and expressed in centimetre.

4. Number of branches

Total number of branches at the time of harvest were counted and recorded.

5. Leaf area

Leaf area was measured as per the "linear measurement method" proposed by Ramanujam and Indira (1978). Three leaves were chosen from each observational plant representing the top, middle and bottom portions of the canopy. The maximum length and width of middle lobe and number of lobes in each leaf were recorded for linear measurements. In order to get the leaf area the product of these three values was multiplied by appropriate constant (leaf factor) 0.44 and 0.62 for the varieties having L/W ratio of middle lobe from 2-5 and 5-9 respectively. The area of all the three leaves were calculated, averaged and expressed in centimetre.

6. Number of tubers per plant

The total number of tubers in each observational plant were counted and recorded.

7. Yield of tuber per plant

The tubers harvested from each observational plant were weighed and expressed in Kilograms.

8. Length of tuber

Length of tubers from observational plants were averaged and expressed in centimetre.

9. Girth of tuber

Girth of tubers from proximal, middle and distal regions were recorded from each observational plant, averaged and expressed in centimetre.

10. Single tuber weight

Calculated from total tuber yield and number of tubers.

11. Utilization index

Calculated as per Obigbesan (1973). The ratio of tuber weight to the top weight from all observational plants were averaged and recorded.

3.3.2 Observations on quality attributes

1. Starch content

Starch content of the tubers was estimated as per AOAC (1965) and the values were expressed as percentage of fresh weight of tubers.

2. Hydrocyanic acid content of tubers

The hydrocyanic acid content of fresh tubers was estimated by the colorimetric method of Indira and Sinha (1969) and expressed in ppm.

3. Cooking quality (cooking expansion and palatability)

Cooking quality was determined as per the standard procedures practiced at CTCRI, Trivandrum. The tubers were derinded and cut into pieces. Uniform sized pieces from each variety were weighed before cooking and after cooking. Then the difference in weight was percentaged over fresh weight and expressed as cooking expansion. The taste, texture, bitterness and fibre content were evaluated subjectively after cooking.

3.3.3 Reaction to pests and Diseases

3.3.3.1 Pests

1. Red spider mite

Scoring on the incidence of red spider mite was done as per the method suggested by Lal and Hrishi (1983). The presence of both nymphs and adults on 5 leaves (representing the lower, middle and upper portions of the canopy) from observational plants were recorded during fourth and fifth months after planting. The average number of mites present per leaf were calculated.

3.3.3.2 Diseases

(1) Cassava Mosaic disease

Intensity of cassava mosaic was calculated as per the basic system suggested by Terry (1975). The scoring system was based on the following classes of severity.

Grades	Symptom
0	No symptom (Normal leaves)
1	Specks or minute patches of mosaic not exceeding 100 sq. mm.
2	A mild chlorotic pattern over entire leaflets or mild distortion only at the base of the leaflets, with remainder of the leaflets appearing green and healthy.
3	Strong mosaic pattern all over the leaf, and narrowing and distortion of lower one-third of leaflets.
4	Severe mosaic patterns, severe distortion of two-third of leaflets and general reduction of leaf size.
5	Severe mosaic, severe distortion of four-fifth or more of leaflets, twisted and misshapen leaves and severe reduction of leaf size.

Scoring was done on five leaves per plant starting from the first fully opened leaf. The observational plants used for recording other attributes were used for scoring cassava mosaic disease.

2. Leaf spot disease

The eight tapioca varieties were scored for their reaction/resistance to leaf spot disease under field condition by following the method suggested by Thankappan and Govindaswamy (1979). The disease rating was done based on the following scale.

0 - No apparent infection
1 - 1-15 spots per leaf
2 - 16-30 spots per leaf
3 - 31-45 spots per leaf
4 - 46-60 spots per leaf
5 - > 61 spots per leaf

The disease incidence was measured from ten randomly selected leaves of each observational plant.

For the sake of operational convenience the twenty four variables were given the following symbols.

Sl.No.	Variable	Symbol
1	Total number of leaves per plant	x_1
2	Number of leaves retained at harvest	x_2
3	Plant height	x_3
4	Number of branches	x_4
5	Number of tubers per plant	x_5
6	Length of tuber	x_6
7	Girth of tuber	x_7
8	Single tuber weight	x_8
9	Tuber yield per plant	x_9
10	Utilization index	x_{10}
11	Starch content	x_{11}
12	Hydrocyanic acid content	x_{12}
13	Cooking expansion	x_{13}
14	Leaf area - 3 months after planting	x_{14}
15	Leaf area - 4 months after planting	x_{15}
16	Leaf area - 5 months after planting	x_{16}
17	Cassava mosaic (disease rating) 3 months after planting	x_{17}
18	Cassava mosaic (disease rating) 4 months after planting	x_{18}
19	Cassava mosaic (disease rating) 5 months after planting	x_{19}
20	Leaf spot (disease index)- 3 months after planting	x_{20}

Sl.No.	Variable	Symbol
21	Leaf spot (disease index) - 4 months after planting	x_{21}
22	Leaf spot (disease index) - 5 months after planting	x_{22}
23	Mean number of mites per leaf - 4 months after planting	x_{23}
24	Mean number of mites per leaf - 5 months after planting	x_{24}

3.4 Statistical analysis

The data collected for the metric traits, quality attributes and scores for pests and diseases were tabulated and mean values subjected to statistical analysis.

3.4.1 Analysis of variance (ANOVA)

ANOVA was computed according to the methods of Panse and Sukhatma (1957). Significance of computed F values were tested with reference to 'F' table (Panse and Sukhatma, 1957).

ANOVA TABLE

Source	Degrees of Freedom	Sum of squares	Mean sum of squares	F
Replication (Blocks)	(r-1)	SSR	s^2R	s^2R/s^2VR
Treatment (varieties)	(v-1)	SSV	s^2V	s^2V/s^2VR
Error	(r-1)(v-1)	SSVR	s^2VR	

where

r = number of replications

v = number of varieties

SSR = replication sum of squares

SSV = variety sum of squares

SSVR = Error sum of squares

S^2R = replication mean square

S^2V = variety mean square

S^2E = Error mean square

3.4.2 Variance

The observed variability for each character was partitioned into genetic and environmental, since the effect of environment on the expression of quantitative character was enormous. Components of variance for each character were worked out following the procedure of Johnson et al. (1955).

$$\text{Genotypic variance (Vg)} = \frac{S^2V - S^2E}{r}$$

where

S^2V = Mean sum of squares due to varieties

S^2E = Mean sum of squares due to error

r = number of replications

Phenotypic variance (Vp)

$$Vp = Vg + Ve.$$

Where

Vg = Genotypic variance

Ve = Error variance = Error mean sum of squares

3.4.3 Coefficient of variation

Both phenotypic and genotypic coefficients of variation were calculated as suggested by Burton (1952).

Phenotypic coefficient of variation (pcv)

$$pcv = \frac{\sqrt{Vp}}{Mean} \times 100$$

Where

Vp = Phenotypic variance

Genotypic coefficient of variation (gcv)

$$gcv = \frac{\sqrt{Vg}}{Mean} \times 100$$

Where

Vg = genotypic variance

3.4.4 Heritability, Genetic advance and Genetic gain

Heritability, Genetic advance and Genetic gain were worked out for each character to make meaningful deductions from the data.

1. Heritability in broad sense (Allard, 1960).

$$h^2 = \frac{Vg}{Vp} \times 100$$

Where

h^2 = heritability

Vg = genotypic variance

Vp = phenotypic variance

2. Expected genetic Advance (G.A) under selection (Johnson _et al_. 1955)

$$G.A = kh^2\sqrt{Vp}$$

Where

k, the selection differential, is 2.06 at 5% selection in larger samples (Allard, 1960)

3. Expected Genetic Gain (G.G.) under selection (Johnson _et al_., 1955)

$$G.G = \frac{G.A}{\bar{x}} \times 100$$

Where

$\bar{x}$ = General Mean

G.A = Genetic advance under selection

3.4.5 Phenotypic & Genotypic correlation coefficients

Phenotypic and genotypic correlation coefficients were estimated following Singh and Choudary (1979).

1. Phenotypic correlation coefficient

$$r_{p_1p_2} = \frac{Cov\ (p_1 \cdot p_2)}{\sqrt{Var\ (p_1)\ Var\ (p_2)}}$$

Where

$Cov(p_1 \cdot p_2)$ = Phenotypic covariance between the two traits

$V(p_1)$ = Phenotypic variance of first trait

and $V(p_2)$ = Phenotypic variance of second trait

2. Genotypic correlation coefficient

$$r_{g_1g_2} = \frac{Cov\ (g_1 \cdot g_2)}{\sqrt{V(g_1) \cdot V(g_2)}}$$

Where Cov (g_1g_2) = Genotypic covariance between the two traits

$V(g_1)$ = Genotypic variance of first trait

and $V(g_2)$ = Genotypic variance of second trait

3.4.6 Path coefficient Analysis

Path coefficient analysis (Wright, 1921) was employed for evaluating the association between yield which is a complex entity, and the component characters. Methods evolved by Wright (1921) and later elaborated by Dewey and Lu (1959) were used to partition the direct as well as indirect effects on yield. Path coefficients were obtained by the simultaneous solution of the following equations.

$$r1y = p1y + r12\, p_{2y} + \ldots\ldots + r1k\, p_{ky}$$

$$rky = rk1\, p_{1y} + rk_2\, p_{2y} + \ldots\ldots + r(k-1),\, k^{p}(k-1),\, y + p_{ky}$$

Where

r1y to rky denote the genotypic correlation coefficients between causal factors 1 to k and dependent variable (y); r_{12} to $r_{k-1,k}$ denote the correlation coefficients among all possible combinations of causal factors and p_{1y} to p_{ky} denote the direct effects of characters 1 to k on yield (y)

The above equations can be written in the matrix form as shown below.

$$\begin{Bmatrix} r_1y \\ | \\ | \\ | \\ r_{ky} \end{Bmatrix} = \begin{Bmatrix} 1 & r_{12} & r_{13} \ldots\ldots & r_{1k} \\ r_{21} & 1 & r_{23} \ldots\ldots & r_{2k} \\ \vdots & & & \vdots \\ r_{k1} & r_{k2} & r_{k3} \ldots\ldots & 1 \end{Bmatrix} \begin{Bmatrix} p_1Y \\ p_2Y \\ \vdots \\ p_kY \end{Bmatrix}$$

A C B

$$A = CB$$

$$\text{Hence } B = C^{-1} A$$

C^{-1}= is the inverse matrix of C

$$\text{Let } C^{-1} = \begin{bmatrix} C_{11} & C_{12} \cdots\cdots\cdots & C_{1k} \\ C_{21} & C_{22} \cdots\cdots\cdots & C_{2k} \\ \vdots & \cdots\cdots\cdots & \vdots \\ C_{k1} & C_{k2} \cdots\cdots\cdots & C_{kk} \end{bmatrix}$$

Path coefficients were obtained as

$$p_1y = \sum_{i=1}^{K} C_{1i}\, r_{iy}$$

$$P_2y = \sum_{i=1}^{K} C_{2i}\, r_{iy} \quad \text{etc.}$$

The residual factor (x) which measures the contribution of the rest of the characters is not considered in this causal scheme and sampling error was obtained as

$$P_xy = \sqrt{1-R^2}$$

$$\text{Where } R^2 = \sqrt{1-(P_{1y}\, r_{1y} + P_{2y}r_{2y} + \cdots\cdots P_{ky}r_{ky})}$$

Indirect effects of different characters on yield were obtained as follows.

Indirect effect of i^{th} character on yield through j^{th} character $= p_i y_{rij}$

RESULTS

4. RESULTS

The analysis of variance for the twenty four characters revealed that the differences among the various genotypes were significant for all the characters except HCN content of the tuber.

The abstract of ANOVA relating to twenty four characters are presented in Table 1.

The mean performance of the eight varieties in respect of yield and other characters are furnished in Table 2 & 3 and graphically represented in Fig.1 to 11.

4.1 Comparison of eight genotypes

1. Total number of leaves per plant

Among the eight varieties studied Mankozhanthan produced maximum number of leaves per plant followed by 6/84. No significant difference was observed in the production of leaves among the varieties Pravuvella, Padinjattinkara vella and Karukannan. Chavaravella produced lowest total number of leaves per plant, however it was on par with 2/84, 4/84 and Karukannan in leaf production.

Table 1. Analysis of variance for twenty four characters in eight varieties of tapioca

Sl. No.	Characters	Mean sum of squares		
		Replications df = 3	Varieties df = 7	Error df = 21
1.	Total number of leaves per plant	1380.25	22515.57**	403.01
2.	Number of leaves retained at harvest	323.60	13385.76**	269.19
3.	Plant height	1170.63	1437.32*	465.77
4.	Number of branches	3.57	69.85**	3.10
5.	Number of tubers per plant	21.97	9.68**	1.47
6.	Length of tuber	6.27	22.99**	2.22
7.	Girth of tuber	4.47	7.51**	0.58
8.	Single tuber weight	5548.33	16924.20**	833.95
9.	Tuber yield per plant	0.84	1.08**	0.13
10.	Utilization index	1.15	0.34**	0.03
11.	Starch content	8.63	8.65*	3.03
12.	HCN content	1878.52	1209.38 NS	960.77
13.	Cooking expansion	6.149	10.675**	2.447
14.	Leaf area - 3 months after planting	313.33	9605.86**	1290.62
15.	Leaf area - 4 months after planting	1084.33	15306.43**	1552.64
16.	Leaf area - 5 months after planting	8306.17	21805.47**	3049.31

(contd..)

Table 1 (contd.)

Sl. No.	Characters	Mean sum of squares		
		Replications dF = 3	Varieties dF = 7	Error dF= 21
17	Cassava Mosaic - 3 months after planting	0.11	0.76**	0.02
18	Cassava Mosaic - 4 months after planting	8.38	2.66**	0.05
19	Cassava Mosaic - 5 months after planting	4.30	3.79**	0.03
20	Leaf spot - 3 months after planting	0.25	0.19**	0.02
21	Leaf spot - 4 months after planting	5.47	0.16**	0.01
22	Leaf spot - 5 months after planting	0.03	0.65**	0.06
23	Mites - 4 months after planting	1.27	6.93**	0.51
24	Mites - 5 months after planting	1.60	16.45**	0.94

* Significant at 5 per cent level
** Significant at 1 per cent level

NS - Not significant.

Table 2. Mean values of twenty one characters in eight varieties of tapioca

Variety	Total No. of leaves per plant	Number of leaves retained at harvest	Plant height (cm)	Number of branches	Number of tubers per plant	Length of tuber (cm)	Girth of tuber (cm)
Mankozhanthan	445.43	258.95	235.25	13.70	11.15	17.54	9.97
Karukannan	244.60	122.25	236.42	4.18	11.35	19.09	12.29
Pravuvella	257.75	148.33	195.08	7.40	9.25	22.93	13.48
4/84	227.85	85.30	186.14	2.05	12.70	20.32	12.78
6/84	298.28	155.88	228.89	8.58	12.78	15.92	10.11
2/84	225.38	97.85	202.85	1.95	9.80	21.69	11.85
Padinjattin-karavella	250.75	154.60	216.68	7.80	8.65	21.09	12.94
Chavaravella	216.15	79.20	223.74	2.03	9.75	21.99	10.52
Critical difference (CD)	29.53	24.13	31.74	2.59	1.79	2.19	1.12

Variety	Single tuber weight (gm)	Tuber yield per plant (kg)	Utilization index	Leaf area-3 months after planting (cm^2)	Leaf area-4 months after planting (cm^2)	Leaf area - 5 months after planting (cm^2)
Mankozhanthan	161.83	1.76	0.38	305.63	294.41	273.62
Karukannan	261.39	2.85	1.00	299.04	301.48	288.79
Pravuvella	352.43	3.07	1.19	301.79	285.56	266.14
4/84	261.66	3.15	1.16	315.21	360.91	404.66
6/84	165.42	2.05	0.60	331.34	327.09	302.73
2/84	262.96	2.49	0.97	368.93	376.38	365.66
Padinjattinkara-vella	300.07	2.52	0.81	289.45	307.37	290.14
Chavaravella	213.81	1.97	0.59	435.29	471.42	471.75
Critical difference (CD)	42.47	0.54	0.25	52.84	57.95	81.22

Variety	Cassava mosaic- 3 months after planting	Cassava mosaic- 4 months after planting	Cassava mosaic- 5 months after planting	Leaf spot- 3 months after planting	Leaf spot- 4 months after planting	Leaf spot- 5 months after planting	Mites- 4 months after planting	Mites- 5 months after planting
Mankozhanthan	0.18	0.89	0.75	0.88	0.84	0.81	0.86	1.25
Karukannan	0.90	2.35	2.46	0.94	1.03	1.03	0.97	1.60
Pravuvella	0.80	2.13	2.13	1.30	1.28	1.18	1.09	1.46
4/84	0.25	0.90	0.69	1.41	1.37	1.27	4.70	6.93
6/84	0.29	0.59	0.49	1.22	1.16	1.27	2.07	3.64
2/84	1.40	2.78	2.98	1.21	1.30	1.62	1.10	1.79
Padinjattinkara-vella	0.40	1.50	1.92	1.01	0.96	1.01	0.70	0.68
Chavaravella	0.99	2.25	2.61	1.48	1.38	2.09	1.36	3.32
Critical difference (CD)	0.22	0.33	0.27	0.24	0.16	0.38	1.05	1.43

Table 3. Quality attributes in eight varieties of tapioca

Variety	Starch content (per cent)	HCN content (ppm)	Cooking expansion (per cent)	Quality of tuber
Mankozhanthan	28.99	13.13	3.75	Required more time for cooking, hard,nonbitter and nonfibrous.
Karukannan	28.03	60.94	2.11	Required more time for cooking, hard,nonbitter and nonfibrous.
Pravuvella	31.05	51.56	2.40	Easily cookable, hard, nonbitter and nonfibrous.
4/84	28.14	60.00	3.77	Easily cookable, soft, nonbitter and nonfirbous.
6/84	29.18	31.88	6.52	-do-
2/84	28.11	52.50	4.44	-do-
Padinjattinkaravella	28.10	30.00	6.23	-do-
Chavaravella	25.80	56.25	5.32	Easily cookable, soft, nonbitter and slightly fibrous.
Critical difference (CD)	2.56	45.59	2.30	

FIG. 1. TOTAL NUMBER OF LEAVES PER PLANT AND NUMBER OF LEAVES RETAINED AT HARVEST IN EIGHT VARIETIES OF TAPIOCA

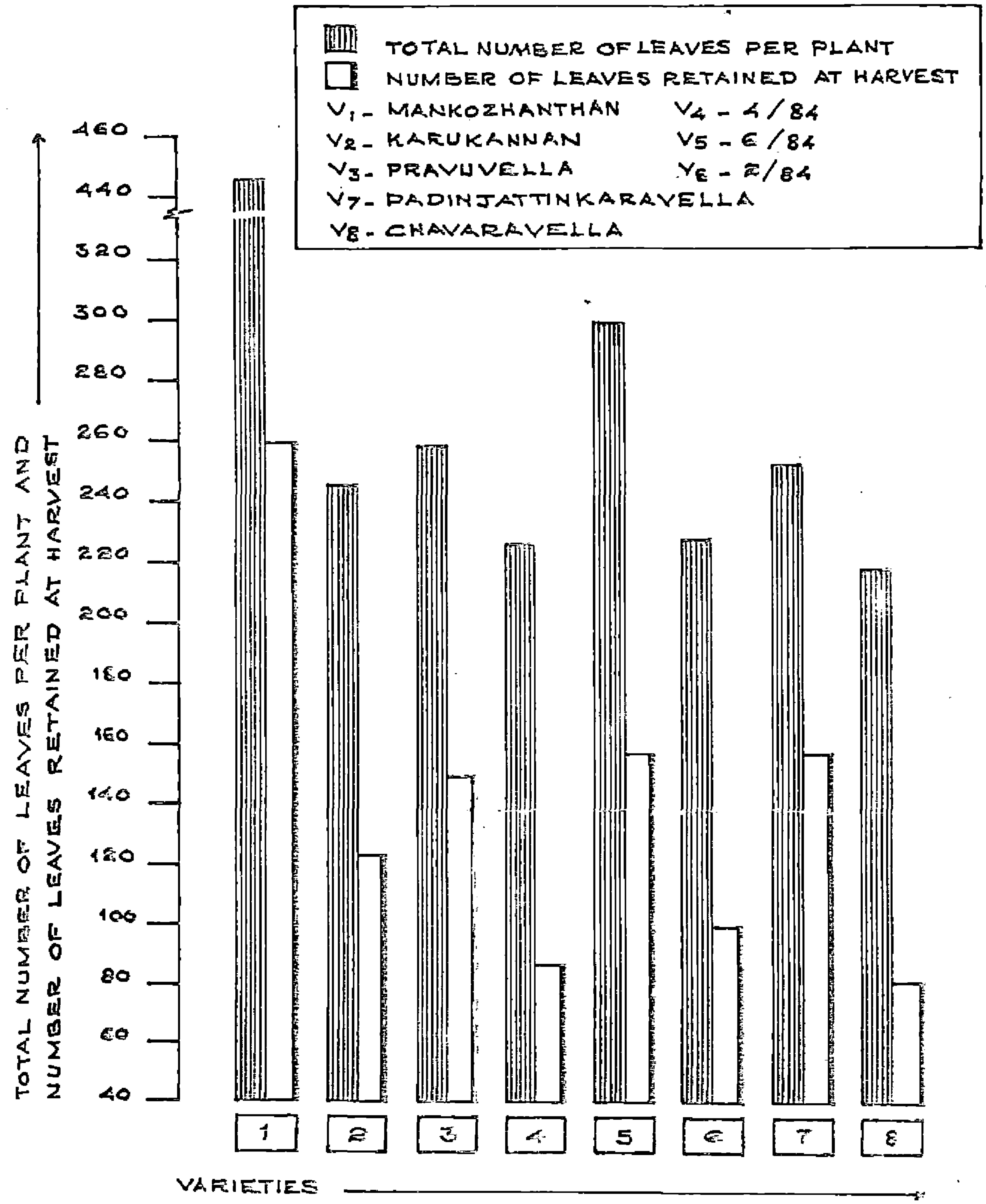


FIG. 2. PLANT HEIGHT IN EIGHT VARIETIES OF TAPIOCA

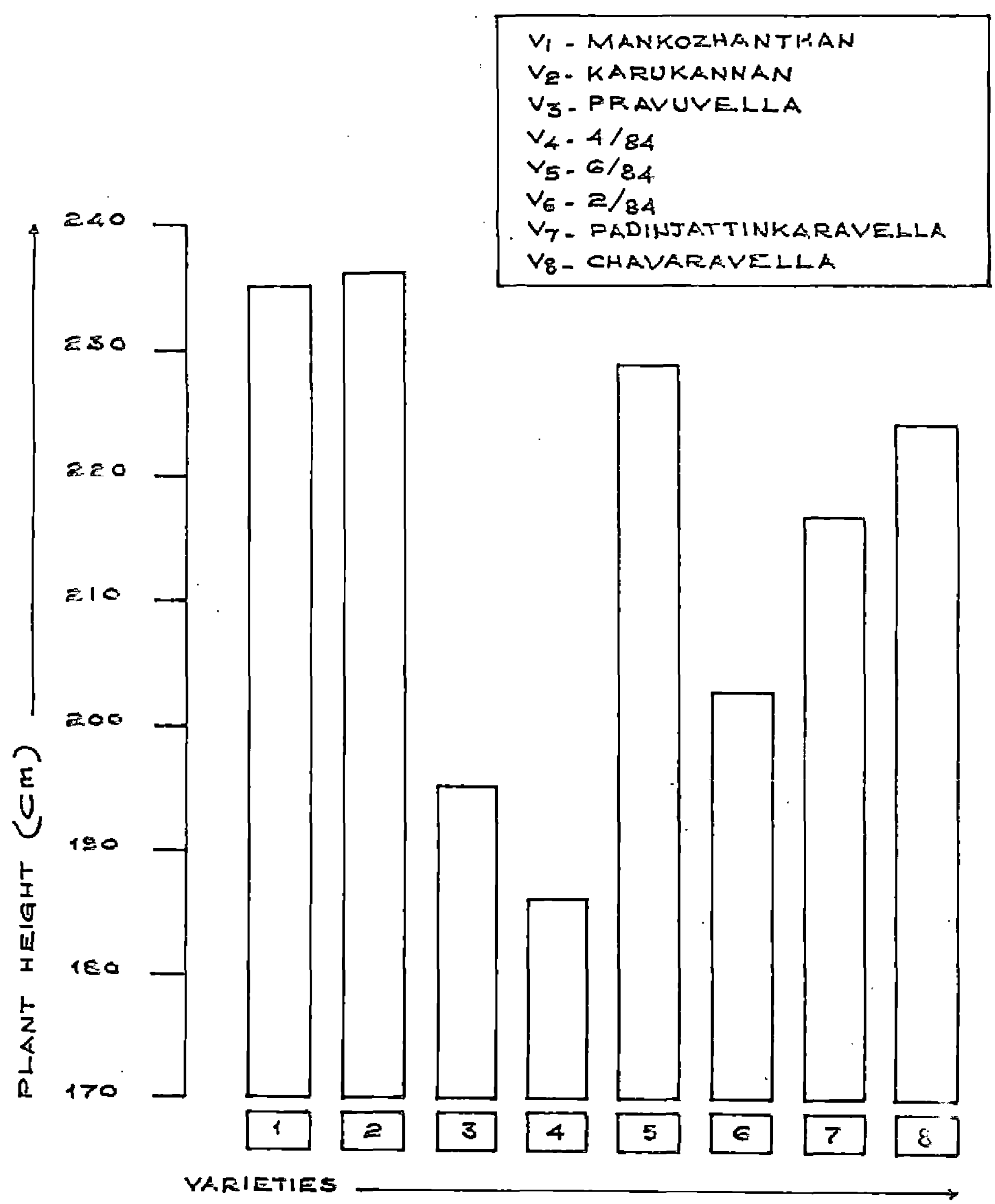


FIG. 3. NUMBER OF BRANCHES IN EIGHT VARIETIES OF TAPIOCA

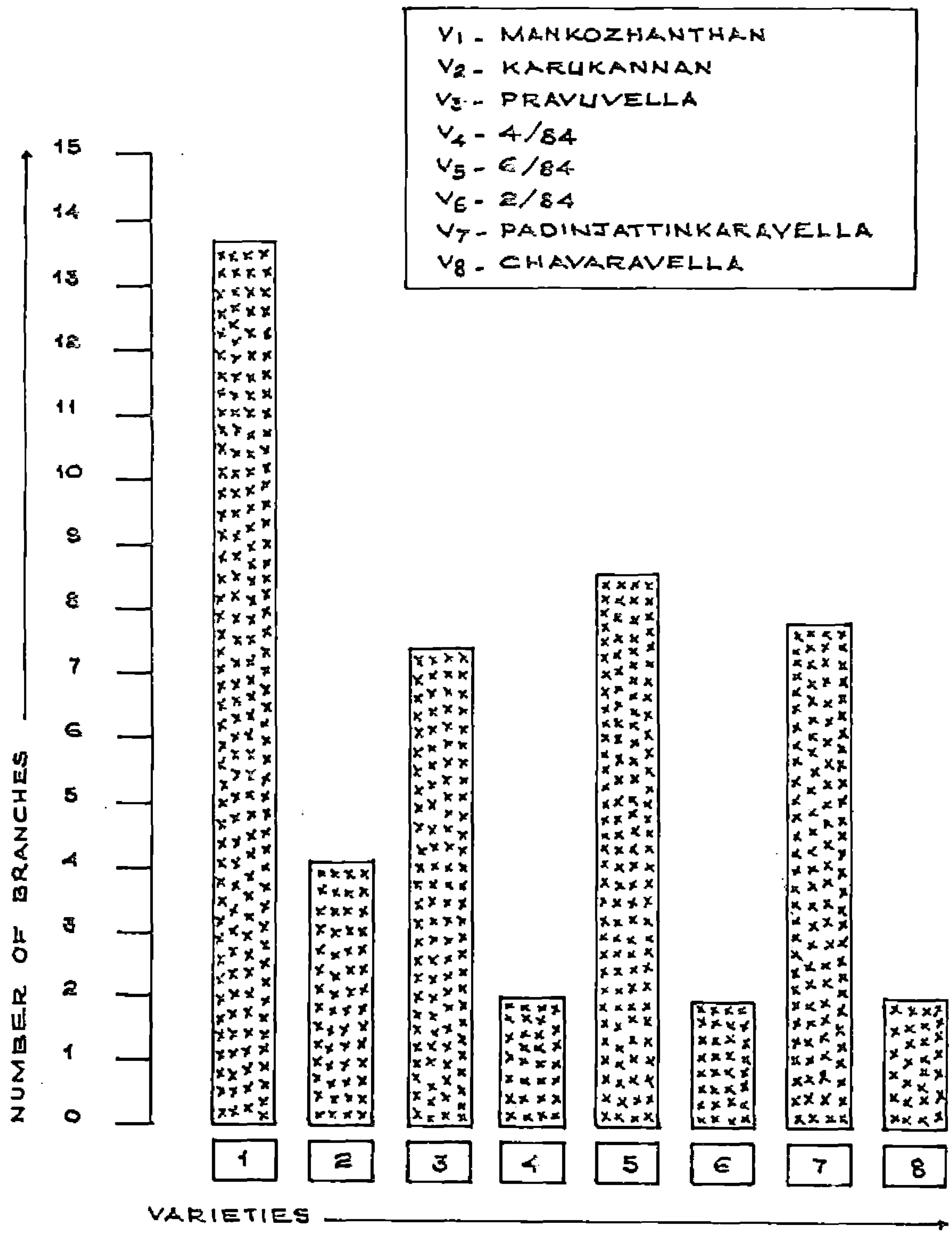


FIG. 4. NUMBER OF TUBERS PER PLANT IN EIGHT VARIETIES OF TAPIOCA

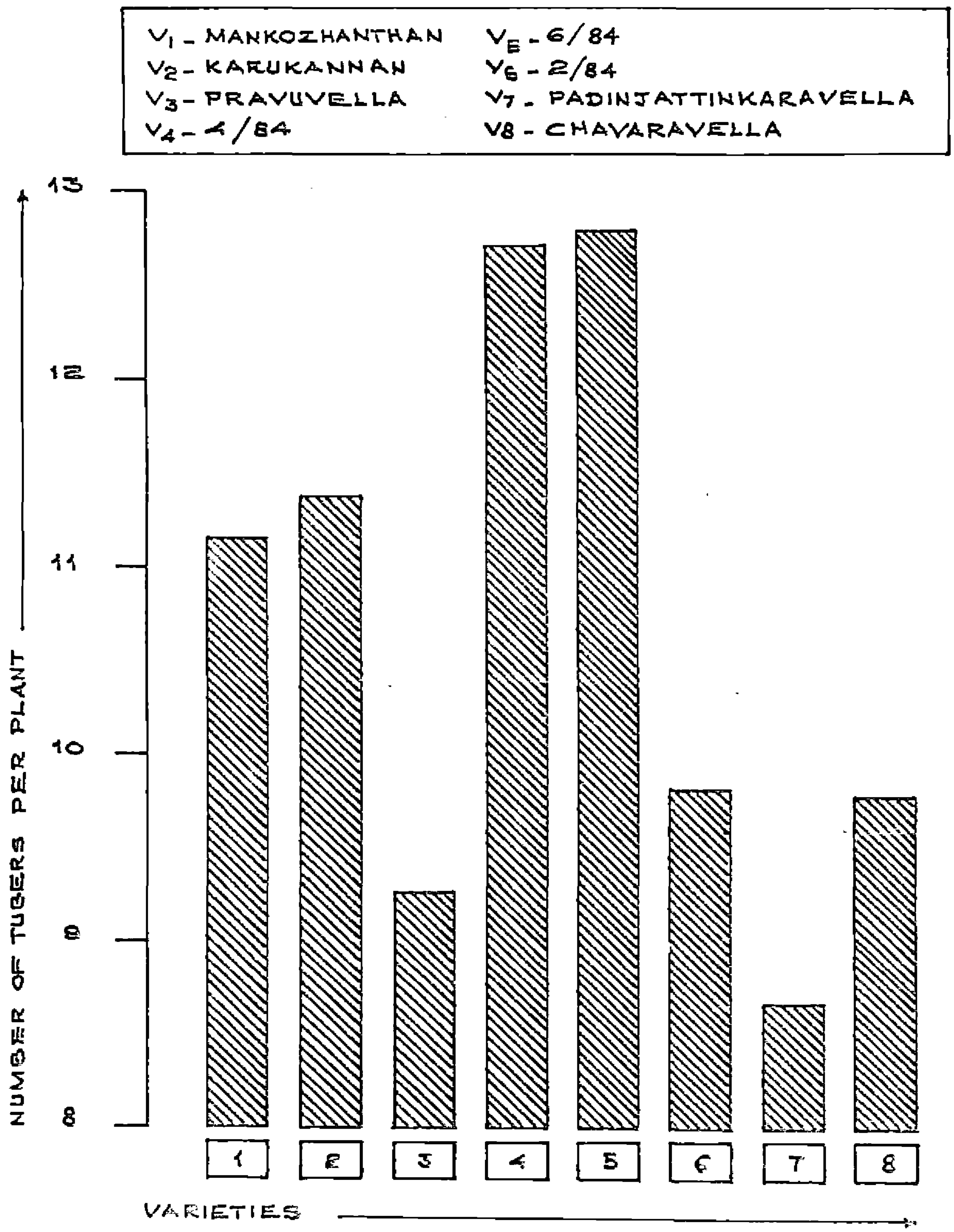


FIG. 5. YIELD PER HECTARE IN EIGHT VARIETIES OF TAPIOCA

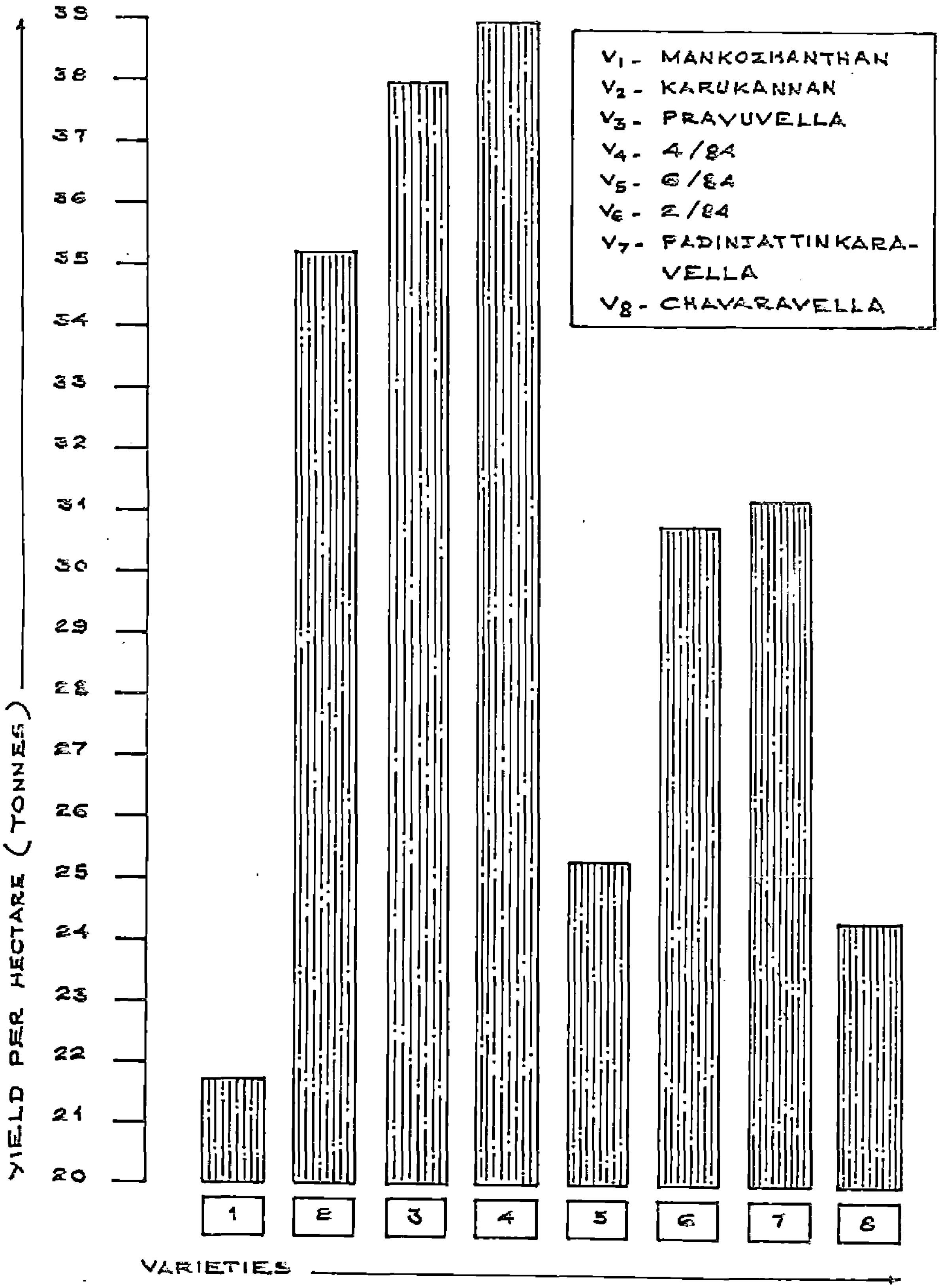


FIG. 6. LENGTH AND GIRTH OF TUBER IN EIGHT VARIETIES OF TAPIOCA

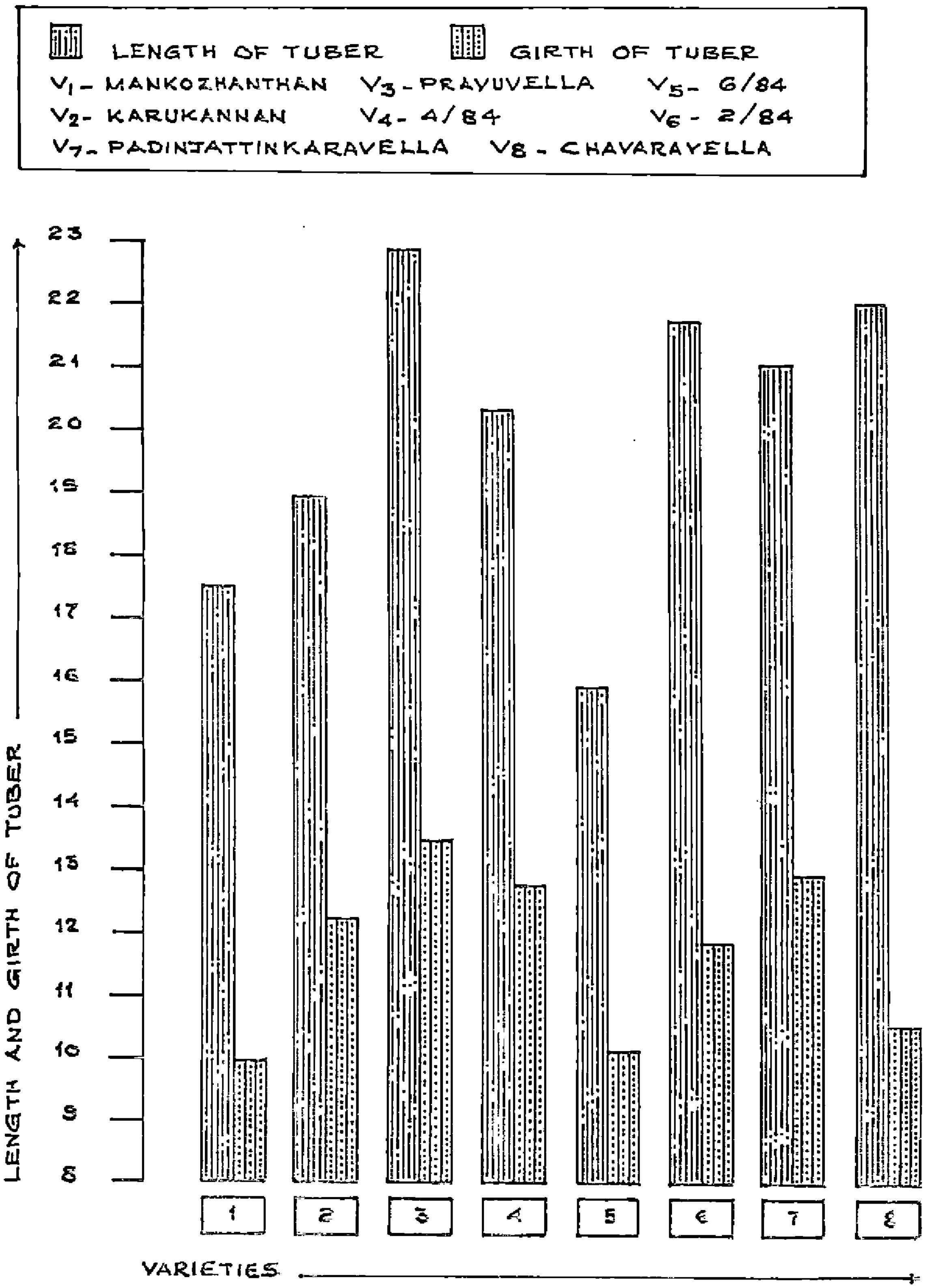


FIG. 7. WEIGHT OF SINGLE TUBER IN EIGHT VARIETIES OF TAPIOCA

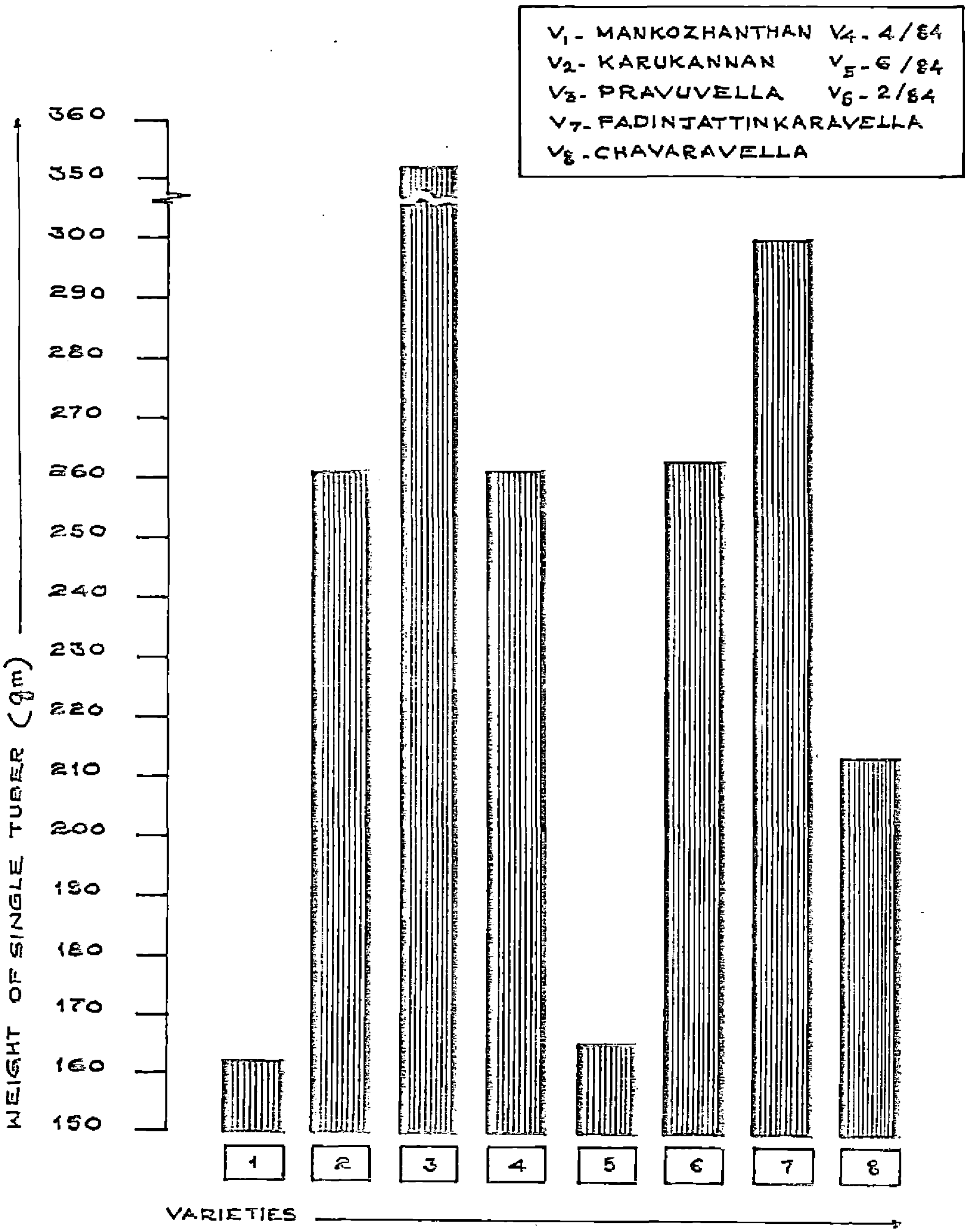


FIG. 8. UTILIZATION INDEX IN EIGHT VARIETIES OF TAPIOCA

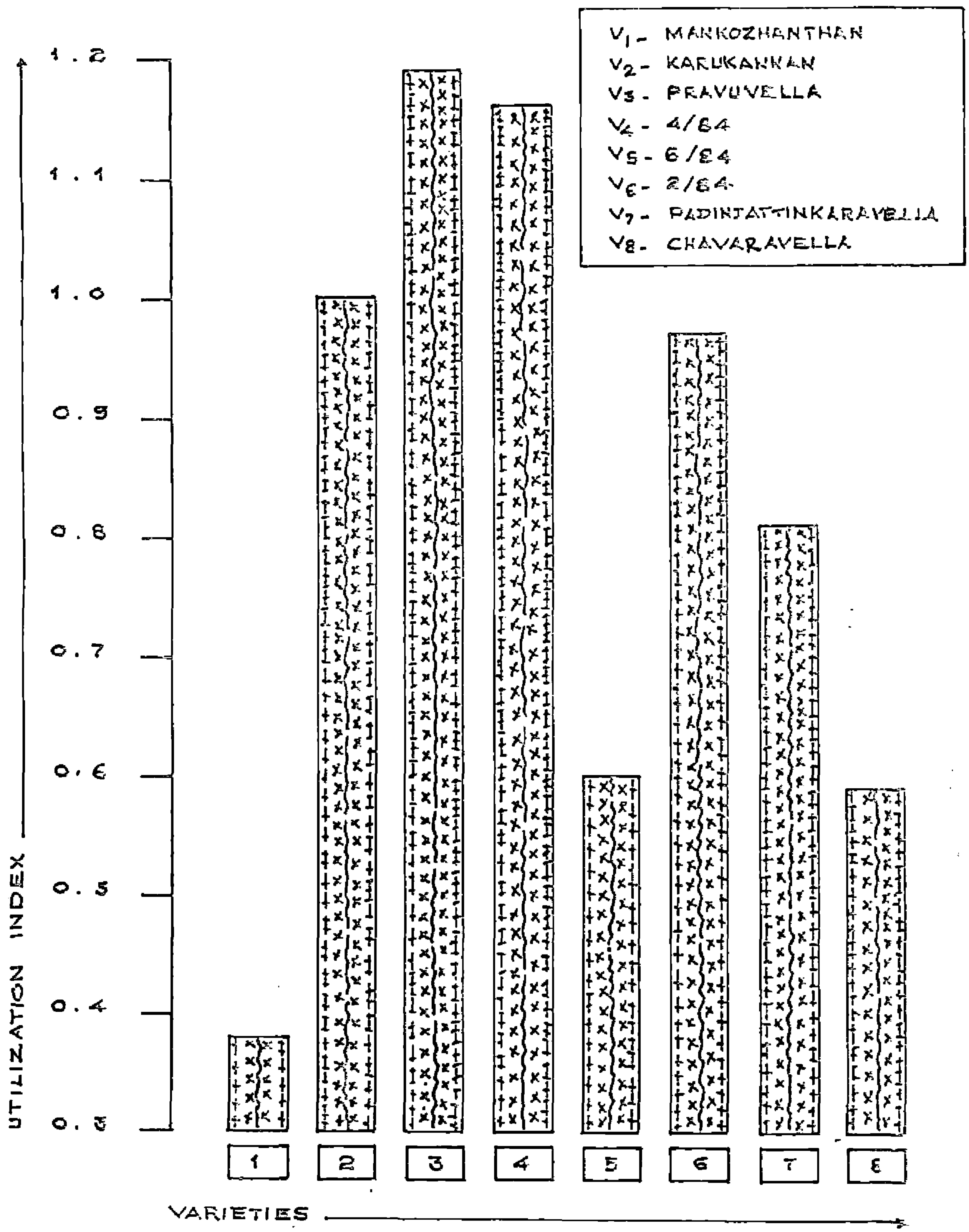


FIG. 9. STARCH CONTENT IN EIGHT VARIETIES OF TAPIOCA

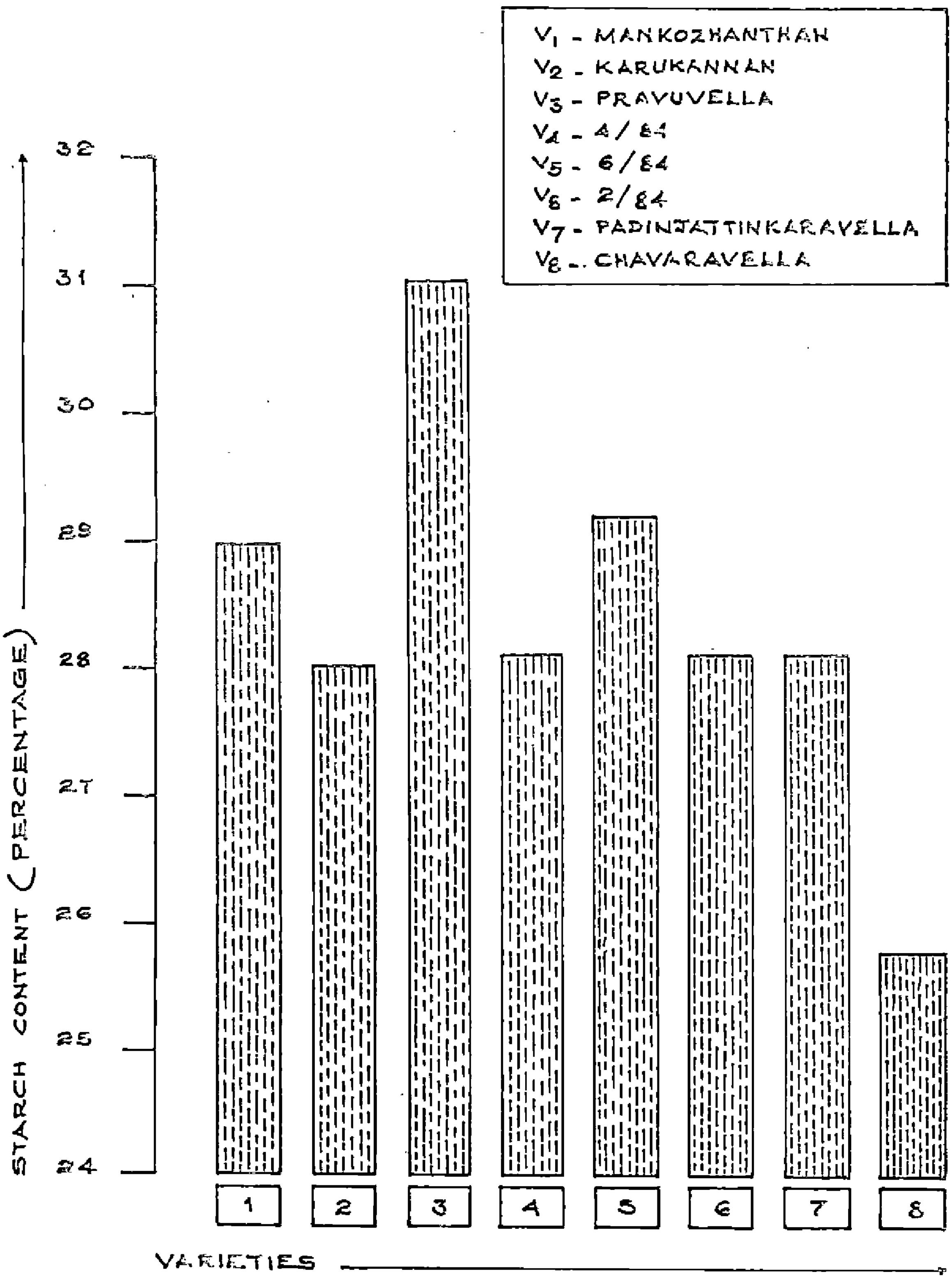


FIG. 10. HYDROCYANIC ACID CONTENT IN EIGHT VARIETIES OF TAPIOCA

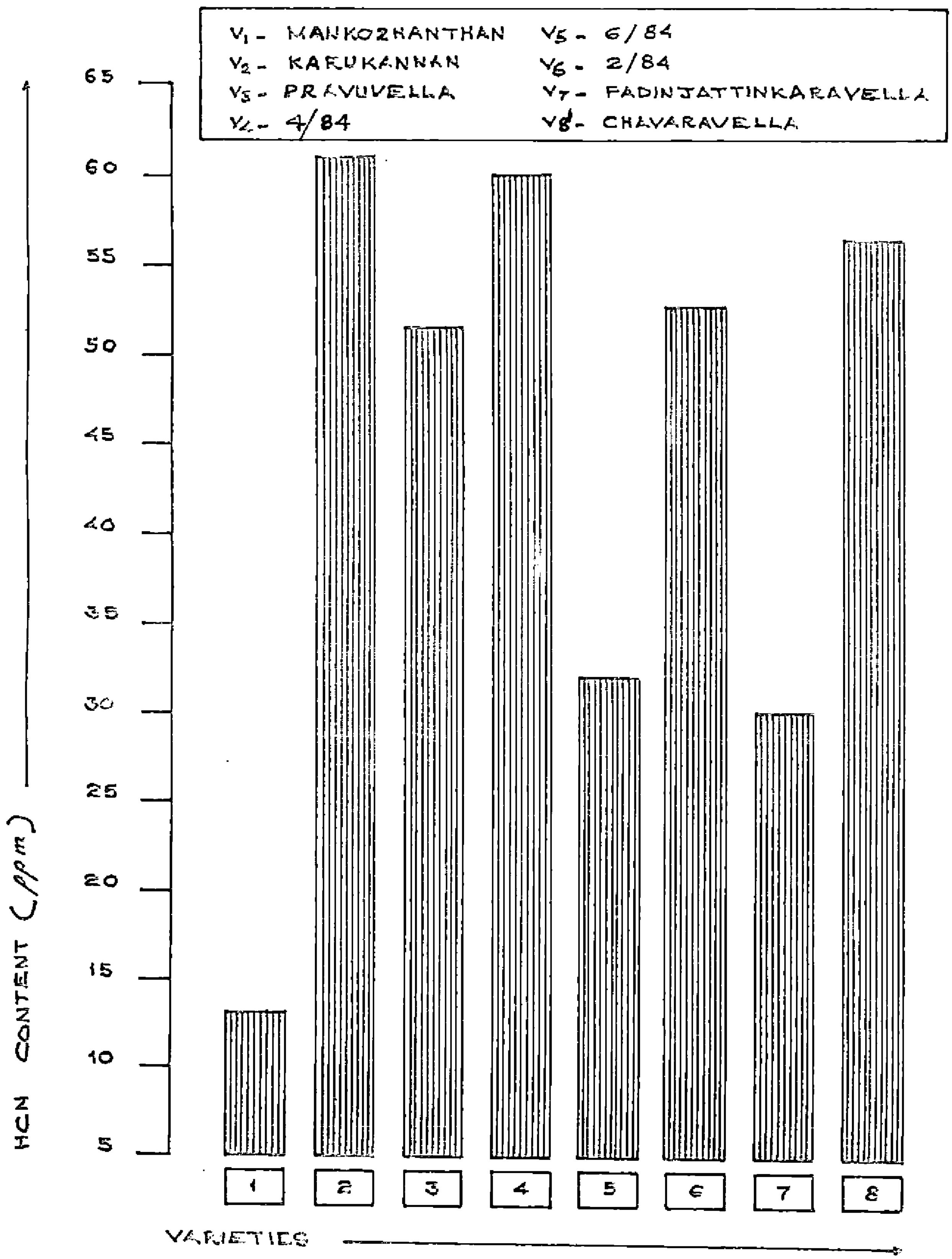
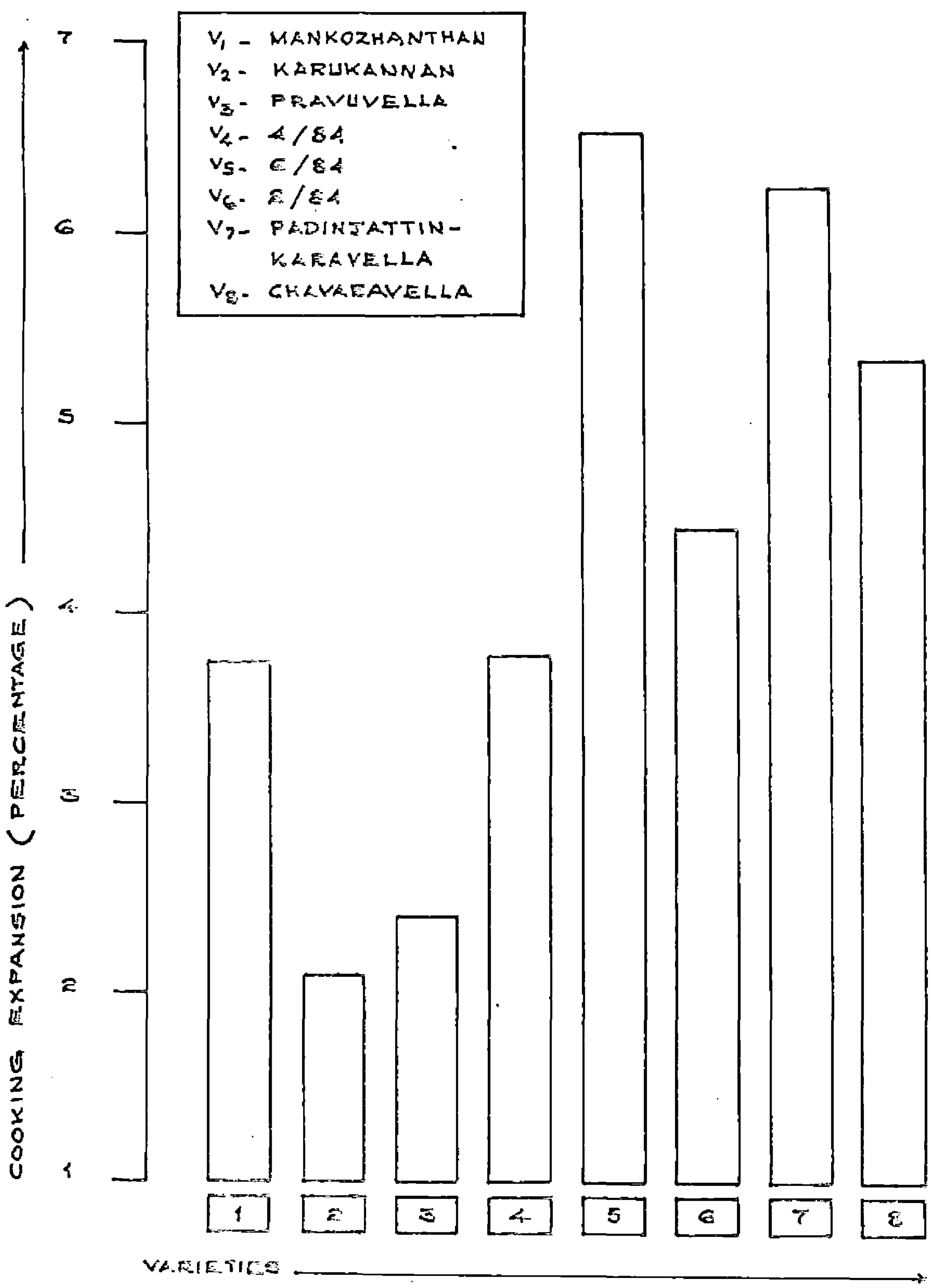


FIG.11. COOKING EXPANSION OF TUBERS IN EIGHT VARIETIES OF TAPIOCA



2. Number of leaves retained at harvest

Mankozhanthan retained maximum number of leaves at harvest. No significant difference was exhibited by 6/84, Padinjattinkara vella and Pravu vella. Chavaravella retained minimum number of leaves at harvest but the variety was on par with 4/84 and 2/84. Karukannan retained higher number of leaves than 2/84, 4/84 and Chavaravella.

3. Plant height

There was no significant difference among Karukannan, Mankozhanthan, 6/84, Chavaravella and Padinjattinkara vella, but they were found to be taller than 2/84, Pravu vella and 4/84. 4/84 was the shortest. However, there was no significant difference in plant height among 4/84, pravuvella, 2/84 and Padinjattinkaravella.

4. Number of branches

Among the eight varieties studied Mankozhanthan produced maximum number of branches. No significant difference was observed in this trait among 6/84, Padinjattinkaravella and Prauvella but they possessed more number of branches than Karukannan, 4/84, Chavaravella and 2/84 which showed no significant difference in branching pattern among themselves.

5. Number of tubers per plant

There was no significant difference in the number of tubers produced by 6/84, 4/84, Karukannan and Mankozhanthan. However, they produced more number of tubers than 2/84, Chavaravella, Pravuvella and Padinjattinkaravella, which showed no significant difference among themselves in number of tubers produced per plant. Varieties Karukannan, Mankozhanthan 2/84 and Chavaravella were found to be on par.

6. Length of tuber

As regards length of tuber there was no significant difference among Pravuvella, Chavaravella, 2/84 and Padinjattinkaravella. Padinjattinkaravella, 4/84 and Karukannan were found to be on par for length of tuber. There was no significant difference in length of tuber produced by Karukannan and Mankzohanthan. The clone 6/84 produced the shortest tubers and the same was on par with Mankozhanthan.

7. Girth of tuber

Pravuvella produced tubers with maximum girth, However, there was no significant difference in tuber girth among Pravuvella, Padinjattinkaravella and 4/84. Likewise Padinjattinkaravella, 4/84, Karukannan and 2/84 were found to be on par. Mankozhanthan produced tubers with lowest girth but it was on par with 6/84 and Chavaravella.

8. Single tuber weight

The highest value for single tuber weight was registered by Pravuvella. There was no significant difference in single tuber weight for Padinjattinkaravella, 2/84, 4/84 and Karukannan and they were found to be superior to Chavaravella, 6/84 and Mankozhanthan. The lowest single tuber weight was recorded by Mankozhanthan but it was found to be on par with 6/84.

9. Tuber yield per plant

Among the eight varieties studied 4/84 recorded the highest tuber yield per plant but it was on par with Pravuvella and Karukannan. There was no significant difference in tuber yield per plant for Karukannan, Padinjattinkara vella and 2/84. Chavaravella, 2/84, 6/84 were on par for tubor yield. Mankozhanthan recorded the lowest yield however, no significant difference in yield was observed among Mankozhanthan, Chavaravella and 6/84.

10. Utilization index

Pravuvella registered the highest utilization index, but there was no significant difference among Pravuvella, 4/84, Karukannan and 2/84, and they were found to be superior to Padinjattinkaravella, 6/84, Chavaravella and Mankozhanthan. The varieties Padinjattinkaravella 2/84 and Karukannan were found to be on par. Similarly Padinjattinkaravella was found to be on par with 6/84 and Chavaravella. The lowest value for utilization index was registered by Mankozhanthan but there was no significant difference in utilization index among Mankozhanthan, Chavaravella and 6/84.

11. Starch content

Pravuvella registered maximum starch content but it was found to be on par with 6/84 and Mankozhanthan which were on par with 4/84, 2/84, Padinjattinkaravella and Karukannan. Chavaravella had the lowest starch content but there was no significant difference in starch content among Chavaravella, Karukannan, Padinjattinkaravella, 2/84 and 4/84.

12. Cooking expansion of tubers

Maximum cooking expansion of tubers was recorded by 6/84 followed by Padinjattinkaravella but they were on par with Chavaravella and 2/84. There was no significant difference in cooking expansion for 2/84, 4/84, Mankozhanthan and Pravuvella, Karukannan recorded lowest cooking expansion but it was on par with Pravuvella, Mankozhanthan and 4/84.

13. Leaf area at three months after planting

Among the eight varieties studied Chavaravella recorded maximum leaf area at three months after planting. There was no significant difference in leaf area recorded by 2/84 and 6/84, but 2/84 was found to be superior to 4/84, Mankozhanthan, Pravuvella, Karukannan and Padinjattin-karavella, Padinjattinkaravella had the lowest leaf area at 3 months after planting, however, there was no significant difference among Padinjattinkaravella, Karukannan, Pravuvella, Mankozhanthan, 4/84 and 6/84.

14. Leaf area at four months after planting

After four months maximum leaf area was displayed by Chavaravella. There was no significant difference in leaf area among 2/84, 4/84 and 6/84. Pravuvella had the lowest leaf area but it was on par with Mankozhanthan, Karukannan, Padinjattinkaravella and 6/84.

15. Leaf area at five months after planting

Chavaravella had the maximum leaf area at five months after planting but there was no significant difference between Chavaravella and 4/84 and 4/84 and 2/84. The varieties 2/84, 6/84, Padinjattinkaravella and Karukannan were found to be on par. Pravuvella had the lowest leaf area but it was on par with Mankozhanthan, Karukannan, Padinjattinkaravella and 6/84.

16. Mosaic disease - three months after planting

At three months after planting disease intensity was found to be lowest for Mankozhanthan and it was on par with 4/84, 6/84 and Padinjattinkaravella. There was no significant difference in disease resistance among Pravuvella, Karukannan and Chavaravella. The lowest resistance for the disease was shown by 2/84.

17. Mosaic disease - four months after planting

Highest resistance for cassava mosaic disease was exhibited by 6/84. However, there was no significant difference in disease resistance for 6/84, Mankozhanthan and 4/84. Padinjattinkaravella was superior to Pravuvella, Chavaravella, Karukannan and 2/84 for disease resistance. Pravuvella, Chavaravella and Karukannan were on par for disease resistance. The resistance was minimum for 2/84.

18. Mosaic disease - five months after planting

During five months after planting also disease rating maintained more or less the same trend. Highest resistance was exhibited by 6/84 and it was on par with 4/84 and Mankozhanthan. There was no significant difference in disease resistance between varieties Padinjattinkara vella and Pravuvella, Similarly between Karukannan and Chavaravella. The lowest resistance for the diseases was exhibited by 2/84.

19. Leaf spot disease - three months after planting

Among the eight varieties studied Mankozhanthan recorded the highest resistance for leaf spot disease and the variety was found to be on par with Karukannan and Padinjattinkaravella. There was no significant difference between Padinjattinkaravella, 2/84 and 6/84 for disease resistance. Chavaravella was found to be the most susceptible variety but it was on par with 4/84 and Pravuvella for disease resistance. There was no significant difference for disease resistance among 4/84, Pravuvella, 6/84 and 2/84.

20. Leaf spot disease - four months after planting

During four months after planting also resistance for leaf spot disease maintained a similar trend. The resistance was maximum for Mankozhanthan and it was on par with Padinjattinkaravella and Padinjattinkaravella was on par with Karukannan which was on par with 6/84. There was no significant difference in disease resistance among the varieties 6/84, Pravuvella and 2/84. Chavaravella had the lowest resistance for leaf spot disease, but it was on par with 4/84, 2/84 and Pravuvella.

21. Leaf spot disease - five months after planting

Mankozhanthan had the highest resistance for leaf spot disease at five months after planting and it was on par with Padinjattinkaravella, Karukannan and Pravuvella. There was no significant difference among Padinjattinkaravella, Karukannan, Pravuvella, 4/84 and 6/84 for resistance to leaf spot disease but they were found to be superior to 2/84 and Chavaravella. The variety 2/84 was on par with 6/84 and 4/84. Chavaravella recorded the lowest resistance for leaf spot disease at five months after planting also.

22. Mites present per leaf - four months after planting

Among the eight varieties studied Padinjattinkaravella had the highest resistance for mite attack and there was no significant difference among Padinjattinkaravella, Mankozhanthan, Karukannan, Pravuvella, 2/84 and Chavaravella for resistance to mite attack, similarly among the varieties Chavaravella, 6/84, 2/84 and Pravuvella. The lowest resistance for mite attack was registered by 4/84.

23. Mites present per leaf - five months after planting

At five months after planting also same trend was observed. Padinjattinkaravella had the highest resistance and it was on par with Mankozhanthan, Pravuvella, Karukannan and 2/84 but they were having higher resistance than Chavaravella and 6/84 and the latter two were on par. Among the eight varieties 4/84 had the lowest resistance for mite attack.

General means, phenotypic, genotypic and environmental variances and phenotypic and genotypic coefficients of variation for twenty four characters are furnished in Table 4.

4.2.1 <u>Coefficients of variation for yield and its components</u>

The maximum amount of phenotypic coefficient of variation was registered by number of branches (74.64) followed by number of leaves retained at harvest (43.23). Plant height recorded minimum phenotypic coefficient of variation (12.35).

The maximum (68.54) and minimum (7.23) amount of genotypic coefficients of variation were recorded by number of branches and plant height respectively.

Table 4. General mean, variance and coefficients of variation for twenty four characters in eight varieties of tapioca.

Sl. No.	Characters	General mean	Pheno-typic variance	Geno-typic variance	Environ-mental variance	Phenotypic coefficient of variation	Genotypic coefficient of variation
1.	Total number of leaves per plant.	270.77	5931.15	5528.14	403.01	28.44	27.46
2.	Number of leaves retained at harvest	137.79	3548.34	3279.14	269.20	43.23	41.56
3.	Plant height	215.63	708.66	242.89	465.77	12.35	7.23
4.	Number of branches	5.96	19.79	16.69	3.10	74.64	68.54
5.	Number of tubers per plant	10.68	3.53	2.05	1.47	17.58	13.41
6.	Length of tuber	20.07	7.41	5.19	2.22	13.57	11.35
7.	Girth of tuber	11.74	2.31	1.73	0.58	12.96	11.20
8.	Single tuber weight	247.44	4856.51	4022.56	833.95	28.16	25.63
9.	Tuber yield per plant	2.48	0.37	0.24	0.13	24.56	19.63
10.	Utilization index	0.84	0.11	0.08	0.03	38.94	33.46
11.	Starch content	28.42	4.44	1.41	3.03	7.41	4.17
12.	HCN content	44.53	1022.92	62.15	960.77	71.82	17.70

Table 4 (contd.)

Sl. No.	Characters	General mean	Phenotypic variance	Genotypic variance	Environmental variance	Phenotypic coefficient of variation	Genotypic coefficient of variation
13.	Cooking expansion	4.32	4.50	2.06	2.44	49.13	33.20
14.	Leaf area - 3 months after planting	330.83	3369.43	2078.81	1290.62	17.55	13.78
15.	Leaf area - 4 months after planting	340.58	4991.09	3438.45	1552.64	20.74	17.22
16.	Leaf area - 5 months after planting	332.94	7738.35	4689.04	3049.31	26.42	20.57
17.	Cassava mosaic - 3 months after planting	0.65	0.21	0.18	0.03	69.99	65.99
18.	Cassava mosaic- 4 months after planting	1.67	0.70	0.65	0.05	50.17	48.35
19.	Cassava-mosaic- 5 months after planting	1.75	0.98	0.94	0.04	56.42	55.43
20.	Leaf spot - 3 months after planting	1.18	0.07	0.04	0.03	21.94	17.16
21.	Leaf spot - 4 months after planting	1.16	0.05	0.04	0.01	19.28	16.81
22.	Leaf spot - 5 months after planting	1.28	0.21	0.15	0.06	36.14	29.95
23.	Mites present per leaf - 4 months after planting	1.60	2.12	1.61	0.51	90.92	79.21
24.	Mites present per leaf - 5 months after planting	2.58	4.82	3.88	0.94	85.07	76.33

4.2.2 Coefficient of variation for quality attributes

Among the quality attributes studied HCN content displayed maximum amount of phenotypic coefficient of variation (71.82) followed by cooking expansion of tubers (49.13). Starch content displayed minimum phenotypic coefficient of variation (7.41). Genotypic coefficient of variation was maximum for cooking expansion (33.20) and minimum for starch content (4.17).

4.2.3 Coefficient of variation for reaction to pest and diseases

As regards phenotypic coefficient of variation maximum (90.92) and minimum (19.28) values were exhibited by mites present per leaf at four months after planting and leaf spot disease at four months after planting respectively. Similar trend was reflected in genotypic coefficient of variation also. Maximum value for genotypic coefficient of variation was shown by mites present per leaf at four months after planting (79.21) and minimum value by leaf spot disease at four months after planting (16.81).

Heritability, genetic advance and genetic gain for twenty four characters are presented in Table 5.

Table 5. Heritability (h^2), genetic advance (GA) and genetic gain (GG) for twenty four characters in eight varieties of tapioca

Sl. No.	Character	Heritability per cent	Genetic advance	Genetic gain per cent
1.	Total number of leaves per plant	93.21	147.87	54.61
2.	Number of leaves retained at harvest	92.41	113.40	82.30
3.	Plant height	34.27	18.80	8.72
4.	Number of branches	84.32	7.73	129.65
5.	Number of tubers per plant	58.20	2.25	21.08
6.	Length of tuber	70.05	3.93	19.58
7.	Girth of tuber	74.77	2.34	19.96
8.	Single tuber weight	82.83	118.91	48.06
9.	Tuber yield per plant	63.81	0.80	32.30
10.	Utilization index	73.16	0.49	58.81
11.	Starch content	31.66	1.37	4.84
12.	HCN content	6.08	4.00	8.99
13.	Cooking expansion	45.67	2.00	46.23
14.	Leaf area - 3 months after planting	61.70	73.77	22.30
15.	Leaf area - 4 months after planting	68.89	100.26	29.44
16.	Leaf area - 5 months after planting	60.60	109.81	32.98

Contd..

Table 5 (contd.)

Sl. No.	Character	Herita-bility per cent	Genetic advance	Genetic gain per cent
17.	Cassava Mosaic - 3 months after planting	88.94	0.83	128.31
18.	Cassava Mosaic - 4 months after planting	92.86	1.60	95.99
19.	Cassava Mosaic - 5 months after planting	96.48	1.96	112.11
20.	Leaf spot - 3 months after planting	61.81	0.33	27.80
21.	Leaf spot - 4 months after planting	76.37	0.35	30.26
22.	Leaf spot - 5 months after planting	68.56	0.65	51.02
23.	Mites - 4 months after planting	75.91	2.27	142.18
24.	Mites - 5 months after planting	80.50	3.64	141.09

4.3.1 Heritability, genetic advance and genetic gain for yield and its components

The maximum heritability in broad sense (93.21) was displayed by total number of leaves per plant, followed by number of leaves retained at harvest (92.41), number of branches (84.32), single tuber weight (82.83), girth of tuber (74.77) and utilization index (73.16). The characters length of tuber, tuber yield per plant, leaf area at three, four and five months after planting and number of tubers per plant manifested moderately high heritability values. Among the quantitative characters lowest heritability (34.27) was observed for plant height. Genetic advance was maximum for total number of leaves per plant (147.87) followed by number of leaves retained at harvest (113.40). Tuber yield per plant registered the minimum value (0.80) for genetic advance. Expected genetic advance expressed as percentage of mean was maximum (129.65) for number of branches followed by number of leaves retained at harvest (82.30). Plant height exhibited minimum value for this parameter (8.72).

4.3.2 Heritability, genetic advance and genetic gain for quality attributes

Cooking expansion of tubers exhibited maximum amount of heritability (45.67). Minimum amount of heritability was registered by HCN content (6.08). All the three quality attributes such as starch content, HCN content and cooking expansion displayed low estimates for genetic advance. Genetic advance expressed as percentage of mean was maximum for cooking expansion (46.22). The remaining two quality attributes displayed low estimates for this parameter.

4.3.3 Heritability, genetic advance and genetic gain for reaction to pest and diseases

Cassava mosaic disease at five months after planting displayed maximum amount of heritability (96.48) followed by the incidence of the disease at four (92.86) and three months after planting (88.94) and mites present per leaf at five months after planting (80.50). The lowest heritability was observed for leaf spot disease at three months after planting (61.81). All the characters displayed very low values for genetic advance. Expected genetic advance expressed as percentage of mean was maximum for mites present per leaf at four months after planting (142.13) followed by mites present per leaf at five months after planting (141.09), Cassava mosaic disease at three months after planting (128.31). Leaf spot disease at three months after planting registered the lowest value for this parameter (27.80).

4.4.1 Correlation among the different quantitative attributes

The correlation between all possible combinations of twenty four characters are presented in Table 6.

The association among the eleven important quantitative characters are diagramatically represented in Fig.12.

Total number of leaves per plant displayed significant positive genotypic correlation with number of leaves retained at harvest, plant height and number of branches while the former character was also found to be positively correlated with number of tubers per plant. Length of tuber, girth of tuber, single tuber weight, tuber yield per plant, utilization index and leaf area at four and five months after planting displayed significant negative correlation with number of leaves per plant. Number of leaves retained at harvest displayed significant positive association with plant height and number of branches. Number of tubers per plant had nonsignificant positive correlation with number of leaves retained at harvest, while the correlation with length of tuber, tuber yield, utilization index and leaf area at three, four and five months after planting were negative and significant.

Girth of tuber and single tuber weight displayed non-significant negative correlation with number of leaves retained at harvest. Plant height had significant positive correlation with number of branches. Length of tuber, girth of tuber, single tuber weight, tuber yield per plant, utilization index and leaf area at three, four and five months after planting showed negative association with plant height, and the values were significant except for leaf area at three and four months after planting. Number of branches displayed significant negative correlation with length of tuber, tuber yield per plant, utilization index and leaf area at three, four and five months after planting. But it was positively and non-significantly correlated with number of tubers per plant.

Number of tubers per plant exhibited significant negative correlation with length of tuber, girth of tuber and single tuber weight. Number of tubers per plant was also found to be negatively associated with tuber yield per plant, utilization index and leaf area at three and four months after planting. Length of tuber manifested significant positive correlation with girth of tuber, single tuber weight, tuber yield per plant and utilization index while it showed nonsignificant positive correlation with leaf area at three, four and five months after planting. Girth of the tuber was found to be significantly and positively correlated with single tuber weight, tuber yield per plant and utilization index. Leaf area at three, four and five months after planting were found to be negatively associated with girth of tuber and the association of the former was significant.

Single tuber weight manifested significant positive correlation with tuber yield per plant and utilization index besides length of tuber and girth of tuber, but it had nonsignificant negative association with leaf area at three, four and five months after planting.

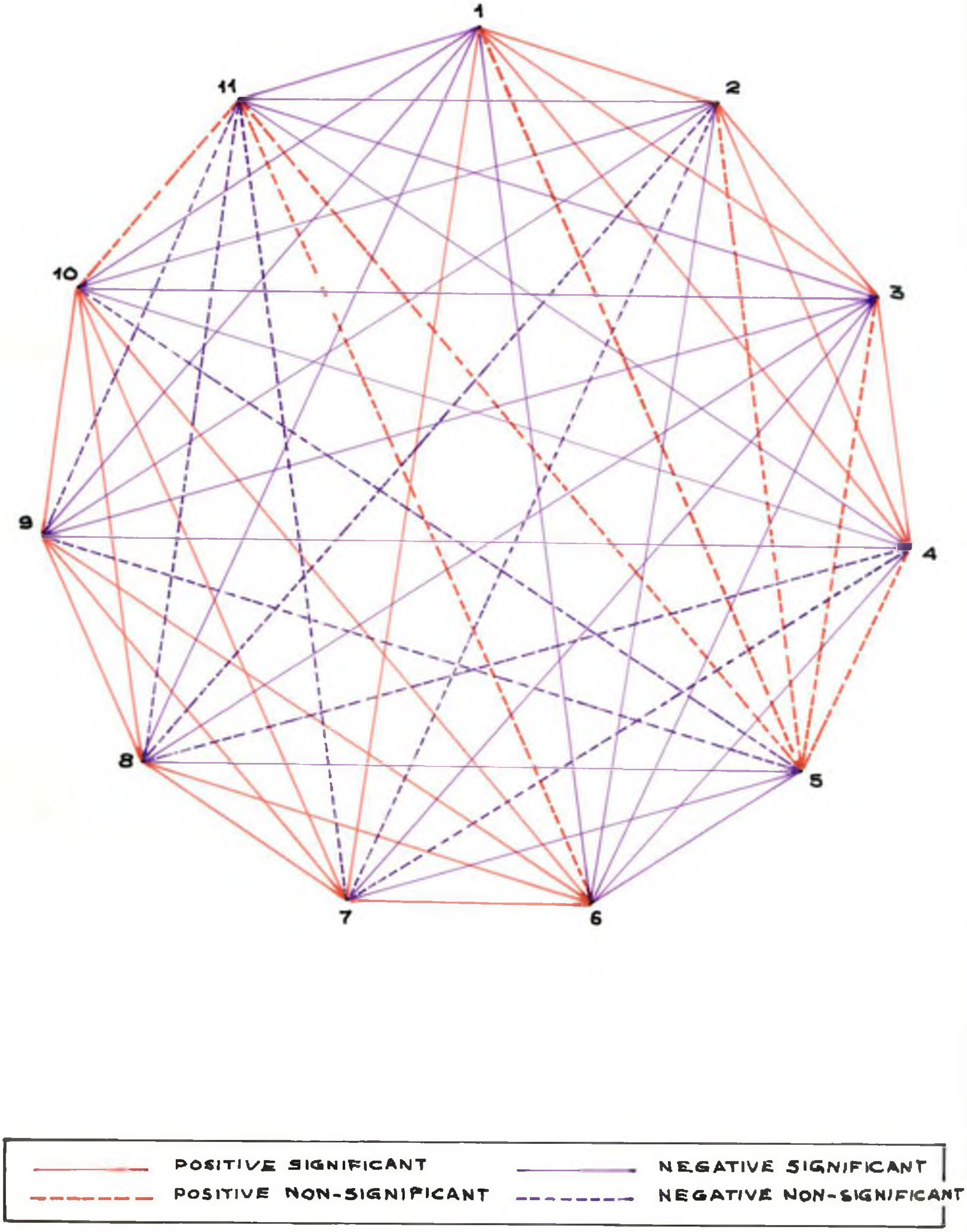
The genotypic correlation between tuber yield and leaf area at four and five months after planting were negative and nonsignificant, while the character exhibited significant negative correlation with leaf area at three months after planting and significant positive correlation with utilization index.

4.4.2 Correlation among quality attributes and important yield contributing characters

The number of tubers per plant was found to be positively correlated with HCN content, but its association with cooking expansion was negative and nonsignificant.

1. Total number of leaves per plant
2. Number of leaves retained at harvest
3. Plant height
4. Number of branches
5. Number of tubers per plant
6. Length of tuber
7. Girth of tuber
8. Single tuber weight
9. Tuber yield per plant
10. Utilization index
11. Leaf area - 5 months after planting

FIG. 12. DIAGRAM SHOWING CORRELATION AMONG IMPORTANT ATTRIBUTES IN TAPIOCA



However, number of tubers per plant displayed positive association with starch content of the tubers.

Tuber yield per plant had positive association with HCN content and starch content and the association of the former character was significant. But it displayed significant negative correlation with cooking expansion of tubers. Single tuber weight also displayed the same trend.

The association of length of tuber with starch content and cooking expansion were negative and non-significant where as its association with HCN content was positive and significant. Girth of tuber showed positive correlation with starch content and HCN content and the association of the latter was significant. The association of girth of tuber with cooking expansion was negative and significant.

Starch content had significant negative correlation with HCN content and cooking expansion. Significant negative association was noticed between HCN content and cooking expansion.

4.4.3 Correlation between important yield contributing characters and reaction to pests and diseases

While considering the reaction to pest and diseases cassava mosaic disease at three, four and five months after planting and leaf spot disease at three, four and five months after planting were negatively and significantly correlated with total number of leaves per plant. Mites present per leaf at four and five months after planting recorded nonsignificant negative association with total number of leaves per plant. Similar trend was reflected in number of leaves retained at harvest, but all the correlations were significant.

Plant height had significant negative correlation with leaf spot disease at three and four months after planting and mites present per leaf at four and five months after planting. The character also showed negative correlation with cassava mosaic disease at three, four and five months after planting.

Number of tubers per plant displayed significant positive correlation with mites present per leaf at four and five months after planting. Its correlation with leaf spot disease at three and four months after planting were also positive but the character was significantly and negatively correlated with mosaic disease at three, four and five months after planting.

Single tuber weight displayed positive correlation with cassava mosaic disease at three, four and five months after planting, Leaf spot disease at three and four months after planting and mites present per leaf at five months after planting and the values were significant only for mosaic disease at four and five months after planting.

Tuber yield showed nonsignificant positive correlation with cassava mosaic disease at three, four and five months after planting, leaf spot disease at three and four months after planting and mites present per leaf at four and five months after planting. It had negative correlation with leaf spot disease at five months after planting.

Leaf area at three months after planting had significant positive correlation with cassava mosaic disease at three and five months after planting and leaf spot disease at three, four and five months after planting. Its association with mites present per leaf at four and five months after planting were also positive.

Leaf area at four months after planting displayed positive correlation with cassava mosaic disease at three, four and five months after planting, Leaf spot disease at three, four and five months after planting and mites present per leaf at four and five months after planting. All the values were significant except for cassava mosaic disease at four and five months after planting and mites present per leaf at four months after planting.

Leaf spot disease at three, four and five months after planting and mites present per leaf at four and five months after planting had significant positive association with leaf area at five months after planting. Its association with cassava mosaic disease at three, four and five months after planting were positive but non-significant.

4.5 Path analysis

Path coefficient analysis was undertaken with nine characters to obtain a clear picture of the cause and effect relationship of various plant characters and tuber yield. The observed genotypic correlation coefficients were partitioned into direct and indirect effects. The direct and indirect effects of the components are presented in Table 7. The cause and effect relationship brought out by path coefficient analysis is represented in Fig.13.

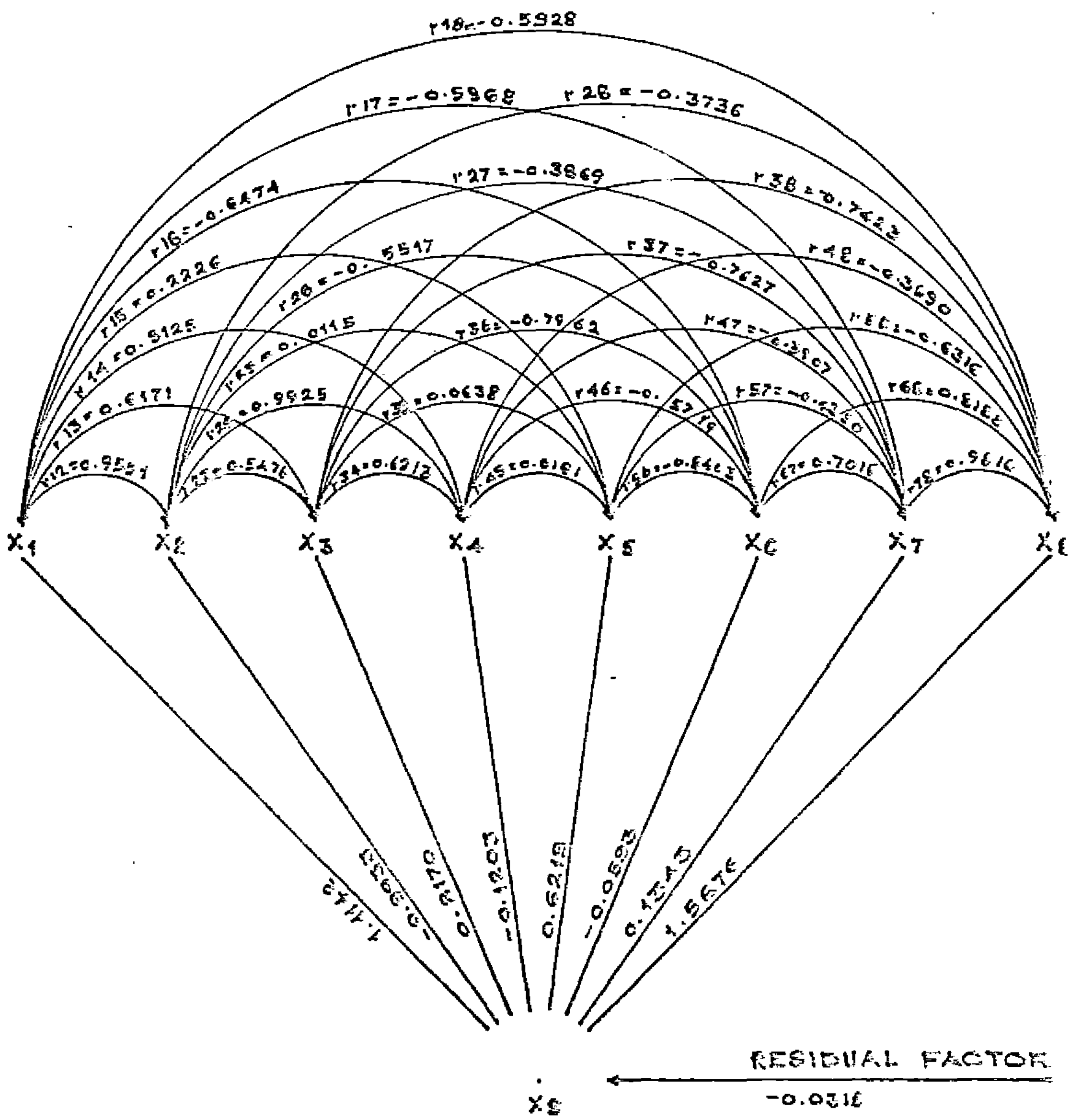
Table 7. Direct and indirect effects of various characters on tuber yield in tapioca

Character	Total No. of leaves per plant (x_1)	Number of leaves retained at harvest (x_2)	Plant height (x_3)	Number of branches (x_4)	Number of tubers per plant (x_5)	Length of tuber (x_6)	Girth of tuber (x_7)	Single tuber weight (x_8)	Total correlation
Total No. of leaves per plant (x_1)	1.1142	-0.9487	0.1339	-0.1098	0.1384	0.0384	-0.0801	-0.9293	-0.6429
No. of leaves retained at harvest (x_2)	1.0642	-0.9933	0.1188	-0.1194	0.0072	0.0327	-0.0519	-0.5856	-0.5274
Plant height (x_3)	0.6876	-0.5439	0.2170	-0.0747	0.0397	0.0473	-0.1024	-1.1636	-0.8932
No. of branches (x_4)	1.0167	-0.9859	0.1348	-0.1203	0.0119	0.0339	-0.0525	-0.5784	-0.5397
No. of tubers per plant (x_5)	0.2480	-0.0114	0.0138	-0.0023	0.6219	0.0499	-0.0569	-0.9901	-0.1291
Length of tuber (x_6)	-0.7213	0.5480	-0.1728	0.0688	-0.5226	-0.0593	0.0942	1.2835	0.5185
Girth of tuber(x_7)	-0.6649	0.3843	-0.1655	0.0470	-0.2730	-0.0416	0.1343	1.5387	0.9592
Single tuber weight (x_8)	-0.6605	0.3711	-0.1611	0.0444	-0.3928	-0.0486	0.1318	1.5676	0.8519

Residual factor : -0.0318

Fig.13. Unidirectional arrows indicate the direct path coefficients and bi-directional arrows indicate the correlation coefficients.

FIG. 13. PATH DIAGRAM SHOWING DIRECT EFFECTS AND GENOTYPIC CORRELATIONS IN TAPIOCA



X_1 -	TOTAL NUMBER OF LEAVES / PLANT
X_2 -	NUMBER OF LEAVES RETAINED AT HARVEST
X_3 -	PLANT HEIGHT
X_4 -	NUMBER OF BRANCHES
X_5 -	NUMBER OF TUBERS / PLANT
X_6 -	LENGTH OF TUBER
X_7 -	GIRTH OF TUBER
X_8 -	SINGLE TUBER WEIGHT
X_9 -	TUBER YIELD / PLANT

Among the eight components of tuber yield, the direct effect was highest for single tuber weight(1.5676) followed by total number of leaves per plant (1.1142) and number of tubers per plant (0.6219).

Number of leaves retained at harvest, number of branches and length of tuber had negative direct effects on tuber yield, the values being -0.9933, -0.1203 and -0.0593. The square of the residual effect (R^2) worked out to only -0.0318.

The indirect effect of the above characters were also considered. Total number of leaves per plant had a strong negative correlation with tuber yield (-0.6429). Its indirect effect via plant height and number of tuber per plant were 0.1339 and 0.1384 respectively. Indirect effect via number of leaves retained at harvest and single tuber weight were negative, the values being -0.9487 and -0.9293.

Number of leaves retained at harvest also had significant negative correlation with tuber yield, the correlation coefficient being -0.5274. Indirect effect via total number of leaves per plant was very high (1.0642). The highest negative indirect effect was through single tuber weight (-0.5856).

Plant height was strongly and negatively correlated with tuber yield (-0.8932). Here also the indirect effect was maximum through total number of leaves per plant (0.6876). The indirect effects through single tuber weight and number of leaves retained at harvest were -1.1636 and -0.5439 respectively. Single tuber weight had the highest negative indirect effect on tuber yield.

Number of branches showed significant negative association with tuber yield (-0.5397). Number of branches also influenced the yield maximum through total number of leaves per plant (1.0167). The indirect effect via number of leaves retained at harvest and single tuber weight were negative the values being -0.9859 and -0.5784 respectively.

Number of tubers per plant had nonsignificant negative correlation with tuber yield (-0.1291). Here also indirect effect was maximum through total number of leaves per plant (0.2480). The highest negative indirect effect was through single tuber weight(-0.9901).

Length of tuber showed significant positive correlation with tuber yield (0.5185). The indirect effect via single tuber weight and number of leaves retained at harvest were positive, the values being 1.2835 and 0.5480. Maximum indirect effect was through single tuber weight. The characters total number of leaves per plant and number of tubers per plant had negative indirect effect on tuber yield, the values being -0.7213 and -0.5226 respectively.

Girth of the tuber had the highest positive correlation with tuber yield (0.9592). Its indirect effect via single tuber weight and number of leaves retained at harvest were positive, the values being 1.5387 and 0.3843 respectively. Girth of tuber also influenced the yield maximum through single tuber weight. Indirect effect via total number of leaves per plant was negative and very high (-0.6649).

Single tuber weight also had high positive correlation with tuber yield (0.8519). Its indirect effect via number of leaves retained at harvest and girth of tuber were positive, the values being 0.3711 and 0.1318 respectively. Total number of leaves per plant (-0.6605) and number of tubers per plant (-0.3928) had negative indirect effects on tuber yield.

DISCUSSION

5. DISCUSSION

A knowledge of the genetic factors that influence yield in crop plants is of great value for the efficient utilization of available germplasm. Tuber yield in tapioca is controlled by a number of plant and tuber characters. The identification, as well as assessment of the magnitude of association of these characters are important in directing the breeding efforts.

Yield being a complex quantitative character is controlled by polygenic system. The basic information on genetic parameters like coefficient of variation, heritability and genetic advance are essential pre-requisites in any breeding programme. In the present study efforts were made to estimate some of these basic parameters of quantitative variability and association of yield an its components. The contribution of yield components to tuber yield could be partitioned into direct and indirect effects by path analysis and it also helps to rank the order of importance given to the different characters on a sound basis.

Eight varieties of tapioca which are commonly cultivated in rice fallows, collected from different agroclimatic zones of Kerala formed the base material of the present investigation. These varieties were evaluated in a randomised block design with four replications from January to June in 1986. Besides yield and associated ten quantitative characters observations on the incidence of pests and diseases were also recorded. Chemical assay was conducted to elucidate the quality attributes such as starch content, HCN content and cooking expansion of tubers. The data were statistically analysed for the estimation of genetic parameters and association among characters. Path analysis was also done to assess the direct and indirect effects of the components of yield.

The results of the investigation are discussed in the succeeding pages.

5.1. Genetic parameters

The analysis of variance of twenty four characters revealed significant difference among the genotypes in respect of all characters except HCN content of the tubers. Significant differences among the genotypes were observed for all characters studied in tapioca by Biradar *et al*. 1978 and Radhakrishnan and Gopakumar 1984. In sweet potato Singh and Mishra (1975) and Thamburaj and Muthukrishnan (1976) recorded similar results.

Variability is indeed a valuable prerequisite for genetic improvement through selection. The more the variation better will be the response to selection. The present study provides ample scope for selection among the populations.

Genetic improvement of a crop depends on the variability present in the population. In respect of yield and its components a wide range of variability was noticed for characters like number of branches, number of leaves retained at harvest, utilization index, total number of leaves per plant, single tuber weight and tuber yield per plant. The range of variability was lowest for length of tuber.

Among the quality attributes cooking expansion and HCN content expressed higher magnitudes of variability. Starch content registered the lowest range of variability.

Reaction to pests and diseases displayed wide range of variability.

Thus the material studied provides ample scope in bringing about genetic improvement using traditional breeding methods.

5.1.1 Yield and its components

In general the genotypic coefficient of variation was lower than the phenotypic coefficient of variation for all the characters studied, indicating considerable environmental influence for the expression of these traits. Similar observations were recorded by Thamburaj and Muthukrishnan (1976) in sweet potato, Kamalam *et al.* (1977) and Biradar *et al.* (1978) in tapioca.

In the present study genotypic and phenotypic coefficients of variation were high for number of branches, number of leaves retained at harvest, utilization index, total number of leaves per plant and single tuber weight. Number of branches displayed maximum phenotypic and genotypic coefficients of variation. This observation differs from that of Singh and Mishra (1975) and Mahungu *et al.* (1983) who reported only moderate values for phenotypic and genotypic coefficients of variation for number of branches. High genotypic coefficient of variation for number of leaves per plant as in the present study was observed in sweet potato by Singh and Mishra (1975) and Thamburaj and Muthukrishnan (1976) and in tapioca by Biradar *et al.* (1978).

Contrary to the findings of the present study only moderate values for phenotypic and genotypic coefficients of variation were reported for harvest index by Mahungu et al. (1983) in tapioca. High genotypic coefficient of variation obtained for single tuber weight in the present study is in agreement with the report of Thamburaj and Muthukrishnan (1976) in sweet potato.

Plant height recorded lowest phenotypic and genotypic coefficients of variation indicating little scope for improvement of this trait by selection. Similar observations were made in tapioca by Biradar et al. (1978) and Mahungu et al. (1983).

The genotypic coefficient of variation gives a measure of the magnitude of genetic variability present in a population and provides an index for the nature of genetic improvement to be effected.

Tuber yield per plant and leaf area at four and five months after planting displayed only moderate genotypic coefficient of variation. Moderate genotypic coefficient of variation observed for tuber yield per plant is contrary to the findings of Thamburaj and Muthukrishnan (1976) in sweet potato. Biradar et al.

(1978) and Mahungu et al.(1983) had also reported high genotypic coefficient of variation for tuber yield in tapioca.

The characters number of tubers per plant, length of tuber, girth of tuber and leaf area at three months after planting displayed low values for genotypic coefficient of variation.

The low genotypic coefficient of variation for number of tubers per plant in the present study was not in agreement with the reports of Kamalam et al. (1977) and Mahungu et al. (1983) in tapioca.

Similar low genotypic coefficient of variation for girth of tuber and length of tuber were reported in sweet potato by Thamburaj and Muthukrishnan (1976).

5.1.2 Quality attributes

Among the quality attributes HCN content registered high phenotypic coefficient of variation and very low genotypic coefficient of variation indicating larger environmental influence. This finding supports the view that hydrocyanic acid content of tubers was a very much variable characteristic which was subjected to environmental influence (Jones, 1959). Cooking expansion of tubers displayed high values for both phenotypic and genotypic coefficients of variation. Starch content registered the lowest phenotypic and genotypic coefficients of variation indicating very little scope for improvement of this trait by selection.

5.1.3 Reaction to pests and diseases

In the present investigation highest values for phenotypic and genotypic coefficients of variation were displayed by mites present per leaf at four and five months after planting.

Cassava mosaic disease at three, four and five months after planting displayed relatively higher values for phenotypic and genotypic coefficients of variation.

Leaf spot disease at three, four and five months after planting had low phenotypic and genotypic coefficients of variation.

5.2 Heritability and genetic gain

The extent of success in selection programme depends upon the magnitude of heritable variation. Burton (1952) suggested that genotypic coefficient of variation together with heritability gave the best picture of the amount of progress to be expected by selection.

5.2.1 Yield and its components

In the present investigation high heritability estimates were observed for total number of leaves per plant, number of leaves retained at harvest, number of branches, single tuber weight, girth of tuber and utilization index, indicating that these characters were less influenced by environmental factors and had more number of fixable additive genes.

High heritability estimate for number of leaves per plant as in the present study was reported by Biradar et al. (1978) in tapioca, Singh and Mishra (1975) and Thamburaj and Muthukrishnan (1976) in sweet potato.

Radhakrishnan and Gopakumar (1984) reported very low heritability estimate for number of leaves retained at harvest in tapioca. Contrary to this finding very high heritability estimate was obtained for number of leaves retained at harvest in the present investigation.

The high heritability estimates for single tuber weight reported by Li (1975) in sweet potato is in full agreement with the present results.

A similar high heritability estimate for girth of tuber was reported by Thamburaj and Muthukrishnan (1976) in sweet potato. However, Radhakrishnan and Gopakumar (1984) reported very low heritability for girth of tuber in tapioca.

Kawano et al.(1978) reported high heritability for harvest index in tapioca. Relatively high heritability was reported for this variable by Mahungu et al. (1983) in tapioca.

Plant height displayed the lowest estimate of heritability in the present investigation. This result is in conformity with the report of Radhakrishnan and Gopakumar (1984) and Mahungu et al. (1983) in tapioca.

Heritability estimate was moderate for length of tuber, tuber yield per plant, leaf area at three, four and five months after planting and number of tubers per plant. Moderate heritability estimate for tuber yield per plant and number of tubers per plant obtained in this study are in full agreement with the findings of Mahungu et al. (1983) in cassava. Biradar et al.(1978) reported high heritability estimate for tuber yield indicating considerable scope for the improvement of this trait by selection. In sweet potato moderately high heritability for tuber yield was reported by Singh and Mishra (1975).

The expected genetic advance expressed as percentage of mean revealed large differences among the various characters studied. Genetic gain was maximum for number of branches (129.65) followed by number of leaves retained at harvest (82.30) and minimum for plant height (8.72).

Number of branches, number of leaves retained at harvest, total number of leaves per plant, utilization index, single tuber weight, tuber yield per plant and leaf area at five months after planting displayed high genetic gain in the present study. Report of Biradar et al (1978) in cassava is in agreement with the high genetic gain observed for total number of leaves per plant in the present investigation. The observation regarding number of branches, total number of leaves per plant, number of leaves retained at harvest and tuber yield per plant are in disagreement with the findings of Radhakrishnan and Gopakumar (1984) in tapioca. A similar high genetic gain for tuber yield was observed by Singh and Mishra (1975) in sweet potato.

Other quantitative traits such as leaf area at three and four months after planting, number of tubers per plant, length of tuber, girth of tuber and plant height showed moderate to low genetic gain. High genetic gain observed for number of tubers per vine by Thamburaj and Muthukrishnan (1976) and Kamalam et al. (1977) in sweet potato are in disagreement with the moderate genetic gain obtained in the present study. Similar low genetic gain for length of tuber as in the present study were reported by Thamburaj and Muthukrishnan (1976) in sweet potato and Radhakrishnan and Gopakumar (1984) in cassava. Low genetic gain for girth of tuber in the present study is in conformity with the findings of Radhakrishnan and Gopakumar (1984) in tapioca but contrary to the findings of Thamburaj and Muthukrishnan (1976) in sweet potato. Low genetic gain obtained for plant height in the present investigation is in conformity with the findings of Biradar et al. (1978) in cassava. However, the result reported by Radhakrishnan and Gopakumar (1984) in cassava is contrary to the present results.

Johnson et al. (1955) in their studies with soyabean had reported that heritability estimates along with genetic advance is more useful than heritability alone in predicting the resultant effect of selection. Since heritability determines the component of heritable variation and genetic advance measures the extent of its stability under selection, these two parameters should be considered in conjunction so as to bring effective improvement in tuber yield and other complex characters.

In the present study high heritability accompanied by high genetic gain was observed for number of leaves retained at harvest, number of branches, total number of leaves per plant, single tuber weight and utilization index. In cassava Biradar et al. (1978) also observed high heritability coupled with high genetic gain for total number of leaves per plant whereas Radhakrishnan and Gopakumar (1984) reported low heritability and low genetic gain for this trait. For number of branches a similar result was observed in sweet potato by Lin (1983). However, Radhakrishnan and Gopakumar (1984) reported moderate heritability and moderate genetic gain for number of branches. A similar result for single tuber weight as in the present study was observed in tapioca by Radhakrishnan and Gopakumar (1984) and in sweet potato by Li (1975).

High heritability accompanied by high genetic gain for the above characters in the present investigation indicates the possibility of further improvement of these characters through selection. If high heritability is mainly due to additive gene action, then the genetic gain will be high (Panse, 1957).

Tuber yield per plant had moderately high heritability and high genetic gain. But Singh and Mishra (1975) in sweet potato and Biradar et al.(1978) in cassava observed high heritability and genetic gain for tuber yield per plant. In sweet potato high heritability and high genetic gain for girth of tuber was observed by Thamburaj and Muthukrishnan (1976) but the character showed high heritability and low genetic gain in the present study. Moderately high heritability and low genetic gain for length of tuber as in the present study was reported by Thamburaj and Muthukrishnan (1976) in sweet potato and Radhakrishnan and Gopakumar (1984) in tapioca.

Number of tubers per plant had moderately high heritability and low genetic gain. Contrary to this result Thamburaj and Muthukrishnan (1976) and Kamalam et al. (1977) reported high heritability and high genetic gain for this trait.

High heritability coupled with low genetic gain for girth of tuber, length of tuber and number of tubers per plant shows that selection has only limited scope for improving these traits. Johnson et al.(1955) based on their work on soy bean pointed out that high heritability need not be accompanied by high genetic gain estimates. If high heritability is mainly due to nonadditive gene action then the genetic gain will be low (Panse, 1957).

Plant height had low heritability accompanied by low genetic gain. Similar trend was noticed by Biradar et al.(1978) in cassava. This character is therefore, not likely to responsed favourably to selection.

Characters which had high coefficient of variation had genetic gain also. Number of branches, number of leaves retained at harvest, utilization index, total number of leaves per plant and single tuber weight had high genetic gain and genotypic coefficient of variation. In addition these characters had high heritability also. These characters also form components of yield. Hence it would be advantageous for the breeder to formulate selection programme for high yielding strains in tapioca on the basis of these characters.

5.2.2 Quality attributes

The important quality attributes namely starch and HCN content displayed both low heritability and low genetic gain, suggesting that the characters are under the control of nonadditive gene action. As such selection cannot be profitably employed for improving starch content of tubers. Cooking expansion of tubers exhibited moderately high heritability and genetic gain indicating very little scope for the improvement of this character by selection.

5.2.3 Reaction to pests and diseases

Cassava mosaic disease at three, four and five months after planting, leaf spot at four months after planting and mites present per leaf at four and five months after planting displayed high heritability in the present experiment. Leaf spot at three and five months after planting showed moderate heritability.

Cassava mosaic disease at three, four and five months after planting, leaf spot disease at five months after planting and mites present per leaf at four and five months after planting displayed higher estimates of genetic gain. Leaf spot disease at three and four months after planting displayed low estimates for genetic gain.

Characters having high heritability as well as high genetic gain in the present experiment were cassava mosaic disease at three, four and five months after planting, leaf spot disease at five months after planting and mites present per leaf at four and five months after planting. High heritability accompanied by high genetic gain in these characters indicates that the feasibility of reducing the incidence of this pest and diseases is remote by employing selection procedures.

5.3 Correlation Studies

5.3.1 Association of yield and its components

A number of interesting relationships could be observed from genotypic correlation matrix. At genotypic level yield bears significant positive association with length and girth of tuber, single tuber weight and utilization index.

A similar high positive association between yield and length of tuber as in the present study was observed by Magoon (1972), Muthukrishnan *et al.* (1973) and Magoon and Krishnan (1973) in tapioca, Pushkaran et al.(1976) and Thamburaj and Muthukrishnan (1976) in sweet potato.

A significant positive association between yield and girth of tuber as in the present study was reported by Magoon (1972), Muthukrishnan et al.(1973), Magoon and Krishnan (1973), Williams (1974) and Radhakrishnan and Gopakumar (1984) in tapioca and in sweet potato by Pushkaran et al.(1976) and Thamburaj and Muthukrishnan (1976).

Yield had genotypically significant positive association with single tuber weight. Wilson (1970), William (1974), Biradar et al.(1978) and Radhakrishnan and Gopakumar (1984) in tapioca and Lowe and Wilson (1975) in sweet potato had reported earlier the occurrence of significant positive association between yield and single tuber weight.

Significant positive association between harvest index and yield was reported by many workers (Holmes and Wilson, 1974; Cock, 1976; Kawano et al., 1976; Kawano et al. 1977; Biradar et al. 1978; Kamalam et al. 1978; Kawano, 1978; Kawano et al. 1978 and Radha krishnan Gopakumar, 1984).

The other quantitative traits such as total number of leaves per plant, number of leaves retained at harvest, plant height, number of branches, number of tubers per plant and leaf area at three, four and five months after planting were found to be negatively associated with tuber yield.

Engi (1973) reported that in tapioca high yields could be achieved with a low leaf production cultivar provided that high harvest indices were realised. This is true for varieties like Karukannan, Pravuvella and 4/84. They are high yielders with utilization indices above one and having comparitively low leaf production potential. Biradar et al.(1978) also made a similar report. In the present study yield had registered a negative correlation with total number of leaves and number of leaves retained at harvest. This was clearly demonstrated in the performance of Mankozhanthan and 4/84. This may be attributed to the conversion of more photosynthates for vegetative growth and thus making available very little metabolites for tuberization. Contrary to the findings in this study Radhakrishnand Gopakumar (1984) reported significant positive correlation between yield and number of leaves retained at harvest.

Significant positive association between plant height and tuber yield reported by Muthukrishnan _et al_. (1973) and Kamalam _et al_. (1978) in tapioca are in disagreement with the present results.

Tuber yield and number of branches displayed a negative correlation. This was obvious in Mankozhanthan, 2/84, 4/84 and the negative association observed between number of branches and tuber yield in the present study is not in conformity with the reports from CTCRI in tapioca (Anon. 1973).

Negative association between number of tubers and tuber yield observed in the present study differs from the reports of Wilson (1970), Magoon (1972), Kamalam _et al_. (1977), Biradar _et al_.(1978) and Kamalam _et al_. (1978) in tapioca.

Engi (1972) reported negative relationship between leaf area and tuber yield in multishoot plants of tapioca. Similar reports were also made by Muthukrishnan _et al_. (1973) in tapioca and Pushkaran _et al_. (1976) in sweet potato, while significant positive association between leaf area and tuber yield reported by Sushama _et al_. (1982) is in disagreement with the present results.

Total number of leaves per plant was found to be significantly and positively correlated with plant height. Similar observation was made by Muthukrishnan et al.(1973) in tapioca. The character exhibited significant negative correlation with length of tuber contrary to the report of Muthukrishnan et al.(1973). Significant negative association between utilization index and total number of leaves per plant in the present study is in agreement with the report of Kamalam et al. (1978) in tapioca.

Single tuber weight and leaf area at four and five months after planting displayed negative correlation with total number of leaves per plant.

Number of leaves retained at harvest displayed significant positive correlation with plant height and number of branches, while the character showed significant negative association with length of tuber and utilization index. Contrary to the present results Radhakrishnan and Gopakumar (1984) reported significant negative association between number of leaves retained at harvest and number of branches and significant positive correlation between number of leaves retained at harvest and length of tuber.

Significant negative association was noticed between plant height and length of tuber. However, Muthukrishnan *et al.*(1973) obtained a positive association between these two traits in tapioca. A strong negative association observed between plant height and girth of tuber disagrees with the report of Muthukrishnan *et al.* (1973) in tapioca. Plant height was found to be significantly and negatively correlated with single tuber weight and utilization index.

The association of number of branches with length of tuber and utilization index were negative and significant and the character also displayed negative association with girth of tuber and single tuber weight.

Length of tuber and number of tubers per plant and girth of tuber and number of tuber per plant had significant negative association.

A negative significant association obtained in the present study between tuber number per plant and single tuber weight is in conformity with the reports of Holmes and Wilson (1974) and Lowe and Wilson (1975) in tapioca indicating that cultivars with lower tuber numbers normally produce a higher percentage of marketable yields. It is well demonstrated in varieties Pravuvella and Padinjattinkara vella.

Correlation between length of tuber and girth of tuber was significant and positive. Similar result was reported in tapioca by Magoon (1972). Length of tuber had significant positive correlation with single tuber weight and utilization index. Muthukrishnan *et al.* (1973) reported a negative relationship between length of tuber and leaf area, but the association between length of tuber and leaf area was positive and nonsignificant in the present study.

Girth of tuber was found to be significantly and positively correlated with single tuber weight and utilization index. Negative association observed between girth of tuber and leaf area is in conformity with the reports of Muthukrishnan *et al.* (1973) in tapioca and Pushkaran *et al.* (1976) in sweet potato.

The association of single tuber weight with utilization index was significantly positive. The character displayed nonsignificant negative association with leaf area. Utilization index was found to be negatively correlated with leaf area.

5.3.2 Association among quality attributes and yield components.

Correlation studies among quantitative characters and quality attributes namely starch content, HCN content and cooking expansion of tubers unveiled interesting aspects. Starch content displayed positive association with tuber yield. HCN content also manifested significant positive association with tuber yield. However, Magoon and Krishnan (1973) reported that in tapioca traits such as starch content and HCN content were independently inherited. Tuber yield per plant displayed significant negative correlation with cooking expansion of tubers.

In the present study heavier and longer tubers were found to contain more HCN. The situation was same in the case of tubers with higher girth. Heavier tubers contained more starch but its cooking expansion was found to be poor. Longer tubers are found to be poor in starch while thicker tubers possessed higher starch. Cooking expansion of longer as well as thicker tubers are poor.

From the correlation studies among the quality attributes it is clear that tubers with high starch content possess low HCN and poor cooking expansion. This may be due to the presence of higher sugar in the tubers. Cooking quality of cassava tubers were not only governed by starch content alone but also by the distribution of starch, its swelling properties and sugar content. High starch content, uniform starch distribution and low sugar content led to soft and mealy nature of cooked tubers. Cassava varieties with low starch and high sugar content did not cook well owing to the increased solubility of starch in the presence of sucrose, thereby reducing the swelling power (Anon. 1985).

5.3.3 Association among important yield contributing characters and reaction to pest and diseases

Number of leaves per plant was found to be negatively correlated with cassava mosaic disease, leaf spot disease and mites present per leaf. This finding is in agreement with the reports of Hunt (1974) who reported that tapioca cultivars producing leaves rapidly were better as they were able to replace damaged leaves and no significant reduction in yield was realised. Nair and Malathi (1981) reported that effect of cassava mosaic disease on number of leaves produced was not significant.

Negative association was observed between plant height and cassava mosaic disease indicating that virus infection significantly reduced the plant height.

Thankappan and Chacko (1976) reported 16.4 per cent reduction of plant height by the infection of virus disease while, Nair and Malathi (1981) observed little reduction of height by the occurrence of cassava mosaic disease. Plant height was also found to be negatively correlated with leaf spot disease and mite attack.

In the present investigation it was observed that the occurrence of leaf spot did not significantly affect the number of tubers per plant and this finding is in conformity with the observation made by Teri et al.(1980).

Single tuber weight displayed positive association with cassava mosaic disease, leaf spot and mite attack.

Non-significant positive association was observed among tuber yield and cassava mosaic disease, leaf spot and mite attack indicating that there was no considerable yield reduction on account of neither diseases nor pest attack. However, Golding (1936), Tidbury (1937), Thankappan and Chacko (1976) reported yield reduction to varying degrees due to cassava mosaic disease. This may be attributed to the different materials subjected for experimentation.

5.4 Path analysis

Path analysis revealed that single tuber weight contributed the maximum direct effect to tuber yield in tapioca. Similar report was made by Radhakrishnan and Gopakumar (1984), while Kamalam *et al.* (1977) reported high positive direct effect for weight of individual tubers in sweet potato.

Total number of leaves per plant registered strong positive direct effect on tuber yield in the present study. This result differs from the finding of Radha krishnan and Gopakumar (1984) in tapioca who reported very low value for direct effect of this trait. Thambu raj and Muthukrishnan (1976) reported negative direct effect of number of leaves per plant on tuber yield contrary to the present results.

The negative association between number of leaves per plant and yield inspite of very high direct effect was mainly due to the negative indirect effect of number of leaves retained at harvest. Such a situation suggests that if there are more number of leaves per plant higher would be the number retained at harvest with consequent reduction in yield. Therefore selection should be based on higher number of total leaves per plant but when the plant approaches harvest majority of them should get abscissed in a relatively brief period. Number of tubers per plant also showed significant positive direct effect on tuber yield. Pushkaran et al. (1976) and Kamalam et al. (1977) in sweet potato and Radhakrishnan and Gopakumar (1984) in tapioca obtained similar results. The high direct effect of number of tubers per plant was nullified by the high negative indirect effect mainly through single tuber weight.

Girth of tuber registered positive direct effect on tuber yield. Thamburaj and Muthukrishnan (1976) and Pushkaran et al. (1976) reported that girth of tuber contributed maximum direct effect on tuber yield, but Radhakrishnan and Gopakumar (1984) reported that girth of tuber recorded negative direct effect on tuber yield. Its indirect effect via single tuber weight was higher than its direct effect on tuber yield.

All other characters except plant height showed negative direct effect on tuber yield. Plant height had a positive and nonsignificant direct effect on yield. The positive direct effect of plant height was insignificant when compared to its high negative correlation with tuber yield which is due to the high negative indirect effect (via) single tuber weight. Similar result was reported by Kamalam et al. (1977) in sweet potato.

The characters number of leaves retained at harvest and number of branches had negative association and negative direct effect on tuber yield. Hence these two traits are unsuitable for prediction of yield.

Plant height, number of branches and number of leaves retained at harvest exhibited significant positive indirect effects on yield through total number of leaves per plant. These three traits had significant positive association with total number of leaves per plant and significant negative correlation with yield. Total number of leaves per plant also had significant negative correlation with yield.

Girth of tuber had the strongest positive correlation with yield but its direct effect on yield was low when compared to single tuber weight and total number of leaves per plant.

The direct effect of length of tuber on yield was negative and low inspite of the high genotypic correlation coefficient ($r = 0.5185$). This was mainly because of high negative indirect effects via total number of leaves per plant and number of tubers per plant. Length of tuber though positively correlated with yield does not seem to be a desirable character for selection in tapioca in contrast to the earlier reports of Pushkaran et al. (1976) in sweet potato.

Single tuber weight had the highest direct effect on tuber yield. In addition the indirect effects of length of tuber and girth of tuber through single tuber weight were high. Hence it is evident that single tuber weight would be a valid criterion for selection of high yielding plant type in tapioca.

Girth of tuber also had a positive direct effect on tuber yield. Its magnitude was mainly enhanced by indirect effect through single tuber weight. It is significant that other characters effected tuber yield through single tuber weight. However, single tuber weight and total number of leaves per plant exerted opposite influences on tuber yield though both showed high direct effects. Had there been no strong negative indirect effect via total number of leaves per plant the correlation between single tuber weight and tuber yield would have been still higher. Hence if maximum tuber yield is to be obtained in tapioca a compromise between single tuber weight and total number of leaves per plant would be rewarding. According to Thamburaj and Muthukrishnan (1976) in order to get higher yield in sweet potato the weight of foliage, girth of tuber and number of tubers being the most important yield components, they must be improved with a reduction in number of leaves, length of petiole and length of tuber. The present study suggested the importance of single tuber weight and girth of tuber as major components of tuber yield in tapioca. If a selection programme is designed to improve the single tuber weight and girth of tuber to a certain limit, the tuber yield could be increased considerably, simultaneously total number of leaves per plant is to be reduced to the optimum level. Length of tuber though had a negative direct effect it had significant positive correlation with tuber yield and influenced the tuber yield indirectly through single tuber weight. In order to effect considerable improvement in tuber yield it is however, suggested that due importance to length of tuber to a certain extent should also be given.

The path analysis thus projects single tuber weight, girth of tuber and to a lesser extent length of tuber as the three factors exerting the greatest influence directly and indirectly upon tuber yield in tapioca.

Based on the present investigation an ideal plant type of tapioca would consists of dwarf stature, minimum number of branches optimum number of leaves with minimum to be retained at maturity coupled with a reasonable number of tubers, maximum single tuber weight and high girth and reasonable length of tuber.

An estimation of tuber production per day revealed that the high yielding and local varieties produced 10.79 and 3.78 gm of tuber per day per plant respectively while the top yielders of the present investigation namely 4/84 Pravuvella, Karukannan, Padinjattinkaravella produced 17.5, 17.03, 15.85 and 14.02 gm per day per plant respectively and matures in 180 days. These genotypes will indeed be high yielders, ideally suitable to be cultivated in paddy fields.

SUMMARY

6. SUMMARY

Eight varieties of tapioca (Manihot esculenta Crantz) were tested in a randomised block design with four replications and evaluated for yield and ten quantitative characters besides three quality attributes and reaction to pest and diseases. The major objectives of the study were to assess the extent of variability present in the population by estimating genetic parameters, to identify early maturing superior genotypes, to find out the association of different characters and to determine the direct and indirect influence of different component characters on yield using path coefficient analysis.

The salient results of the study are summarised below.

6.1. Coefficient of variation, heritability and genetic advance

Among the characters studied genotypic coefficient of variation was maximum for number of branches followed by number of leaves retained at harvest and utilization index. Relatively high heritability was manifested by total number of leaves per plant, number of leaves retained at harvest, number of branches, single tuber weight and utilization index suggesting that these characters have more number of fixable additive genes. Tuber yield displayed moderately high heritability and genetic gain indicating scope for selection of high yielding types.

Heritability and genetic gain estimates were low for root quality attributes namely starch, HCN content and cooking expansion of tubers which indicated that the characters were governed by nonadditive genes. High heritability accompanied by high genetic gain observed in Cassava mosaic, leaf spot disease and mite attack indicated that the feasibility of reducing the incidence of this pest and diseases is remote through selection in the present materials.

6.2 Correlation

Correlation studies revealed that length of tuber, single tuber weight and utilization index were the important contributing characters to yield. Yield had registered negative correlation with total number of leaves per plant, number of leaves retained at harvest and number of branches. Sparsely branching plant type can be advantageously utilized for adopting closer spacing and thereby enhancing yield.

Increased yield was generally associated with increased starch and HCN content. Heavier and longer tubers were found to contain more HCN. Heavier tubers contained more starch, while the cooking expansion was found to be poor. The correlation between starch and HCN content was negative.

Tuber yield, single tuber weight and utilization index showed positive correlation with cassava mosaic disease leafspot disease and mite attack, while number of leaves per plant, number of leaves retained at harvest and plant height were found to be negatively correlated with the diseases and pest.

6.3 Path analysis

Path analysis revealed that total number of leaves per plant, single tuber weight and number of tubers per plant were the three major factors exerting significant direct influence on yield. A tendency for relatively more number of leaves to become abscissed towards the time of harvest should be considered as a positive sign of high tuber yield. Girth of tuber had the strongest positive correlation with yield but its direct effect on yield was low when compaired to single tuber weight and number of leaves per plant. Single tuber weight had the highest direct effect on yield besides, the indirect effect of length of tuber and girth of tuber through single tuber weight were also high. Single tuber weight and total number of leaves per plant exerted opposite influences on tuber yield though both showed high direct effects. Hence if maximum tuber yield is to be obtained in tapioca a compromise between single tuber weight and number of leaves per plant would be rewarding in selection programmes.

The path analysis thus projects single tuber weight, girth of tuber and to a lesser extent length of tuber as the three factors exerting greatest influence directly and indirectly upon tuber yield in tapioca.

Based on the present investigation an ideal plant type in tapioca would consists of dwarf stature, minimum number of branches, optimum number of leaves with minimum to be retained at maturity coupled with a reasonable number of tubers, maximum single tuber weight and length and girth of tuber.

An estimation of tuber production per day per plant revealed that the varieties 4/84, pravuvella, karukannan and padinjattinkaravella produced 17.5, 17.03, 15.85 and 14.02 g of tuber per day per plant respectively and matures in 180 days. These genotypes will indeed be high yielders ideally suitable for cultivation in wet land.

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* Original not seen.

STUDIES ON GENETIC PARAMETERS AND ASSOCIATION OF YIELD AND ITS COMPONENTS IN SHORT DURATION TAPIOCA VARIETIES (*Manihot esculenta* Crantz.)

BY

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ABSTRACT OF A THESIS
SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT
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MASTER OF SCIENCE IN AGRICULTURE
FACULTY OF AGRICULTURE
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DEPARTMENT OF PLANT BREEDING
COLLEGE OF AGRICULTURE
VELLAYANI, TRIVANDRUM

1987

ABSTRACT

A study was conducted at the Department of Plant Breeding, College of Agriculture, Vellayani during January to June 1986 with eight varieties of tapioca to identify suitable medium duration variety for wet land. Study of variability in the population, association among characters and determination of direct and indirect influence of different component characters on yield formed part of the objectives.

Genotypic coefficient of variation was maximum for number of branches followed by number of leaves retained at harvest and utilization index. High heritability was manifested by total number of leaves per plant, number of leaves retained at harvest, single tuber weight and utilization index. Quality attributes registered low estimates for heritability and genetic gain. High heritability accompanied by high genetic gain for cassava mosaic, leaf spot disease and mite attack indicated that the feasibility of reducing the incidence of this pest and disease is remote through selection in the present varieties. At genotypic level yield showed significant positive correlation with length and girth of tuber, single tuber weight and utilization index. Sparsely branching plant type can be advantageously utilized for adopting closer spacing and thereby enhancing yield.

Tubers with high starch content possess low HCN besides poor cooking expansion. Significant negative association existed between HCN content and cooking expansion. Tuber yield, utilization index and single tuber weight showed positive correlation with the incidence of pest and diseases.

Path analysis projects, single tuber weight, girth of tuber and to a lesser extent length of tuber as the three factors exerting greatest influence directly and indirectly upon tuber yield in tapioca.

Based on the present investigation it is proposed that potentially high yielders in this crop could be identified among relatively short statured ones with minimum number of branches, optimum number of leaves with minimum to be retained at maturity coupled with reasonable number of tubers having maximum single tuber weight with high length and girth. An estimationof tuber production per day per plant revealed that the varieties 4/84, pravuvella, karukannan and padinjattinkaravella are high yielders ideally suitable for cultivation in wet land.