MORPHOLOGICAL AND CYTOLOGICAL INVESTIGATIONS IN THE GENUS *Curcuma* Linn.

by

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Thesis submitted to the University of Bombay

For The Degree of

DOCTOR OF PHILOSOPHY IN BOTANY

1979

DEPARTMENT OF BOTANY

BHAVAN'S COLLEGE, ANDHERI, BOMBAY 400 058

SYNOPSIS OF THE THESIS

ENTITLED

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FOR

THE DEGREE OF DOCTOR OF PHILOSOPHY

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INTRODUCTION

Turmeric of commerce is the dried rhizome of two species, Curcuma longa Linn. (Syn. C. domestica Val.) and Curcuma aromatica Salisb. belonging to the family Zingiberaceae. India is the largest turmeric producing country in the world. During 1977-78 India produced 1,23,800 tons of turmeric from an area of 72,900 ha. Andhra Pradesh is the major turmeric growing state, which accounts for more than 30% of the total production in the country. Maharashtra, Tamilnadu, Orissa, Kerala and Bihar are the other important turmeric producing states in that order. Besides India, Sri Lanka, and Pakisthan are the major turmeric producing countries in the world.

The genus Curcuma comprises about 70 species of rhizomatous herb and from India about 30 species have been reported. Besides the two species of commercial importance, C. amada Roxb., Mango ginger; C. angustifolia Roxb., East Indian arrowroot; C. zedoaria Rosc., Zedoary; C. caesia, Black zedoary are of minor economic importance. More than

50 commercial cultivars are distinguished in this country by the names of localities where they are extensively cultivated. Majority of these cultivars belongs to the species C. longa, while a few cultivars with bright coloured rhizome belong to the species C. aromatica. Some of the popular cultivars are: Armoor, Duggirala, Erdukur, Tekurpetta, Allepey, Dindigam and Amalapuram. These cultivars are classified as long duration (9 months), medium duration (8 months) or short duration (7 months) based on the time taken for maturity of rhizome.

Though some of the improved cultivars are capable of yielding 30 to 35 tons of green turmeric from one hectare, the actually realised yield in this country is much less. The low average yield is to be attributed to the very little crop improvement work carried out till recently. Improved cultural and manurial recommendations are seldom adopted by the farmers. Earlier research works on improvement of turmeric were confined to varietal trials at some of the Agricultural Research Stations belonging to State Departments of Agriculture and Agricultural Universities in Andhra Pradesh, Tamilnadu and Kerala. However, systematic crop improvement work on turmeric was initiated after the sanctioning of All India Co-ordinated Spices and Cashewnut Improvement Project in 1971 with its headquarters at Kasaragod.

OBJECTIVES

While more than 50 commercial cultivars are available in turmeric, detailed information on morphological characteristics and rhizome development are not available even for popular cultivars. Earlier works in the genus were confined mostly to quality of rhizomes and processing techniques. The main objective of the present investigation is to describe morphologically the important commercial cultivars of C. longa and C. aromatica, and bring out morphological differences as well as inter-relationship based on generalised distance D^2 statistics and path co-efficient analysis. In literature it is reported that C. longa is a sterile triploid. In the present study, out of the 16 longa types under observation, seven have flowered and none of them has set seeds. All the 11 C. aromatica types have flowered and set seeds. Seedling progenies raised from seeds of aromatica types have also produced rhizomes. The possibility of inducing fruitset in C. longa is being investigated. The observations have indicated the possibility of bringing out inherent genetic variability in the cultivated types. Accordingly one of the objectives of the present investigation is to establish the possibilities of improving turmeric cultivars based on scientific breeding programme by exploiting the seedling variability. Chromosome number, meiotic behaviour and biochemical differences with reference to peroxidase banding

pattern, essential oil and curcumin contents are expected to show the differences among cultivars and species. Attempt has been made to classify the turmeric cultivars based on these morphological characters, rhizome development pattern, chromosome number and biochemical differences.

REVIEW OF EARLIER WORK

Curcuma longa is reported to be a native of southern or south-eastern Asia and according to Sopher (1964) no longer seemed to have capacity for fruiting. Burkill (1935) considered the species to be a cultigen. Till recently the species was believed to be a sterile triploid and the indication was that this species has resulted from continued selection and cultivation by vegetative propagation of some unidentified wild ancestor.

The classification and nomenclature of the genus Curcuma in spite of the authoritative works of Valeton (1918) remains very confused. According to Watt (1908) though several species of Curcuma are native to India, there is little positive evidence to justify the supposition that C. longa is native to India. C. longa is one of the 27 species of the sub-genus Eucurcuma whose original habitats include north-eastern India, Indo-China and Indonesian group of islands. Hooker (1894) described Curcuma under the natural order Scitamineae and tribe Zingiberese. But Rendle (1904) introduced the sub-family

zingiberoideae under Zingiberaceae and described Curcuma under the tribe Hedychieae. Hutchinson (1934) also described Curcuma under the tribe Hedychieae in the family Zingiberaceae.

Growth characteristics and rhizome development in turmeric were described in some detail by Shah and Raju (1975). Ambekar (1927) distinguished two groups of turmeric on the basis of rhizome characteristics, one with hard and bright coloured rhizomes and the other with softer, larger and light coloured rhizomes. The former variety of rhizome is mainly used for dyeing and the latter as a condiment. Some types of rhizome producing sweet aroma have been described by Rajaratnam (1923). Distinct differences in quality and yield were observed in the same variety when grown at different elevations (Narasimhan 1931). The crop grown on higher elevation gave better quality rhizomes. Valenton (1918) observed that all the cultivars in Java came to flowering, but the fruit set was observed in only two cultivars. Patnaik et al. (1960) and Pai (1961) reported floral biology and flowering behaviour of C. longa.

Cytological studies in the genus have been limited to the report of chromosome number and the first report on chromosome number in C. longa was by Saguira in 1931. Raghavan and Venkatasubban (1943) reported the chromosome

number for C. aromatica and C. longa. While a chromosome number of 2n = 42 was reported in C. aromatica, 2n = 62 was reported in C. longa. Venkatasubban (1946) made a preliminary survey on chromosome number in 38 species of various families of Zingiberaceae including C. sedoaria (2n = 64) and C. petiolata (2n = 64). An unusual chromosome number of 2n = 34 was reported in C. longa by Sato (1948). Chakravorti (1948) made considerable contribution to the karyological study of Zingiberaceae as a whole and reported for the first time the chromosome number of C. amada (2n = 42), C. sedoaria (2n = 63-64), seven cultivars of C. longa (2n = 62, 63, 64) and C. angustifolia (2n = 42). Cytology of six species and several varieties of Curcuma has been reported by Ramachandran (1961). He also studied in detail meiosis in C. decipiens (2n = 42), and C. longa (2n = 63). Based on the investigation he concluded that natural crossing has taken place between C. longa and C. aromatica and one of these is evolved from other by successful mutational steps, represented by many of the intermediate types available.

PLAN OF WORK

Seventeen cultivars of C. longa, eight cultivars of C. aromatica, one type of C. amada and one Indonesian type were planted in a replicated trial for 3 consecutive years starting from 1976. The plot size was 3 x 1 m

with 40 clumps for individual plot. Important morphological characters like number of tillers, number of leaves, height of the shoot and length and breadth of the last fully opened leaf and stomatal characters were recorded at 45th, 90th, 120th, and 150th days after planting. The data were subjected to generalised distance - D^2 statistic and path co-efficient analysis. Attempt has also been made to group cultivars based on morphology, rhizome development patterns, chromosome number, meiotic behaviour and biochemical characters. Seedling progenies were raised from 11 cultivars and implications of this discovery in the crop improvement work have been brought out.

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Signature of the Guiding Teacher

CERTIFICATE

I certify that the Thesis entitled "Morphological and cytological investigations in the genus *Curcuma*" embodies the results of investigations carried out by Shri M.C. Nambiar, under my supervision and guidance.

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STATEMENT

Curcuma is a genus comprising about 70 species of rhizomatous herbs belonging to the family Zingiberaceae. About 30 species of Curcuma are available in India, of which only two species, Curcuma longa Linn. (Syn. C. domestica Val.), and Curcuma aromatica Salisb. are of economic importance. India is the largest producer and exporter of turmeric. During 1977-78 India produced an estimated 1,23,800 tons of turmeric from an area of 72,900 ha. Besides India, Sri Lanka and Pakistan are the other major turmeric producing countries in that order. Orissa, Andhra Pradesh, Maharashtra, Tamilnadu, Kerala, Bihar, Himachal Pradesh, Uttar Pradesh, Karnataka, Assam and Meghalaya are the major turmeric growing states in India, among which Andhra Pradesh alone contributes for more than 30% of the total production.

More than 50 commercial cultivars are recognised in this country by the names of localities, where they are cultivated. Majority of the popular cultivars belongs to the species C. longa, while a few cultivars belong to C. aromatica. Armoor, Duggirala, Mydukur, Tekurpetta, Alleppey, Dindigam and Amalapuram of C. longa, Kasturi and Udayagiri of C. aromatica are some of the popular cultivars grown mostly in Andhra Pradesh. Though some

of the selections from the cultivars mentioned above are capable of yielding 30 to 35 tonnes of green turmeric from one hectare, the average yield realised is only about 10 tonnes per hectare. The low average yield (in this country) has been attributed to non-adoption of cultural and manurial practices by the farmers and very little crop improvement work carried out till now.

Systematic crop improvement work on turmeric was initiated after the sanctioning of All India Co-ordinated Spices and Cashewnut Improvement Project (AICSCIP) in 1971 with its Headquarters at Kasaragod. However, the crop improvement work being carried out under the AICSCIP confines to collections of cultivars from different localities and their comparative yield evaluation on regional basis, and selection. The work carried out under the AICSCIP has helped to identify some of the high yielding cultivars like Rydukur, Amalapuram, Duggirala Alleppey and Armoor types and cultivars with high curcumin content and oleoresin content.

The investigation reported here is the original contribution of the author. The study involved describing morphologically the important commercial cultivars of C. longa and C. aromatica to bring out the morphological differences as well as their inter-relationship based on generalised distance - D^2 statistics and path co-efficient

analysis. The biochemical studies with reference to peroxidase banding pattern, oil and curcumin contents have highlighted the differences between the cultivars within the species, as well as between the species. Cytological investigation with reference to somatic chromosome numbers, meiotic behaviour, pollen fertility and stomatal characteristics have further contributed towards understanding the relationship. The practical advantages of this study will be: (1) to classify the turmeric cultivars as differentiated based on descriptio D^2 statistics, path co-efficient analysis, biochemical characteristics as well as cytological behaviour, and (2) to formulate breeding programmes in the cultivated species, taking advantage of the seedling progenies reported for the first time.

SIGNATURE OF THE GUIDING TEACHER

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ACKNOWLEDGEMENTS

It is a pleasure to express my deep sense of gratitude and indebtedness to Dr. KA Patel, M.Sc., Ph.D., Vice Principal and Head of Biology Department, Bhavan's College, Andheri, Bombay for his valuable guidance, constant advice and keen interest throughout the progress of this investigation.

I would not have ventured to undertake this investigation, but for the advice and encouragement given by Dr. MS Swaminathan, FRS, the then Director-General, ICAR and present Secretary, Department of Agriculture, Government of India, and I record my respectful thanks to him for the same.

I am thankful to the Principal, Bhavan's College, Andheri, Bombay, Dr. KVA Bavappa, the former Director, and Dr. NM Nayar, the present Director, Central Plantation Crops Research Institute, Kasaragod for the laboratory and field facilities provided for this work.

I am also thankful to Mrs. PK Thankamma Pillai, Scientist S1, Central Plantation Crops Research Institute, Kasaragod for the help and assistance rendered at various stages of this work.

I wish to record my appreciation and thanks to my colleagues at Central Plantation Crops Research Institute, namely Shri R. Balakrishnan, Shri Jacob Mathew, Shri MV George, Dr.(Mrs.) MJ Ratnambal, Dr. YR Sarma and Dr. Balasimha for their help and assistance in conducting this investigation.

I also express my appreciation to Shri VL Jacob and Shri TK Narayanan Nambiar for typing the manuscript.

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INTRODUCTION

Turmeric of commerce is the dried rhizome of *Curcuma longa* Linn. (Syn. *C. domestica* Val.) belonging to the family Zingiberaceae, though *Curcuma aromatica* Salisb. a semi-wild species is also cultivated as a spice in certain parts of India. Other species of lesser commercial importance are *Curcuma amada* Roxb., Mango ginger; *Curcuma angustifolia* Roxb., East Indian arrowroot; *C. caesia* Roxb., Black Zedoary; *Curcuma xanthorrhiza* Roxb., and *Curcuma zedoaria* (Berg.) Rosc. Among the turmeric producing countries, India has the largest share in terms of area as well as production. The crop is commercially important to almost all the southern states with 30% of the total production being from Andhra Pradesh. The classification and nomenclature of genus *Curcuma* remains very confused, though systematic treatment has been given earlier by Watt (1908), Hooker (1894), Valeton (1918), Rendle (1904) and Hutchinson (1959). Holttum's (1950) classification of family Zingiberaceae has been presumed to be the most authoritative one, wherein he divided the family into two sub-families, i.e., Zingiberoideae and Costoideae. Hooker (1894) described *Curcuma* under the natural order Scitamineae and tribe Zingibereae. But, Rendle (1904) introduced the sub-family Zingiberoideae under Zingiberaceae and described

Curcuma under the tribe Hedychieae, with which Hutchinson (1959) also agreed.

Over 50 cultivars have been recognised in this country based on collection and evaluation. However, no attempt has been made so far to describe these cultivars scientifically. The breeding work has also been confined to only selection of the cultivars and comparative yield evaluation, since seed set had not been reported in the cultivated species till this investigation was undertaken. The variability observed among the cultivars of *C. longa* and *C. aromatica* has also not been investigated.

In earlier works, it is reported that *C. longa* is a sterile triploid. However, seed set has been observed in all the *C. aromatica* types that have flowered among the materials used in the present investigation.

Among different families under the order Scitamineae, only Musaceae has been investigated cytologically to some extent. Chromosome number in *C. longa* was reported by Saguira in 1931. Raghavan and Venkatasubban (1943) reported the chromosome number for *C. aromatica* and *C. longa*. Venkatasubban (1946), Sato (1948), Chakravarti (1948), and Ramachandran (1961, 1969) have also reported chromosome number in about six species. The only detailed meiotic study

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so far reported has been in Curcuma decipiens Dals. and C. longa (Ramachandran, 1961). Based on the cytological investigations Ramachandran (1961) concluded that natural crossing had taken place between C. longa and C. aromatica and one of these was evolved from the other by successful mutational steps, represented by many of the intermediate types available.

The biological population has been classified based on the multivariate analysis as established in several species (Nair and Mukherjee, 1960; Rao, 1960; Murthy and Pavate, 1962; Cassie, 1963), though this type of work has not been undertaken so far in the family Zingiberaceae except for the report on Zingiber officinale (Ratnambal, 1979). Biochemical approach to the classification of biological population has also been increasingly reported in recent years and an attempt has been made here for the first time to apply this latest technique in classifying Curcuma species and cultivars.

In the present investigation an attempt has been made to study the important morphological differences based on the generalised distance - D^2 statistics and path co-efficient analysis. An attempt has been made to group the cultivars based on morphology, rhizome development patterns, biochemical characteristics, chromosome number and microsporogenesis.

Seedling progenies were raised from 9 cultivars of G. aromatica and implications of this in crop improvement work have been brought out in detail.

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REVIEW OF LITERATURE

ORIGIN AND DISTRIBUTION

Turmeric (*Curcuma longa* L. Syn. *C. domestica* Val. and *Curcuma aromatica* Salisb.) is best known as a condiment, though the plant has other uses that are important in the social and religious life of the people in south-east Asia. The genus *Curcuma* belongs to the family Zingiberaceae and the cultivated species were domesticated in south-east Asian countries during the very early times. Though the source of cultivated species is not known with certainty, it has become naturalised in some areas specially in the north-eastern parts of India and the island of Java. The cultivated species were reported to be sterile triploid (Burkill, 1935, Purseglove, 1972), though seed set has been reported in a few species, recently. Turmeric combines the properties of a spice and a brilliant yellow dye stuff. The colouring matter, curcumin content, in the plant rhizome has for many centuries been used as a vegetable dye in the far-east.

Turmeric is listed as a colouring plant as early as 600 BC (Assyrian Herbals). In the medieval time, turmeric was known in Europe as 'Indian Saffron' (Rosengarten, 1972). It was cultivated in India from time immemorial and was referred to, in the early Sanskrit writings of 4th and 5th century AD. India is the major producer and exporter of turmeric at present and it is cultivated extensively in almost

all the states in India. From India, it is believed to have reached China by the 7th century. The distribution of turmeric outside India, specially in Celebes, Moluccas, Polynesian and Indonesian group of islands has been established beyond doubt (Sopher, 1964).

Among all spices, turmeric is considered to be the most versatile. Besides being used as a condiment it has been employed as a cheap colouring substitute for saffron and also in medicine. It forms even today a traditional part of wedding ritual and other religious ceremonies in India. In Indonesia, turmeric water is rubbed on the body just like the use of cologne (Rosengarten, 1973). In many parts of India, a form of the turmeric is applied on human body as a cosmetic, mostly due to its antiseptic properties. In many Asian countries it is also used medicinally as a carminative or as a cure for liver troubles. Boiled with milk and sugar it is recommended as a common remedy for cold. The dried turmeric tubers contain 2 to 6 per cent essential oils, which finds its use in flavouring spice products and perfumery.

Though the country of origin is not known definitely, it is undoubtedly of south-east Asian origin. According to Watt (1908) though several species of Curcuma are native to India, there is little positive evidence to justify the claim that C. longa itself is a native of India. According

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to Burkill (1935) turmeric reached East Africa in the 8th century and West Africa in the 13th century. The spice was introduced to Jamaica in 1783 by Edwards, where it has become naturalised at present. The crop is widely distributed throughout the tropical belt though its commercial cultivation is largely confined to India and other east Asian countries.

India is the largest turmeric producing country in the world. The estimated production of turmeric in India during 1977-'78 is 1,23,800 tonnes from an area of 72,900 ha. Andhra Pradesh is the major turmeric growing state which accounts for more than 30% of the total production in the country. Maharashtra, Tamilnadu, Orissa, Kerala and Bihar are the other important turmeric producing states (Anonymous, 1978).

TAXONOMY

The family Zingiberaceae was first described botanically by Koeing in 1783. According to Schumman (1904) Koeing's description of the family was much better than that of many of the later taxonomists. Our knowledge of the Indian Zingiberaceae has been greatly improved by the description of Roxburgh in Calcutta (Roxburgh, 1832) and the Malaysian Zingiberaceae was first described by Griffith in 1851. According to Holttum (1950), Baraninow in 1861 was the first to publish a monograph on the family Zingiberaceae. In 1904 Schumman published his most important work as a

monograph on the family Zingiberaceae in Englers "Pflanzenreich" in 1904. The family Zingiberaceae was separated into two sub-families namely Zingiberoideae and Costoideae by him and the sub-family Zingiberoideae was again divided into three tribes nemely Globbeae, Hedychiae, and Zingibereae. Hutchinson (1934) divided the family into four tribes namely Costoideae, Hedychiae, Globbae, and Zingibereae. Holttum (1950) generally concurred with Schumman's classification of the family into two sub-families viz., Zingiberoideae and Costoideae. He proposed three tribes viz., Globbae, Hedychiae and Alpinae under sub-family Zingiberoideae and the sub-family Costoideae included only the genus Costus.

The genus Curcuma is included in the tribe Hedychieae (Rendle, 1904; Hutchinson, 1934; Holttum, 1950). Seven other genera namely Zingiber, Hedychium, Cenantanbra, Scaphochlamys, Roscoeniberria, Kaempferia and Haniffia are also included in this tribe.

The classification and nomenclature of the genus Curcuma in spite of the authoritative works of Valeton (1918), Hooker (1894) and Holttum (1950) remains very confused. The genus Curcuma comprises about 70 species of rhizomatous herb, out of which about 29 species have been described by Hooker (1894) from India. A comparative description of the three species included in the present study is given below based on Hooker (1894), Holttum (1950), Purseglove (1972).

Curcuma L.

Root stock tuber bearing sessile and long stipitate tubers; leaves normally oblong, often very large. Flowers in dense compound spikes crowned by a coma of coloured enlarged bracts; lower bracts ovate, membraneous enclosing several bracteolate fugitive flowers which open in succession. Calyx short, cylindric minutely toothed. Corolla tube funnel shaped, segments usually ovate or oblong, upper longer and more concave. Lateral staminodes oblong, petaloid, connate with short filament, anther not crested, cells contiguous, spurred at the base, lips orbicular, tip deflexed. Ovary three celled, many ovuled; style filiform; stigma two lipped; lips ciliate. Capsule globose, membraneous, finally 3 valved, seeds ovoid or oblong, usually arillate.

1. C. longa L. widely cultivated in India. Rootstock ovoid, sessile tubers thick, cylindric. Leaf tuft 4-5 ft., petiole as long as the plain green blade, Peduncle hidden by the sheathing petiole. Spike autumnal, flower bracts pale green, ovate, those of the coma pale pink. Flowers as longas the bracts, like those of C. zedoaria and C. aromatica in structure.

2. C. aromatica Salisb. generally referred to as wild turmeric but cultivated in certain parts of India. Root stocks tuberous biennial, petiole as long as the blade. The blade is caudate, base deltoid, plain green above or variegated

with lighter and darker green, clothed beneath with fine persistent pubescence. Spike with peduncle produced with or before leaves; flower bracts ovate, pale green, those of the coma larger and more or less tinged with pink. Flowers shorter than the bracts. Upper half of the corolla to be funnel shaped, lateral segments oblong, upper longer, ovate, concave. Staminode obtuse, as long as the corolla segments; lips deflexed, orbicular yellow, obscurily 3-lobed; stigma obscurely 2-lobed.

3. C. amada Roxb., Mango ginger. Root stock ovoid, sessile tubers thick cylindric. Leaf tuft, petiole as long as the blade, plain green, tapering gradually to the base and apex. Peduncle hidden by sheathing base of the leaves. Spikes autumnal. Flowering bracts about 1", those of the coma tinged with pink. Flowers about as long as the bracts. Corolla whitish, lip pale yellow.

Some of the other species of economic importance are:

1. C. angustifolia Roxb., Indian arrowroot, occurs wild in India. It is cultivated for extracting starch from the rhizome and used similar to the true arrow-root.

2. C. zedoaria (Berg.) Rosc., Zedoary, spread in cultivation throughout India. The interior of the rhizomes is yellow and when dried has an agreeable musky odour with a slight smell of stimulant and carminative properties.

C. mangga Val. The rhizomes which smell like mango are used as seasoning for food.

C. zaccia Roxb. Black sedoary is a native of Bengal, where it is also cultivated. The aromatic rhizomes contain camphor and are used as a cosmetic and in indigenous medicine.

C. xanthorrhiza Roxb. It is the largest species of Curcuma reaching a height of 2 m and cultivated in Java and Malaysia. The deep yellow rhizome has a pungent smell and bitter taste. It is used in indigenous medicine and sometimes for food.

Growth characteristics and rhizome development in turmeric were described in some detail by Shah and Raju (1975) on the basis of rhizome characteristics. Ambekar (1927) distinguished two groups of turmeric, one with hard and bright coloured rhizomes and the other with softer, larger and light coloured rhizomes. According to him , the variety with bright coloured rhizome is mostly used for dying, whereas the variety with larger and light coloured rhizome are used as condiment. Rajaratnam (1923) described some cultivars, with rhizome producing sweet aroma. Differences in yield and quality has been observed in the same variety when grown at different elevations, and according to Narasimhan (1931) the crops grown on higher elevation have given better quality rhizomes. Valenton (1920) observed that all the cultivars in Java

came to flowering, but the fruit set was observed only in two. The floral biology, and flowering behaviour of C. longa has been reported by Patnaik et al. (1960) and Pai (1961).

BIOMETRIC STUDIES

Use of multivariate methods of statistical analysis like the D^2 statistic to classify biological populations has been well known in several species (Nair and Mukherjee, 1960; Rao, 1960; Murthy and Pavate, 1962 and Cassie, 1963).

Biometrical approach to the improvement of turmeric has not been attempted so far, though some work has been recently reported in ginger (Ratnambal, 1979; Mohanty and Sarma, 1979). Based on the multiple regression analysis using morphological characters, ie. height of plant, number of leaves and breadth and length of last fully opened leaf, Ratnambal (1979) concluded that the final yield could be fairly accurately estimated based on the data on 90th and 120th day after planting. Mohanty and Sarma (1971) estimated the genetic variability and heritability for 14 characters in 28 exotic and indigenous varieties of Zingiber officinale. They observed that the genetic co-efficient of variability, genetic advancement and heritability values were high for number of secondary fingers and totoal weight of roots. This study also indicated that straight selection can be made to improve all characters, except weight of root tubers.

number of tertiary fingers and straw yield. The path co-efficient analysis in 10 cultivars of Zingiber carried out by Rathambal (1979) revealed that the phenotypic correlation between the yield and height was quite high and also the direct effect of height towards the correlation was very high.

ELECTROPHORETIC STUDIES

Zone electrophoresis on polyacrylamide gels provides a useful tool for the evaluation of proteins and their taxonomic relationships. A crude protein extract when fractionated on a suitable gel medium produces a spectrum of bands. Homology among the bands of different species based on similarity in migration velocity provides a criterion of genetic affinity. The usefulness of electrophoretic techniques in plant systematics has been established by earlier workers (Boulter et al., 1967). Enzyme activity revealed as band on gels (isoenzymes) by specific enzyme staining methods has been employed to relate and compare proteins (Hart and Bhatia, 1967; Mitra et al., 1970). The studies have also been useful in the study of species relationships. Electrophoresis of analogous enzyme proteins has been done in Fabaceae (Thurman et al., 1967), among members of Triticinae (Bhatia, 1968; Barber et al., 1968), and in Brassica species (Vaughan and Waite, 1967) and also in fungi

(Clare et al., 1968, Hall et al., 1969).

CYTOGENETICS

Cytological studies in the order Zingiberales have been limited to the report of chromosome numbers except in Musaceae, which had been thoroughly investigated by various workers (Agharkar and Bhaduri, 1935; Cheesman 1932; Cheesman and Larter, 1935; Dodds, 1943, 1945; Chakravarti, 1948 and Simmonds, 1962). Sugiura (1936) was the first to report the chromosome number in G. longa.

A cyto-taxonomical approach to the family Zingiberaceae was made by Raghavan and Venkatasubban in 1943 wherein they reported chromosome numbers for 24 species including that of G. aromatica and G. longa. These authors reported a chromosome number of 2n = 42 for G. aromatica and 2n = 62 for G. longa. Venkatasubban (1946) made a preliminary survey of chromosome numbers in 38 species of various families of Zingiberaceae including two species of Curcuma, i.e., C. petiolata (2n = 64) and G. sedoaria (2n = 64). An unusual chromosome number of 2n = 34 was reported in G. longa by Sato (1948), which is probably a miscount. Sharma and Bhattacharya (1959) made an extensive study on the karyology of Zingiberaceae wherein they reported the widespread inconsistency for chromosome numbers in individual species. The significance of this in the evaluation of cultivated species has been

elaborated by them. Their study included C. amada (2n=42) and C. anguistifolia (2n=42).

Sato (1960) carried out the karyotype analysis in Zingiberales with special reference to the protokaryotype and stable karyotype, and in this study he reported a chromosome number of 2n=32 for C. longa and concluded that the species seems to be an allotetraploid with a basic number of x=8. Karyologically he found one pair of 'A' chromosome with medium constriction, and five pairs of 'A' chromosome with sub-median constriction, six pairs of 'B' chromosome with sub-median and sub-terminal constrictions and four pairs of 'C' chromosomes with sub-median and sub-terminal constrictions. He also observed a satellite at the proximal arm of one pair of 'A' chromosome and one pair of 'C' chromosomes. He concluded that the basic number for the genus Curcuma seems to be x=7 and 8, judging from the observation on the somatic chromosomes, and reported chromosome number of 2n=32, 62 and 64.

Chakravarti (1948) made considerable contribution to the karyological study of Zingiberaceae as a whole and reported for the first time the chromosome number of C. amada (2n=42), C. zedoaria (2n=63 and 64), seven cultivars of C. longa (2n=62, 63 and 64) and C. anguistifolia (2n=42).

Cytology of six species and seven cultivars of C. longa was reported by Ramachandran (1961). In this study he reported chromosome number of 2n=86 for the species C. aromatica, for the first time and concluded that the species is a tetraploid. In this report he also observed the meiosis of two species, C. decipiens (2n=42) and C. longa (2n=63). He observed a regular formation of bivalents in the former and high percentage of trivalent association in C. longa inspite of the small size of the chromosomes. The sterility of C. longa has been assumed to be due to its auto-triploid constitution. Based on the presence of forms showing character intermediate between C. longa and C. aromatica he concluded that natural crossing has taken place between these two species or alternately one of these is evolved from the other by successive mutational steps represented by these intermediate types. The herbaceous perennial habit of this plant, their vegetative mode of propagation and the small size of chromosomes favour the perpetuation of polyploid in this genus.

A further report on the chromosome numbers in Zingiberaceae by Ramachandran appeared in 1969, wherein he reported again the chromosome number for C. amada (2n=20,42), C. decipiens (n=21, 2n=42), C. neilgherrensis (2n=42), C. aromatica (2n=63,86), C. longa (2n=62) and C. zedoaria (2n=63). The study indicated a high basic number of n=21 for Hitchenia and Curcuma and he presumed

that Curcuma might have been derived either by dibasic amphidiploidy (by combination of lower basic number 9 and 12 found in some genera of the family) or by secondary polyploidy. The reported chromosome numbers in the genus Curcuma so far are given in Table 1.

Microsporogenesis and megasporogenesis in C. aurantiaca and C. loreyengii were reported by Sastrapradja and Aminah (1970). Among the two species, fruit set was observed only in C. aurantiaca and they concluded that the absence of fruit set in C. loreyengii was due to pollen abortion.

CROP IMPROVEMENT

More than 50 commercial cultivars of turmeric are distinguished in C. longa and C. aromatica in the country by the name of localities, where they are extensively cultivated. Majority of these cultivars belongs to the species C. longa, while a few cultivars with bright coloured rhizome belong to C. aromatica. Some of the popular cultivars are: Armoor, Duggirala, Mydukur, Tekurpetta, Alleppey, Dindigam and Amalapuram (Rao, Reddy and Subbarayudu, 1975). These cultivars are classified as long duration (9 months), medium duration (8 months) or short duration (7 months), based on the time taken for maturity of rhizome. Turmeric is a tropical crop grown in areas with an annual rainfall of 1,200 mm, though it can be grown in lesser rainfall

Table 1. Chromosome number in Curcuma Linn.

Sl. No.	Species/Cultivars	Chromosome number		Author and year
		n	2n	
1.	C. decipiens Dals.	21	42	Ramachandran, 1961, 1969
2.	C. neilgherrensis Wt.	—	42	Ramachandran, 1961, 1969
3.	C. amada Roxb.	—	42	Chakravarti, 1948; Sarma and Bhattacharyya, 1959 Ramachandran, 1969
4.	C. zedoaria Rosc.	—	64	Venkatasubban, 1946
		—	64	Chakravarti, 1948
		—	63	Ramachandran, 1961, 1969
5.	C. angustifolia Roxb.	—	42	Chakravarti, 1948
		—	42	Sarma and Bhattacharyya, 1959
6.	C. petiolata Roxb.	—	64	Venkatasubban, 1946
7.	C. aromatica Salisb.	—	42 ✓	Raghavan and Venkatasubban, 1943
8.	C. aromatica (GL puram)	—	63	Ramachandran, 1961
9.	C. aromatica (Kasturi Amalapuram)	—	86	Ramachandran, 1961
10.	C. aromatica (Polavarum)	—	86	Ramachandran, 1961
11.	C. longa	—	64	Suguira, 1936
		—	32	Sato, 1948
		—	62	Raghavan and Venkatasubban, 1943
		—	62	Sarma and Bhattacharyya, 1959
		—	62,63, 64	Chakravarti, 1948
12.	C. longa Duggirala	—	63	Ramachandran, 1961
13.	C. longa Kovvur Desavali	—	63	Ramachandran, 1961
14.	C. longa Thekurpetta	—	63	Ramachandran, 1961
15.	C. longa GL Puram-2	—	63	Ramachandran, 1961
16.	C. longa Kasturi Duggirala	—	63	Ramachandran, 1961
17.	C. longa Nellakntla Basupu	—	63	Ramachandran, 1961

areas under irrigation. The crop is cultivated from the sea level up to about 2,000 m in the Himalayan foot hills. It thrives best in loamy or drained loose fertile soils and cannot stand water logging.

Though some of the improved cultivars are capable of yielding 30 to 35 tons of green turmeric from one ha, the actual realised yield in this country is much less. The low average yield is attributed to the very little crop improvement work carried out till recently, and improved cultural and manurial practices seldom adopted by the farmers. Earlier research works on improvement of turmeric were confined to varietal trials at the Agricultural Research Stations belonging to the State Department of Agriculture.

However, systematic crop improvement work on turmeric was initiated after the sanctioning of the All India Co-ordinated Spices and Cashewnut Improvement Project in 1971. The crop improvement work even under this co-ordinated scheme has been confined to collection of cultivars from different localities, introduction from other turmeric growing countries and their comparative yield evaluation and selection. The comparative yield evaluation conducted under the AICSCIP so far has been helpful to identify the types with high yield potential (Selection No.15 from amalapuram type, Selection No.2

from Mydukur type) and high curcumin content (Selection No.21 (Alleppey type) and Selection No.20 (Theduppuzha Moovattupuzha type). Earlier reports indicate that turmeric is a sterile triploid which flowers but fails to set seed (Burkill, 1935; Purseglove, 1972). In view of the reported sterility no plant breeding work has been undertaken in this crop so far. The present investigation has clearly shown that at least C. aromatica has set viable seed which germinated and produced healthy seedlings, and thus opens out a new vistas in crop improvement programme of this important spice.

Very little information is available on the cultural and manurial requirements of turmeric. Isolated reports have appeared on the effect of spacing, weight of seed rhizome and time of sowing on the yield. Hussain and Said (1965) obtained higher yield with larger-sized seed rhizome. Early sowing resulted in higher yield, probably because of an early start to the crop (Agnihotri, 1949; Randhawa and Nandpuri 1966; and Randhawa and Misra, 1974). Closer plant spacing recorded better yield in turmeric, evidently due to higher plant population per unit area (Randhawa and Nandpuri, 1966; Said and Altaf, 1963). This observation was confirmed by Randhawa and Misra (1974) in their study, wherein higher yield was obtained in 22 x 22 cm spacing compared to wider spacing up to 38 x 46 cm.

MATERIALS AND METHODS

I. MATERIALS

Sixteen cultivars of Curcuma longa, eleven cultivars of Curcuma aromatica, one type of Curcuma amada and one Indonesian type used in the present investigation, were from the germplasm collection maintained at the Central Plantation Crops Research Institute, Kasaragod. The materials were planted in two replications of 40 plants each planted in raised beds of 3 m^2, consecutively for 3 years during 1976-'78. During 1976 the weight of the seed rhizomes, its length and number of nodes were recorded, for mother rhizomes as well as fingers at the time of planting. The details of the materials used for the present study are given in Table 2.

II. METHODS

(1) Morphology. For the morphological and biometrical studies 16 cultivars of C. longa and two cultivars of C. aromatica were used. In addition to these, six more cultivars of C. aromatica for which data on morphological characters were available during 1977-78, were also used for part of the investigation. The morphological characters were recorded for 18 plants selected at random from each bed. Number of tillers, number of leaves,

Table 2. Cultivars of C. longa and C. aromatica

Sl. No.	Name of species	Selection No.	Name
1.	Curcuma longa	2a	Mydukur
2.	"	4a	Gorakhpur
3.	"	8e	Kuchipudi
4.	"	11a	Ventimitta
5.	"	12a	Amritapani
6.	"	13e	Nandyal type
7.	"	14b	Rajapuri local
8.	"	15b	Amalapuram
9.	"	16a	Wynad local
10.	"	18a	T. Sunder
11.	"	20a	Moovattupusha
12.	"	21a	Alleppey
13.	"	23a	Duggirala
14.	"	24d	No. 24
15.	"	27a	Ethamukula
16.	"	28a	Thodupusha
17.	Curcuma aromatica	50	Kasturi
18.	"	51	Kasturi tanuka
19.	"	52	GL Puram
20.	"	53	Jobedi
21.	"	54	Dahgi
22.	"	55	Dindigam
23.	"	56	Katergia
24.	"	57	Udayagiri
25.	"	58	Amalapuram
26.	"	59	GL Puram-I
27.	"	60	Chayapasupu
28.	Curcuma amada		
29.	Curcuma sp. Indonesian type		

height of plant, and length and breadth of last fully opened leaf were recorded at 45th, 90th, 120th and 150th days after planting. The rhizome characters such as number of mother rhizomes and fingers, number of nodes per unit length, length and circumference of mother rhizomes and fingers and yield per clump were recorded. In the first year, data pertaining to fifteen cultivars alone were used for analysis, as rhizome characters and final yield could not be recorded for the other three cultivars, due to the severe incidence of rhizome rot disease caused by Pythium sp.

Analysis of variance was carried out, for the morphological characters recorded on the 120th day and the rhizome characters were recorded at the time of harvest, to test for the differences between cultivars, based on individual characters.

Data recorded on seed rhizomes were made use of, for regression analysis, to study the effect of initial morphological characters on final yield.

The differences among the cultivars for the aggregate of four morphological characters and five rhizome characters, excluding yield, were tested by Wilk's λ criterion (Rao, 1952).

For understanding the divergence between the cultivars, the individual D^2 values were obtained, for all the possible pair-wise combinations of them, for both the years. There were 105 such D^2 values during the first year (for 15 cultivars) and 153 during the second year, when data for all the cultivars were available. Utilising D^2 values, the cultivars were grouped into different clusters, following Tocher's method (Rao, 1952).

Based on the phenotypic correlation between the variables under study, and yield of plant, the standardised partial regression coefficients were worked out. The correlation between yield and individual morphological characters were partitioned into direct and indirect effects, to study the magnitude of character association.

The linear relationship between morphological characters observed on the 120th day and the final yield was studied, using the multiple regression technique, with a view to examining the possibility of predicting the final yield.

In order to study the linear relationship between yield (Y) and morphological characters such as number of tillers (x_1), number of leaves (x_2), height of the plant (x_3), the product of length and breadth of the last fully opened leaf (x_4), number of mother rhizomes (x_5),

number of fingers (x_6) and average number of nodes per unit length of the fingers (x_7), a multiple linear regression analysis was carried out.

(2) Biochemical studies. Fractionation of the protein extract was done by gel electrophoresis in 10 per cent SDS polyacrylamide gels (Shapiro, Vinuela and Maisel, 1967).

Protein extracts from leaf samples were prepared in 0.1M phosphate buffer (one part leaf sample to three parts phosphate buffer - pH 7.2, by weight). The mixture was shaken well in a separating funnel with three to four changes of chloroform to remove chlorophyll and then a 1:1 mixture of chloroform and petroleum ether. The extract was then shaken well with pure petroleum ether for several times until the last trace of oil is removed. The extract was concentrated in saturated sucrose solution for 24 hours.

The phosphate buffer extractable protein was heated in a boiling water bath for 5 minutes. Enough glycerol phosphate was then added to give a final concentration of 20% glycerol phosphate. Bromophenol blue (0.05%) was used as tracking dye.

Electrophoresis was performed at 4 m amps/running tube for five hrs. The gel was stained with 1% Coomassie brilliant blue (for 2 hrs) and then destained by

successive changes in 7% acetic acid during a period of 24-36 hrs until the stained bands were clear. The migration of bromophenol blue was taken as the reference band within each gel for calculation of Rf values.

Oil and curcumin content were estimated for 16 cultivars of C. longa and 6 cultivars of C. aromatica, based on the method reported by Janaki and Bose (1967 in Shankaracharya and Natarajan, 1974). For estimation of oil, 20 g of well-powdered turmeric sample was put on a filter paper, folded and put into a Whatman extraction thimble. The thimble was put in the extraction column of the Soxhlet Extraction apparatus and extracted with petroleum ether for about 16 hrs. The contents were poured into a previously weighed evaporating dish, all the ether was allowed to evaporate, cooled and weighed as oil.

The residue obtained from the extraction of oil was again extracted with benzene for about 48 hours (or till the condensing liquid was free of any yellow colour). The contents of the flask was evaporated and weighed as curcumin.

Colour grading for leaf and turmeric powder in 16 cultivars of C. longa and 2 cultivars of C. aromatica was carried out based on Nickerson's Colour Chart.

(3) Seed propagation. Though flowering is observed in C. longa and C. aromatica, seed set was obtained in the

latter species only. The mature and dry inflorescences were harvested and trashed in December-January to extract the seed. The extracted seeds were sown in 15 cm diameter petri plates lined with filter papers inside. Only dark and comparatively heavier seeds were selected for germination trial. Before sowing, seeds were washed thoroughly in water and treated with Bavistin (0.1%) solution for 30 minutes to avoid fungal and bacterial contamination. The seeds germinated in 8 to 20 days and the seedlings were transplanted to polythene co tainers at 2-leaved stage. At the end of the first season, when the aerial parts started withering, the plants were uprooted and examined. After recording observations, the small rhizomes were transplanted to the bigger polythene bags containing potting mixture. During the second season normal growth of the clump was observed. The germination data during the first season and seedling characters including stomatal measurements and chromosome numbers for each progeny rows were recorded.

(4) Cytology. Three cultivars of C. longa and five cultivars of C. aromatica were studied for their meiotic behaviour. The remaining cultivars could not be used for cytological investigation as they failed to flower in the experimental plots. For the meiotic study, flower buds were collected between 10.00 and 11.00 a.m.

and fixed in Carnoy's fluid (6 parts of ether alcohol, 3 part chloroform and one part acetic acid), after extracting the buds from the inflorescence. 24 hours after fixation, the materials were washed and stored in 70% alcohol. The anthers were smeared in 1% acetocarmine. Meiotic stages were analysed from temporary preparations and were made permanent subsequently.

Somatic chromosome numbers were determined from the root tip squashes following the method adopted by Ratnambal (1979) in ginger. The technique consisted of collecting root-tips at different times in saturated solution of alpha bromonaphthalene for 4 hours at low temperature and fixing in Ostergren and Heneen's (1962) fixative. The materials were fixed for 24 hours, hydrolysed in 1N HCl for 10 minutes, stained in 0.5% leuco basic fuchsin and squashed in 1% acetocarmine. Intact and well-spread metaphase plates alone were considered for counting the chromosome numbers. For the study of pollen fertility, fully opened flowers were collected and anthers about to dehisce were squeezed in 1 per cent acetocarmine - glycerine (1:1). Only well stained and full grains were considered as fertile.

A fine peeling from the lower epidermis of the leaf was obtained and treated with methanol for four minutes to fix the stomata in open condition. The peeling was washed carefully in distilled water and mounted in glycerine. Stomatal counts were taken by a graticule and measurements were made by an ocular micrometer.

RESULTS

I MORPHOLOGICAL CHARACTERS

The mean values for the morphological characters recorded on the 120th day after planting and rhizome characters recorded at the time of harvest, are presented in Table 3. Analysis of variance revealed that the differences among the cultivars were significant for number of tillers per plant height, ratio of length to circumference of fingers, and yield, in the years 1977-'78 and 1978-'79 (Table 4). For the ratio of length to breadth of leaf and ratio of length to circumference of mother rhizomes, the differences between cultivars were not significant in any of the years. For other characters, these differences were significant only during the second year.

In both the years, the number of tillers per plant was uniformly high (above 4) in selection No.24 (Table 3). During the first year, the highest value of 4.23 was recorded by selection No.16a Wynad local, whereas during the second year, selection No.12a Amritapani recorded the highest value of 4.83 tillers per plant. In all the cultivars, plants were uniformly taller during the second year, compared to the first year. Maximum height was recorded by selection No.28a Thodupuzha during the two years.

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Table 3. Morphological characters of 16 cultivars of C. longa

Sl. No.	Name of species/ cultivars	Year	No. of tillers per plant	No. of leaves	Height (cm)	Leaf length/ breadth ratio
I.	C. longa					
1.	2a Mydukur	1977-78	2.50	10.53	93.05	3.87
		1978-79	2.53	16.31	112.06	3.89
2.	4a Gorakhpur	1977-78	2.10	9.60	81.80	3.73
		1978-79	2.67	14.64	98.73	3.71
3.	8e Kuchipudi	1977-78	2.70	12.00	86.20	4.12
		1978-79	2.83	7.53	89.84	3.84
4.	11a Vontimitta	1977-78	1.45	8.03	65.88	3.55
		1978-79	3.31	18.45	110.28	3.07
5.	12a Amritapani	1977-78	2.40	12.05	80.65	4.57
		1978-79	4.83	28.09	106.59	3.25
6.	13c Nandiyal type	1977-78	2.30	11.33	96.73	4.36
		1978-79	2.81	12.37	99.67	3.04
7.	14b Rajpuri local	1977-78	2.70	11.05	98.75	3.58
		1978-79	2.61	14.64	93.95	3.08
8.	15b Amalapuram	1977-78	2.65	11.80	91.80	3.87
		1978-79	2.89	17.67	108.00	3.24
9.	16a Wynad local	1977-78	4.23	15.68	86.53	3.84
		1978-79	3.20	16.11	115.50	3.62
10.	18a T. Sunder	1977-78	3.43	13.00	85.23	4.31
		1978-79	3.36	20.31	117.98	4.11
11.	20a Moovattupusha	1977-78	Not available			
		1978-79	3.89	18.42	106.78	4.08
12.	21a Alleppey	1977-78	2.47	11.77	78.24	3.69
		1978-79	2.64	13.36	79.61	3.68
13.	23a Duggirala	1977-78	Not available			
		1978-79	2.98	15.23	110.17	3.79
14.	24d No. 24	1977-78	4.03	16.00	86.25	3.99
		1978-79	4.06	23.67	80.89	3.58
15.	27a Ethamukula	1977-78	Not available			
		1978-79	2.45	15.98	100.67	3.84
16.	28a Thodupusha	1977-78	2.90	15.72	103.47	3.84
		1978-79	3.81	23.03	121.31	3.14
II.	C. aromatica					
17.	50 Kasturi	1977-78	1.70	8.25	94.95	3.88
		1978-79	2.53	15.89	104.11	3.65
18.	57 Udayagiri	1977-78	2.30	10.15	90.70	3.77
		1978-79	2.56	15.70	100.20	3.76

and 2 cultivars of *Q. aromatica*

No. of mother rhizomes	No. of fingers	No. of nodes per unit length	Length/ circumference ratio of mother rhizomes	Length/ circumference ratio of fingers	Yield/ clump (gm)
2.40	5.60	0.89	0.10	1.19	262.50
2.39	12.00	1.12	0.69	0.92	369.17
2.25	10.85	1.02	0.61	1.19	365.00
2.09	5.11	1.29	0.62	0.95	180.14
1.50	4.95	1.11	0.68	0.99	267.50
1.97	4.50	1.33	0.69	0.93	144.02
2.20	7.15	0.99	0.63	1.17	192.50
3.25	12.25	1.45	0.71	0.95	360.83
1.70	4.50	0.89	0.57	1.31	120.00
5.36	17.42	1.55	0.75	1.20	415.64
2.05	8.85	1.13	0.57	1.17	432.50
2.81	5.81	1.45	0.72	0.89	155.70
2.80	7.95	1.02	0.53	1.27	375.00
2.70	10.03	1.18	0.69	0.92	280.06
2.10	6.35	1.06	0.51	1.18	267.50
2.81	11.61	1.23	0.69	1.04	438.34
2.20	5.25	0.93	0.58	1.26	172.50
3.03	8.20	1.39	0.74	0.95	250.42
3.00	8.20	0.96	0.54	1.31	302.50
3.53	14.50	1.30	0.70	1.01	420.14
2.98	9.61	1.28	0.71	0.79	242.47
2.77	6.66	1.13	0.73	0.82	216.00
2.42	4.22	1.59	0.67	0.80	142.50
2.37	2.37	6.56	1.27	0.77	177.47
3.10	5.05	0.80	0.60	1.53	195.00
2.87	6.97	1.43	0.77	1.01	156.06
2.36	6.25	1.38	0.60	0.83	186.81
2.40	5.44	1.20	0.71	1.11	191.00
3.64	11.95	1.52	0.66	0.90	314.67
1.65	6.60	1.09	0.51	2.23	265.00
2.25	7.17	1.16	0.75	1.50	208.32
2.70	7.50	1.03	0.57	1.75	265.00
2.67	11.55	1.12	0.66	1.66	300.83

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Table 4. Summary of analysis of variance (M.S.S.) and 2 cultivars of C. aromatica

Characters	1977-1978	
	Replications (d.f = 1)	Cultivars (d.f.= 14)
1. No. of tillers per plant	0.8979	1.1495**
2. No. of leaves	24.0487	12.3365
3. Height	0.8944	174.2794**
4. Length/breadth of leaf	0.3521	0.1714
5. No. of mother rhizomes	0.0691	0.4745
6. No. of fingers	8.9544	6.0231
7. No. of nodes per unit length	0.0046	0.0236
8. Length/circumference of mother rhizomes	0.0005	0.0091
9. Length/circumference of fingers	0.0567	0.2230**
10. Yield	9870.09	21076.44

* Significant at P = 0.05 ** Significant at P

for morphological characters in 16 cultivars of *G. longa*

	1978-1979		
Error (d.f = 14)	Replications (d.f = 1)	Cultivars (d.f = 17)	Error (d.f = 17)
0.1905	0.3364	0.8045**	0.2207
5.7058	30.8210	43.6596**	9.0916
43.9436	240.8187	269.2819*	93.5616
0.1492	0.5725	0.1468	0.1300
0.4617	0.1482	1.2051**	0.1628
8.0808	4.2230	27.3756**	7.6129
0.0515	0.0036	0.0426**	0.0078
0.0059	0.0078	0.0043	0.0041
0.0263	0.0191	0.1056**	0.0047
5792.47	1.6300	14101.20*	6371.56

= 0.01

PLATE I

General view of turmeric plantation

PLATE 1

PLATE II

Morphological characteristics of *Curcuma* species

Fig. 1 : *C. longa* 14 Rajapuri local

Fig. 2 : *C. aromatica* 70 Katergia

Fig. 3 : *C. amada*

Fig. 4 : *Curcuma* sp. Indonesian type

PLATE II

1

2

3

4

PLATE III

Rhizomes in *G. longa*

Fig. 1 : 8e Kuchipudi

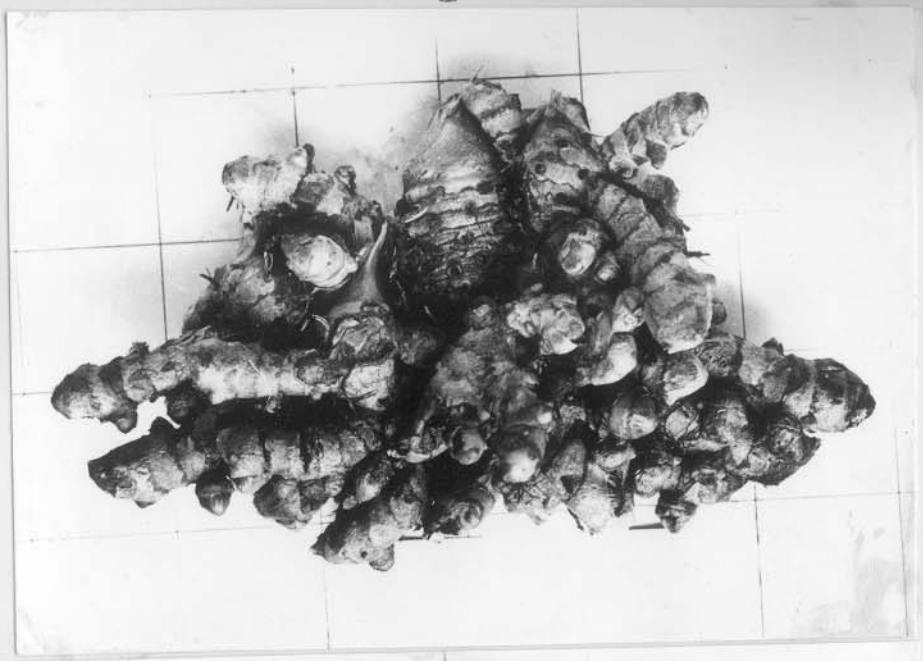
Fig. 2 : 13a Nandyal type

Fig. 3 : 14b Rajpuri local

Fig. 4 : 15b Amalapuram

PLATE III

1



2

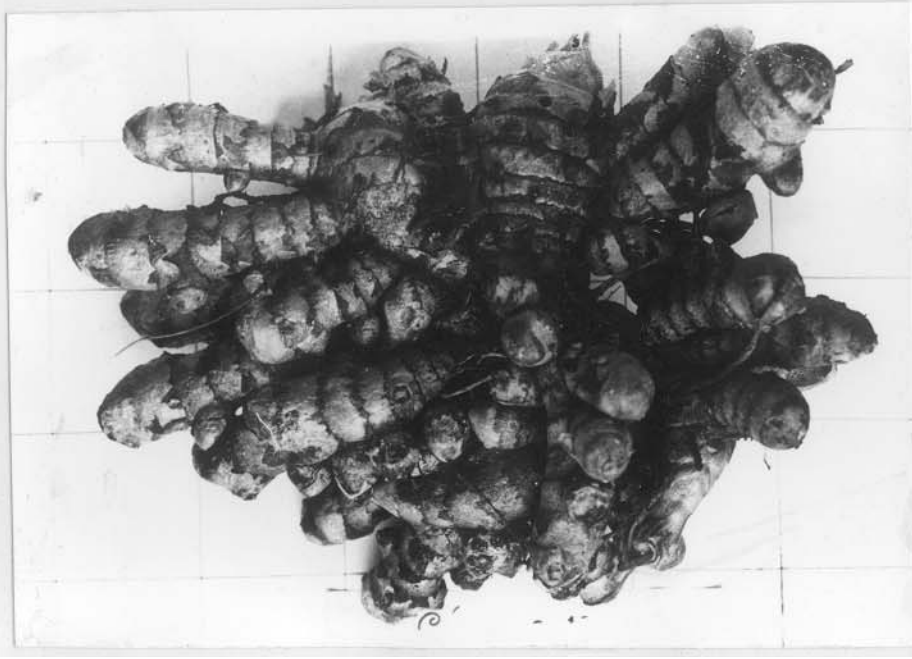


PLATE IV

Rhizomes in *C. longa*

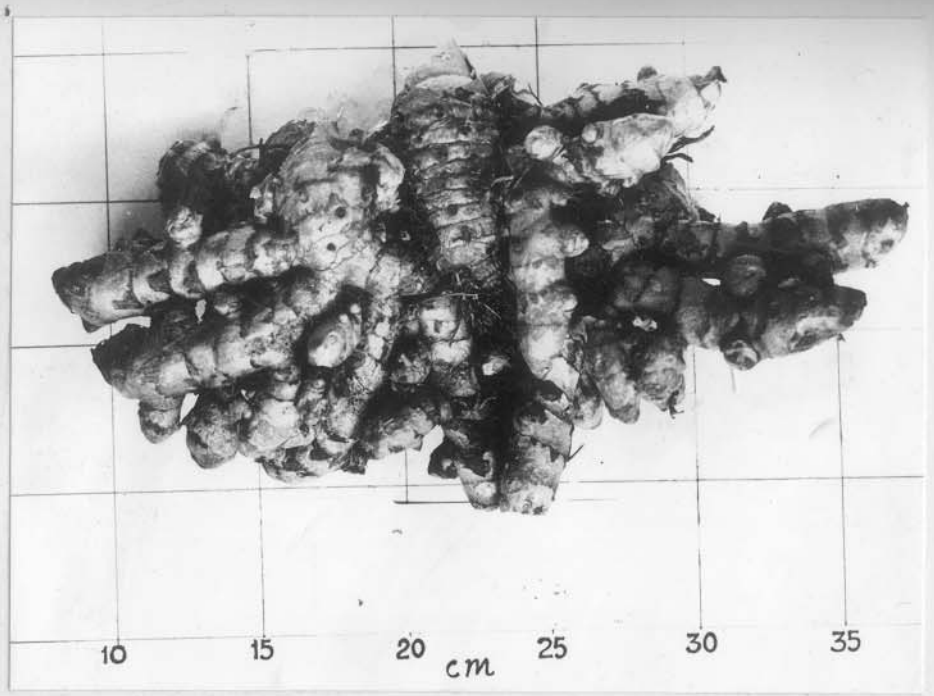
Fig. 1 : 16a Wynad local

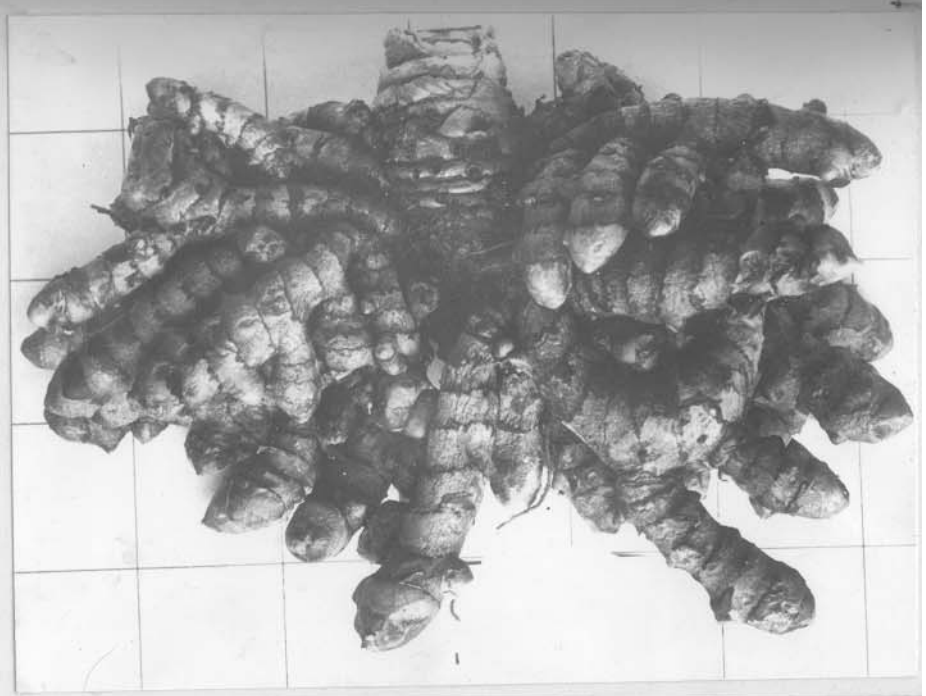
Fig. 2 : 18a T. Sunder

Fig. 3 : 21a Alleppey

Fig. 4 : 28a Thodupuzha

PLATE IV





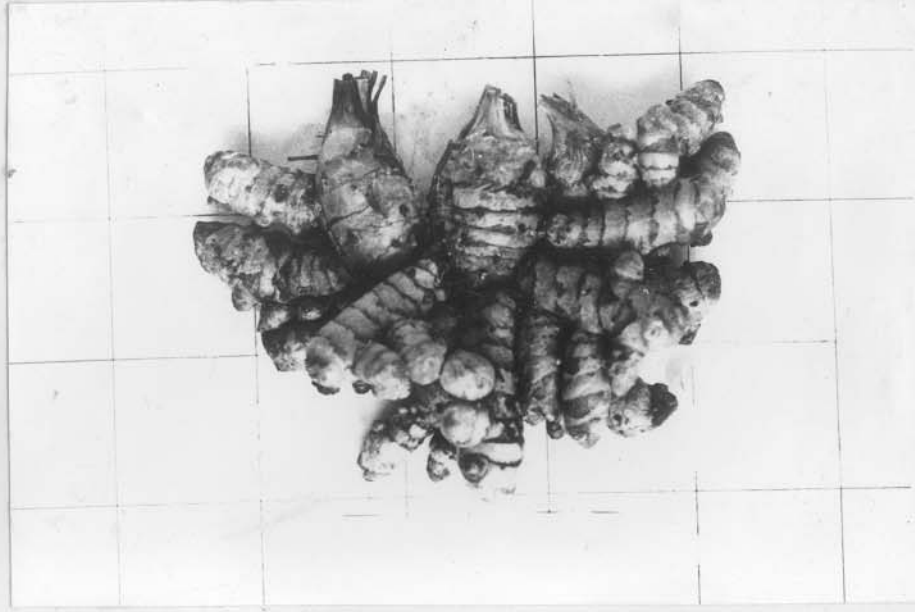


PLATE V

Rhizomes in *Curcuma* species

Fig. 1 : *C. longa* 24d No.24.

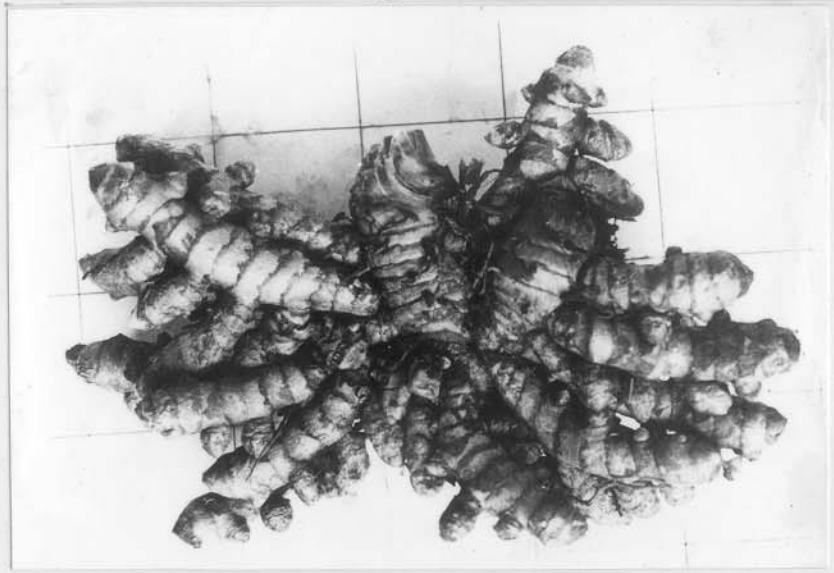
Fig. 2 : *C. aromatica* 57 Udayagiri

Fig. 3 : *C. amada*

Fig. 4 : *Curcuma* sp. Indonesian type

PLATE V

1



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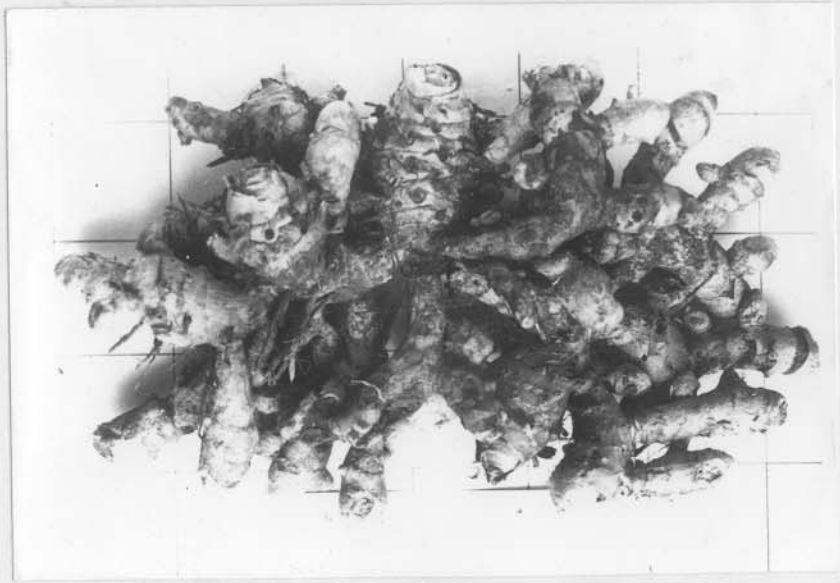
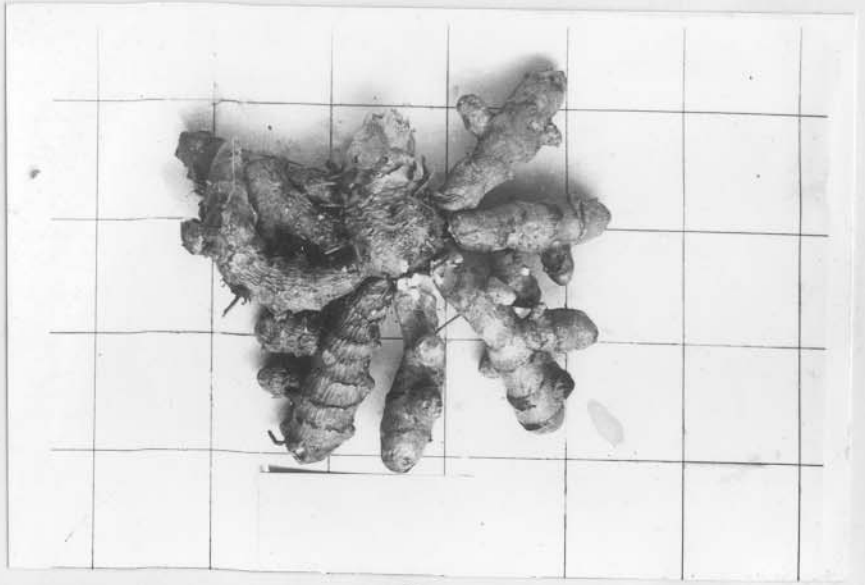


3



4

Length/circumference ratio of fingers was found to vary between 0.82 and 2.23 among the cultivars, during 1977-'78 and between 0.80 and 1.66 during 1978-'79. In both the years selection No.21a Alleppey recorded the lowest length/circumference ratio and the ratio was very high in two cultivars belonging to C. aromatica. Yield was also found to vary considerably among the cultivars. During the first year, the highest yield of 432.50 g per clump was recorded by selection No.13c Nandyal type, followed by selection No.14b Rajapuri local. During the second year, selection No.15b Amalapuram recorded the highest yield (438.34 g) closely followed by selection No.18a T. Sunder. Over the years fluctuation in yield was high, especially in cultivars like selection No.12a Amritapani, followed by selection No.15b Amalapuram.

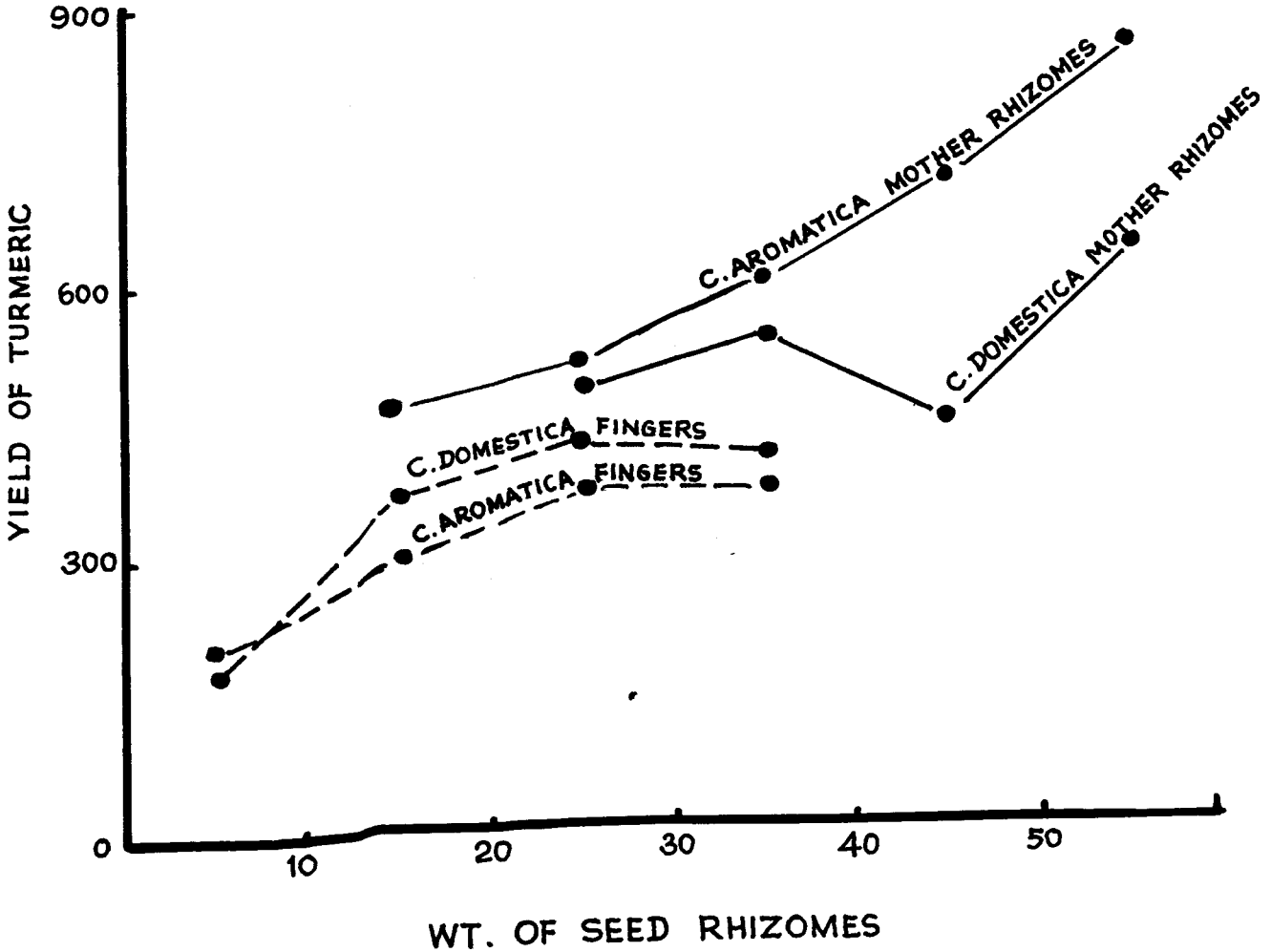
Yield data recorded on plants raised separately from mother rhizomes and fingers in 10 cultivars of C. longa and 8 cultivars of C. aromatica are given in Table 5. The yield differences observed in the above two species due to the differences in weight of mother rhizomes and fingers used as planting material, are given in Table 6 and diagramatically represented in Plate VI.

In order to study the relationship between yield (y) and morphological characters such as number of tillers (x1), number of leaves (x2), plant height (x3), length x breadth of the last fully opened leaf (x4) and

PLATE VI

Yield in turmeric in relation to the type (mother rhizome/fingers) and weight of seed material

PLATE VI. YIELD OF TURMERIC IN RELATION TO THE TYPE (MOTHER RHIZOME OR FINGERS) AND WEIGHT OF SEED MATERIAL



33

Table 5. Differences in yield of turmeric due to difference in seed weight of mother rhizomes and fingers

Sl. No.	Name of species/ cultivars	Mother rhizomes		Fingers	
		Wt. of seed rhizome (gm)	Yield per clump (gm)	Wt. of seed rhizome (gm)	Yield per clump (gm)
I.	C. longa				
1.	2a Myadukur	69.6	654	23.4	334
2.	4a Gorakhpur	72.8	551	20.1	538
3.	8e Kuchipudi	54.9	572	28.5	341
4.	11a Ventimitta	59.0	444	18.5	357
5.	12a Amritapani	66.6	354	25.4	309
6.	13c Nandiyal type	57.7	600	23.4	471
7.	14b Rajpuri local	56.9	876	13.9	447
8.	15b Amalapuram	60.6	637	19.5	377
9.	24d No. 24	34.7	558	11.9	440
10.	27a Ethamukula	55.9	395	23.0	234
	Mean	58.9	564	20.8	385
II.	C. aromatica				
11.	50 Kasturi	33.5	625	19.8	273
12.	51 Kasturi tanuka	29.5	538	18.5	428
13.	57 Udayagiri	24.8	430	17.0	276
14.	53 Jobedi	40.3	712	17.3	308
15.	54 Dehgi	32.3	509	15.1	266
16.	55 Dindigam	35.3	469	21.4	432
17.	56 Katergia	33.5	613	17.9	289
18.	58 Amalapuram	52.2	610	21.4	303
	Mean	35.2	563	18.6	322
	Overall mean	48.3	564	19.8	357

Table 6. Relationship between seed weight of mother rhizome and fingers, and final yield.

Sl. No.	Wt. of seed rhizome (gm)	C. longa		C. aromatica	
		Mother rhizome (wt. in gm)	Finger (wt. in gm)	Mother rhizome (wt. in gm.)	Fingers (wt. in gm)
1.	Less than 10	—	176.0	—	197.5
2.	10-20	—	353.8	461.6	296.7
3.	20-30	482.0	414.4	496.9	366.1
4.	30-40	522.8	405.0	595.6	374.8
5.	40-50	434.9	—	708.8	—
6.	Above 50	630.7	—	—	—

number of mother rhizomes (x5), number of fingers (x6) and average number of nodes per unit length of the finger, the intercorrelation coefficients were worked out. These are presented in Table 7. It was observed that yield of a plant can be estimated by the linear prediction equation: Y=60.69 - 24.34 x 1-5.15 x 2+6.27 x 3-0.36 x 4+16.17 x 5+18.24 x 6-167-74 x 7, with a coefficient of determination R2=0.9046, which is highly significant.

The standardised partial regression coefficients were worked out to find out the contribution of any one morphological character, either directly or indirectly towards the manifestation of correlation with yield. The results are presented in Tables 8a - 8g. The inter-relationships between yield and morphological characters have been diagrammatically presented in Plate VII. It is seen that the effect due to residual factors is only 0.0982, thereby establishing the suitability of the above linear causal scheme.

Wilk's criterion, obtained from multivariate analysis of variance, based on all the nine characters excluding yield was 9.002 x 10-7 for 1977-78 and 2.3084 x 10-7 for 1978-79, both of which turned out to be highly significant, showing thereby differences between cultivars for the aggregate of the characters.

PLATE VII

Diagrammatic representation of inter-relationships between yield and morphological characters

PLATE VII

Diagramatic representation of interrelationship between yield & morphological characters

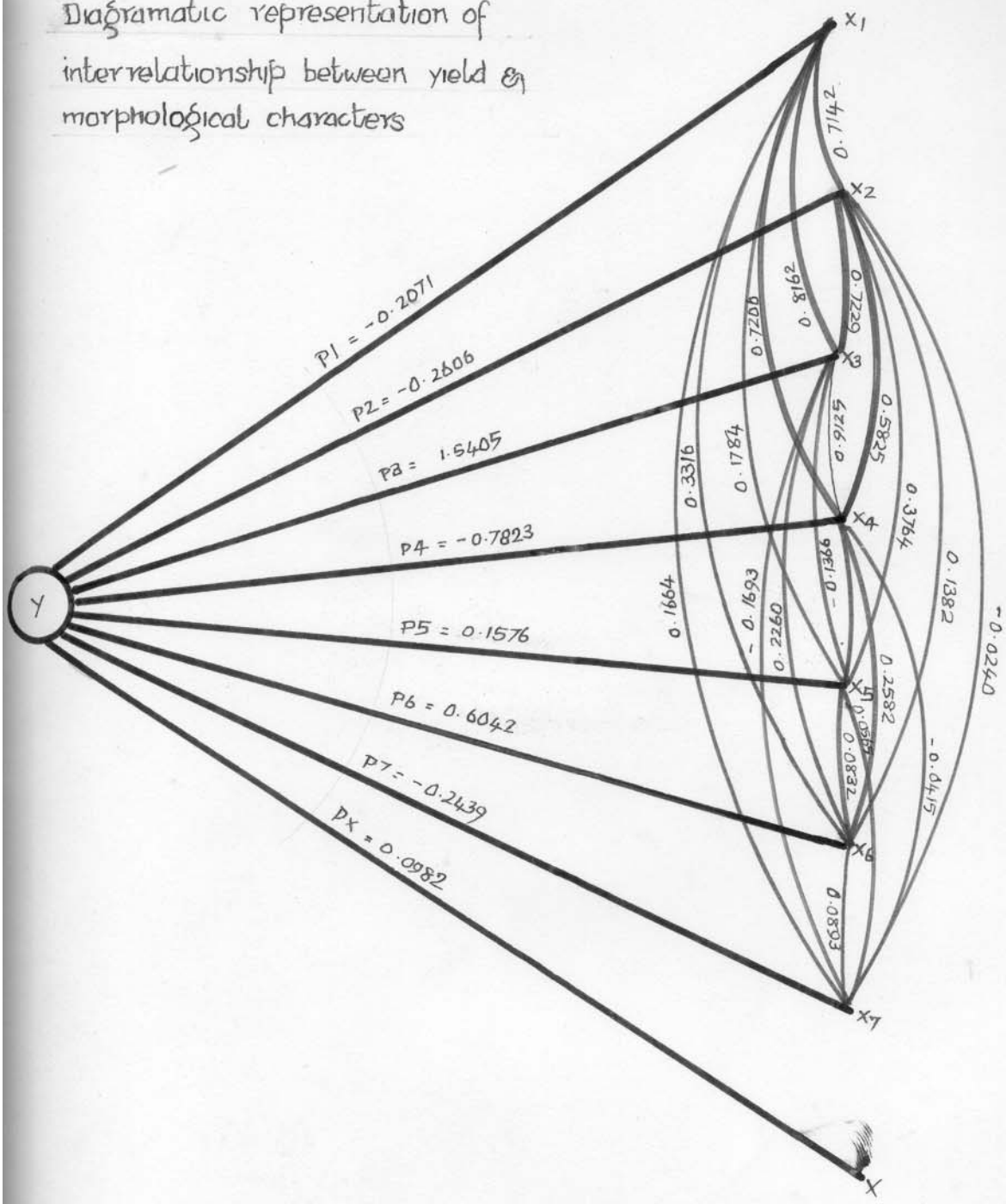


Table 7. Intercorrelation coefficients among morphological characters and yield in turmeric +

	x1	x2	x3	x4	x5	x6	x7	y
x1	1.0000	0.7142**	0.8162**	0.7206**	0.1784	0.3316	0.1664	0.4883*
x2		1.0000	0.7229**	0.5825**	0.3764	0.1382	-0.0240	0.3981
x3			1.0000	0.9125**	-0.1366	0.2260	-0.1693	0.6256**
x4				1.0000	-0.2325	0.2582	-0.0415	0.4520
x5					1.0000	0.0832	0.0565	0.0305
x6						1.0000	0.0093	0.6370**
x7							1.0000	-0.4376
y								1.0000

* Significant at 5% level

** Significant at 1% level

+ x1 - Number of tillers
x2 - Number of leaves
x3 - Height of the pseudostem
x4 - Product of length and breadth of last fully opened leaf
x5 - Number of mother rhizomes
x6 - Number of fingers
x7 - Number of nodes/cm of fingers
y - Yield of the clump

Table 8. Partitioning of correlations between yield and morphological characters into direct and indirect effects.

Table 8a. Yield vs number of tillers

Direct/indirect effect	Character	Contribution
Direct	Number of tillers	- 0.2071
Indirect	Number of leaves	- 0.1861
"	Plant height	1.2574
"	Length x breadth of last fully opened leaf	- 0.5637
"	Number of mother rhizomes	0.0281
"	Number of fingers	0.2003
"	Number of nodes/cm of finger	0.0406
Total	Correlation coefficient between yield and number of tillers	0.4883

Table 8b. Yield vs number of leaves

Direct/indirect effect	Character	Contribution
Direct	Number of leaves	- 0.2606
Indirect	Number of tillers	- 0.1479
"	Plant height	1.1136
"	Length x breadth of leaf	- 0.4537
"	Number of mother rhizomes	0.0593
"	Number of fingers	0.0835
"	Number of nodes/cm of finger	0.0059
Total	Correlation coefficient between yield and number of leaves	0.3981

Table 8c. Yield vs plant height

Direct/indirect effect	Character	Contribution
Direct	Plant height	1.5404
Indirect	Number of tillers	- 0.1690
"	Number of leaves	- 0.1804
"	Length x breadth of leaf	- 0.7138
"	Number of mother rhizome	- 0.0215
"	Number of fingers	- 0.1366
"	Number of nodes/cm of finger	- 0.0413
Total	Correlation coefficient between yield and plant height	0.6256

Table 8d. Yield vs length x breadth of last fully opened leaf

Direct/indirect effect	Character	Contribution
Direct	Length x breadth of leaf	-0.7823
Indirect	Number of tillers	-0.1492
"	Number of leaves	-0.1518
"	Plant height	1.4057
"	Number of mother rhizomes	-0.0366
"	Number of fingers	0.1560
"	Number of nodes/cm of finger	0.0102
Total	Correlation coefficient between yield and length x breadth of leaf	0.4520

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Table 8e. Yield vs number of mother rhizomes

Direct/indirect effect	Character	Contribution
Direct	Number of mother rhizomes	0.1576
Indirect	Number of tillers	-0.0369
"	Number of leaves	-0.0981
"	Plant height	-0.2104
"	Length x breadth of leaf	0.1818
"	Number of fingers	0.0503
"	Number of nodes/cm of finger	-0.0136
Total	Correlation coefficient between yield and number of mother rhizomes	0.0305

Table 8f. Yield vs number of fingers

Direct/indirect effect	Character	Contribution
Direct	Number of fingers	0.6042
Indirect	Number of tillers	-0.0687
"	Number of leaves	-0.0360
"	Plant height	0.3482
"	Length x breadth of leaf	-0.2020
"	Number of mother rhizomes	0.0131
"	Number of nodes/cm of finger	-0.0218
Total	Correlation coefficient between yield and number of fingers	0.6370

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Table 8g. Yield vs number of nodes/cm of fingers

Direct/indirect effect	Character	Contribution
Direct	Number of nodes/cm of finger	-0.2439
Indirect	Number of tillers	-0.0345
"	Number of leaves	0.0062
"	Plant height	-0.2608
"	Length x breadth of leaf	0.0325
"	Number of mother rhizome	0.0089
"	Number of finger	0.0540
Total	Correlation coefficient between yield and number of nodes/cm of finger	-0.4376

41

The quantitative differences with respect to the morphological characters were evaluated using the Mahalanobis D^2 statistic. The D^2 values were more or less similar in both the years (Table 9). The values ranged from 8.8 to 493.3 during 1977-78 and from 9.3 to 848.1 during 1978-79. The data available on the contribution of each character to the total D^2 value revealed that the ratio of length to circumference of fingers was the most important discriminating factor, in both the years. Other characters of importance in the study of genetic divergence were the height of the plant, number of nodes per unit length and number of mother rhizomes.

II ELECTROPHORETIC STUDIES

Diagrammatic representation of electrophoretic spectra on acrylamide gels is given in Plate VIII. The Rf values for 16 cultivars of C. longa, two cultivars of C. aromatica, one type of C. amada and one Indonesian type of Curcuma sp. are given in Table 10.

In all, 13 bands could be resolved varying in Rf values, though in none of the types studied all the bands were present. It is noteworthy that band number 8 was resolved in all the types and band numbers 12 and 13 in most of the types. In general the fast moving proteins were more abundant in distribution among the types studied. Another interesting feature was the high intensity of certain bands resolved. Among C. longa types, band No.12 was most

PLATE VIII

Diagram of electrophoretic spectra of *Curcuma* species

C. longa

1. 2a Mydukur
2. 4a Gorakhpur
3. 8c Kuchipudi
4. 11a Vontimitta
5. 12a Amritapani
6. 13c Nandyal type
7. 14b Rajapuri local
8. 15b Amalapuram
9. 16a Wynad local
10. 18a T. Sunder
11. 20a Meovattupuzha
12. 21a Alleppey
13. 23a Duggirala
14. 24d No.24
15. 27a Ethamukula
16. 28a Thodupuzha

C. aromatica

17. 50 Kasturi
18. 57 Udayagiri
19. *C. amada*
20. *Curcuma* sp. Indonesian type

PLATE VIII

DIAGRAM OF ELECTROPHORETIC SPECTRA OF CURCUMA SP.

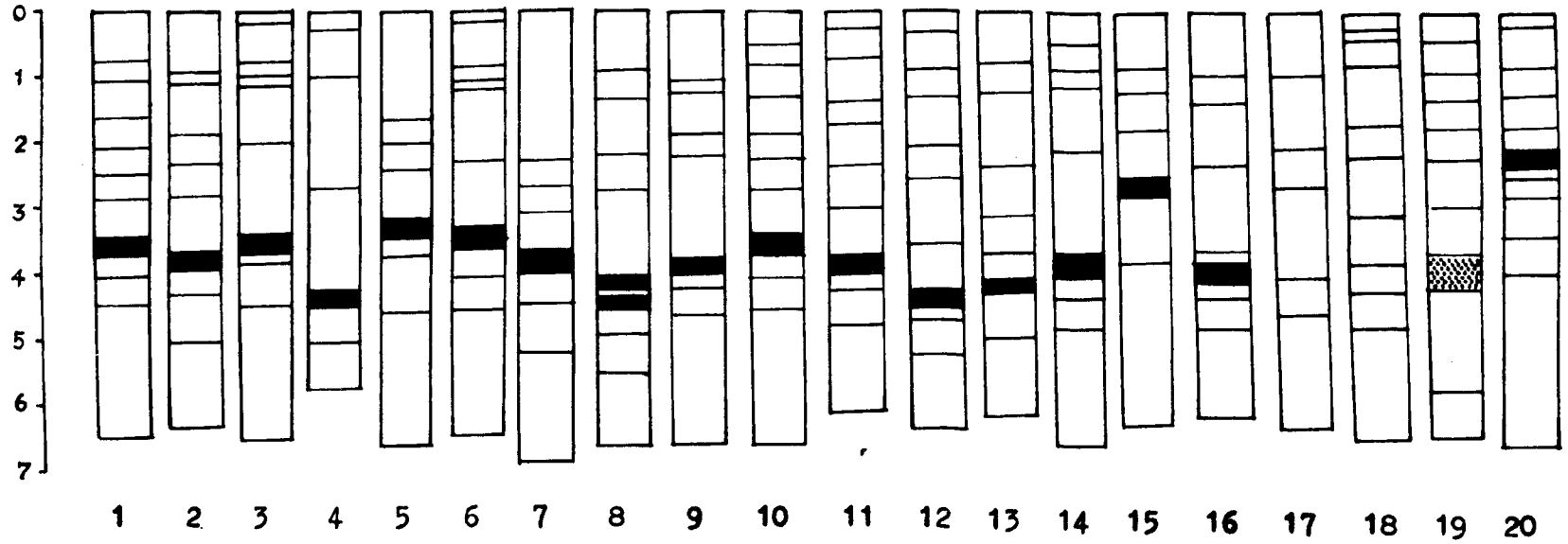

Table 9. D^2 values based on nine characters in turmeric for the

Sl. No.	Name of species/ cultivars	2a	4a	8c	11a	12a	13c	14b	15b
I.	C. longa								
1.	2a Mydukur	-	22.6	51.4	30.5	32.0	20.0	15.0	8.8
2.	4a Gorakhpur	18.3	-	81.3	15.9	53.9	27.3	18.2	16.0
3.	8c Kuchipudi	78.3	90.2	-	84.2	25.7	69.9	104.2	46.1
4.	11a Vontimitta	51.6	36.5	140.3	-	53.6	58.5	43.4	36.8
5.	12a Amritapani	445.3	351.5	675.6	245.6	-	38.8	74.0	28.6
6.	13c Nandyal type	39.3	30.9	62.0	29.9	365.0	-	25.5	15.0
7.	14b Rajpuri local	14.4	9.5	103.5	34.2	334.7	33.8	-	15.2
8.	15b Amalapuram	29.9	12.5	147.3	25.7	261.3	49.7	11.7	-
9.	16a Wynad local	31.8	26.2	85.9	15.3	348.1	9.3	30.5	37.4
10.	18a T. Sunder	53.0	37.0	182.9	15.2	194.1	47.6	30.0	13.6
11.	20a Moovattupusha	40.8	58.2	73.0	53.4	439.5	19.4	50.6	81.8
12.	21a Alleppey	59.6	39.7	89.3	22.2	318.4	10.3	40.2	53.7
13.	23a Duggirala	23.1	30.2	38.3	55.9	496.0	21.4	40.4	61.3
14.	24d No.24	92.4	53.2	146.1	37.2	225.2	41.2	56.6	52.5
15.	27a Ethamukula	19.3	9.6	99.5	20.2	324.3	17.1	10.7	17.9
16.	28a Thodupusha	105.8	81.2	234.1	19.0	174.8	66.0	78.6	58.4
II.	C. aromatica								
17.	50 Kasturi	297.7	213.8	481.5	279.3	337.3	351.7	240.4	171.8
18.	57 Udayagiri	584.4	468.7	848.1	532.1	404.1	661.2	490.0	387.5

Note: Values for 1977-1978 are given above the diagonal and 1978-

) years 1977-1978 and 1978-1979

16a	18a	20a	21a	23a	24d	27a	28a	50	57
135.9	35.8	-	48.1	-	89.0	-	32.5	196.1	41.2
160.1	50.1	-	78.0	-	111.9	-	76.8	159.9	31.8
52.1	33.0	-	30.8	-	47.4	-	39.6	349.0	145.9
160.2	51.6	-	51.7	-	97.0	-	86.1	215.2	52.7
95.7	36.7	-	53.8	-	50.6	-	26.2	238.3	82.9
188.0	75.5	-	101.7	-	135.3	-	33.1	136.4	37.0
187.8	63.9	-	101.2	-	127.2	-	64.5	138.7	21.0
114.5	30.4	-	64.7	-	76.0	-	39.2	174.5	39.0
-	42.7	-	82.1	-	25.9	-	146.2	495.3	243.3
35.9	-	-	33.4	-	21.0	-	76.2	311.5	104.1
24.6	71.5	-	-	-	-	-	-	-	-
19.1	47.5	32.3	-	-	52.4	-	70.4	404.2	152.6
18.0	83.7	31.8	43.7	-	-	-	-	-	-
49.6	41.8	70.5	26.3	83.5	-	-	92.4	383.0	156.3
13.3	23.6	32.6	21.4	32.5	47.5	-	-	-	-
45.7	22.2	82.6	51.6	116.6	52.3	49.2	-	227.0	84.9
325.9	232.8	473.2	353.6	350.1	286.8	279.6	331.2	-	66.4
624.8	452.3	817.5	646.7	683.6	539.2	549.3	571.6	62.9	-

1979 below the diagonal.

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Table 10. Rf values of phosphate buffer extractable I

Sl. No.	Name of species/ cultivars	Band numbers					
		1	2	3	4	5	6
I.	C. longa						
	1. 2a Mydukur	-	-	0.18	-	0.24	-
	2. 4a Gorakhpur	-	-	0.18	0.22	-	-
	3. 8e Kuchipudi	0.02	-	0.16	0.23	0.25	-
	4. 11a Ventimitta	0.04	-	0.15	-	-	-
	5. 12a Amritapani	-	-	-	-	-	-
	6. 13a Nandyal type	0.02	-	-	0.20	0.24	0.27
	7. 14b Rajapuri local	-	-	-	-	-	-
	8. 15b Amalapuram	-	-	0.18	-	0.25	-
	9. 16a Wynad local	-	-	-	0.22	0.26	-
	10. 18a T. Sunder	-	0.11	0.18	-	-	0.29
	11. 20a Moovattupusha	0.06	-	0.15	-	-	0.29
	12. 21a Alleppey	-	0.07	0.17	-	0.25	-
	13. 23a Duggirala	-	-	0.15	-	0.24	-
	14. 24d No.24	-	0.10	0.17	0.23	-	-
	15. 27a Ethamukula	-	-	-	0.21	-	0.30
	16. 28a Thodupusha	0.02	-	-	-	-	0.29
II.	C. aromatica						
	17. 50 Kasturi	-	-	-	0.22	-	-
	18. 57 Udayagiri	0.06	0.09	0.17	-	-	-
III.	C. amada	0.06	-	0.15	0.23	-	-
IV.	Curcuma sp. Indonesian type	0.02	-	-	0.23	-	0.31

proteins in polyacrylamide gels.

7	8	9	10	11	12	13
0.35	0.49	0.55	0.68	-	0.82	0.91
0.38	0.46	0.56	-	-	0.80	0.94
-	0.46	-	-	-	0.86	0.88
-	0.46	-	-	0.79	-	0.87
0.35	0.44	0.58	-	0.78	0.84	-
-	0.47	-	-	-	0.80	0.89
0.40	0.46	0.52	0.68	0.77	-	-
0.40	0.42	-	-	0.76	0.82	0.89
0.38	0.49	-	-	-	0.84	0.91
0.40	0.46	0.58	-	0.78	-	0.89
0.35	0.49	-	0.62	-	0.83	0.87
0.38	0.49	-	0.67	-	0.86	0.88
-	0.45	-	0.61	0.73	0.85	-
-	0.48	-	-	-	0.83	0.89
-	0.48	-	-	0.73	-	-
-	0.47	-	-	0.73	0.83	0.89
-	0.44	0.58	-	-	-	0.89
0.34	0.46	-	0.63	0.79	-	0.87
0.32	0.42	0.55	-	-	0.80	-
-	0.45	0.55	0.61	0.71	0.84	-

prominent except in 27a, 12a, and 14b. Band No.11 was prominent in types 27a and 12a while band No.10 was prominent in type 14b. High intensity of band No.9 was noticed in Indonesian type. All the protein bands were uniformly faint in two types of C. aromatica investigated. In C. amada band No.12 was slightly prominent though very faint compared to that of C. longa.

III ESTIMATION OF OIL AND CURCUMIN CONTENTS

Oil and curcumin contents estimated for 16 cultivars of C. longa and six cultivars of C. aromatica are given in Table 11.

IV COLOUR GRADING IN LEAF AND POWDER OF TURMERIC

Colour grading for leaf and turmeric powder in 16 cultivars of C. longa and two cultivars of C. aromatica was carried out based on Nickerson's colour chart and the data are presented in Table 12.

V SEED PROPAGATION

Among 16 cultivars of C. longa and 11 cultivars of C. aromatica, 6 cultivars in the former and all the 11 cultivars in the latter species flowered. The flowering period was August-September under Kasaragod conditions. The flowering clumps were observed on the outer rows of the beds exposed to sun light. The mature capsules were observed in October-November. The number of days taken for flowering from the time of sowing, and maturity of the seed, and

Table 11. Oil and curcumin content in 16 cultivars of *C. longa* and 6 cultivars of *C. aromatica*

Sl. No.	Name of species/ cultivars		Oil (%)	Curcumin content (%)
I.	*C. longa*			
1.	2a	Mydukur	4.19	9.98
2.	4a	Gorakhpur	4.98	8.90
3.	8e	Kuchipudi	6.00	7.28
4.	11a	Ventimitta	6.92	12.25
5.	12a	Amritapani	4.46	11.50
6.	13a	Nandiyal type	4.97	10.98
7.	14b	Rajpuri local	4.82	9.50
8.	15b	Amalapuram	4.94	9.20
9.	16a	Wynad local	5.65	13.90
10.	18a	T. Sunder	3.02	9.98
11.	20a	Meevattupusha	4.54	14.48
12.	21a	Alleppey	6.43	13.93
13.	23a	Duggirala	4.25	10.58
14.	24d	No.24	5.40	14.02
15.	27a	Ethamukula	8.45	10.20
16.	28a	Thodupusha	4.91	13.48
II.	*C. aromatica*			
17.	50	Kasturi	9.10	8.10
18.	57	Udayagiri	7.54	8.48
19.	51	Kasturi tanuka	9.1	8.4
20.	53	Jobedi	8.2	7.3
21.	54	Dahgi	6.9	6.3
22.	58	Amalapuram	5.1	7.2

Table 12. Colour gradings in leaf and powder of turmeric (According to Nickerson's colour chart)*

Sl. No.	Name of species/ cultivars	Top leaf	Powder
I.	C. longa		
1.	2a Mydukur	5 GY 5/6 MYG	7.5 YR 6/9 DOY
2.	4a Gorakhpur	5 GY 5/6 MYG	7.5 YR 6/9 DOY
3.	8c Kuchipudi	5 GY 5/6 MYG	7.5 YR 5/7 SYB
4.	11a Ventimitta	5 GY 5/6 MYG	7.5 YR 6/9 DOY
5.	12a Amritapani	5 GY 5/7 MYG	5 YR 6/11 SO
6.	13a Nandiyal type	5 GY 5/6 MYG	7.5 YR 5/7 SYB
7.	14b Rajpuri local	5 GY 5/6 MYG	7.5 YR 6/9 DOY
8.	15b Amalapuram	5 GY 5/6 MYG	7.5 YR 6/9 DOY
9.	16 a Wynad local	5 GY 5/6 MYG	5 YR 6/11 SO
10.	18a T. Sunder	5 GY 5/6 MYG	7.5 YR 7/11 SOY
11.	20a Moovattupusha	5 GY 5/6 MYG	5 YR 6/11 SO
12.	21a Alleppey	5 GY 5/6 MYG	5 YR 6/11 SO
13.	23a Duggirala	7.5 GY 5/7 MYG	10 YR 7/10 SOY
14.	24d No.24	5 GY 5/6 MYG	5 YR 6/11 SO
15.	27a Ethamukula	5 GY 5/6 MYG	7.5 YR 6/9 DOY
16.	28a Theodupusha	5 GY 6/8 SYG	5 YR 6/11 SO
II.	C. aromatica		
17.	50 Kasturi	5 GY 4/3 MOG	7.5 YR 6/9 DOY
18.	57 Udayagiri	5 GY 4/3 MOG	7.5 YR 6/9 DOY

*MOG - Moderate olive green
MYG - Moderate yellow green
SYG - Strong yellow green
DOY - Dark orange yellow
SYB - Strong yellow brown
SOY - Strong orange yellow
SO - Strong orange

germination particulars for nine cultivars are given in Table 13. From the Table it is evident that the number of days taken for flowering in C. longa varies from 118 to 143 days, whereas in the case of C. aromatica it varies from 95 to 104 days. The time taken for the maturity of seeds from flowering varies from 23 to 29 days in C. aromatica. Seed set was not observed in any of the six cultivars of C. longa that have flowered.

On extraction from capsule two distinct types of seeds (dark heavy and light brown) were observed. The seed has a smooth surface and an apical micropylar ring with a wavy outline. Percentage of germination varied from cultivar to cultivar in C. aromatica (Table 13). Seventy to ninety per cent of germination was recorded in about 8 - 20 days after sowing. There was practically no germination ~~the~~ after the 20th day. At the time of germination the seed absorbs moisture and becomes enlarged before the emergence of the plumule. The plumule is about 4 - 5 cm long with two protuberances at the base, which later develop into the first two primary roots (Plate IX, Fig. 1). The seedlings at two-leaf stage were transplanted to polythene bags (Plate IX, Fig.2). During the first year only roots and root tubers were observed (Plate IX, Fig.3). Normal rhizome development occurs during the second year (Plate IX, Fig.4).

PLATE IX

Seed propagation in *C. aromaticus*

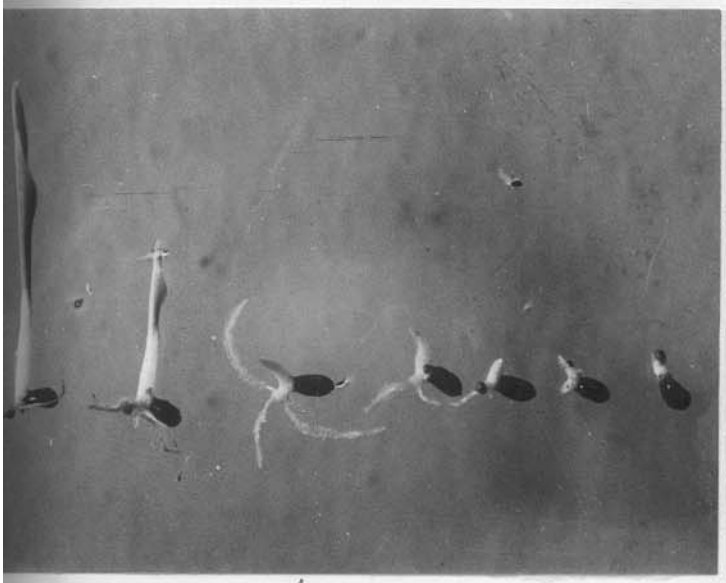
Fig. 1 : Germinating seeds

Fig. 2 : Seedlings transplanted in polythene bags

Fig. 3 : One-year old seedling with root tubers

Fig. 4 : Two-year old seedling showing development of rhizomes

PLATE IX



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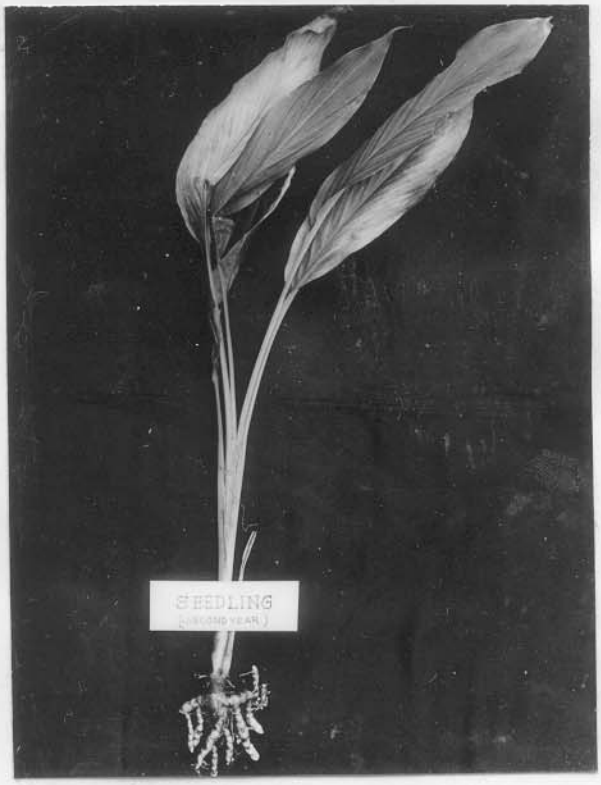


4

Table 13. Details of flowering and fruit set in turmeric

Sl. No.	Name of species/ cultivars	No. of days taken for flowering	No. of days taken for maturity of seeds	No.of days taken for germination (Mean)	Percentage of germination (Mean)
I	C. aromatica				
1.	50 Kasturi	104	26	14	37.2
2.	51 Kasturi tanuka	103	29	13	49.9
3.	52 GL Puram	102	25	15	35.9
4.	53 Jobedi	104	24	16	43.9
5.	54 Dahgi	103	25	11	60.3
6.	56 Katergia	102	23	16	39.5
7.	57 Udayagiri	101	27	18	35.8
8.	58 Amalapuram	95	26	11	62.5
9.	60 Chayapasupu	104	27	10	30.5
10.	55 Dindigam	102	27	--	--
11.	59 GL Puram-I	100	29	--	--
II.	C. longa				
12.	8c Kuchipudi	133	--	--	--
13.	13c Nandyal type	134	--	--	--
14.	24d No. 24	118	--	--	--
15.	18a T. Sunder	128	--	--	--
16.	16a Wynad local	135	--	--	--
17.	21a Alleppey	143	--	--	--

V/ CYTOLOGY

1. Somatic chromosomes

The somatic chromosome numbers were determined for the following species and cultivars (Table 14; Plates X - XII).

Table 14. Somatic chromosome in *Curcuma* species and cultivars.

Sl. No.	Name of species/ cultivars	Number of cells analysed	2n	'Off type' somatic cells with	
				Chromosome number	Percentage of cells
I.	*C. longa*				
1.	2a Mydukur	50	63	62	7.0
2.	13a Nandyal type	35	63	—	—
3.	16a Wynad local	35	63	—	—
4.	24d No.24	50	63	62	4.0
5.	28a Thodupuzha	20	63	—	—
II.	*C. aromatica*				
6.	50 Kasturi	41	84	82,86	19.5
7.	51 Kasturi tamukn	25	84	86	14.0
8.	57 Udayagiri	30	84	—	—
9.	54 Dahgi	20	84	86	26.0
10.	56 Katergia	20	84	—	—
11.	58 Amalapuram	20	84	—	—
III.	*C. amada*	40	42	—	—
IV.	*Curcuma* sp. Indonesian type	20	42	—	—

PLATE X

Somatic chromosomes in *S. longa*

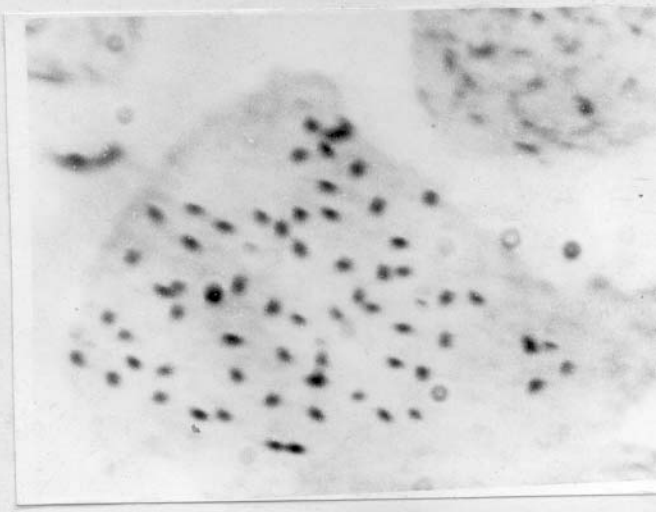
Fig. 1 : 2a Mydukur, 2n = 63

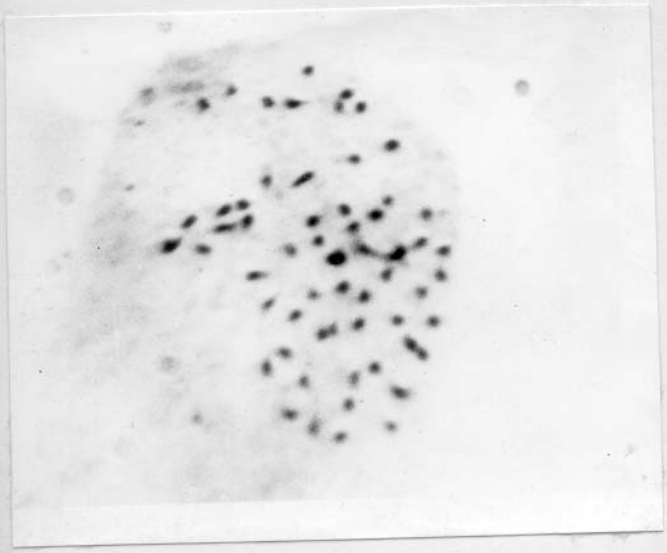
Fig. 2 : 13c Mandyal type, 2n = 63

Fig. 3 : 16a Eynad local , 2n = 63

Fig. 4 : 16a Eynad local, chromosome mosaic with 2n = 62

PLATE X





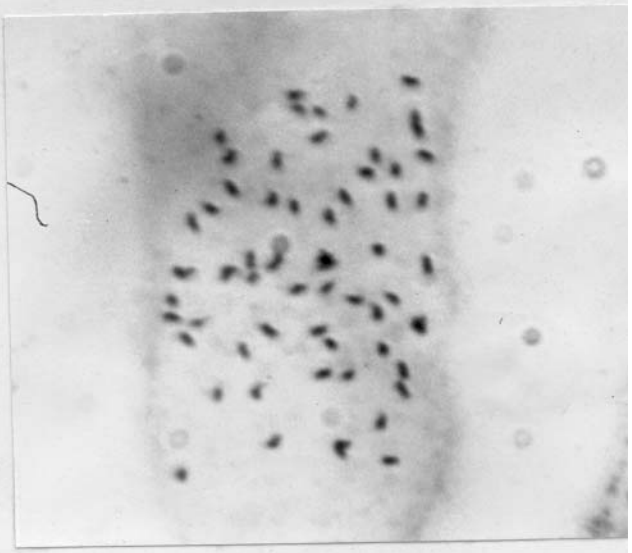


PLATE XI

Somatic chromosomes in *C. aromatica*.

Fig. 1 : 50, Kasturi, 2n = 84

Fig. 2 : 51, Kasturi tanuka, 2n = 84

Fig. 3 : 57, Udayagiri, 2n = 84

Fig. 4 : 54, Dahgi, 2n = 84

PLATE XI

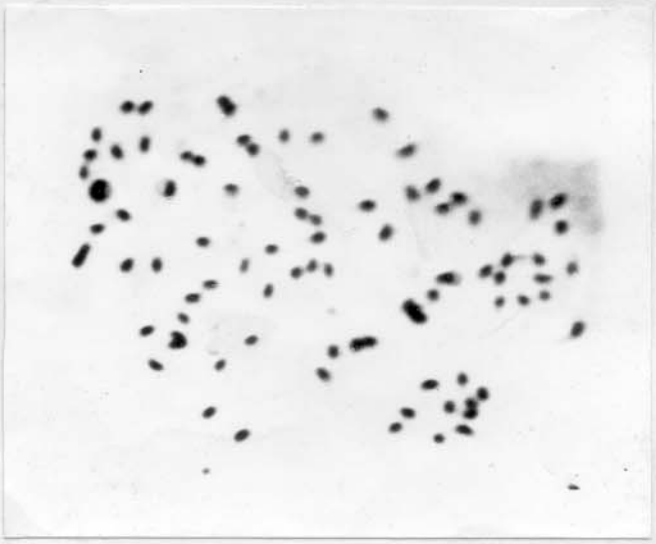


PLATE XII

Somatic chromosomes in *Curcuma* species

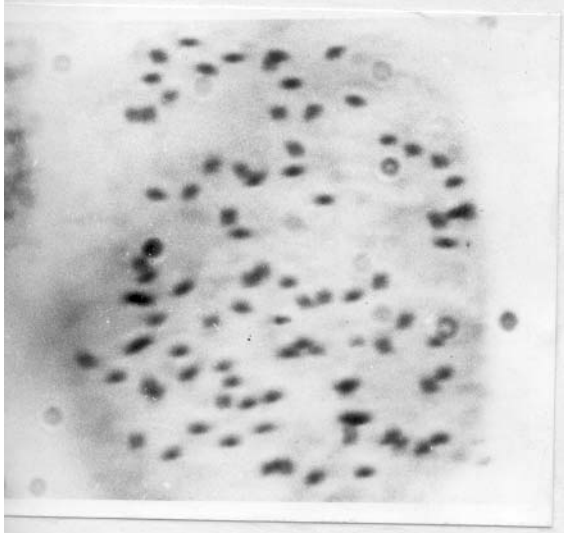
Fig. 1 : *C. aromatica*, 56 Kategia, 2n = 84

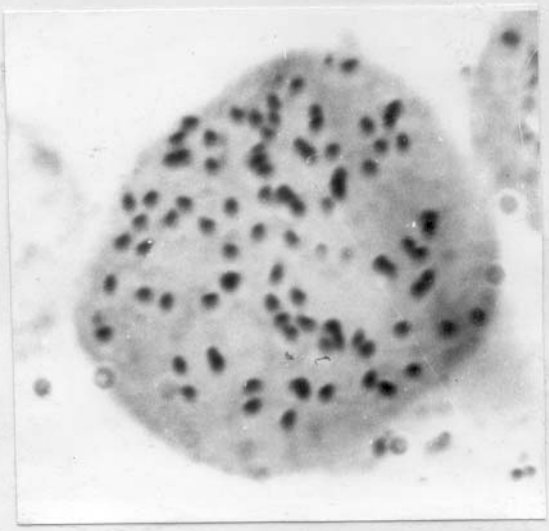
Fig. 2 : *C. aromatica*, 58 Amalapuram, 2n=84

Fig. 3 : *C. amada*, 2n = 42

Fig. 4 : *Curcuma* sp. Indonesian type, 2n = 42

PLATE XII





2. Meiosis

(a) C. longa

i) 24d No.24 (2n=63): One quadrivalent, one trivalent, twenty seven bivalents and two univalents were the maximum association observed at diakinesis as well as metaphase - I (16.7 and 19.1% respectively). One to two trivalents were observed in 81.5 per cent of the cells examined. A minimum of two univalents were observed in all associations. The number of univalents varied from 2 to 3. One trivalent + 29 bivalents + 2 univalents were the highest frequency at diakinesis as well as at metaphase - I. The later stages of meiosis were abnormal, with normal separation of chromosomes only in 18.2 per cent of the cells. The rest of the cells had laggards varying from 1 to 3. The pollen fertility was 48.5%.

Table 15. Chromosome association in C. longa 24d No.24

Chromosome association				Frequency of PMCs	
IV	III	II	I	Diakinesis	Metaphase-I
1	1	27	2	1	4
-	2	27	3	-	5
-	1	29	2	4	8
-	-	30	3	1	4
			Total	6	21

ii) 8c Kuchipudi (2n = 63): In this cultivar also the maximum pairing observed was a quadrivalent in 50% of the cells analysed at diakinesis. However, at metaphase-I, only trivalents were observed as the maximum pairing. Thirty bivalents and three univalents were of the highest frequency at metaphase-I. Normal separation was observed only in 27.8% of the cells at anaphase-I. Laggards varied from 1—3 in 6.7% of the cells analysed, the remaining showing one bridge. The pollen fertility was 45.7%.

Table 16. Chromosome association in C. longa 8c Kuchipudi

Chromosome association				Frequency of PMCs	
IV	III	II	I	Diakinesis	Metaphase-I
1	-	28	3	4	-
-	1	29	2	1	6
-	-	30	3	3	8
			Total	8	14

iii) 13a Mandvai type (2n = 63): At diakinesis, only two types of association were observed, ie. one trivalent + 29 bivalents + 2 univalents (25.0%) and 30 bivalents and three univalents (75%). However, at metaphase-I, a quadrivalent was also observed in 15.8% of the pollen mother cells. The highest frequency of cells at this stage had 30 bivalents + 3 univalents (52.6%). Number of

univalents varied from 0 to 6.

Later stage of meiosis was normal in 53.3% of the cells analysed. The only abnormality observed was one laggard for remaining cells. The pollen fertility was 46.4%.

Table 17. Chromosome association in C. longa 15a Nandyal type.

Chromosome association				Frequency of PMCs	
IV	III	II	I	Diakinesis	Metaphase-I
1	1	27	2	-	3
-	1	29	2	2	6
-	-	30	3	6	10
			Total	8	19

(b) C. aromatica

1) 30 Kasturi (2n = 84): At diakinesis 44.4% of the cells had 42 bivalents. The maximum association observed at this stage was 4 quadrivalents, 32 bivalents and four univalents. The univalents varied from 0 - 4 at this stage. At metaphase-I, the maximum association observed was also $4_{IV}+32_{II}+4_{I}$ (9.1%). Two quadrivalents, 37 bivalents and two univalents were of the highest frequency at metaphase-I. Forty bivalents and 4 univalents were observed in 22.2% of the pollen mother cells at diakinesis and 20.4% of the cells at metaphase-I.

53

Table 18. Chromosome association in Q. arcuatica 50 Kasturi

Chromosome association			Frequency of PMCs	
IV	II	I	Diakinesis	Metaphase-I
4	32	4	1	4
4	34	-	2	6
3	36	-	-	3
2	37	2	3	12
-	40	4	4	9
-	42	-	8	10
		Total	18	44

The later stages of divisions were normal in 85.7% of the cells. Laggards and bridges were observed in the remaining cells. The pollen fertility was 74.5% (Table 25).

ii) 57 Udayagiri (2n = 84): One hexavalent was observed in 40% of the mother cells analysed at diakinesis. However, the maximum association observed at metaphase-I was only quadrivalents. Forty two bivalents were observed in 30% of the cells at diakinesis and 33.3% of the cells at metaphase-I. Number of univalents varied from 0 - 4 at diakinesis as well as metaphase-I.

Table 19. Chromosome association in *G. arcuatum* 57 Udayagiri

Chromosome association				Frequency of PMCs	
VI	IV	II	I	Diakinesis	Metaphase-I
1	1	37	-	4	-
-	5	32	-	1	-
-	3	36	-	-	6
-	2	37	2	1	4
-	2	38	-	1	12
-	-	40	4	-	6
-	-	42	-	3	14
			Total	10	42

Normal separation was observed only in 46.7% of the cells. Laggards were observed in 40% and bridges in 13.3% of the cells. Pollen fertility was 69.8% (Table 23).

iii) *51 Kasturi tanuka (2n = 84):* The highest frequency of chromosome association observed at diakinesis was one hexavalent, one quadrivalent and 37 bivalents. Forty two bivalents were of the highest frequency both at diakinesis as well as at metaphase-I (41.7% and 55.5% respectively). Univalents were not observed in any of the cells analysed (Table 20).

55

Table 20. Chromosome association in Q. aromatica

51 Kasturi tanuka

Chromosome association				Frequency of PMCs	
VI	IV	II	I	Diakinesis	Metaphase-I
1	1	37	-	1	-
-	3	36	-	4	3
-	1	40	-	2	5
-	-	42	-	5	10
			Total	12	18

33.3% of the pollen mother cells at diakinesis and 16.7% of pollen mother cells at metaphase-I had 3 quadrivalents and 36 bivalents. The anaphase separation was normal in 66.7% of the cells. One to two laggards were observed in the remaining cells analysed. Abnormalities were not observed in the second division. The pollen fertility was 74.2% (Table 23).

iv) 52 Johedi (2n = 84): At diakinesis as well as metaphase-I, 4 quadrivalents and 34 bivalents were of the maximum frequency. This association also forms the highest frequency at diakinesis. The highest frequency observed at metaphase-I was 42 bivalents (50.0%). Four univalents were observed at diakinesis as well as metaphase-I in 40.0% and 33.3% respectively. The later stages of divisions were normal in 55.6% of the cells.

Four laggards were observed in the remaining cells. No other abnormalities were observed in the later stages of the division. The pollen fertility was 56.8% (Table 23).

Table 21. Chromosome association in G. aromatica 53 Jobedi

Chromosome association			Frequency of PMCs	
IV	II	I	Diakinesis	Metaphase-I
4	34	-	2	1
3	36	-	-	4
-	40	4	2	10
-	42	-	1	15
		Total	5	30

v) 54 Dabgi (2n = 84): One hexavalent and 39 bivalents were observed in 33.3% of the cells at diakinesis. Hexavalent was the maximum associations observed. Highest frequency observed at diakinesis was 42 bivalents (50.0%). The number of univalents varied from 0 - 4 at metaphase-I. The maximum association observed was two quadrivalents and 38 bivalents (36.4%). It also forms the highest frequency. The later stages of meiotic behaviour was normal in 71.4% of the cells investigated. Laggards varying from 1 - 2 were observed in 28.6% and bridges were observed in 7.1% of the cells.

The pollen fertility was 68.6% (Table 23).

Table 22. Chromosome association in C. aromatica 54 Dahgi

Chromosome association				Frequency of PMCs	
VI	IV	II	I	Diakinesis	Metaphase-I
1	-	39	-	4	-
-	2	37	2	1	3
-	2	38	-	1	12
-	-	40	4	-	8
-	-	42	-	6	10
			Total	12	33

Table 23. Pollen fertility in C. longa and C. aromatica

Sl No.	Name of species/ cultivars		Pollen fertility (%)
I.	C. longa		
1.	8c	Kuchipudi	45.74
2.	13a	Nandyal type	46.43
3.	24d	No.24	48.48
II.	C. aromatica		
4.	50	Kasturi	74.49
5.	57	Udayagiri	69.84
6.	56	Katergia	73.38
7.	54	Dahgi	68.56
8.	58	Amalapuram	70.01

PLATE XIII

Meiosis in *Q. longa* and *Q. aromatica*

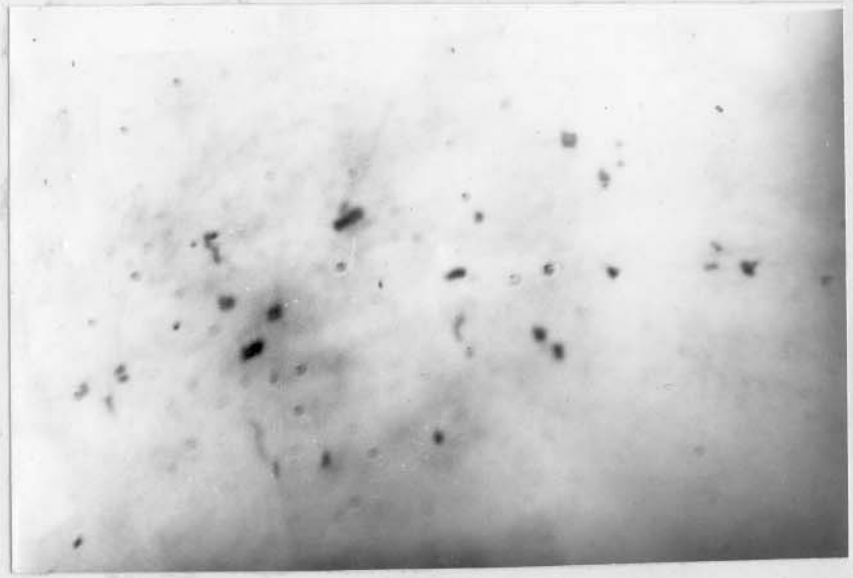
Fig. 1 : *Q. longa*, metaphase-I

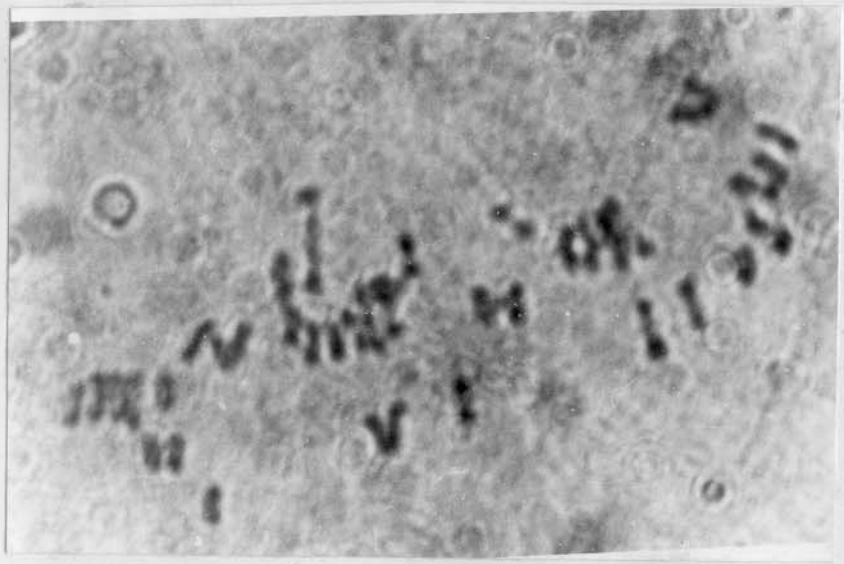
Fig. 2 : *Q. longa*, metaphase-I

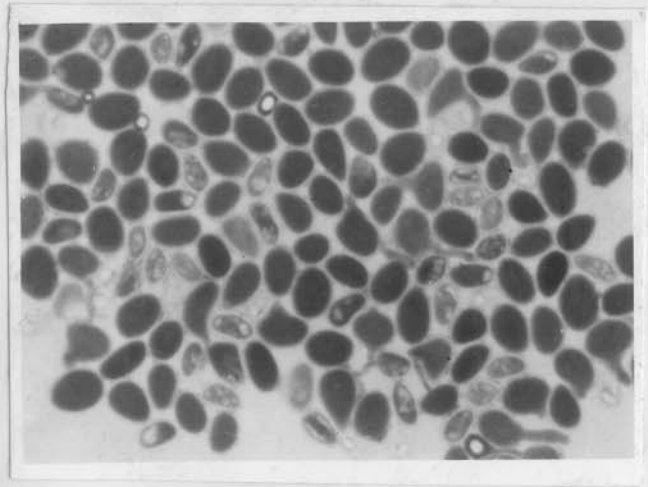
Fig. 3 : *Q. aromatica*, metaphase-I

Fig. 4 : Pollen grains in *Q. aromatica*

PLATE XIII







DISCUSSION

The genus *Curcuma* comprises about seventy species of rhizomatous herbs found mainly in Indo-Malayaian region. Starch, pigments, dyes and aromatic oils are extracted from some of the species of economic importance. Among them *C. longa*, the true turmeric of commerce, is the only species cultivated, though *C. aromatica*, a semi-wild species is also cultivated in certain regions of India to produce turmeric. Though the domestication, propagation and commercial uses of turmeric are well documented (Sopher, 1964; Rosengarten 1973), work on crop improvement has received attention only in recent years.

I. MORPHOLOGY

A critical analysis of the data (Table 3) in different cultivars of *C. longa* and *C. aromatica* revealed that the differences in yield was due to the difference in the planting materials used. The differences in yield of turmeric due to differences in seed weight of mother rhizomes and fingers have been shown in Table 5. The data indicated that about 60% higher yield was obtained, when mother rhizome was used as the planting material instead of fingers. When the cultivars of *C. aromatica* were considered separately, this increase in yield was of the order of 75%. Since the mother rhizomes used as

planting material are heavier than the fingers, the obvious inference is that the final yield is influenced more by the weight of the seed material. Hussain and Said (1965) and Randhawa and Misra (1974) also recorded significant increase in yield, when larger sized seed rhizomes were used as planting material.

This relationship was further examined by grouping the data on the basis of the weight of the seed material used separately for the two species (Table 6). When mother rhizomes were used as planting material, a progressive increase in yield was noticed, with increase in the weight of the seed rhizome. However, when fingers were used for planting, proportionate increase in yield was noticed only up to a seed rhizome weight of about 30 g. Further increase in the weight of seed rhizome was not reflected in the proportionate increase in yield. The obvious conclusion is that the optimum weight of fingers as seed material is about 30 g, when planted at a spacing of 30 cm x 25 cm under Kasaragod condition. It was also observed that when the mother rhizome and fingers of the same weight were used as planting material, the final yield was higher in plots planted with mother rhizomes (Plate IV). The data thus indicate that the final yield in turmeric is dependant on the weight and type of the seed material (mother rhizome/fingers) used for planting.

An analysis of inter-correlation of coefficients among morphological characters and yield (Table 7) reveals that only three characters, viz., number of tillers, plant height and number of fingers have significant correlations with yield. Even though the correlation between length x breadth of leaf and yield is positive and fairly high, it is not significant at 5% level. In the case of average number of nodes per unit length of the fingers, there is a negative correlation, but this correlation is not significant at 5% level. Length x breadth of leaf is an index of leaf area and in general it is expected to have a high correlation with yield. The correlation is not significant in the present case probably due to the wide variation in yield, and the length/breadth of leaf area not exhibiting a similar variation, to give a significant correlation coefficient.

The number of tillers, number of leaves, plant height and leaf length x breadth, have highly significant intercorrelations among themselves. Table 8a reveals that though there is a positive correlation between yield and number of tillers as such, the direct effect due to this character is negative. It is also seen that the indirect effects through number of leaves and length x breadth of leaf are also negative. The positive correlation is mainly due to a high positive indirect effect through plant height and a positive indirect

effect through number of fingers, both of which have highly significant correlations with yield.

Even though the positive correlation between yield and number of leaves is not significant, it is observed from Table 8b that the plant height contributes a high positive indirect effect though the direct effect due to number of leaves is negative.

The splitting up of correlation between yield and plant height (as seen in Table 8e) shows that the high correlation between these two characters is again due to a high positive direct effect. The number of fingers also contributes to a positive indirect effect, whereas the other characters having significant correlations with plant height have negative indirect effect.

The direct effect of length x breadth of last fully opened leaf towards the establishment of a positive correlation with yield is seen to be negative but here again, plant height contributes a substantial positive indirect effect, nullifying the negative indirect effect of other characters having significant correlations with length x breadth of leaf (as seen in Table 8d).

'Number of mother rhizomes' has a positive direct effect together with a positive indirect effect through length x breadth of leaf, but these are nullified by a negative indirect effect contributed by plant height resulting in almost no correlation with yield.

Table 8f reveals that a highly significant correlation between yield and number of fingers, mainly due to a substantial positive direct effect through this character and positive indirect effect through plant height. As in the previous cases, number of tillers, number of leaves and length x breadth of leaf contribute negative indirect effects.

Table 8g shows that the negative correlation between yield and number of nodes per unit length of finger is mainly due to a negative direct effect and a negative indirect effect through plant height.

Summing up the above results, by the method of path coefficient analysis, it is observed that wherever significant positive correlation between yield and a morphological character is established, it is mainly due to substantial positive contribution by plant height and number of fingers, either directly or indirectly. Characters such as number of tillers, number of leaves and length x breadth of leaf contribute vegetative effects, either directly or indirectly in most of the cases. It may be concluded that the plant height in turmeric is a single important morphological character based on which selection for yield could be made. Number of fingers per clump is a secondary character which also may help in selection of better yielding cultivars.

63

Based on the D^2 statistics, the fifteen cultivars could be grouped into three clusters during 1977-'78, whereas the eighteen cultivars fell into four clusters during the subsequent year. The clustering pattern in the two years has been given in Table 24. Two cultivars belonging to the species G. aromatica were keeping their separate identity in both the years. The cultivars belonging to the species G. longa were almost equally divided among the other two clusters during the first year, whereas in the second year, two of the cultivars belonging to the species were in two distinct clusters and all the remaining 14 cultivars were in one single cluster.

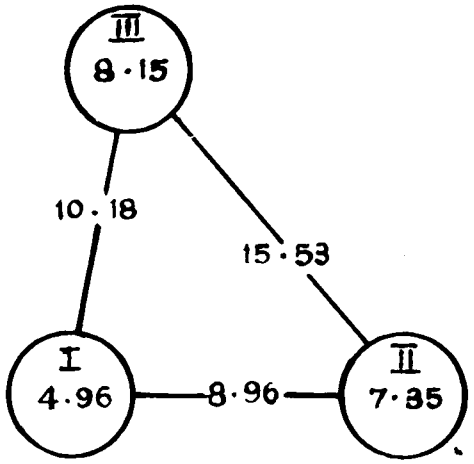
The intra and inter-cluster D^2 values, for both the years have been presented in Table 25 (see also Plate XIV). Table 26 gives the cluster means for the two years.

During 1977-'78, the maximum inter-cluster D^2 value of 241.16 was noticed between clusters II and III, the latter being comprised of the two cultivars belonging to G. aromatica. This was due to the long, narrow and cylindrical shape of the fingers, as reflected in the length/circumference ratio and the tall stature of the plants, belonging to G. aromatica. Cultivars in cluster III were conspicuous for their lesser number of mother rhizomes, tillers and leaves per clump.

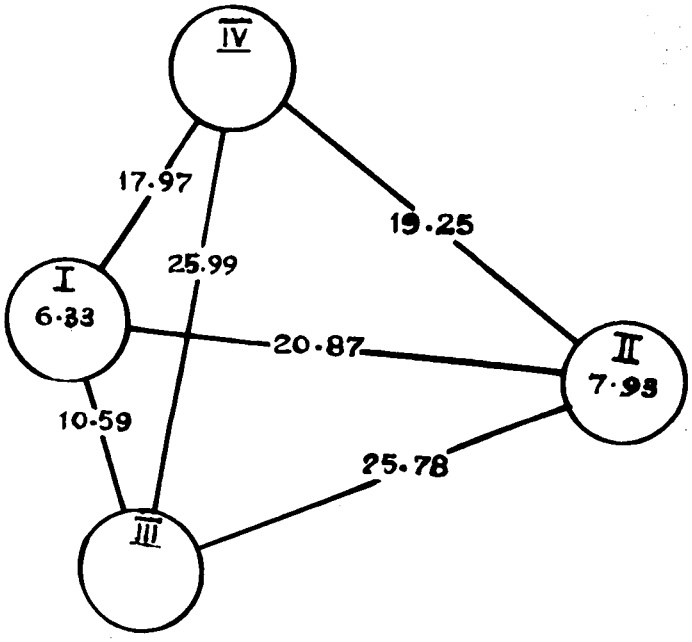
PLATE XIV

Spatial distribution of clusters
during 1977-1978 and 1978-1979

PLATE XIV. SPATIAL DISTRIBUTION OF CLUSTERS DURING 1977-'78 AND 1978-'79



i) 1977-'78



ii) 1978-'79

Table 24. Pattern of clustering of the cultivars of *O. longa* and *O. aromatica* during 1977-1978 and 1978-1979.

Cluster No.	1977-1978 (15 cultivars)	1978-1979 (18 cultivars)
I	2a 4a 11a 13c 14b 15b	2a 4a 11a 13c 14b 15b 16a 18a 20a 21a 23a 24d 27a 28a
II	8c 12a 16a 18a 21a 24d 28a	50 57
III	50 57	8c
IV		12a

O. longa

2a	Mydukur	14b	Rajapuri local	23a	Duggirala
4a	Gorakhpur	15b	Amalapuram	24d	No.24
8c	Kuchipudi	16a	Wynad local	27a	Ethamkula
11a	Ventimitta	18a	T. Sunder	28a	Thodupusha
12a	Amritapani	21a	Alleppey	*O. aromatica*	
13c	Nandiyal type	20a	Moovattupusha	50	Kasturi
				57	Udayagiri

Table 25. Intra and inter-cluster D^2 values during 1977-1978 and 1978-1979

Cluster No.	1977-1978			1978-1979			
	I	II	III	I	II	III	IV
I	24.58	80.37	103.62	40.04	435.53	112.20	322.98
II		54.02	241.16		62.87	664.79	370.70
III			66.36			0	675.63
IV							0

Note: For pattern of clustering, see Table 24

Table 26. Cluster means for 1977-'78 and 1978-'79

Sl. No.	Characters	1977-78			1978-79			
		Cluster I	Cluster II	Cluster III	Cluster I	Cluster II	Cluster III	Cluster IV
1.	No. of tillers (per plant)	2.28	3.17	2.00	3.09	2.55	2.83	4.83
2.	No. of leaves	10.39	13.75	9.20	17.01	15.80	7.53	28.09
3.	Height (cm)	88.00	86.65	92.83	103.97	102.16	89.84	100.59
4.	Length/breadth of leaf	3.83	4.05	3.83	3.88	3.83	4.12	4.57
5.	No. of mother rhizomes	2.30	2.38	2.18	2.80	2.46	1.97	5.36
6.	No. of fingers	7.79	5.72	7.05	8.93	9.35	4.50	17.42
7.	No. of nodes/unit length	1.02	1.00	1.06	1.35	1.14	1.33	1.55
8.	Length/circumference of mother rhizomes	0.49	0.63	0.54	0.70	0.71	0.69	0.75
9.	Length/circumference of fingers	1.20	1.19	1.99	0.92	1.58	0.93	1.20
	Yield per clump (gm)	315.83	209.21	265.00	262.46	254.58	144.02	415.64

Note: For pattern of clustering, see Table 24

Number of nodes per unit length was low indicating comparatively wider internodal distance for these cultivars. Distance between clusters I and III was also high, mainly due to the differences in length/ circumference ratio of fingers. Though clusters I and II consisted of cultivars belonging to G. longa, the cultivars in the latter cluster were found to have more number of narrower leaves, lesser number of fingers and elongated mother rhizomes. Maximum differences in yield was noticed between these two clusters.

Though during 1978-'79, cluster I consisted of 14 cultivars, all belonging to the species G. longa, the intra-cluster D^2 value was only 40.04. However, the highest inter-cluster D^2 value of 675.63 was noticed between clusters III and IV, consisting of the remaining two cultivars of G. longa viz., 8e Kuchipudi and 12a Amritapani. This divergence was due to the differences in the shape of fingers and mother rhizomes (length/circumference ratio). Cultivar 8e Kuchipudi (cluster III) was equally distant from cluster II, consisting of the cultivars belonging to G. aromatica. Elongated shape of fingers of the cultivars belonging to the latter species was found to be the main contributing factor for this. However, clusters III and IV were found to be nearer to cluster I, consisting

of cultivars of C. longa than to cluster II, formed with the cultivars of C. aromatica.

A comparison of the D^2 values computed in both the years revealed that the intra-clusters value for the cultivars of C. aromatica (cluster III during 1977-'78 and cluster II during the succeeding year) were more or less similar. In both the years, number of tillers was minimum and length/circumference ratio of fingers maximum, for the cultivars of this species.

II. BIOCHEMICAL STUDIES

The protein zymogram from electrophoretic studies has revealed prominent inter-specific variation specially in band numbers 9 and 12. Among C. longa types, band number 12 was found to be most prominent except in a few cultivars like 27a, 12a and 14b. On the other hand, in C. amada band number 12 was slightly prominent, though the band is very faint compared to C. longa. The Indonesian type was quite different with band 9 having the highest intensity. All the protein bands were uniformly faint in cultivars belonging to C. aromatica. Similar inter-specific difference has been observed in specific enzyme protein among other group of plants also (Mitra et al., 1970; Vaughan and Waite, 1967) and variation in protein and enzyme has been considered as one of the criteria to study the

species relationships (Fox et al., 1964; Garber, 1965; Hart and Bhatia, 1967). The data obtained from the electrophoretic studies indicate the possible use of these information in the classification of species and cultivars of turmeric and along with the D^2 analysis ege data, form an useful complimentary tool for understanding the relationship and differences among the cultivars and species. However, the study has also indicated that it may be necessary to work out the separation of genetically demarcated isoenzymes like malate dehydrogenase, alcohol dehydrogenase and esterases to get a clear picture about the differences and relationships.

The oil and curcumin contents estimated in C. longa and C. aromatica cultivars also supplement the conclusion drawn from the D^2 analysis and electrophoretic studies. The cultivars belonging to C. longa have a very high variation in curcumin content, ranging from 7.8 to 14.5%, whereas in C. aromatica, the range of curcumin content was very narrow (6.3 to 8.48%). The oil content in C. longa cultivars was relatively low (3.0 to 8.45%). The investigation has clearly brought out the fact that in C. longa the variability for oil as well as curcumin content is very high compared to C. aromatica, and for identifying cultivars with

high curcumin and oil contents it may be worthwhile to carry out selection in C. longa alone. The study has also helped to identify cultivars with high curcumin content like Selection Nos. 20a, 24d, 21a, 16a, 28a which incidentally are in the same genetic cluster based on the D^2 analysis. Interestingly, the study has also indicated that the cultivars with high oil content (C. aromatica selection Nos. 50 and 57) have relatively low curcumin content and hence it may not be worthwhile to attempt to select a variety with high oil as well as high curcumin content.

The data on colour of leaves and turmeric powder revealed that in C. aromatica the colour was dark orange yellow and in C. longa it was strong yellowish and dark orange yellow.

III. CYTOGENETICAL ASPECTS

In the present investigation, chromosome numbers for three species have been reported, i.e., C. longa, 2n = 63; C. aromatica, 2n = 84; C. amada, 2n = 42; and Curcuma sp. (Indonesian type) 2n = 42. A perusal of the earlier reported chromosome numbers shows that a chromosome number of 2n = 32, 62, 63 and 64 for C. longa (Sugiura 1936; Sato 1960; Raghavan and Venkatasubban 1943; Chakravorti 1948; Sharma and Bhattacharyya 1959; Ramachandran 1961 and 1969), 2n = 42, 63, and 86 for

C. aromatica (Raghavan and Venkatasubban 1943; Ramachandran 1961, 1969) and 2n = 42 for C. amada (Chakravorti 1948; Sharma and Bhattacharyya 1959 and Ramachandran 1969). Other chromosome numbers reported for the genus are 2n = 42 for C. decipiens, C. neilgherrensis and C. angustifolia (Ramachandran 1961, 1969; Chakravorti, 1948; Sharma and Bhattacharya, 1959), 2n = 63 and 64 for C. zedoaria (Venkatasubbah, 1946; Chakravorti 1948; Ramachandran, 1961, 1969) and 2n = 64 for C. petiolata (Venkatasubbah, 1946). Thus chromosome numbers for 8 species of Curcuma with 2n = 32, 42, 62, 63, 64 and 86 have been reported so far. The present investigation has clearly shown that all the cultivars of C. aromatica have 2n = 84 and C. longa 2n = 63. This along with 2n = 42 for C. amada and Curcuma sp. (Indonesian type) reported here show a polyploid series with multiples of n = 21 and somatic chromosome numbers of 2n = 42, 63, and 84. If a basic number of n = 21 is assumed, then C. amada, Curcuma sp. (Indonesian type), C. decipiens, C. neilgherrensis and C. angustifolia are to be considered as diploids, C. longa, a triploid, and C. aromatica, a tetraploid.

Based on the number of cultivars in C. aromatica and C. longa investigated at present, it is to be now presumed that the earlier reported chromosome number of 2n = 32, 62 and 64 for C. longa and 42, 63 and 86 for C. aromatica are exceptional cases and correct chromosome

numbers for these two species are 2n = 63 and 2n = 84 respectively. This has been further confirmed by a gametic number of n = 42 for C. aromatica reported here for the first time.

Based on the karyotype analysis in C. longa, Sato (1960) found that the species has one pair of A chromosome with median constriction, 5 pairs of A chromosomes with sub-median constriction, 6 pairs of B chromosomes with sub-median and sub-terminal constriction, and 4 pairs of C chromosomes with sub-median and terminal constrictions. He assumed that the genus Curcuma seems to have a basic number of 7 and 8, judging from the somatic chromosome number of 2n = 32, 42, 62 and 64 reported earlier. Ramachandran (1961) proposed a basic number of x = 21 in Curcuma, derived either by dibasic amphidiploidy (derived from a combination of lower basic numbers x = 9 and 12) or by secondary polyploidy.

Polyploidy and aneuploidy combined with structural changes of chromosomes are presumed to be the main causes for higher numbers in different families of Scitamineae (Raghavan and Venkatasubban, 1943; Venkatasubban, 1946; Sharma and Bhattacharyya, 1956, 1959 and Sato, 1960). Most of these authors agree that lower numbers such as 4, 5 and 6 are the original basic numbers and secondary basic numbers such as 9, 10, 11, 12 and 13 are derived numbers through further evolution. On the basis of the

available cytological information, it is to be assumed that 2n = 42, 63 and 84 are the correct somatic chromosome numbers for the three species investigated here. The reported chromosome numbers for different species of Curcuma (i.e., 2n = 42, 63 and 84) could be explained if a basic number of either x = 7 or x = 21 is assumed. However, from the pairing behaviour of chromosomes as indicated by quadrivalents and hexavalents respectively during microsporogenesis in C. longa and C. aromatica, it may not be reasonable to assume a basic number of x = 7. The observed quadrivalents and hexavalents could be explained if the basic number of x = 21 is assumed for the genus, and in which case C. amada will be a diploid, C. longa a triploid and C. aromatica a tetraploid.

A survey on the distribution of basic chromosome numbers in Zingiberales (Sato, 1960) revealed that out of 132 species belonging to 21 genera, basic numbers of 9, 11, and 12 were found in 96 species, obviously indicating the predominance of these three basic numbers. In the light of the above observation, it is to be presumed that x = 21 for Curcuma is a secondary basic number probably derived from a combination of x = 9 and 12 as postulated by Ramachandran (1961).

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Absence of multivalents and presence of bivalents in polyploid species normally indicate its alloploid nature. Presence of multivalent association at meiosis cannot necessarily be treated as the sole evidence for autoploidy, because of genotypically controlled tendency to form bivalents as reported in Phleum pratens (Muntzing and Prakken, 1940). Chromosome pairing and all the events of meiosis are presumed to be under genetic control and the specificity of synapsis can be induced or narrowed by gene action to permit the pairing of chromosome related genetically or evolutionarily (Riley and Law, 1965). Thus the apparent diploid like behaviour of the triploids and tetraploids in Curcuma can be explained on the presumption that the failure of pairing between genomes is not due to lack of homology between constituent genomes, but due to genetic mechanism suppressing pairing between homologous and homoeologous chromosomes, as explained in the classical examples of Triticum aestivum (Riley and Chapman, 1958; Riley, 1960). A similar gene controlled phenomenon, suppressing multivalent formation has also been reported to be in operation in tetraploid Cuscuta reflexa. In addition to delicately balanced gene, controlling homologous chromosomes pairing genus suppressing or permitting chromosome pairing and combination of these, may also happen in the same species as reported for wheat (Riley and Chapman 1958, Kempanna

and Riley 1962; Driscoll, 1972 and Lang and Riley, 1973). Any one of the above situation may not be exclusively occurring in Curcuma, since most of the species are propagated by vegetative methods.

Meiotic pairing has been regarded as reliable indicator of the polyploidy involved. The presence of quadrivalent in C. longa and hexavalent in C. aromatica indicates a degree of homology between constituent genomes. Based on the assumption that C. aromatica is a tetraploid, one would have expected much higher frequency of multivalents for this species. One would ordinarily expect to find a much higher frequency of multivalents in autopolyploids. However, the presence of few multivalents indicates, that the species may not be a true tetraploid but at best a segmental allotetraploid. The meiotic behaviour of C. aromatica revealed that few of its chromosomes could associate to form multivalents.

Morphological resemblances, chromosome behaviour, tetrasomic segregation, and fertility or sterility of the putative diploid form, are some of the basis on which the nature of polyploidy is determined (Stebbins, 1950; Swaminathan, 1954). Any one of the following three explanation could be put forward to interpret the low frequency of multivalents in C. aromatica. The species is a segmental allopolyploid, with some chromosomes in four complete structural homologues which regularly

pair as multivalents, and other so strongly differentiated that they form only bivalents. Such a meiotic behaviour also could be expected in an autopolyploid which has undergone a long period of chromosomal and genetic differentiation to finally form predominantly bivalents. Species exhibiting genotypically controlled tendency to form bivalents can also show this type of pairing.

Tetraploids like G. arvensis when first arose would presumably have been relatively sterile. Obviously they showed more advantageous character than the diploid, and might have survived the initial period by reproducing vegetatively. Inevitably they would be more powerfully selected for increased fertility, and consequently favouring selection of predominantly bivalents. This indicates that either there is an inhibited gene suppressing the pairing of chromosomes between homologous partners, thus limiting the multivalent formation, or alternately an evolutionary process extended for a period of time wherein the newly produced autoploidy becomes converted into segmental allopolyploid.

Based on the variation pattern as evidenced from correlation studies and D^2 analysis, and further supported by cytological observations, it is tempting to presume that G. lanata (2n = 63) is a natural hybrid between 2n = 42 and 2n = 84 types. Though the species is relatively sterile, the chromosome pairing in meiosis

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is nearly normal with few trivalents and univalents. In a triploid plant, meiosis is expected to be quite irregular with high frequency of trivalents, univalents, bridges and fragments (Goodspeed, 1930; Upcott, 1938). Predominantly bivalent formation in the triploid G. longa could be explained if it is assumed that the putative diploid (2n = 42) and tetraploid (2n = 84) parental species with secondary basic number of n = 21 had arisen from primary basic number of 9 and 12 with the following probable constitution.

Diploid (2n = 42) x Tetraploid (2n = 84)

x = 9 (AA) x = 9(AAAA)

\+ +

x = 12(A_1A_1) x =12($A_1A_1A_1A_1$)

↓

Triploid (2n = 63)

A A A

\+

$A_1A_1A_1$

(A = 9; A_1 = 12 chromosomes)

Certain amount of homology between A and A_1 genomes is indicated by the presence of quadrivalents in G. longa and hexavalents in G. aromatica. The logical corollary of this assumption is that the A genome of the diploid may not be completely homologous

with the A_1 genome of the tetraploids and hence the limited number of multivalents observed. Besides, as in the present case, mostly bivalents have been reported in triploid Fragaria (Yarnell, 1930) and tobacco (East, 1933), and this has been attributed to non-homologous pairing or some sort of 'non-gene-by-gene' pairing.

In perennial plants with efficient vegetative reproduction, a high degree of seed sterility is not a barrier to the existence of either the individual or the population. Numerous examples are available in literature with abundant wild species distributed over large areas, entirely reproduced by vegetative means, eg. Acorus calamus, Eichhornia, Gramineae, Anacharis canadensis and Lemna sp. (Ernst, 1918; Stebbins, 1950) and sterile triploid form of Fritillaria camschatcensis (Matsuura, 1935). In all such cases the reproductive potential and spreading is by means of asexual propagation, but genetic variability is brought about by occasional sexual reproduction. The most important effect of this on evolution is to lessen the selective value of complete sterility in sexual reproduction. Highly sterile genotypes may live for such long time and successfully compete with the fully sterile relatives. Such situation has been reported in the case of Elymus tritiecides by Stebbins (1950).

In the present case, although the tetraploid semi-wild species, C. aromatica produces seed, the seed production seems to be mainly controlled by environmental factors. Cultivars of C. longa are completely sterile and have greater vegetative vigour and ability to spread by rhizomes and have proved to be an equal competitor, if not better than C. aromatica under the rigorous selection carried over centuries. By the vegetative propagation this sterile triploid has been able to maintain its remarkable genetic identity for considerably long time.

A little flexibility in the vegetatively propagated species of Curcuma has been indicated by the presence of chromosome mosaics both in pollen mother cells and somatic cells (Table 14). The evolutionary significance of the altered chromosome number for the somatic cells in vegetatively propagated plants has been well established by Sharma and his associates (Sharma, 1956; Sharma and Sharma, 1959; Sharma and Bhattacharyya, 1956, 1959; Sharma and Mukhopadhyaya, 1963). Speciation in such vegetatively propagated plants is brought about through the entrance of a nucleus with altered chromosome number into the young growing shoots, resulting in clones with altered chromosome number. It is probable that alteration in somatic chromosome number, followed by vegetative propagation might have given rise to clones with 2n = 62, 64

reported in C. longa and 2n = 86 reported in C. aromatica. Even then, unless these clones with altered chromosome numbers have an adaptively superior attribute, they are likely to be eliminated in the selection. Such clones may not have much of a chance to survive in competition with the established cultivars and hence their relative infrequency in the germplasm collections.

IV. SEED PROPAGATION

All the cultivars belonging to C. aromatica flowered and set seed. Among C. longa cultivars, only Alleppey, Kuchipudi, Kandyal type, Wynad local flowered, but none of them set seed, obviously confirming complete sterility. The seedlings raised from the seeds of some of the cultivars of C. aromatica had remarkable morphological similarities to the parental clones. All the progenies had 2n = 84 only, just like the parental clones of C. aromatica. Leaf epidermal pattern as indicated from the measurement of stomatal and epethelial cells also showed very little variation. On the basis of chromosome counts of the progenies and uniform morphological characteristics, the possibility of apomixis occurring in C. aromatica cannot be ruled out. In fact the limited extent of meiotic irregularities, reduced pollen fertility, together with the morphological

and cytological evidences indicated in the present investigation strongly suggest apomictic reproduction. However, positive evidence for apomixis can be obtained only by properly conducted breeding tests along with studies of megaspore, embryosac and embryo development (Stebbins, 1950). The processes of apomixis and sexuality run concurrently in higher plants (Gustafsson, 1946, 1947). Relationship between apomixis and polyploidy has been reported in many groups of plants and a polyploid which is apomictic, has distinct advantages in reproduction, because they circumvent the complicated process of gene exchange and produce seed through a cloning process that reproduces the genotype of the mother plant (Clausen, 1961).

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SUMMARY

Sixteen cultivars of Curcuma longa, 11 cultivars of Curcuma aromatica, one type of Curcuma amada and one Indonesian type of Curcuma species were used for morphological, biometrical, biochemical and cytogenetical investigations.

Critical analysis on the morphological and yield data of different cultivars of C. longa and C. aromatica revealed that the differences in yield were due to the differences in seed weight of mother rhizomes and fingers. When mother rhizomes were used as planting material, a progressive increase in yield was noticed with the increase in the weight of seed rhizomes. However, when fingers were used for planting, it was observed that the optimum weight of fingers as seed material was about 30 gm, when planted at a spacing of 30 x 25 cm.

An analysis of inter correlation of co-efficients among the morphological characters and yield revealed that number of tillers, plant height and number of fingers had significant correlation with the yield. The number of tillers, number of leaves, plant height and leaf length x breadth, were found to have highly significant inter-correlation among themselves. Path co-efficient analysis indicated that wherever significant positive

correlation between yield and morphological characters was established, it was mainly due to substantial positive contribution by plant height and number of fingers, either directly or indirectly. Based on this, it is concluded that plant height in turmeric is a single important morphological character on which selection for yield could be made.

Cultivars of C. longa and C. aromatica were grouped into three clusters during 1977-'78 and four clusters during 1978-'79 based generalised distance D^2 statistic. Two cultivars belonging to C. aromatica were keeping separate identity in both the years. The maximum inter-cluster D^2 value during 1977-'78 was noticed between clusters II and III, the latter being comprised of two cultivars belonging to C. aromatica. Long, narrow cylindrical shape of fingers as reflected in the length/ circumference ratio, characteristic of C. aromatica, were responsible for this. Though clusters I and II consisted of cultivars belonging to C. longa, the cultivars in the latter cluster were found to have more number of leaves, lesser number of fingers and elongated mother rhizomes.

A comparison of D^2 values computed in both the years revealed that intra-cluster values for the cultivars of C. aromatica were more or less similar. In both the years number of tillers was minimum and length/circumference

ratio of fingers maximum for the cultivars of this species.

The protein zymogram from electro-pheretic studies revealed prominent inter-specific variation with respect to band numbers 9 and 12. Band number 12 was found to be most prominent among C. longa cultivars, except in the case of 27a, 12a and 14b. All the protein bands were uniformally faint in cultivars belonging to C. aromatica. C. amada was characterised by the prominence of band number 12 though its intensity was low as compared to that of C. longa. Curcuma species (Indonesian type) was quite distinct with band No.9 having the highest intensity. The data indicated the possible use of electropheretic studies in classification of species and cultivars of turmeric.

Estimation of oil and curcumin contents in different cultivars indicated that in C. longa the variability for oil as well as curcumin content was very high compared to C. aromatica and for identifying cultivars with high curcumin and oil contents it may be worthwhile to carry out selection in C. longa alone. The study also indicated that the cultivars with high curcumin content had relatively low oil content.

The cytological investigation has clearly shown that all the cultivars of C. aromatica have 2n = 84 and C. longa 2n = 63 chromosomes in their somatic complement. This along with 2n = 42 for C. amada and Indonesian type of Curcuma sp. showed a polyploid series with multiples of n = 21 and chromosome numbers of 2n = 42, 63 and 84. It is suggested that the earlier reported chromosome numbers of 2n = 32, 62 and 64 for C. longa and 42, 63 and 86 for C. aromatica are exceptional cases and the correct chromosome numbers of these two species are 2n = 63 and 84 respectively. Further, it is also suggested that the basic number of x = 21 for Curcuma is a secondary basic number probably derived from a combination of x = 9 and 12.

Detailed meiotic analysis was carried out for 3 cultivars of C. longa and 5 cultivars of C. aromatica. A maximum of quadrivalents and hexavalents were found in C. longa and C. aromatica respectively. Bivalents were predominant in all the cultivars of both the species. The later stages of meiosis were almost regular in the cultivars of C. aromatica, though increased abnormalities were observed in the cultivars of C. longa. The pollen fertility in C. longa ranged from 45.7 to 48.5% and in C. aromatica from 62.0 to 74.5%. The apparent diploid-like behaviour of triploid and tetraploid Curcuma sp. has been explained under the presumption that the failure of pairing between genomes is due to genetic mechanism

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suppressing pairing between homologous and homeologous chromosomes. However, a certain degree of homology between constituent genomes has been indicated due to the presence of quadrivalents in C. longa and hexavalents in C. aromatica.

Based on the variation pattern as evidenced from correlation study and D^2 analysis and further supported by cytological observation, it has been suggested that C. longa 2n = 63 is probably a natural hybrid between 2n = 42 and 2n = 84 types.

A little flexibility in the vegetatively propagated species of Curcuma has been indicated by the presence of chromosome mosaics and the evolutionary significance of this in the vegetatively propagated plants has been indicated.

All the cultivars belonging to C. aromatica flowered and set seeds have been recorded for the first time in this investigation. Among C. longa, cultivars only Alleppey, Kuchipudi, Mandyal type, Wynad local flowered, but none of them set seed. The seedlings raised from the seeds of C. aromatica had remarkable morphological similarities to the parental clones. All the progenies had 2n = 84 chromosomes just like the parental clones of C. aromatica. On the basis of chromosome counts of the progenies, and uniform morphological characteristics supported by other cytological evidences, it is suggested that apomixis occurs in C. aromatica.

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* Original not seen.