STUDIES ON GENETIC DIVERSITY AND IMPROVEMENT OF WILD TURMERIC (*CURCUMA AROMATICA* SALISB.) OF KERALA

Thesis submitted
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of
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by

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CERTIFICATE

Certified that this thesis titled **"Studies on genetic diversity and improvement of wild turmeric (*Curcuma aromatica* Salisb.) of Kerala"** embodies the results of a piece of bona fide research work carried out as part fulfilment of requirements for the degree of Doctor of Philosophy in Botany of University of Calicut by **Ms. Neethu K.** under my guidance and supervision and that no part of the thesis has been submitted for any other degree.

I further certify that such helps or sources of information availed of in this connection have been duly acknowledged.

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DECLARATION

I, **Neethu K.**, hereby declare that this thesis entitled **"Studies on genetic diversity and improvement of wild turmeric (*Curcuma aromatica* Salisb.) of Kerala"** being submitted in part fulfilment of requirements for the degree of Doctor of Philosophy in Botany of University of Calicut embodies the results of a bona fide research work done by me under the guidance of **Dr. V.V. Radhakrishnan**, Professor & Head, Department of Botany, University of Calicut, Kerala, India and that no part of it has previously formed the basis for the award of any degree, diploma, associateship, fellowship, title or recognition.

Neethu K.

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PREFACE

Genetic diversity is the key pillar of biodiversity and diversity between species, within species and of ecosystems. Globally it is recognized that genetic diversity of valuable medicinal plants has been disappearing over the past decades and it is important to preserve the existing genetic wealth for future. Anthropogenic habitat fragmentation leads to spatial isolation of plant populations increasing extinction risk. Furthermore, overexploitation of wild resources through indiscriminate collection, excessive grazing, diseases and pests, unsustainable harvests, introduction of invasive species and climate change have destroyed genetic wealth. Understanding genetic variability and genetic diversity of threatened plants is of great importance for setting up conservation plans and the improvement of crops.

Curcuma aromatica Salisb., is a member of the genus *Curcuma* belonging to the family Zingiberaceae. It is a threatened medicinal plant and flourishes in wild. Commonly the plant is known as wild turmeric and in Malayalam *Kasthurimanjal*. Almost all the parts of this plant have been used for therapeutic purposes and as raw material for the production of useful drugs and cosmetic products. Hence it can be considered as a future drug owing to its unexploited medicinal and cosmetic properties. Presence of genetic variability in a crop is essential for its further improvement by giving options to plant breeders to develop new varieties and the assessment and maintenance of the genetic diversity is a prerequisite. However, efforts for the assessment of the genetic diversity for the improvement of *Curcuma aromatica* in Kerala State of India are scarce. Therefore, the present studies have been designed and carried out so as to collect, conserve and scrutinize the genetic diversity of the crop in this area and also to identify superior genotypes from the germplasm.

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INTRODUCTION

Biodiversity conservation is one of the major current concerns all over the world as wild species, domestic breeds and strains are disappearing at an alarming rate. Genetic diversity is the base for survival of plants and animals in nature. Better understanding of genetic diversity will help in determining what to conserve as well as where to conserve the genotypes.

Genetic diversity of crop plants is the cornerstone for the sustainable development of novel varieties. It is the underlying cause of several agriculturally important phenomena like heterosis and transgressive segregation. Diverse lines are necessary for improvement and defect correction of commercial varieties and development of new varieties. Therefore, development of new diversity, discovery of diverse lines and its successive application are the major targets of any crop improvement programme.

Reduced genetic variability and diversity among crop plant species have caused critical problems to plant breeders. With the progress of time, natural variability of crops got declined due to continuous use of selected genotypes as parents in different crop improvement programmes, unbalanced breeding practices focusing on development of only a few traits such as yield and its component traits and introduction of a few superior lines to several countries thereby leading to increased genetic resemblance between modern crop varieties. With reduced genetic diversity, further development in crop varieties will be a strenuous task.

Under the present changing environmental conditions, new plant breeding approaches are of increased importance in the development of crop varieties resistant to multiple types of environmental stresses (Ceccarelli *et*

al., 2010). Plant breeding techniques are exceptionally successful and have been widely utilised in agriculture to improve the yield of several crop plants. The ultimate goal of all the plant breeders is to increase the stability of yield, upgradation of the usable yield, ensuring the nutritive quality and production of new improved varieties that suite specific growing conditions, climates and farming needs. The type and dimension of genetic variability help the breeder to develop selection criteria and breeding schemes useful for improvement programmes. This is because selection of superior genotypes corresponds to the magnitude of genetic variability present and the extent to which the characters are inherited (Briggs and Knowles, 1967). If environmental variability is scanty compared to genetic variability, selection will be a success in improving the character, if such character is with high genotypic variability. Plant breeding will continue to be highly dependent on classical techniques but will undoubtedly get improved in efficiency and effectiveness by the development of new techniques.

Since the dawn of human civilization, mankind has used different medicinal plants to cure many ailments. In India, the traditional system of medicine plays a significant role in health care for all types of diseases. The healing potential of traditional herbal medicines has been realized and illustrated since *Rigveda* and *Atharvaveda*. Since then plant extracts have been used therapeutically and even today plant based drugs continue to play an essential role in world health care. Nearly 80% of the world population relies on conventional medicines for primary health care, most of which include the use of plant extracts.

The genus *Curcuma* exhibits great morphological differences, the overlapping affinities among them make confusion in the identification of the species (Sirirugsa *et al*., 2007). *Curcuma* belonging to the family Zingiberaceae is gaining immense importance all over the world as a potential

source of new drugs to resist a variety of diseases as the species have got constituents credited with antidiabetic, anticancerous, hypercholesteraemic, choleretic, antimicrobial, insect repellent, antivenomous, antirheumatic, antifibrotic, antiviral, antihepatotoxic, antiinflammatory as well as cosmetic properties (Sasikumar, 2005).

Curcuma aromatica Salisb. is a wild, aromatic and attractive turmeric which is one of the most useful among the turmeric members for its unique medicinal values. Cosmetic use of the plant is highly appreciated globally. It is commonly called wild turmeric or musk turmeric in English, *kasthurimanjal* in Malayalam and *vanaharidra* in Sanskrit (Ahamed *et al*., 2011; Sikha *et al*., 2015). It is native to southern India (Sabu, 2006). The aromatic rhizome is the economically important part and the rhizomes have a pleasant fragrance possessing a prominent property to enhance health conditions by arresting ageing with immunomodulatory effects (Shah *et al*., 2010; Sastri, 1950; Nadakarni, 1998).

Inappropriate cultivation practices, habitat destruction, deforestation and the high demand of pharmaceutical industries on wild sources make this plant threatened in many south Asian countries (Kumar and Sikarwar, 2002). In some regions of India *C. aromatica* is replaced by *C. zanthorrhiza* due to the non-availability of *C. aromatica* and it shows that the demand for *C. aromatica* is on the rise in order to meet the ever increasing pharmaceutical needs. In addition to over exploitation, the plant species faces threats of changes in landscape ecology caused by climatic and anthropogenic factors. Moreover, lack of organized cultivation and devastation of its natural habitats have resulted in quick erosion of the genetic stock of this plant.

The importance of the species as an underutilized medicinal plant has augmented its significance under the changing scenario of shift to herbal sources for pharmaceutical compounds. *C. aromatica* being an important

medicinal herb, there are no high yielding hybrid varieties released yet and improvement of *C. aromatica* is laborious task, as it does not set seeds. Enhancement in the production of any crop relies on the magnitude of genetic variability and the amount of transmission of characters from one generation to the next (Sujatha and Renuga, 2013). The study of genetic variability is the crucial step for the understanding of the genetic diversity of the plant species at a particular geographical area. It gives the basic foundation for the genetic improvement of the species (Hughes *et al*., 2008). Evaluation and characterization of the germplasm is beneficial to find out the qualitative and quantitative characters useful for breeding programmes. Therefore, the present study has been designed and executed as an effort to know, conserve and improve *Curcuma aromatica* Salisb. in Kerala State of India.

Chapter II

REVIEW OF LITERATURE

Plants belonging to the family Zingiberaceae have been valued and used since primeval times in Asia as spices, food preservatives and important medicines (Ravindran *et al*., 2007). Ancient Indian books on medicines namely 'Charaka Samhita' and 'Sushruta Samhita' illustrate the wonderful curative effects of Zingiberaceae especially *Curcuma* L. and *Zingiber* Boehm. due to their medicinal and chemical properties. The medicinal and aromatic properties of Indian Zingiberaceae members have been reported in Materia Indica (Whitelaw, 1826).

2.1. Zingiberaceae

Zingiberaceae is the largest monocotyledonous family in India (Jain, 1995). The members of Zingiberaceae occur mostly on the tropical regions of the world with about 53 genera and 1200 species (Kress, 1990; Kress *et al*., 2002). The highest concentration of genera and species are in the Indo Malayan area of Asia. The family has held a place of importance for hundreds of years since the infusions and tinctures of several aromatic species have been used and are being still used as ingredients of herbal remedies for a variety of diseases (Alviano and Alviano, 2009). Economically, many members of Zingiberaceae are of outstanding importance as their volatiles form essential constituents of flavour, perfumery, fragrance and pharmaceutical industries (Janatan *et al*., 2003; Prabhuseenivasan *et al*., 2006).

According to Kong *et al*. (2010) Zingiberaceae is the largest among the eight families of Zingiberales, with about 1377 species belonging to 53 genera. The family is dispersed pantropically with one genus (*Renealmia*) found in the Neotropics, four genera (*Aframomum*, *Aulotandra*, *Siphonochilus*

and *Renealmia*) in Africa and the rest of the genera distributed in the Pacific Islands and East Asia. However, the family is poorly investigated taxonomically (Theilade and Mood, 1997; Sakai and Na-gamasu, 1998; Poulsen *et al*., 1999; Williams *et al*., 2002).

Members of family Zingiberaceae, commonly known as gingers, are an important group of monocotyledons with considerable economic and ornamental potentials (Uma and Muthukumar, 2014). The family was classified into 4 tribes by Burtt and Smith (1972) and *Curcuma* was placed in the tribe Hedychieae. Currently accepted classification of Zingiberaceae includes four tribes, i.e., Zingibereae: 1 genus, Hedychieae: 22 genera, Alpinieae: 25 genera and Globbeae: 4 genera (Peterson, 1889; Holttum, 1950; Kress *et al*., 2002). Wu and Larsen (2000) described some largely represented genera along with the number of their worldwide recorded species such as *Alpinia* (230), *Amomum* (150), *Curcuma* (50), *Zingiber* (100-150), *Kaempferia* (50), *Boesenbergia* (50), *Elettaria* (8), *Etlingera* (70), *Globba* (100), *Hedychium* (50) and *Roscoe* (18).

The family is of significant ethnobotanical value and utilised in many ancient medical systems. The important genera coming under Zingiberaceae are *Curcuma*, *Zingiber*, *Elettaria*, *Alpinia*, *Kaempferia*, *Hedychium* and *Amomum* (Warrier *et al*., 1994; Warrier *et al*., 1995). As per Jatoi *et al*. (2007), the most often used gingers belong to the genera *Curcuma*, *Zingiber*, *Alpinia* and *Amomum* and to a lesser extent *Kaempferia*, *Elettaria*, *Elettariopsis*, *Hedychium*, *Etlingera* and *Boesenbergia*.

India is one of the richest and diverse regions of Zingiberaceae, represented with about 22 genera and 178 species. The biological wealth in the Manipur - Nagaland (NE India) region contributes 19 genera and 88 species (Prakash and Mehrotra, 1996a). According to Sabu (2006), India has 21 genera and 200 species, out of which 10 genera, 65 species and 2 varieties

are recorded from wild source of South India and some grown as ornamentals. Maharashtra state has reported 11 genera and 32 species under this family, which occur in cultivated and wild state (Sharma *et al*., 1996).

Rhizomes of *Curcuma longa*, *Zingiber officinale* and *Alpinia galanga*, seeds of *Elettaria cardamomum* and *Amomum subulatum* and roots of *Alpinia officinarum* are used as spices, condiments and flavouring agents. The product zedoary, employed as a tonic and in perfumery is extracted from the tubers of *Curcuma zedoaria*. Ginger oil from the rhizome of *Zingiber officinale* is utilised in perfumery and for medicinal purposes. Abir, the famous scented powder, is prepared from *Hedychium spicatum*. Some of the ornamental genera cultivated in green houses and gardens for decorative purposes are *Hedychium*, *Globba*, *Alpinia*, *Coutleya*, *Roscoea* and *Kaempferia*. Several gingers are also known to exhibit useful bioactive molecules, which would help in designing and manufacturing various medicinal drugs (Sharma *et al*., 2011).

The plants are distinguished by the occurrence of volatile oils and oleoresins of export value. The rhizomes and fruits are aromatic, tonic and stimulant. Some are used as food as they have starch in large quantities (Joy *et al*., 1998), whereas others yield an astringent and diaphoretic juice (Prabhu *et al*., 2013a). The family has great traditional medicinal value being used in many indigenous medical systems since time immemorial. Several species of Zingiberaceae are used in Ayurvedic, Unani, and Homoeopathic systems of medicine.

Rhizome extracts of some members of the medicinal Zingiberales are widely used in dietary intake as well as in the traditional system of medicine. Many terpenoid compounds with varied physiological activities; antimicrobial, antiarthritic, antioxidant, anticancer, antiinflammatory, cardioprotective, antiarrhythmic, antidiabetic, antiHIV and neuroprotective

have been identified in the essential oils of zingiberaceous plants. Plants that contain cardiac glycosides are employed for the treatment of heart failure and some arrhythmias. Herbs in the Zingiberaceae family find great importance in the treatment of cardiovascular diseases and these herbs normalize the rate and increase the strength of heartbeat (Walden and Tomlinson, 2011).

In all civilizations, aromatic plants were given high importance and many were used as offerings to gods. Gradually man might have started using them for curing different diseases and in the course of time, spices and aromatic plants acquired magical associations about their properties.

2.1.1. Morphological features of the family Zingiberaceae

The members of Zingiberaceae are annual or perennial rhizomatous herbs. The rhizome is sympodially branched and composed of distinct segments (Tomlinson, 1956). Leafy shoots are commonly unbranched and true aerial stem is present in some genera and absent in others. True stem is very short as in *Kaempferia* or pseudostem with clasping leaf sheaths as in *Curcuma*. The leaves are distichous and they show morphological variation in structure, size, shape, texture and venation. The rhizomes are variously coloured ranging from pale yellow, deep yellow, greenish blue, pink or combinations of these in various species. The young rhizomes and axillary buds are protected by scale leaves (Sabu, 2006).

Prabhu *et al*. (2010) explained that the leaves are distichously arranged, transverse or parallel to rhizome and with aromatic oil cells. Labellum is large or small and showy. Lateral staminodes are predominantly present. Filament is long, narrow and exerted. Epigynous glands usually two, linear, or rarely absent. Ovary unilocular or trilocular. The important genera having medicinal uses coming under Zingiberaceae are *Curcuma, Zingiber, Alpinia*, *Amomum*, *Elettaria*, *Hedychium* and *Kaempferia*.

Joy *et al*. (1998) has illustrated the morphological characters of Zingiberaceous members. The plants are commonly herbs, often large, with a pseudostem of convolute leaf-sheaths. Leaves are radial or cauline and usually membranous. Sheaths are usually large, clasping the stem; lamina with a strong central nerve and pinnate close secondary nerves. Petioles are short or nil. Flowers are hermaphrodite, irregular, solitary or spicate, bracts membranous, bracteoles membranous or nil. Perianth is 2-serrate, superior, outer segments three, calyx free and imbricate or connate in an entire toothed or spathaceous tube. Inner segments are petaloid, connate in a long or short corolla tube, free or adnate to the petaloid staminodes, or 5-perfect with a six imperfect or obsolete. Anthers are linear and 2-celled. Ovary is 3-celled, inferior with many ovules, anatropous and axile. Style is generally slender with 2 short stylodes and crowning the ovary. Stigma is usually entire or sub entire. Fruit is loculicidally a 3-valved capsule, or indehiscent and membranous or fleshy, usually crowned by the remains of the perianth. Seeds are often arillate, albumen floury and embryo small.

2.2. Medicinally important gingers

2.2.1. *Zingiber* Boehm.

Sabu (2006) has described that the name *Zingiber*, the generic epithet was derived from Tamil “ingiver” meaning ginger rhizome. This name had spread to ancient Greece and Rome through the Arab traders and from them to Western Europe. The genus is represented by 141 species distributed mainly in tropical Asia. In India, the genus is represented by 12 species out of which *Zingiber officinale* has an important role in the preparation of various Ayurvedic drugs (Theilade, 1996). *Zingiber* species have many physiological and pharmacological effects and are common constituents of ancient medicines. The rhizomes are useful in the treatment of various medical conditions including ulcers, stomach discomfort, cough, sore throat,

vomiting, epilepsy, nausea, common cold, rheumatism, atherosclerosis, muscular pains, high cholesterol and migraine headache (Shukla and Singh, 2007). *Z. officinale*, the most popular spice, commonly known as ginger, is consumed worldwide as a spice and flavouring agent and is attributed to possessing several medicinal properties (Sabulal *et al*., 2006; Ghasemzadeh *et al*., 2010; Sivasothy *et al*., 2011).

2.2.2. *Alpinia* Roxb.

The tropical and subtropical genus *Alpinia* Roxb., with about 230 species, is mainly distributed in the Indo-Pacific region. *Alpinia*, the largest genus of the family Zingiberaceae, was classified by Charles Plumier, the famous French Botanist and named after Prospero Alpini, an Italian Botanist, Physician to the Prince of Melfi and Professor of Botany at the University of Padua (Kress *et al*., 2005; Sabu, 2006). Warrier *et al*. (1994) and Warrier *et al*. (1995) explains that the rhizomes of *Alpinia* are used in bronchial problems and as a carminative. It is one of the constituents of medicated "*pān*" employed for removing the foul smell of the mouth and getting relief in throat infection. In Ayurveda, "*Rāsnā saptaka kvātham*" and "*Rāsnā adikāmath*" are utilised as antiinflammatory decoctions that contain *Alpinia* (Thakur *et al*., 1989). Joy *et al*. (1998) reported that Charaka included *Rāsnā* (*Alpinia*) in the *vayaḥsthāpana varga*, the group of drugs that are capable of maintaining youthful vigour and strength. It is employed in "*Arq pan*" as a cardiac stimulant carminative. They are also useful in vitiated conditions of *vata* and *kapha*, pharyngopathy, cough, rheumatoid arthritis, intermittent fevers, inflammations, diabetes, hiccough, dyspepsia, stomachalgia, obesity, asthma, tubercular glands and cephalalgia (Warrier *et al*., 1994; Warrier *et al*., 1995). Some popular medicinally used species are *Alpinia galanga*, *A. officinarum*, *A. zerumbet*, *A. blepherocalyx*, etc. (Kong *et*

al., 2016). *A. galanga* have varying uses in Ayurvedic preparations such as "*Rāsnādi powder*" (Prabhu *et al*., 2013a).

2.2.3. *Elettaria* Maton.

The generic epithet *Elettaria* is derived from Rheed's *Elettari*. *Elathari* (modern transcription of Rheed's name) is still used for the seeds of *Elettaria cardamomum* (*thari* means granules). The genus involves 8 species. Only one species, *E. cardamomum* is found in India and this is the only economically significant species. The genus is distributed from Sri Lanka to Malaysia and Indonesia (Sabu, 2006). *E. cardamomum* Maton. is commonly known as queen of spices (Holttum, 1950; Husain and Ali, 2014; Savan and Kucukbay, 2014). Dried fruits of cardamom are widely used as a flavouring agent in food preparations and for the treatment of gastrointestinal diseases. One of the constituents of cardamom oil, D-Limonene, is reported to exhibit tumour suppressing activity against mammary gland, liver, colon, stomach, skin and lung cancers in rodents (Samir *et al*., 2015).

2.2.4. *Amomum* Roxb.

Xia *et al*., (2004) states that the genus *Amomum* is the second largest genus after *Alpinia* coming under Zingiberaceae with about 150-180 species, extensively distributed in South East Asia. The name *Amomum* is originated from the Greek word *ammos* meaning, *a* = not and *momos* = impurity; an indication to its use as an antidote for poison. In India, the genus is represented by 22 species, mainly restricted to north eastern India and southern India (Thomas *et al*., 2012). The seeds and essential oil from the seeds of many species are widely used. Medicinally the seeds are credited with stimulant, alexipharmic, stomachic and astringent properties. The seeds and essential oil from the seeds of several species are extensively used. Some members of the genus are well known in ethnobotany and economics,

especially *Amomum testaceum* Ridl. which is a very important and famous spicy material in Asian cuisines. It is commercially known as "Siam cardamom". Its dried fruits are used for improving food flavour and antiflatulence in the Thai folk herbal formula (Chaveerach *et al*., 2008).

2.2.5. *Hedychium* Koenig.

The genus *Hedychium* is composed of 80 species worldwide (He, 2000; Sabu, 2006). The name *Hedychium* is derived from the Greek words, *Hedys* meaning sweet and *chion* meaning snow, referring to the fragrant white flowers. The genus, popularly known as 'ginger lily' produces one of the aromatic and most beautiful flowers in the family. The genus is mainly distributed in Indo-Malayan region. Only one species, *Hedychium spicatum* is used as a raw drug for various Ayurvedic preparations (Sanoj *et al*., 2013). Several species are used in traditional medicines for the treatment of asthma, gastric diseases, blood purification, bronchitis and antiemetics especially among the hill tribes of Uttarakhand (Sharma *et al*., 1979; Malhotra and Balodi, 1984).

2.2.6. *Kaempferia* L.

Kam, (1980) reported that the genus *Kaempferia* consists of about 70 species, two-third of which occur in Asia and the remaining one-third in Africa. The generic name commemorates Engelert Kaempfer, a German naturalist and physician. In southern India, 3 species are observed *Kaempferia galanga*, *K. rotunda* and one ornamental species *K. elegans* (Prabhu *et al*., 2013b). *Kaempferia* species are ethnomedicinally utilised in the treatment of pneumonia, abdominal illness, dysentery, bronchial complaints, leucorrhoea, diarrhoea and insect bites (Chuakul and Boonpleng, 2003; Chuakul and Boonpleng, 2004; Rangan *et al*., 2010). *K. galanga* has become very common and is reported to have tremendous effect

in curing bronchial and gastric diseases. It is being used in preparations of oral deodorants and mouth washes. *K. rotunda* has potential for great exploitation on a commercial basis (Prabhu *et al*., 2013b).

2.2.7. *Curcuma* Linn.

Curcuma L. is one of the largest genera belonging to the family Zingiberaceae and comprises of about 120 species of rhizomatous herbs with widespread adaptation from sea level to altitudes as high as 2000 m in the Western Ghats and Himalayas. Having originated in the Indo-Malayan region, the genus is widely distributed in the tropics of Asia to Africa and Australia (Kojima *et al*., 1998; Sastri, 1950; Larsen, 2005; Rajkumari and Sanatombi, 2017). The name *Curcuma* derived from the Arabic word "kurkum", meaning yellow, apparently refers to the colour of the rhizome or the flowers. Its rhizomes yield curcumin and aromatic oils (Skornickova *et al*., 2004).

Member of the genus *Curcuma* have long been used in folk medicine (Tsai *et al*., 2011). The genus includes *Curcuma longa*, *C. aromatica*, *C. zanthorrhiza, C. zedoaria* and *C. amada*, used in traditional systems of medicine such as Ayurveda, Siddha, Unani, Naturopathy and Homeopathy. In India, it is cultivated in numerous agro-ecological conditions right from the coastal areas to elevations as high as 1880 m in the subtropics and tropics of the country (Asolkar *et al*., 1992; Hussain *et al*., 1992; Ghani, 1998, Joy *et al*., 1998). The genus is distributed throughout tropical Asia from India to South China, South East Asia, Papua New Guinea and northern Australia. In Thailand, 38 species have been found (Sirirugsa *et al*., 2007).

Taxonomic knowledge of this genus is mandatory for citing correctly the species used commercially as spices, ornamentals and medicines. As per the new classification of the Zingiberaceae proposed by Kress *et al*. (1990),

this genus belongs to the tribe Zingibereae. Formerly *Curcuma* was a member of the tribe Hedychieae. Baker (1890) divided *Curcuma* into three sections: section Exantha (the spikes separate from the shoot), Section Mesantha (the spikes borne on the shoot either with or without leaves) and section Hitcheniopsis (characterized by autumnal spikes from the centre of the tuft of leaves, bracts very obtuse, adnate at the sides and spreading at the tip). The genus exhibits considerable morphological differences, the overlapping resemblances among them making confusion in the identification of species. According to Schumann (1904), the genus is divided into subgenus *Eucurcuma* and subgenus *Paracurcuma* raising the taxonomic rank of Hitcheniopsis Baker to subgenus *Eucurcuma* and again dividing it into section Exantha and section Mesantha. Valeton (1918) divided the genus into subgenus *Eucurcuma* and subgenus *Paracurcuma* and divided the subgenus *Eucurcuma* into section Exantha and Mesantha. Subgenus *Paracurcuma* is characterised by bracts connected at least partly beyond the middle and often very numerous. Spike is cylindrical with comparatively short coma bracts and anther spur is very short (not a quarter of the anther) or none.

Farrel (1990) pointed out that turmeric is being utilised since ancient times as a medicine, dye, ceremonial colour and as a magical symbol. In India, ladies anoint their bodies with turmeric paste, which is antiseptic. Turmeric dye is employed in combination with alkalies to colour cotton and silk. It is also used in many countries as a colouring material in food industries, pharmacy and confectionery. It is an essential and sacred component of religious, cultural and social functions and rituals in India, especially in the south (Velayudhan *et al*., 1994).

Prabhu *et al*. (2010) evaluated its medicinal uses in various kapha and vāta diseases. On the whole it is employed in the treatment of vertigo, bronchitis, skin diseases, dropsy, liver infections, fevers, burns, boils, bruises,

elephantiasis, sprains, hysteric effects, swellings, snake, scorpion and leech bites, chronic gonorrhoea, small pox, chicken pox, congestions, scabies, dyspepsia, ring worm, etc. Kirtikar *et al*., (1987) described that the rhizome is very pungent, bitter, laxative, healing, anthelmintic, vulnerary, tonic, emollient and alexiteric.

Curcuma is gaining immense value all over the world as a potential source of new drugs to resist a variety of diseases as the species has got constituents credited with antidiabetic, anticancerous, hypercholesteraemic, choleretic, antimicrobial, insect repellent, antivenomous, antirheumatic, antifibrotic, antiviral, antihepatotoxic as well as antiinflammatory effects. Turmeric oil is used in perfume industry and in aromatherapy. Although the ancient Indian Ayurvedic system of medicine and Chinese system of medicine long ago recognized the medicinal activity of turmeric in its crude form, the last few decades have witnessed extensive research works in the biological properties and pharmacological effects of *Curcuma*. Curcuminoids, the biologically active principles from *Curcuma*, promise a potential role in the control of carcinogenesis, rheumatism and oxidative stress related pathogenesis (Kojima, 1998; Sasikumar, 2007).

Plants belonging to the genus *Curcuma* are given importance globally in food and traditional medicines. Apart from being regarded as nutritionally rich products, interest in the medicinal properties of *Curcuma* species has raised because of the discovery of new bioactive constituents (Rajkumari and Sanatombi, 2017). Many *Curcuma* species are a rich source of starch, an important dietary source of energy for people (Policegoudra and Aradhya, 2008). Sasikumar and Sajitha (2015) pointed out that *Curcuma* species appear to be promising alternative sources of starch for commercial applications not only because they offer many desirable physicochemical properties but also because they are easy to cultivate, widely adapted and

adaptable to adverse climatic conditions. However, the genus has not been properly exploited as a source of starch (Rajeevkumar *et al*., 2010). The plants are commonly aromatic and carminative and are used to treat indigestion, diabetes, hepatitis, jaundice, atherosclerosis and bacterial infections. Among the *Curcuma* species *C. longa*, *C. aromatica* and *C. zanthorrhiza* are common (Lee *et al*., 2008).

The crop improvement work has been done mainly in *C. longa* and to a little extent in *C. amada*. At present there are about 20 improved varieties of *C. longa* in India and one of *C. amada*, evolved through germplasm/clonal selection, mutation breeding or open pollinated progeny selection (Sasikumar, 2007). The members of the genus *Curcuma* are widely utilised as spice, food preservative and colouring material, in religious applications as well as household remedy for biliary and hepatic disorders, rheumatism, diabetic wounds, sinusitis and anorexia in India, China and South East Asia (Kojima *et al*., 1998).

The rhizome is very pungent, laxative, bitter, healing, anthelmentic, vulnerary, tonic, alexiteric and emollient. It is applied as a medicine in various *kapha* and *vata* diseases. In Cambodia it is utilised as an antipyretic and tonic. It is used as carminative, stimulant, aspirant, emmenagogue, astringent, detergent and diuretic in China. It is used in Unani system in treating jaundice, bruises and scabies. On the whole it is employed in the treatment of skin diseases, bronchitis, dropsy, vertigo, liver infections, burns, boils, elephantiasis, sprains, hysteric effects, fevers, swellings, chronic gonorrhoea, small pox, chicken pox, snake, scorpion and leech bites, congestions, scabies, dyspepsia, ring worm, etc. (Kirtikar *et al*.,1987).

Tribal and local people in most Asian countries utilised *Curcuma* species as medicinal plants, in religious rituals and as food stuff. Their greatest diversity is in India, Thailand and Myanmar, with a few species

extending to China, Australia and South Pacific though some popular species can be found cultivated and naturalized all over the tropics. In their native range, they are an important component of the under storey in shaded, wet areas or as some of the first pioneers in distributed areas such as ditches and roadsides. Their true identity is often unclear. Many *Curcuma* species were illustrated as early as 200 years ago. Lack of type specimens, poor description and difficulties in preserving useful specimens (making it necessary to work with living flowering material) make their research one of the most difficult among gingers. In the past 20 years, modern medicine and the pharmacological industry have turned towards *Curcuma* with the hope of finding medications for serious diseases as well as natural treatments for common diseases (Skornickova *et al*., 2007a). Despite the considerable economic potential of this genus, its phylogeny and taxonomy remain poorly understood, mainly due to extensive polyploidisation (2x-15x) and hybridisation (Skornickova *et al*., 2007b; Zaveska *et al*., 2011) resulting in different levels of genetic and morphological variations among species and in blurred species boundaries (Skornickova, 2007).

The economically important species of the genus are *C. longa* and *C. aromatica* used in medicine and cosmetic industry; *C. kwangsiensis*, *C. zedoaria*, *C. ochrorhiza*, *C. caesia* *C. pierreana*, etc. used in folk medicines of the South East Asian nations; *C. alismatifolia*, *C. roscoeana,* etc. with floricultural importance; *C. amada* employed as medicine and in a variety of culinary preparations, pickles and salads and *C. zedoaria*, *C. malabarica*, *C. montana*, *C. pseudomontana*, *C. decipiens*, *C. rubescens*, *C. haritha*, *C. caulina*, *C. angustifolia*, etc. utilised in arrowroot manufacturing (Sasikumar, 2007).

2.3. *Curcuma aromatica* Salisb.

As obvious from its specific epithet, this plant is esteemed for the warm, aromatic flavour of its rhizomes. The species has an obscure history. Anthony Salisbury explained it in 1807 from material sent for cultivation to England and there is no authentication of its type locality, nor a reliable type specimen. There are many taxa fitting to the original illustration contributed by Salisbury, and this name is now attached to different plants. Thus several uses mentioned in the literature for *C. aromatica* must be taken with a grain of salt, as most references to *C. aromatica* are likely that of *C. zanthorrhiza* Roxb., *C. zedoaria* (Christstm.) Roscoe or an unknown complex of species (Skornickova *et al*., 2007a).

C. aromatica is commonly called wild turmeric or musk turmeric in English, *kasthurimanjal* in Malayalam, *vanaharidra* in Sanskrit and *jangli haldi* in Hindi. Currently only local types are available for cultivation (Warrier *et al*., 1994; Warrier *et al*., 1995; Sikha *et al*., 2015). In India, annual production of rhizome is approximately 2t (Vaze, 2003). The aromatic rhizome is the economically important part and it has camphoraceous odour (Nadakarni, 1998). In some regions of India, *C. aromatica* is replaced by *C. zanthorrhiza* due to the non-availability of *C. aromatica* (Anjusha and Gangaprasad, 2014).

The cosmetic use of the plant is highly exploited, providing protection to skin from pollution, bacteria and allergies. The paste made from the rhizome is commonly used in skin care to treat pimples, acne and blackheads and it helps to slower the superfluous hair (Zawar, 2011; Sikha *et al*., 2015). Curcumin content, which is responsible for the yellow colour of the rhizome, is very low in wild turmeric as compared to normal turmeric. The rhizome of the plant is rich in flavonoids, tannins, alkaloids, curcuminoids and terpenoids which are reported to be the reasons for its different pharmacological

activities. The extract of the rhizome is highly effective against many human pathogens as well as microorganisms causing food spoilage and food borne diseases (Anoop, 2015; Anonymous, 2019a).

2.3.1. Origin and distribution

According to Purseglove (1968) and Harlan (1975) the genus *Curcuma* developed in the Indo-Malayan region. Considering the great diversity of the genus represented by over 80 species in Indo-Malayan region, it is legitimate to regard the genus originated in the Indo-Malayan region. Over 40 species are native to India and is supportive to its Indian origin. The genus *Curcuma* has a widespread occurrence in the tropical Asia and Australia. At present the crop is distributed in India, Thailand, Pakistan, Malaysia, Indonesia, Myanmar, Vietnam, Philippines, China, Korea, Sri Lanka, Nepal, South Pacific Islands, East and West African nations, Malagasy, Japan, Caribbean islands and Central America. In India, it is widespread. It is reported to occur widely in Eastern and Western Ghats (Purseglove, 1968; Purseglove *et al*., 1981).

Curcuma aromatica Salisb. is native to southern India, widely cultivated for its aromatic rhizome (Sabu, 2006; Jain *et al.,* 2013). *C. aromatica* is distributed in India, Sri Lanka and China (Sharma *et al*., 2011). Krishnamurthy (1993) described that the plant grows best in different soils from light black sandy loam and red soils to clay loams. The ecology of the species differs so much that their habitat ranges from sea level (sandy coastal habitat) to high altitude such as above 2000 m in the Western Ghats and Himalayas in India, whereas species such as *C. aromatica, C. longa*, *C. zedoaria* and *C. amada* are found commonly in plains; *C. angustifolia*, *C. neilgherrensis*, *C. thalakaveriensis*, *C. pseudomontana*, *C. kudagensis* and *C. coriacea* are confined to hills at 1000–2500 m altitude (Velayudhan *et al*., 1999).

2.3.2. Morphology

Wild turmeric or *jujin* is a wild plant occurring in the warm forests of the eastern Himalayas in India (Ravindran *et al*., 2007). Warrier *et al*. (1994) Warrier *et al*. (1995) and Kumar and Sikarwar (2002) observed that the plant is a perennial, erect and rhizomatous herb propagated by rhizomes. The above ground appearance of the plant is much similar to *C. longa* but the rhizomes are less pigmented with characteristic camphoraceous smell. The broad and elliptic leaves which can grow 3-4 ft. in height appear later. During monsoon season, the plant shows fast and vigorous growth. The foliage dries up by late autumn and the rhizomes remain dormant during winter. The rhizomes possess characteristic fragrance on attaining maturity. Corolla tube is funnel shaped, lobes unequal, dorsal lobe broadly ovate and lateral lobes oblong. Lateral staminodes are oblong; style filiform. Flowers are borne on peduncles with crown of bracts. Peduncle is covered by sheaths. It does not set seeds properly. The inflorescence comes out first from the dormant underground rhizomes in early spring (Anoop, 2015).

C. aromatica is a perennial erect herb. The whole plant is about 70-100 cm tall with large greyish yellow aromatic rhizome which is the economically important part. Root fibres are not ending in tubers. Leaves are pale green, densely pubescent below, distichous with lanceolate and acuminate lamina. Inflorescence is a spike, 15-30×9 cm and lateral in position. Peduncle is 5-8 cm long and is covered by sheaths. Coma bracts are large, pink and spreading. Fertile bracts are up to 6 cm long, tips re-curved, slightly hairy on upper surface and pale greenish white in colour. Bracteoles are 2 cm long, white and sparely pubescent. Calyx is short and cylindrical. Corolla tubes are funnel shaped and just exceeding the calyx, lobes are unequal, dorsal lobes broadly ovate, arching over the anther and hooded whereas lateral lobes are narrower and oblong. Labellum is obscurely 3

lobed, orbicular and deep yellow. Lateral staminodes are petalloid, oblong and obtuse and as long as the corolla lobes. Anther thecae parallel, each ending in a long sharp spur at the base. Style long and filiform. Stigma two lobed with a perforation in the centre. Ovules many and axile. Fruit is a 3 valved capsule, tardially dehiscent and globose (Chopra *et al*., 1980; Sabu, 2006; Sharma *et al*., 2011; Fischer, 2013; Sikha *et al.,* 2015).

Scanning electron micrographs unveiled the shape and size of starch granules of *C. aromatica* as oval to elliptical, flat with concentric rings on the surface, 6-24 µm wide and 9-60 µm long (Sasikumar and Sajitha, 2015).

2.3.3. Taxonomy

Curcuma aromatica Salisb. belongs to Kingdom: Plantae, Clade: Angiosperms, Clade: Monocots, Clade: Commelinids, Order: Zingiberales and Family: Zingiberaceae (Angiosperm Phylogeny Group, 2009; Fischer, 2013).

2.3.4. Cytology

Different chromosome numbers were reported by different authors. According to Raghavan and Venkatasubban (1943), Chakravorti (1948) and Mathai (1976) chromosome number of *C. aromatica* has been found to be 2n=42. As per Nambiar *et al*. (1982) the chromosome number is 2n=84. *C. aromatica* collected from China was reported to be a triploid with chromosome number 2n=63 (Chen and Chen, 1984). Ramachandran, (1961) and Ramachandran, (1969) also reported two different chromosome numbers for *C. aromatica i.e.,* 2n= 63 and 86.

2.3.5. Pollination biology

Flowering not usually occurs under Kerala conditions (Anonymous, 2019a). The flowering season of *C. aromatica* extends from May to June in

South India (Sabu, 2006). Nambiar *et al*. (1982) documented that the flowering time was between 06.00 and 07.00 h and lasted for 94 to 104 days. Flower is bisexual, epigynous and zygomorphic (Larsen *et al*., 1998). Seeds matured in 23-29 days and germinated in 10-16 days; average germination ranging from 35.8% to 62.5% and lasting for 8-20 days. Pollen fertility ranged from 68.56% to 74.49% and seedlings, like their parents, had 2n=84 chromosomes (Skornickova *et al*., 2007b).

2.3.6. Agronomy

Agronomy is the art and underlying science of handling the crops and soils to produce the highest possible quality and quantity of the desired crop products from each unit of land and soil, water and light (Ball, 1925) with a minimal use of resources in productivity related with profitability, lower costs and sustained competitiveness (Sivaraman, 2006).

Fu *et al*. (1996) opined that planting date had a superior effect than planting density on plant growth. Plant height, branch number, leaf number, leaf length, leaf width, total number of finger sets per plant, rhizome dry weight and curcumin content were the best for planting dates from 15 March to 16 May related with planting in June in Taiwan. The agro-climatic factors of cultivation conditions such as temperature, rainfall, humidity and soil nutrient largely affect the quality and production of constituents of any crop (Sanghamitra *et al*., 2015; Zhang *et al*., 2017).

2.3.6.1. Climate and soil

The species is distributed in South East Asia. The plant grows wild in the eastern Himalayas and in moist deciduous forests of Kerala and Karnataka. *C. aromatica* is cultivated in different agro-ecological climates right from the coastal areas to elevations as high as 1880 m in the tropics and the sub-tropics of India. It is grown as a subsistence crop in backyard, kitchen

garden and interspaces of other crops in areas with good rainfall. Well drained rich loamy soils are ideal for the crop (Joy *et al*., 1998; Anonymous, 2019b).

2.3.6.2. Land preparation

Land preparation involves clearing the area, removing all the pebbles and stones and ploughing the field to good tilth. Incorporate farmyard manure (FYM) or organic manure at 10-15 t/ha. Prepare raised seed beds of 1.2 m breadth and of convenient length (Anonymous, 2019b).

2.3.6.3. Seed rate

A healthy disease free mother rhizome with at least one germinated sprout is the planting material. It is required at the rate of 1500 kg/ha (Anonymous, 2019b).

2.3.6.4. Planting

Take small pits at 60x40 cm spacing on the seed bed and plant seed rhizomes with the germinating sprout facing upwards. Cover the rhizome with farmyard manure and mulch the bed with leaves or straw (Anonymous, 2019b).

2.3.6.5. Manuring

Wild turmeric is an important cosmetic cum medicinal plant and therefore quality of rhizomes assumes significant importance. The quality of any crop is influenced by the biochemical components present in the economic part. Nirmalatha (2009) reported that vermicompost + mi (microbial inoculum) produced best quality rhizomes with the highest volatile oil, starch and non-volatile ether extract and with minimum fibre content. Combined application of microbial inoculants also recorded the lowest

percentage of crude fibre in wild turmeric. The control plants documented the maximum crude fibre content in the rhizome. Effects of organic manures on yield parameters of *C. aromatica* was studied by Nirmalatha *et al*. (2010). They pointed out that vermicompost 25 t/ha and neem cake 6 t/ha were significantly superior to all other treatments.

Gopichand *et al*. (2006) observed the effect of plant spacing (25 cm x 25 cm, 50 cm x 25 cm and 50 cm x 50 cm) and farmyard manure (FYM-15, 22.5, 30 & 37.5 t/ha) on growth, yield and quality of oil from *C. aromatica*. The crop responded markedly to different types of spacing. The observed plant height increased with reduction in plant spacing from 50 cm x 50 cm to 25 cm x 25 cm, while the number of plantlets followed the reverse trend. Leaf length: leaf breadth ratio and leaf area density exhibited an increasing trend with closer spacing. Wider plant spacing provided higher fresh rhizome yield. Application of FYM did not affect plant growth notably. Difference in FYM level and plant spacing did not influence the oil content. Application of 22.5 t/ha of FYM contributed higher oil yield (234.4 kg/ha) as related to 15 t/ha of FYM (174.1 kg/ha). Also, oil yield was maximum at 50 cm x 50 cm spacing (213.5 kg/ha) as compared to closer spacing of 25 cm x 25 cm (191.6 kg/ha).

Bhende and Jessykutty (2017) revealed that the volatile oil content of wild turmeric was significantly enhanced by the application of organic manures and microbial inoculants. Full dose of vermicompost and neem cake were found to be superior. Among the different organic manures tested FYM (farmyard manure) was found to have the minimum influence while, vermicompost was found to have maximum significant influence. The results described that application of vermicompost 25 t/ha + mi (microbial inoculants = *Azospirillum* + AMF + *Trichoderma* + *Pseudomonas*) observed significantly higher values for rhizome biochemical traits like volatile oil

(6.60%), non-volatile ether extract (6.73%) and starch (22.58%) followed by neem cake 6 t/ha + mi and FYM 20 t/ha + vermicompost 6.25 t/ha + neem cake 1.5 t/ha + mi. Apply fertilizers at 199:50:50 N: P_2O_5: K_2O kg/ha; entire P_2O_5 as basal and N and K_2O in two equal splits at planting and two months after planting (Anonymous, 2019b).

2.3.6.6. Plant protection

No serious pests and diseases are encountered in the crop (Anonymous, 2019b). Brown rot disease has been reported in the rhizomes of *C. aromatica* by Sharma and Nambiar (1974). This was found to be associated with *Fusarium* species and a nematode, *Pratylenchus* species was isolated from the affected tissues.

2.3.6.7. After cultivation

Gap filling is carried out if necessary within one month. Remove weeds two months after planting followed by top dressing, earthing up and mulching (Anonymous, 2019b).

2.3.6.8. Harvesting and yield

The crop matures in 7 months. Drying up of leaves is the sign of maturity. Dig out the rhizomes without causing damage. Remove the dry leaves and roots. The cleaned rhizomes are either marketed or dried and stored. The average yield of fresh rhizome is 28 t/ha which on drying gives 27% recovery (Anonymous, 2019b).

2.3.6.9. Processing

The rhizome is thinly sliced and steam distilled for 3-4 hours for extracting the essential oil and the yield is 90 litres/ha. Oil recovery is 0.33% on fresh weight basis and 1.05% on dry weight basis (Anonymous, 2019b).

2.3.7. Pharmacognosy

Srivastava *et al*. (2007) evaluated pharmacognostic characters of the rhizome of *C. aromatica*. The rhizome contains moisture content of 43.4%, starch 30.6%, alcohol soluble extractives 7.9%, total ash 6.2%, acid insoluble ash 0.5%, water soluble extractives 11.7%, sugar 6% and total volatile oil 1.8%.

2.3.8. Anatomical and histochemical studies

In spite of the economic importance of the genus *Curcuma*, our understanding on the anatomical characteristics of this genus is very limited. A comparative study on histochemical and anatomical aspects of four medicinally important species of *Curcuma*, namely *C. longa* (turmeric), *C. aromatica* (wild turmeric), *C. zedoaria* (yellow zedoary) and *C. amada* (mango ginger) were carried out to find out the variation by Sherlija *et al*. (1998) and Remashree and Balachandran (2006). Though all the species had basically similar anatomical characters, variations were recorded in the orientation of tissues, number and arrangement of primary and secondary bundles and number and shape of curcumin cells, starch grains and oil cells. The primary vascular bundles are scattered and abundant in both outer and inner zone in *C. longa* and *C. amada*, less in *C. zedoaria* and least in *C. aromatica*. The highest numbers of curcumin cells were found in *C. longa* and *C. zedoaria* and it was the minimum in *C. aromatica* and *C. amada*. At maturity, the size and number of starch grains differ among species and this is a significant characteristic for identification. Maximum number and large size of starch grains are present in *C. aromatica* and *C. zedoaria*. Oil cells are present more or less in spherical shape and contain stored volatile oil. The number of oil cells and curcumin cells varies in the four species and they are higher in the apical and nodal region than in the internodal region. The size of the oil cells is dependent on their number. The endodermoid layer form a

continuous ring along with the pericycle in *C. longa* and is more or less circular in *C. amada*. But in *C. aromatica* and *C. zedoaria*, this layer is wavy and discontinuous in nature. Some of the general anatomical features include epidermal hairs half celled and branched and walls thick and lignified. Epidermis is single layered and periderm with 4-7 layers of cells. Outer cortex is occupied with a few number of collateral scattered vascular bundles, while in inner cortex amphicribral vascular bundles are arranged in patches. Endodermoid layer is continuous and wavy. Meristematic cells occur in cambium. Xylem tracheids show scalariform and spiral thickening. Phloem is composed of sieve tube, 1-2 companion cells and phloem parenchyma. Bundle sheath is absent. A few numbers of fibre are present. Curcumin cells uniformly occur in both zones, but smaller in size compared to *C. longa* and *C. amada*. Lysigenous oil cells are present. Starch grains are densely packed in each cell.

2.3.9. Phytochemical aspects

The oil extracted from the *C. aromatica* rhizome is a blue black dark liquid with camphoraceous, woody, amber with spicy characteristic odour (Vaze, 2003). The rhizome is a rich source of essential volatile oils such as curcumol, demethoxy curcumin, etc. (Dulak, 2005). The total phenolic concentration present in the ethanolic extract of the rhizome was 195 mg/ml (Sahu and Nahak, 2011). When compared to *C. longa, C. aromatica* has a higher level of volatile oil content. The presence of camphene, camphor and a high boiling alcohol in the volatile oil are the characteristics of *C. aromatica* (Ratnambal, 1986; Jain *et al.,* 2013). Jarikasem *et al*. (2005) stated that the major constituents appeared in the essential oil of *C. aromatica* were camphor (26.94%), ar-curcumene (23.18%) and xanthorrhizol (18.70%). Parida *et al*. (2020) disclosed that ar-tumerone (36.86%) was found to be the major constituent of rhizome essential oil of micropropagated wild turmeric.

Rhizomes yield 6.1% of essential oil (Chopra *et al*., 1980). Fresh rhizome contains the sesquiterpenes 1-curcumene, 1,8-cineole, isofuranogermacrone, a and b-pinene, borneol, isoborneol, tetramethyl pyrazine, germacrone, curdione, zedoarondiol, curcumenone, curcumol, neocurdinone, curcumin and demethoxy curcumin (Anonymous, 2001). The major components of the leaf oil were found to be camphor (28.5%), ar-turmerone (13.2%), curzerenone (6.2%), 1,8-cineole (6%) and a-turmerone (2.5%). The rhizome oil contained mainly of camphor (32.3%), curzerenone (11.0%), ar-turmerone (6.3%), a-turmerone (6.7%) and 1,8-cineole (5.5%) (Kojima *et al*., 1998). Kuroyanagi *et al*. (1987) and Kuroyanagi *et al*. (1990) isolated many sesquiterpenes, isozedoarondiol, methylzedoarondiol, neocurdione, germacrone, curdione, (4s,5s)-germacrone, 4,5-epoxide, dehydrocurdione, curcumenone, procurcumenol and zedoarondiol from *C. aromatica*. Neocurdione, isoprocurcumenol and 9-oxo-neoprocurcumenol were extracted from fresh rhizomes of *C. aromatica* by Etoh *et al*. (2003).

Tsai *et al*. (2011) revealed that the key components obtained from the rhizome were curcumol (35.77%) and 1,8-cineole (12.22%). The essential oil from *C. aromatica* rhizomes collected in northern Vietnam has been analysed by Giang and Son (2000). Six oxygenated terpenes (furanodiene, germacrone, furanodienone, curcumenone, curzerenone and zederonone) and three sesquiterpenes (α-humulene, β-selinene and α-selinene) were obtained. The rhizome is rich in a wide variety of secondary metabolites like alkaloids, tannins, terpenoids and flavonoids (Bordoloi *et al*., 1999). The compounds like caryophyllene oxide, patchouli alcohol and elsholtzia ketone in the petiole oil and limonene in the leaf oil were reported by Choudhury *et al*. (1996). Huang *et al*. (2000) analysed the petroleum ether extract from the rhizomes of *C. aromatica* from Vietnam and obtained curdione, neocurdione, curcumol, tetramethyl pyrazine and 1,2-hexadecanediol. Neeraja *et al*. (2001) reported a sesquiterpene ketodioxide called zederone from the rhizome.

Significant difference in the composition of phytochemical constituents has been reported within the species by Behura *et al*. (2002). The volatile oil mainly included β-curcumene, ar-curcumene, camphor, xanthorrhizol, curzerenone, 7-methanoazulene, 1,8-cineole, β-elemene, germacrone and linalool (Kojima *et al*., 1998; Zhang *et al*., 2004; Choochote *et al*., 2005; Al-Reza *et al*., 2010) and curcumene (Lee *et al*., 2008). Gurdip *et al*. (2004) revealed that the rhizome extract composed of p-cymene 2-oxabicyclo octane, 1,4-dimethyl-8-methylene, p-cymen-8-ol, bicycle heptane-1-1-acetyl-7-methylene, L-carveol and α-pinene. *C. aromatica* oil extracted from rhizome contains a different spectrum of components related to sesquiterpenoids rather than curcuminoids (Jiang *et al*., 2005).

Lis-Balchin, (2002) pointed out that the differences in the essential oil composition can be caused by variations in species, country of origin, climate, time of harvest, fertilizer application and extraction and analysis methods. The comparative analysis of essential oil constituents of the rhizome from India and Japan showed that oil from Japan contained germacrone, curdione, 1,8-cineole, (45-5s) germacrone-4,5-epoxide, β-elemene and linalool as major elements while, those in the oil from India were β-curcumene, ar-curcumene, camphor, xanthorhizol, germacrone, camphor and curzerenone (Kojima *et al*., 1998). Three phytochemicals demethoxycurcumin, curcumin and β-sitosterol-3-o-β-D-glucopyranoside have been extracted from the ethyl acetate extract of rhizomes of *C. aromatica*. β-sitosterol-3-o-β-D-glucopyranoside has been isolated for the first time by Jain *et al*. (2013). Ling *et al*. (2012) revealed that major constituents in the rhizome were eucalyptol, linalool, neocurdione, camphor, 2-terpeniol and germacrone.

The chemical composition of the essential oils from the rhizomes of five *Curcuma* species from India and Indonesia was examined by Zwaving and Bos (1992). The oils showed the presence of the following compounds:

C. aromatica: *ar*-curcumene (18.6%), β-curcumene (25.5%) and xanthorrhizol (25.7%); *C. xanthorrhiza* : *ar*-curcumene (41.4%) and xanthorrhizol (21.5%); *C. domestica* : *ar*-turmerone (24.7%), turmerone (29.5%), turmerol (20.0%) and α-atlantone (2.4%); *C. aeruginosa* : isocurcumenol (8.5%), β-eudesmol (6.5%), curdione (3.6%), curcumenol (9.9%), curcumanolides A, B (11.4%), dehydrocurdione (9.4%) and curcumenone (1.9%); *C. heyneana* : 1,8-cineole/limonene (14.2%), isocurcumenol (7.4%), β-eudesmol (4.7%), curcumanolides A, B (13.1%), dehydrocurdione (10.2%) and curcumenone (2.3%).

Feng *et al*. (2013) discovered curdione as the major constituent in the rhizomes of different growth phases. Analysis of hexane extract revealed the presence of 13 compounds. The important constituent was germacrone (40.46%) followed by a-vatirenene with 34.73% and androstan-17-one, 3-ethyl-3-hydroxy (5a) with 13.42% (Revathi and Malathy, 2013). Studies carried out on the essential oils in *C. aromatica*, *C. zedoaria* and *C. aeruginosa* have reported the presence of a large number of terpenoids and sesquiterpenoids (Zwaving and Bos, 1992; Choudhury *et al*., 1996; Sirat *et al*., 1998; Lai *et al*., 2004; Jarikasem *et al*., 2005). Nambisan *et al*. (2014) evaluated the chemical composition of essential oils from eight underutilized starchy *Curcuma* species and was characterized by the presence of peculiar compounds which varied in concentration from 0.25% to 70%. These included β-endesmol in *C. aeruginosa*, α-fenchene in *C. sylvatica*, elemenone in *C. rakthakanta*, epicurzerenone and curzerene in *C. zedoaria*, curcumene in *C. malabarica*, and curdione and xanthorrhizol in *C. aromatica*.

Three novel phytoconstituents characterized as n-heneitriacontan-14-one, n-pentatriacontan-5-one and 11α-cyclopentyl-n-decan-1-ol along with the known compounds curcumol, curdione, zederone, 1,2-hexadecanediol, isoprocurcumenol 1,9-oxo-nessential oil procurcumenol, curcumenol,

curcumin, demethoxycurcumin, β-sitosterol-3-0-β-D-glucopyranoside and n-non acosan-1-ol were yielded from the chloroform extracts of the rhizomes of *C. aromatica* (Ahamed *et al*., 2011). The chemical investigation by Gurdip *et al*. (2002a) on the volatile oils of *C. aromatica* leaf reported 1,8-cineole (24.8%) and p-cymene (25.2%) as important constituents. Al-Reza *et al*. (2010) evaluated the essential oils of the leaves and rhizomes of cultivated wild turmeric. About 50 compounds have been distinguished in these oils, accounting for more than 85% of the contents. The important constituents of the leaf oil were found to be camphor (28.5%), ar-turmerone (13.2%), curzerenone (6.2%), 1,8-cineole (6.0%) and α-turmerone (2.5%). The rhizome oil included mainly of camphor (32.3%), curzerone (11.0%), α-turmerone (6.7%), ar-turmerone (6.3%) and 1,8-cineole (5.5%).

Catalan *et al*. (1989) declared that germacrene D, curzerenone, xanthorrhizol, curcuphenol and hydroxy isogermafurenolide were the most notable components obtained from the rhizomes of *C. aromatica*. Choudhury *et al*. (1996) reported that the oils obtained from the leaves, petiole and rhizomes of *C. aromatica* from Assam, India, contained more than 51, 50 and 61 phytoconstituents respectively of which 43, 41 and 53 constituents were discovered, accounting to about 96.8%, 86.3% and 86.3% of the bulk of the respective oils. The significant constituents in the leaf, petiole and rhizome oils were found to be 1,8-cineole (20.0%, 8.8% and 9.3% respectvely), camphor (18.0%, 16.8% and 25.6%), germacrone (11.8%, 0.2% and 10.6%), isoborneol (6.4%, 6.8% and 8.2%) and camphene (9.4%, 1.2% and 7.4%). In addition, caryophyllene oxide (8.7%), patchouli alcohol (8.4%) and elsholtzia ketone (6.0%) were observed in the petiole oil, limonene (8.6%) in the leaf oil and curzerenone (10.9%) in the rhizome oil.

According to Vasundhara *et al*. (2019) the major components of leaf oil includes isofuranogermacrone, ar-curcumene, 1,8-cineole, xanthorrhizol

and camphor while the rhizome oil composed of cedrene, xanthorrhizol, ar-curcumene, camphor and germacrone. Also they concluded that oxygenated monoterpenes, monoterpene hydrocarbons, sesquiterpenes and sesquiterpene hydrocarbons are the major elements of both rhizome and leaf essential oil. Leaf essential oil of *C. aromatica* showed the presence of more than 18 components such as 1,8-cineole (24%), p-cymene (25.2%), 2-oxabicyclo (3-2-1) octane 1-4-dimethyl-8-methylene (8.1%), p-cymen-8-ol (4.6%), bicycle (2-2-1) heptanes-1-acetyl-7-methylene (3.8%), α-pinene (2.6%) and L-carveol (2.1%) as the major elements (Gurdip *et al*., 2004). Hyun *et al*. (2016) disclosed the chemical constituents of the essential oil from the leaves as α-terpinolene (44.81%), 1,8-cineole (13.88%), bicycle [3-1-1] heptane and 6,6-dimethyl-2-methylene (11.76%).

Nampoothiri *et al*. (2015) examined the essential oil from the rhizome of *C. aromatica*. The significant constituents in the oil were xanthorrhizol (26.3%) followed by ar-curcumene (19.5%) and di-epi-alpha-cedrene (16.5%). Volatile oil from the rhizomes of *C. aromatica* included mainly ar-turmerone (58.9%) followed by bicyclogermacrene (11.7%), (E)-2-hexanal (5.3%), γ-himachalene (4.01%), its isomer (3.8%), caryophyllene oxide (3.4%) and valencene (3.2%). Totally five monoterpenes (3.3%) were found in the oil consisting of four hydrocarbons (2.3%) and one alcohol (1.0%). About thirteen compounds occurred in trace amounts in the oil. Among sixteen sesquiterpenes which included 91.6%, the prominent sesquiterpenes were ar-turmerone (58.9%), bicyclogermacrene (11.7%) and γ-himachalene (4.01%) (Ali *et al*., 2013). The rhizomes contained zederone, oxoneoprocurcumenol, neoprocurcumenol, curcumin and the volatile oil mainly composed of curzerenone, ar-curcumene, β-curcumene, camphor, xanthorrhizol, germacrone, 7-methanoazulene, 1,8-cineole, linalool and β-elemene (Kojima *et al*., 1998; Neeraja *et al*., 2001; Jiang *et al*., 2005;

Choochote *et al*., 2005; Lee *et al*., 2008; Minami *et al*., 2009; Al-Reza *et al*., 2010; Madhu *et al*., 2010).

Methanolic and petroleum ether extracts of the rhizome consisted of camphor, L-camphor, 1,8-cineole, germacrene-B, furanodiene, germacrone, 1-linalool, vetiverol, linalyl acetate, curzerene, 6,10-dimethyl-3-curdione, limonene and cycloocten as the significant secondary metabolites (Benjamin *et al*., 2010). Curcumol, elemicin and curione were the major active antitumour ingredients extracted from the rhizome of wild turmeric (Yang *et al.,* 1996; Dong *et al*., 1997). Anjusha and Gangaprasad (2014) reported the presence of flavonoids, tannin, saponin, sterols and terpenoids in the methanolic and aqueous extracts of the rhizome of *C. aromatica*.

It was explained that the constituents like curdione, curcumol, neocurdione, tetramethyl pyrazine and (R)-(+)-1,2-hexadecanediol occurred in *C. aromatica*. Eocurdione and (R)-(+)-1,2-hexadecanediol were isolated for the first time from *C. aromatica*. Methanolic extract of the rhizomes also yielded three new homosesterterpenoids characterized as 5,9,13,17,20-pentamethyl-n-heneicos-cis-3-en-6b,7b,8b-triol (curcusesterterpene A); 5,9,13,17,20-pentamethyl-n-heneicos-cis-6-en-2b,4b,5a-triol (curcusesterterpene B); 5,9,13,17,20-pentamethyl-n-heneicos-cis-3-en-6β,7β,9α-triol (curcusesterterpene C) along with the known components curcumin and n-nonacosan-1-ol. The most notable elements from the rhizome were germacrene-D, curzerene, xanthorrhizol, germacrone, curcuphenol, curzerenone and hydroxyisogermafurenolide (Asolkar *et al*., 1992). Behura *et al.,* (2002) revealed that the *C. aromatica* leaves are used as a basic material for making perfumes, because of the presence of the significant compounds 1,8-cineole [28.01%] and linalool [7.67%]. Apart from these, a-pinene [4.74%], b-pinene [3.70%] and C_8-aldehyde [2.62%] are also present in the leaf samples.

2.3.10. Cosmetic uses

C. aromatica is popular for its cosmetic uses in India. The rhizome paste is used as facial application to reduce acne and excessive hair growth and also to improve skin tone and complexion (Anoop, 2015). Various commercially available cosmetics and Ayurvedic preparations have kasthuri turmeric. Skin care is the major use of this aromatic plant (Kojima *et al*., 1998). *C. aromatica* is used in the treatment of skin diseases and is extensively used in vanishing creams (Joy *et al*., 1998; Warrier *et al*., 1994; Warrier *et al*., 1995).

The rhizome is an esteemed drug for skin care. It is ideal for protection against skin infections because it possess superior germicidal activity. Traditionally the rhizome paste is used in bathing new born babies. It is a component of good quality Ayurvedic skin care products. It is generally used by Indian women for skin rejuvenation (Anonymous, 2019a). The rhizome has high cosmetic value and is applied externally to the skin to get a peculiar lively tinge to the naturally dark complexion and a delicious fragrance (Watt, 1972). In Thailand, the rhizomes and roots are generally used in cosmetics and spas for skin nourishment (Shi *et al.,* 1981).

Its effectiveness as a cosmetic ingredient has been investigated by Hyun *et al*. (2016). The antibacterial, antielastase and antimelanogenic activities of the essential oil from the leaves of *C. aromatica* were examined for the first time. The antibacterial activities of *C. aromatica* oil (CAO) against drug susceptible and drug resistant skin pathogens were also studied. The minimum bactericidal concentration (MBC) and the minimum inhibitory concentration (MIC) values indicated that *C. aromatica* oil possess excellent antibacterial properties. The MIC of *C. aromatica* oil against drug susceptible and drug resistant skin pathogens ranged from 70 µg/mL to 400 µg/mL. Moreover, the capacity of *C. aromatica* oil to suppress elastase, an

important enzyme known to be involved in skin wrinkle formation, was investigated. *C. aromatica* oil has moderate antielastase activity (IC50: 667.88 µg/mL). Besides, *C. aromatica* oil decreased α-melanocyte stimulating hormone (α-MSH)-induced production of melanin in B16/F10 murine melanoma cells, designating that it has antimelanogenic effects. These findings illustrate that *C. aromatica* oil has significant potential for use in promoting human skin health. *C. aromatica* oil was also investigated for its antielastase and antimelanogenic activities as well as cytotoxicity towards B16/F10 melanoma cells for development as a potential ingredient in cosmetic product.

The plant is broadly used in vanishing creams and its roots are used as an ingredient in the preparation of body deodorants (Zawar, 2011). The cosmetic use of the plant is highly exploited, providing protection to skin from pollution, bacteria and allergies. The paste made from the rhizome is commonly used in skin care to treat against pimples, acne, blackheads and also, it helps to slower the superfluous hair (Zawar, 2011; Sikha *et al*., 2015). The rhizome of *C. aromatica* is used for curing skin eruptions, pimples, leucoderma and itching and also used as a cosmetic by Kani, Malasar, Madugga and Irular tribes (Soudhamini *et al*., 2005; Kingston *et al*., 2009; Johnsy *et al*., 2012; Govindasamy and Arumugam, 2012).

2.3.11. Medicinal values

C. aromatica is economically highly valued, it has high ethnobotanical value and in India, it is used as a tonic (Tiwari *et al*., 2003), carminative, antidote to snake bite and astringent (Chopra *et al*., 1941; Jain *et al*., 1991). The rhizomes of *C. aromatica* have been used medicinally in China, Japan and South East Asia (Vo, 1997). Marina *et al*. (2008) stated that *C. aromatica* rhizome extract showed significant antitussive activity in a dose dependant manner. The rhizome powder is taken either alone or in combination with

other species of *Curcuma* against intestinal worms by tribals of Meghalaya (Anonymous, 2001). *C. aromatica* has long been used as a medicinal plant for reducing pain and relieving inflammation. It has been documented that the extracts or essential oil from the rhizome of *C. aromatica* exhibited antiinflammatory activity (Li, 1985; Jangde *et al*., 1998). *C. aromatica* is an important drug in Ayurveda possessing a wide range of beneficial advantages such as anticancerous activity, antidiabetic activity, antimicrobial activity, antifungal activity, antiinflammatory activity as well as mosquito repellent activity (Rao, 1976; Kim *et al.,* 2002; Madhu *et al.,* 2010; Saleem *et al*., 2011; Zawar, 2011; Jain *et al*., 2013; Liu *et al.,* 2014;).

The aromatic oils are popular for their medicinal and antiseptic properties and their fragrance. They are utilised in food preservation, embalment and as antimicrobial, analgesic, sedative, antiinflammatory and locally anesthetic remedies (Bakkali *et al*., 2008). *C. aromatica* has been applied for the treatment of prurigo, bruise, arthritis and gastrointestinal disorders (Pongboonrod, 1979). The rhizome of *C. aromatica* along with the seeds of *Terminalia chebula* made into paste is applied on the affected skin to cure impetigo (Jeeva *et al*., 2007).

Jeon *et al*. (2015) reveals that *C. aromatica* water extract protects against ethanol induced gastric mucosa injury by enhancing antioxidant status. *C. aromatica* water extract could be developed for the treatment of gastritis induced by alcohol. *C. aromatica* water extract decreased ethanol induced inflammation and loss of epithelial cells and enhanced the mucus production in the stomach. *C. aromatica* water extract lowered the increase in lipid peroxidation related with ethanol induced gastritis, enhanced mucosal GSH content, catalase activity and also increased the production of prostaglandin E2. Rhizome paste or powder is applied externally in scabies, leucoderma and smallpox. It is regarded useful in blood diseases and the

juice is given orally as a strong remedy against rheumatism. Also, the rhizome powder is mixed with juices of other gingers and provided for smooth delivery in North East India. *C. aromatica* rhizomes are used as tonic and carminative (Prakash and Mehrotra, 1996a; Prakash and Mehrotra, 1996b). Its rhizome paste mixed with milk is used in stomach ache and blood dysentery (Kulkarni *et al*., 2003).

Kojima *et al*. (1998) disclosed that in Japan, rhizomes of *C. aromatica* are considered as health food and also used in medicines as an emmenogogue, stomachic carminative and for skin diseases. Li *et al*. (2016) reported that the extracts had favourable cardio protective effects on iso-proterenol-induced acute ischemia and it may cause food drug interactions through potent inhibitory effect against cytochrome p450 by sesquiterpene 7 and curcuminoids 11 and 12 (Bamba *et al*., 2011). Saxena *et al*. (2009) revealed that the leaf extract of *C. aromatica* showed antinephrotoxic activity by modulating the renal dysfunction induced by arsenic trioxide in rats.

C. aromatica is never used as a spice but in indigenous medicine for external applications on skin diseases, sprains and bruises (Maheshwari and Singh, 1965). Khasi and Garo tribes of Meghalaya make the rhizome of *C. aromatica* into a paste and take with water to kill intestinal worms (Rao, 1981). In India this plant is used as an antidote to snake-bite, astringent, on bruises, corms and sprains (Jain *et al*., 1991). Xuan *et al*. (2013), examined the antagonist effect of *C. aromatica* on renal tubular epithelial-myofibroblast transdifferentiation (EMT) induced by transforming growth factor- β1, (TGF-β1). *C. aromatica* could inhibit the appearance of TGF-β1 promoted EMT. Therefore, it could be utilised as a potent drug for treating chronic renal insufficiency.

Dhal *et al*. (2011) observed that the catalase enzyme extracted from leaf samples can be used in the treatment of cardiovascular and

antiinflammatory diseases. The rhizome is an odoriferous ingredient of the cosmetics utilised for the cure of chronic skin diseases caused by impure blood. It is used as appetizer and tonic to women after childbirth. It is also useful against high fever and worm infestation. Rhizome extracts are used in combination with astringents and aromatics for hiccough, bruises, skin eruptions, sprains, bronchitis, leucoderma and cough (Warrier *et al*., 1994; Warrier *et al*., 1995).

The cardioprotective activity of various hydroalcoholic extracts of the rhizome of *C. aromatica* was evaluated in the rat model of acute myocardial ischemia (AMI). *C. aromatica* hydro alcoholic extracts possessed considerable cardio protective activity against AMI in rats. The 70% extracts possessed the strongest bioactivity. These results indicate that ethanol concentration in preparation of extracts of *C. aromatica* plays a significant role in the protective effect against AMI (Li *et al*., 2016). Revathi and Malathy (2013) reported that the paste made from the rhizome of wild turmeric is commonly used as a domestic remedy in head ache. Rhizome is used to get rid of still born baby from the womb (Saleem *et al.,* 2011). Curcumin isolated from the *C. aromatica* rhizome was the most potent antiplatelet compound as it inhibited AA-, collagen and ADP induced platelet (Janatan *et al*., 2008).

Three items from *Curcuma* plants are officially registered in the Chinese Pharmacopoeia, Yujin. Radix Curcumae, is the dry tubers of *C. aromatica*, *C. kwangsiensis*, *C. longa* or *C. zedoaria* collected in winter when the aerial part of the plant has withered. It is utilised as a sedative, choleretic and analgesic and in the treatment of hepatitis, menstrual disorders and epilepsy (Tang and Eisenbrand, 1992).

C. aromatica is a conventional Chinese herb for treating diseases with blood stasis (Bing *et al*., 2011). Raj (1975) described that the alcoholic

extract of rhizomes has adequate anthelmintic effect against human parasite large round worm (*Ascaris lumbricoides*). Rajiv *et al*. (2013) investigated the inhibition of hyperlipidemic atherosclerosis by *C. aromatica* and it was related with an increase in antioxidative activities and a decrease in plasma lipids was reported in Triton X-100 induced hyperlipidemic rat model.

C. aromatica rhizome extract was found to be effective against snake venom of viper (*Daboia russelli* and *Echis carinatus*) and cobra (*Naja kaouthia* and *Ophiophagus hannah*) venom both *in vivo* and *in vitro* (Alam, 2014). Aqueous extracts of the rhizomes are effective for curing indigestion, rheumatism and dysentery. The leaves are also used for healing wounds and fractured bones (Santhanam and Nagarajan, 1990; Saleem *et al.,* 2011). The plant is conventionally used for skin infections, gastrointestinal ailments, arthritic pain and insect bites. The use of rhizome extracts as components in several medicines by indigenous people is now being explored in phytopharmaceutical researches (Anoop, 2015).

2.3.12. Anticancer activity

Ar-turmerone, turmerone and curdione from *C. aromatica* oil possess anti proliferative effect on laryngeal cancer Hep-2 cells and the plant exhibits inhibitory effects on UVA mediated melanogenesis in G 361 melanoma cells (Tao *et al*., 2006; Panich *et al*., 2010). Kao *et al*. (2016) carried out a comparative study between the autumn *C. aromatica* essential oil and spring *C. aromatica* essential oil. The result explained that the autumn *C. aromatica* essential oil have more potent cytotoxicity than spring *C. aromatica* essential oil in non-small cell lung cancer. Autumn *C. aromatica* essential oil caused apoptosis through the cleavage and activation of caspases 3, 8, 9 and poly (ADP ribose) polymerase (PARP) in NCI-H1299 cells. After treatment with autumn *C. aromatica* essential oil, proapoptosis protein Bax expression increased and antiapoptosis protein Bcl-2 and Bcl-xL expression reduced.

Also, autumn *C. aromatica* essential oil could elevate tumour suppressor protein p53 expression, retard the phosphorylation of ERK1/2 and increase the phosphorylation of JNK1/2 and p38. These findings highlighted that the autumn *C. aromatica* essential oil induced apoptosis and had a possibility to become a novel functional food ingredient for the prevention and treatment of non-small cell lung cancer.

Curcuminoids extracted from the rhizomes of *C. aromatica* exhibited vigorous activity inhibiting both tumour cell invasion and migration in a concentration dependent manner (Siripong *et al*., 2002). Asolkar *et al*. (1992) revealed that *C. aromatica* rhizome oil is utilised for the treatment of early stage of cervix cancer. An intra-peritonial injection daily for 8 days containing *C. aromatica* as one of the components to adult mice with a hepatoma H22 ascites tumour prevented 87% of cancer (Anonymous, 2001). A combination of resveratrol from *Polygonam cuspidatum* and curcumin from *C. aromatica* is a promising novel anticancer strategy for liver cancer. It generated a synergistic anti proliferative effect and up regulated intracellular reactive oxygen species (ROS) levels in Hepa1-6 cells (Qin *et al*., 2013). Chang *et al*. (2007) found that zingiberene from the rhizome possess a remarkable potential to be used as a natural anticancer agent in nueroblastoma N2a-NB cells. Curcumin a significant antioxidant extracted from *C. aromatica* showed anticarcinogenic properties in a different variety of cell lines (Ruby *et al*., 1995; Jee *et al*., 1998; Deng *et al*., 2004).

Matsuda *et al*., (2011) elucidated that (-)-β-sesquiphellandrene showed antiinvasion effects in human fibrosarcoma HT1080 cells. B-elemene has antiproliferative effect on various cancer cell lines. It could retard the growth of laryngeal cancer Hep-2 cells *in vitro* and *in vivo* (Tao *et al*., 2006). *C. aromatica* has been detailed to exert numerous medicinal activities such as promoting blood circulation to remove blood stasis and for the treatment of

cancer (Shi *et al*., 1981). The infusion of oil via the hepatic artery has been proved to employ therapeutic effects in humans with primary liver cancer and rats with transplanted hepatoma (Cheng *et al*., 1999). Niyomploy *et al*. (2010) examined the antiproliferative activity of two comparatively abundant polysaccharide fractions called p11 and p21, and a much less common fraction p22 derived from the rhizomes of *C. aromatica*. p11 (100 µg/ml) could markedly induce human gingival fibroblast cells proliferation by 30%, whereas p21 (100 µg/ml) could significantly prevent gingival fibroblast cells proliferation by 92%.

Thippeswamy and Bharathi, (2006) described the potent antiangiogenic and proapoptotic properties of ethanolic extract of rhizome under *in vivo* condition that can be developed into a potential anticancer drug. Decreased incidences of intestinal metaplasia and esophagoduodenal anastomosis (EDA) were noticed in the EDA rats with *C. aromatica* oil treatment (Li *et al*., 2009). Polyxylulose from hot water soluble crude polysaccharide extract from the rhizomes can significantly prevent gingival fibroblast cells proliferation by 92% (Polypat *et al*., 2010). Curdione, one of the important element of *C. aromatica* plays a significant role in the CYP3A4 inhibitory activity and this activity might be stimulating the degradation of CYP3A4 (Hou *et al*., 2011). Curcumin from *C. aromatica* can induce apoptosis by modulation of bax/ bcl-2 in SMMC-7721 cells and therefore can act as an anticancer agent for human hepatomes. A sesquiterpene, β-elemene from *C. aromatica* rhizome is declared to have the ability to arrest proliferation and induce apoptosis in hepatoma HepG2 cells. The apoptosis induction is related with upregulating of Fas/Fas L expression (Jun *et al*., 2011; Dai *et al*., 2013).

Germacrone, one of the major bioactive components of the *C. aromatica* extracts can inhibit the proliferation of human glioma cells via

regulating the expression of proteins associated with apoptosis and G1 cell cycle arrest (Liu *et al*., 2014). Zhao *et al*. (2014) described *C. aromatica* oil as an effective antifibrosis medicine especially in early renal fibrosis stage. It also could decrease levels of lipid, acetoacetate, glucose, phosphorylcholine/choline, trimethylamineoxide and increase levels of glycine in the serum of the rats. So administration of the oil can improve renal fibrosis symptoms by preventing lipid metabolism, glycolysis and methylamine metabolism.

Dong *et al*. (1997) and Wu *et al*. (2000) reported that *C. aromatica* oil contains several major antitumour active ingredients were found in extracts including elemicin, curcumol, curdione, etc. and oil extract of *C. aromatica* has been exhibited to employ diverse medical activities such as promoting blood circulation to remove blood stasis and treating cancer. Liu *et al*. (2011) observed that β-elemene in the essential oil can protect against carbon tetrachloride (CCl_4) induced liver fibrosis in rats by down regulating the expression levels of plasma endotoxin, serum tumour necrosis factor α (TNF-α) and hepatic cluster of differentiation 14(CD14).

Kaushik *et al*. (2017) investigated the antitumor activity of the petroleum ether and ethanol extracts of *C. aromatica* rhizome in Swiss albino mice against Ehrlich Ascites Carcinoma (EAC) cell line and they found that ethanolic extract showed highly potent antitumour activity than petroleum ether extract. Aqueous extract of *C. aromatica* might be valuable as an antiproliferative herb for colon carcinoma. The antitumour activity of aqueous extract of *C. aromatica* may involve both extrinsic and intrinsic apoptosis, and induces G2/M phase arrest through down regulation of cyclin B1 and CDK1 and without the involvement of p53. Thus it has been considered as an anticancer herb in modern clinical practice (Bing *et al*., 2011).

2.3.13. Antidiabetic activity

Traditional medicinal plants are used all over the world for a range of diabetic complications. As the number of people with diabetes increases worldwide, the disease takes an ever growing proportion of national and international health care budget. Apart from currently available therapeutic options, many herbal medicines have been recommended for the treatment of diabetes (Nagappa *et al*., 2003). Nampoothiri *et al*. (2015) states that the rhizome extracts of *C. aromatica* have antidiabetic activity by inhibiting α-amylase. Toluene extract of *C. aromatica* possesses significant antioxidant and antidiabetic activity in both *in vitro* and *in vivo* models. Thus, *C. aromatica* can be used as an alternative herbal medicine in the treatment of diabetes and diabetic complications (Srividya *et al*., 2012).

The effects of *C. aromatica* on the pathologic events in streptozotocin treated diabetic rats was studied by Sato *et al*. (2006). Administration of streptozotocin increased plasma levels of cholesterol, creatinine, glucose, triglyceride, urea, nitrogen and lipid peroxidation products and reduced plasma albumin levels and arrested the growth of animals. When animals were given 1.5% *C. aromatica* containing diet for 1 week before and 8 weeks after administration of streptozotocin, all the events induced by streptozotocin except hyperglycemia decreased markedly. Therefore, *C. aromatica* may have therapeutic potential for the prevention of hyperglycemia associated diabetic complications.

2.3.14 Antioxidant activity

The rhizome extracts of *C. aromatica* were found to be effective antioxidant agents. Tsai *et al*. (2011) described high scavenging abilities of *C. aromatica* rhizome on 1,1-diphenyl-2-picrylhydrazyl (DPPH) by hot water and ethanolic extracts. The essential oil from the leaves showed significant

superoxide radical scavenging activities (Al-Reza *et al*., 2010). Srividya *et al*. (2012) stated that toluene extract of *C. aromatica* exhibited significant antioxidant activities in both *in vitro* and *in vivo* models. The sesquiterpenoids present in the volatile oil of *C. aromatica* function as antiinflammatory, antivirus, and antioxidation agents (Jiang *et al*., 2005). Ethyl acetate and dichloromethane extracts are reported to possess high antioxidant activity (Rachana and Venugopal, 2014).

The ethanol extracts of *C. aromatica* from India, which had higher total polyphenol content and strong radical scavenging activities, indicated relatively high Acetylcholin Esterase (AChE) inhibitory effect similar to that of *C. longa*. from Myanmar (Yeon *et al*., 2012). The dichloromethane extract of *C. aromatica* have maximum antioxidant potential and peculiar free radical quenching property (Nampoothiri *et al*., 2015). Dhal *et al*., (2011) first reported the concentration of catalase enzyme in the leaves of *C. aromatica*. The concentration of catalase enzyme in the leaves of *C. aromatica* was found to be 17µg/ml. *C. aromatica* is extensively used as cosmetics rather than for medicinal purposes as it has low therapeutic value pertaining to oxidative stress diseases. These antioxidants have been reported to inhibit oxidative damage caused by free radicals.

Ethanolic extract of the rhizome indicated good antioxidant properties and had the potential to be developed into nutraceuticals and dietary supplements (Tsai *et al*., 2011; YuLing *et al*., 2007). Therefore, the rhizome extracts and oil of *C. aromatica* could serve as principal bio-resource of antioxidants for use in food industries.

2.3.15. Hepatoprotective activity

Saxena *et al*. (2009) investigated the hepatoprotective activity of wild turmeric leaf extract in a white rat with liver injury originated by acute and

sub-acute arsenic trioxide intoxication. Treatment with hundred times diluted leaf extract at the rate of 1 ml/kg body weight brings back the altered biochemical profile of aminotransferases and total proteins to normalcy. The result revealed that wild turmeric leaf extract has hepatoprotective property against arsenic trioxide toxicity.

2.3.16. Antifertility activity

Traditionally the control of fertility in most parts of India is based on the uses of plant medicines for several years. *C. aromatica* is traditionally and conventionally used as an antifertility plant. Trishna *et al*. (2010) studied the antifertility activity of *C. aromatica*. Aqueous and ethanolic extract of *C. aromatica* at two different doses of 200 mg/kg and 400 mg/kg of body weight arrested pregnancy. The aqueous extracts were found to have more remarkable antifertility effect compared to alcoholic extract although the ethanolic extract at the lower dose of 200 mg/kg possessed more reduction in implants as compared to the higher dose of 400 mg/kg.

2.3.17. Antidepressant activity

C. aromatica has been used in the Chinese commercial medicine suyu-jiaonang, which can generate antidepressant like effects in chronic unpredictable stress induced depression (Mao *et al*., 2010).

2.3.18. Wound healing

Wound healing is a physiological process of restoration of tissue integrity and functional anatomy after an injury (Nagori and Solanki, 2011). It is a complex coordinated operation which includes 4 overlapping stages such as hemostasis, inflammation, proliferation and remodelling (Steencamp *et al*., 2004). Swamy *et al*. (2016) isolated a novel serine protease CAP-11 from *C. aromatica*, which has been demonstrated to stop bleeding and

commence wound healing through its procoagulant and fibrin(ogen)olytic activities. They explain the possible role of CAP-11 as therapeutic enzyme to arrest bleeding at the time of wounding. Protease plays an important role in stopping bleeding and enhancing wound healing process with relevance to haemostasis. This may give highlights on herbal and spice based therapeutical agent as a better choice in replacement of synthetic ones. This may also justify the molecular basis of conventional use of turmeric in ceasing bleeding and stimulating wound healing practiced by Indian folk medicine.

A comparative study was conducted by Swamy *et al*. (2015) on the procoagulant and fibrinogenolytic activity of crude protease fraction from various turmeric species such as, *C. aromatica*, *C. longa*, *C. caesia*, *C. amada* and *C. zedoaria*, to stop blood loss from wounds. Among these, *C. aromatica* showed potent procoagulant and fibrinogenolytic activity by hydrolyzing all the subunits of fibrinogen. Santhanam and Nagarajan (1990) explained that ointment of white soft paraffin containing 1% of powdered *C. aromatica* rhizome stimulates contraction of wound and epithelialisation. Kumar *et al*. (2009) also described that the dried rhizome ethanol extract of *C. aromatica* considerably improved wound contraction in rat excision wound model.

2.3.19. Antimicrobial activity

In view of increasing resistance to exciting antimicrobial factors, herbal medicines are being looked as very fundamental source to discover novel agents for treating various diseases related to bacterial inflammations. Aqueous extract of the rhizome revealed the antimicrobial activity against both gram negative bacteria (*Escherichia coli*, *Staphylococcus flexineria* and *Pseudomonas aeruginosa*) and gram positive bacteria (*Staphylococcus aureus*, *S. epidermis* and *Bacillus subtilis*) (Sharma *et al*., 2010). The plant has been utilising against different kinds of skin infections since time

immemorial. It is famous for its antimicrobial activity against several plant as well as human pathogens. Aqueous extracts of rhizomes revealed better antibacterial effect as compared to their ethanolic, methanolic and petroleum ether extracts against pathogens like *Bacillus subtilis*, *Staphylococcus aureus*, *S. epidermis*, *S. flexineria*, *Escherichia coli* and *Pseudomonas aeruginosa* (Smita *et al*., 2010).

C. aromatica oils also possess high inhibitory effect against *Staphylococcus aureus, Bacillus subtilis* and *Escherichia coli* bacteria (Nambisan *et al*., 2012). The hexane, chloroform, ethyl acetate, methanol and petroleum ether extracts of *C. aromatica* showed significant antibacterial activity against *Bacillus subtilis, Staphylococcus aureus*, *Listeria monocytogenes*, *Pseudomonas aeruginosa*, *Escherichia coli* and *Salmonella typhimurium*. Therefore, *C. aromatica* can be used as a natural preservative in food against causal agents of food borne diseases and food spoilage (Al-Reza *et al*., 2010). Ara *et al*. (2011) reported that the rhizome extract showed antibacterial activity against *Bacillus licheniformis*, *Micrococcus luteus* and *Salmonella typhimurium*, because of the presence of large phenolic contents.

Sharmin *et al*. (2013) reported potential antimicrobial activities of petroleum ether and chloroform extracts of *C. aromatica* against several human pathogenic bacteria including *Pseudomonas aeruginosa*, *Shigella sonnei*, *Shigella dysenteriae*, *Bacillus subtilis* and *Staphylococcus aureus*. It also exhibited quick killing activity, broad fungicidal spectrum, long shelf life and an edge over some synthetic antifungal compounds. The rhizome extract of *C. aromatica* is potent against numerous multi-resistant urinary tract infectious agents *Pseudomonas aeruginosa*, Vancomycin resistant *Enterococcus faecalis* (VRE), Methicillin resistant *Staphylococcus aureus* (MRSA) and *Escherichia coli* (Saleem *et al*., 2011). The hexane extract of the rhizome showed bactericidal activity against *Staphylococcus aureus*,

Streptococcus sp., *Enterococcus faecalis* and it was inactive against gram negative strains (Revathi and Malathy, 2013).

Hexane, dichloromethane and ethyl acetate extracts of rhizomes are reported to possess activity against *Staphylococcus aureus*, *Pseudomonas aeruginosa* and *Escherichia coli* (Rachana and Venugopalan, 2014). The oil has shown antimicrobial activity against *Staphylococcus aureus*, *Salmonella paratyphi*, *Erwinia cartovora*, *Pseudomonas solanacearum* and *Purpureocillium lilicinum* (Anonymous, 2001). Singh *et al*. (2000) isolated a compound curcumin from the rhizome of *C. aromatica* and subjected to antimicrobial experiments against bacteria (*Staphylococcus aureus*) and fungi (*Saccharomyces cerevisiae*). The compound was found to be particularly active against both bacteria and fungi.

Suresh *et al*., (2018) investigated the antibacterial activity of rhizome extracts of *C. aromatica* and *C. longa* from southern Western Ghats of Tamil Nadu, India, against bacterial human pathogens such as *Klebsiella pneumoniae*, *Escherichia coli*, *β-haemo streptococci*, *Salmonella typhii*, *Bacillus subtilis*, *Pseudomonas aeruginosa* and *Staphylococcus aureus*. Except *Pseudomonas aeruginosa*, all the pathogens were inhibited by different extracts (methanol, ethanol, n-butanol and acetone) of *Curcuma* spp. and was sometimes far superior than the control antibiotic Amoxicillin. *Pseudomonas aeruginosa* was hindered by n-Butanol extract of *Curcuma longa* as equal as standard antibiotic. Thus it is clearly elucidated that *C. aromatica* and *C. longa* collected from the wild exhibited higher antibacterial effect than that of standard antibiotics.

2.3.20. Antiinflammatory activity

The ethanolic extracts of *C. aromatica* and *Coscinium fenestratum* Colebr. were evaluated for antiinflammatory activity using the carrageenan-

induced rat paw edema method. The ethanolic extracts of both the plants and the standard diclofenac sodium exhibited significant antiinflammatory activity in terms of inhibition of paw edema. It was found that ethanolic extracts of *C. aromatica* was more potent than *Coscinium fenestratum* (Sudharshan *et al*., 2010).

2.3.21. Antifungal activity

Amritesh *et al*. (2011) revealed that *C. aromatica* oil exhibited potent antidermatophytic property and acted effectively against three common dermatophytic fungi viz, *Trichophyton rubrum*, *Epidermophyton floccosum*, and *Microsporum gypseum* causing ringworm infection in human beings. The volatile oil possesses antifungal activity against plant pathogens such as *Aspergillus terreus*, *Aspergillus niger*, *Fusarium moniliforme*, *Colletotrichum falcatum* and *Curvularia palliscens* (Gurdip *et al*., 2004). Bhagwat and Datar, (2014) declared that ethyl acetate extract of rhizomes of *C. aromatica* was also effective against three plant pathogenic fungi like, *Botrytis cinerea*, *Rhizopus stolonifer* and *Colletotrichum coccodes*.

The antifungal activities of ethanolic extracts of rhizomes of four *Curcuma* species such as *C. aromatica* (wild turmeric), *C. longa* (turmeric), *C. amada* (mango ginger) and *Curcuma caesia* (black turmeric) were studied by Harit *et al*. (2013). Ethanolic extract of *C. aromatica* and *C. longa* exhibited better antifungal properties than others. The volatile oil of wild turmeric showed good antifungal effect against, *Aspergillus terreus*, *Aspergillus niger*, *Fusarium moniliforme*, *Colletotrichum falcatum* and *Curvularia palliscens*. It was ineffective against *Fusarium oxysporum* and less effective against *Trichothecium roseum*. Also, the volatile oils of *C. aromatica* possess potent insecticidal behaviour (Gurdip *et al*., 2002b).

2.3.22. Antimosquito activity

Vector management has become critically laborious due to the development of resistance to traditionally used synthetic insecticides. Pitasawat *et al*. (2003) investigated mosquito repellent activities of *C. aromatica, C. aeruginosa* and *C. zanthorrhiza*. Only *C. aromatica* possessed repellency against *Aedes togoi*. It also contributed biting protection for 3.5 h when applied at a concentration of 25 g. The ethanolic extract of *C. aromatica* also exhibited protective effect against *Culex quinquefasciatus*, *Culex tritaeniorhynchus* and *Amigeres subalbatus*. The ethanol extract of *C. aromatica* did not cause dermal irritation when applied to human skin. No adverse effects on human volunteers were recorded 2 months after application. Thus, it is proved that *C. aromatica* extract can be used as an effective personal protection measure against mosquito bites.

Two larvicidal components namely 9-oxoneoprocurcumenol and neoprocurcumenol were isolated from *C. aromatica* and the efficacy of these compounds against the larvae of filariasis vector mosquitoes, *Culex quinquefasciatus* examined. Between the two, 9-oxoneoprocurcumenol possessed significant toxicity on mosquito larvae with LC50 value of 5.81 ppm and LC90 being 9.99 ppm compared to neoprocurcumenol with 13.69 and 23.92 ppm of LC50 and LC90 values respectively. Thus *C. aromatica* could be regarded as one of the powerful candidates to bring out appropriate botanicals so as to hinder the resurgence of the vector mosquitoes (Madhu *et al*., 2010). Certain elements of *C. aromatica*, such as curcumene, xanthorrhizol and 7-methanoazulene exert antimosquito activity (Choochote *et al*., 2005; Cao *et al*., 2006). Coconut oil and mustard oil based rhizome extracts were evaluated against mosquitoes by Das *et al*. (1999) and reported protection in both the cases at all the tested concentrations. The volatile oil

has insecticidal activity against *Odontotermes obesus* Rhamb. (white termite) from sugarcane fields (Gurdip *et al*., 2004).

2.3.23. Micropropagation

The optimized micropropagation method may provide large scale production of plantlets to meet commercial demand for the rhizome of this economically important plant. An improved and rapid micropropagation protocol was developed by Sharmin *et al*. (2013) for *C. aromatica* using rhizome sprout as the explants. The use of the cytokinin benzylaminopurine (BAP) either singly or in association with naphthalene acetic acid (NAA) for shoot induction and multiplication, use of BAP singly was found to be the most effective. As carbon source, 3% (w/v) sucrose possessed the greatest useful effect on shoot initiation and proliferation compared with other carbon sources applied. Among the basal media, full strength Murashige and Skoog (MS) medium produced the best results, compared to other media studied. By using the most effective treatment from each category, an average of 13.2 shoots per explants was produced after six weeks of culture. Furthermore 85% survival was attained when rooted explants acclimatised *ex vitro* utilising a mixture of sand, sterile soil and farmyard manure (1:1:1).

Effect of light and carbon source (sucrose) on *in vitro* microrhizome induction of wild turmeric was examined by Shameena and Reghunath (2013). Seven per cent sucrose was found to be the most appropriate for microrhizome induction when incubated under a photoperiod of 8 h light and 16 h darkness. Benjamin *et al*., (2010) cultivated rhizome segments of *C. aromatica in vitro*. A mixture of Benzyl Adenine and Indole Acetic Acid yielded about 12 shoots per explant with roots on Murashige and Skoog medium. 85% plantlets were successfully established to the field conditions.

Wu *et al*. (2014) showed that a 5% sucrose medium supplemented with 3.0 mg/L of 6-BA and 0.5 mg/L of NAA promoted the levels of curcuminoids and curcumin in *C. aromatica* and exposure to red light further enhanced the production. Anand and Molly (1999) cultured an excised section from young rhizome buds of *C. aromatica* on MS medium supplemented with various concentrations and combinations of growth regulators. The presence of NAA (1 mg/litre), 2,4-D (1.5 mg/litre) and BAP (benzyladenine) (0.5 mg/litre) together in MS medium triggered callus growth from young rhizome. Organogenesis and plantlet formation were obtained when 2,4-D and NAA were replaced with gibberellic acid (0.5 mg/litre) and IAA (0.5 mg/litre) in addition to BAP (1 mg/litre) in MS medium. An increased rate of regeneration was observed in the medium containing 0.5 mg IAA+1.5 mg BAP/litre. The plantlets produced extensive root system in the same medium and were successfully transferred to soil with about 80% success.

2.3.24. Molecular characterization

A novel procedure for the identification of *C. aromatica* and *C. longa* called 'loop-mediated isothermal amplification (LAMP) based on trnK gene sequences was developed by Sasaki and Nagumo (2007). It enabled not only identification but also detection with high specificity. This convenient, rapid, sensitive and specific method is expected to be applicable to the recognition of the botanical identity of commercially available herbal products.

Zaveska *et al*. (2011) analysed the intra-populational genetic variability in *Curcuma* species with the use of AFLP. They found that the hexaploid species have significantly higher genetic diversity than higher polyploids and it is largely induced by the mode of reproduction since the higher polyploids reproduce vegetatively while the hexaploid species mainly reproduce sexually.

Nambisan *et al*. (2008) assessed genetic variability in starchy *Curcuma* species using Random Amplified Polymorphic DNA (RAPD) technique. The RAPD pattern generated by 20 primers unveiled a high degree of polymorphism. All the species were differentiated into 3 clusters using UPGMA. *C. aromatica*, *C. brog* and *C. leucorrhiza* formed a cluster with which *C. longa* and *C. zedoaria* formed a subgroup. *C. harita* was genetically different from all the other *Curcuma* species. Because it is tough to separate dissimilar species by leaf morphology, the RAPD pattern has high benefit in the identification of starchy *Curcuma*. *C. aromatica* along with *C. longa*, *C. amada*, *C. latifolia*, *C. anguistifolia*, *C. aeruginosa*, *C. comosa*, *C. zanthorrhiza*, *C. mangga*, *C. leucorhiza*, *C. rubescens*, *C. viridiflora* and *C. zedoaria* are grouped in to 'Longa' group based on morphological characters during their taxonomic studies on the genus *Curcuma* in Thailand (Sirirugsa *et al*., 2007).

2.3.25. Genetic diversity studies

Luiram *et al*. (2018) interprets that the creation of genetic variability, variation in heritability and the expected genetic gain forms the basis for plant breeding. The availability of genetic variability among population is most important for judicious selection and breeding of desired plant genotypes in any future crop improvement programme. In order to protect the genetic resources and get consistent variability, genetic studies on morphological and other characters of agronomically important plants are crucial. Major studies on the members of the genus *Curcuma* and some related genera with emphasis on *C. aromatica* are presented below.

Jayasree, (2009) analysed character association, genetic variability and genetic divergence in *Kaempferia galanga* and *C. amada* to find out the best performing genotypes from them. In the case of *K. galanga*, the highest coefficient of variation was shown by number of leaves followed by leaf area.

Phenotypic coefficient of variation (PCV) was higher than genotypic coefficient of variation (GCV) in all the characters. Among the yield characters, the highest PCV was shown by yield per plant followed by number of secondary fingers and the lowest PCV was shown by diameter of rhizome. Among the growth characters, the highest GCV and PCV were shown by number of leaves. As a result of cluster analysis, 8 clusters were obtained from 50 accessions of *K. galanga*. In the case of *C. amada*, the agronomic characters exhibited continuous frequency distribution. PCV was higher than GCV and the highest genetic advance was shown by yield per plant in the case of yield characters and leaf area in the case of growth characters.

Yield characters and seven yield contributing characters in *C. longa* were studied by Yadav and Singh (1996). Significant variability was shown by all the characters except leaf width. Plant height and yield per plant showed wide range of variations. The genetic variability and heritability of yield components in 65 accessions of *C. longa* grown in Himachal Pradesh, India was examined by Singh *et al*. (2003). Lynrah *et al*. (1998) described the pattern of variability in 25 accessions of *C. longa*. High genetic variation and broad sense heritability was shown by curcumin content, tillers per clump and mother and finger rhizome yield. Yield per plant and curcumin content exhibited negative correlation. The genetic variability, character association and path coefficient analysis in 32 divergent genotypes of *C. longa* were evaluated by Prajapati *et al*. (2014). The characters like weight of mother rhizome per plant, weight of primary rhizome per plant and weight of secondary rhizome per plant were identified as the significant characters in the genetic improvement of *C. longa* with respect to rhizome yield.

Mishra *et al*. (2015) described that considerable amount of natural and genetic variability were observed among 65 germplasm accessions of *C.*

longa. Broad sense heritability was high for fresh weight of rhizome. Fresh weight of rhizome showed the highest PCV and PCV was higher than GCV. Path coefficient analysis disclosed that the highest direct contribution to rhizome thickness was made by dry weight of rhizome.

Soorya *et al*., (2016) analysed the genetic variability and genetic control of the important morphometric characters of *C. aeruginosa*. All the fifteen morphometric characters studied showed continuous distribution indicating their polygenic control. Among the yield characters length of primary finger and length of secondary finger showed a balanced distribution of genotypes, number of primary fingers, number of secondary fingers, diameter of primary finger, length of mother rhizome and yield per plant showed skewness towards the assembly of higher number of recessive factors and diameter of primary finger and diameter of secondary finger showed skewness towards the assembly of dominant contributing factors. Among the growth characters, plant height, leaf length, leaf breadth and leaf area exhibited accumulation of higher number of dominant alleles in their gene pool and number of tillers and number of leaves per tiller showed greater accumulation of recessive factors.

The occurrence of genetic base and also the feasibility of selection of superior genotypes in arrowroot (*Maranta arundinacea*) based on the characters that possess broad range of genetic variation have been reported. The highest range of performance was exhibited by yield per plant and followed by starch content and leaf area. The lowest range of performance was recorded for diameter of primary fingers. Wide range of characters indicates the participation of higher number of contributing alleles and greater involvement of environmental factors in the expression of the characters while narrow range stipulates the participation of lower number of contributing alleles and lesser involvement of environment. The highest

heritability was exhibited by starch content, which was followed by plant height and yield per plant. Genetic advance was found to be the maximum for starch content followed by number of primary fingers and number of tillers. The results indicate the occurrence of broad genetic base in the case of the Indian arrowroot populations studied and also the feasibility of selection of superior genotypes in *M. arundinacea* based on the characters that possess broad range of variation (Shintu *et al*., 2016).

Mourya *et al*. (2018) experimented with twenty two genotypes of *C. longa* collected from different regions under field condition. The characters such as number of tertiary rhizomes per plant, number of secondary rhizomes per plant, weight of primary rhizome, number of primary rhizomes per plant, weight of fresh rhizome per plant and number of tillers per clump showed high genotypic and phenotypic coefficient of variation. The phenotypic coefficient of variation was superior to genotypic coefficient of variation, which designates possibility of obtaining very high selection response in respect of these traits. The presence of high heritability in broad sense was found for most of the characters except oleoresin content. High heritability coupled with high genetic advance was recorded for all the characters except oleoresin content and dry matter percent, which indicated wide scope for improvement through selection of these traits

Meena *et al*. (2016) reported that significant mean square of accessions for all the traits examined indicates the existence of adequate genetic variability among the accessions. They observed high genotypic and phenotypic variances in the case of weight of rhizomes per plant, weight of primary rhizomes per plant, weight of secondary rhizomes per plant, rhizome yield, days to maturity and dry matter recovery while, low values were observed in the case of primary rhizomes per plant and diameter of primary rhizome. High genotypic variance indicates higher contribution of genetic

components for total variation. Thus, these traits could be utilised for selection purposes, whereas, high phenotypic variance stipulate strong effect of environmental factors during the growth period in their expression. Character association analysis disclosed that rhizome yield showed highly significant and positive association with plant height, number of tillers per plant, number of leaves per plant, weight of rhizomes per plant, length of primary rhizome and dry matter recovery. The highest positive direct impact on rhizome yield was exerted by plant height. Multivariate analysis enabled an effective study of genetic divergence and the grouping of the 25 accessions into six clusters. The highest inter-cluster distance occurred between cluster II and IV and hence accessions from these clusters can be used as potential parents for further breeding programmes.

Salimath *et al*., (2017) studied the genetic variability, heritability and genetic advance of nineteen turmeric genotypes. High heritability was recorded for the growth characters such as plant height, number of leaves per plant, number of tillers per plant and petiole length. High heritability observed for the yield characters such as number of mother rhizomes, number of primary fingers, number of secondary fingers, weight of mother rhizome, weight of primary rhizome, weight of secondary finger, length of mother rhizome, fresh rhizome yield per hectare, length of primary finger, fresh rhizome per plot and length of secondary finger suggesting that selection will be effective for these characters.

Thirty two genotypes of turmeric (*C. longa*) from all the north eastern states of India along with Duggirala Red as check variety were examined to study the genetic parameters in respect of yield and yield attributing characters by Luiram *et al*. (2018). Fifty three traits were studied for PCV, GCV, heritability and expected genetic advance at 5 per cent selection intensity. The experiment unveiled the presence of significant genetic variability and moderate to high heritability along with good genetic advance.

Kumar *et al*. (2000) conducted a field survey on the impact of mineral nutrient composition on curcumin content of rhizomes in 10 cultivars of *C. aromatica* and *C. longa*. Nitrogen (N), Manganese (Mn) and Zinc (Zn) components of rhizomes had a positive significant correlation with curcumin content, while the contents of Phosphorus (P), Calcium (Ca), Magnesium (Mg), Sulphur (S), Copper (Cu) and Iron (Fe) had no significant correlations with curcumin content.

C. aromatica is an important medicinal herb and there are no high yielding varieties released yet. Evaluation and characterization of the germplasm is beneficial to find out the qualitative and quantitative characters useful for breeding programmes. This study will help to assess the genetic variability of the germplasm and confirm the presence of any genetic variability accountable to yield, an essential character in a breeding programme (Virmany *et al*., 1983; Hakim, 2013).

Chapter III
MATERIALS AND METHODS

Curcuma aromatica Salisb. is one of the most valuable medicinal plants belonging to the ginger family Zingiberaceae. It is mentioned as *vanaharidra* and *aaranyaharidra* in Ayurveda. The plant is a promising ayurvedic drug in the field of cosmetics and pharmaceuticals and there are no high yielding varieties released so far. Scientific attempts to study its genetic variability, genetic diversity and crop improvement programmes reported are very rare. Therefore, the present experiments were designed to study the genetic variability, genetic control and variation of agronomic morphometric characters, character association and genetic divergence with reference to the germplasm collected for the purpose from different locations of Kerala State, India. Experiments were also carried out to identify superior genotypes from the different accessions of *C. aromatica* based on the overall performance. Also, an effort has been made to evaluate the performance of plants based on the status of planting materials used. The experimental programmes were designed and carried out from 2015 to 2018 in the experimental plot of Department of Botany, University of Calicut, Kerala, India.

3.1. The experimental material

Wild turmeric (*Curcuma aromatica* Salisb.), a threatened medicinal plant credited with numerous cosmetic and medicinal properties formed the experimental material (Fig. 3.1). It is a perennial erect herb. The whole plant is about 70-100 cm tall with large greyish yellow aromatic rhizome which is the economically important part. Root fibres are not ending in tubers. Leaves are pale green, densely pubescent below, distichous with lanceolate and with acuminate lamina. Inflorescence is a spike. Peduncle is 5-8 cm long and is covered by sheaths. Coma bracts are large, pink and spreading. Fertile bracts

are up to 6 cm long, tips re-curved, slightly hairy on upper surface and pale greenish white in colour. Bracteoles are white and sparsely pubescent. Calyx is short and cylindrical. Corolla tubes are funnel shaped and just exceeding the calyx, lobes are unequal, dorsal lobes broadly ovate, arching over the anther and hooded whereas lateral lobes are narrower and oblong. Labellum is obscurely 3 lobed, orbicular and deep yellow. Lateral staminodes are petalloid, oblong and obtuse and as long as the corolla lobes. Anther thecae are parallel, each ending in a long sharp spur at the base. Style is long and filiform. Stigma is two lobed with a perforation in the centre. Ovules are many with axile placentation. Fruit is a 3 valved capsule (Sabu, 2006; Fischer, 2013).

3.2. The experimental plot

The present investigation was conducted in the experimental plot of the Genetics and Plant Breeding Division of Department of Botany, University of Calicut, Kerala, India. The experimental plot is located at $11^0 25' - 11^0 45'$ N latitude and $75^0 45' - 75^0 50'$ E longitude in the Malappuram District of Kerala (Umamaheswari and Mohanan, 2011). The area has got tropical monsoon climate with southwest monsoon rains from June to September, northeast monsoon rains in October-November and dry spell from December to May with summer showers in March, April and May (Tables 3.1 to 3.4). Annual rainfall is about 2127 mm and average temperature varies from 24.99^0C-34.61^0C (Anonymous, 2018).

Table 3.1. Weather data of the experimental plot for 2015.

Months	Rainfall (mm)	Temperature (^{0}C)		Relative humidity (%)	
		Minimum	Maximum	Minimum	Maximum
January	7.20	19.66	36.66	36.16	89.16
February	1.50	21.83	40.50	24.50	81.83
March	27.10	23	39.83	29	89.50
April	54.20	25	38.83	38.83	89.16
May	119.40	24.83	36.66	80.83	95.33
June	755	23.16	34	60.16	92.50
July	279.20	22.50	38.83	60.66	94.50
August	155.10	22.16	33.66	56.33	96.33
September	209.20	22.66	34.33	54.33	97
October	188.20	23.16	35.33	49.33	94.66
November	243.20	22.66	34	58	95.50
December	107.10	22.83	36.33	44.83	91.33
Yearly value	2146.40	22.78	36.58	49.41	92.23

Table 3.2. Weather data of the experimental plot for 2016.

Months	Rainfall (mm)	Temperature (^{0}C)		Relative humidity (%)	
		Minimum	Maximum	Minimum	Maximum
January	6.70	24	35	45.50	76.66
February	5.90	24.83	35.17	52.16	81.16
March	3.80	26.17	36.17	55.16	83.83
April	6	26.83	37	59.33	82.33
May	152.30	27.17	36.83	60.50	69.66
June	787.60	25.13	32.17	73.33	86.83
July	651.60	25.17	31.83	77	87.30
August	224.60	24.67	32.50	71	85.33
September	99.60	24.33	33.17	68.33	86.16
October	91.90	23.50	34.67	66	88
November	40.60	24.67	35.83	62.33	85.16
December	56.40	23.50	35	55.66	84
Yearly value	2127	24.99	34.61	62.19	83.03

Table 3.3. Weather data of the experimental plot for 2017.

Months	Rainfall (mm)	Temperature (^{0}C)		Relative humidity (%)	
		Minimum	Maximum	Minimum	Maximum
January	32.70	23.17	35.17	47	78.16
February	1.80	23	35.33	56.5	81.16
March	26.30	25.50	35.67	56.66	81.50
April	19.80	26.50	36.50	64	85.50
May	208.10	26.67	32.17	66.83	87.16
June	647.80	25	27.50	88.33	92.83
July	361.70	25.17	33	68.66	83.66
August	459	25.83	32.50	75.33	86.66
September	226.2	25.67	29.83	71.66	87.50
October	213	24.67	29.50	71.83	89.16
November	237.90	25	30.83	64	85.83
December	35.90	24.17	29.67	63	83.66
Yearly value	2470.2	25.02	32.30	62.27	78.64

Table 3.4. Weather data of the experimental plot for 2018.

Months	Rainfall (mm)	Temperature (^{0}C)		Relative humidity (%)	
		Minimum	Maximum	Minimum	Maximum
January	1.90	22.16	29.83	51	77.33
February	3.20	22.66	31.66	49.50	77.50
March	56	24.50	32.83	55.16	83.83
April	41.40	25.66	32	60.66	88.33
May	344.30	26	31.16	63	85.16
June	546.01	24.66	28	74.83	87.50
July	54.46	24.16	27	80.33	89
August	66.72	23.66	26.83	78.66	89.83
September	95.81	23.83	29	63.16	89.16
October	170.79	24	29.33	69.50	88.33
November	104.27	23.66	30.16	59	84
December	81.30	23.50	30.16	57	85.50
Yearly value	1566.16	24.04	29.83	63.48	85.46

Fig. 3.1. *Curcuma aromatica*- single plant, inflorescence and rhizome.

a. Single plant; b. Abaxial side of the leaf; c. Inflorescence; d. Flower; e. Rhizome; f. Rhizome CS; g. Dry rhizome powder.

3.3. The experimental programme

Sixty two accessions of *C. aromatica* were collected from different locations across the length and breadth of Kerala. The experimental programmes were designed and carried out from 2015 to 2018, to evaluate the genetic diversity of the experimental plant and to identify superior genotypes from the germplasm collected from different places of Kerala. All the collected accessions were planted in a screening plot during the crop season of 2015 and sufficient planting materials were raised. The experiments were carried out during the first crop seasons of 2016, 2017 and 2018 adopting standard cropping procedure. The experiment was laid out in randomized block design (RBD) with three replications in polybags under open conditions (Fig. 3.2). The details of the accessions collected and the places of collection are given in Table 3.5 and Fig. 3.3.

Table 3.5. Accessions of *Curcuma aromatica* studied.

Accession Number	Source	District	Latitude & Longitude
CUK 1	Nellikunnu	Thrissur	$10^0$31’54”N $76^0$14’40”E
CUK 2	Kottakkal	Malappuram	$10^0$59’55”N $76^0$00’05”E
CUK 3	Peruvannamuzhi	Kozhikode	$11^0$36’10”N $75^0$49’28”E
CUK 4	Puliyilapara	Thrissur	$10^0$18’42”N $76^0$37’56”E
CUK 5	Kumali	Idukki	$09^0$36’19”N $77^0$10’11”E
CUK 6	Pokalapara	Thrissur	$10^0$18’08”N $76^0$36’43”E
CUK 7	Muthanga	Wayanad	$11^0$40’19”N $76^0$22’07”E
CUK 8	Kurishupara	Idukki	$09^0$51’35”N $76^0$59’56”E
CUK 9	Villunniyal	Malappuram	$11^0$07’50”N $75^0$53’19”E
CUK 10	Audit 1	Idukki	$09^0$48’13”N $76^0$50’56”E
CUK 11	Kundalamtheru	Kozhikode	$11^0$28’51”N $76^0$01’27”E

CUK 12	Mukkam	Kozhikode	$11^0$19’09”N $75^0$59’46”E
CUK 13	Thoppipala	Idukki	$09^0$44’17”N $77^0$03’24”E
CUK 14	West Manasseri	Kozhikode	$11^0$18’26”N $75^0$58’08”E
CUK 15	Meenkunnam	Ernakulam	$09^0$55’48”N $76^0$34’35”E
CUK 16	Dhottapankulam	Wayanad	$11^0$39’37”N $76^0$14’33”E
CUK 17	Vetilapara	Thrissur	$10^0$17’24”N $76^0$30’53”E
CUK 18	Cheruthoni dam top	Idukki	$09^0$50’36”N $76^0$58’54”E
CUK 19	Maradi	Ernakulam	$09^0$57’27”N $76^0$33’40”E
CUK 20	Anakkayam	Thrissur	$10^0$17’46”N $76^0$41’01”E
CUK 21	Odakkali	Ernakulam	$10^0$05’44”N $76^0$33’22”E
CUK 22	Thankamani	Idukki	$09^0$50’50”N $77^0$02’00”E
CUK 23	Vazhara waterfalls	Idukki	$09^0$47’47”N $77^0$03’43”E
CUK 24	Sholayar (Thottupura)	Thrissur	$10^0$18’12”N $76^0$46’07”E
CUK 25	Vazhachal	Thrissur	$10^0$18’14”N $76^0$35’42”E
CUK 26	Narakakkanam	Idukki	$09^0$50’20”N $76^0$59’50”E
CUK 27	Mariyapuram	Idukki	$09^0$51’17”N $76^0$59’23”E
CUK 28	Kalkkandi	Palakkad	$11^0$03’58”N $76^0$33’11”E
CUK 29	Palakkal	Kozhikode	$11^0$12’19”N $75^0$47’34”E
CUK 30	Pambla	Idukki	$09^0$57’13”N $76^0$58’28”E
CUK 31	Mukkali	Palakkad	$11^0$03’12”N $76^0$32’21”E
CUK 32	3rd mile, Kumali	Idukki	$09^0$38’02”N $77^0$09’45”E
CUK 33	Vazhikadav	Malappuram	$11^0$23’14”N $76^0$21’16”E
CUK 34	Kunduthod	Malappuram	$11^0$13’46”N $76^0$09’27”E

CUK 35	Mathamangalam	Wayanad	$11^0$39’02”N $76^0$19’03”E
CUK 36	Kukupadi	Palakkad	$11^0$03’52”N $76^0$32’53”E
CUK 37	Nadukani churam	Malappuram	$11^0$25’38”N $76^0$23’00”E
CUK 38	Kuppadi	Wayanad	$11^0$40’59”N $76^0$16’04”E
CUK 39	Koravankandi	Palakkad	$11^0$05’12”N $76^0$35’37”E
CUK 40	Thavalam	Palakkad	$11^0$05’15”N $76^0$35’28”E
CUK 41	Mannuthi	Thrissur	$10^0$32’41”N $76^0$16’37”E
CUK 42	Kangazha	Kottayam	$09^0$30’57”N $76^0$41’34”E
CUK 43	Tholpetti	Wayanad	$11^0$56’45”N $76^0$03’52”E
CUK 44	Kalpetta	Wayanad	$11^0$36’03”N $76^0$04’54”E
CUK 45	Thookupara	Idukki	$10^0$01’16”N $77^0$01’24”E
CUK 46	Chambakkara	Kottayam	$09^0$30’40”N $76^0$37’39”E
CUK 47	Mailamood	Kottayam	$08^0$45’21”N $77^0$00’06”E
CUK 48	Palaruvi	Kollam	$08^0$56’40”N $77^0$09’35”E
CUK 49	Chippanchira	Thiruvananthapuram	$08^0$45’10”N $77^0$01’17”E
CUK 50	Kulathupuzha	Kollam	$08^0$54’33”N $77^0$03’32”E
CUK 51	Madathara	Thiruvananthapuram	$08^0$48’58”N $77^0$00’41”E
CUK 52	West Maradi	Ernakulam	$09^0$56’45”N $76^0$32’46”E
CUK 53	Mannur	Ernakulam	$10^0$02’33”N $76^0$32’13”E
CUK 54	Poothankuti	Ernakulam	$10^0$16’03”N $76^0$25’55”E
CUK 55	Manjikadu	Ernakulam	$10^0$14’48”N $76^0$25’48”E
CUK 56	Matnampadi	Kottayam	$9^0$33’57’’N $76^0$42’33’’E
CUK 57	Poovakulath	Kottayam	$09^0$50’36”N $76^0$37’35”E

CUK 58	Mangalasseri	Kannur	$12^0$02’04”N $75^0$19’54”E
CUK 59	Edathwa	Alappuzha	$09^0$22’07”N $76^0$27’43”E
CUK 60	Thuruthikkad	Pathanamthitta	$09^0$24’54”N $76^0$39’43”E
CUK 61	Vazhoor	Kottayam	$09^0$33’32”N $76^0$42’15”E
CUK 62	Pallikathod	Kottayam	$09^0$36’19”N $76^0$40’50’’E

3.4. Planting and aftercare

The evaluation trials and other experiments were started in the first cropping season of 2016 in the first week of May before the onset of south west monsoon. Healthy rhizomes each of about 4 cm-7 cm length and 25 g-30 g weight were used as the planting material. The seed rhizomes were planted in 38 cm × 35 cm polybags filled with garden soil, sand and enriched compost in 3:1:1 ratio. Irrigation was carried out once a day on all non-rainy days and weeding was done as and when required. 2 g of NPK (18:18:18) was added at monthly intervals starting from the 30^{th} day of planting up to the 5^{th} month of growth. The plants were harvested simultaneously after 8 months of growth. Recommended package of practices and plant protection measures were followed to raise a healthy crop (KAU, 2011).

3.5. Data recording

Each accession was planted in three replications and each plot included of 18 plants. Data were taken from 9 plants each and averaged. The data on growth characters were observed at the end of six months after planting and the data on yield characters were recorded after the harvest by destructive sampling method (Table 3.6.). Leaf area was calculated from leaf length and leaf breadth using the formula:

Leaf area = leaf length × leaf breadth × conversion factor.

Fig. 3.2. *Curcuma aromatica* in the experimental layout.

Fig. 3.3. Different locations of collection of *Curcuma aromatica*.

The conversion factor for leaf area was calculated as given in Table 3.7. To find out the conversion factor, area of five leaves was measured randomly and the mean was calculated.

Table 3.6. Characters of *Curcuma aromatica* observed in the present study.

Sl. No.	Character
Growth characters	
1	Plant height(cm)
2	Number of tillers
3	Number of leaves per tiller
4	Leaf length (cm)
5	Leaf breadth (cm)
6	Leaf area (cm^2)
Yield characters	
7	Number of primary fingers
8	Length of primary finger (cm)
9	Diameter of primary finger (cm)
10	Number of secondary fingers (cm)
11	Length of secondary finger (cm)
12	Diameter of secondary finger (cm)
13	Length of mother rhizome (cm)
14	Diameter of mother rhizome (cm)
15	Yield per plant (g)

Table 3.7. Calculation of conversion factor for leaf area.

Species	Conversion factor for leaf area					
C. aromatica	R1	R2	R3	R4	R5	Mean
	0.59	0.60	0.60	0.60	0.61	0.60

3.6. Genetic variability

Variability in plant genetic resources gives an opportunity for plant breeders to develop novel and improved cultivars having desirable characteristics. Therefore, genetic variability has been widely exploited in the agricultural field. A population with high genetic variability has more fitness as it survives and flourishes better than those that possess less variability under different environmental conditions and climate change. Genetic variability studies of a germplasm are crucial for making effective selection of superior breeding material. Hence, genetic variability of *C. aromatica* populations in the study area has been investigated presently using standard statistical tools.

3.6.1. Genetic control of agronomic characters

The experimental material for this study consisted of 547 plants raised from the germplasm of *C. aromatica* collected from different locations of Kerala. Observations on all the growth and yield characters were recorded. The data were pooled and subjected to frequency distribution analysis so as to investigate the nature of genetic control of characters and also the distribution pattern of dominant and recessive contributing factors in the case of each agronomic character in the pooled population.

3.6.2. Phenotypic and genotypic variability

The success of selecting highly potential genotypes in plant breeding programme rely on the nature and extend of phenotypic and genotypic variability. Phenotypic and genotypic variability of *C. aromatica* has been studied based on the agronomic characters of the experimental population during 2016, 2017 and 2018. The experimental population was raised in Randomised Block Design with 62 accessions, three replications per accession and 18 plants per plot.

Variation within population and between populations was evaluated and analysis of variance (ANOVA) carried out to reveal the significant differences existed between the accessions in terms of the fifteen morphometric characters studied presently. F value was calculated for the purpose and its significance was tested with reference to standard F table (Fischer and Yates, 1963). Critical Difference (CD) was found out with the formula:

$$CD = t_{0.05} \times \sqrt{\frac{2VE}{r}}$$

Where $t_{0.05}$ = t at error degree of freedom at 5% level, VE = Error mean square and r = Number of replications.

Genotypic and phenotypic variance of the different characters studied was calculated as per Singh and Choudhary (1985) using the following formula:

$$\text{Genotypic variance } (\sigma^2 g) = \frac{\text{MSS for treatment - MSS for error}}{\text{Number of replications}}$$

$$\text{Phenotypic variance } (\sigma^2 p) = \sigma^2 g + \sigma^2 e$$

where $\sigma^2 e$ = Error variance.

Phenotypic and genotypic coefficients of variation of the agronomic characters studied were calculated as per Burton and Devane (1953). Since different traits are examined in different units, coefficients of variation are useful for comparing their relative variability (Stansfield, 1991).

$$\text{Phenotypic coefficient of variation (GCV)} = \frac{\sigma p}{\bar{x}} \times 100$$

Where σp = Phenotypic standard deviation and $\bar{x}$ is the grand mean of the character.

Genotypic coefficient of variation (GCV) = $\frac{\sigma g}{\bar{x}} \times 100$

Where σg = Genotypic standard deviation.

3.6.3. Heritability of agronomic characters

Estimates of heritability not only offer an indication of the degree of transmissibility of a specific character but also show the effectiveness of selection (Shukla *et al*., 2006; Asfaw *et al*., 2017). The parameter of heritability (broad sense) involves all types of gene action and thus forms a broad estimate of heritability (Chahal and Gosal, 2002). It is the fraction of the total variance that is heritable and is estimated as the percentage of genotypic variance over phenotypic variance (Jain, 1982). The information about the heritable characters of a species helps a plant breeder to predict the behaviour of succeeding generations and guides him to predict the response to selection (Ul-Haq *et al*., 2008).

Heritability (broad sense) = $\frac{\sigma^2 g}{\sigma^2 p} \times 100$

Where $\sigma^2 g$ = Genotypic variance and $\sigma^2 p$ = Phenotypic variance.

3.6.4. Genetic advance under selection

Generally, traits that display high genetic advance along with high values of heritability could possibly suggest that when selected together they might lead to improved yield. Therefore, using high heritability (broad sense) coupled with higher genetic advance is more preferred. Genetic advance is the extent of genetic improvement of the progeny possible through selection over the original population (Chahal and Gosal, 2002). Genetic advance is estimated as per Singh and Choudhary (1985).

Genetic Advance (GA) = $\frac{KH^2\sigma p}{\bar{x}}$

Where H^2= Heritability (broad sense), K= Selection differential which is 2.06 at 5% intensity of selection in large samples and σp= Phenotypic standard deviation (Allard, 1960).

3.7. Genetic divergence

Study of genetic divergence between the 62 accessions of *C. aromatica* was carried out by principal component analysis using the statistical software STATISTICA following Unweighted Pair Group Method with Arithmetic mean (UPGMA) as per Sneath and Sokal (1973).

3.8. Correlation of agronomic characters

Correlation studies measure the mutual relationship between different agronomic characters and determine the component characters on which the selection is based for genetic improvement for a particular character. To find out the interrelationship among the fifteen agronomic characters, correlation coefficients were worked out presently by adopting the method described by Rangaswamy (1995). Correlation coefficients indicated the direction and intensity of interrelationship of characters under study.

3.9. Character association

Factor analysis by means of principal component analysis has been done for the purpose presently using the statistical software STATISTICA based on the fifteen growth and yield characters. The morphometric characters of a species show different levels of associations between them. Study of association of characters is carried out for grouping of variables and data reduction so as to find out the lead characters that can be used in selection procedures in plant breeding programmes.

3.10. Performance analysis of the accessions collected

Based on the six growth and nine yield characters of *C. aromatica* under study, comparative performance of the different accessions has been evaluated with the help of performance indices calculated for each agronomic characters according to Amaravenmathy and Srinivasan (2003).

$$\text{Performance index} = \frac{\text{Accession mean of the character}}{\text{Grand mean of the character}}$$

3.11. Study of the performance of *Curcuma aromatica* Salisb. populations based on the status of the planting materials used

An experiment was designed to investigate the variation in yield of this crop in relation to the status of the planting material used so as to study the possibility of using mother rhizomes, primary fingers and secondary fingers as the planting material. The three types of seed materials collected from the germplasm of *C. aromatica* maintained at University of Calicut were used to raise populations consisting of 60 plants for each type of seed material. The plants were raised from healthy rhizomes of about 4 cm-7 cm length and 25 g-30 g weight planted during 2017 to 2018. The growth characters were recorded in the field after six months of maturity. The plants were harvested simultaneously after 8 months of growth and the yield characters were recorded. The data were subjected to analysis for comparative performance of the plants developed from planting materials of different status using analysis of variance.

Chapter IV

RESULTS AND DISCUSSION

Evolution of crop plants either natural or human directed is primarily based on the genetic diversity existing in the population. Intra and interpopulational variability is the foundation of all the systematic plant breeding programmes. *Curcuma aromatica* Salisb., though it is an important component of several ayurvedic preparations, the plant still continues as an underutilized crop. The present study was conducted in the experimental plot of Genetics and Plant Breeding Division of the Department of Botany, University of Calicut, Kerala, India, as an effort to investigate the genetic variability, genetic divergence, character association and performance of the genotypes of the species collected from Kerala State of India. The data recorded for the purpose are presented and discussed below under appropriate heads.

4.1. Genetic variability of *Curcuma aromatica* Salisb.

The magnitude and nature of genetic variability of a crop help the breeder to determine the selection criteria and breeding methods to develop novel varieties of that species. Results of the experiments carried out presently are given below.

4.1.1. Genetic control of growth and yield characters

Frequency distribution analysis of agronomic characters of crop plants will help to identify the mechanism of genetic control involved in them. Distribution pattern of recessive and dominant contributing alleles or factors in the gene pools of these characters is analysed here. An experiment was conducted presently to evaluate the genetic control of six growth characters and nine yield characters namely, plant height, number of tillers, number of

leaves per tiller, leaf length, leaf breadth, leaf area, yield per plant, number of primary fingers, number of secondary fingers, length of primary finger, diameter of primary finger, length of secondary finger, diameter of secondary finger, length of mother rhizome and diameter of mother rhizome of a population of 547 plants grown for the purpose.

As per Chahal and Gosal (2002), quantitative characters with polygenic control show normal frequency distribution when the recessive and dominant alleles are in equal frequency. The bell shaped normal frequency distribution curve shows skewness when there is a variation in the frequency of recessive or dominant alleles in the distribution. In the present experiment all the morphometric characters exhibited continuous frequency distribution as evidenced by their frequency curves as shown in tables 4.1 to 4.15 and figures 4.1 to 4.15. Continuous frequency distribution with all possible intermediates implies polygenic control of these traits.

Among the growth characters of *C. aromatica* studied plant height, leaf length and leaf breadth showed continuous distribution with skewness towards the distal side of the distribution. This distribution indicates that the gene pool of these characters show accumulation of higher number of dominant alleles even when maintaining fairly good genetic base ranging from comparatively lower to higher values. However, the frequencies of the classes with higher values are comparatively less. Therefore, while maintaining the broad genetic base for selection of promising genotypes, conservation with maximum accumulation of dominant contributing factors is important for the development of promising varieties.

Number of tillers showed continuous frequency distribution with skewness towards the proximal end of the distribution. Here accumulation of recessive contributing factors is higher and accumulation of dominant contributing factors is comparatively low. Hence scientific selection process

has to be conducted to develop varieties with higher accumulation of dominant alleles of this character. This character also showed comparatively broad genetic base indicating the genotypes with different levels of allelic combinations ensuring the genetic diversity of the plant population under study.

Number of leaves per tiller and leaf area showed comparatively balanced distribution of genotypes almost equally towards the proximal and distal sides of the distributions indicating the occurrence of equal frequency of the recessive and dominant alleles contributing to these characters. Balanced frequency distribution can be regarded as an ideal situation in the case of a non-selected natural population.

Among the nine yield characters studied, seven characters showed skewness towards the proximal side of the distribution namely yield per plant, number of primary fingers, number of secondary fingers, length of primary finger, diameter of primary finger, length of secondary finger and diameter of mother rhizome indicating the accumulation of higher number of recessive contributing alleles in the population studied. It also confirms the importance of selection for better genotypes and phenotypes with maximum number of dominant contributing alleles so as to develop superior varieties.

Diameter of secondary finger and length of mother rhizome showed skewness almost equally towards the proximal and distal end of the frequency distributions. This balanced distribution of genotypes indicated the existence of almost equal frequency of the recessive and dominant alleles contributing to these characters. Among the yield characters studied there is no character which is controlled by a dominant allelic frequency in the genepool of the population.

Table 4.1. Frequency distribution of plant height in *Curcuma aromatica* population.

Plant height (cm)	Number of plants
25-50	2
50-75	40
75-100	201
100-125	244
125-150	60

Fig. 4.1. Frequency curve of plant height.

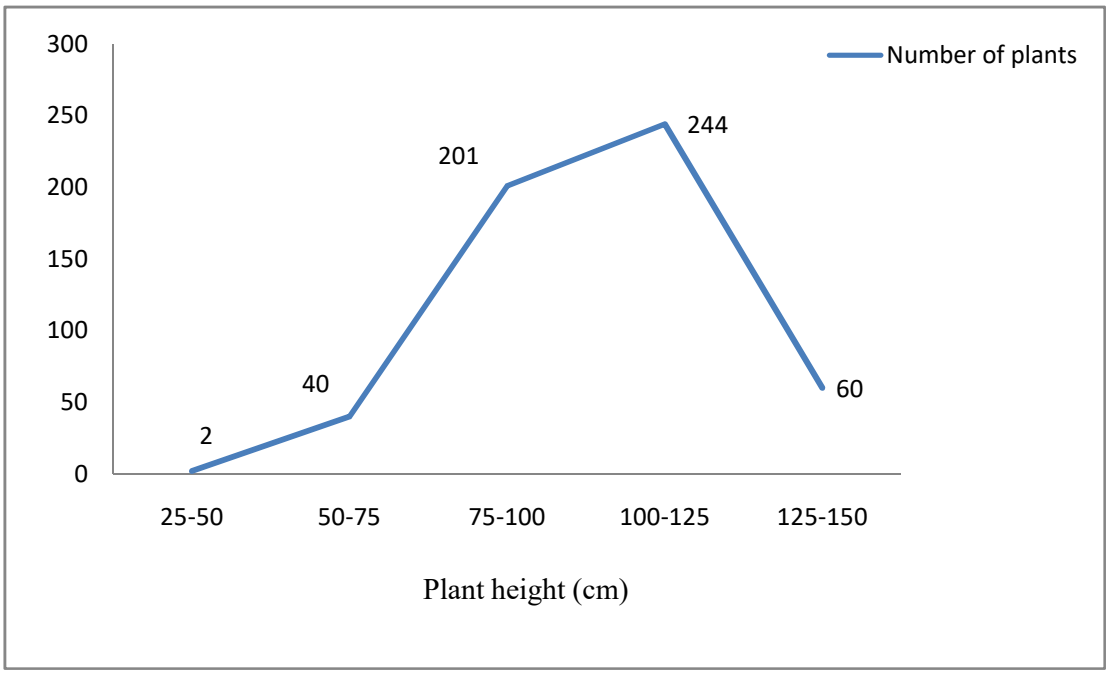


Table 4.2. Frequency distribution of number of tillers.

Number of tillers	Number of plants
1-2	428
2-3	103
3-4	16

Fig. 4.2. Frequency curve of number of tillers.

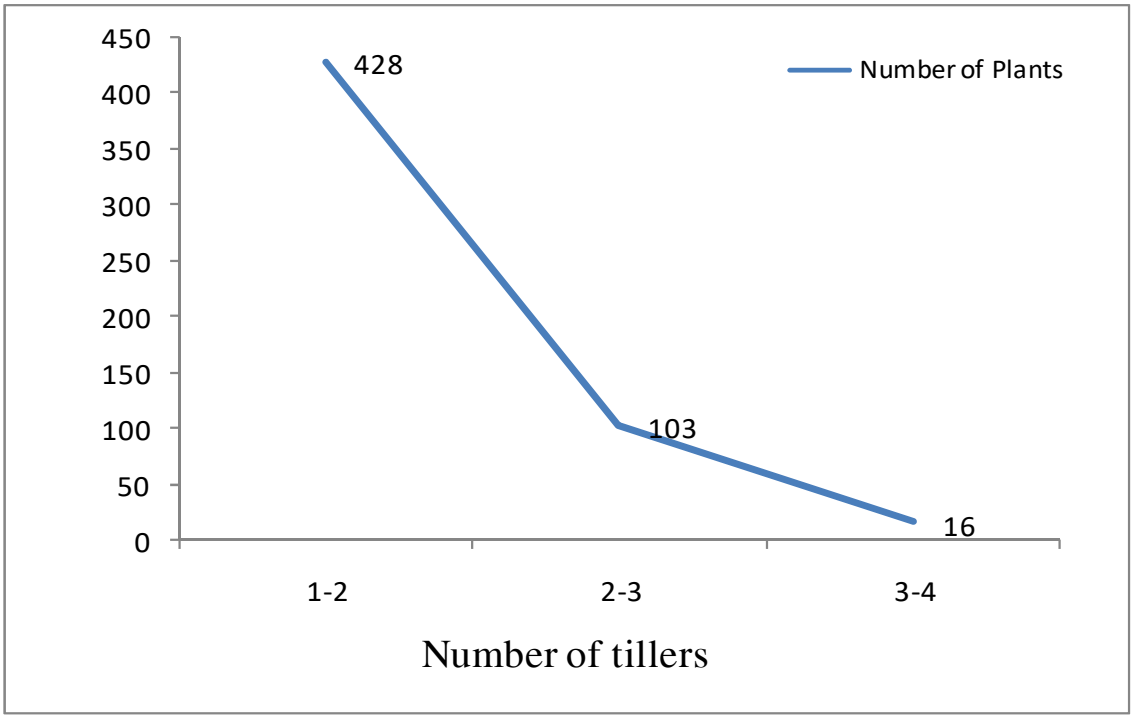


Table 4.3. Frequency distribution of number of leaves per tiller.

Number of leaves per tiller	Number of plants
1–5	8
5–10	377
10–15	162

Fig. 4.3. Frequency curve of number of leaves per tiller.

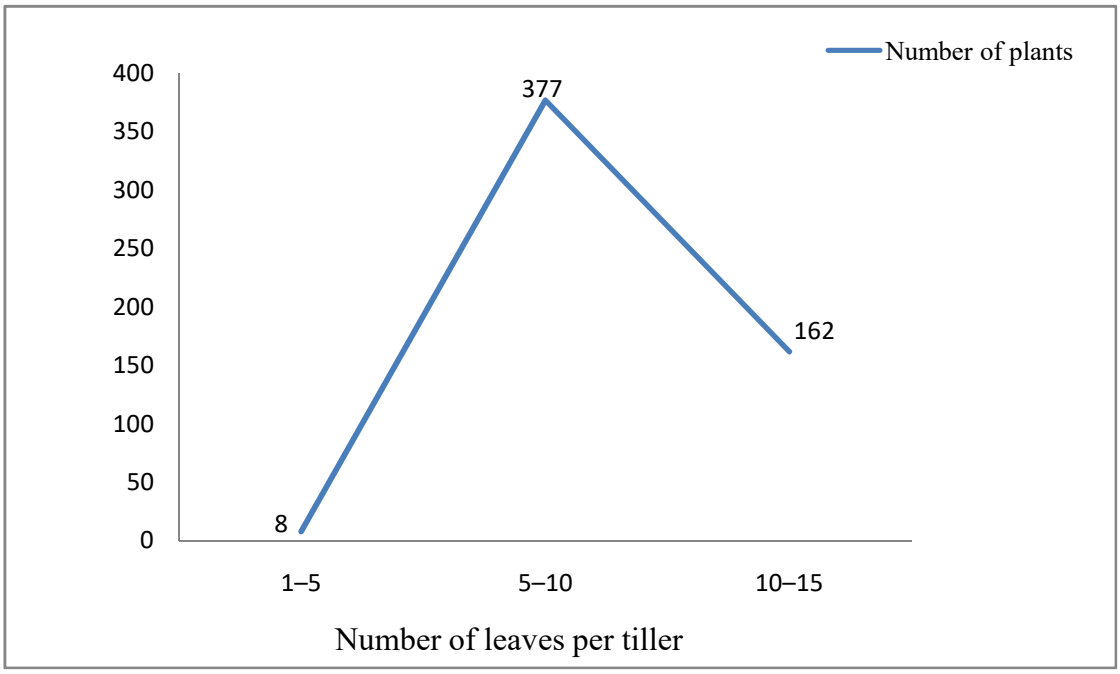


Table 4.4. Frequency distribution of leaf length.

Leaf length (cm)	Number of plants
20-25	1
25-30	3
30-35	19
35-40	32
40-45	57
45-50	120
50-55	139
55-60	93
60-65	49
65-70	28
70-75	6

Fig. 4.4. Frequency curve of leaf length.

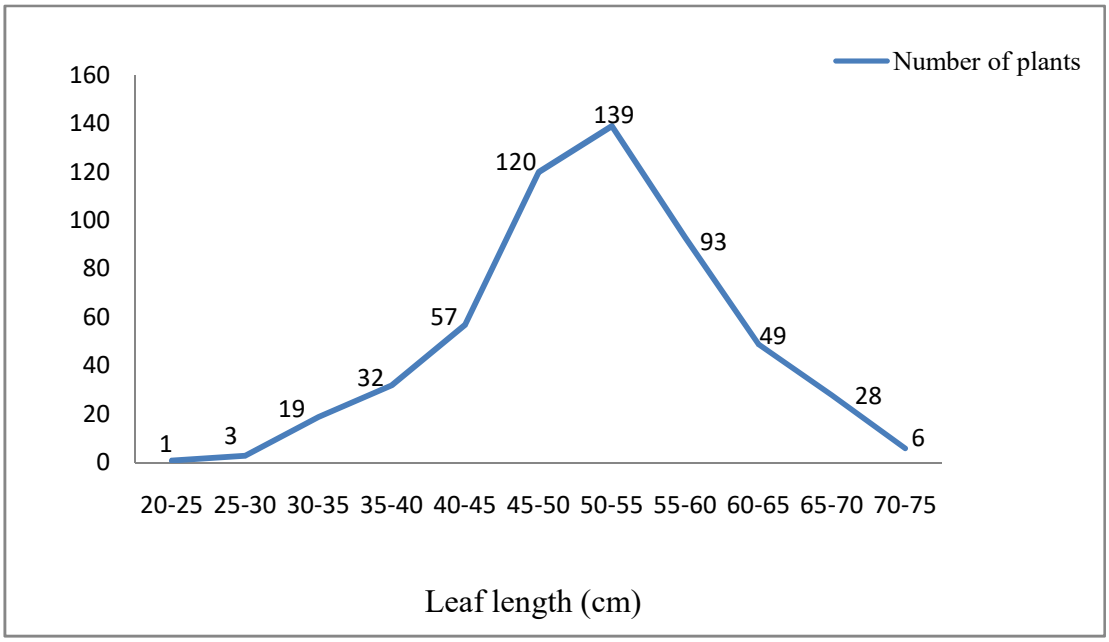


Table 4.5. Frequency distribution of leaf breadth.

Leaf breadth (cm)	Number of plants
7.30-8.30	2
8.30-9.30	8
9.30-10.30	16
10.30-11.30	38
11.30-12.30	46
12.30-13.30	71
13.30-14.30	89
14.30-15.30	120
15.30-16.30	63
16.30-17.30	53
17.30-18.30	31
18.30-19.30	6
19.30-20.30	4

Fig. 4.5. Frequency curve of leaf breadth.

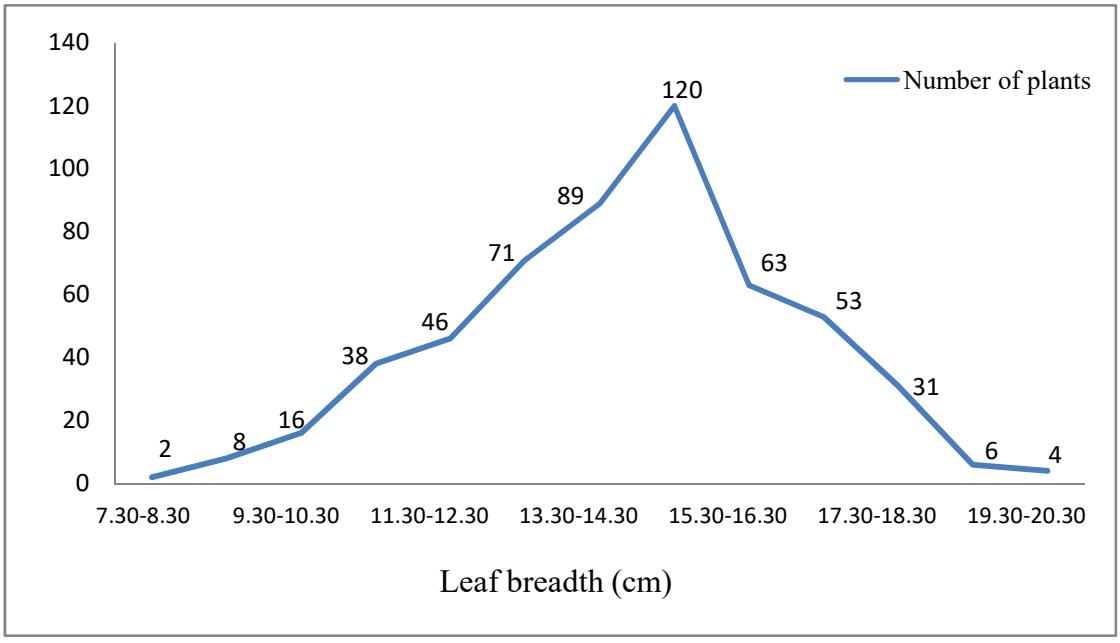


Table 4.6. Frequency distribution of leaf area.

Leaf area ($cm^{2)}$	Number of plants
100-160	2
160-220	22
220-280	33
280-340	53
340-400	81
400-460	121
460-520	82
520-580	73
580-640	39
640-700	23
700-760	12
760-820	4
820-880	2

Fig. 4.6. Frequency curve of leaf area.

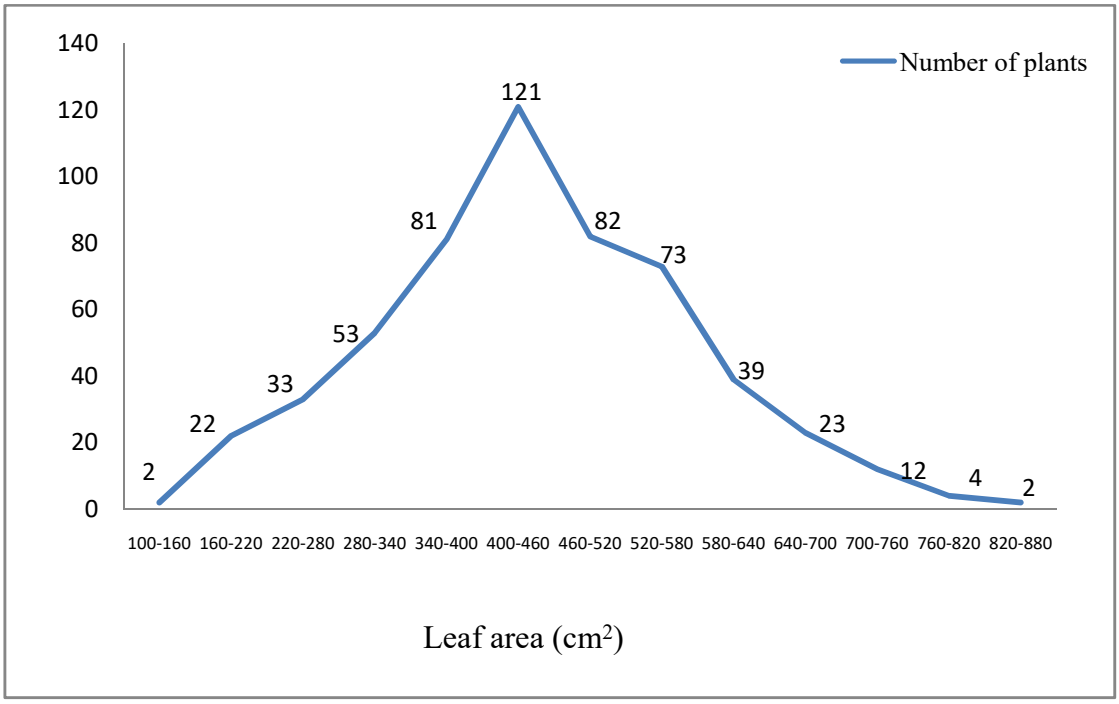


Table 4.7. Frequency distribution of yield per plant.

Yield per plant (g)	Number of plants
0-60	9
60-120	88
120-180	183
180-240	101
240-300	84
300-360	27
360-420	24
420-480	12
480-540	9
540-600	7
600-660	1
660-720	1
720-780	1

Fig. 4.7. Frequency curve of yield per plant.

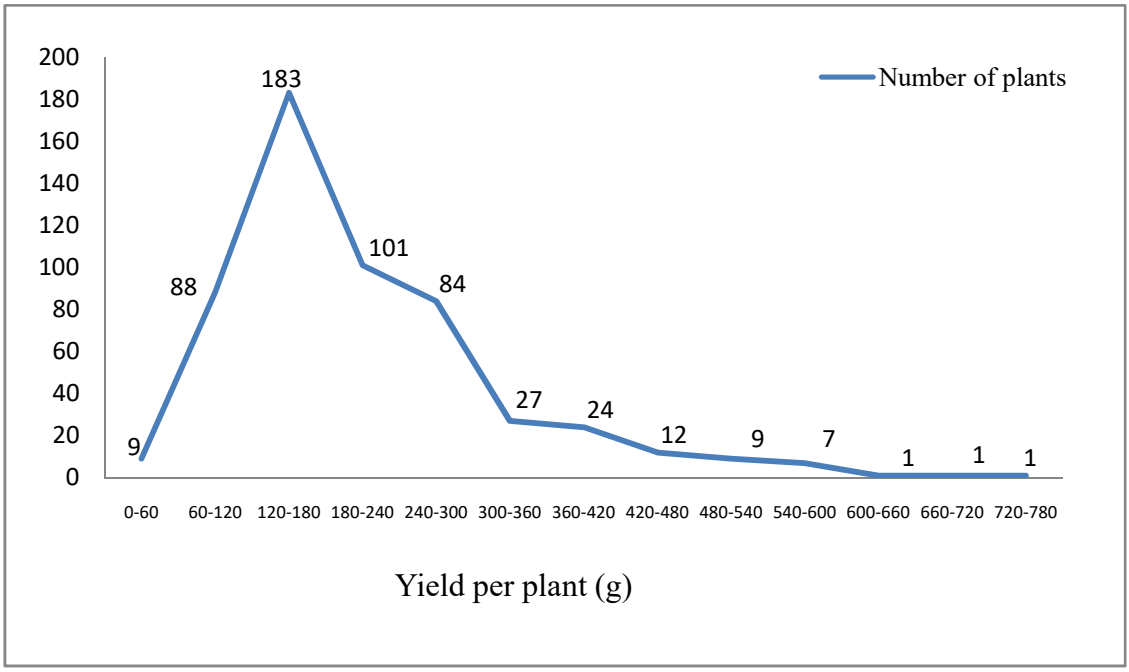


Table 4.8. Frequency distribution of number of primary fingers.

Number of primary fingers	Number of plants
4–5	144
5–6	194
6–7	168
7–8	38
8–9	3

Fig. 4.8. Frequency curve of number of primary fingers.

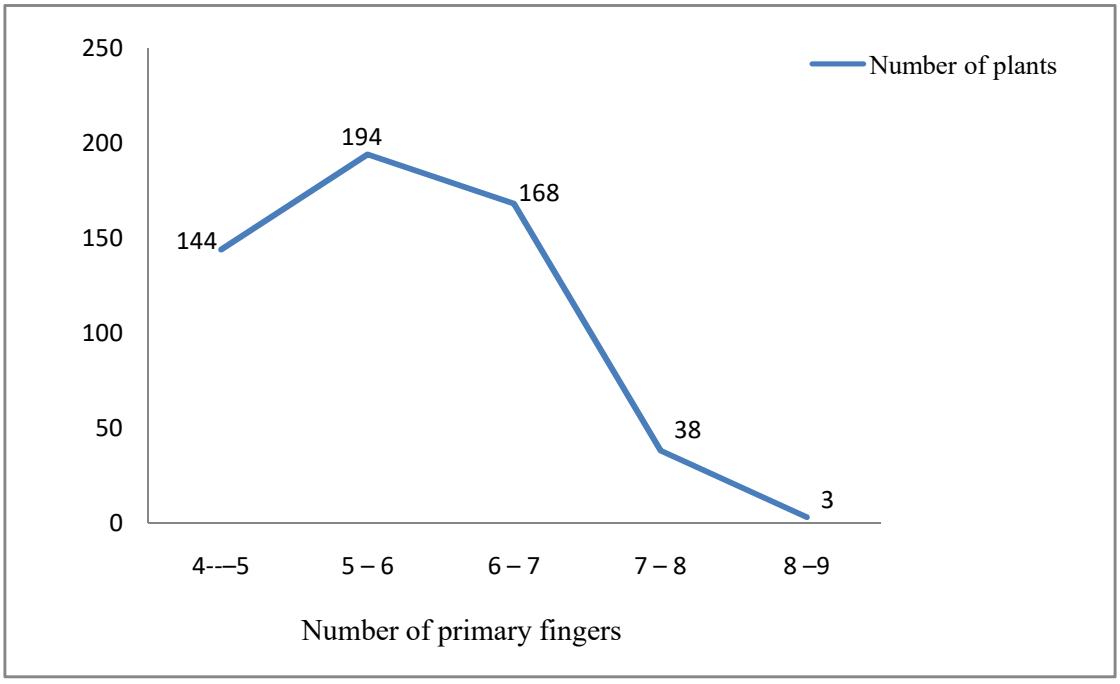


Table 4.9. Frequency distribution of number of secondary fingers.

Number of secondary fingers	Number of plants
10–20	2
20–30	56
30–40	205
40–50	189
50–60	78
60–70	14
70–80	3

Fig. 4.9. Frequency curve of number of secondary fingers.

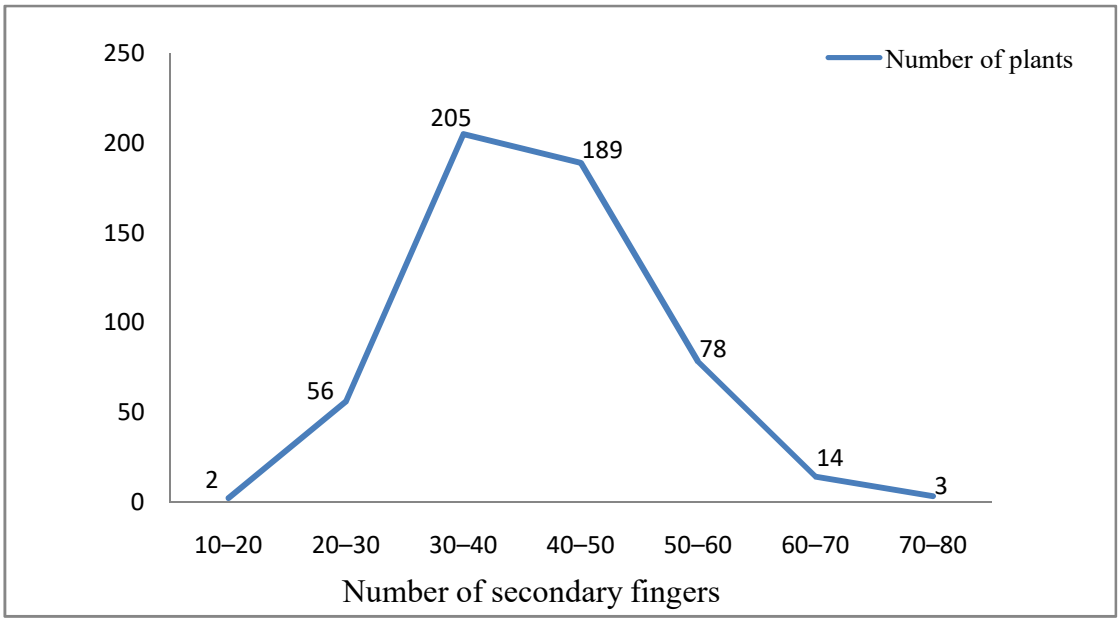


Table 4.10. Frequency distribution of length of primary finger.

Length of primary finger (cm)	Number of plants
3–5	4
5–7	64
7–9	230
9–11	172
11–13	61
13–15	12
15–17	4

Fig. 4.10. Frequency curve of length of primary finger.

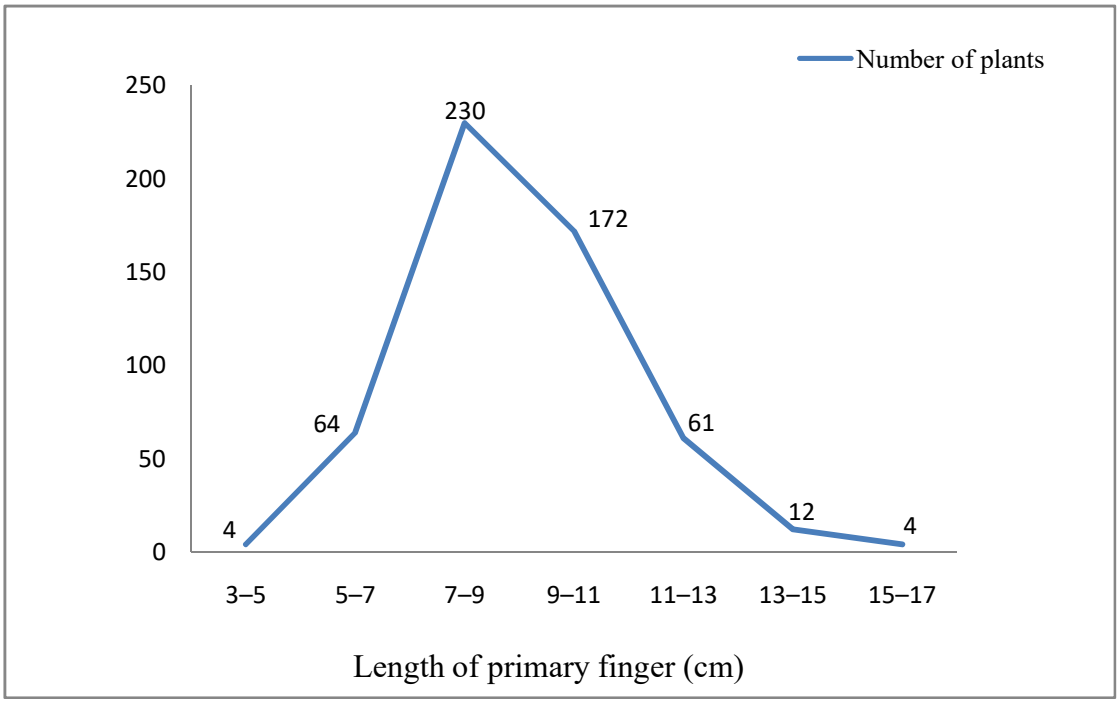


Table 4.11. Frequency distribution of diameter of primary finger.

Diameter of primary finger (cm)	Number of plants
1.00-1.25	3
1.25-1.50	13
1.50-1.75	39
1.75-2.00	88
2.00-2.25	157
2.25-2.50	95
2.50-2.75	120
2.75-3.00	22
3.00-3.25	5
3.25-3.50	4
3.50-3.75	1

Fig. 4.11. Frequency curve of diameter of primary finger.

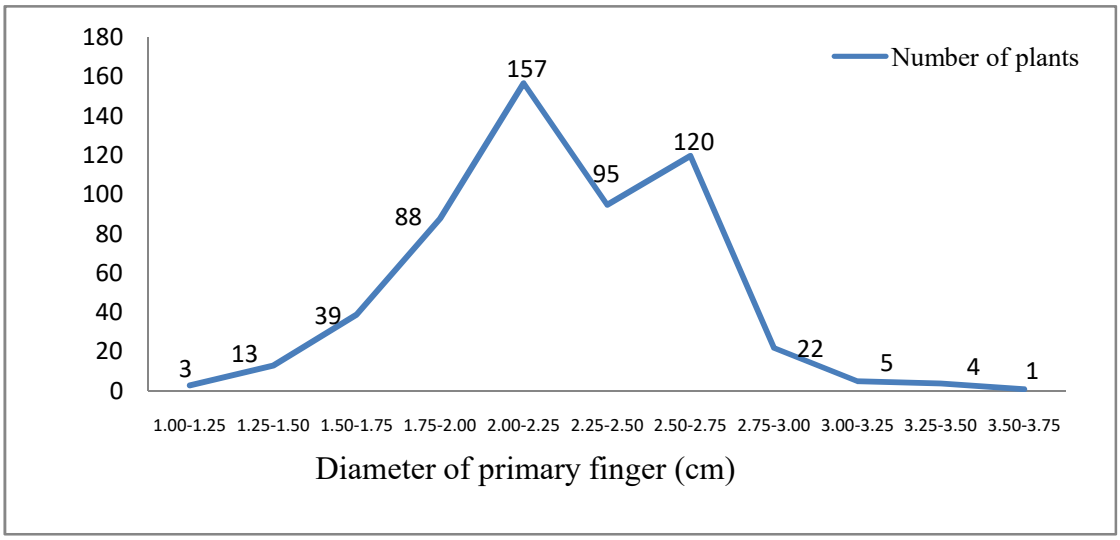


Table 4.12. Frequency distribution of length of secondary finger.

Length of secondary finger (cm)	Number of plants
1–2	51
2–3	70
3–4	94
4–5	107
5–6	103
6–7	72
7–8	28
8–9	15
9–10	7

Fig. 4.12. Frequency curve of length of secondary finger.

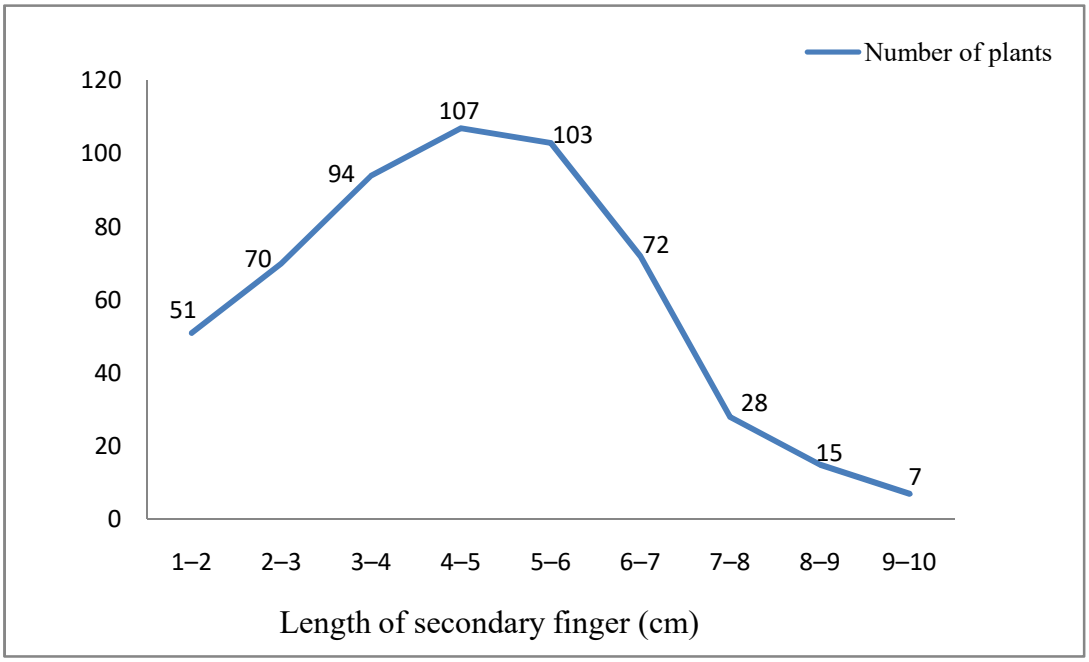


Table 4.13. Frequency distribution of diameter of secondary finger.

Diameter of secondary finger (cm)	Number of plants
0.30-0.60	21
0.60-0.90	17
0.90-1.20	52
1.20-1.50	122
1.50-1.80	139
1.80-2.10	133
2.10-2.40	54
2.40-2.70	8
2.70-3.00	1

Fig. 4.13. Frequency curve of diameter of secondary finger.

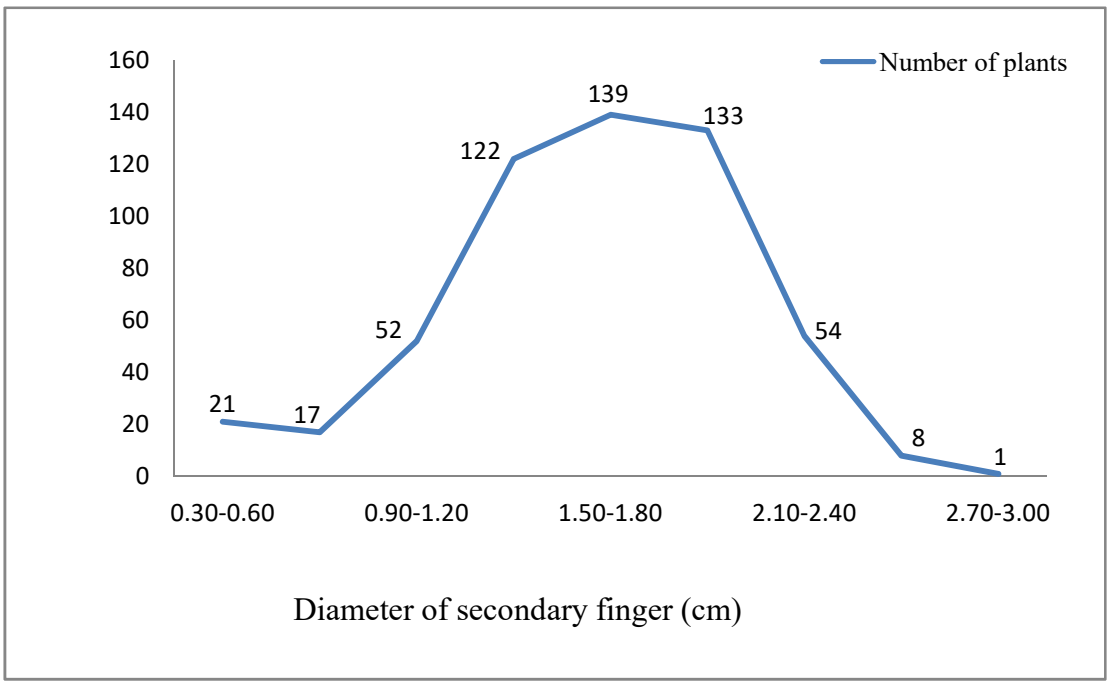


Table 4.14. Frequency distribution of length of mother rhizome.

Length of mother rhizome (cm)	Number of plants
2–3	1
3–4	19
4–5	73
5–6	172
6–7	166
7–8	91
8–9	18
9–10	6
10–11	1

Fig. 4.14. Frequency curve of length of mother rhizome.

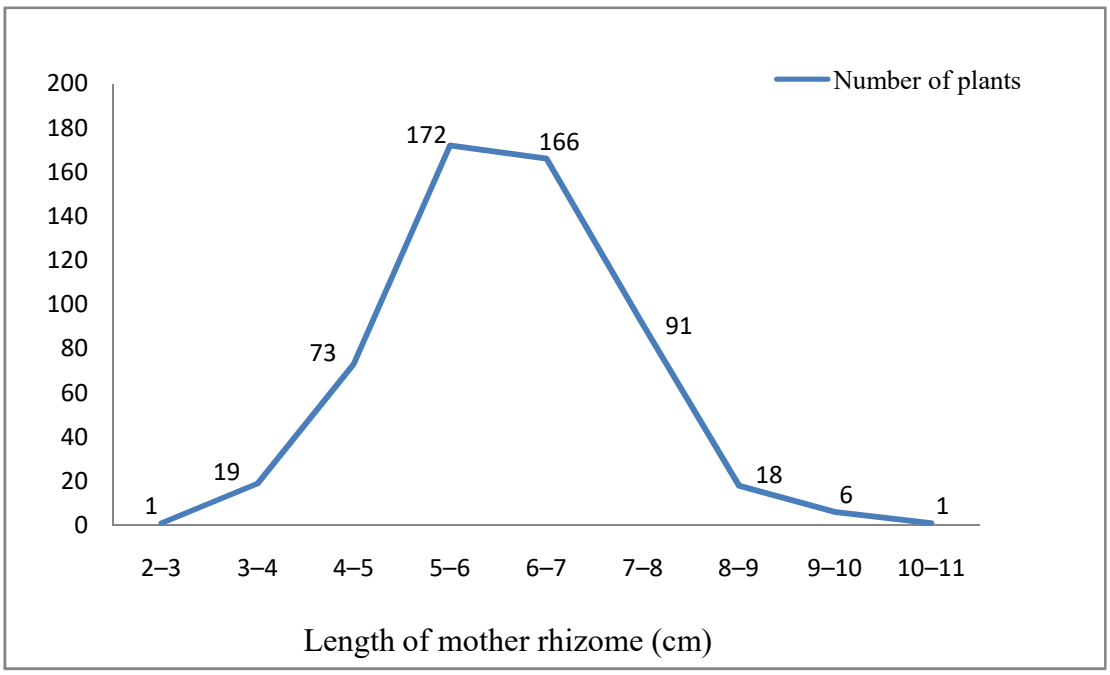
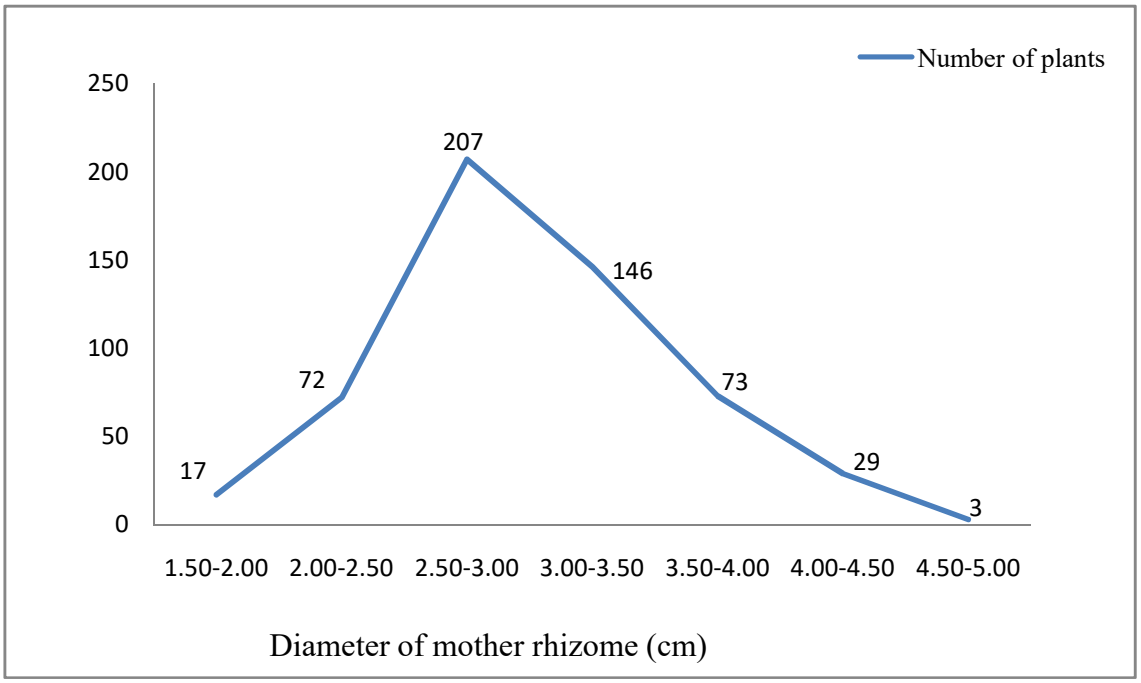


Table 4.15. Frequency distribution of diameter of mother rhizome.

Diameter of mother rhizome (cm)	Number of plants
1.50-2.00	17
2.00-2.50	72
2.50-3.00	207
3.00-3.50	146
3.50-4.00	73
4.00-4.50	29
4.50-5.00	3

Fig. 4.15. Frequency curve of diameter of mother rhizome.



From this analysis, it is clear that among the six growth characters, three characters show skewness towards the distal side of the frequency distribution, two characters show almost equal distribution of recessive and dominant alleles and only one character shows skewness towards the proximal side of the frequency distribution. Among the nine yield characters majority of them including yield and yield contributing characters show skewness towards the proximal side indicating that the gene pool of these characters are mostly controlled by recessive alleles, seriously limiting the yield of the crop due to the existence of a very high frequency of recessive alleles in the gene pool of the natural populations. Rest of the two characters showed balanced distribution with almost equal recessive and dominant alleles. However, the genetic base of *C. aromatica* is comparatively broad and there exists no threat of narrowing of its genetic variability.

The above study indicates the necessity of selection for better phenotypes and genotypes to develop novel and superior varieties of this species with dominant and desirable alleles, so that better yield is ensured to farmers carrying out cultivation of this medicinally valuable crop in an organized manner and thus farmers are not forced to stop cultivation of this important crop due to economic reasons.

The analysis of the nature of allelic distribution of agronomic characters in the gene pools of crops have been conducted by earlier workers like Paramasivan and Srirangaswamy (1988) in rice, Raghu *et al*. (2003) in coffee, Chandramohanan and Mohanan (2005) in *Cassia tora* and Soorya *et al*. (2016a) in *Curcuma aeruginosa*.

4.1.2. Phenotypic and genotypic variability

Studies on the phenotypic and genotypic variability in the case of the germplasm collected and maintained presently has been carried out based on the experiments conducted on the sixty two accessions of *Curcuma aromatica* Salisb. with respect to fifteen agronomic morphological characters.

The findings are presented in Table 4.16. and Table 4.17. Analysis of variance showed statistically significant variations between the accessions studied. All the growth characters studied showed statistically significant variation at 1% level of significance. Plant height showed a mean value of 102.02 cm and the range varied from 45 cm to 149.60 cm and the coefficient of variation was 15.26%. Number of tillers per plant ranged from 1 to 3 and it showed a mean value of 1.25 with a coefficient of variation of 17.60%. Number of leaves per tiller ranged from 4 to 15 and the mean value was 9.50 and coefficient of variation was 11.79%. Leaf length varied from 23.33 cm to 73.10 cm with a mean value of 50.92 cm and coefficient of variation of 13.51%. Leaf breadth showed a mean value of 14.12 cm and it ranged from 8.06 cm to 19.93 cm with a coefficient of variation of 10.62%. Leaf area ranged from 113.44 cm^2 to 844.28 cm^2 and the mean value was 442.48 cm^2 with a coefficient of variation of 22.18%. Among the growth characters studied, the highest coefficient of variation was shown by leaf area followed by number of tillers. The lowest coefficient of variation was shown by leaf breadth (Table 4.16).

Table 4.16. Genetic variability of the growth characters in *Curcuma aromatica* studied.

Accession number	Plant height**	Number of tillers**	Number of leaves per tiller**	Leaf length**	Leaf breadth**	Leaf area**
CUK1	130.01±4.00	1.66±0.19	9.79±0.60	63.18±1.97	16.68±1.00	638.36±54.29
CUK2	107.91±10.69	1.44±0.21	10.90±0.56	53.35±4.94	15.59±1.02	543.54±59.64
CUK3	127.63±11.38	1.11±0.10	11.05±0.47	62.23±0.43	15.21±0.52	609.80±28.82
CUK4	128.44±2.88	1.33±0.32	9.72±0.96	65.74±0.56	17.43±0.49	694.56±22.08
CUK5	124.13±2.81	1.33±0	10.83±0.24	59.64±1.52	15.57±0.71	563.59±33.91
CUK6	113.08±1.91	1.55±0.10	8.09±0.54	57.14±0.58	17.82±0.05	609.40±4.93
CUK7	132.61±5.21	1.33±0.18	11.89±0.67	64.02±2.18	15.28±0.42	591.29±35.38
CUK8	96.97±3.17	1.00±0	1.00±0.50	49.36±1.79	14.09±0.51	421.14±29.09
CUK9	111.41±6.23	1.22±0.10	1.00±1.01	57.19±4.22	15.15±1.00	527.34±67.91
CUK10	122.69±2.87	1.11±0.10	11.72±0.33	59.51±1.02	15.45±0.67	553.46±31.64
CUK11	124.28±5.46	1.33±0	10.44±0.43	58.09±3.35	14±0.91	492.30±59.26
CUK12	124.78±3.65	1.11±0.10	11.00±0.66	61.62±2.86	16.24±0.65	604.91±45.60
CUK13	95.54±1.69	1.44±0.10	8.88±0.14	47.21±0.45	12.51±0.17	370.71±9.61
CUK14	119.43±0.24	1.11±0.10	11.00±0.57	59.13±0.46	14.93±0.09	534.75±6.56
CUK15	102.23±3.46	1.44±0.10	9.27±0.83	50.34±0.84	13.26±0.21	411.55±8.36
CUK16	106.53±3.41	1.22±0.10	9.88±0.54	52.29±0.93	12.51±0.20	390.83±2.04
CUK17	107.12±2.87	1.00±0	9.55±0.10	52.69±1.20	15.89±0.36	502.87±4.90
CUK18	90.81±1.71	1.44±0.21	8.05±0.30	44.56±1.41	12.89±0.24	397.43±26.63
CUK19	116.03±2.66	1.22±0.10	10.83±0.24	57.82±0.31	15.79±0.37	547.83±10.90
CUK20	101.18±5.12	1.00±0	9.00±0	54.14±2.31	15.34±0.45	504.66±33.50
CUK21	90.39±1.49	1.00±0	8.55±0.10	45.31±1.04	12.63±0.13	355.94±10.16
CUK22	89.13±3.69	1.44±0.10	9.05±0.43	46.27±1.62	12.77±0.34	359.09±21.82

CUK23	109.50±5.80	1.00±0	10.27±0.30	53.67±2.54	14.56±0.89	472.93±46.83
CUK24	93.76±4.15	1.00±0	9.11±0.39	46.08±1.83	14.72±0.57	408.89±31.23
CUK25	98.94±1.58	1.11±0.10	8.89±0.43	49.49±1.43	15.26±0.30	463.41±11.20
CUK26	112.69±1.27	1.11±0.10	9.05±0.33	55.37±0.41	14.93±0.33	495.75±10.67
CUK27	115.54±3.80	1.22±0.21	10.00±0.57	56.59±2.03	14.09±0.60	481.24±37.72
CUK28	99.90±3.76	1.33±0.18	9.39±0.45	42.47±5.78	12.78±0.87	330.81±63.08
CUK29	105.51±3.28	1.22±0.10	8.22±0.38	51.18±1.58	14.69±0.31	456.38±19.51
CUK30	97.05±4.93	1.11±0.10	10.22±0.94	48.78±2.33	11.62±0.33	332.99±20.32
CUK31	98.62±5.63	1.22±0.10	11.39±0.45	48.47±2.20	13.26±0.21	390.35±22.01
CUK32	115.42±5.16	1.66±0.32	7.53±0.59	53.85±2.46	14.61±0.48	473.27±35.71
CUK33	97.64±3.10	1.11±0.10	10.33±0.68	51.22±0.74	14.25±0.61	441.90±21.67
CUK34	99.56±3.48	1.33±0.18	7.50±0.67	49.98±2.56	14.34±0.80	435.32±43.89
CUK35	112.49±2.45	1.33±0.18	9.11±0.44	47.37±5.44	12.23±1.24	446.32±24.67
CUK36	90.08±2.76	1.44±0.28	9.08±0.98	47.16±1.11	14.61±0.23	402.28±13.10
CUK37	88.28±3.28	1.11±0.10	8.72±0.19	46.29±1.53	13.33±0.79	372.40±34.26
CUK38	110.55±2.09	1.33±0	8.00±0.09	56.00±1.52	14.87±0.36	499.46±17.59
CUK39	92.04±3.31	1.00±0	9.11±0.10	44.80±1.61	12.05±0.66	328.91±29.17
CUK40	106.40±2.77	1.00±0	8.44±0.28	55.06±1.09	14.46±0.05	479.29±8.02
CUK41	118.72±2.07	1.00±0	11.55±0.44	59.75±0.76	14.41±0.09	516.81±6.01
CUK42	100.80±2.99	1.00±0	9.44±0.21	51.83±0.61	16.03±0.52	501.50±17.56
CUK43	101.45±2.65	1.33±0.18	8.72±0.61	52.93±0.54	16.37±0.26	498.78±34.92
CUK44	102.78±7.21	1.55±0.21	9.05±0.43	48.29±2.04	13.39±0.72	390.32±36.21
CUK45	114.53±5.93	1.33±0.32	9.83±1.51	52.80±3.99	13.66±1.28	441.45±70.41
CUK46	66.73±5.15	1.55±0.28	8.36±0.89	37.65±1.90	11.36±0.58	259.31±22.75
CUK47	87.64±2.99	1.00±0	8.83±0.43	44.87±0.81	12.31±0.17	332.62±10.33
CUK48	86.59±3.62	1.44±0.28	9.05±0.96	45.66±0.81	13.94±0.49	382.63±19.21

CUK49	62.18±3.14	2.00±0.19	7.20±0.29	32.95±1.86	11.19±0.66	226.33±25.26
CUK50	105.73±3.24	1.22±0.10	10.11±0.04	53.46±0.93	14.50±0.43	465.72±17.28
CUK51	88.55±4.42	1.55±0.21	8.11±0.60	48.01±2.32	14.08±0.29	413.55±26.91
CUK52	101.69±3.37	1.11±0.10	9.83±0.53	50.49±1.71	14.46±0.30	439.80±21.07
CUK53	98.49±2.48	1.00±0	9.67±0.32	49.67±0.61	12.89±0.58	384.22±15.95
CUK54	100.86±3.52	1.00±0	10.78±0.77	50.77±1.81	13.48±0.54	410.05±26.14
CUK55	92.73±2.45	1.00±0	9.89±0.11	47.06±1.46	14.02±0.31	396.18±21.30
CUK56	89.92±0.75	1.77±0.10	8.33±0.19	47.29±1.19	13.95±0.16	395.70±13.90
CUK57	75.53±1.42	1.33±0.18	8.72±0.54	39.36±1.10	12.13±0.76	290.45±26.64
CUK58	96.75±5.55	1.22±0.10	10.27±0.38	48.00±2.38	14.36±0.73	416.40±41.10
CUK59	101.22±0.98	1.00±0	11.33±0	51.99±0.92	14.68±0.60	459.58±24.46
CUK60	68.86±5.69	1.11±0.10	8.16±0.24	36.18±2.76	10.99±0.83	244.27±34.90
CUK61	71.80±1.96	1.11±0.10	8.55±0.28	37.40±0.84	11.96±0.53	262.67±17.57
CUK62	85.35±0.61	1.11±0.10	9.16±0.53	45.94±0.65	13.32±0.65	367.96±21.80
Mean	102.02	1.25	9.50	50.92	14.12	442.48
Range	45-149.60	1-3	4-15	23.33-73.10	8.06-19.93	113.44-844.28
CV	15.26	17.60	11.79	13.51	10.62	22.18
SD	15.57	0.22	1.12	6.88	1.50	98.14
CD at 5%	10.65	0.43	1.53	5.78	1.65	85.77

**: Significant variation at 1% level.

Yield per plant varied from 25 g to 775 g with a mean value of 205.96 g and coefficient of variation of 42.82%. Number of primary fingers showed mean value of 6.17 and the range varied from 4 to 9 with a coefficient of variation of 11.02%. Length of primary finger ranged from 3.4 cm to 16.5 cm and the mean value was 9.09 cm with a coefficient of variation of 16.17%. Diameter of primary finger ranged from 1.14 cm to 3.63 cm with a mean value of 2.23 cm and coefficient of variation of 11.21%. Number of secondary fingers ranged from 10 to 76 and the mean value was 41.73 with a coefficient of variation of 14.52%. The mean value of length of secondary finger was 4.66 cm with a range varying from 1 cm to 10 cm and coefficient of variation of 30.69%. Diameter of secondary finger varied from 0.31 cm to 2.88 cm with a mean value of 1.59 cm and coefficient of variation of 20.13%. Length of mother rhizome ranged from 3 cm to 10.30 cm and the mean value was 6.20 cm with a coefficient of variation of 13.71%. Diameter of mother rhizome varied from 1.56 cm to 4.77 cm with a mean value of 2.98 cm and coefficient of variation of 15.77%. Among the yield characters studied, the lowest coefficient of variation was shown by number of primary fingers and the highest coefficient of variation by yield per plant followed by length of secondary finger (Table 4.17).

Table 4.17. Genetic variability of the yield characters in *Curcuma aromatica* studied.

Accession number	Number of primary fingers**	Length of primary finger** (cm)	Diameter of primary finger** (cm)	Number of secondary fingers**	Length of secondary finger** (cm)	Diameter of secondary finger** (cm)	Length of mother rhizome** (cm)	Diameter of mother rhizome** (cm)	Yield per plant** (g)
CUK1	6.78±0.21	11.71±0.50	2.31±0.03	48.66±6.90	7.41±0.28	2.01±0.09	6.52±0.41	3.85±0.15	380.55±63.60
CUK2	7.05±0.24	13.21±0.61	2.34±0.15	54.89±4.24	8.40±0.10	1.99±0.19	5.83±0.11	3.80±0.11	381.94±93.54
CUK3	7.11±0.11	12.99±0.60	2.51±0.02	60.66±2.03	7.06±0.19	1.95±0.05	5.80±0.16	2.88±0.88	422.22±31.34
CUK4	6.66±0.19	12.21±0.78	2.81±0.13	54.00±1.89	8.06±0.54	2.23±0.08	5.94±0.19	4.17±0	491.66±50.28
CUK5	6.00±0.19	10.80±0.61	2.53±0.21	43.44±2.65	5.76±0.83	1.77±0.11	5.76±0.27	3.64±0.05	311.11±39.23
CUK6	5.44±0.28	9.82±0.17	2.66±0.12	37.22±0.48	7.42±0.36	2.25±0.08	5.29±0.21	3.63±0	405.55±5.55
CUK7	5.99±0.32	10.30±0.17	2.28±0	48.22±0.40	5.95±0.45	1.80±0.11	6.18±0.17	3.33±0.05	250.00±4.82
CUK8	7.33±0.19	8.61±0.34	1.91±0.05	50.00±1.45	4.42±0.39	1.52±0.09	6.00±0.09	3.26±0.04	183.33±9.63
CUK9	6.55±0.39	10.39±0.69	2.40±0.13	44.11±5.50	5.80±0.50	1.85±0.08	5.77±0.67	3.96±0.19	272.22±53.06
CUK10	6.55±0.21	10.73±0.24	2.37±0.13	48.11±0.89	6.20±0.56	1.77±0.12	6.00±0.16	3.73±0.17	302.77±32.79
CUK11	6.00±0.19	11.49±0.46	2.34±0.01	49.66±4.76	6.02±0.72	1.95±0.08	5.81±0.31	3.38±0.15	313.89±41.53
CUK12	6.11±0.21	10.71±0.65	2.80±0.13	42.77±2.60	6.86±0.39	2.08±0.09	7.13±0.35	3.86±0.16	341.64±38.25
CUK13	5.55±0.11	8.20±0.42	2.08±0.05	32.44±1.82	4.22±0.31	1.50±0.09	6.51±0.08	3.33±0.17	169.44±10.02
CUK14	5.55±0.11	9.93±0.01	2.52±0.08	43.55±0.54	5.31±0.83	1.81±0.11	5.78±0.30	3.66±0.07	252.77±7.35
CUK15	5.77±0.28	9.45±0.12	2.21±0.05	35.11±1.84	4.33±0.27	1.62±0.09	5.28±0.08	3.10±0.04	200.00±4.82
CUK16	5.89±0.28	8.59±0.52	2.19±0.15	41.44±1.87	4.52±0.87	1.54±0.24	6.02±0.36	3.31±0.06	197.22±29.03
CUK17	6.22±0.28	8.67±0.23	2.20±0.04	43.33±2.96	3.54±0.52	1.32±0.19	6.16±0.26	3.02±0.01	180.55±27.39
CUK18	5.00±0	7.95±0.66	2.23±0.08	32.77±1.49	3.38±0.43	1.28±0.15	5.44±0.15	2.83±0.08	147.22±21.72
CUK19	5.77±0.11	10.12±0.20	2.49±0.06	41.44±2.85	5.64±0.30	1.96±0.09	5.40±0.35	3.50±0.14	252.77±29.43

CUK20	5.77±0.11	9.89±0.48	2.50±0.11	40.33±1.92	6.29±0.36	2.20±0.08	5.12±0.16	3.50±0.05	338.89±30.59
CUK21	6.66±0.69	8.25±0.49	2.01±0.17	40.00±5.61	3.05±0.30	1.20±0.05	6.73±0.33	2.86±0.30	191.66±17.37
CUK22	5.77±0.28	7.50±0.17	1.93±0.08	34.78±1.30	2.86±0.11	1.14±0.02	7.50±0.15	2.88±0.02	150.00±9.63
CUK23	5.11±39	8.23±0.60	2.19±0.16	35.33±1.85	4.09±0.75	1.33±0.27	6.51±0.40	2.78±0.27	184.72±25.53
CUK24	4.55±0.21	8.93±0.60	2.14±0.02	37.33±2.50	6.09±0.21	1.88±0.02	5.76±0.11	2.90±0.05	202.77±15.48
CUK25	4.89±0.11	8.91±0.11	2.30±0.04	40.44±1.15	5.76±0.28	1.97±0.05	5.29±0.13	2.87±0.09	241.66±12.74
CUK26	6.22±0.21	9.67±0.24	2.76±0.06	44.22±1.61	3.99±0.14	1.84±0.09	6.18±0.17	3.09±0.08	266.67±16.69
CUK27	6.78±0.21	7.34±0.45	1.69±0.30	38.27±3.65	2.24±0.47	0.99±0.08	6.00±0.05	2.80±0	127.78±2.77
CUK28	7.22±0.21	7.17±0.82	2.04±0.11	47.67±3.84	2.55±0.42	1.08±0.20	5.77±0.21	2.53±0.16	137.50±26.49
CUK29	6.33±0.32	8.57±0.25	2.28±0.09	43.33±1.34	3.43±0.11	1.46±0.02	6.00±0.23	2.77±0.09	169.44±7.35
CUK30	5.66±0.19	8.31±0.30	1.99±0.02	41.44±1.27	3.23±0.35	1.21±0.08	5.81±0.15	2.51±0.05	136.11±7.35
CUK31	7.22±0.21	9.18±0.46	2.18±0.11	45.11±1.49	4.68±0.36	1.60±0.09	7.13±0.08	2.65±0.05	169.44±12.12
CUK32	6.00±0.19	9.95±0.41	2.31±0.06	40.44±2.80	4.78±0.54	1.55±0.08	6.51±0.15	2.99±0.09	183.33±16.69
CUK33	7.00±0	10.54±0.49	2.25±0.02	53.88±1.74	5.62±0.35	1.82±0.09	5.78±0.37	2.93±0.05	258.33±14.45
CUK34	6.11±0.55	8.30±0.53	2.10±0.07	40.33±2.59	4.49±0.58	1.53±0.21	5.28±0.30	2.68±0.19	175.00±33.72
CUK35	6.00±0.19	10.07±0.28	2.44±0.07	39.39±0.73	4.67±0.53	1.79±0.23	6.02±0.36	3.04±0.17	211.11±15.48
CUK36	6.89±0.11	7.10±0.16	1.82±0.07	43.44±7.02	2.33±0.36	0.97±0.09	6.16±0.16	2.53±0.34	123.61±9.12
CUK37	6.77±0.11	8.10±0.34	2.10±0.18	42.11±2.41	3.73±0.43	1.40±0.13	5.44±0.47	2.78±0.13	152.77±18.24
CUK38	5.44±0.28	9.97±0.21	2.26±0.11	37.00±1.34	4.85±0.26	1.65±0.05	5.40±0.09	2.71±0.03	200.00±4.82
CUK39	6.22±0.21	8.66±0.15	2.01±0.08	35.88±0.77	3.20±0.32	1.01±0.13	5.12±0.25	2.43±0.17	133.33±8.34
CUK40	6.11±0.11	9.56±0.25	2.34±0.04	43.55±2.00	4.65±0.27	1.70±0.11	6.73±0.19	3.02±0.05	216.66±12.74
CUK41	5.67±0.32	11.02±0.21	2.52±0.04	41.55±2.21	6.74±0.24	1.92±0.12	7.50±0.23	3.39±0.08	233.33±12.74
CUK42	5.55±0.21	9.96±0.30	2.33±0.06	47.00±2.83	5.84±0.27	1.95±0.08	6.51±0.20	3.04±0.08	238.88±14.71
CUK43	4.89±0.11	8.67±0.21	2.33±0.06	38.55±1.92	5.41±0.36	1.87±0.09	5.39±0.08	3.15±0.17	258.33±9.63
CUK44	6.22±0.11	9.13±0.47	2.26±0.14	36.11±1.36	4.36±0.16	1.54±0.02	5.78±0.43	2.63±0.11	183.33±17.36
CUK45	6.11±0.11	8.11±0.72	2.44±0.16	39.22±3.82	3.40±0.98	1.47±0.24	6.30±0.58	2.82±0.11	172.22±36.47

CUK46	4.88±0.21	7.98±0.58	1.83±0.09	34.00±2.64	4.19±0.64	1.34±0.12	4.53±0.17	2.19±0.05	111.11±12.12
CUK47	5.78±0.39	9.02±0.39	2.11±0.05	39.66±1.01	3.93±0.18	1.50±0.04	4.72±0.20	2.43±0.05	105.55±10.12
CUK48	6.11±0.11	8.86±0.32	2.08±0.06	39.33±0.84	4.00±0.17	1.57±0.01	5.07±0.16	2.48±0.04	163.89±22.76
CUK49	5.77±0.28	7.81±0.19	1.80±0.02	34.89±2.44	3.65±0.58	1.29±0.09	4.62±0.09	2.09±0.09	130.55±18.23
CUK50	7.00±0.32	9.05±0.19	2.20±0.02	48.22±1.31	4.14±0.20	1.51±0.04	6.61±0.26	3.00±0.05	97.22±7.35
CUK51	7.00±0.19	8.59±0.52	2.35±0.04	40.89±1.49	3.74±0.21	1.57±0.12	6.42±0.30	3.11±0.01	144.44±22.76
CUK52	6.44±0.21	8.81±0.23	2.09±0.05	43.50±1.10	3.81±0.10	1.43±0.05	6.36±0.23	2.89±0.08	147.22±5.56
CUK53	7.11±0.21	5.76±0.38	1.84±0.07	30.67±0.87	2.82±0.23	1.27±0.08	6.55±0.08	2.67±0.05	116.66±9.63
CUK54	6.39±0.19	8.52±0.94	2.34±0.11	42.67±2.84	4.56±0.79	1.53±0.19	6.50±0.27	2.77±0.08	159.72±21.86
CUK55	7.22±0.28	7.64±0.30	2.18±0.07	41.77±2.47	3.34±0.41	1.30±0.08	6.11±0.12	2.66±0.08	130.55±12.12
CUK56	6.16±0.34	7.57±0.17	2.06±0.04	44.05±2.84	3.89±0.17	1.36±0.04	5.57±0.15	2.43±0.01	123.61±6.06
CUK57	6.55±0.48	7.98±0.31	2.10±0.09	37.11±0.94	3.86±0.39	1.45±0.11	5.91±0.27	2.69±0.08	158.33±12.74
CUK58	6.33±0.32	7.41±0.41	1.65±0.17	32.33±3.46	2.66±0.63	0.84±0.20	5.59±0.87	2.44±0.24	86.11±22.76
CUK59	6.66±0.19	9.29±0.21	2.36±0.05	49.33±0.76	5.29±0.09	1.85±0.04	6.25±0.13	2.85±0.05	211.11±14.71
CUK60	5.00±0.19	7.23±0.41	1.95±0.14	33.55±0.98	4.18±0.72	1.58±0.13	4.26±0.38	2.12±0.12	105.55±19.47
CUK61	7.16±0.25	6.70±0.64	2.10±0.09	35.00±0.50	3.13±0.16	1.43±0.08	5.95±0.34	2.52±0.11	105.55±16.91
CUK62	6.44±0.21	8.19±0.27	2.26±0.07	41.77±1.45	4.64±0.16	1.72±0.01	6.43±0.33	2.66±0.01	158.33±26.82
Mean	6.17	9.09	2.23	41.73	4.66	1.59	6.20	2.98	205.96
Range	4-9	3.4-16.5	1.14-3.63	10-76	1-10	0.31-2.88	3-10.3	1.56-4.77	25-775
CV	11.02	16.17	11.21	14.52	30.69	20.13	13.71	15.77	42.82
SD	0.68	1.47	0.25	6.06	1.43	0.32	0.85	0.47	88.19
CD at 5%	0.73	1.22	0.33	7.29	1.25	0.33	0.80	0.47	71.35

**: significance at 1% level.

All the studied characters are statistically significant indicating the possibility of selection of promising genotypes based on the above characters in future improvement programmes in this valuable medicinal plant. Based on this study it is clear that in the *C. aromatica* accessions, yield per plant, length of secondary finger and leaf area are the most variable characters and these characters could be given due consideration while selection.

Phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV) and heritability (broad sense) of characters can provide an idea of the degree of environmental impact on the agronomic characters of a crop. In the present study, PCV was higher than GCV among all the characters, symbolizing the additive nature, polygenic control and differential degrees of environmental influences on the characters under study. The PCV of the observed characters varied from 12.18% to 46.32% and the GCV of the observed characters ranged from 9.77% to 40.95%. The highest PCV and GCV were observed for yield per plant followed by length of secondary finger whereas the lowest PCV and GCV were recorded for leaf breadth (Table 4.18).

Number of tillers showed a PCV of 25.60% and marked the highest among the six growth characters studied. The lowest PCV was obtained for leaf breadth (12.18%). Leaf area showed a GCV of 21.05% and a PCV of 24.28% and in the case of plant height it was 14.79% and 16.16% respectively. PCV for leaf length was 14.69% and for number of leaves per tiller it was 14.32% while GCV of these characters were 12.86% and 10.21% respectively. The GCV of number of tillers and leaf breadth were 13.60% and 9.77%. Of the nine yield characters studied the maximum GCV and PCV were recorded for yield per plant followed by length of secondary finger and diameter of secondary finger. GCV for yield per plant was 40.95%, for length of secondary finger it was 29.18% and for diameter of secondary finger it was

18.87% whereas PCV was 46.32%, 33.69% and 23.27% respectively. The lowest GCV was shown by diameter of primary finger (9.87%) and the lowest PCV was observed for number of primary fingers (12.64%).

The differences between PCV and GCV were comparatively higher in the case of yield characters. The characters with higher differences between PCV and GCV reflect comparatively higher impact of environment on the phenotypic expression of the characters and the least difference indicates the limited influence of the environment on the expression of the characters which helps in direct selection based on the phenotypic performance of these agronomic traits for further improvement of the crop, if the heritability and genetic advance values of these characters coincide with the above mentioned characters. In this experiment, differences between PCV and the corresponding GCV were higher in the case of number of tillers, yield per plant and length of secondary finger and the remaining characters showed low differences.

Similar studies have been done on genetic variability of different species by earlier workers namely Radhakrishnan *et al*. (2006) in cardamom, Jayasree *et al*. (2014a) in mango ginger, Lal *et al*. (2015) in turmeric, Mishra *et al*. (2015) in strawberry, Shintu *et al*. (2016) in west Indian arrowroot, Soorya *et al*. (2016a) in *Curcuma aeruginosa* and Azimi *et al*. (2017) in wheat.

Table 4.18. Genotypic variance, phenotypic variance, GCV, PCV, heritability and genetic advance in the case of the growth and yield characters of *Curcuma aromatica*.

Character	Genotypic variance	Phenotypic variance	Genotypic Coefficient of Variation	Phenotypic Coefficient of Variation	Heritability (Broad Sense) (%)	Genetic Advance (%)
Plant height (cm)**	227.62	271.93	14.79	16.16	83.71	27.87
Number of tillers**	0.03	0.1	13.60	25.60	30	15.82
Number of leaves per tiller**	0.95	1.86	10.21	14.32	51.08	15.06
Leaf length (cm)**	42.91	56	12.86	14.69	76.63	23.19
Leaf breadth (cm)**	1.90	2.95	9.77	12.18	64.41	16.16
Leaf area (sq.cm)**	8673.64	11545.82	21.05	24.28	75.12	37.58
Yield per plant (g)**	7115.67	9103.69	40.95	46.32	78.16	74.59
Number of primary fingers**	0.4	0.61	10.21	12.64	65.57	17.08
Length of primary finger (cm)**	1.97	2.56	15.40	17.60	76.95	27.90
Diameter of primary finger (cm)**	0.05	0.09	9.87	13.45	55.56	15.40
Number of secondary fingers**	29.81	50.53	13.08	17.04	58.99	20.70
Length of secondary finger (cm)**	1.85	2.46	29.18	33.69	75.20	52.19
Diameter of secondary finger (cm)**	0.09	0.14	18.87	23.27	64.29	30.82
Length of mother rhizome (cm)**	0.64	0.89	12.90	15.16	71.91	22.46
Diameter of mother rhizome (cm)**	0.19	0.28	14.77	17.79	67.86	24.86

4.1.3. Heritability (broad sense) of fifteen agronomic characters

Evaluation of heritability (broad sense) provides authentic information about a particular trait which will be transmitted to the successive generations and constitute an important guide for plant breeders in the selection of parent plants in a crop improvement programme. It is the breeding value that determines how much of the phenotype would be passed onto the next generation of a crop. Heritability in broad sense consists of the contribution of all types of gene actions like, dominant, additive, maternal and paternal and epistatic effects of a character to a population's phenotypic variance.

Broad sense heritability of the fifteen agronomic characters studied ranged from 30% to 83.71%. The maximum heritability value was observed for plant height (83.71%) followed by yield per plant (78.16%), length of primary finger (76.95%) and leaf length (76.63%). Lowest heritability was recorded for number of tillers (30%). High heritability of characters indicate that they are influenced by environmental factors to a very low extent on the expression of such characters in a population establishing the scope of effective selection based on such characters for improvement. The minimum heritability value shows the highest influence of environment on the character.

Growth characters exhibited a heritability ranging from 30% to 83.71%. Number of leaves per tiller showed 51.08% heritability, leaf length showed 76.63% heritability, leaf breadth showed 64.41% heritability and leaf area showed a heritability of 75.12%. Heritability of yield characters varied from 55.56% in the case of diameter of primary finger to 78.16% in the case of yield per plant. Number of secondary fingers exhibited a heritability of 58.99%, diameter of secondary finger exhibited a heritability of 64.29%, number of primary fingers showed 65.57% of heritability, diameter of mother rhizome showed 67.86% heritability, length of mother rhizome exhibited a

heritability of 71.91%, length of secondary finger showed 75.20% heritability and length of primary finger exhibited 76.95% of heritability.

According to Babu *et al*. (2012) heritability is low below 30%, medium between 30% and 60% and high above 60%. As per the classification here among growth characters four characters namely plant height, leaf length, leaf breadth and leaf area showed high heritability and two other characters showed medium heritability. Out of the nine yield characters seven characters such as yield per plant, number of primary fingers, length of primary finger, length of secondary finger, diameter of secondary finger, length of mother rhizome and diameter of mother rhizome showed high heritability and comparatively medium heritability was shown by rest of the characters. Therefore, based on the present study plant height, yield per plant, length of primary finger and leaf length with very high heritability will respond to selection in a better way and the upgradation of these traits can be achieved through direct selection.

Similar experiments on heritability have been done in soybeans (Johnson *et al*., 1955), coriander (Tripathi *et al.,* 2000), coffee (Nikhila *et al*., 2008), wheat (Ali *et al*., 2008), cowpea (Omoigui *et al*., 2006), brinjal (Shekar *et al*., 2012) and sugarcane (Gowda *et al*., 2016).

4.1.4. Genetic advance

Heritability alone may not be helpful in a crop improvement programme and therefore estimates of heritability along with genetic advance are helpful in the prediction of the gain under selection. As per Allard (1960), genetic advance is a selection parameter, which indicates the quantum of improvement of a character that is possible through selection.

Fifteen agronomic characters studied presently showed different levels of genetic advance varying from 15.06% to 74.59% and comparatively higher

genetic advance was shown by yield characters. In the case of growth characters, the highest genetic advance was recorded for leaf area (37.58%) followed by plant height (27.87%), leaf length (23.19%), leaf breadth (16.16%), number of tillers (15.82%) and the lowest genetic advance by number of leaves per tiller (15.06%). Among the yield characters, the highest genetic advance was shown by yield per plant (74.59%) followed by length of secondary finger (52.19%) and diameter of secondary finger (30.82%). The lowest genetic advance was observed in diameter of primary finger (15.40%). Values of genetic advance recorded in the case of number of primary fingers, length of primary finger, number of secondary fingers, length of mother rhizome and diameter of mother rhizome were 17.08%, 27.90%, 20.70%, 22.46% and 24.86% respectively.

Characters possessing high heritability with high genetic advance estimates offer higher selection potential than those with low heritability and genetic advance. Therefore, genetic advance is yet another important selection parameter that aids breeder in a selection programme to develop a superior variety.

Similar works on genetic advance have been conducted by earlier workers in different crops like small cardamom by Hrideek *et al*. (2015), maize by Sesay *et al*. (2016), rice by Adhikari *et al*. (2018), sesame by Kebede *et al*. (2014), chilli pepper by Rafi *et al*. (2014) and linseed by Singh *et al*. (2019). Studies on genetic advance of agronomic characters in wild turmeric are new to science and it will give better information on genetic gain feasible through selection in this crop.

All the agronomic characters of *C. aromatica* investigated show significant variation between the accessions indicating the presence of a strong and diverse genetic base for the crop in the experimental area. *C. aromatica* being a valuable medicinal plant, utilisation of this variability both for conservation and improvement of the species is very important.

4.2. Correlation of agronomic characters

Understanding the nature and intensity of interrelationship between yield and yield contributing traits is a prerequisite for any improvement programmes for sustainable genetic enhancement. The relationship existing between two or more traits under consideration is called correlation and correlation analysis is an important tool to find out the degree as well as direction of relationship prevailing between the characters. Plant breeders always work with yield related components in the selection process and it is very important to evaluate the relative importance of such characters contributing to yield directly or indirectly.

Therefore, to find out the interrelationship existing between fifteen agronomic characters of *C. aromatica*, correlation analysis has been carried out presently using the data recorded from the experimental population raised from sixty two accessions as described elsewhere. In the present experiment number of leaves per tiller revealed significant correlation with the maximum number of characters and number of tillers revealed significant correlation with only one variable (Tables 4.19 and 4.20). Studies on correlation of various growth and yield characters of *C. aromatica* is new to science and therefore the present experiment should provide better understanding of association existing between different agronomic characters in this crop.

Number of leaves per tiller exhibited significant correlation with all the other characters namely plant height, number of tillers, leaf length, leaf breadth, leaf area, yield per plant, number of primary fingers, number of secondary fingers, length of primary finger, diameter of primary finger, length of secondary finger, diameter of secondary finger, length of mother rhizome and diameter of mother rhizome. It points out that these characters possess some inherent interrelationship with number of leaves per tiller.

Leaf length showed significant correlation with plant height, number of leaves per tiller, leaf breadth, leaf area, yield per plant, number of primary

fingers, number of secondary fingers, length of primary finger, diameter of primary finger, length of secondary finger, diameter of secondary finger, length of mother rhizome and diameter of mother rhizome. Diameter of primary finger exhibited significant correlation with plant height, number of leaves per tiller, leaf length, leaf breadth, leaf area, yield per plant, number of primary fingers, number of secondary fingers, length of primary finger, length of secondary finger, diameter of secondary finger, length of mother rhizome and diameter of mother rhizome. Length of mother rhizome revealed significant correlation with plant height, number of leaves per tiller, leaf length, leaf breadth, leaf area, yield per plant, number of primary fingers, number of secondary fingers, length of primary finger, diameter of primary finger, length of secondary finger, diameter of secondary finger and diameter of mother rhizome. Diameter of mother rhizome showed significant correlation with plant height, number of leaves per tiller, leaf length, leaf breadth, leaf area, yield per plant, number of primary fingers, number of secondary fingers, length of primary finger, diameter of primary finger, length of secondary finger, diameter of secondary finger and length of mother rhizome.

Plant height displayed significant correlation with number of leaves per tiller, leaf length, leaf breadth, leaf area, yield per plant, number of secondary fingers, length of primary finger, diameter of primary finger, length of secondary finger, diameter of secondary finger, length of mother rhizome and diameter of mother rhizome. Leaf breadth showed significant correlation with plant height, number of leaves per tiller, leaf length, leaf area, yield per plant, number of secondary fingers, length of primary finger, diameter of primary finger, length of secondary finger, diameter of secondary finger, length of mother rhizome and diameter of mother rhizome. Leaf area showed significant correlation with plant height, number of leaves per tiller, leaf length, leaf breadth, yield per plant, number of secondary fingers, length of primary finger, diameter of primary finger, length of secondary finger,

diameter of secondary finger, length of mother rhizome and diameter of mother rhizome. Yield per plant exhibited significant correlation with plant height, number of leaves per tiller, leaf length, leaf breadth, leaf area, number of secondary fingers, length of primary finger, diameter of primary finger, length of secondary finger, diameter of secondary finger, length of mother rhizome and diameter of mother rhizome. Number of secondary fingers revealed significant correlation with plant height, number of leaves per tiller, leaf length, leaf breadth, leaf area, yield per plant, length of primary finger, diameter of primary finger, length of secondary finger, diameter of secondary finger, length of mother rhizome and diameter of mother rhizome. Length of primary finger showed significant correlation with plant height, number of leaves per tiller, leaf length, leaf breadth, leaf area, yield per plant, number of secondary fingers, diameter of primary finger, length of secondary finger, diameter of secondary finger, length of mother rhizome and diameter of mother rhizome. Length of secondary finger showed significant correlation with plant height, number of leaves per tiller, leaf length, leaf breadth, leaf area, yield per plant, number of secondary fingers, length of primary finger, diameter of primary finger, diameter of secondary finger, length of mother rhizome and diameter of mother rhizome. Diameter of secondary finger revealed significant correlation with plant height, number of leaves per tiller, leaf length, leaf breadth, leaf area, yield per plant, number of secondary fingers, length of primary finger, diameter of primary finger, length of secondary finger, length of mother rhizome and diameter of mother rhizome.

Number of primary fingers showed significant correlation with number of leaves per tiller, leaf length, diameter of primary finger, length of mother rhizome and diameter of mother rhizome. Number of tillers showed significant correlation with only one character namely number of leaves per tiller. Correlation studies help the plant breeder during selection and provide the understanding of yield components.

Table 4.19. Correlation of agronomic characters in the case of *Curcuma aromatica* studied.

Characters	Plant height	Number of tillers	Leaves per tiller	Leaf length	Leaf breadth	Leaf area	Yield per plant	Number of primary fingers	Number of secondary fingers	Length of primary finger	Diameter of primary finger	Length of secondary finger	Diameter of secondary finger	Length of mother rhizome
Plant height	1													
Number of tillers	-0.11204	1												
Leaves per tiller	0.58191*	-0.41119*	1											
Leaf length	0.954768*	-0.14809	0.57805*	1										
Leaf breadth	0.708193*	-0.05364	0.309374*	0.799597*	1									
Leaf area	0.904108*	-0.06933	0.47431*	0.951671*	0.910512*	1								
Yield per plant	0.691342*	0.021472	0.343182*	0.739893*	0.732412*	0.8288*	1							
Number of primary fingers	0.089598	-0.09201	0.282984*	0.081458*	0.021952	0.052083	0.000278	1						
Number of secondary fingers	0.695786*	0.015963	0.44697*	0.71882*	0.599947*	0.762342*	0.856438*	0.036037	1					
Length of primary finger	0.644765*	-0.11233	0.287242*	0.668648*	0.629533*	0.720915*	0.762228*	-0.07794	0.715597*	1				
Diameter of primary finger	0.521473*	-0.14239	0.519281*	0.550476*	0.4898*	0.566543*	0.584444*	0.495361*	0.687428*	0.43867*	1			
Length of secondary finger	0.571476*	0.014965	0.375167*	0.641999*	0.661507*	0.732827*	0.886367*	-0.13229	0.874485*	0.719368*	0.543488*	1		
Diameter of secondary finger	0.508776*	-0.05986	0.253376*	0.58461*	0.628516*	0.672639*	0.823007*	-0.18036	0.769619*	0.826459*	0.460132*	0.913573*	1	
Length of mother rhizome	0.711585*	-0.13151	0.6247*	0.745387*	0.598879*	0.7428*	0.673221*	0.411505*	0.663223*	0.599352*	0.613695*	0.609915*	0.508393*	1
Diameter of mother rhizome	0.744712*	-0.04382	0.445007*	0.791912*	0.712127*	0.823205*	0.80488*	0.059299*	0.715221*	0.70668*	0.450636*	0.737013*	0.69882*	0.793456*

*: significant at 5% level

Table 4.20. Details of the characters correlated.

Character	Number of characters showing significant correlation	Characters correlated
Plant height	12	Number of leaves per tiller, leaf length, leaf breadth, leaf area, yield per plant, number of secondary fingers, length of primary finger, diameter of primary finger, length of secondary finger, diameter of secondary finger, length of mother rhizome, diameter of mother rhizome.
Number of tillers	1	Number of leaves per tiller
Number of leaves per tiller	14	Plant height, number of tillers, leaf length, leaf breadth, leaf area, yield per plant, number of primary fingers, number of secondary fingers, length of primary finger, diameter of primary finger, length of secondary finger, diameter of secondary finger, length of mother rhizome, diameter of mother rhizome.
Leaf length	13	Plant height, number of leaves per tiller, leaf breadth, leaf area, yield per plant, number of primary fingers, number of secondary fingers, length of primary finger, diameter of primary finger, length of secondary finger, diameter of secondary finger, length of mother rhizome, diameter of mother rhizome.
Leaf breadth	12	Plant height, number of leaves per tiller, leaf length, leaf area, yield per plant, number of secondary fingers, length of primary finger, diameter of primary finger, length of secondary finger, diameter of secondary finger, length of mother rhizome, diameter of mother rhizome.

Leaf area	12	Plant height, number of leaves per tiller, leaf length, leaf breadth, yield per plant, number of secondary fingers, length of primary finger, diameter of primary finger, length of secondary finger, diameter of secondary finger, length of mother rhizome, diameter of mother rhizome.
Yield per plant	12	Plant height, number of leaves per tiller, leaf length, leaf breadth, leaf area, number of secondary fingers, length of primary finger, diameter of primary finger, length of secondary finger, diameter of secondary finger, length of mother rhizome, diameter of mother rhizome.
Number of primary fingers	5	Number of leaves per tiller, leaf length, diameter of primary finger, length of mother rhizome, diameter of mother rhizome.
Number of secondary fingers	12	Plant height, number of leaves per tiller, leaf length, leaf breadth, leaf area, yield per plant, length of primary finger, diameter of primary finger, length of secondary finger, diameter of secondary finger, length of mother rhizome, diameter of mother rhizome.
Length of primary finger	12	Plant height, number of leaves per tiller, leaf length, leaf breadth, leaf area, yield per plant, number of secondary fingers, diameter of primary finger, length of secondary finger, diameter of secondary finger, length of mother rhizome, diameter of mother rhizome.
Diameter of primary finger	13	Plant height, number of leaves per tiller, leaf length, leaf breadth, leaf area, yield per plant, number of primary fingers, number of secondary fingers, length of primary finger, length of secondary finger, diameter of secondary finger, length of mother rhizome, diameter of mother rhizome.
Length of secondary finger	12	Plant height, number of leaves per tiller, leaf length, leaf breadth, leaf area, yield per plant, number of secondary fingers, length of primary finger, diameter of primary finger, diameter of secondary finger, length of mother rhizome, diameter of mother rhizome.

Diameter of secondary finger	12	Plant height, number of leaves per tiller, leaf length, leaf breadth, leaf area, yield per plant, number of secondary fingers, length of primary finger, diameter of primary finger, length of secondary finger, length of mother rhizome, diameter of mother rhizome.
Length of mother rhizome	13	Plant height, number of leaves per tiller, leaf length, leaf breadth, leaf area, yield per plant, number of primary fingers, number of secondary fingers, length of primary finger, diameter of primary finger, length of secondary finger, diameter of secondary finger, diameter of mother rhizome.
Diameter of mother rhizome	13	Plant height, number of leaves per tiller, leaf length, leaf breadth, leaf area, yield per plant, number of primary fingers, number of secondary fingers, length of primary finger, diameter of primary finger, length of secondary finger, diameter of secondary finger, length of mother rhizome.

As per the present study except number of tillers and number of primary fingers all the other twelve characters are yield contributing traits and plant breeders can work with these yield contributing traits to enhance the yield of *C. aromatica* for a better variety.

Similar studies on correlation of agronomic characters have been conducted by earlier workers in different crops. Sokoto *et al*. (2012) observed that in wheat, plant height, number of spikes, number of spikelets per spike, leaf area index, crop growth rate, number of grains per spike, total aerial phytomass yield, grain yield, harvest index and 1000 grain weight were the major contributors towards grain yield since these characters had high correlation and thus direct selection for these characters should be major concern for plant breeder. Kassahun *et al*. (2013) concluded that positive association of fatty oil content with essential oil content will facilitate simultaneous improvement through selection for the two traits of coriander.

Correlation studies were also conducted by Konate *et al*. (2016) in rice, Khan *et al*. (2009) in pointed guard, Taha *et al*. (2003) in *Cucumis*, Rohman *et al*. (2003) in mung bean, Tena *et al*. (2016) in sugarcane and Walle *et al*. (2018) in cowpea.

4.3. Character association

Scientific attempts to study the genetics and the relation between major agronomic characters and thereby to practise crop improvement programmes have not been reported in this valuable medicinal plant. Most of the agronomic characters of crop plants are polygenic in nature and the same is the case of this crop also. Such characters show different levels of association due to sharing of common genes. Further, study of association of characters is helpful in grouping of variables and data reduction so as to find out lead characters that can be used in conducting breeding experiments. Characters with higher factor loading could be regarded as lead characters and based on this, selection of promising genotypes could be easily practised in such a way that other agronomic characters associated with the lead characters get automatically selected (Hrideek *et al*., 2008).

Character association in *C. aromatica* has been analysed presently with the help of factor analysis using fifteen variables. Fifteen agronomic characters of *C. aromatica* experimented could be grouped into three factors based on factor loading (Tables 4.21 to 4.23). The first factor group consisted of twelve variables such as leaf area, yield per plant, leaf length, number of secondary fingers, diameter of mother rhizome, length of secondary finger, plant height, length of mother rhizome, leaf breadth, length of primary finger, diameter of secondary finger and diameter of primary finger. The second factor group consisted of two variables namely, number of primary fingers and number of leaves per tiller. The third factor group was occupied by only one variable.

Table 4.21. Factor analysis in the case of *Curcuma aromatica* – Factor loadings.

Characters	Factor I	Factor II	Factor III
Plant height	**-0.859996**	-0.138176	-0.119776
Number of tillers	0.114194	0.455183	**0.760292**
Number of leaves per tiller	-0.563238	**-0.577303**	-0.281193
Leaf length	**-0.906235**	-0.109294	-0.133415
Leaf breadth	**-0.822231**	0.099042	-0.023972
Leaf area	**-0.942312**	0.018915	-0.041730
Yield per plant	**-0.908258**	0.217042	0.118337
Number of primary fingers	-0.102714	**-0.793234**	0.486676
Number of secondary fingers	**-0.882152**	0.110650	0.149158
Length of primary finger	**-0.814314**	0.246313	-0.100140
Diameter of primary finger	**-0.681397**	-0.404826	0.307132
Length of secondary finger	**-0.861082**	0.310262	0.053937
Diameter of secondary finger	**-0.806175**	0.395618	-0.045359
Length of mother rhizome	**-0.823907**	-0.341567	0.123755
Diameter of mother rhizome	**-0.880145**	0.060313	-0.000541

Table 4.22. Factor analysis in the case of *Curcuma aromatica* – Eigen values, percentage of total variance.

Factors	Eigen value	% of total variance	Cumulative eigen value	Cumulative % of variance
I	9.041091	60.27394	9.04109	60.27394
II	1.867882	12.45255	10.90897	72.72649
III	1.089322	7.26214	11.99829	79.98863

Table 4.23. Factor analysis in the case of *Curcuma aromatica* - characters showing association as per factor analysis.

Factors	**Characters**
I	Plant height, leaf length, leaf breadth, leaf area, yield per plant, length of primary finger, diameter of primary finger, number of secondary fingers, length of secondary finger, diameter of secondary finger, length of mother rhizome, diameter of mother rhizome.
II	Number of leaves per tiller, number of primary fingers
III	Number of tillers

First factor consisted of the characters such as plant height, leaf length, leaf breadth, leaf area, yield per plant, length of primary finger, diameter of primary finger, number of secondary fingers, length of secondary finger, diameter of secondary finger, length of mother rhizome and diameter of mother rhizome with factor loadings of -0.859996, -0.906235, -0.822231, -0.942312, -0.908258, -0.814314, -0.681397, -0.882152, -0.861082, -0.806175, -0.823907 and -0.880145 respectively. The second factor was found to be associated with number of leaves per tiller and number of primary fingers with respective factor loadings of -0.577303 and -0.793234. Number of tillers was grouped under the third factor with factor loading of 0.760292.

The characters belonging to the same factor group share common alleles to a considerable extend in their expression and the characters with the maximum factor loading are considered as the lead characters. From this study it is clear that leaf area, yield per plant and leaf length with the maximum factor loadings are considered as the lead characters in the first factor. Number of primary fingers and number of leaves per tiller credited with the maximum factor loading are regarded the lead characters in the second factor. The only lead character with maximum factor loading in the third group was number of tillers. These lead characters could be given due consideration while practising selection and other crop improvement programmes because the improvement of these lead characters will lead to the simultaneous improvement of the other agronomic characters associated with them.

For selection and further crop improvement programmes in *C. aromatica* the characters such as leaf area, yield per plant, leaf length and number of secondary fingers with higher factor loading could be given due consideration so that the bulk of the characters for analysis could be reduced without affecting the outcome of research. Study of association of agronomic characters in different crops is an important approach in determining the

relationship between quantitative morphometric characters since such studies could provide genetic foundation for further breeding and improvement.

The percentage of variance shared by the characters of the first factor is 60.27%, that contributed by the characters of the second factor is 12.45% and that contributed by the characters of the third factor is 7.26%. These three factors cumulatively contribute 79.98% of the total variance of the present experiment population based on the characters studied (Table 4.22).

Factor analysis is an important tool to analyse character association prevailing in crop plants and it has been widely employed for grouping of variables by earlier investigators like Tadesse and Bekele (2001) in grasspea, Radhakrishnan *et al*. (2004) and Hrideek *et al*. (2008) in small cardamom, Yol *et al*. (2010) in sesame, Umamaheswari and Mohanan (2011) in vanilla and Soorya *et al*. (2018) in *Curcuma aeruginosa*.

4.4. Genetic divergence

Identification of diverse lines is one of the important goals of any crop improvement programme because diverse lines are needed for the development of new varieties and defect correction of commercial varieties (Bhanu *et al*., 2017). In this context, sixty two accessions of *C. aromatica* have been subjected to genetic divergence analysis through cluster analysis using the software STATISTICA, following UPGMA (Unweighted Pair Group Method with Arithmetic mean) method to identify the closeness and distance that pertain between the accessions on the basis of fifteen agromorphometric characters.

Cluster analysis grouped the entire accessions into two clusters at a linkage distance of 0.998 (Fig 4.16). The first cluster is composed of fifty nine accessions having maximum accommodation of related genotypes. The first cluster is bifurcated again into two sub clusters at a linkage distance of 0.997. The first sub cluster consists of 28 genotypes and the second sub cluster consisting of 31 genotypes. These sub clusters got again repeatedly

divided into different groups with maximum genetic closeness. The second cluster is occupied by three genotypes such as CUK 6, CUK 46 and CUK 51 and these genotypes bifurcated at a linkage distance of 0.933. The genotypes of the second cluster were collected from dissimilar agroclimatic regions of Kerala (Table 4.24).

Cluster I has got genotypes from all the districts and cluster II has got genotypes from three districts selected namely Thrissur, Kottayam and Thiruvananthapuram. Cluster I is divided to form two sub clusters and these sub clusters again bifurcate to form sixteen groups. All the sixteen groups are genetically related. The sixteen groups are CUK 1 and CUK 32; CUK 5, CUK 7, CUK 11 and CUK 35; CUK 34 and CUK 45; CUK 37 and CUK 57; CUK 12 and CUK 14; CUK 52 and CUK 61; CUK 26 and CUK 44; CUK 55 and CUK 62; CUK 13 and CUK 48; CUK 15 and CUK 22; CUK 8 and CUK 27; CUK 29 and CUK 31; CUK 16 and CUK 19; CUK 17 and CUK 39; CUK 21 and CUK 59 and CUK 40 and CUK 54. These sixteen groups bifurcate at a linkage distance of 0.867. Majority of these related groups are collected from different districts. Therefore, each cluster is a mixture of genotypes collected from different geographical and agroclimatic regions and it stipulates that geographical separation is not an important criterion for genetic distance and closeness between the accessions studied. Genotypes belonging to the same clusters show maximum similarity and it is generally indicated that they show genetic proximity and the genotypes belonging to different clusters are genetically distant from each other thus exhibiting higher levels of divergence in their genetic makeup.

Distantly related accessions can be regarded as the genetically diverse genotypes and hence there is higher scope for the selection of genetically divergent parents for crosses and this will lead to the development of promising and improved planting material. The accessions showing closeness might have developed from similar parental lines and so there is lesser scope for selection process.

Fig. 4.16. Dendrogram showing the diversity of the sixty two accessions of *Curcuma aromatica* studied.

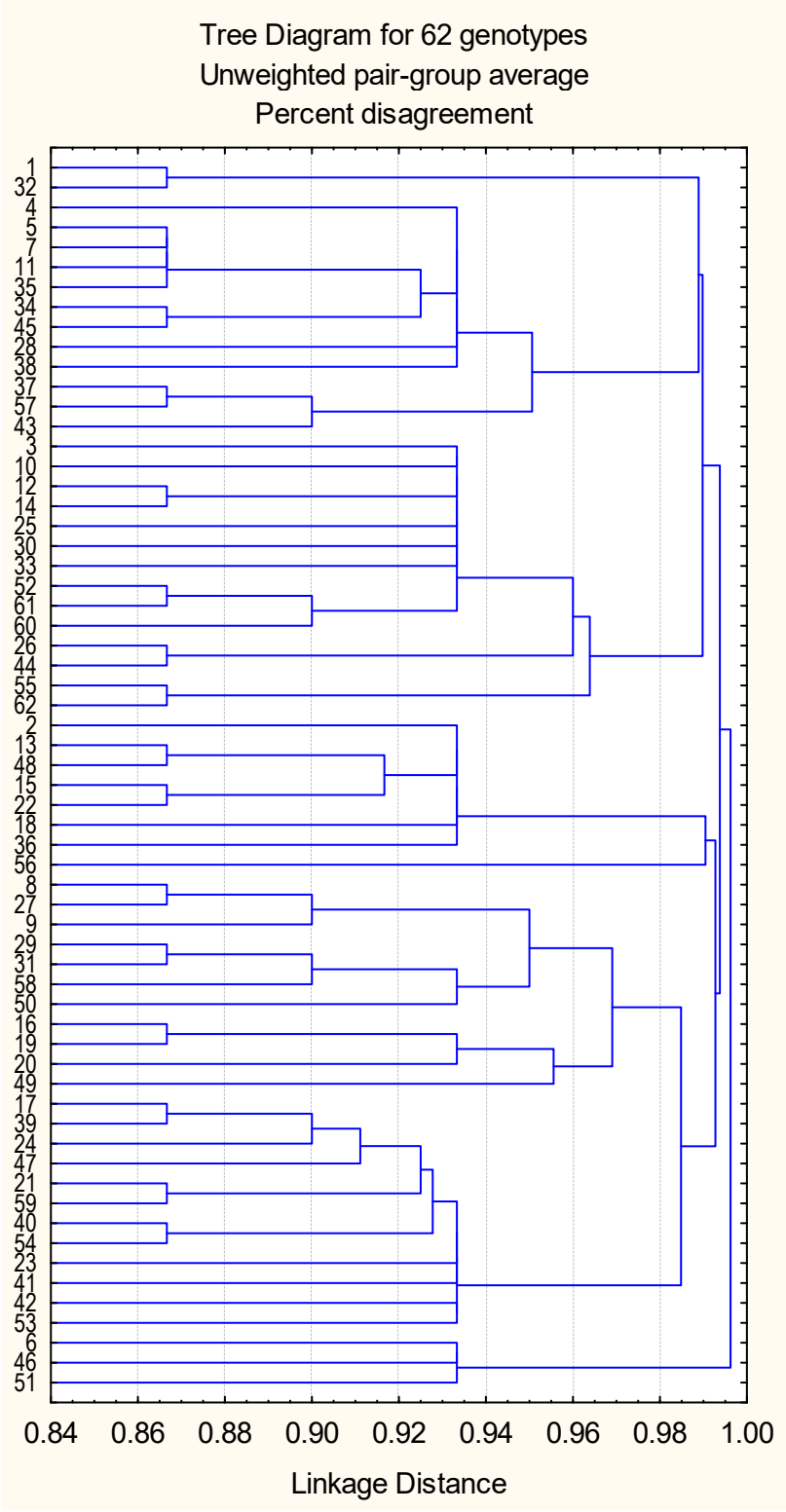


Table 4.24. Clustering of the genotypes studied in *Curcuma aromatica*.

Cluster Number	Sub cluster Number	Accessions
I	IA	CUK 1, CUK 32, CUK 4, CUK 5, CUK 7, CUK 11, CUK 35, CUK 34, CUK 45, CUK 28, CUK 38, CUK 37, CUK 57, CUK 43, CUK 3, CUK 10, CUK 12, CUK 14, CUK 25, CUK 30, CUK 33, CUK 52, CUK 61, CUK 60, CUK 26, CUK 44, CUK 55, CUK 62.
	IB	CUK 2, CUK 13, CUK 48, CUK 15, CUK 22, CUK 18, CUK 36, CUK 56, CUK 8, CUK 27, CUK 9, CUK 29, CUK 31, CUK 58, CUK 50, CUK 16, CUK 19, CUK 20, CUK 49, CUK 17, CUK 39, CUK 24, CUK 47, CUK 21, CUK 59, CUK 40, CUK 54, CUK 23, CUK 41, CUK 42, CUK 53.
II		CUK 6, CUK 46, CUK 51.

The present study reveals the extent of genetic distance and genetic affinity between the different accessions of *C. aromatica* collected from Kerala and subjected for the analysis. Based on this study, most of the genotypes collected presently belong to the same cluster indicating limited genetic variability. The limited variability of crop is an arduous task for a breeder to develop a superior variety and the drain of genetic diversity will prove critical if proper attention is not taken for the conservation of the existing diversity of *C. aromatica*. Cluster II composed of CUK 6, CUK 46 and CUK 51 can be considered as genetically divergent from cluster one. Accession number CUK 6 can be used as promising parental line in hybridisation programmes aimed to developing heterotic cross or selecting most desirable plants. CUK 46 and CUK 51 although they were divergent they performed comparatively low in performance analysis.

Similar works on cluster analysis have been carried out by earlier workers like Radhakrishnan *et al*. (2006) in cardamom, Punitha *et al*. (2010) in sunflower, Syed *et al*. (2012) in chickpea, Reddy *et al*. (2013) in tomato and Janaki *et al*. (2016) and Sharma *et al*. (2018) in wheat. These studies have proved their importance in finding out the genetic distance and genetic closeness of different genotypes of various crops.

4.5. Performance analysis of the *Curcuma aromatica* Salisb. accessions collected

Performance analysis of sixty two accessions of *C. aromatica* has been carried out presently on the basis of the performance indices of major morphometric characters. The cumulative performance index calculated as described earlier can be used to find out the most promising genotypes with the desirable characters for further crop improvement programmes. Of the sixty two accessions of *C. aromatica*, accession number CUK 4 ranked first with a cumulative performance index of 20.68. The accessions CUK 1 and CUK 2 have been placed at the second and third rank with a cumulative performance index of 19.27 and 19.20 respectively. The accessions CUK 3, CUK 12, CUK 6, CUK 10, CUK 5, CUK 7 and CUK 11 ranked from 4 to 10 with a cumulative performance index of 19.16, 18.36, 18.10, 17.65, 17.58, 17.39 and 17.26 in that order (Table 4.25 and 4.26; Figs. 4.17-4.26). These superior accessions possess significantly maximum values of agronomic characters compared to the other accessions and these superior accessions can be subjected to further breeding experiments so that promising genotypes with better agronomic characters can be made available to the farmers.

Similar experiments on performance analysis of different crops for the selection of superior genotypes from the existing germplasm have been carried out by earlier workers such as Chaudhary *et al*. (2006) in turmeric, Hrideek *et al*. (2011) in small cardamom and Chandramohanan *et al*. (2016) in rice.

Table. 4.25. Performance analysis of the accessions of *Curcuma aromatica* studied – Mean value of the characters.

Acc. No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
CUK 1	130.01	1.66	9.79	63.18	16.68	638.36	380.55	6.78	48.66	11.71	2.31	7.41	2.01	7.35	3.85
CUK 2	107.91	1.44	10.90	53.35	15.59	543.54	381.94	7.05	54.89	13.21	2.34	8.40	1.99	8.18	3.80
CUK 3	127.63	1.11	11.05	62.23	15.21	609.80	422.22	7.11	60.66	12.99	2.51	7.06	1.95	7.73	2.88
CUK 4	128.44	1.33	9.72	65.74	17.43	694.56	491.66	6.66	54.00	12.21	2.81	8.06	2.23	8.42	4.17
CUK 5	124.13	1.33	10.83	59.64	15.57	563.59	311.11	6.00	43.44	10.80	2.53	5.76	1.77	7.48	3.64
CUK 6	113.08	1.55	8.09	57.14	17.82	609.40	405.55	5.44	37.22	9.82	2.66	7.42	2.25	6.23	3.63
CUK 7	132.61	1.33	11.89	64.02	15.28	591.29	250.00	5.99	48.22	10.30	2.28	5.95	1.80	6.68	3.33
CUK 8	96.97	1.00	1.00	49.36	14.09	421.14	183.33	7.33	50.00	8.61	1.91	4.42	1.52	6.43	3.26
CUK 9	111.41	1.22	1.00	57.19	15.15	527.34	272.22	6.55	44.11	10.39	2.40	5.80	1.85	7.76	3.96
CUK 10	122.69	1.11	11.72	59.51	15.45	553.46	302.77	6.55	48.11	10.73	2.37	6.20	1.77	7.50	3.73
CUK 11	124.28	1.33	10.44	58.09	14.00	492.30	313.89	6.00	49.66	11.49	2.34	6.02	1.95	6.23	3.38
CUK 12	124.78	1.11	11.00	61.62	16.24	604.91	341.64	6.11	42.77	10.71	2.80	6.86	2.08	7.25	3.86
CUK 13	95.54	1.44	8.88	47.21	12.51	370.71	169.44	5.55	32.44	8.20	2.08	4.22	1.50	6.26	3.33
CUK 14	119.43	1.11	11.00	59.13	14.93	534.75	252.77	5.55	43.55	9.93	2.52	5.31	1.81	7.00	3.66
CUK 15	102.23	1.44	9.27	50.34	13.26	411.55	200.00	5.77	35.11	9.45	2.21	4.33	1.62	5.64	3.10
CUK 16	106.53	1.22	9.88	52.29	12.51	390.83	197.22	5.89	41.44	8.59	2.19	4.52	1.54	6.17	3.31
CUK 17	107.12	1.00	9.55	52.69	15.89	502.87	180.55	6.22	43.33	8.67	2.20	3.54	1.32	6.05	3.02
CUK 18	90.81	1.44	8.05	44.56	12.89	397.43	147.22	5.00	32.77	7.95	2.23	3.38	1.28	5.70	2.83
CUK 19	116.03	1.22	10.83	57.82	15.79	547.83	252.77	5.77	41.44	10.12	2.49	5.64	1.96	6.70	3.50
CUK 20	101.18	1.00	9.00	54.14	15.34	504.66	338.89	5.77	40.33	9.89	2.50	6.29	2.20	6.52	3.50
CUK 21	90.39	1.00	8.55	45.31	12.63	355.94	191.66	6.66	40.00	8.25	2.01	3.05	1.20	5.83	2.86
CUK 22	89.13	1.44	9.05	46.27	12.77	359.09	150.00	5.77	34.78	7.50	1.93	2.86	1.14	5.80	2.88
CUK 23	109.50	1.00	10.27	53.67	14.56	472.93	184.72	5.11	35.33	8.23	2.19	4.09	1.33	5.94	2.78
CUK 24	93.76	1.00	9.11	46.08	14.72	408.89	202.77	4.55	37.33	8.93	2.14	6.09	1.88	5.76	2.90

CUK 25	98.94	1.11	8.89	49.49	15.26	463.41	241.66	4.89	40.44	8.91	2.30	5.76	1.97	5.29	2.87
CUK 26	112.69	1.11	9.05	55.37	14.93	495.75	266.67	6.22	44.22	9.67	2.76	3.99	1.84	6.18	3.09
CUK 27	115.54	1.22	10.00	56.59	14.09	481.24	127.78	6.78	38.27	7.34	1.69	2.24	0.99	6.00	2.80
CUK 28	99.90	1.33	9.39	42.47	12.78	330.81	137.50	7.22	47.67	7.17	2.04	2.55	1.08	5.77	2.53
CUK 29	105.51	1.22	8.22	51.18	14.69	456.38	169.44	6.33	43.33	8.57	2.28	3.43	1.46	6.00	2.77
CUK 30	97.05	1.11	10.22	48.78	11.62	332.99	136.11	5.66	41.44	8.31	1.99	3.23	1.21	5.81	2.51
CUK 31	98.62	1.22	11.39	48.47	13.26	390.35	169.44	7.22	45.11	9.18	2.18	4.68	1.60	7.13	2.65
CUK 32	115.42	1.66	7.53	53.85	14.61	473.27	183.33	6.00	40.44	9.95	2.31	4.78	1.55	6.51	2.99
CUK 33	97.64	1.11	10.33	51.22	14.25	441.90	258.33	7.00	53.88	10.54	2.25	5.62	1.82	5.78	2.93
CUK 34	99.56	1.33	7.50	49.98	14.34	435.32	175.00	6.11	40.33	8.30	2.10	4.49	1.53	5.28	2.68
CUK 35	112.49	1.33	9.11	47.37	12.23	446.32	211.11	6.00	39.39	10.07	2.44	4.67	1.79	6.02	3.04
CUK 36	90.08	1.44	9.08	47.16	14.61	402.28	123.61	6.89	43.44	7.10	1.82	2.33	0.97	6.16	2.53
CUK 37	88.28	1.11	8.72	46.29	13.33	372.40	152.77	6.77	42.11	8.10	2.10	3.73	1.40	5.44	2.78
CUK 38	110.55	1.33	8.00	56.00	14.87	499.46	200.00	5.44	37.00	9.97	2.26	4.85	1.65	5.40	2.71
CUK 39	92.04	1.00	9.11	44.80	12.05	328.91	133.33	6.22	35.88	8.66	2.01	3.20	1.01	5.12	2.43
CUK 40	106.40	1.00	8.44	55.06	14.46	479.29	216.66	6.11	43.55	9.56	2.34	4.65	1.70	6.73	3.02
CUK 41	118.72	1.00	11.55	59.75	14.41	516.81	233.33	5.67	41.55	11.02	2.52	6.74	1.92	7.50	3.39
CUK 42	100.80	1.00	9.44	51.83	16.03	501.50	238.88	5.55	47.00	9.96	2.33	5.84	1.95	6.51	3.04
CUK 43	101.45	1.33	8.72	52.93	16.37	498.78	258.33	4.89	38.55	8.67	2.33	5.41	1.87	5.39	3.15
CUK 44	102.78	1.55	9.05	48.29	13.39	390.32	183.33	6.22	36.11	9.13	2.26	4.36	1.54	5.78	2.63
CUK 45	114.53	1.33	9.83	52.80	13.66	441.45	172.22	6.11	39.22	8.11	2.44	3.40	1.47	6.30	2.82
CUK 46	66.73	1.55	8.36	37.65	11.36	259.31	111.11	4.88	34.00	7.98	1.83	4.19	1.34	4.53	2.19
CUK 47	87.64	1.00	8.83	44.87	12.31	332.62	105.55	5.78	39.66	9.02	2.11	3.93	1.50	4.72	2.43
CUK 48	86.59	1.44	9.05	45.66	13.94	382.63	163.89	6.11	39.33	8.86	2.08	4.00	1.57	5.07	2.48
CUK 49	62.18	2.00	7.20	32.95	11.19	226.33	130.55	5.77	34.89	7.81	1.80	3.65	1.29	4.62	2.09
CUK 50	105.73	1.22	10.11	53.46	14.50	465.72	97.22	7.00	48.22	9.05	2.20	4.14	1.51	6.61	3.00
CUK 51	88.55	1.55	8.11	48.01	14.08	413.55	144.44	7.00	40.89	8.59	2.35	3.74	1.57	6.42	3.11
CUK 52	101.69	1.11	9.83	50.49	14.46	439.80	147.22	6.44	43.50	8.81	2.09	3.81	1.43	6.36	2.89

CUK 53	98.49	1.00	9.67	49.67	12.89	384.22	116.66	7.11	30.67	5.76	1.84	2.82	1.27	6.55	2.67
CUK 54	100.86	1.00	10.78	50.77	13.48	410.05	159.72	6.39	42.67	8.52	2.34	4.56	1.53	6.50	2.77
CUK 55	92.73	1.00	9.89	47.06	14.02	396.18	130.55	7.22	41.77	7.64	2.18	3.34	1.30	6.11	2.66
CUK 56	89.92	1.77	8.33	47.29	13.95	395.70	123.61	6.16	44.05	7.57	2.06	3.89	1.36	5.57	2.43
CUK 57	75.53	1.33	8.72	39.36	12.13	290.45	158.33	6.55	37.11	7.98	2.10	3.86	1.45	5.91	2.69
CUK 58	96.75	1.22	10.27	48.00	14.36	416.40	86.11	6.33	32.33	7.41	1.65	2.66	0.84	5.59	2.44
CUK 59	101.22	1.00	11.33	51.99	14.68	459.58	211.11	6.66	49.33	9.29	2.36	5.29	1.85	6.25	2.85
CUK 60	68.86	1.11	8.16	36.18	10.99	244.27	105.55	5.00	33.55	7.23	1.95	4.18	1.58	4.26	2.12
CUK 61	71.80	1.11	8.55	37.40	11.96	262.67	105.55	7.16	35.00	6.70	2.10	3.13	1.43	5.95	2.52
CUK 62	85.35	1.11	9.16	45.94	13.32	367.96	158.33	6.44	41.77	8.19	2.26	4.64	1.72	6.43	2.66
Mean	102.02	1.25	9.50	50.92	14.12	442.48	205.96	6.17	41.73	9.09	2.23	4.66	1.59	6.20	2.98

1: Plant height (cm); 2: Number of tillers; 3: Number of leaves per tiller; 4: Leaf length (cm); 5: Leaf breadth (cm); 6: Leaf area (cm^2); 7: Yield per plant (g); 8: Number of primary fingers; 9: Number of secondary fingers; 10: Length of primary finger (cm); 11: Diameter of primary finger (cm); 12: length of secondary finger (cm); 13: Diameter of secondary finger (cm); 14: Length of mother rhizome (cm); 15: Diameter of mother rhizome (cm).

Table 4.26. Performance analysis of the different genotypes of *Curcuma aromatica* studied- Performance Indices.

Acc. No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total	Rank
CUK1	1.27	1.33	1.03	1.24	1.18	1.44	1.85	1.10	1.17	1.29	1.04	1.59	1.26	1.19	1.29	19.27	**2**
CUK2	1.06	1.15	1.15	1.05	1.10	1.23	1.85	1.14	1.32	1.45	1.05	1.80	1.25	1.32	1.28	19.20	**3**
CUK3	1.25	0.89	1.16	1.22	1.08	1.38	2.05	1.15	1.45	1.43	1.13	1.52	1.23	1.25	0.97	19.16	**4**
CUK4	1.26	1.06	1.02	1.29	1.23	1.57	2.39	1.08	1.29	1.34	1.26	1.73	1.40	1.36	1.40	20.68	**1**
CUK5	1.22	1.06	1.14	1.17	1.10	1.27	1.51	0.97	1.04	1.19	1.13	1.24	1.11	1.21	1.22	17.58	**8**
CUK6	1.01	1.24	0.85	1.12	1.26	1.38	1.97	0.88	0.89	1.08	1.19	1.59	1.42	1.00	1.22	18.10	**6**
CUK7	1.30	1.06	1.25	1.26	1.08	1.34	1.21	0.97	1.16	1.13	1.02	1.28	1.13	1.08	1.12	17.39	**9**
CUK8	0.95	0.80	1.05	0.97	1.00	0.95	0.89	1.19	1.20	0.95	0.86	0.95	0.96	1.04	1.09	14.85	28
CUK9	1.09	0.98	1.05	1.12	1.07	1.19	1.32	1.06	1.06	1.14	1.08	1.24	1.16	1.25	1.33	17.14	11
CUK10	1.20	0.89	1.23	1.17	1.09	1.25	1.47	1.06	1.15	1.18	1.06	1.33	1.11	1.21	1.25	17.65	**7**
CUK11	1.22	1.06	1.10	1.14	0.99	1.11	1.52	0.97	1.19	1.26	1.05	1.29	1.23	1.00	1.13	17.26	**10**
CUK12	1.22	0.89	1.16	1.21	1.15	1.37	1.66	0.99	1.02	1.18	1.26	1.47	1.31	1.17	1.30	18.36	**5**
CUK13	0.94	1.15	0.93	0.93	0.89	0.84	0.82	0.90	0.78	0.90	0.93	0.91	0.94	1.01	1.12	13.99	41
CUK14	1.17	0.89	1.16	1.16	1.06	1.21	1.23	0.90	1.04	1.09	1.13	1.14	1.13	1.13	1.23	16.67	15
CUK15	1.00	1.15	0.98	0.99	0.94	0.93	0.97	0.94	0.84	1.04	0.99	0.93	1.02	0.91	1.04	14.67	30
CUK16	1.04	0.98	1.04	1.03	0.89	0.88	0.96	0.95	0.99	0.94	0.98	0.97	0.97	1.00	1.11	14.73	29
CUK17	1.05	0.80	1.01	1.03	1.13	1.14	0.88	1.01	1.04	0.95	0.99	0.76	0.83	0.98	1.01	14.61	32
CUK18	0.89	1.15	0.85	0.88	0.91	0.90	0.71	0.81	0.79	0.87	1.00	0.73	0.81	0.92	0.95	13.17	48
CUK19	1.14	0.98	1.14	1.14	1.12	1.24	1.23	0.94	0.99	1.11	1.12	1.21	1.23	1.08	1.17	16.84	13
CUK20	0.99	0.80	0.95	1.06	1.09	1.14	1.65	0.94	0.97	1.09	1.12	1.35	1.38	1.05	1.17	16.75	14
CUK21	0.89	0.80	0.90	0.89	0.89	0.80	0.93	1.08	0.96	0.91	0.90	0.65	0.75	0.94	0.96	13.25	46
CUK22	0.87	1.15	0.95	0.91	0.90	0.81	0.73	0.94	0.83	0.82	0.87	0.61	0.72	0.94	0.97	13.02	50
CUK23	1.07	0.80	1.08	1.05	1.03	1.07	0.90	0.83	0.85	0.90	0.98	0.88	0.84	0.96	0.93	14.17	38
CUK24	0.92	0.80	0.96	0.90	1.04	0.92	0.98	0.74	0.89	0.98	0.96	1.31	1.18	0.93	0.97	14.48	35

CUK25	0.97	0.89	0.94	0.97	1.08	1.05	1.17	0.79	0.97	0.98	1.03	1.24	1.24	0.85	0.96	15.13	24
CUK26	1.10	0.89	0.95	1.09	1.06	1.12	1.29	1.01	1.06	1.06	1.24	0.86	1.16	1.00	1.04	15.93	18
CUK27	1.13	0.98	1.05	1.11	1.00	1.09	0.62	1.10	0.92	0.81	0.78	0.48	0.62	0.97	0.94	13.60	43
CUK28	0.98	1.06	0.99	0.83	0.91	0.75	0.67	1.17	1.14	0.79	0.91	0.55	0.68	0.93	0.85	13.21	47
CUK29	1.03	0.98	0.87	1.01	1.04	1.03	0.82	1.03	1.04	0.94	1.02	0.74	0.92	0.97	0.93	14.37	36
CUK30	0.95	0.89	1.08	0.96	0.82	0.75	0.66	0.92	0.99	0.91	0.89	0.69	0.76	0.94	0.84	13.05	49
CUK31	0.97	0.98	1.20	0.95	0.94	0.88	0.82	1.17	1.08	1.01	0.98	1.00	1.01	1.15	0.89	15.03	25
CUK32	1.13	1.33	0.79	1.06	1.03	1.07	0.89	0.97	0.97	1.09	1.04	1.03	0.97	1.05	1.00	15.42	21
CUK33	0.96	0.89	1.09	1.01	1.01	1.00	1.25	1.13	1.29	1.16	1.01	1.21	1.14	0.93	0.98	16.06	16
CUK34	0.98	1.06	0.79	0.98	1.02	0.98	0.85	0.99	0.97	0.91	0.94	0.96	0.96	0.85	0.90	14.14	39
CUK35	1.10	1.06	0.96	0.93	0.87	1.01	1.03	0.97	0.94	1.11	1.09	1.00	1.13	0.97	1.02	15.19	23
CUK36	0.88	1.15	0.96	0.93	1.03	0.91	0.60	1.12	1.04	0.78	0.82	0.50	0.61	0.99	0.85	13.17	48
CUK37	0.87	0.89	0.92	0.91	0.94	0.84	0.74	1.10	1.01	0.89	0.94	0.80	0.88	0.88	0.93	13.54	44
CUK38	1.08	1.06	0.84	1.10	1.05	1.13	0.97	0.88	0.89	1.10	1.01	1.04	1.04	0.87	0.91	14.97	26
CUK39	0.90	0.80	0.96	0.88	0.85	0.74	0.65	1.01	0.86	0.95	0.90	0.69	0.64	0.83	0.82	12.48	54
CUK40	1.04	0.80	0.89	1.08	1.02	1.08	1.05	0.99	1.04	1.05	1.05	1.00	1.07	1.09	1.01	15.26	22
CUK41	1.16	0.80	1.22	1.17	1.02	1.17	1.13	0.92	1.00	1.21	1.13	1.45	1.21	1.21	1.14	16.94	12
CUK42	0.99	0.80	0.99	1.02	1.14	1.13	1.16	0.90	1.13	1.09	1.04	1.25	1.23	1.05	1.02	15.94	17
CUK43	0.99	1.06	0.92	1.04	1.16	1.13	1.25	0.79	0.92	0.95	1.04	1.16	1.18	0.87	1.06	15.52	20
CUK44	1.01	1.24	0.95	0.95	0.95	0.88	0.89	1.01	0.87	1.00	1.01	0.94	0.97	0.93	0.88	14.48	35
CUK45	1.12	1.06	1.03	1.04	0.97	1.00	0.84	0.99	0.94	0.89	1.09	0.77	0.92	1.02	0.95	14.63	31
CUK46	0.65	1.24	0.88	0.74	0.80	0.59	0.54	0.79	0.81	0.88	0.82	0.90	0.84	0.73	0.73	11.94	57
CUK47	0.86	0.80	0.93	0.88	0.87	0.75	0.51	0.94	0.95	0.99	0.95	0.84	0.94	0.76	0.82	12.79	52
CUK48	0.85	1.15	0.95	0.90	0.99	0.86	0.80	0.99	0.94	0.97	0.93	0.86	0.99	0.80	0.83	13.81	42
CUK49	0.61	1.60	0.76	0.65	0.79	0.51	0.63	0.94	0.84	0.86	0.81	0.78	0.81	0.75	0.70	12.04	56
CUK50	1.04	0.98	1.06	1.05	1.03	1.05	0.47	1.13	1.16	0.99	0.99	0.89	0.95	1.07	1.01	14.87	27
CUK51	0.87	1.24	0.85	0.94	1.00	0.93	0.70	1.13	0.98	0.94	1.05	0.80	0.99	1.04	1.04	14.50	34
CUK52	1.00	0.89	1.03	1.00	1.02	0.99	0.71	1.04	1.04	0.97	0.94	0.82	0.90	1.03	0.97	14.35	37

CUK53	0.97	0.80	1.02	0.98	0.91	0.87	0.57	1.15	0.73	0.63	0.83	0.61	0.80	1.06	0.90	12.83	51
CUK54	0.99	0.80	1.13	1.00	0.95	0.93	0.78	1.04	1.02	0.94	1.05	0.98	0.96	1.04	0.93	14.54	33
CUK55	0.91	0.80	1.04	0.92	0.99	0.90	0.63	1.17	1.00	0.84	0.98	0.72	0.82	0.99	0.89	13.60	43
CUK56	0.88	1.42	0.88	0.93	0.99	0.89	0.60	1.00	1.06	0.83	0.92	0.83	0.86	0.90	0.82	13.81	42
CUK57	0.74	1.06	0.92	0.77	0.86	0.66	0.77	1.06	0.89	0.88	0.94	0.83	0.91	0.95	1.11	13.35	45
CUK58	0.95	0.98	1.08	0.94	1.02	0.94	0.42	1.03	0.77	0.81	0.74	0.69	0.53	0.90	0.82	12.62	53
CUK59	0.99	0.80	1.19	1.02	1.04	1.04	1.03	1.08	1.18	1.02	1.06	1.14	1.16	1.01	0.96	15.72	19
CUK60	0.67	0.89	0.86	0.71	0.78	0.55	0.51	0.81	0.80	0.79	0.87	0.90	0.99	0.69	0.71	11.53	58
CUK61	0.70	0.89	0.90	0.73	0.85	0.59	0.51	1.16	0.84	0.76	0.94	0.67	0.90	0.96	0.85	12.25	55
CUK62	0.84	0.89	0.96	0.90	0.94	0.83	0.77	1.04	1.00	0.90	1.01	1.00	1.08	1.04	0.89	14.09	40

1: Plant height (cm); 2: Number of tillers; 3: Number of leaves per tiller; 4: Leaf length (cm); 5: Leaf breadth (cm); 6: Leaf area (cm^2); 7: Yield per plant (g); 8: Number of primary fingers; 9: Number of secondary fingers; 10: Length of primary finger (cm); 11: Diameter of primary finger (cm); 12: length of secondary finger (cm); 13: Diameter of secondary finger (cm); 14: Length of mother rhizome (cm); 15: Diameter of mother rhizome (cm).

Fig. 4.17. Rhizome of *Curcuma aromatica*
Rank No. 1, Accession No. 4.

Plant height (cm)	:	128.44
Number of tillers	:	1.33
Number of leaves per tiller	:	9.72
Leaf area (cm^2)	:	694.56
Number of primary fingers	:	6.66
Number of secondary fingers	:	54
Yield per plant (g)	:	491.66

Fig. 4.18. Rhizome of *Curcuma aromatica*
Rank No. 2, Accession No. 1.

Plant height (cm)	:	133.01
Number of tillers	:	1.66
Number of leaves per tiller	:	9.79
Leaf area (cm2)	:	638.36
Number of primary fingers	:	6.78
Number of secondary fingers	:	48.66
Yield per plant (g)	:	380.55

Fig. 4.19. Rhizome of *Curcuma aromatica*
Rank No. 3, Accession No. 2.

Plant height (cm)	:	107.91
Number of tillers	:	1.44
Number of leaves per tiller	:	10.90
Leaf area (cm2)	:	543.54
Number of primary fingers	:	7.05
Number of secondary fingers	:	54.89
Yield per plant (g)	:	381.94

Fig. 4.20. Rhizome of *Curcuma aromatica*
Rank No. 4, Accession No. 3.

Plant height (cm)	:	127.63
Number of tillers	:	1.11
Number of leaves per tiller	:	11.05
Leaf area (cm2)	:	609.80
Number of primary fingers	:	7.11
Number of secondary fingers	:	60.66
Yield per plant (g)	:	422.22

Fig. 4.21. Rhizome of *Curcuma aromatica*
Rank No. 5, Accession No. 12.

Plant height (cm)	:	124.78
Number of tillers	:	1.11
Number of leaves per tiller	:	11
Leaf area (cm2)	:	604.91
Number of primary fingers	:	6.11
Number of secondary fingers	:	42.77
Yield per plant (g)	:	341.64

Fig. 4.22. Rhizome of *Curcuma aromatica*
Rank No. 6, Accession No. 6.

Plant height (cm)	:	113.08
Number of tillers	:	1.55
Number of leaves per tiller	:	8.09
Leaf area (cm2)	:	609.40
Number of primary fingers	:	5.44
Number of secondary fingers	:	37.22
Yield per plant (g)	:	405.55

Fig. 4.23. Rhizome of *Curcuma aromatica*
Rank No. 7, Accession No. 10.

Plant height (cm)	:	122.69
Number of tillers	:	1.11
Number of leaves per tiller	:	11.72
Leaf area (cm2)	:	553.46
Number of primary fingers	:	6.55
Number of secondary fingers	:	48.11
Yield per plant (g)	:	302.77

Fig. 4.24. Rhizome of *Curcuma aromatica*
Rank No. 8, Accession No. 5.

Plant height (cm)	:	124.13
Number of tillers	:	1.33
Number of leaves per tiller	:	10.83
Leaf area (cm2)	:	563.59
Number of primary fingers	:	6
Number of secondary fingers	:	43.44
Yield per plant (g)	:	311.11

Fig. 4.25. Rhizome of *Curcuma aromatica*
Rank No. 9, Accession No. 7.

Plant height (cm)	:	132.61
Number of tillers	:	1.33
Number of leaves per tiller	:	11.89
Leaf area (cm2)	:	591.29
Number of primary fingers	:	5.99
Number of secondary fingers	:	48.22
Yield per plant (g)	:	250

Fig. 4.26. Rhizome of *Curcuma aromatica*
Rank No. 10, Accession No. 11.

Plant height (cm)	:	124.28
Number of tillers	:	1.33
Number of leaves per tiller	:	10.44
Leaf area (cm2)	:	492.30
Number of primary fingers	:	6
Number of secondary fingers	:	49.66
Yield per plant (g)	:	313.89

4.6. Performance of *Curcuma aromatica* Salisb. based on the status of the planting material used

C. aromatica is an underutilized medicinal plant has augmented its significance under the changing scenario of shift to herbal sources for pharmaceutical compounds. Moreover, lack of organized cultivation and devastation of its natural habitats have resulted in quick erosion of the genetic stock of this plant. Scarcity of planting material is a major problem in popularizing the crop. Under the circumstances, the present experiment has been carried out to explore the possibility of using the mother rhizomes, primary fingers and secondary fingers of the rhizome as planting material so that the crop can be popularized in a better way.

The effect of the morphological status of planting materials on fifteen agronomic characters was examined. Out of the observed characters, thirteen characters showed statistically significant variations based on the status of the planting material used (Table.4.27). All the growth characters and seven yield characters exhibited statistically significant variations. The characters that showed statistically significant variations are plant height, number of tillers, number of leaves per tiller, leaf length, leaf breadth, leaf area, yield per plant, length of primary finger, diameter of primary finger, length of secondary finger, diameter of secondary finger, length of mother rhizome and diameter of mother rhizome.

Table. 4.27. Observations on the growth and yield characters of *Curcuma aromatica* in relation to the status of the planting material used.

Sl.No.	Characters	Mother rhizome		Primary finger		Secondary finger		CD 5%
		Mean ±SE	CV	Mean±SE	CV	Mean±SE	CV	
1	Plant height	108.51±2.49	17.75	110.87±2.30	16.09	99.05±2.24	17.56	6.51
2	Number of tillers	1.58±0.08	41.14	1.17±0.06	39.32	1.32±0.06	37.88	0.20
3	Number of leaves per tiller	8.93±0.28	24.64	10.53±0.30	21.75	9.74±0.27	21.36	0.78
4	Leaf length	53.89±1.43	20.52	54.44±1.14	16.26	48.69±1.19	18.94	3.49
5	Leaf breadth	14.39±0.31	16.89	14.53±0.25	13.35	13.52±0.30	16.94	0.80
6	Leaf area	483.12±18.74	30.07	481.33±17.13	27.58	400.70±15.48	29.94	47.61
7	Yield per plant	228.33±17.19	58.34	218.33±12.05	42.78	135±7.35	42.20	35.61
8	Number of primary fingers	6.85±0.15	16.93	7.17±0.14	15.62	7.20±0.18	19.58	NS
9	Length of primary finger	11.67±0.31	20.82	12.13±0.27	17.07	10.19±0.29	22.18	0.80
10	Diameter of primary finger	2.41±0.05	17.01	2.42±0.04	13.22	2.04±0.04	16.18	0.14
11	Number of secondary fingers	33.77±1.31	29.97	35.98±1.37	29.41	31.67±1.15	28.26	NS
12	Length of secondary finger	6.79±0.23	26.51	6.84±0.22	25	5.27±0.23	34.54	0.65
13	Diameter of secondary finger	1.94±0.05	19.07	1.92±0.04	15.63	1.54±0.05	16.81	0.14
14	Length of mother rhizome	8.15±0.18	16.81	8.34±0.15	13.67	7.28±0.16	17.31	0.43
15	Diameter of mother rhizome	4.22±0.08	15.17	4.19±0.06	10.74	3.66±0.07	14.48	0.20

Plant height, number of leaves per tiller, leaf length, leaf breadth, length of primary finger, diameter of primary finger, number of secondary fingers, length of secondary finger and length of mother rhizome showed comparatively higher values in the case of plants produced by primary fingers and this difference has been found to be statistically significant except number of secondary fingers. Number of tillers, leaf area, yield per plant, diameter of secondary finger and diameter of mother rhizome revealed maximum values in the case of plants produced from mother rhizomes. Only number of primary fingers showed higher value in the case of secondary fingers as seed material.

In the case of yield, plants raised from mother rhizomes (228.33 g) and primary fingers (218.33 g) as planting materials performed better. Maximum numbers of growth and yield characters are higher in the case of both mother rhizomes and primary fingers. Plants developed from secondary fingers produced the lowest yield (135 g). Conventionally farmers use mother rhizome as planting material. Based on this study it can be proposed that farmers can use mother rhizomes as well as primary fingers as planting material for the large scale cultivation of *C. aromatica* for maximum yield.

Studies in some other rhizomatous crops have disclosed different types of results in relation to the status of the planting materials used. According to Soorya *et al*. (2016b) there was no significant reduction in yield when rhizomes with different statuses are used as seed material in *Curcuma aeruginosa*. Jayasree *et al*. (2014b) recommend the use of mother rhizomes as planting material as it produces better yield over primary and secondary finger planting in *Curcuma amada*. Similarly, Rajagopalan and Gopalakrishnan (1985) observed *Kaempferia galanga* developed from mother rhizome showed significant superiority over other types of planting material. Manhas *et al*. (2010) noticed the use of mother rhizomes as planting material provides higher yield over primary and secondary fingers in *Curcuma longa*.

Chapter V
SUMMARY AND CONCLUSION

Curcuma aromatica Salisb. belonging to the family Zingiberaceae is indigenous to South Asia. This plant proves to be a promising element for the designing and development of novel drugs for several diseases. This aromatic crop is probably the most important among the turmeric members for its unique pharmacological and cosmetic values.

Inappropriate cultivation practices, deforestation, habitat destruction and the high demand from pharmaceutical industries on wild sources make the existence of this plant threatened. In some regions of India *C. aromatica* is replaced by *C. zanthorrhiza* due to the non-availability of *C. aromatica* and therefore the demand for *C. aromatica* is on the rise in order to meet the ever increasing pharmaceutical needs. In addition to over exploitation, the plant species faces threats of changes in landscape ecology caused by climatic and anthropogenic factors. In this context, the present experiments were designed and developed so as to analyse the genetic variability and association and interrelationship of fifteen agronomic characters of *C. aromatica* using standard statistical tools based on the accessions collected from Kerala State of India for the purpose. An effort has also been made to find out the best accessions and also to find out the variation in yield based on the type of planting material used.

The investigations were carried out in the experimental plot of the Genetics and Plant Breeding Division of the Department of Botany, University of Calicut, Kerala, India from 2015 to 2018. Sixty two accessions of *C. aromatica* collected from different parts of Kerala formed the study material. Fresh and healthy rhizomes were collected during December, January and February 2015 and planted for multiplication and preliminary

screening of the seed material in the experimental plot. The evaluation trials and experiments were initiated during the first cropping season of May 2016 before the onset of south west monsoon. Healthy rhizomes of approximately 4 cm – 7 cm length and 25 g – 30 g weight were used as planting material in the case of all the studies. Growth characters were recorded after six months of planting whereas yield characters were recorded at nine months after reaching maturity by destructive sampling.

Frequency distribution analysis of agronomic characters of crop plants will help to analyse the mechanism of genetic control involved in them. Among the growth characters studied three agronomic characters namely plant height, leaf length and leaf breadth showed continuous distribution with skewness towards the distal side of the distribution. Number of tillers showed continuous frequency distribution with skewness towards the proximal end of the distribution. Number of leaves per tiller and leaf area showed a comparatively balanced distribution of genotypes almost equally towards the proximal and distal ends of the frequency distribution. Of the yield characters, seven showed skewness towards the proximal side of the distribution namely yield per plant, number of primary fingers, number of secondary fingers, length of primary finger, diameter of primary finger, length of secondary finger and diameter of mother rhizome. Diameter of secondary finger and length of mother rhizome showed skewness almost equally towards the proximal and distal sides of the frequency. No characters showed higher frequency of dominant alleles in the gene pool of the population. In summary, among the fifteen agronomic characters eight characters showed continuous frequency distribution with skewness towards the proximal side, four characters showed a balanced frequency distribution and only three characters showed continuous frequency distribution with skewness towards the distal side of the distribution.

While showing improved genetic potential in the case of growth characters, most of the yield characters of *C. aromatica* showed continuous frequency distribution with skewness towards the proximal side of the distribution indicating the higher accumulation of recessive contributing factors and therefore scientific selection processes are to be conducted to design and develop varieties with higher accumulation of dominant alleles of these characters. Majority of these characters are yield contributing characters and hence it substantiates the importance of crop improvement programmes for better yield of this immensely valuable crop. Further selection process should be started to develop high yielding varieties of *C. aromatica* so that better yield is ensured to farmers carrying out cultivation of this crop in an organized way.

Plant genetic variability indicates the heritable variations within and between the populations among plant species and it is the basis for selection as well as other plant improvement programmes. Here, evaluation of the genetic variability of fifteen agronomic characters of *C. aromatica* disclosed that all the growth and yield characters studied showed statistically significant variation at 1% level of significance. Value of coefficient of variation determines the variability of the character. Among the growth characters leaf area was found to be the most variable character followed by number of tillers and the least variable character was leaf breadth. Among the yield characters the highest coefficient of variation was shown by yield per plant followed by length of secondary finger and the lowest coefficient of variation was shown by number of primary fingers. Thus out of the fifteen agronomic characters yield per plant, length of secondary finger and leaf area were the most variable characters. Number of primary fingers and leaf breadth were found to be the least variable characters. Statistically significant level of variability in the case of all the studied characters indicates the possibility of selection of

improved genotypes based on the mentioned characters in future improvement programmes of the crop.

Phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV) and heritability (broad sense) of characters can provide an idea of the degree of environmental impact on the agronomic characters of a crop. Among the fifteen characters studied, the highest PCV was shown by yield per plant followed by length of secondary finger and number of tillers and the highest GCV was shown by yield per plant followed by length of secondary finger and leaf area. The lowest PCV and GCV were recorded for leaf breadth. All the agronomic characters studied observed higher values of phenotypic coefficient of variation when compared to corresponding values of genotypic coefficient of variation indicating the polygenic control, additive nature and differential degrees of environmental impacts on the characters under study. Of the growth characters the highest GCV was shown by leaf area followed by plant height and the lowest GCV was recorded for leaf breadth. Among the yield characters the maximum GCV was recorded for yield per plant followed by length of secondary finger and diameter of primary finger showed the lowest GCV. In the case of PCV for growth characters the maximum was recorded for number of tillers followed by leaf area and the lowest for leaf breadth. Among the yield characters the highest PCV was observed for yield per plant followed by length of secondary finger and the lowest PCV was shown by number of primary fingers.

The agronomic characters with low difference between PCV and GCV have got only limited influence of the environment on their expression and this condition favours direct selection based on phenotypic performance of the crop. The differences between PCV and GCV were comparatively higher in the case of yield characters. The differences between PCV and the corresponding GCV were the maximum in the case of number of tillers, yield

per plant and length of secondary finger respectively, indicating comparatively higher impact of environment in the phenotypic expression of these three characters. The characters with least differences between PCV and GCV indicate the limited influence of the environment on the expression of these characters which supports direct selection based on phenotypic performance of these traits for further improvement of the crop.

Crop improvement programmes for quantitative characters require reliable estimates of heritability in order to design an efficient breeding strategy. Heritability plays a predictive role in breeding in which it determines how much of the phenotype would be passed on to the next generation. Hence, all the agronomic characters of *C. aromatica* have been evaluated presently for broad sense heritability. Eleven characters comprising of four growth and seven yield characters showed higher heritability and the remaining four characters showed medium level of heritability. The highest heritability was recorded for plant height followed by yield per plant, length of primary finger and leaf length respectively. The lowest heritability was observed for number of tillers.

With the help of estimates of heritability and genetic advance, a plant breeder can anticipate the intensities of selection and improvement of a crop. Comparatively low to high genetic advance was observed in this study. Highest genetic advance was observed for yield per plant, length of secondary finger and leaf area respectively. The lowest genetic advance was shown by number of leaves per tiller. Among the growth characters the highest genetic advance was shown by leaf area followed by plant height and the lowest by number of leaves per tiller. Among the yield characters studied, yield per plant, length of secondary finger and diameter of secondary finger showed the highest genetic advance and diameter of primary finger showed the lowest genetic advance.

Genotypic and phenotypic coefficients of variation combined with heritability as well as genetic advance are very important for the improvement of any crop. Low heritability, coupled with low GCV, PCV and genetic advance suggests that selection will be less effective for the traits and high heritability coupled with high genetic advance indicate that the traits are controlled by additive gene action. In the present study, yield per plant, length of secondary finger, leaf area, number of tillers, plant height and length of primary finger are the characters showing comparatively higher values of heritability, GCV, PCV and genetic advance, therefore these characters should be given due consideration while practising selection and other crop improvement programmes in *C. aromatica*.

The study of interrelationship among different agronomic characters is useful to plant breeders in selecting genotypes having a group of desired characteristics. Correlation analysis of six growth and nine yield characters was carried out presently using the data obtained from the germplasm of *C. aromatica*. Yield of a plant is a complex trait highly influenced by many genetic factors and environmental fluctuations. In the present study it has been observed that plant height, number of leaves per tiller, leaf length, leaf breadth, leaf area, number of secondary fingers, length of primary finger, diameter of primary finger, length of secondary finger, diameter of secondary finger, length of mother rhizome and diameter of mother rhizome are the major contributors towards yield per plant. Hence, plant breeders can work with these yield contributing traits in order to improve the yield of wild turmeric in a better way.

Association of agronomic characters of *C. aromatica* using fifteen agronomic characters with the aid of factor analysis by means of principal component analysis so as to categorize the agronomic characters into different groups with maximum gene sharing and to find out the lead characters was

carried out. The experimental population consisted of 3348 plants. The fifteen agronomic characters of *C. aromatica* experimented presently could be grouped into three factors based on factor loading. The first factor group was found to be associated with twelve variables such as leaf area, yield per tiller, leaf length, number of secondary fingers, diameter of mother rhizome, length of secondary finger, plant height, length of mother rhizome, leaf breadth, length of primary finger, diameter of secondary finger and diameter of primary finger. The second factor group consisted of two variables namely, number of primary fingers and number of leaves per tiller. The third factor group was occupied by only one variable i.e., number of tillers. Characters belonging to the same factor group share common alleles to a considerable extent in their phenotypic expression. Based on the results it can be concluded that the characters such as leaf area, yield per plant, leaf length and number of secondary fingers with maximum factor loading can be considered as the lead characters which could be given due consideration while practising selection and further crop improvement in *C. aromatica* so that the bulk of the characters for analysis could be reduced without affecting the outcome.

Cluster analysis helps to depict the pattern of relatedness between genotypes based on evolutionary relationship or phenotypic performances. Cluster analysis grouped the sixty two accessions of *C. aromatica* into two clusters at a linkage distance of 0.998. The first cluster was composed of fifty nine accessions exhibiting maximum accommodation of genotypes which are associated. The second cluster was composed of only three accessions namely CUK 6, CUK 46 and CUK 51 and they exhibited closeness at a linkage distance of 0.933 and these three accessions were collected from almost different agro-climatic regions. The first cluster bifurcated into two sub clusters at a linkage distance of 0.997. These sub clusters again repeatedly divided into different subclusters with maximum genetic closeness and distantly related genotypes could be regarded as genetically diverse.

Cluster I has got genotypes from all the districts and cluster II has got genotypes from three districts only namely Thrissur, Kottayam and Thiruvananthapuram.

Genotypes belonging to different clusters show higher levels of genetic divergence in their genetic makeup and those belonging to the same cluster show higher levels of genetic similarity. Therefore, there is a scope to think that genotypes possessing closeness might have evolved from same parental lines; thus there is lesser scope for the selection of genetically divergent parents from the same cluster for crosses. Selection between clusters for better genotypes for use in selection and clonal propagation programmes will lead to the development of novel and improved varieties of this underutilized crop.

Performance analysis was conducted to find out the superior accessions of *C. aromatica* of Kerala. Among sixty two accessions of *C. aromatica* accession number CUK 4 ranked first with a cumulative performance index of 20.68. The accessions CUK 1 CUK 2, CUK 3, CUK 12, CUK 6, CUK 10, CUK 5, CUK 7 and CUK 11 ranked from second to tenth respectively. These superior accessions can be used for further breeding programmes because they possess maximum values of agronomic characters over the remaining accessions so that better genotypes with superior agronomic characters can be made available to the farming community.

Traditionally farmers use mother rhizome as planting material in the case of this crop. However, the availability of sufficient planting material hinders large scale cultivation. Hence a study was carried out to find out the feasibility of using primary and secondary fingers as planting material. In this experiment mother rhizome, primary finger and secondary finger were used as the seed material. The effect of the morphological status of planting materials on fifteen agronomic characters was examined. All the growth characters and seven yield characters exhibited statistically significant

variations. In the case of yield, plants derived from secondary fingers produced the lowest yield. Plants derived from mother rhizomes (228.33 g) and primary fingers (218.33 g) as planting materials performed better. Maximum numbers of growth and yield characters are higher in the case of both mother rhizomes and primary fingers. So based on this study it can be proposed that farmers can use mother rhizomes as well as primary fingers as planting material for the large scale cultivation of *C. aromatica* for maximum yield.

Conservation of the plant genetic diversity is important for present and future human well-being. Information from genetic diversity studies should be of direct value for the conservation and improvement of any species. Therefore, this study has got great importance in the conservation and providing opportunity for plant breeders to develop new and improved varieties of *Curcuma aromatica* Salisb. with desirable characteristics. The study also proposed ten superior genotypes from the gene pool of *Curcuma aromatica* Salisb. collected and this best performing genotypes identified presently could be used for further breeding programmes.

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