"GENETIC ANALYSIS OF PHENOLOGICAL VARIATIONS FOR YIELD AND QUALITY IN TURMERIC (*Curcuma longa* L.)"

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GENETIC ANALYSIS OF PHENOLOGICAL VARIATIONS FOR YIELD AND QUALITY IN TURMERIC (*Curcuma longa* L.)

by

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(2013-11-123)

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2015

DECLARATION

I, hereby declare that this thesis entitled **"GENETIC ANALYSIS OF PHENOLOGICAL VARIATIONS FOR YIELD AND QUALITY IN TURMERIC (*Curcuma longa* L.)"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled **"GENETIC ANALYSIS OF PHENOLOGICAL VARIATIONS FOR YIELD AND QUALITY IN TURMERIC (*Curcuma longa* L.)"** is a record of bonafide research work done independently by Ms. Anju Vijayan (2013-11-123) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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DEDICATED TO

MY FAMILY

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Anju Vijayan

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LIST OF ABBREVIATIONS AND SYMBOLS USED

%	Per cent
<	Less than
>	Greater than
°C	Degree Celsius
CD	Critical difference
cm	Centimeter
DAP	Days after planting
DAS	Days after sowing
et al.	And other co workers
Fig.	Figure
g	Gram
GA	Genetic advance
GCV	Genotypic coefficient of variation
h	Hours
i.e.	That is
kg	Kilo gram
m	Metre
min	Minutes
ml	Milli litre
mm	Milli metre
MP	Main plot
nm	Nano metre
No.	Number
NS	Not significant
PCV	Phenotypic coefficient of variation

RH	Relative humidity
RLI	Relative light intensity
rpm	Revolutions per minute
S	Significant
sp. or spp.	Species (Singular and plural)
t/ ha	Tonnes per hectare
V_E	Environmental variance
V_G	Genotypic variance
V_P	Phenotypic variance

INTRODUCTION

1. INTRODUCTION

Turmeric (*Curcuma longa* L.) the most ancient medicinal spice, traditionally ubiquitous and held sacred is a rhizomatous herbaceous perennial plant of the family, Zingiberaceae. The history of turmeric is entwined with the history of Indian culture and also with the socio-religious practices of the country.

It is native to tropical South Asia but is now widely cultivated in the tropical and subtropical regions of the world. India leads in turmeric production in the world and also is the leading exporter and consumer. It was popular even in Vedic times because of its unique properties of colour, flavour and also its importance as a medicine in Ayurveda, besides its use as a cosmetic and significance in religious ceremonies and auspicious occasions. Turmeric is valued globally as a condiment, colourant, dye and medicine. It is gaining importance world over as a potential source of new drug(s) to combat a variety of ailments.

Rich cultivar diversity of turmeric exists in India. ‘Wynadan turmeric’ and ‘Alleppey turmeric’ of Kerala are of legendary fame. Even though Andhra Pradesh and Tamil Nadu lead in turmeric cultivation, at present, there is a renewed interest in Kerala to cultivate turmeric. The agro- climatic conditions in Kerala are favourable for successful turmeric cultivation. Thus the state has very good scope for turmeric production.

To take up cultivation in a competitive manner, varieties which will show high yield in specific agro climatic conditions are needed. Turmeric is a vegetatively propagated crop. So its scope of improvement through conventional breeding methods is limited. Yield is a complex character governed by a large number of genes and is greatly influenced by environmental factors. Therefore, the knowledge of association of various characters with yield is an important factor to be considered.

Turmeric is usually planted in April, and the shoot development continues until October, turns yellow from early December and withers in January in several countries in tropical and subtropical regions, such as India, Bangladesh, Myanmar and Japan. It is important to harvest a plant species in an appropriate time for increasing yield, quality and storability, and reducing disease incidence (Adler *et al.,* 2006).

Turmeric is harvested from September to January for commercial and household needs without considering yield per unit area and dry yield percentage. In some areas, shoots will be removed before complete withering for early harvest of the rhizomes. It is assumed that removing green shoots affect turmeric yield and there is a correlation between harvest time and yield of turmeric. There is a widely held view among the farmers that the earlier harvest yields better quality produce.

Hence the study has been conducted

- To evaluate the effects of harvest time on yield and quality of turmeric
- To fix the optimum time for harvest of rhizomes in turmeric
- To study PCV, GCV, heritability, genetic advance, correlation and path analysis of different characters
- To calculate the selection indices of different genotypes

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

2.1 ORIGIN AND DISTRIBUTION

The origin of *Curcuma longa* is not certain but it is thought to originate from southern Asia, most probably from India. *Curcuma*, a very important genus in the family Zingiberaceae, consists of about 110 sp., distributed in tropical Asia and the Asia- Pacific region. It reached China before the 7th century, East Africa in the 8th century and West Africa in the 13th century. It was introduced into Jamaica in the 18th century. At present turmeric is widely cultivated throughout the tropics, but commercial production is concentrated in India and South-East Asia. In Africa it is cultivated in home gardens in many countries and is for sale in numerous markets.

2.2 TAXONOMY

Turmeric (*Curcuma longa*) is a rhizomatous herbaceous perennial plant of the ginger family, Zingiberaceae. (Chan *et al.,* 2009).

Kingdom - Plantae
Subkingdom - Tracheobionta---Vascular plants
Superdivision - Spermatophyta---Seed plants
Division - Magnoliophyta---Flowering plants
Class- Liliopsida--Monocotyledons
Subclass - Zingiberidae
Order - Zingiberales
Family - *Zingiberaceae*---Ginger family
Genus - *Curcuma*
Species - *Curcuma longa* L.

2.3 IMPORTANCE OF THE CROP

Turmeric, the sacred and ancient spice of India known as the ‘Indian saffron’, is an important commercial spice crop grown in India. It is an important herb and is widely used worldwide as medicine, condiment, dye and cosmetic (Jayaprakasha *et al.,* 2005). It is the third important spice crop in India next to Chilli and black pepper. The usage of turmeric started as a food ingredient to depoisonize the cuisine. In Ayurveda, turmeric is considered as 'Vighnaushadha' means the sacred medicine.

The demand of turmeric increased all over the world as new ingredients of therapeutic and life saving properties were discovered. Turmeric is the major spice in which maximum number of products has been patented. Another factor that could influence the demand for turmeric is its increasing use as food colour, since synthetic colours are failing to disfavour in many countries (Anonymous, 1992). Its bright yellow colour is due to the presence of curcumin pigment, which is also a powerful antioxidant, anti-parasitic, antispasmodic, anti-inflammatory and anticarcinogenic compound (Sasikumar 2005; Ravindran *et al.,* 2007).

Curcuma is gaining importance world over as a potential source of new drug(s) to combat a variety of ailments as the species contain molecules credited with anti-inflammatory, hypocholestraemic, choleratic, antimicrobial, insect repellent, antirheumatic, antifibrotic, antivenomous, antiviral, antidiabetic, antihepatotoxic as well as anticancerous properties (Sasikumar, 2005). The primary active constituent of turmeric is an important secondary metabolite namely, curcumin. Its role as an antimalarial (Nandakumar *et al.,* 2006), anti-inflammatory (Gupta *et al.,* 2012; 2013) and antitumor (Gupta *et al.,* 2012) compound has been well appreciated worldwide and it has also been known to modulate lipid metabolism, which has been implicated in obesity (Alappat and Award, 2010). In addition, curcumin is also used in clinical trials to treat Alzheimer’s (Hamaguchi *et al.,* 2010).

Turmeric is mainly known as a spice all over the world. The literature is redolent with its use as a spice in curry powder, chicken bouillon, sauces, gravies, dry seasoning, baking mixes, processed cheese pickles, relishes, breading soup, beverages and confections (Sasikumar, 2001).

The plant has also been recognized as a pharmaceutical crop for production of standardized therapeutic extracts (STEs) or small therapeutic molecules (STMs) (Li *et al.,* 2010). Low incidence of Alzheimer's disease in regions where turmeric is extensively used in cuisine and as an herbal remedy suggests that it may protect against this disease since areas of high consumption such as those in India have very low Alzheimer's incidence (Travis, 2001).

There are two dominant types of turmeric found on the world market: 'Madras', and 'Alleppey', both named after the regions of production in India. The orange-yellow flesh Alleppey turmeric is predominantly imported by the United States, where users prefer it as a spice and a food colorant. (ASTA, 2002).

2.4 VARIABILITY

Genetic variability for yield and yield contributing traits in the base population is essential for successful crop improvement (Allard, 1960). The larger the variability; the better is the chance of identifying superior genotypes.

C. longa, cultivated turmeric, is now grown in countries like India, China, Pakistan, Bangladesh, Vietnam, Thailand, Philippines, Japan, Korea, Sri Lanka, Nepal, South Pacific Islands, East and West Africa, Malaysia, Caribbean Islands and Central America. India harbours rich diversity of Curcuma, especially in species and cultivar diversity (Sasikumar *et al.,* 1999).

Pillai and Nambiar (1975) and Rao *et al.* (1975) noticed variation in thickness, length, internodal length and colour of rhizomes among turmeric types.

According to Philip (1978) there exist significant differences among different types of turmeric in morphological and growth characters such as height of the plant, number of leaves per tiller, plant height, leaf characters, length of roots and rhizomes and characters of mother, primary and secondary fingers. He noticed no significant variation in tiller production among the types. The study revealed that morphological characters were not reliable to classify the types although some of them could be distinguished by rhizome character.

Mohanty and Sharma (1979) studied genetic variability and heritability for a number of characters in different cultivars of ginger. Their study indicated that straight selection can be made to improve almost all characters except number of tertiary fingers and straw yield.

George (1981) reported that morphological characters such as number of tillers, height of the plant, number of leaves on both the main plant and tiller, number of roots, length, girth and intermodal length of primary and secondary fingers were significantly different among the various lines of turmeric.

High heritability for curing percentage, curcumin and oleoresin content was reported by Philip and Nair (1986) in turmeric. Genetic advance was reported to be high for plant height, green yield, curing percentage, leaf blotch resistance and curcumin and oleoresin content with which he suggested that selection within the existing germplasm would lead to improvement for those characters.

Significant variation was observed for shoots per clump, leaves per shoot, plant height and yield per plant in a germplasm collection of turmeric lines (Mukhopadhayay *et al.* 1986). Genetic coefficient of variation was highest for total plot yield while heritability estimate was moderate for shoots per clump.

Turmeric cultivars at Brahmavar were found to have high significant variation between the cultivars for many of the characters studied *viz.,* yield of cured turmeric, number of primary fingers and yield of secondary fingers (Jalgaonkar *et al.,* 1990).

Reports also showed significant difference between open pollinated progenies of *Curcuma aromatica* cultivar Nandiyal, for all the plant traits except tillers per plant as well as rhizome characters, yield, curing percentage and curcumin content (Menon *et al.,* 1992).

Indiresh *et al.* (1992) studied the genetic variability in turmeric and reported highly significant variation in characters such as plant height, petiole length, fresh rhizome yield, length of primary and secondary fingers per plant, girth of primary and secondary fingers and weight of mother rhizome.

Comparative study between four exotic cultivars of ginger *viz.,* Maran, Himachal Pradesh, Wayanad local and Rio-de-jenario and two Nigerian land races viz., Taffin Yiwa and Yatsun biri showed significant difference for root yield, leaf number and shoot height at crop maturity but the stem tuber yield was not significantly different (Okwvowulu, 1992).

Prakash and Krishnan (1994) observed variations in various accessions and inter varietal hybrid of *Curcuma forskholii* at different stages of growth.

Korla and Tiwari (1999) evaluated 24 genotypes of ginger *(Zingiber officinale)* for yield and yield components under rainfed and irrigated conditions at Solan. The study revealed significant effects of rainfed and irrigated conditions on pseudostem length, tillers per plot, leaf length, leaf breadth and yield per plant. Significant genotypic differences were observed for pseudostem length, rhizome length, rhizome breadth and yield per plant.

Singh *et al.* (1999) evaluated 18 cultivars of ginger for growth, yield and quality in Nagaland during 1992. The cultivar Thingladium, Nadra and Khasi local were the tallest, had most tillers per plant and highest rhizome yield.

Genotypic coefficient of variation was studied in ginger genotypes by Yadav (1999) and Singh and Mittal (2003). The genotypic coefficient of variation was high for length and weight of secondary and primary rizhomes and rizhome yield.

Lynrah and Chakrabarthy (2000) evaluated the performance of 25 genotypes of turmeric including *Curcuma longa, Curcuma aromatica* and *Curcuma caesia* during 1994-95 which revealed significant variation with respect to growth, yield and quality parameters due to genotypes. Among the genotypes, black turmeric (*Curcuma caesia*) a semi wild type showed the most vigorous growth and yield with higher number of tillers, leaves and leaf area per clump.

Poduval *et al.* (2001) studied *Curcuma aromatica* cv.Kasthuri, *Curcuma zeodoaria* cv. Manjakoova and 13 cultivars of *Curcuma domestica* for yield in a field experiment conducted in West Bengal during 1997 and revealed that the cultivars of *C. aromatica* and *C.zeodoaria* yielded more than the cultivars of *Curcuma domestica*.

Narayanpur *et al.* (2003) analysed 16 cultivars of turmeric for morphological and yield characteristics where plant height, number of leaves, number of tillers and leaf area index differed significantly. High significant variations were noticed among the cultivars for fresh and cured rhizome yield for which the reason was attributed to genetic characteristics and their response for particular agro- climatic conditions.

The investigation of Singh *et al.* (2003) on sixty five genotypes of turmeric (*Curcuma longa* L.) showed that the characters like yield, weight of secondary rhizome per plant and number of secondary rhizomes per plant exhibit wide range of variability, heritability and genetic gain. It indicates that the individual plant selection based on these characters can effectively bring about genetic improvement in turmeric.

Kurian *et al.* (2004) reported that the dry rhizome yield of turmeric varieties from KAU viz. Kanthi, Sobha, Sona and Varna ranged from 4.02 to 8.27 t/ ha with a driage ranging from 18.88 to 20.15 %.

A study was carried out using 50 accessions of mango ginger (*Curcuma amada* Roxb*)* collected from farmer's households of Kerala. The study revealed that there existed significant variation between the accessions. Phenotypic coefficient of variation (PCV) was higher in all cases than genotypic coefficient of variation (GCV). Heritability varied from 15.83% to 65.02%. Genetic advance was also high for vegetative and yield characters (Jayasree *et al.,* 2006)

Jan *et al*. (2012) studied a total of 20 turmeric genotypes collected from three eco-geographical areas (Bannu, Haripur and Kasur) of turmeric cultivation in Pakistan under field conditions and the largest variation was observed for plant height, leaf length, leaf width, total and fresh number of leaves, whereas relatively low level of variability was detected in most of the remaining quantitative traits.

The study conducted by Verma *et al.* (2014) in 83 turmeric genotypes at Faizabad (U.P.), showed the highest magnitude for coefficient of variation at genotypic (GCV) and phenotypic levels (PCV) for number of tertiary rhizomes per plant followed by number of tillers per clump and number of secondary rhizomes per plant.

2.5 INFLUENCE OF DATE OF HARVEST

Subramaniam *et al.* (1978) recorded 46.3% increase in fresh rhizome yield when turmeric was harvested after 9 months as compared to the 7 months.

According to Nerk and Torne (1984), kacholam rhizomes collected from Chowgat College campus was found to vary in essential oil content depending on the month of collection of the plant material. The maximum oil content was reported when the plant material was collected in October and minimum in June.

Govind and Gupta (1987) reported that the total number of rhizomes increased from 7.6 to 47.5 plant^{-1} and there was a continuous increase in oil content as the harvesting of turmeric was delayed from mid of August to end of December.

A study conducted by Cooray *et al.* (1988) to check the effect of maturity on rhizome yield, essential oil and curcumin content in turmeric showed that the optimum time of harvest for maximum rhizome yield and curcumin was 9 months and maximum amount of essential oil was reported during 7.5- 8 months.

Chempakam *et al.* (2000) reported that the process of methoxylation of curcumin II & III to yield curcumin I is maximum at 180 days after sowing (DAS) and it continues until maturity. Higher content of curcumin was seen in primary and secondary rhizomes compared to mother rhizomes and the analysis of the pooled rhizome samples showed maximum content of curcumin I at 180 DAS (63.9% of pigments present in oleoresin), while it was lower (53.3%) at full maturity with a concomittant increase in curcumin II and III.

Pachauri *et al.* (2002) suggested that January-February is the ideal period of turmeric harvesting in the Indo- Gangetic plains of India.

Hanashiro *et al*. (2003) reported an increase in curcumin content of *C. longa* with maturation of the plant.

Policegoudra, *et al.* (2007) reported that in mango ginger, the peak accumulation of phenolics, difurocumenonol, and total protein were noticed in 180 day old rhizome and the abundance of these components on 180 days was set as an optimum maturity standard for harvest of mango ginger rhizome, compared with a conventional harvest period that ranges from 200 to 240 days.

A study conducted to evaluate the curcuminoids and essential oil composition as well as curcumin content at different stages of growth of *C. longa* rhizome cultivated in Isfahan, Asghari *et al.* (2009) reported that the dry weight and curcumin content of *C. longa* rhizome increased over maturation of the plant and the values for curcumin contents ranged from 0.25 to 2.7% depending on the phenological stages.

An experiment was conducted at Ludhiana (Punjab) by Kumar and Gill (2009) to study the influence of method of planting (flat and ridge planting) and harvesting time (10 November to 12 March) on growth, yield and quality of turmeric (*Curcuma longa* L.). The results suggest that the planting methods did not influence growth, yield and quality of turmeric significantly but the number and weight of rhizomes improved significantly with delay in harvesting. The oil and curcumin content also increased with delay in harvesting.

A study conducted by Hossain (2010) to evaluate the effects of harvest time on shoot biomass and yield of turmeric for determining critical harvest time in Okinawa, Japan showed that the maximum dry yield is obtained when turmeric shoots wither completely, and they concluded that the turmeric should be harvested in January for higher dry yield in Okinawa.

Growth, yield and quality of turmeric vary with the time of harvest as well as the time of planting. A field experiment carried out to evaluate the performance of 11 released varieties in three planting dates under mild-tropical climatic conditions by Singh *et al.* (2013) showed that the planting of turmeric at last week of April in Mizoram result in better plant growth, higher fresh and dried rhizome yield, and greater curcumin content. Any delay in planting significantly affects the yield as well as quality of rhizomes.

Sajitha *et al*. (2014) in *Curcuma aromatica* and *Curcuma amada* for variations in yield and quality profile over three growth stages revealed significant variations for the parameters such as plant height, yield per plant, dry recovery and for the biochemical characters such as starch, curcumin, crude fibre and oil content. However, protein and tiller number did not show any significant variation over three growth stages and remained almost same.

2.6 WEATHER AND CROP GROWTH

Growth, yield and quality of a plant species is influenced by environmental factors such as water, temperature, photoperiod, radiation, shading and soil nutrient status (Chapman *et al.,* 1993; Miller *et al.,* 1993; Kobata *et al.,* 2000; Kakiuchi and Kobata, 2004; Cohen *et al.,* 2005; Hossain and Ishimine, 2005; Sharma *et al.,* 2006; Akamine *et al.,* 2007; Kasajima *et al.,* 2007). Light is an important environmental factor that influences phenological characteristics including growth, yield and quality of plant (Knake, 1972; Deen *et al.,* 1998a, 1998b; Kobata *et al.,* 2000; Kakiuchi and Kobata, 2004; Kasajima *et al.,* 2007).

Shahi *et al.* (1994) evaluated 40 genotypes of turmeric and data were collected on dry matter, oleoresin and curcumin content. Significant differences were observed due to genotypes and genotype x environmental interaction. High yielding genotypes showed high dry matter content with wide adaptability and stability.

Turmeric grown under lower relative light intensity had increased vegetative parameters, and a higher shoot biomass. It was reported that the shoot biomass increased with the increasing plant height, leaf number and tiller number of turmeric (Hossain *et al.,* 2005a, 2005b; Hossain and Ishimine, 2005).

A study conducted by Hossain *et al.* (2009) in Okinawa, Japan for understanding the effects of relative light intensity (RLI) on the growth, yield and curcumin content of turmeric (*Curcuma longa* L.) showed that turmeric shoot biomass and yield increased significantly at 59−82% RLI and they were highest at 73% RLI. Curcumin content of turmeric increased markedly at 59−73% RLI. This study indicates that turmeric is a partial shade tolerant plant that could be cultivated at around 59−73% RLI for higher yield and curcumin content in Okinawa.

Similarly, Kobata *et al.* (2000) reported that rice can grow well with partial shading. Other studies revealed that plant height, leaf area development and leaf life are influenced by climatic and edaphic factors (Tworkoski, 1992; Ghersa and Holt, 1995; Deen *et al*., 1998a). Clemente and Marler (1996) reported that stomatal conductance in papaya was influenced by the irradiance level. Cohen *et al.* (2005) reported that CO_2 uptake and conductance increased in grape leaf when grown under shading condition.

Cohen *et al.* (2005) and Joscelyne *et al.* (2007) reported that sugar content, pH level and phenolics content in grapes vary with the light exposure level.

Studies conducted by Sharma *et al.* (2000) and Alam and Naik (2009) revealed that there occur variation in phytoconstituent (curcumin, oleoresin and essential oils) of turmeric collected from different locations. It might be attributed to the difference in climate and soil condition of different agroclimatic zones from which turmeric samples were collected.

Ancy and Jayachandran (1993) and Jayachandran *et al.* (1991) observed enhanced rhizome yield in ginger under artificial shaded situations. Zhao *et al.* (1991) observed that in ginger, low light intensities are favourable for increased photosynthetic efficiency. George (1992) reported increase in volatile oil content with increasing shade intensity in ginger. Ancy and Jayachandran (1993) found that volatile oil content under open condition is significantly lower when compared to that in different shade levels.

In a study conducted by Vastrad (2006), higher fresh yield of 11.54 tonnes per hectare was recorded in ginger under normal light condition than under reduced light condition (6.40t/ha). Same trend was observed by Jayachandran *et al*. (1991) and Wilson and Ovid (1993) in ginger and by Singh and Kar (1991) in turmeric.

In ginger, Aclan and Quisumbig (1976), Lalithabai (1981), Jayachandran *et al.* (1991) and Vastrad *et al.* (2006) reported increase in plant height at reduced light intensity.

A study conducted by Ajithkumar and Jayachandran (2003) to understand the effect of different levels of shade on yield and quality of Ginger reported that the shade levels 20 to 40 percentage were favourable for obtaining higher dry ginger yield and non volatile ether extract. Volatile oil content showed increasing trend with increasing shade. Higher starch content was observed at 20 percentage shade level but crude fibre reduced with increasing shade.

Singh *et al.* (2013) and Rao and Rao (1994) also reported that phytoconstituent of turmeric varies from place to place due to influence of environment and agro-climatic conditions.

2.7 CORRELATION STUDIES

Selection of desirable genotypes is the principal step of crop improvement. Most of the economically important characters like yield is extremely complex and is the result of many growth functions of the plant. An estimation of inter relationship of yield with other traits is of immense help in any crop improvement programme. Correlation studies would facilitate effective selection for simultaneous improvement of one or many yield contributing components.

Jalgaonkar *et al.* (1990) reported that the yield of cured turmeric was significantly correlated with yield of secondary fingers. He also reported that the yield of cured turmeric was significantly correlated with yield of secondary fingers and there was significant relation of quantitative characters of secondary finger with each other and with those of primary fingers.

Roy and Wamanan (1990) reported that yield was correlated with shoot height, leaves per clump of shoot and tillers per clump in ginger.

Twelve yield components of ten genotypes of *Curcuma longa* were evaluated for genetic variance and yield correlations by Jalgaonkar *et al.* (1990). Cured yield of all the genotypes was found significantly and positively correlated with yield of secondary fingers.

Okwvowulu (1992) compared four exotic cultivars of ginger with the Nigerian land races and reported a significant positive correlation between stem tuber yield and shoot number in Wayanad local and between stem tuber and root yield in Maran.

In turmeric, phenotypic coefficient of variation was higher than the genotypic coefficient of variation in general. Genotypic coefficient of variation was very high for fresh rhizome yield (63.30) indicating the high degree of genetic variability for this character (Indiresh *et al.,* 1992)

Ali *et al.* (1994) studied genotypic coefficient of variation in ginger genotypes and reported that genotypic coefficient of variation was high for length and weight of secondary and primary rhizomes and rhizome yield per plant.

In kacholam, number of leaves, leaf area index, days to flowering and spread of flowering had high correlation and direct effects on yield with moderately high heritability and genetic advance in open condition while under shade; plant spread recorded moderately high heritability but low genetic advance (Latha, 1994).

Stability in rhizome yield and its determining characters in turmeric were evaluated by Shahi *et al.* (1994) and it revealed that stability in rhizome yield was associated with length and girth of rhizome, number of leaves and tillers per plant.

Correlation coefficient between yield and its component characters in kacholam indicated significant positive association of yield with number of leaves, tillers, leaf length, plant spread and rhizome number (Kanakamony, 1997).

Fifteen ginger cultivars were studied for variability and association of characters among them by Prasad *et al.* (1998). High coefficient of variability was observed for number of tillers followed by number of leaves. Moderate to low variability was noticed for length and breadth of rhizomes, breadth of leaves, number of primary fingers, rhizome weight per plant, plant height and length of leaves.

Chandra *et al.* (1999) evaluated the performance of 25 genotypes of turmeric at Meghalaya for three consecutive years. Among the 19 characters studied, weight of primary finger rhizome, number of primary and secondary finger rhizomes per clump, plant height, length of leaf, diameter and secondary finger rhizomes per clump, plant height, length of leaf, diameter and weight of primary rhizome, internodal distance of primary finger rhizome and rhizome yield per hectare were significantly and positively associated with fresh rhizome yield per clump.

An investigation was carried out on 22 genotypes of turmeric by Hazra *et al.* (2000) to elucidate the role of different growth characters and components of rhizome yield. Genetic variability and correlation were studied to assess the direct and indirect relationships in respect of growth characters and yield of the growth characters only. Leaves per clump at 180 days after planting exhibited significant positive phenotypic correlation with yield.

In *Curcuma longa,* number of leaves per clump, leaf area, leaf area index and number of primary and secondary fingers had strong positive association with rhizome yield at both genotypic and phenotypic levels (Jana *et al.,* 2001).

The genotypic correlation coefficient was in general higher than the phenotypic correlation coefficient thus revealing strong association at genotypic level between the characters in turmeric (Shanmugasundaram *et al.,* 2001 and Reddy, 1987).

Singh *et al.* (2003) studied the genetic variation for rhizome yield and components in 65 turmeric genotypes and observed that the greatest variation was recorded for yield, followed by weight of mother rhizome per plant, plant height, weight of primary rhizome per plant and number of leaves. The phenotypic coefficient of variation was generally higher than genotypic coefficient of variation. The result suggested that superior genotypes may be obtained through selection based on the number and weight of primary and secondary rhizomes.

In *Curcuma longa,* correlation studies showed that number of leaves per clump, leaf area, leaf area index and number of primary and secondary fingers had strong positive association with rhizome yield at both genotypic and phenotypic levels (Narayanpur and Hanashetti, 2003: Singh *et al.,* 2003).

Correlation analysis of 11 characters of turmeric (*Curcuma longa*) carried out using 22 genotypes revealed that the plant height, leaf length, thickness of primary and secondary rhizomes and number of secondary rhizomes had significant positive association with rhizome yield (Tomar *et al.,* 2005).

Forty one turmeric genotypes were evaluated at ICAR Research complex for North Eastern Hilly Region, Umaiam, Meghalaya. The study revealed that all the characters under study viz., plant height, number of clumps per plant, number of leaves per plant, number of primary and secondary rhizomes, length of mother rhizomes and yield per plant showed positive correlation with yield both at phenotypic and genotypic levels (Yadav *et al.,* 2006).

In an experiment to study the agro- morphological diversity in turmeric, Roy *et al.* (2011) reported that plant height, leaf number, primary fingers size and suckers number showed positive and significant association with rhizome yield.

Singh *et al.* (2012) found that the rhizome yield had positive and significant correlation with plant height, number of leaves on main shoot, plant girth, length and width of mother rhizome, number and weight of primary rhizome per plant, number of secondary rhizome per plant, rhizome girth, drymatter (%) and weight of fresh rhizome per plant.

Rajyalakshmi *et al.* (2013) studied the correlation of rhizome yield in turmeric with different morphological characters and found that yield was positively and significantly correlated with plant height, number of tillers per plant and number of leaves per plant. Number of tillers per plant followed by plant height exerted the highest positive direct effect on rhizome yield, which indicated that selection for these characters would directly improve the yield in turmeric.

The correlation of yield parameters with phytoconstituent content (curcumin, oleoresin, and essential oil) of 10 selected turmeric genotypes was analyzed by Singh *et al.* (2014) to find out a promising turmeric genotype. The study showed that the leaf area exerted high positive significant correlation with yield and phytoconstituent content followed by tiller number.

2.8 PATH COEFFICIENT ANALYSIS

Path coefficient analysis is important for partitioning the genotypic correlation coefficient into direct and indirect effects of component characters. A path coefficient is simply a standardized partial regression coefficient and it measures the direct influence of one variable upon another (Dewey and Lu, 1959). An estimation of the actual contribution of a trait and its influence through other traits is done. Works done by various authors in this line is reviewed here.

In turmeric, path analysis showed significant positive correlation between yield and morphological characters and it was due to substantial positive contribution by plant height and number of fingers either directly or indirectly. Based on this, Nambiar (1979) concluded that plant height of pseudostem in turmeric was a single important morphological character for which selection for yield could be made.

According to Geetha (1985), in a study conducted in turmeric, the direct effects of number of leaves per tiller and girth of mother rhizome was positive where as number of nodes per primary finger and petiole length had high negative direct effect on rhizome yield.

In turmeric, plant height had the maximum direct effect on yield, followed by tillers per clump (Mukhopadhyay and Roy, 1986). Tillers per clump, leaves per shoot and plant height were recommended as selection criteria for improving yield.

Rattan *et al.* (1980), Geetha and Prabhakaran (1987) and Lal *et al.* (1986) reported that in turmeric, at genotypic level, the highest positive direct effect was recorded by width of mother rhizome per plant followed by plant height, weight of mother rhizomes, number of secondary rhizomes per plant and number of primary rhizomes per plant.

Panja *et al.* (2002) reported a negative direct effect of number of primary rhizomes and significant positive association with yield due to high indirect effect with number of leaflets and thickness of secondary rhizomes in turmeric.

The path analysis studies conducted by Singh (1993), Datta *et al.* (2006) and Pandey *et al.* (2003) in turmeric reported that at phenotypic level, positive direct effect with rhizome yield was recorded by weight of primary rhizome per plant followed by plant girth, number of leaves on main shoot, curcumin, dry matter, length of mother rhizome and number of tillers per clump.

Path analysis of 11 characters of turmeric (*Curcuma longa*) carried out using 22 genotypes revealed plant height, leaf length, thickness of primary and secondary rhizomes and number of secondary rhizomes to have positive direct effect on rhizome yield. These traits may be given due emphasis while making selections for improvement in rhizome yield of turmeric (Tomar *et al*., 2005).

A study conducted by Rao *et al*. (2006) in fifty four turmeric cultivars, to work out path analysis to investigate the direct and indirect contribution of various characters on cured yield revealed that selection for more weight of the mother, finger rhizome and curing percentage would be more effective as they have positive direct effect as well as significant positive association with cured yield.

Singh *et al.* (2012) reported that the maximum positive direct effect on rhizome yield was expressed by width of mother rhizome followed by plant height, weight of mother rhizome, number of secondary rhizome and number of primary rhizome at genotypic and phenotypic levels.

Genetic variability, correlation and path analysis was studied for rhizome yield and its component characters in 30 diverse genotype of turmeric by Prajapati *et al.* (2014). The path analysis indicated that weight of secondary rhizomes, weight of mother rhizomes, number of leaves per plant and plant height had maximum direct effect on rhizome yield.

An investigation conducted by Shankar *et al.* (2014) for analysis of path coefficient in Tikhur (*Curcuma angustifolia* Roxb.) for rhizome yield, starch recovery and component characters showed that dependent variables, total rhizome yield t ha^{-1} and starch recovery per cent have direct contribution of leaf breadth, harvest index, weight of primary finger rhizome per plant, weight of secondary finger rhizome per plant, thickness of mother rhizome per plant, total rhizome yield t ha^{-1}, starch recovery per cent, dry matter per cent of rhizomes per plant, number of mother rhizome per plant and weight of mother rhizome per plant.

2.9 SELECTION INDEX

In population improvement programmes, selection is based on the phenotypic evaluation of several traits that are frequently obtained from the means of several replications. Selection indices evaluate the total genotypic value of individuals or families for several traits. Selection based on indices permits maximizing the response to selection for one or a group of traits. In reality, selection based on indices reflects not only the response with direct selection, but also the correlated response as selection is practiced for other traits simultaneously.

Analysis of different traits in fifty four turmeric cultivars collected from different parts of the country with respect to path coefficient analysis revealed that selection for more weight of the mother, finger rhizome and curing percentage would be more effective (Rao *et al.,* 2006).

In an experiment to study genetic variability, character association and path coefficient analysis in turmeric, Prajapati *et al.* (2014) reported that weight of secondary rhizomes, weight of mother rhizomes, number of leaves per plant and plant height should be used as selection criterion for improvement of rhizome yield in turmeric.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The experiment entitled "Genetic analysis of phenological variations for yield and quality in turmeric (*Curcuma longa* L.) was conducted at the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani, during the period from May, 2014 to January, 2015. The experimental site was located at 8º 5' N latitude and 77º 1' E longitude at an altitude of 29 m above mean sea level. Predominant soil type of the experimental site was red loam belonging to Vellayani series, texturally classified as sandy clay loam. The objective of the study was to assess the effect of different dates of harvest on growth, yield and quality of turmeric rhizome.

3.1 MATERIALS

The experimental material comprised of 12 turmeric genotypes collected from IISR, KAU and Wayanad. The details of turmeric genotypes used for the experiment are given in table 1. Healthy, disease and pest free rhizome bits weighing 20g were used as planting material.

3.2 METHODS

3.2.1 Design and layout

Design : Split plot
Main plot (3) : Dates of harvest (160 DAP, 200 DAP and 240 DAP)
Sub plot (12) : Varieties
Plot size : 3m^2
Spacing : 0. 25 m x0. 25 m
Replication : 5

Layout of the experiment is given in Fig. 1. The crop received timely management practices as per package of practices recommendations of Kerala Agricultural University (KAU, 2011). Since main thrust was given for different dates of harvest, plants were harvested at 160, 200 and 240 DAP.

3.2.2 Planting

Rhizome bits were planted in raised beds at a depth of 5 cm with buds facing upwards at a spacing of 25 cm X 25 cm and covered with soil.

Table 1. Details of genotypes of Turmeric (*Curcuma longa* L.) collected:

Sl. No.	Genotypes	Source
1	Prabha	IISR, Kozhikode
2	Prathibha	IISR, Kozhikode
3	Kedaram	IISR, Kozhikode
4	Alleppey Supreme	IISR, Kozhikode
5	Suvarna	IISR, Kozhikode
6	Sudarsana	IISR, Kozhikode
7	Kanthi	KAU , Vellanikkara
8	Varna	KAU , Vellanikkara
9	Sona	KAU , Vellanikkara
10	Shobha	KAU , Vellanikkara
11	Suguna	IISR, Kozhikode
12	Wayanad local	RARS, Ambalavayal

Replication – I

T7	T2	T6	T12	T10	T9	T11	T8	T4	T3	T1	T5	MP III
T8	T4	T5	T3	T7	T10	T12	T11	T2	T6	T9	T1	MPII
T10	T1	T6	T5	T4	T9	T11	T12	T7	T8	T3	T2	MPI

Replication – II

T3	T5	T2	T10	T11	T1	T12	T8	T6	T4	T9	T7	MP III
T9	T1	T6	T3	T12	T10	T2	T4	T11	T8	T7	T5	MPII
T1	T6	T8	T9	T4	T3	T12	T2	T5	T11	T7	T10	MPI

Replication – III

T12	T9	T2	T6	T11	T1	T10	T5	T7	T8	T4	T3	MP I
T5	T1	T9	T12	T2	T10	T6	T4	T7	T11	T8	T3	MPII
T1	T12	T10	T5	T6	T2	T8	T7	T4	T3	T11	T9	MP III

Replication – IV

T7	T1	T8	T4	T10	T12	T3	T11	T2	T9	T6	T5	MP III
T9	T12	T5	T3	T6	T8	T4	T2	T10	T7	T1	T11	MP II
T8	T1	T11	T10	T12	T2	T6	T4	T3	T7	T9	T5	MP I

Replication – V

T6	T8	T1	T3	T9	T4	T12	T10	T5	T7	T2	T11	MP II
T2	T8	T11	T12	T10	T9	T4	T1	T7	T6	T3	T5	MP III
T1	T10	T9	T12	T2	T5	T11	T3	T6	T4	T8	T7	MP I

MP I- Harvest at 160 DAP MP II- Harvest at 200 DAP MP III- Harvest at 240 DAP

T1- Prabha T2- Prathibha T3- Kedaram T4- Alleppey Supreme

T5- Suvarna T6- Sudarsana T7- Kanthi T8- Varna

T9- Sona T10- Shobha T11- Suguna T12- Wayanad local

Fig.1. Lay out plan- Split plot design

Plate 1. Field view

3.3 OBSERVATIONS

Random sampling method was adopted. For recording the different biometric observations at 160, 200 and 240 DAP, five plants were selected at random from each genotype as observational plants and means were calculated for each replication. The characters studied and techniques adopted to record the observations are given below.

3.3.1 Plant Characters

3.3.1.1 Plant height (cm)

The height of the plants was measured at 160, 200 and 240 DAP from the base of the main pseudo stem to the tip of the top most leaf and plant height was expressed in cm.

3.3.1.2 Number of tillers

Number of tillers was determined by counting the number of aerial shoots arising around a single plant at 160, 200 and 240 DAP.

3.3.1.3 Number of leaves

Number of leaves was determined by counting the number of leaves of all the tillers at 160, 200 and 240 DAP.

3.3.1.4 Leaf length (cm)

The maximum length of leaves was measured and the mean length expressed in cm.

3.3.1.5 Leaf breadth (cm)

The maximum breadth of leaves was measured and the mean breadth expressed in cm.

3.3.2 Yield Characters

3.3.2.1 Fresh rhizome yield per plant (g)

The yield of fresh rhizome from each genotype was recorded at 160, 200 and 240 DAP and expressed as g/ plant.

3.3.2.2 Dry rhizome yield per plant (g)

Immediately after each harvest at 160, 200 and 240 DAP rhizome samples were taken. The rhizomes were washed and kept to dry under sun for one week. After this, it was kept in hot air oven at 70˚C. The dry weight of turmeric rhizome was expressed in g/ plant.

3.3.2.3 Fresh rhizome yield per plot (kg)

The yield of fresh rhizome from each genotype was recorded from respective plots at 160, 200 and 240 DAP and expressed as kg / plot.

3.3.2.4 Dry rhizome yield per plot (kg)

Immediately after each harvest at 160, 200 and 240 DAP rhizomes from respective plots were taken. The rhizomes were washed and kept to dry under sun for one week. After this, it was kept in hot air oven at 70˚C. The dry weight of turmeric rhizome was expressed in kg / plot.

3.3.3 Quality Characters

3.3.3.1 Oleoresin (%)

Oleoresin in turmeric was extracted in a Soxhlet's apparatus using the solvent acetone (Sadasivam and Manickam, 2002). Hundred gram dried powdered rhizome was distilled with 250 ml acetone for 2 hours and oleoresin was collected after desolventization and weight recorded.

3.3.3.2 Volatile oil (%)

Coarsely ground powder of rhizomes was used for estimation of volatile oil. The method adopted was hydro- distillation using Clevenger distillation apparatus. Four hour distillation was done and oil was collected. The oil content was expressed in percentage (V/ W) on dry weight basis (AOAC, 1975).

3.3.3.3 Starch (%)

Sample weighing 0.5 g was homogenized in hot 80% ethanol to remove sugars and centrifuged. The residue was retained. The residue was repeatedly washed with hot 80% ethanol till the washing does not give colour with anthrone reagent. The residue was dried over a water bath. To that residue 5 ml of water and 6.5 ml of 52% perchloric acid were added and extracted at 0^0C for 20min. Again centrifuged and saved the supernatant. The extraction was repeated using fresh perchloric acid, centrifuged and pooled the supernatant and made up to 100ml. 0.1 or 0.2 ml of the supernatant was pipetted and made up the volume to 1 ml with water. The standard were prepared by taking 0.2, 0.4, 0.6, 0.8 and 1ml of the working standard and made up the volume to 1 ml in each tube with water. 4 ml of anthrone reagent was added to each tube and heated for eight minutes in a boiling water bath, cooled it and the intensity of green to dark green colour was measured at 630 nm. (Sadasivam and Manickam, 2002).

3.3.3.4 Curcumin (%)

Moisture- free turmeric powder weighing 0.5 g was dissolved in 250 ml of absolute ethanol. The contents were refluxed in the flask fitted with an air condenser over a heating mantle for 3-5 h. The extract was cooled and decanted into a volumetric flask and made up the volume. Suitable aliquot of 1-2 ml was diluted to 10 ml with absolute alcohol and the intensity of yellow colour was measured at 425nm in a spectrophotometer (Sadasivam and Manickam,2002)

Curcumin content g/ 100g = $\frac{0.0025 \times A_{425} \times volume\ made\ up \times dilution\ factor \times 100}{0.42 \times weight\ of\ the\ sample\ (g) \times 1000}$

Since 0.42 absorbance at 425 nm = 0.0025g curcumin

3.3.4 Weather parameters

Following weather parameters during the course of investigation were recorded.

a. Maximum temperature (ºC)
b. Minimum temperature (ºC)
c. Relative humidity (%)
d. Rainfall (mm)
e. Evaporation (mm)

3.4 STATISTICAL ANALYSIS

Data recorded from experimental plants were statistically analysed.

3.4.1 Analysis of variance (ANOVA)

The biometric observations recorded were subjected to ANOVA (Panse and Sukhatme, 1985) for comparison among various treatments and to estimate variance components (Table 2).

Table 2. ANOVA for each character

Sources of variation	Degrees of freedom	Mean square	F ratio
Blocks	$r-1$	MSR	MSR/E_a
Main plot factor	$m-1$	MSM	MSM/E_a
Error (a)	$(r-1)(m-1)$	E_a	
Total (a)	$rm-1$		
Sub plot factor	$(s-1)$	MSS	MSS/E_b
Interaction: Sub plot × main plot factor	$(m-1)(s-1)$	MSI	MSI/E_b
Error (b)	$m(r-1)(s-1)$	E_b	
Total(b)	$r \times m \times s - 1$		

Where, r = number of replications

E_a = Main plot error

m = number of main plot factor

E_b = sub plot error

s = number of subplot factor

MSS = Sub plot factor mean square

MSR = Replication mean square

MSI = Interaction mean square

MSM = Main plot factor mean square

Critical difference (CD) for comparing means of main plot factor = $t_a \times \sqrt{\frac{2 \times E_a}{r \times s}}$

Where, t_a is the student's "t" table value at 5 % level for (r-1) (m-1) degrees of freedom.

Critical difference (CD) for comparing means of sub plot factor = $t_b \times \sqrt{\frac{2 \times E_b}{r \times m}}$

Where, t_b is the student's "t" table value at 5 % level for m x (r-1) (s-1) degrees of freedom.

C.D. for comparing two sub plot factor means at a given main plot treatment

$$= \quad t_b \times \sqrt{\frac{2 \times E_b}{r}}$$

3.4.2 Estimation of genetic parameters

3.4.2.1 Genetic components of variance

The phenotypic and genotypic variances were calculated by utilizing the respective mean square values (Johnson *et al.,* 1955).

1) Genotypic variance (V_G)

$$V_G = \frac{MST - MSE}{r}$$

2) Environmental variance (V_E)

$$V_E = MSE$$

3) Phenotypic variance (V_P)

$$V_P = V_G + V_E$$

3.4.2.2 Coefficient of variation

The genotypic and phenotypic coefficients of variation were calculated by following Burton (1952).

a) Phenotypic coefficient of variation (PCV)

$$PCV = \frac{\sqrt{V_P}}{\overline{X}} \times 100$$

b) Genotypic coefficient of variation (GCV)

$$GCV = \frac{\sqrt{V_G}}{\overline{X}} \times 100$$

$\overline{X}$ = General mean of characters

Categorization of the range of variation was effected as proposed by Sivasubramanian and Menon (1973).

Category	Range
Low	< 10%
Moderate	10- 20%
High	>20%

3.4.2.3 Heritability

Heritability percentage in broad sense was estimated for various characters as per the formulae suggested by Johnson *et al*. (1955).

Heritability (h^2) = $\frac{V_G}{V_P} \times 100$

As suggested by Johnson *et al.* (1955) heritability in broad sense estimates were categorized as,

Category	Range
Low	0- 30%
Medium	30- 60%
High	> 60%

3.4.2.4 Genetic advance

Genetic advance is the measure of genetic gain under selection which depends upon standardized selection differential, heritability and phenotypic standard deviation (Allard, 1960). The genetic advance was calculated in percent by the formulae suggested by Johnson *et al.* (1955).

Genetic advance (GA) = $k \times h^2 \sqrt{V_P}$

GA as percentage of mean = $\frac{GA}{\overline{X}} \times 100$

Where, k = standardized selection differential (2.06 at 5% selection intensity)

h^2 = heritability

The range of genetic advance as per cent of mean was classified as suggested by Johnson *et al.* (1955).

Category	Range
Low	<10%
Moderate	10- 20%
High	> 20%

Estimation of Corelation

Phenotypic, genotypic and environmental correlation coefficients were calculated by using the respective variances and covariances of the characters. The equation suggested by Falconer (1981) was used.

Phenotypic correlation coefficient, $r_{PXY} = \frac{Cov_P(X,Y)}{\sqrt{V_P(X) \times V_P(Y)}}$

Genotypic correlation coefficient, $r_{GXY} = \frac{Cov_G(X,Y)}{\sqrt{V_G(X) \times V_G(Y)}}$

Environmental correlation coefficient, $r_{EXY} = \frac{Cov_E(X,Y)}{\sqrt{V_E(X) \times V_E(Y)}}$

Where $Cov_P(X,Y)$, $Cov_G(X,Y)$ and $Cov_E(X,Y)$ denote the phenotypic, genotypic and environmental covariances between the two traits X and Y respectively. $V_P(X)$, $V_G(X)$ and $V_E(X)$ respectively are the phenotypic, genotypic and environmental variance for X and $V_P(Y)$, $V_G(Y)$ and $V_E(Y)$ indicate the phenotypic, genotypic and environmental variance for Y in that order.

3.4.4 Path co-efficient analysis

The use of path coefficient analysis explains cause and effect relationship among the variables. It is a standardized partial regression coefficient and as such measures the direct influence of one variable upon another and permits the separation of the correlation coefficients into components of direct and indirect effects (Dewey and Lu, 1959). This method permits the breeder to identify relatively important components of a variable, on the basis of their direct and indirect influences.

The direct and indirect effects both at genotypic and phenotypic level were estimated by taking fresh yield per plant as dependent variable using path coefficient analysis suggested by Wright (1954) and Dewey and Lu (1959).

$$r_{1y} = P_{1y}r_{11} + P_{2y}r_{12} + P_{3y}r_{13} \ldots\ldots\ldots + P_{ny}r_{1n}$$

$$r_{2y} = P_{1y}r_{21} + P_{2y}r_{22} + P_{3y}r_{23} \ldots\ldots\ldots + P_{ny}r_{2n}$$

. . . . .

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$$r_{ny} = P_{1y}r_{n1} + P_{2y}r_{n2} + P_{3y}r_{n3} \ldots\ldots\ldots + P_{ny}r_{3n}$$

Where;

$1,2\ldots\ldots\ldots n$ = Independent variables

y = Dependent variable

$r_{1y}, r_{2y} \ldots\ldots\ldots r_{ny}$ = Coefficient of correlation between casual factors `1` to `n` on dependent character 1

$P_{1y}, P_{2y} \ldots\ldots P_{ny}$ = Direct effect of character 1 to n on character

It can be written in matrix form as:

$$\underset{A}{\begin{bmatrix} r_{iy} \\ r_{2y} \\ . \\ . \\ r_{ny} \end{bmatrix}} = \underset{C}{\begin{bmatrix} 1 & r_{12} & r_{13} & \ldots\ldots & r_{1n} \\ r_{21} & 1 & r_{23} & \ldots\ldots & r_{2n} \\ . & . & . & \ldots\ldots & . \\ . & . & . & \ldots\ldots & . \\ r_{n1} & r_{n2} & r_{n3} & \ldots\ldots & 1 \end{bmatrix}} \quad \underset{B}{\begin{bmatrix} P_{1y} \\ P_{2y} \\ . \\ . \\ P_{ny} \end{bmatrix}}$$

Then,

$$B = (C)^{-1} A \text{ where } (C)^{-1} = \begin{bmatrix} C_{11} & C_{12} & C_{13} & \ldots\ldots\ldots & C_{1n} \\ C_{21} & C_{22} & C_{23} & \ldots\ldots\ldots & C_{2n} \\ . & . & . & \ldots\ldots\ldots & . \\ . & . & . & \ldots\ldots\ldots & . \\ . & . & . & \ldots\ldots\ldots & . \\ C_{n1} & C_{n2} & C_{n3} & \ldots\ldots\ldots & C_{nn} \end{bmatrix}$$

Direct effects were as follows:

$$P_{1y} = \sum_{i=1}^{k} c_{1i} \; r_{iy}$$

$$P_{2y} = \sum_{i=1}^{k} c_{2i} \; r_{iy}$$

$$P_{ny} = \sum_{i=1}^{k} c_{nj} \; r_{iy}$$

Residual effect (PR_y), which measures the contribution of characters not considered, in the causal scheme was obtained as:

$$\text{Residual effect } (PR_y) = \sqrt{(1 - r^2)}$$

Where,

$$r^2 = P_{1y} r_{1y} + P_{2y} r_{2y} + \ldots\ldots\ldots\ldots P_{ny} r_{ny}$$

P_{ny} = Direct effect of X_n on Y

r_{ny} = Correlation coefficient of X_n on Y.

3.4.5 Selection index

The various genotypes were discriminated based on nine characters using the selection index developed by Smith (1947) using the discriminant function of Fisher (1936).

The selection index is described by the function, $H = a_1 G_1 + a_2 G_2 + \ldots\ldots\ldots + a_k G_k$ where,

H = genetic worth of the plant

$G_1, G_2, \ldots\ldots, G_k$ = genotypic values of the plant with respect to the characters $X_1, X_2, \ldots\ldots\ldots, X_k$.

The economic weightages assigned to each character is assumed to be equal to unity i. e., $a_1, a_2, \ldots\ldots\ldots a_k = 1$.

RESULTS

4. RESULTS

An experiment entitled "Genetic analysis of phenological variations for yield and quality in turmeric (*Curcuma longa* L.)" was undertaken at the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani during the period from May, 2014 to January, 2015. Twelve genotypes of turmeric were evaluated and data collected on thirteen characters were subjected to statistical analysis. The results of the experiment are presented in this chapter.

4.1 WEATHER AND CROP GROWTH

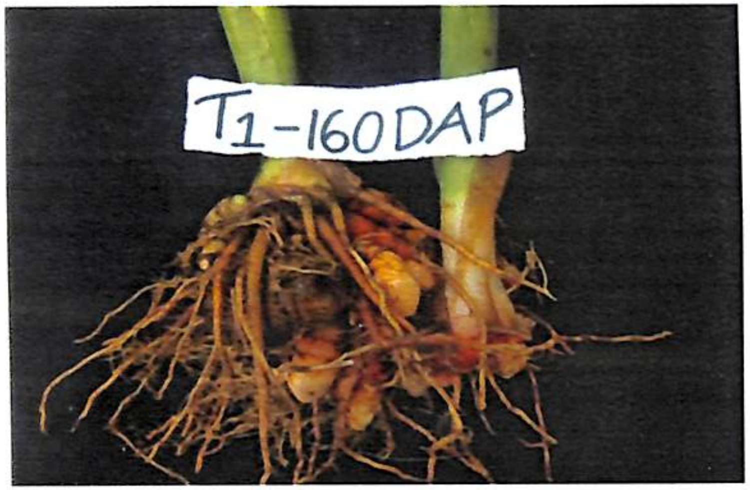
The average rainfall received during the crop period was 12.56 mm. The maximum temperature recorded during the cropping season was in the range of 29.55 ºC to 31.94 ºC and minimum temperature was 21.56 ºC to 24.73 ºC. Relative humidity during the entire crop season ranged between 79.43 and 92.47 per cent. Evaporation during the cropping season was in the range of 1.60 mm to 5.40 mm. The weather parameters during crop growth period are given in Table 3 and Fig 2.

4.2 ANALYSIS OF VARIANCE

4.2.1 Effect of different dates of harvest and varieties on plant height

The data recorded at160, 200 and 240 days after planting (Table 4) suggest that the plant height differs significantly during the three dates of harvest. Plant height was the maximum at 240 days after planting (97.08 cm). Among the three dates of harvest, the minimum plant height was recorded at 160 days after planting (72.96 cm).

Interaction of different dates of harvest with the genotypes was also found significant. For all the genotypes, plant height was the maximum at 240 DAP. Among the genotypes, Sudarsana recorded the highest plant height (108.68cm) and Suvarna recorded the lowest (88.04 cm).



A

B

C

Plate 2. Rhizome of genotype Prabha at different growth stages

A- 160 DAP **B- 200 DAP**

C- 240 DAP

Table 3. Weather data during crop growth (Monthly average)

Month	Max. temp (˚C)	Min. temp (˚C)	Rainfall (mm)	RH (%)	Evaporation (mm)
May	31.94	24.73	21.56	90.03	3.60
June	30.91	23.19	3.14	92. 47	3.20
July	29.99	24.30	5.83	84.74	3.80
August	29.55	23.74	31.55	86.00	5.40
September	30.21	24.19	16.88	84.88	4.20
October	30.52	23.82	12.11	84.67	4.00
November	30.18	23.38	6.87	85.35	1.60
December	30.19	23.38	11.12	83.52	2.00
January	30.60	21.56	4.00	79.43	3.05

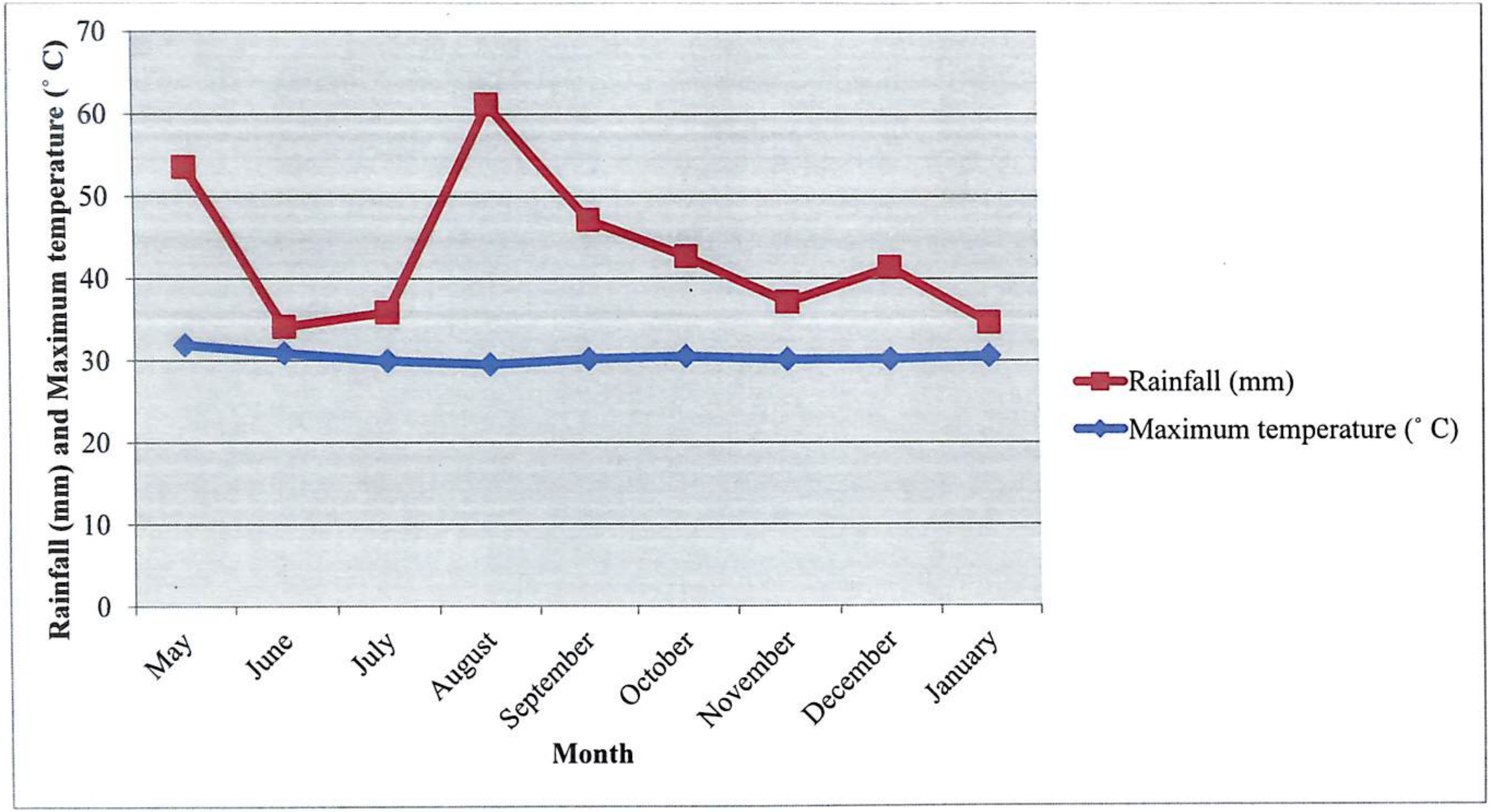


Fig. 2 Rainfall and maximum temperature distribution pattern during the crop growth period

A

B

C

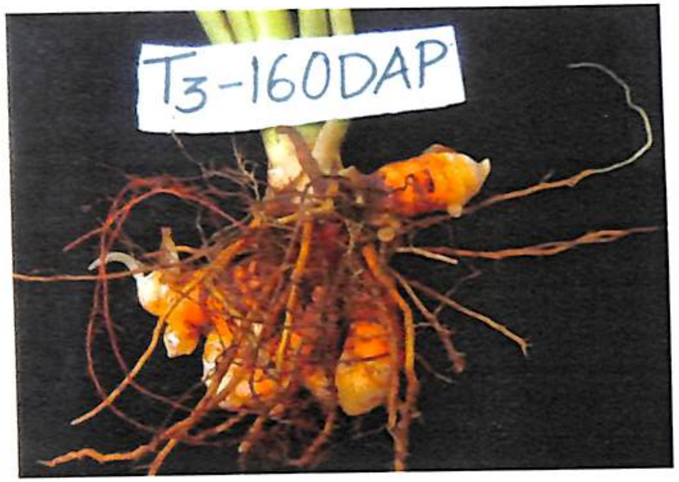
A- 160 DAP B- 200 DAP

C- 240 DAP

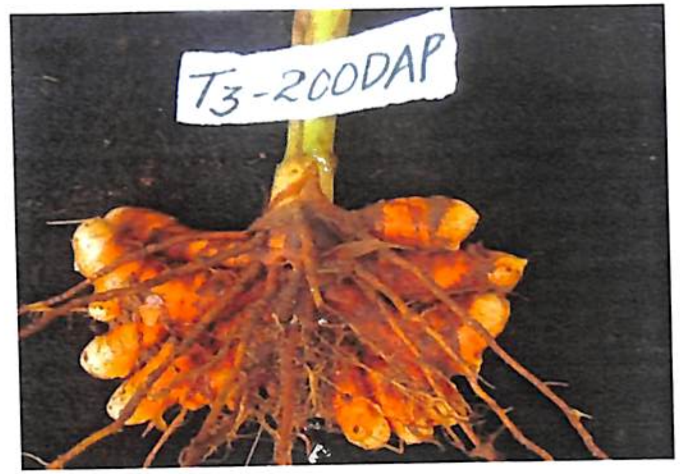
Plate 3. Rhizome of genotype Prathibha at different growth stages

Table 4. Effect of different dates of harvest and varieties on plant height, cm

Varieties	Harvest		
	160 DAP	200 DAP	240 DAP
Prabha	81.98	87.54	94.26
Prathibha	65.20	89.92	100.20
Kedaram	73.40	92.16	106.22
Alleppey Supreme	75.74	91.28	104.04
Suvarna	68.34	80.18	88.04
Sudarsana	67.26	93.28	108.68
Kanthi	70.08	85.40	95.22
Varna	78.16	83.32	90.26
Sona	72.56	88.72	98.38
Shobha	66.10	77.24	97.22
Suguna	76.56	86.32	90.10
Wayanad local	80.12	84.46	92.28
Mean (Harvest)	72.96	86.65	97.08
SE	Harvest (Mean) 0.02		Variety x Harvest (Mean) 0.16
CD (0.05)	Harvest (S) 0.07		Variety x Harvest (S) 0.46



A



B

C

A- 160 DAP B- 200 DAP

C- 240 DAP

Plate 4. Rhizome of genotype Kedaram at different growth stages

4.2.2 Effect of different dates of harvest and varieties on number of tillers

The number of tillers recorded at 160, 200 and 240 DAP differs significantly (Table 5). The maximum number of tillers was observed at 240 DAP (2.74) and it was on par with the number of tillers observed at 200 DAP (2.73). Among the three dates of harvest, the minimum number of tillers was recorded at 160 days after planting (2.61).

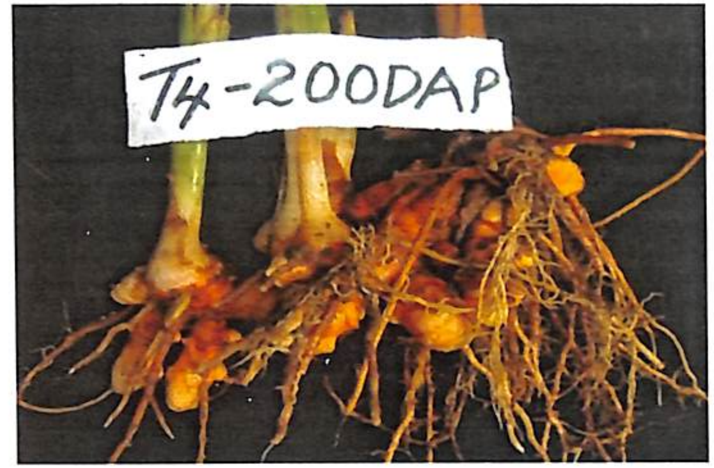
Interaction of different dates of harvest with the genotypes was also found significant. All the genotypes except Prathibha, Kedaram, Suvarna, Sudarsana and Kanthi have the same number of tillers at 200 and 240 DAP. Among the genotypes, Prabha and Alleppey Supreme recorded the maximum number of tillers (3.54) and the genotypes Shobha and Wayanad local recorded the minimum (2.18).

4.2.3 Effect of different dates of harvest and varieties on number of leaves

The data recorded at 160, 200 and 240 days after planting (Table 6) suggest that the number of leaves differed significantly during the three dates of harvest. Among the three dates of harvest, number of leaves was recorded the maximum at 200 DAP (14.12). Among the three dates of harvest, the minimum number of leaves was observed at 160 DAP (11.62).

Interaction of different dates of harvest with the genotypes was also found significant. Among the genotypes, the maximum number of leaves was recorded for Prabha (19.56). For all genotypes, number of leaves got reduced from 200 to 240 DAP.

A



B

C

A- 160 DAP B- 200 DAP

C- 240 DAP

Plate 5. Rhizome of genotype Alleppey Supreme at different growth stages

4.2.4 Effect of different dates of harvest and varieties on leaf length

Leaf length showed significant differences over the three dates of harvest (Table 7). The maximum leaf length was obtained at 240 DAP (49.95 cm) and minimum at 160 DAP (35.54 cm).

Interaction of different dates of harvest with the genotypes was also found significant. Among the genotypes, Sona recorded the maximum leaf length (57.26 cm) and Alleppey Supreme recorded the minimum leaf length (45.30 cm).

4.2.5 Effect of different dates of harvest and varieties on leaf breadth

The data recorded at 160, 200 and 240 DAP suggest that the leaf breadth differ significantly during the three dates of harvest (Table 8). The maximum leaf breadth was recorded at 200 DAP (12.62 cm) and minimum was recorded at 160 DAP (11.13 cm).

Interaction of different dates of harvest with the genotypes was also found significant. All the genotypes recorded the maximum leaf breadth at 200 DAP and it decreased at 240 DAP. Among the genotypes, the maximum leaf breadth was recorded by Sona (13.68 cm) at 200 DAP.

4.2.6 Effect of different dates of harvest and varieties on fresh rhizome yield per plant

Fresh rhizome yield per plant at three different dates of harvest showed significant difference (Table 9). Fresh rhizome yield per plant was recorded the maximum at 240 DAP (418.80 g) and the minimum at 160 DAP (149.38 g).

Interaction of different dates of harvest with the genotypes was also found significant. For all the genotypes, yield was the maximum at 240 DAP. Among the genotypes, Sudarsana recorded the maximum fresh rhizome yield per plant (650 g) and Suvarna recorded the minimum (215.80 g).

A

B

C

A- 160 DAP B- 200 DAP

C- 240 DAP

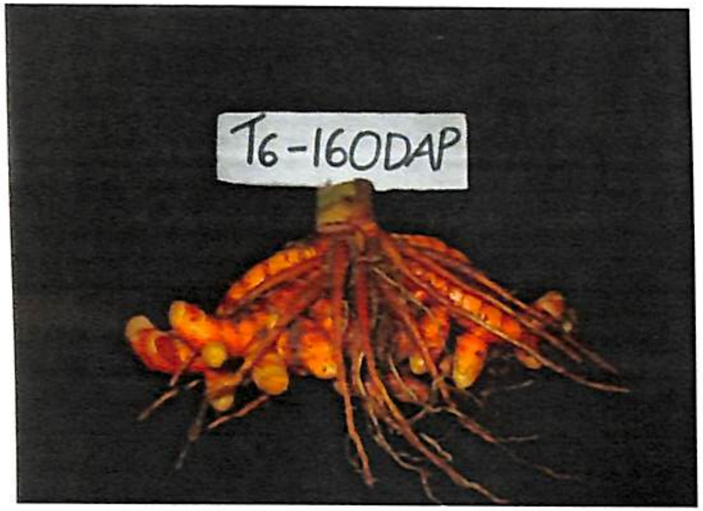
Plate 6. Rhizome of genotype Suvarna at different growth stages

Table 6. Effect of different dates of harvest and varieties on number of leaves

Varieties	Harvest		
	160 DAP	200 DAP	240 DAP
Prabha	15.80	19.56	11.74
Prathibha	13.64	15.94	15.12
Kedaram	14.28	15.74	15.10
Alleppey Supreme	14.40	19.53	17.76
Suvarna	10.42	13.26	12.46
Sudarsana	9.80	12.32	11.36
Kanthi	8.56	10.46	9.64
Varna	7.90	12.64	11.66
Sona	13.56	14.92	13.92
Shobha	8.70	10.28	9.50
Suguna	13.54	14.26	13.30
Wayanad local	8.80	10.54	9.76
Mean(Harvest)	11.62	14.12	12.61
SE	Harvest (Mean) 0.02		Variety x Harvest(Mean) 0.21
CD (0.05)	Harvest (S) 0.07		Variety x Harvest (S) 0.58

Table 7. Effect of different dates of harvest and varieties on leaf length, cm

Varieties	Harvest		
	160 DAP	200 DAP	240 DAP
Prabha	34.88	48.12	48.98
Prathibha	38.24	47.80	55.36
Kedaram	43.38	45.78	48.62
Alleppey Supreme	33.24	41.06	45.30
Suvarna	39.44	42.94	49.37
Sudarsana	32.76	37.88	49.04
Kanthi	30.13	46.80	48.82
Varna	36.52	41.06	53.65
Sona	36.04	39.11	57.26
Shobha	32.00	46.17	48.59
Suguna	36.56	38.20	39.00
Wayanad local	33.28	50.78	55.47
Mean (Harvest)	35.54	43.81	49.95
SE	Harvest(Mean) 0.09		Variety x Harvest (Mean) 0.71
CD (0.05)	Harvest(S) 0.29		Variety x Harvest(S) 1.98



A

B

C

A- 160 DAP B- 200 DAP

C- 240 DAP

Plate 7. Rhizome of genotype Sudarsana at different growth stages

Table 8. Effect of different dates of harvest and varieties on leaf breadth, cm

Varieties	Harvest		
	160 DAP	200 DAP	240 DAP
Prabha	10.93	12.28	9.86
Prathibha	11.91	13.51	13.10
Kedaram	12.23	13.41	12.96
Alleppey Supreme	10.50	12.22	11.60
Suvarna	11.57	12.29	11.26
Sudarsana	11.09	12.78	12.13
Kanthi	11.92	12.55	12.30
Varna	10.60	12.89	11.84
Sona	10.42	13.68	13.16
Shobha	11.04	11.68	11.31
Suguna	10.38	10.84	10.24
Wayanad local	10.96	13.33	12.92
Mean (Harvest)	11.13	12.62	11.89
SE	Harvest(Mean) 0.08		Variety x Harvest (Mean) 0.35
CD (0.05)	Harvest (S) 0.25		Variety x Harvest (S) 0.97

Table 9. Effect of different dates of harvest and varieties on fresh rhizome yield per plant, g

Varieties	Harvest		
	160 DAP	200 DAP	240 DAP
Prabha	223.38	249.00	353.92
Prathibha	85.34	303.24	483.74
Kedaram	138.08	378.28	629.94
Alleppey Supreme	158.38	366.34	514.52
Suvarna	135.54	192.22	215.80
Sudarsana	130.28	384.98	650.00
Kanthi	137.18	234.74	381.36
Varna	186.40	205.68	322.64
Sona	137.34	292.52	430.26
Shobha	87.34	156.06	383.14
Suguna	185.54	236.60	320.82
Wayanad local	187.70	218.74	339.50
Mean(Harvest)	149.38	268.20	418.80
SE	Harvest(Mean) 0.29		Variety x Harvest (Mean) 2.54
CD (0.05)	Harvest (S) 0.98		Variety x Harvest (S) 7.12

A

B

C

A- 160 DAP B- 200 DAP

C- 240 DAP

Plate 8. Rhizome of genotype Kanthi at different growth stages

4.2.7 Effect of different dates of harvest and varieties on dry rhizome yield per plant

The data recorded at 160, 200 and 240 DAP suggest that the dry rhizome yield per plant differ significantly during the three dates of harvest (Table 10). The maximum dry rhizome yield per plant was recorded at 240 DAP (119.06 g) and the minimum was recorded at 160 DAP (8.56 cm).

Interaction of different dates of harvest with the genotypes was also found significant. The entire genotypes recorded the maximum dry rhizome yield per plant at 240 DAP. Among the genotypes, Kedaram recorded the maximum dry rhizome yield per plant (119.06 g) and Suguna recorded the minimum (38.50 g).

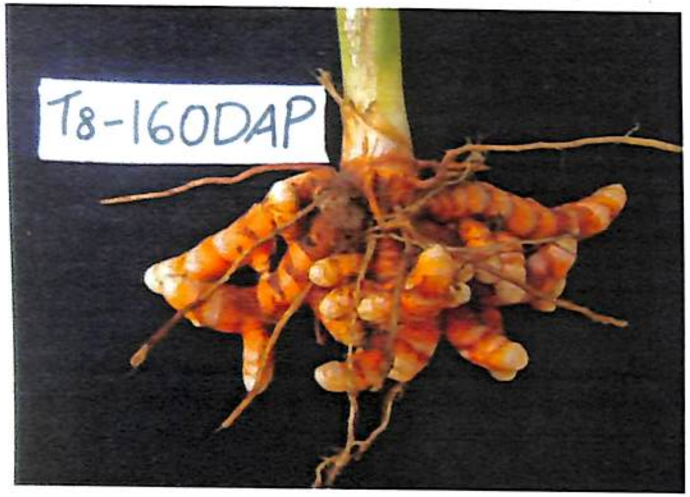
4.2.8 Effect of different dates of harvest and varieties on fresh rhizome yield per plot

Recorded values revealed that the fresh rhizome yield per plot at 160, 200 and 240 DAP differs significantly (Table 11). The maximum fresh rhizome yield per plot was recorded at 240 DAP (12.09 kg). Fresh rhizome yield per plot at 160 DAP recorded the minimum (4.14 kg).

Interaction of different dates of harvest with the genotypes was also found significant. All the genotypes showed an increasing trend in fresh rhizome yield per plot at different dates of harvest. Fresh rhizome yield per plot was recorded the maximum for Sudarsana (18.45 kg) and the minimum for Suvarna (6.38 kg)

4.2.9 Effect of different dates of harvest and varieties on dry rhizome yield per plot

The data presented in Table 12 revealed that the dry rhizome yield per plot was significantly different at different dates of harvest. Better performance was recorded at 240 DAP (1.72 kg). The minimum dry rhizome yield per plot was recorded at 160 DAP (0.47 kg).



A

B

C

A- 160 DAP B- 200 DAP

C- 240 DAP

Plate 9. Rhizome of genotype Varna at different growth stages

Table 10. Effect of different dates of harvest and varieties on dry rhizome yield per plant, g

Varieties	Harvest		
	160 DAP	200 DAP	240 DAP
Prabha	34.17	43.82	69.02
Prathibha	11.52	50.94	91.43
Kedaram	17.95	60.53	119.06
Alleppey Supreme	23.76	62.28	99.30
Suvarna	21.69	34.60	43.16
Sudarsana	11.98	40.81	78.00
Kanthi	13.17	24.30	45.76
Varna	20.97	26.47	48.40
Sona	16.15	34.81	52.34
Shobha	8.56	16.07	47.89
Suguna	17.07	25.08	38.50
Wayanad local	16.89	22.75	40.74
Mean (Harvest)	17.82	36.87	64.47
SE	Harvest (Mean) 0.05		Variety x Harvest (Mean) 0.38
CD (0.05)	Harvest (S) 0.16		Variety x Harvest (S) 1.07

Table 11. Effect of different dates of harvest and varieties on fresh rhizome yield per plot, kg

Varieties	Harvest		
	160 DAP	200 DAP	240 DAP
Prabha	6.45	7.32	10.38
Prathibha	2.23	8.80	14.13
Kedaram	3.80	10.96	16.72
Alleppey Supreme	4.50	10.71	15.32
Suvarna	3.50	5.51	6.38
Sudarsana	3.48	11.27	18.45
Kanthi	3.74	6.67	10.93
Varna	5.30	6.43	9.55
Sona	3.74	8.35	12.79
Shobha	2.42	4.68	11.30
Suguna	5.12	6.93	9.06
Wayanad local	5.45	6.51	10.04
Mean (Harvest)	4.14	7.85	12.09
SE	Harvest (Mean) 0.02		Variety x Harvest (Mean) 0.09
CD (0.05)	Harvest (S) 0.06		Variety x Harvest (S) 0.25

A

B

C

A- 160 DAP **B- 200 DAP**

C- 240 DAP

Plate 10. Rhizome of genotype Sona at different growth stages

Interaction of different dates of harvest with the genotypes was also found significant. For all the genotypes, dry rhizome yield per plot were recorded the maximum at 240 DAP. Among the genotypes, Kedaram recorded the highest value (3.28 kg) and Suguna recorded the lowest (0.98 kg).

4.2.10 Effect of different dates of harvest and varieties on oleoresin

The data (Table 13) suggest that the oleoresin content in the rhizomes differ significantly at 160, 200 and 240 DAP. The maximum oleoresin content was recorded at 240 DAP (11.86 %) and the minimum at 160 DAP (9.73%).

Interaction of different dates of harvest with the genotypes was also found significant. For all the genotypes, oleoresin content increased with the delay in harvesting. Among the genotypes, Sudarsana recorded the maximum oleoresin content (17.58 %). Oleoresin content was recorded minimum by Kanthi (8.64%).

4.2.11 Effect of different dates of harvest and varieties on starch

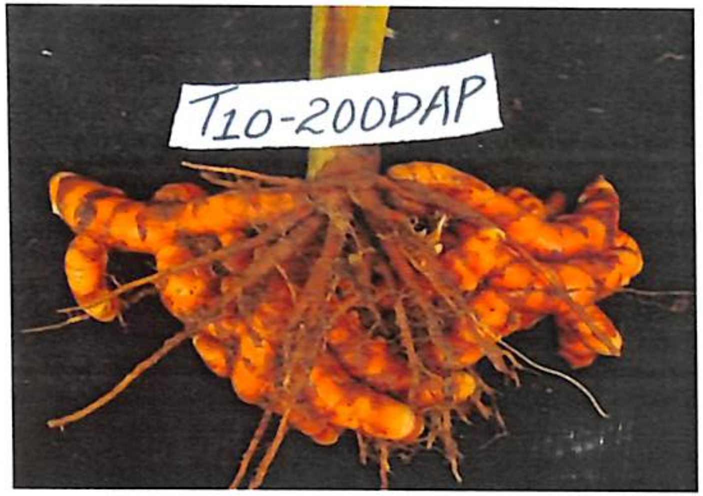
Starch content showed an increasing trend with delay in harvesting (Table 14). The maximum starch content was recorded at 240 DAP (65.93%) and the minimum at 160 DAP (36.33%).

Interaction of different dates of harvest with the genotypes was also found significant. All the genotypes showed an increasing trend in starch content. Kedaram recorded the maximum starch content at 240 DAP (73.60 %) and Varna recorded the minimum starch content of 60.78 % at 240 DAP.

4.2.12 Effect of different dates of harvest and varieties on volatile oil

The data recorded (Table 15) suggest that volatile oil content differ significantly at different dates of harvest. Volatile oil content showed an increasing trend with delay in harvesting. Volatile oil content was the maximum at 240 DAP (5.57 %) and the minimum was recorded at 160 DAP (4.25%).

A



B

C

A-160 DAP B- 200 DAP

C- 240 DAP

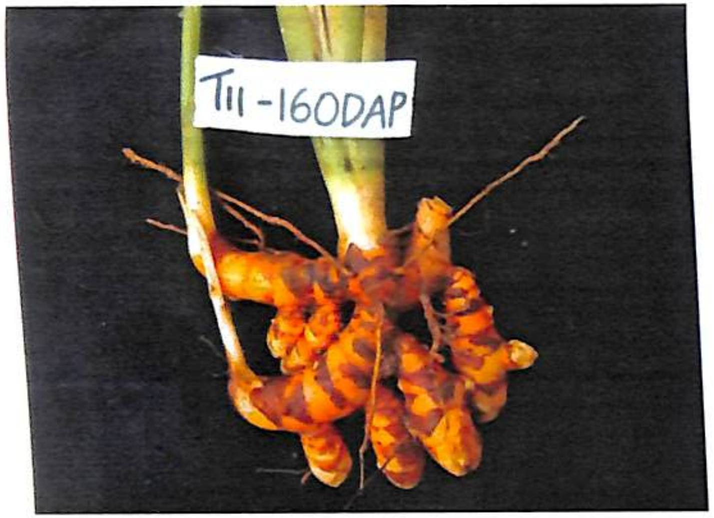
Plate 11. Rhizome of genotype Shobha at different growth stages

Table 12. Effect of different dates of harvest and varieties on dry rhizome yield per plot , kg

Varieties	Harvest		
	160 DAP	200 DAP	240 DAP
Prabha	0.92	1.29	1.98
Prathibha	0.26	1.48	2.13
Kedaram	0.46	1.75	3.28
Alleppey Supreme	0.68	1.80	2.77
Suvarna	0.55	0.95	1.16
Sudarsana	0.31	1.18	2.12
Kanthi	0.45	0.68	1.17
Varna	0.48	0.73	1.29
Sona	0.46	0.99	1.46
Shobha	0.18	0.40	1.24
Suguna	0.46	0.68	0.98
Wayanad local	0.46	0.61	1.04
Mean (Harvest)	0.47	1.05	1.72
SE	Harvest(Mean) 0.011		Variety x Harvest (Mean) 0.035
CD (0.05)	Harvest (S) 0.035		Variety x Harvest (S) 0.096

Table 13. Effect of different dates of harvest and varieties on oleoresin, %

Varieties	Harvest		
	160 DAP	200 DAP	240 DAP
Prabha	8.32	10.28	12.60
Prathibha	9.60	11.52	13.56
Kedaram	11.36	13.24	14.34
Alleppey Supreme	9.14	10.32	12.40
Suvarna	9.26	9.74	10.48
Sudarsana	14.60	15.34	17.58
Kanthi	7.46	8.26	8.64
Varna	9.36	9.84	10.58
Sona	9.18	9.58	10.14
Shobha	8.78	9.56	10.26
Suguna	10.60	11.36	11.70
Wayanad local	9.14	9.50	10.04
Mean (Harvest)	9.73	10.71	11.86
SE	Harvest(Mean) 0.04		Variety x Harvest (Mean) 0.09
CD (0.05)	Harvest (S) 0.13		Variety x Harvest (S) 0.27



A

B

C

A- 160 DAP B- 200 DAP

C- 240 DAP

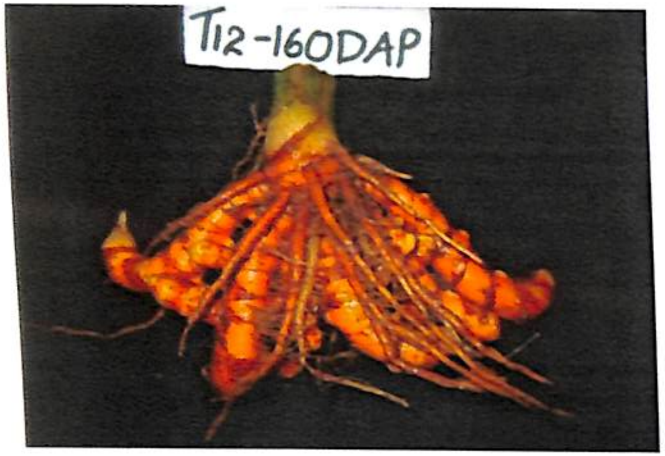
Plate 12. Rhizome of genotype Suguna at different growth stages

Table 14. Effect of different dates of harvest and varieties on starch, %

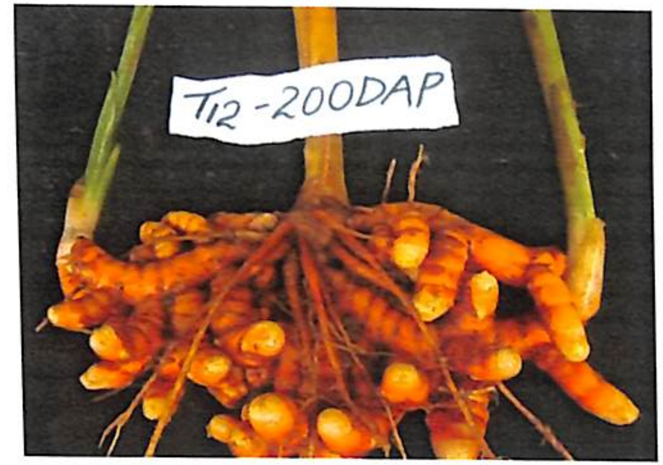
Varieties	Harvest		
	160 DAP	200 DAP	240 DAP
Prabha	35.82	58.06	68.50
Prathibha	32.92	53.60	64.48
Kedaram	41.76	68.22	73.60
Alleppey Supreme	38.28	59.14	65.12
Suvarna	37.56	55.78	66.96
Sudarsana	35.44	66.26	71.86
Kanthi	33.76	53.92	64.04
Varna	35.24	49.62	60.78
Sona	33.86	50.26	61.50
Shobha	38.34	64.72	70.94
Suguna	35.60	48.10	62.14
Wayanad local	37.40	46.88	61.24
Mean (Harvest)	36.33	56.21	65.93
SE	Harvest(Mean) 0.10		Variety x Harvest(Mean) 0.34
CD (0.05)	Harvest (S) 0.33		Variety x Harvest (S) 0.96

Table 15. Effect of different dates of harvest and varieties on volatile oil , %

Varieties	Harvest		
	160 DAP	200 DAP	240 DAP
Prabha	4.44	5.46	6.40
Prathibha	4.48	5.50	6.34
Kedaram	2.26	2.58	3.30
Alleppey Supreme	3.46	3.80	4.54
Suvarna	5.52	6.48	7.46
Sudarsana	5.48	6.38	7.26
Kanthi	4.44	5.30	5.74
Varna	4.84	5.26	5.92
Sona	4.14	4.68	5.06
Shobha	4.70	5.14	5.68
Suguna	5.06	5.40	6.10
Wayanad local	2.16	2.54	3.00
Mean (Harvest)	4.25	4.88	5.57
SE	Harvest(Mean) 0.04		Variety x Harvest (Mean) 0.11
CD (0.05)	Harvest (S) 0.12		Variety x Harvest (S) 1.02



A



B

C

A- 160 DAP B- 200 DAP

C- 240 DAP

Plate 13. Rhizome of genotype Wayanad local at different growth stages

Interaction of different dates of harvest with the genotypes was also found significant. All the genotypes showed an increasing trend in volatile oil content with increase in days after planting. Among the genotypes, Suvarna recorded the maximum amount of volatile oil (7.46 %) and Wayanad local recorded the minimum (3.00 %).

4.2.13 Effect of different dates of harvest and varieties on curcumin

The dates of harvest influenced the curcumin content in the genotypes (Table 16). Curcumin content differ significantly at different dates of harvest. Curcumin content recorded the maximum at 240 DAP (6.05 %) and the minimum at 160 DAP (5.18 %).

Interaction of different dates of harvest with the genotypes was not found significant. When the genotypes were considered, there was not much variation in the curcumin content from 200 DAP to 240 DAP. Among the genotypes, the maximum curcumin content was recorded by the genotypes Kanthi (7.72%) and Varna (7.72 %) at 240 DAP. The minimum curcumin content was recorded by Wayanad local (3.18 %).

4.3 ESTIMATION OF GENETIC PARAMETERS

An attempt was made in the present investigation to study the genetic parameters such as PCV, GCV, heritability and genetic advance expressed as percentage of mean for twelve turmeric genotypes for ten characters. As the genotypic and phenotypic variances are associated with units, the coefficients of variations were worked out for valid comparisons among the characters. The estimates of genetic variability parameters for the ten characters are presented in Table 17 and Fig. 3 and 4.

GCV and PCV were the highest for fresh rhizome yield per plant (30.93 and 31.02) which was followed by volatile oil (24.89 and 25.23), curcumin (23.26 and 23.55), oleoresin (20.53 and 20.66), number of leaves (20.10 and 20.40) and number of tillers (19.09 and 20.40) whereas the GCV and PCV were low for

Table 16. Effect of different dates of harvest and varieties on curcumin, %

Varieties	Harvest		
	160 DAP	200 DAP	240 DAP
Prabha	5.60	6.08	6.60
Prathibha	4.48	4.78	5.46
Kedaram	4.62	4.96	5.60
Alleppey Supreme	5.10	5.50	5.96
Suvarna	3.76	4.36	4.66
Sudarsana	4.72	5.00	5.40
Kanthi	6.62	7.16	7.72
Varna	7.22	7.46	7.72
Sona	6.54	6.98	7.46
Shobha	6.72	7.14	7.56
Suguna	4.28	4.74	5.28
Wayanad local	2.50	2.80	3.18
Mean (Harvest)	5.18	5.58	6.05
SE	Harvest(Mean) 0.03		Variety x Harvest(Mean) 0.10
CD (0.05)	Harvest (S) 0.09		Variety x Harvest (NS) -

Table 17. Estimates of genetic parameters for yield and yield attributing traits of turmeric

Characters	PCV	GCV	Heritability	GA as % of mean
Plant height	6.94	6.85	97.70	13.96
Number of tillers	20.40	19.09	87.61	36.81
Number of leaves	20.40	20.10	97.07	40.79
Leaf length	10.39	9.92	91.09	19.50
Leaf breadth	12.02	8.36	48.41	11.98
Fresh rhizome yield per plant	31.02	30.93	99.44	63.53
Oleoresin	20.66	20.53	98.66	42.00
Starch	6.76	6.70	98.50	13.71
Volatile oil	25.23	24.89	97.31	50.58
Curcumin	23.55	23.26	97.54	47.32

characters such as plant height (6.85 and 6.94), leaf length (9.92 and 10.39), leaf breadth (8.36 and 12.02) and starch (6.70 and 6.76) and all other characters showed moderate GCV and PCV. The PCV values were higher than GCV values for all characters studied (Fig. 3).

Heritability was high for all characters studied except leaf breadth. The highest heritability was shown by fresh rhizome yield per plant (99.44%) followed by oleoresin (98.66%), starch (98.50%), plant height (97.70%), curcumin (97.54%), volatile oil (97.31%) and number of leaves (97.07%) (Table 17 and Fig.4).

Genetic advance (GA) expressed as percentage of mean was highest for fresh rhizome yield per plant (63.53%) followed by volatile oil (50.58%), curcumin (47.32%), oleoresin (42.00%) and number of leaves (40.79%). The characters plant height (13.96%), leaf length (19.50%), leaf breadth (11.98%) and starch (13.71%) showed moderate GA and all other characters expressed high genetic advance (Table 17 and Fig.4).

From the Table 17, it is clear that the characters like fresh rhizome yield of rhizome per plant, number of leaves, oleoresin, volatile oil and curcumin recorded high heritability, genetic advance, GCV and PCV.

4.3 CORRELATION ANALYSIS

The correlation coefficients were estimated for all possible combinations for ten characters at genotypic and phenotypic levels using the data at 240 DAP and the results pertaining to character association is presented in Tables 18 and 19. In general, genotypic correlation coefficients were higher than phenotypic correlation coefficients for all characters. The results of correlation analysis are presented below.

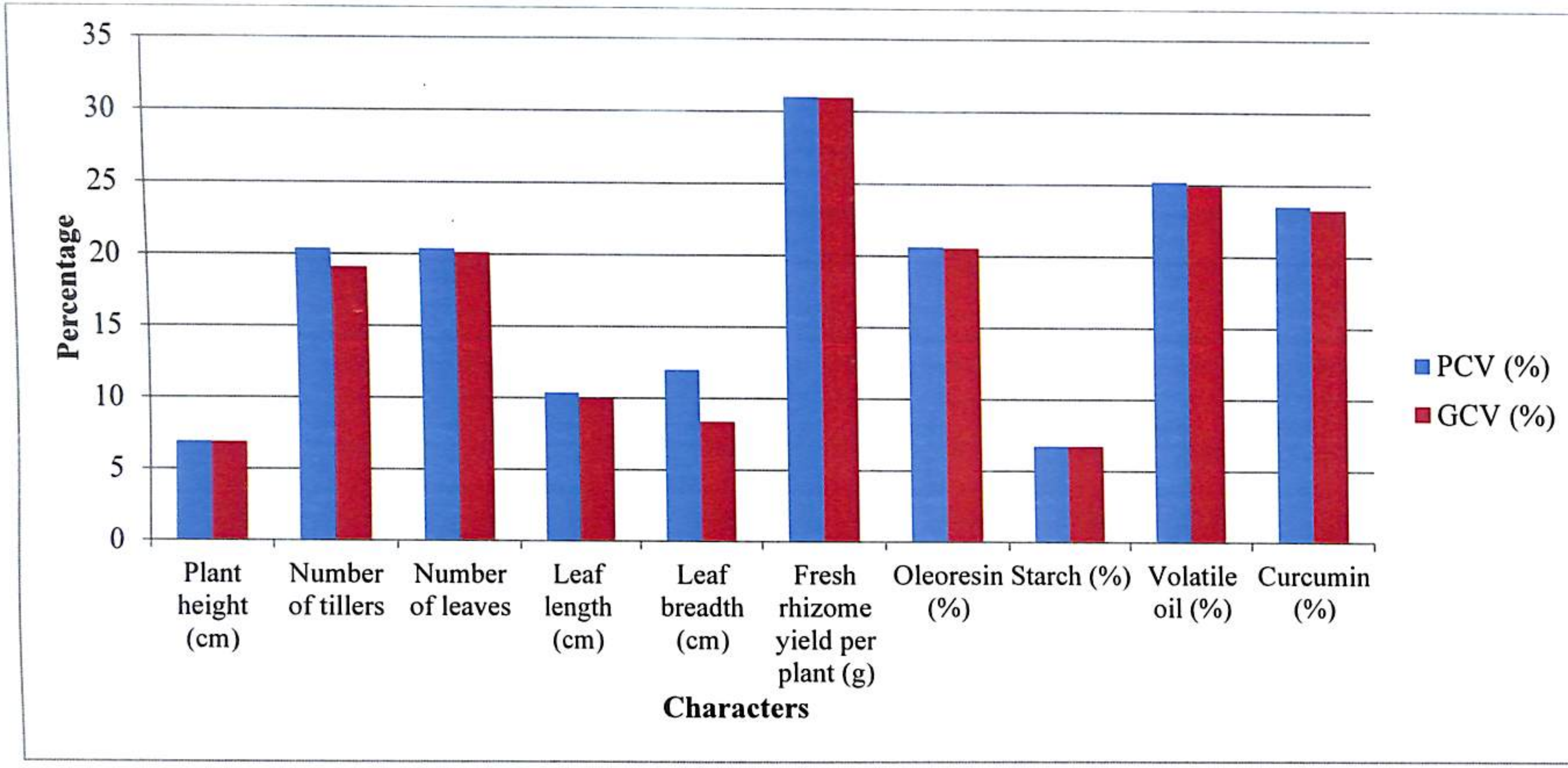


Fig. 3 PCV (%) and GCV (%) for various characters of turmeric genotypes

PCV: Phenotypic coefficient of variation

GCV: Genotypic coefficient of variation

4.3.1 Genotypic correlation

Genotypic correlation with fresh rhizome yield per plant was highly positive and significant for characters such as plant height (0.773), oleoresin (0.716), starch (0.559), number of tillers (0.494), leaf breadth (0.487) and number of leaves (0.404) (Table 18).

Plant height had highly significant positive correlation with fresh rhizome yield per plant (0.773), leaf breadth (0.377), oleoresin (0.486) and starch (0.437).

The character number of tillers had positive and high significant correlation with number of leaves (0.666), fresh rhizome yield per plant (0.494) and oleoresin (0.467). Starch (0.305) had positive correlation with number of tillers.

Number of leaves had high positive significant correlation with number of tillers (0.666), fresh rhizome yield per plant (0.404) and oleoresin (0.357).

The character leaf length had high positive correlation with leaf breadth (0.738) and it is negatively correlated with starch (-0.262).

Association between leaf length (0.738), fresh rhizome yield per plant (0.487) and plant height (0.377) was positive and highly significant with leaf breadth. Leaf breadth was negatively correlated with volatile oil (-0.516).

The character oleoresin had high positive correlation with fresh rhizome yield per plant (0.716), starch (0.607), plant height (0.486), number of tillers (0.467) and number of leaves (0.357). Curcumin (-0.280) showed negative correlation with oleoresin.

Starch was highly significant and positively correlated with oleoresin (0.607), fresh rhizome yield per plant (0.559) and plant height (0.437) while its correlation with leaf length (-0.262) was negative. Number of tillers (0.305) showed positive correlation with starch.

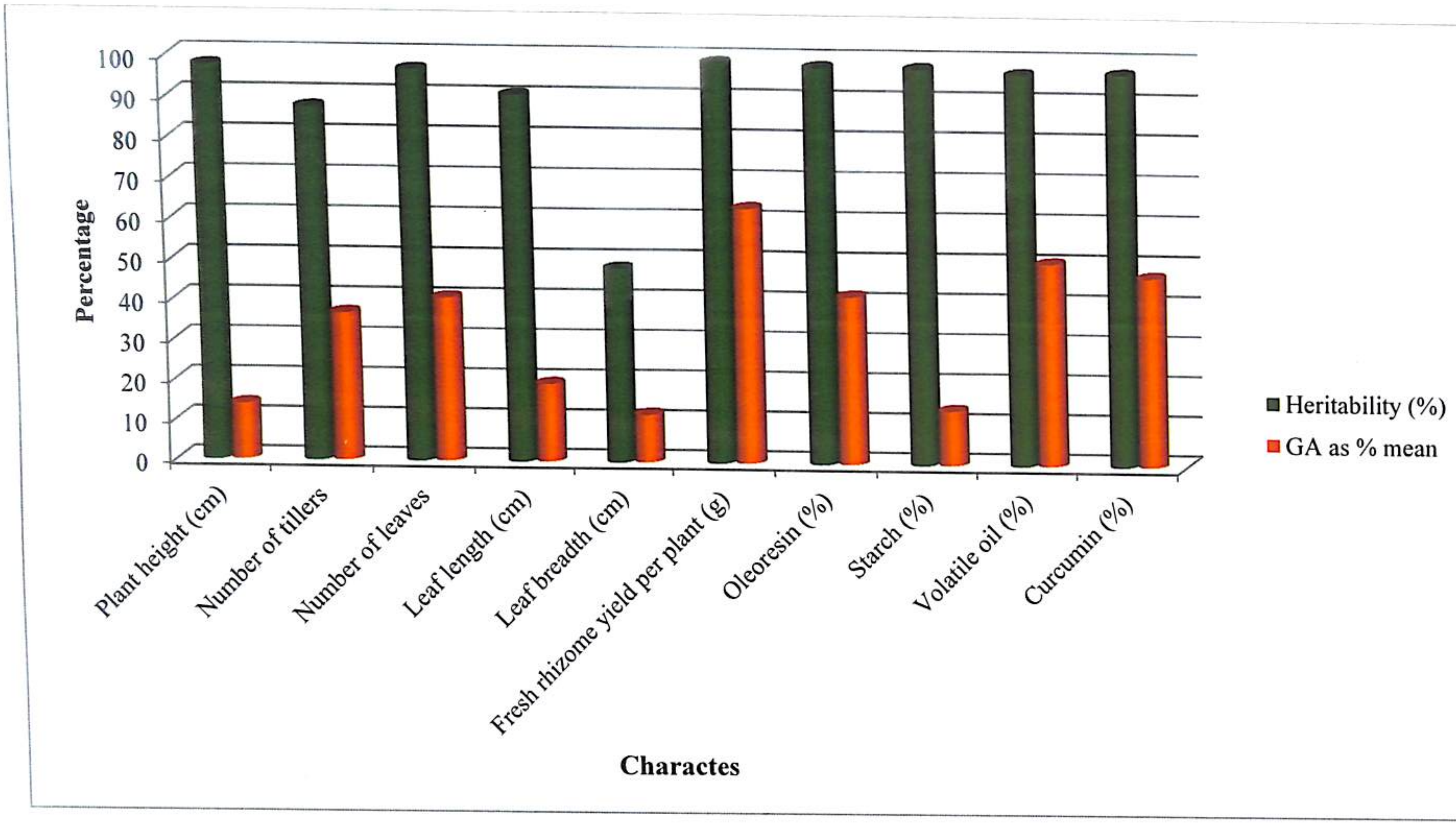


Fig. 4 Heritability (%) and Genetic advance (%) for various characters of turmeric genotypes

GA: Genetic advance

Table 18. Genotypic correlation coefficients for biometric and quality characters in turmeric

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
X1	1.000									
X2	0.130	1.000								
X3	0.107	0.666**	1.000							
X4	0.016	-0.045	-0.154	1.000						
X5	0.377**	-0.018	0.153	0.738**	1.000					
X6	0.773**	0.494**	0.404**	0.007	0.487**	1.000				
X7	0.486**	0.467**	0.357**	-0.160	0.040	0.716**	1.000			
X8	0.437**	0.305*	0.010	-0.262*	-0.114	0.559**	0.607**	1.000		
X9	0.080	-0.075	-0.163	-0.188	-0.516**	-0.239	0.191	0.105	1.000	
X10	0.327*	0.053	-0.109	0.050	-0.110	-0.002	-0.280*	-0.007	0.217	1.000

X1. Plant height (cm)

X2. Number of tillers

X3. Number of leaves

X4. Leaf length (cm)

X5. Leaf breadth (cm)

X6. Fresh rhizome yield per plant (g)

X7. Oleoresin (%)

X8. Starch (%)

X9. Volatile oil (%)

X10. Curcumin (%)

* Significant at 5% level

** Significant at 1% level

Significant negative correlation was observed between leaf breadth (-0.516) and volatile oil.

The character curcumin had positive correlation with plant height (0.327) while its association with oleoresin (-0.280) was negative

4.3.2 Phenotypic correlation

Phenotypic correlation with fresh rhizome yield per plant was highly positive and significant for characters such as plant height (0.766), oleoresin (0.708), starch (0.554), number of tillers (0.475), leaf breadth (0.340) and number of leaves (0.406) (Table 19).

Association between fresh rhizome yield per plant (0.766), oleoresin (0.479) and starch (0.430) was positive and highly significant with plant height. The characters curcumin (0.317) and leaf breadth (0.252) also showed positive correlation with plant height.

The character number of tillers had positive and high significant correlation with number of leaves (0.658), fresh rhizome yield per plant (0.475) and oleoresin (0.438). Starch (0.292) showed positive correlation with number of tillers.

Number of leaves had high positive significant correlation with number of tillers (0.658), fresh rhizome yield per plant (0.406) and oleoresin (0.350).

The character leaf length had high positive correlation with leaf breadth (0.569) and it is negatively correlated with starch (-0.252).

Leaf breadth had high positive significant correlation with leaf length (0.569) and fresh rhizome yield per plant (0.340). It is positively correlated with plant height (0.252). Leaf breadth is negatively correlated with volatile oil (-0.365).

Table 19. Phenotypic correlation coefficients for biometric and quality characters in turmeric

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
X1	1.000									
X2	0.130	1.000								
X3	0.110	0.658**	1.000							
X4	0.018	-0.024	-0.146	1.000						
X5	0.252*	-0.049	0.072	0.569**	1.000					
X6	0.766**	0.475**	0.406**	0.008	0.340**	1.000				
X7	0.479**	0.438**	0.350**	-0.162	0.044	0.708**	1.000			
X8	0.430**	0.292*	0.015	-0.252*	-0.067	0.554**	0.602**	1.000		
X9	0.085	-0.063	-0.158	-0.178	-0.365**	-0.236	0.188	0.107	1.000	
X10	0.317*	0.049	-0.104	0.048	-0.083	-0.002	-0.276*	-0.007	0.215	1.000

X1. Plant height (cm)

X2. Number of tillers

X3. Number of leaves

X4. Leaf length (cm)

X5. Leaf breadth (cm)

X6. Fresh rhizome yield per plant (g)

X7. Oleoresin (%)

X8. Starch (%)

X9. Volatile oil (%)

X10. Curcumin (%)

* Significant at 5% level

** Significant at 1% level

The character oleoresin had high positive correlation with fresh rhizome yield per plant (0.708), starch (0.602), plant height (0.479), number of tillers (0.438) and number of leaves (0.350). Curcumin (-0.276) showed negative correlation with oleoresin.

Association of starch with oleoresin (0.602), fresh rhizome yield per plant (0.554) and plant height (0.430) was highly positive and significant while its association with leaf length (-0.252) was negative. Association between volatile oil and leaf breadth (-0.365) was negative.

The character curcumin had positive correlation with plant height (0.317) while its association with oleoresin (-0.276) was negative.

4.4 PATH ANALYSIS

The genotypic correlation coefficients of fresh rhizome yield per plant with yield contributing characters were partitioned into different components to find out the direct and indirect contribution of each character to yield (Table 20). The analysis was done by taking eight yield contributing characters. The characters selected were plant height, number of tillers, number of leaves, leaf breadth, oleoresin, starch, volatile oil and curcumin.

4. 4. 1 Direct effects

From Table 20 it was clear that plant height (0.7180) and number of tillers (0.3034) had high direct effect on yield. The character curcumin (0.2561) exhibited moderate positive effect on yield while the characters like oleoresin (0.1303) and starch (0.1196) recorded low positive direct effect on yield. Volatile oil (-0.2892) had a negative direct effect on yield.

Table 20. Direct and indirect effects of yield components of turmeric

Characters	Plant height	Number of tillers	Number of leaves	Leaf breadth	Oleoresin	Starch	Volatile oil	Curcumin	Genotypic correlation with yield
Plant height	**0.7180**	0.0200	0.0139	0.0122	0.0633	0.0726	-0.0553	-0.0718	0.7729
Number of tillers	0.0492	**0.3034**	0.0060	-0.0008	0.0289	-0.0136	0.1491	-0.0282	0.4939
Number of leaves	0.0139	0.0285	**0.0390**	0.0464	0.2561	0.0012	0.0473	-0.0280	0.4043
Leaf breadth	0.0169	-0.0055	0.0260	**0.0428**	0.3355	0.0365	0.0216	0.0136	0.4874
Oleoresin	0.3490	0.0055	0.0042	0.1145	**0.1303**	0.0523	-0.0232	0.0838	0.7164
Starch	0.0569	0.0131	0.0004	-0.0346	0.4359	**0.1196**	-0.0305	-0.0017	0.5592
Volatile oil	0.0105	-0.0032	-0.0064	-0.1564	0.1373	0.0126	**-0.2892**	0.0557	-0.2392
Curcumin	0.0427	0.0023	-0.0043	-0.0335	-0.2013	-0.0008	-0.0629	**0.2561**	-0.0016

Residue (R) = 0.1719

(Underlined figures are direct effects)

4. 4. 2 Indirect effects

Oleoresin (0.3490) recorded high indirect effect through plant height. All other characters showed negligible indirect effect through plant height.

Oleoresin (0.1145) recorded low positive indirect effect through leaf breadth and volatile oil (-0.1564) recorded low negative indirect effect through leaf breadth.

Starch (0.4359) and leaf breadth (0.3355) showed high positive indirect effect through oleoresin while number of leaves (0.2561) showed moderate positive indirect effect and volatile oil (0.1373) showed low positive indirect effect through oleoresin while curcumin (-0.2013) showed moderate negative indirect effect through oleoresin.

Number of tillers (0.1491) showed low positive indirect effect through volatile oil.

The residual effect (R = 0.1719) indicates that the selected characters explain the total correlation well and the remaining characters have only minor contribution in the fresh yield per plant.

4.5 SELECTION INDEX

Discriminant function technique was adopted for the construction of selection index for yield using fresh rhizome yield per plant and the component characters *viz.* plant height, number of tillers, number of leaves, leaf length, leaf breadth, oleoresin, starch, volatile oil and curcumin (Table 21). The index value for each genotype was determined and the genotypes were ranked accordingly. The selection indices are presented in Table 22 according to the rank of each genotype.

Table 21. Selection index of different characters

Characters	b coefficients
Plant height	0.85
Number of tillers	-7.72
Number of leaves	1.47
Leaf length	0.88
Leaf breadth	1.41
Fresh rhizome yield per plant	0.97
Oleoresin	3.52
Starch	1.08
Volatile oil	-0.95
Curcumin	3.16

Table 22. Index score of different genotypes

Genotypes	Score	Rank
Sudarsana	1105.527	1
Kedaram	988.644	2
Prathibha	904.051	3
Alleppey Supreme	881.484	4
Sona	829.848	5
Shobha	790.226	6
Kanthi	766.343	7
Prabha	762.483	8
Varna	723.673	9
Suguna	710.382	10
Wayanad local	665.657	11
Suvarna	640.903	12

Based on this, genotype Sudarsana released from IISR, Kozhikode attained the maximum selection index score followed by Kedaram and Prathibha. The minimum estimates were recorded for Suvarna followed by Wayanad local and Suguna. The genotypes Kanthi and Prabha had nearer index score values of 766.343 and 762.483 indicate that these genotypes show similarity in their biometric characters as well as quality characters.

DISCUSSION

5. DISCUSSION

Crop improvement started from ancient days consciously or unconsciously by man for his survival. Evolution and domestication created improved plant species. Selection plays a vital role in crop improvement and has played an important role in the history of mankind. The improvement of any crop depends on the available variability, heritability of the character, genetic advance under selection and the association among the characters.

Turmeric is a vegetatively propagated, ancient and sacred spice crop of India. It is widely used worldwide as medicine, condiment, dye and cosmetic. Even though higher rhizome yield with good quality are the major goals of the plant breeders, being a vegetatively propagated crop, its improvement through conventional breeding methods is limited. Usually turmeric is harvested from September to January for commercial and household needs without considering yield per unit area or dry yield percentage. But there is a widely held view among the farmers that the earlier harvest will result in better yield and quality.

The present study was envisaged to evaluate the effects of harvest time on yield and quality of turmeric, to estimate the variability among different genotypes, to analyze the association between various traits, to find the direct and indirect effect of different characters on yield and to calculate the selection indices of the different genotypes. The results on the genetic analysis of phenological variations in turmeric are discussed in this chapter under different headings.

5.1 WEATHER AND CROP GROWTH

Crop growth is mainly dependent on the environmental factors. Fluctuations in weather conditions greatly influence the growth, development and thereby yielding ability of the crop. The rainfall was not well distributed during the peak growing periods of the crop as a result the crop could not express its maximum yield potential. But the temperature recorded during the experimental period was in the required optimum range.

5.2 INFLUENCE OF DATE OF HARVEST

In the present study, analysis of variance revealed significant differences for growth, yield and quality characters at three dates of harvest. They are discussed below.

5.2.1 Growth characters

The growth characters analysed in the present study were plant height, number of tillers, number of leaves, leaf length and leaf breadth.

Varieties showed significant effects of harvest on height. Variety Sudarsana among the shortest in height at 160DAP became the tallest at 240DAP showing a vigorous nature of growth when duration of harvest was extended. Plant height differs at three dates of harvest and the maximum plant height was obtained at 240 DAP. Among the genotypes studied, Sudarsana recorded the maximum plant height followed by Kedaram and Alleppey Supreme. The significant variation in plant height over the different growth stages observed in the present study was supported by the findings of Sajitha *et al.* (2014) in *Curcuma aromatica* and *Curcuma amada*. But in contrast to the results of the present study, the effect of different harvesting dates on plant height was not significant as reported by Kumar and Gill (2009).

From the result of the present study, it is clear that days to harvest have significant effects on number of tillers irrespective of varieties. Increase of days to harvest resulted in the corresponding increase in tillers among the varieties. There existed no variation in number of tillers produced at 200 DAP and 240 DAP. But tiller number at 200 DAP was more than that at 160 DAP indicating that 160- 200 DAP is a crucial period of growth. Among the genotypes, Prabha and Alleppey Supreme recorded the maximum number of tillers followed by Prathibha and Kedaram. Sajitha *et al.* (2014) also reported the similar findings in *Curcuma aromatica* and *Curcuma amada.*

Number of leaves differs at three dates of harvest and the maximum number of leaves was recorded at 200 DAP. For all the genotypes, number of leaves got reduced from 200 to 240 DAP. Among the different genotypes studied, Prabha recorded the maximum number of leaves at 200 DAP followed by Alleppey Supreme and Prathibha. The reduction in number of green leaves with delay in harvesting might be due to drying and deterioration of leaves with passage of time, especially those which come in contact with the soil. In addition to this, tearing or rotting of leaves also increased as harvesting was delayed. Similar results were reported by Govind and Gupta (1987) where number of leaves per plant increased only upto middle of October and thereafter number of leaves per plant became constant. Similar observation was reported in *Curcuma longa* by Asghari *et al.* (2009).

From the result it is clear that the leaf length differs significantly over the three dates of harvest. The maximum leaf length was recorded at 240 DAP. For all the genotypes, leaf length were recorded the maximum at 240 DAP. Among the genotypes, Sona recorded the maximum leaf length followed by Wayanad local and Prathibha. Leaf breadth also showed significant differences over the three dates of harvest. The maximum leaf breadth for the genotypes was recorded at 200 DAP. There was a decrease in leaf breadth after 200 days. Among the genotypes, Sona recorded the maximum leaf breadth at 200 DAP followed by Kedaram and Prathibha. The results obtained on the growth characters of turmeric at different date of harvest were supported by Kumar and Gill (2009).

5.2.2 Yield characters

Increased fresh rhizome yield per plant was recorded for all genotypes at 240 DAP in the present study. Among the genotypes, Sudarsana recorded the maximum fresh rhizome yield per plant followed by Kedaram and Alleppey Supreme. Due to higher fresh rhizome yield per plant, fresh rhizome yield per plot was also found to be high at 240 DAP. Eventhough all the genotypes showed higher yield at 240 DAP, percentage increase in rhizome yield at different growth

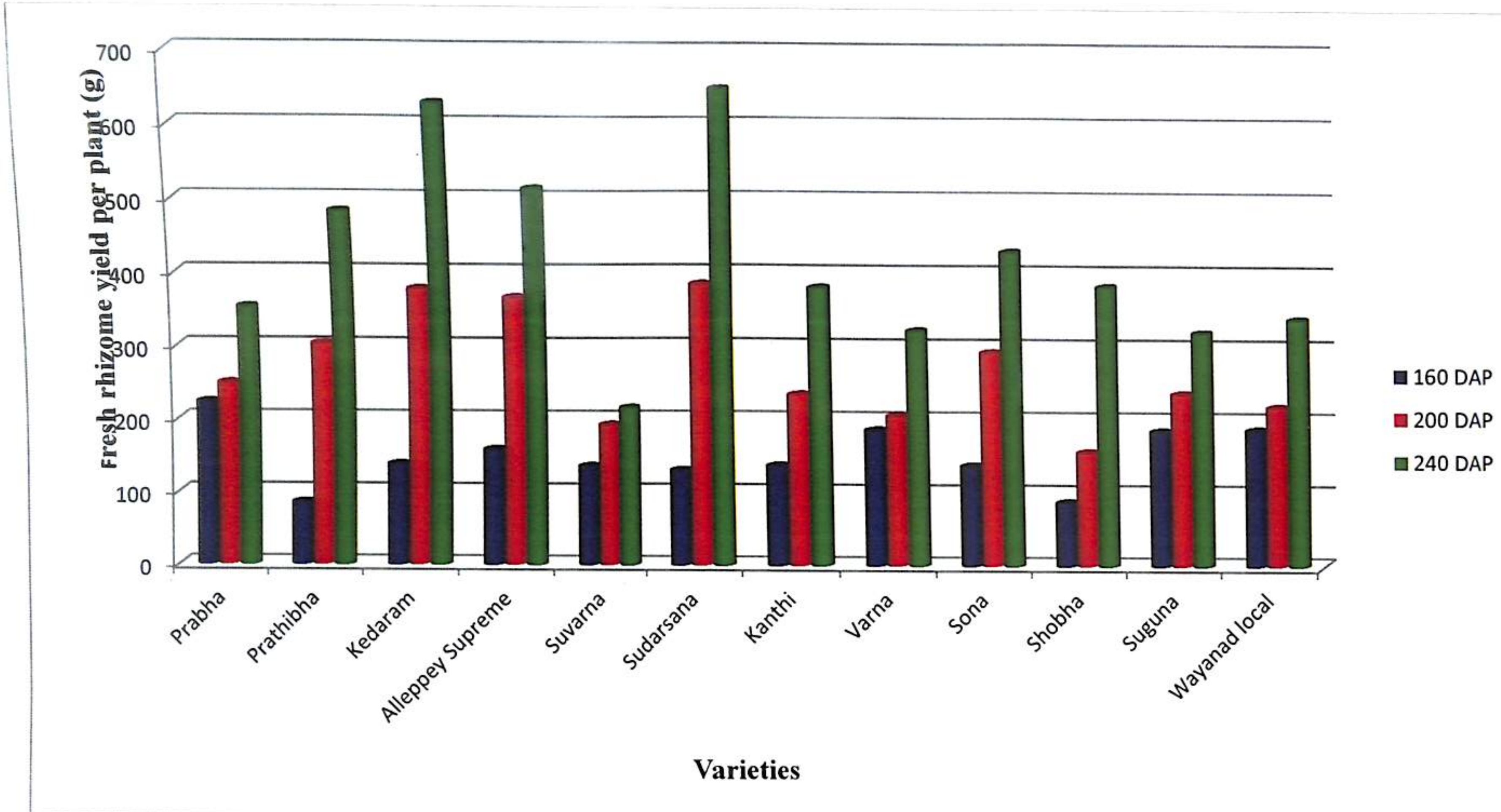


Fig. 5 Effect of different dates of harvest and varieties on fresh rhizome yield per plant (g)

stages are different for different genotypes. The increase in weight of rhizomes with delay in harvesting will be due to the longer growth period of the plants during which the plants may get more moisture and nutrients. This was in accordance with the studies of Govind and Gupta (1987), Subramaniam *et al.* (1978) and Kumar and Gill (2009) in turmeric.

From the result it was found that there was significant difference in dry rhizome yield per plant over different dates of harvest. The maximum dry rhizome yield per plant was recorded at 240 DAP. Among the genotypes, Kedaram recorded the maximum dry rhizome yield followed by Alleppey Supreme and Prathibha. Due to the increased dry rhizome yield per plant at 240 DAP, the dry rhizome yield per plot was also reported maximum at 240 DAP. Similar trend of increased dry rhizome yield in turmeric was noticed by Hossain (2010) and they concluded that the turmeric should be harvested in January for higher dry rhizome yield. The same result was reported in turmeric by Asghari *et al.* (2009).

5.2.3 Quality parameters

From the results it is clear that the oleoresin, starch, volatile oil and curcumin content were found to be more at 240 DAP when compared to the earlier dates of harvest and there exist significant variation among the different dates of harvest. Genotype Sudarsana recorded the maximum oleoresin content followed by Keadaram and Prathibha. Among the genotypes, Kedaram recorded the maximum starch content followed by Sudarsana and Shobha, while, volatile oil content was reported the maximum in Suvarna followed by Sudarsana and Prabha. Curcumin was found the maximum in the genotypes Kanthi and Varna released from KAU followed by Shobha and Sona.

This was in accordance with the reports of Cooray *et al.* (1988). Govind and Gupta (1987) reported that the oil content in turmeric increases continuously when harvesting was delayed from mid of August to end of December.

The increase in curcumin content as the days of harvest was delayed is supported by Hanashiro *et al.* (2003) and Asghari *et al.* (2009). The result of the present study was in contradictory to the findings of Policegoudra *et al.* (2007) in Mango ginger. They reported that the optimum maturity standard for harvest of mango ginger rhizome is 180 days due to the peak accumulation of phenolics, difurocumenonol and total protein. The significant variation in the starch content observed in this study is in accordance with Sajitha *et al.* (2014) in *Curcuma aromatica* and *Curcuma amada.*

The present study on the phenological variations occurring to the growth, yield and quality parameters of turmeric genotypes revealed that the dates of harvest have significant effects on the growth characters. The growth characters *viz.,* plant height and leaf length, yield characters *viz.,* fresh rhizome yield per plant, fresh rhizome yield per plot, dry rhizome yield per plant and dry rhizome yield per plot, the quality parameters such as oleoresin, starch, volatile oil and curcumin were recorded the maximum at 240 DAP. The growth characters number of leaves and leaf breadth were recorded the maximum at 200 DAP, while there was no significant difference in the number of tillers at 200 and 240 DAP. Based on these observations, it can be concluded that the harvesting of turmeric rhizomes at 240 DAP is favourable to get the maximum rhizome yield and quality.

5.3 GENETIC PARAMETERS

Variability is also expressed as coefficients of variation. Phenotypic and genotypic coefficients of variation are better indices for comparison of characters with different units of measurements. The GCV provides a valid basis for comparing and assessing the range of genetic variability for quantitative characters and PCV measures the extent of total variation. There was a close relationship between genotypic and phenotypic coefficients of variation for almost all characters (Table 17). The similarity between PCV and GCV indicated low environmental influence and effectiveness of selection based on phenotypic performance.

In the present study, GCV ranged from 6.70 to 30.93. The highest GCV was for fresh rhizome yield per plant followed by volatile oil and curcumin. The lowest was for starch. GCV and PCV were the highest for fresh rhizome yield of rhizome per plant. This was in agreement with the study of Mukhopadhayay and Roy (1986) and Indiresh *et al.* (1992) in turmeric and Yadav (1999), Singh and Mittal (2003) and Ali *et al.* (1994) in ginger. Plant height, leaf length, leaf breadth and starch recorded low GCV and PCV. This result was supported by the findings of Prasad *et al.* (1998).

High heritability and genetic advance expressed as percentage of mean was recorded for the characters like number of tillers, number of leaves, fresh rhizome yield per plant, oleoresin, volatile oil and curcumin indicating that a major part of the phenotypic variability in these characters was contributed by additive gene effects and hence improvement can be made by simple selection. Similar results have been reported by Philips and Nair (1986) and Pathania *et al.* (1990). The highest heritability and genetic advance was recorded for fresh rhizome yield per plant in the present study. High heritability for number of tillers per plant in the present study was supported by the findings of Mukhopadhayay and Roy (1986) in turmeric genotypes.

In the present study, yield and its components were highly heritable with moderate to high level of genetic advance. Hence there is scope to isolate superior genotypes for improving yield through simple selection procedures. These results are supported by Jalgankar *et al.* (1990) and Indiresh *et al.* (1992).

5.4 CORRELATION STUDIES

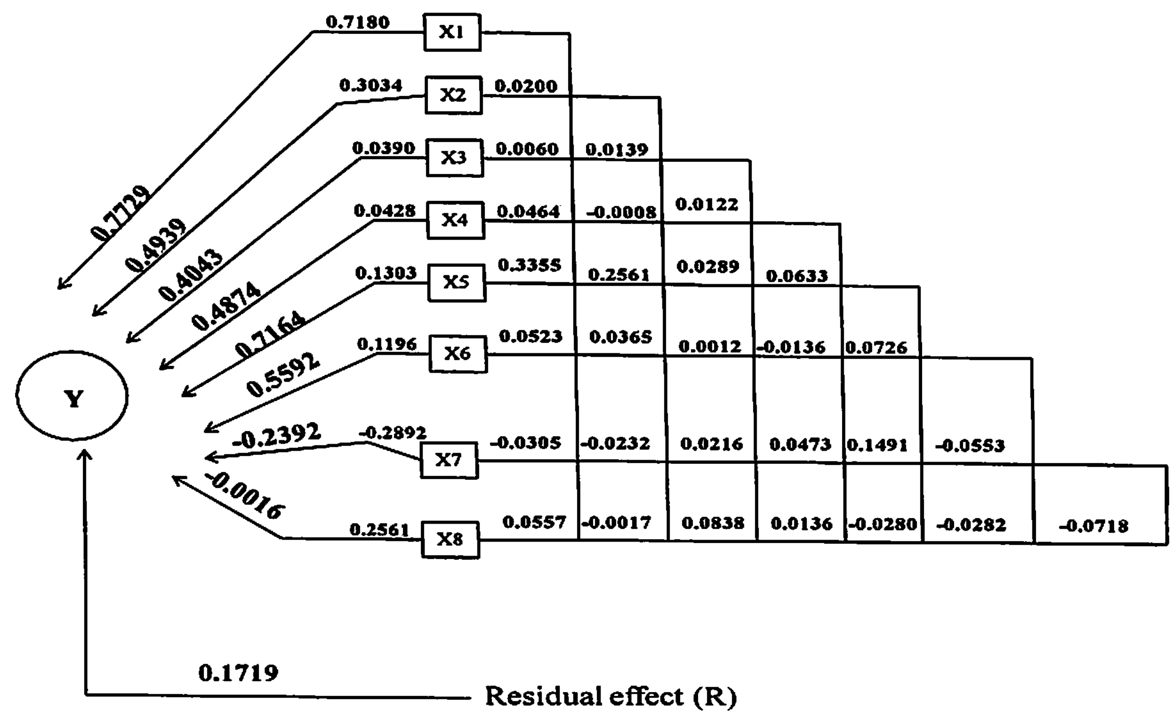
It is well known fact that, there will be a complex association among different characters in the plant system. Yield is a complex character influenced by many characters either positively or negatively. So the knowledge of association of various characters with economic characters will provide necessary information in understanding the yield fluctuations. Correlation provides information on the nature and extent of relationship between pairs of characters. Therefore, analysis of yield in terms of genotypic and phenotypic correlation coefficients of component character leads to the identification of character that can form the basis of selection.

In general, genotypic correlation coefficients were higher than phenotypic correlation coefficients, which might be due to the masking effect of environment in the total expression of the genotypes resulting in reduced phenotypic association. Similar higher genotypic correlation was also reported in turmeric by Mohanty and Sharma (1979) and Rajyalakshmi *et al.* (2013).

In the present investigation, almost all characters showed positive and significant correlation with yield. Highest positive significant correlation was noticed for plant height (0.773) with yield. The characters, plant height, oleoresin, starch, number of tillers, leaf breadth and number of leaves showed significant positive correlation with yield. The results indicated that these traits have certain inherent relationship with yield and suggests the importance of these characters in determining rhizome yield. Similar results were also reported by Shashidhar and Sulikeri (1997) and Rajyalakshmi *et al.* (2013). However, Abraham and Latha (2003) reported high positive association of yield with leaflet number, tiller height and leaf length in ginger.

5.5 PATH ANALYSIS

Correlation of yield and its components does not give an exact picture of the relative importance of the various yield attributes. Rate of crop improvement is expected to be rapid if differential emphasis is laid on the component characters during selection. Path coefficient analysis helps in partitioning the genotypic correlation coefficient into direct and indirect effect of the component character on yield on the basis of which improvement programme can be devised effectively.



Y: Fresh rhizome yield per plant | X1: Plant height | X2: Number of tillers

X3: Number of leaves | X4: Leaf breadth | X5: Oleoresin

X6: Starch | X7: Volatile oil | X8: Curcumin

Fig. 6 Path diagram showing direct and indirect effects of components of yield

In the present study plant height and number of tillers had high positive direct effect on yield. These results are supported by Naresh *et al.* (1981) and Rajyalakshmi *et al.* (2013). Curcumin exhibited moderate positive effect while oleoresin and starch exhibited low positive direct effect on yield. Volatile oil had a negative direct effect on yield. Similar results of improving yield by direct selection based on plant height, leaf number, number of primary and secondary fingers and weight of secondary fingers have been obtained in turmeric by Panja *et al.* (2002). A very low residual effect (R = 0.1719) was also noticed in the present study, which indicates that the selected characters explain the total correlation well and the remaining characters have only minor contribution in the fresh yield per plant.

5.6 SELECTION INDEX

Selection of genotypes based on suitable index is highly efficient in any breeding programme. An estimation of discriminant function based on reliable and effective characters is a valuable tool for plant breeders. Superior genotypes can be selected from a collection of genotypes using selection index employing the discriminant function.

In the present study, the selection indices for the genotypes were computed on the basis of ten characters and are presented in Table 22. Genotype Sudarsana scored the highest index score followed by Kedaram, Prathibha, Alleppey Supreme, Sona, Shobha and so on. The genotypes Kanthi and Prabha had nearer index score values of 766.343 and 762.483 indicate that these genotypes show similarity in their biometric characters as well as quality characters.

The performance of the genotypes Sudarsana, Kedaram, Prathibha, Alleppey Supreme, Sona, Shobha and Kanthi were superior in terms of yield and quality. All these genotypes can be included in future improvement programmes for increased yield and quality in turmeric.

SUMMARY

SUMMARY

Genetic analysis of phenological variations for yield and quality in turmeric (*Curcuma longa* L.) was conducted at the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani during 2014 - 2015. The genotypes were evaluated for growth characters, yield characters and quality parameters at three different dates of harvest (160 DAP, 200 DAP and 240 DAP) to understand the optimum time of harvest in turmeric to get maximum yield as well as a good quality produce. In addition to that, genetic variability, degree and direction of association, direct and indirect effects of various components on yield and selection index studies were also conducted.

Turmeric (*Curcuma longa* L.) is one of the ancient and sacred spice crop of India. Effects of different dates of harvest were evaluated among twelve genotypes (7 released varieties from IISR, 4 released varieties from KAU and 1 local variety) of turmeric. The experiment was aimed at studying the phenological variations occuring to the growth, yield and quality parameters of turmeric. Phenological variations means the variations occuring to the plants according to different seasons or different growth stages. Identification of the optimum time of harvest for getting maximum yield and quality product was also attempted in the study. Various studies including variability studies, estimation of genetic parameters like heritability, genetic advance, correlation studies, path coefficient analysis and selection index were carried out.

The salient results of investigation are summarised below.

- Analysis of variance revealed that different dates of harvest have significant effects on all characters studied.

- Study also revealed that among the three dates of harvest studied, the fresh rhizome yield, dry rhizome yield and the quality parameters like oleoresin, starch, volatile oil and curcumin were maximum at 240 DAP.

- Based on the results, it can be concluded that the harvesting of turmeric rhizomes at 240 DAP is favourable to get the maximum yield and quality.

- The genotype Sudarsana was the best genotype regarding fresh yield of rhizome and Kedaram was the best regarding dry yield of rhizome.

- Genotype Sudarsana recorded the maximum oleoresin content whereas Kedaram recorded maximum starch content.

- Among the genotypes, Suvarna recorded the maximum volatile oil content while the maximum curcumin content was recorded by Kanthi and Varna.

- The characters like fresh yield of rhizome per plant, number of leaves, oleoresin, volatile oil and curcumin recorded high heritability, genetic advance, GCV and PCV which give an indication of the importance of these characters in further selection of genotypes.

- The correlation studies showed that the characters plant height, oleoresin, starch, number of tillers, leaf breadth and number of leaves had high positive correlation with fresh rhizome yield per plant. So selection based on these characters will also be effective.

- Path analysis revealed that the characters plant height and number of tillers had high direct effect on yield. So these characters can be considered while formulating the crop improvement programmes.

- Selection indices for twelve genotypes were worked out and the genotypes were ranked. Highest index value was obtained for the genotype Sudarsana followed by Kedaram. The minimum estimates were recorded by Wayanad local followed by Suguna.

- The genotypes Kanthi and Prabha had nearer index score values of 766.343 and 762.483 indicating that these genotypes show similarity in their biometric characters as well as quality characters.

There is a widely held view among the farmers that the earlier harvest of the crop will give a better yield and better quality product. But from this study, it is clear that the yield as well as the quality of the produce is better at 240 DAP than the earlier dates of harvest. The study of genetic parameters, correlation and path analysis helped in understanding the characters that can be considered while selection of superior plants. Being a vegetatively propagated crop, selection of superior plants have an advantage of keeping specific gene combinations intact for generations.

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ABSTRACT

GENETIC ANALYSIS OF PHENOLOGICAL VARIATIONS FOR YIELD AND QUALITY IN TURMERIC (*Curcuma longa* L.)

by

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ABSTRACT

The present investigation entitled "Genetic analysis of phenological variations for yield and quality in turmeric (*Curcuma longa* L.)" was taken up during the period from May, 2014 to January, 2015. The objective of the study was to understand the phenological variation in yield and quality attributes in turmeric. The intention of the study was to verify if earlier harvest yields better quality which is the widely held view among the farmers.

Twelve genotypes of turmeric were evaluated under split plot design. Genotypes studied were Prabha, Prathibha, Kedaram, Alleppey Supreme, Suvarna, Sudarsana, Kanthi, Varna, Sona, Shobha, Suguna and Wayanad local. Data recorded at 160, 200 and 240 days after planting (DAP) suggest that the plant height, number of tillers, number of leaves, leaf length and leaf breadth differs significantly during the three dates of harvest. Plant height was the maximum at 240 DAP (97.08 cm). The maximum number of tillers was observed at 240 DAP (2.74), it was on par with 200 DAP (2.73). Leaf length recorded the maximum at 240 DAP (49.95 cm) and leaf breadth recorded maximum at 200 DAP (12.62 cm).

Fresh rhizome yield per plant, dry rhizome yield per plant, fresh rhizome yield per plot, dry rhizome yield per plot and the quality parameters like oleoresin, starch, volatile oil and curcumin content differ significantly during the three dates of harvest and they were found to be the maximum at 240 DAP. There was no serious pest or disease incidence during the crop period.

High values of phenotypic coefficient of variation and genotypic coefficient of variation were observed for fresh yield per plant (31.02 and 30.93), volatile oil (25.23 and 24.89), curcumin (23.55 and 23.26), oleoresin (20.66 and 20.53), number of leaves (20.40 and 20.10) and number of tillers (20.40 and 19.09). Heritability was

high for all characters studied except leaf breadth. GA was the highest for fresh yield per plant (63.53%).

The positive phenotypic and genotypic correlation with fresh rhizome yield per plant was observed for plant height (0.766 and 0.773), oleoresin (0.708 and 0.716), starch (0.554 and 0.559), number of tillers (0.475 and 0.494), leaf breadth (0.340 and 0.487) and number of leaves (0.406 and 0.404). Path analysis revealed that plant height exhibited the highest positive direct effect on fresh yield per plant (0.7180) followed by number of tillers (0.3034). The highest selection index value was obtained by Sudarsana followed by Kedaram.

In addition to this, the meteorological parameters like rainfall, maximum temperature, minimum temperature, relative humidity and evaporation were also recorded during the crop period.

Out of the three dates of harvest, third harvest (240 DAP) was found superior in terms of yield and quality. Sudarsana was the best genotype regarding fresh rhizome yield whereas Kedaram was best regarding dry rhizome yield. Maximum curcumin content was recorded by Kanthi and Varna. The characters plant height, number of tillers, fresh rhizome yield, number of leaves, oleoresin, volatile oil and curcumin can be used in selection of genotypes for developing superior varieties.