MORPHO-PHYSIOLOGICAL CHARACTERIZATION OF LITCHI (*Litchi chinensis* Sonn.) IN WAYANAD

By

SANJAY D. CHAVARADAR

2014-12-131

THESIS

Submitted in partial fulfilment of the requirement for the degree of

Master of Science in Horticulture

Faculty of Agriculture

Kerala Agricultural University, Thrissur

DEPARTMENT OF POMOLOGY AND FLORICULTURE

COLLEGE OF HORTICULTURE

VELLANIKKARA, THRISSUR-680 656

KERALA, INDIA

2016

DECLARATION

I hereby declare that the thesis entitled **"Morpho-physiological characterization of litchi (*Litchi chinensis* Sonn.) in Wayanad"** is a bonafide record of research work done by me during the course of research and the thesis has not been previously formed the basis for the award to me any degree, diploma, fellowship or other similar title, of any other University or Society.

Vellanikkara

Date: 22/09/2016

Sanjay D. Chavaradar

(201412-131)

CERTIFICATE

Certified that this thesis entitled **"Morpho-physiological characterization of litchi (*Litchi chinensis* Sonn.) in Wayanad"** is a bonafide record of research work done independently by **Sanjay D. Chavaradar (2014-12-131)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

Dr. K. Ajith Kumar

(Chairperson, Advisory Committee)
Professor
Department of Pomology and Floriculture
College of Horticulture, Vellanikkara
Kerala Agricultural University

Vellanikkara
Date: 22/09/2016

CERTIFICATE

We, the undersigned members of the advisory committee of **Sanjay D. Chavaradar (2014-12-131)** a candidate for the degree of **Master of Science in Horticulture,** with major field in **Pomology and Floriculture,** agree that the thesis entitled **"Morpho-physiological characterization of litchi (*Litchi chinensis* Sonn.) in Wayanad"** may be submitted by him in partial fulfillment of the requirement for the degree.

22.9.16

Dr. K. Ajith Kumar
(Chairperson, Advisory Committee)
Professor
Department of Pomology and Floriculture
College of Horticulture, Vellanikkara

22/9/2016

Dr. C. K. Geetha
Professor and Head
Dept. of Pomology and Floriculture
College of Horticulture, Vellanikkara

Dr. Rajendran P.
Professor & Associate Director of Research
Regional Agricultural Research Station
Ambalavayal

22/9

Dr. A.V. Santhoshkumar
Professor & Head
Dept. of Tree Physiology and Breeding
College of Forestry, Vellanikkara

22/9/16

EXTERNAL EXAMINER
Dr. J. RAJANGAM

ACKNOWLEDGEMENT

First and foremost, I bow my head before the Great Truth, the ***Almighty****, for enlightening and blessing me with confidence, will power and courage to get through the difficult circumstances faced during the period of study.*

My words cannot express the deep sense of immeasurable gratitude and undoubtful indebtedness to ***Dr. K. Ajithkumar****, Professor, Department of Pomology and Floriculture, College of Horticulture and chairman of my advisory committee. With great respect, I wish to place my heartfelt thanks to him for the inspiring guidance, untiring interest, unstinted co-operation, esteemed advice, constructive criticism, valuable suggestion and immense help rendered during the investigation and preparation of the thesis.*

I am extremely thankful to ***Dr. C. K. Geetha,*** *Professor and Head, Department of Pomology and Floriculture, College of Horticulture and member of my advisory committee for her unfailing support, valuable suggestions and guidance rendered to me for the completion of the research programme and preparation of the thesis. I am genuinely indebted to her for the constant encouragement and affectionate advice rendered throughout the academic programme.*

I am deeply obliged to ***Dr. A.V. Santhoshkumar,*** *Professor and Head, Department of Tree physiology and Breeding, College of Forestry and member of my advisory committee for his support and enthusiasm, relevant suggestions and the facilities provided for undertaking the laboratory studies.*

I am highly thankful to ***Dr. Rajendran P****, Professor and Associate Director of Research Regional Agricultural Research Station Ambalavayal and member of my advisory committee for his support and enthusiasm, relevant suggestions and the facilities provided for undertaking the laboratory studies.*

I am highly indebted to ***Dr. P. K. Sudhadevi,*** *Professor Head, AICFIP, Department of Pomology and Floriculture,* ***Dr. Jyothi Bhaskar,*** *Professor, Department of Pomology and Floriculture,* ***Dr. N. K. Parameswaran,*** *Associate professor, Department of Pomology and Floriculture,* ***Dr. Mini Sankar,*** *Assistant Professor, Department of Pomology and Floriculture, for their valuable and constructive suggestions and guidance rendered throughout the period of pursuance of my post graduation*

With deep reverence, I express my sincere gratitude to ***Dr. S. Krishnan*** *Professor, Department of Agricultural Statistics for his valuable guidance and help during the statistical analysis of data.*

I would like to express my sincere gratitude to ***Dr. Gawas*** *Assoc. Professor, BRS Kannara for his continuous support during my study and related research in identifying pests of litchi.*

I express my heartfelt thanks to ***Dr. Usha*** *Professor, Department of Agricultural Entomology, for her relentless support in and valuable suggestions for my thesis work.*

I sincerely thank the faculty and non teaching staff of the Department of Soil Science for the help and facilities provided for laboratory analysis. I am very thankful to ***Sindhu and Arun*** *for their sincere help during my laboratory analysis.*

I sincerely would like to praise all the non teaching staff and field workers of the Department of Pomology and Floriculture, for their support help and cooperation during the course of my research work.

I would like to acknowledge ***Smt. Smitha Revi*** *Asst. Professor RARS Ambalavayal,* ***Mithusha, Vishnu Savant, Rajeesh P. C.*** *and all teaching and non teaching staff, workers of RARS Ambalavayal for their support help and cooperation during the course of my research work.*

I am deeply indebted to all farmers of Wayanad especially ***Mr. Kuruvilla Joseph*** *a pioneer litchi grower for his relentless support and valuable suggestions during my research work. I also thankful to* ***Chandranathan, Thomas, Deviprasad, Bobby Thomas, Jhonson and Freeny sister*** *for their continuous help and support and allowing to research on their litchi plants.*

I am also thankful to my seniors Vikram, Rajanand, Ajithkumar, Basavaraj, Veeresh, Naresh, Anand, Arun, Jeevan, Rajkumar, Siddesh, Harikumar, Ashish and Deepika for their valuable assistance and guidance during entire period of my research.

Let me express my sincere thanks to my batch mates friends, Andrew Aslam, Sameer, Charan, Ningappa, Jyolsna, Arati, Nimisha for their timely help, joyous company and co-operation.

I thank my juniors Umesh and Arjun for their sincere help, support and encouragement.

I am always grateful to my classmates, UG friends for the help and sincere love.

I take this opportunity to extend my profound gratitude to ***Dr. A. T. Francis,*** *Librarian, College of Horticulture, and other library staff for the facilities offered.*

I also thank computer staff and Arun chettan for their timely help during my pg studies.

The award of ***KAU fellowship*** *is thankfully acknowledged.*

Above all, with gratitude and affection, I recall the moral support, boundless affection, constant encouragement, arm blessings and motivation of my ***Family members*** *without which this endeavour would never have become a reality.*

Sanjay D. Chavaradar

Abbreviations

AOAC - Association of Official Agricultural Chemists

^{0}B – Degree brix

°C – Degree celcius

Coll. – Collection

CV – Co-efficient of variation

cv. - Cultivar

cm – centimeter

et al. - and others

Fig. - Figure

g – gram

i.e., - that is

Kg – kilo gram

M – meter

mg – milligram

mg/g - milligram per gram

ml – millilitre

mm – Millimeter

m^2 - Square metres

nm – Nano meter

PCA – Principal Component Analysis

PCs – Principal Components

PC – Principal Component

% - Per cent

RH - Relative humidity

sp. - Species

TSS – Total soluble solids

UPGMA – Unweighted Pair Group Mean Average

viz. – Namely

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

INTRODUCTION

1. INTRODUCTION

Litchi (*Litchi chinensis* Sonn.) is a subtropical evergreen fruit tree of family Sapindaceae. It is one of the most relished fruit by virtue of its colour and distinct taste. It is native to South China and South-Eastern Asia, and has been widely cultivated for its prized fruit even before 1766 B.C. (Menzel, 1984). The litchi fruit consists of about 60 per cent juice, 8 per cent rag, 19 per cent seed and 13 per cent skin which varies depending upon cultivar and climatic conditions under which it is grown. Nutritional value of litchi per 100 g fresh weight contains 84 g water, protein 0.7 g, carbohydrates 15 g, thaimine 0.02 mg, niacin 1.1 mg, riboflavin 0.07 mg, phosphorous 32 mg, iron 0.7 mg, calcium 4 mg (Deng *et al.*, 1999).

Owing to specific climatic requirement, the successful cultivation of litchi is restricted to very few countries in the world. India and China account for 91 per cent of the world litchi production. India is the second largest producer of litchi next to China. Besides China and India, other important litchi growing countries are West Indies, Brazil, Honduras, Hawaii, Madagascar, Southern Japan, Spain, Mexico, North-eastern Australia, Southern United States, Israel, Thailand, New Zealand, Mauritius, Taiwan, Burma, Bangladesh and Nepal.

In India, litchi accounts for around 1 per cent of the total area with 1.5 per cent production of total fruits in the country, having definite economic significance in its growing areas. The climatic requirement restrict its cultivation to only certain regions. Major litchi producing states are Bihar, West Bengal, Jharkhand, Assam, Punjab, UP, Chhattisgarh and Orissa. There is sizable increase in acreage and production of litchi in India over the years, cultivation of litchi has increased from 74,000 ha in 2009-10 to 84,200 ha in 2013-14. In terms of production it has increased from 4,83,100 MT to 5,85,000 MT during the same period. At present, the area of this fruit cultivation is 84,000 hectares and production is 5,94,000 MT (NHB, 2015). Bihar alone accounts for 40 per cent of production hence, litchi cultivation is a major source of livelihood security for a

large population of Bihar. Litchi is also the source of livelihood for millions of people as it provides both on-farm and off-farm employment. Small and marginal farmers get additional income from litchi plants in their homesteads (NRC, 2015). The important cultivars being grown in India are Shahi, China, Ellachi, Rose scented Bedana, Bombai, Dehradun, Late seedless, Late large red, Purbi, Calcuttia. Bombai, Elaichi *etc.*, Bombai, Elaichi, China are of commercial importance in Muzaffarpur, while Kasba and Purbi are the choicest cultivars of the eastern part of the country (Ray *et al.*, 1984).

There has been a tremendous increase in the export of litchi from India both in terms of quantity as well as value. Quantitatively the export rose from 42 MT in 2011-12 to 108 MT in 2013-14 and the value from 19 lakhs to 84 lakhs during the same year (NHB, 2015). In recent years, the demand of litchi has witnessed a sharp increased in the domestic market and premium price has been realized in the distant south Indian market. Indian litchi is mainly exported to SAARC countries, notably Bangladesh, Nepal, Maldives, Bhutan, and the UAE. The European Union also imports sizeable quantities of litchi.

The litchi is one of the most environmentally sensitive fruit tree. It is adapted to the tropics and warm sub-tropics between 13° to 32°N and 6° to 29° S. It grows best in regions with winters that are short, dry and cool, but frost free with temperature around 15°C or lower for successful flowering and summers that are long and hot.

Since, India has varied agro climatic condition apart from North India, litchi also comes up well in the non traditional areas *viz.*, Karnataka, Kerala and Tamil Nadu in regions lying 900 m above MSL. In Kerala, Wayanad situated in the Western Ghats region has been identified as a potential area for litchi cultivation in recent years. Unlike, Northern Indian condition, flowering in litchi plants in southern parts of our country commences from August-September. This being an off season of the crop, the produce normally fetches premium price in the market when no crop from North India is available. Hence there is enough

potential to commercialize the crop by selecting suitable sites in this region; though basic information on flowering and fruiting in litchi with respect to the subtropical situations is available; the morpho-physiological bases as related to the uniqueness of the off season in Wayanad is yet to be fully understood. Keeping the above facts in view, present investigation entitled "Morpho-physiological characterization of litchi (*Litchi chinensis* Sonn.) in Wayanad" was taken up with the objective to study the flowering and fruit set pattern in litchi (*Litchi chinensis* Sonn.) and the related morpho-physiological parameters under the Wayanad situations of Kerala.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Litchi is sensitive to the growing environment; therefore any change in environmental factors severely affects the productivity and fruit quality. On production side, the major problems are poor plant establishment, less fruiting span, low and irregular yields due to poor flowering and fruit set. Likewise, fruit cracking, browning, rotting of fruits, fruit borer and mites, poor shelf life and lack of suitable varieties in the early and late maturity and good quality fruits are some of the factors hindering the growth of the litchi industry at commercial scale.

Even though litchi prefers an exacting subtropical situation for an excellent cropping and yield, the crop performance under the humid tropic Wayanad region. Unlike the conventional cropping season of April to May in Northern India, the season in Wayanad starts from August and ends in December. This being the off season of the crop, the produce normally fetches premium price in the market when no crop from North India is available. Hence there is an enough potential to commercialise the crop by selecting suitable sites in the region. Though the basic information on flowering and fruiting in litchi with respect to the subtropical situation is available, the morpho-physiological bases as related to the awareness of the off season in Wayanad is yet to be fully understood. Hence an attempt has been made to review the literature on litchi. A brief account of the same is presented below.

2.1 Distribution of litchi

Litchi or lychee (*Litchi chinensis* Sonn.) is the most important member of the Sapindaceae family, which contains more than 1000 species and at least 125 genera, widely distributed throughout the warm subtropics and tropics (Merrill, 1923 and Tindall, 1994).

The litchi genus contains three subspecies: *Litchi chinensis ssp. chinensis; L. chinensis ssp. philippinensis; and L. chinensis ssp. Javensis* (Leenhouts, 1978). Subspecies *philippinensis* is indigenous to the Philippines (Sotto, 2002).

Subspecies *javensis* from the Malay Peninsula and Indonesia. Neither of these two subspecies is grown commercially. Subspecies *chinensis*, the commercial form, originated in Southern China and Northern VietNam, from wild populations recorded in these regions (Wu, 1998; Hai and Dung, 2002).

Litchi cultivation was confined to Southern China and Northern VietNam until the late 17th century (Tindall, 1994; Hai and Dung, 2002). Later it spread to the part of Myanmar bordered with Yunnan, China, in the late 17th century. Trees were taken to India in 1798 (Singh and Babita, 2002), and later to Nepal (Budathoki, 2002) and Bangladesh (Siddiqui, 2002). Litchi was introduced from China to the Philippines earlier than 1916 (Sotto, 2002). The crop reached Australia with Chinese migrants around 1854 (Menzel *et al.,* 1988) and was introduced into southern Africa 50 years earlier (Milne, 1999). The introduction of litchi into Madagascar dates back to 1802, there is evidence that the first litchi trees were imported into South Africa from Mauritius in 1876, the litchi arrived in Florida in the 1880s. The first trees were transported to Hawaii in 1873 by Chinese merchants. Litchi was introduced into Israel in the 1930s. Trees from China were sent to India, Sri Lanka, Myanmar, the Philippines, Cuba, the West Indies and Madagascar. The crop was taken to Australia in the mid-1800s, and to Hawaii and Florida by the early to mid-1900s (Menzel *et al.,* 1989).

In India litchi cultivation is distributed in the states of Bihar, Tripura, West Bengal, Uttar Pradesh, Punjab and Haryana. Of the total production of litchi in India, Bihar tops the rank. Litchi was introduced to South India almost a century ago by some of the enthusiastic planters and government farm from Bihar and Uttar Pradesh. Litchi is grown as homestead tree or as isolated trees in coffee and tree plantations in Chikmaglur, Kodagu, Hassan regions in Karnataka, Wayanad and Idukki regions in Kerala and Dharmapuri, Vellore, Tirunalvelli, Krishnagiri, Lower Pauleny hills, Kallar and Burliac of Nilgiri hills and some parts of Kanyakumari district of Tamil Nadu (Tripathy *et al.,* 2015).

2.2 Botany of litchi

The species is a medium to large evergreen tree, which can grow up to 10–12 m or even 20 m in very old specimens (Zhang, 1997). Its crown is generally round, dense, compact and symmetrical. Trees normally have a thick, straight, short trunk and dark brown-grey bark; however, branches often have V-shaped crotches. In some cultivars, the branches are tightly curved or twisted and hang down to the ground.

The leaves are pinnately compound with 4–7 leaflets about 7 cm long. They are glossy dark green on the upper surface and grey-green on the under surface. The leaflets are arranged in opposite or slightly oblique order along the rachis on short petioles of their own. Leaves of litchi slightly stalked (0.3-.08 cm), lanceolate to oblong-lanceolate, entire or slightly wavy, acute or acuminate and glabrous with and over-age size of 13.5 x 4.15 cm (Pandey and Sharma, 1989). Mature leaflets are usually 5–15 cm long and 2.5–4.0 cm wide, and elliptical to lance-shaped. Lychee produces its leaf flushes, flowers and fruit on the terminals of new growth (Menzel, 1991; Menzel and Simpson, 1994).

Litchi inflorescence is compound recemose which is composed of several multiple branched terminal panicle where the flowers occur in cymes (Pandey and Sharma, 1989). The panicles are normally produced which are generally in mixed form with the lowest buds producing leaves only, the middle buds producing floral buds in the axils of the leaves, and the topmost buds producing only floral branches and sometimes very small leaves that do not persist (Joubert, 1985). Panicles are 10–40 cm long and produce hundreds of small, white, green or yellow flowers, which produce a distinctive scent when the tree is in full bloom.

The flowers are 3–6 mm wide when fully open and rest on 1.5 mm pedicles. They possess a cup-shaped calyx with 4–5 short, serrated sepals, but have no petals. Each flower has 6–10 stamens. Litchi produces three basic types of flower *viz.*, Type I-flowers lack ovules and are functionally male (Male 1 =

M1), they have 6–8 stamens, which produce much pollen. Type II-flowers are hermaphrodite but function as female with a well-developed pistil (two carpels) and stigma (two-lobed), and 5–8 stamens, which do not dehisce. Type-III flowers are male (Male 2 = M2), but have a rudimentary pistil lacking style and stigma, they have 6–8 stamens, which produce plentiful and viable pollen (Stern and Gazit, 1998).

2.3 Phenology

The litchi tree produces a number of shoots each year, either vegetative or floral flushes of growth. Each vegetative flush comprises several leaves and internodes while the floral flush is a terminal inflorescence compound dichasium. Each flush, after it is initiated, grows for sometimes, stops and breaks out again till growth finally ceases and found greatly influenced by environmental condition (Popenoe, 1920). Successive flushes are separated by quiescent periods, during which the expanded leaves darken and thicken. The interval between the start of successive flushes can be as short as 6 weeks, but is twice as long at low temperatures (Batten and Lahav, 1994). A new flush begins only when the leaves of the previous flush have matured or been removed (Menzel *et al.,* 2000; Olesen *et al.,* 2002). New flushes are bright red or brown, turning green to dark green when mature.

Flower initiation in litchi starts from white millet stage, require ascending temperatures and increased soil moistures. Temperatures during the white millet stage will determine the fate of the flower panicle. Healthy terminal buds produce flowers after a period of relative low temperatures (Menzel and Simpson, 1995).

Changes in climatic conditions conducive to vegetative growth seems to bring gradual changes in endogenous levels of certain hormones which are further responsible for stimulating vegetative growth in litchi (Menzel and Simpson, 1995; Davenport, 2000).

Flower induction in litchi takes place in the dormant bud and flower initiation in the initial stages of the growing bud in the dormant period of cool season. This occurs in a sequence of vegetative and reproductive phase. The extent and period of low temperature requirement and moisture stress have been found considerably influencing the fate of panicle emergence and flowering in litchi (Menzel and Simpson, 1988).

Madhou *et al.* (2010) conducted phenological studies over four consecutive fruiting cycles (2003/2004 to 2006/2007) of litchi cultivar Maurtius, reveals that accessions could be grouped into early and late-flowering cultivars, which initiated floral panicles from June to July and July to August, respectively. They suggested that phenotypic differences occurred probably due to environmental conditions rather than to genetic variations.

According to Ali and Lovatt (1995) for effective flowering in cool season, temperature of less than 12 °C for a prolonged period during flower induction leads to more flowering.

Das *et al.* (2004) investigated on flushing pattern and panicle emergence and found that the intraplant variation in flushing and shoot growth pattern was found to influence the overall floriferousness of the litchi plants. All the shoots with second flush emerging during August and the third flush emerging during November were found to bear panicle in the month of February. A higher shoot girth and larger number of leaves per unit shoot length in the second flush was found to be crucial for flower bud differentiation. Cessation of growth of second flush before the emergence of third flush was found to result in panicle emergence. The carbohydrate content of previous season flush appeared to be contributing towards the emergence of third flush and ultimately the panicle as the content was found to decrease during the third flushing.

He also reported that the phenol content of all the flushes was found to increase during the initiation of new flushes. Observations on changes in content

soluble proteins, total free amino acids, proline, phenylalanine, alanine, tryptophane and iso-leucine during different flushings have also been recorded.

Young (1970) reported that chilling intensity of below 7.2°C for 200 h required for floral induction in 'Brewster' lychee in Florida. In India floral initiation of three litchi cultivars occurred in three to four weeks after daily minimal temperatures fell down to 10°C or lower (Shukla and Bajpai, 1974). In the experiments of Batten and Lahav (1981) with constant temperature regimes of 10-35°C, of three litchi cultivars formed flowers only under 10°C. A threshold temperature of 20°C for floral induction of a few lychee cultivars as suggested by Menzel and Simpson (1995).

BiYan *et al.* (2010) studied on different temperature regimes like low temperatures (15°C/8°C), or medium low temperatures (18°C/13°C) during flower induction stage and high temperatures (28°C/23°C) in the morphological differentiation, resulted in low percentage of terminal branches flowering and also reduced the number of flowers per panicle.

Chen and Huang (2005) carried out investigation from 1999-2001 in China, showed that after the appearance of whitish millets (visual sign for floral initiation), floral induction effect was initiated at maximum mean temperatures and accumulated hours (AH) below 10°C between 1 December and 15 January. Mean maximum temperatures and AH in the on year were below 20°C and 160 hours respectively whereas that in the off year was above 21° C and 82 AH.

Higher temperature, good sunshine and adequate soil moisture in the rhizosphere result in improved fruit size and quality of litchi in Muzaffarpur. During the full bloom stage, prolonged cloudy weather and rains limit normal cross pollination and thereby reduce fruit set in litchi. In addition, moist weather results in severe attacks of mite and other insects and also there is incidence of lichen growth on the trunk and branches inducing bark splitting, leading to other fungus infestation in the litchi crop. Apart from this, pre harvest low intensity sunshine decreased ascorbic acid and sugar content in the fruit (Kumar, 2014).

Ray *et al.* (1985) reported strong negative correlation between yield and rainfall during flower and fruit setting.

High intensity of sunlight in summer also causes sun-burning and skin cracking in litchi fruits (Kanwar *et al.*, 1972; Shrestha, 1981). Photoperiod is not vital for fruiting in litchi (Nakata and Watanabe, 1966).

In South India regions of Wayanad and Chettalli have showed temperature difference of $<4^0$C and humidity difference of about 6.5% couples with high rainfall during pre blooming period (June-August) triggers flowering in litchi plants (Nath *et al.*, 2015).

2.4 Variability studies

Sarkar *et al.* (1989) conducted a study on flowering behaviour of litchi in West Bengal where panicle emergence was first noticed in Bedana while Elachi and Nafarpal showed late panicle emergence. Flowering duration varied from 24 days (Kasba) to 14-15 days (Elachi). Percentage flower production (in terms of panicles produced) ranged from 51.1 per cent in Muzaffarpur to 27.6 per cent in Elachi. The ratio of male to hermaphrodite flowers was highest in Elachi (4.71:1) followed by Bedana (4.35:1), and lowest in Kasba (1.79:1).

Galán Sauco *et al.* (2001) investigated behaviour of different litchi cultivars in Canary Islands. Flowering occurred from 08 February to 11 April but full bloom lasted less than one month (11 March to 05 April). Fruit weight ranged between 16.58 g to 30.88 g while fruit length 33 mm and 30 mm in width in all the cultivars, which is more satisfy than the export standards. The TSS ranged between 16.8 °Brix and 20.8 °Brix (Froneman *et al.*, 1999).

Fruit size was reported to be a genetic characteristic of the cultivars and is also used for identification of cultivars. The ratio of fruit length: breadth was used as a measure of roundness/flatness of the fruit. The different shapes like round, elongated and flat fruits were recorded (Singh *et al.*, 1999).

Olesen *et al.* (2002) observed that the successive flushes of trees commencing in February (late summer) and June (early winter) were more likely to flower than trees with flushes commencing in April and August because the weather conditions in June were cooler than those in August and more likely to favour induction in litchi under Australian condition.

Evaluation of litchi cultivars in Pakistan was carried out by Haq and Rab, (2001) reported that maximum fruit weight (23.08 g), pulp weight (16.58 g), TSS (22.13° B) and total sugars (21.57 per cent) was reported in litchi cultivar Gola in Pakistan but also had the maximum fruit cracking (43.50 per cent) than the rest of the cultivars. It also recorded highest reducing sugars (17.98 per cent) but the least non-reducing sugars (3.59 per cent) amongst the cultivars while cultivar Bedana exhibited least reducing sugar (5.67 per cent) and but the most non-reducing sugars of 9.76 per cent.

The performance of 15 litchi cultivars were evaluated by Ullah *et al.* (2001) and reported that highest yield was recorded by Bombai (46.62 kg per plant) while China-3 recorded the lowest yield (1.80 kg per plant). Fruit weight varied from 12.00 g (Sonapur) to 23.00 g (V3, BARI). The percentage of edible portion varied from 57.14 (Bombai) to 78.26 (V3, BARI) under Bangladesh conditions.

Chaubey *et al.* (2001) carried out a correlation studies among plant and fruit characters in litchi (*Litchi chinensis* Sonn.) using twelve genotypes. High genetic correlations were observed between fruit weight and fruit volume, fruit weight and aril weight, fruit volume and aril weight, panicle length and panicle breadth, sex ratio and rind weight, plant height and leaf length, plant height and leaf breadth, plant height and leaf volume, chlorophyll *a* and *b*, and chlorophyll *a* and seed weight.

Genetic diversity study on litchi carried out in Pakistan suggested that cultivars Gola and Bedana had light green to green foliage colour, while Calcutti had light green foliage, and Bombay had darkgreen foliage. In case of leaf length and width of variety, Bombay had maximum, while Bedana showed minimum. As

regards of flush colour, reddish brown flush colour was observed in Gola and Bombay while Calcutti and Bedana had brownish red and dark pink flushes, respectively. Gola and Bombay had 45 leaves/flush, while Calcutti and Bedana had 34 leaves/flush (Khurshid *et al.*, 2004).

A study was conducted during 2000 and 2001, in Nadia, West Bengal on on fruit growth and development of litchi cultivars revealed that the optimum harvesting time after fruit set varied from 54-58 days for Nafarpal, 58-62 days for Piazi and Rose Scented, 62-66 days for Purbi, and 66-70 days Seedless Late. All cultivars showed a sigmoid pattern of growth (Pereiera *et al.*, 2006).

Osuna *et al.* (2008) reported that flower orientation (north or south) on the tree has effect on their sexual expression and found that Type I flowers were more abundant in the south (85 per cent), that in the north (54 per cent).

Maximum fruits length (35.1 mm) and 21.2 g of fruit weight and pulp weight (16.8 g) was noticed in Mauritius variety in Mexico (Aguas *et al.*, 2014).

Yang *et al.* (2014) reported changes of flowering under natural winter conditions of China. The total soluble sugar and starch contents in the dark green leaves were the highest and lowest in the yellowish red leaves. Flowering rate was found highest in trees with dark green terminal shoots whereas those with yellowish green or yellowish red shoots had relatively lower flowering rates. They also reported highest SPAD in dark green leaves followed by yellowish red leaves at the beginning of the trial.

2.5 Flowering and fruit set

Robbertse *et al.* (1995) studied the litchi inflorescence in relation to the position and sex of the flowers in Israel and South Africa which revealed that apical bud of a modular branch can only produce one inflorescence but one or more of the lateral buds, directly below the apical bud, may also be transformed into inflorescences. After the fruits have been harvested one or more of the buds

remaining below the zone of inflorescence production will flush to produce new branches.

Qiu *et al.* (2014) studied the flowering pattern and fruit set of litchi variety Feizixiao. They found difference in time of the first stage of female flowers occurred 15 to 25 days earlier than the second and third stage of female flowers respectively, whereas fruit maturity differed by 7 to 10 days among them. While fruit from the early flowers were bigger and ripened earlier than those from late flowers. They reported that quality of fruit from early flowering was better than fruit from late flowering.

2.6 Pollination and fruit set

Floral anthesis occurs in overlapping cycles, normally of 10 days for Type I, 7–10 days for Type II and 7–10 days for Type III (Groff, 1921). The length of the cycle varies with cultivar and weather, and is much shorter under warm temperatures (Stern and Gazit, 2003). Small insects usually pollinate the flowers (Du Toit and Swart, 1995; Singh and Chopra, 1998; Stern and Gazit, 2003), although sometimes fruit-set can occur in their absence (Batten and McConchie, 1992). In such cases the pollen is possibly carried by the wind. The most important pollinators are the honeybees, *Apis dorsata* and *A. mellifera*, along with *A. cerana* and *A. florae* (Kitroo and Abrol, 1996; Kumar *et al.*, 1996; Stern and Gazit, 1996; Abrol, 1999).

Fruit take 80–112 days to mature depending on the cultivar and weather (Groff, 1921). The fruit are round, ovoid or heart-shaped, varying up to 5 cm long and 4 cm wide. The skin or pericarp is thin, tough, hard and frangible. Fruit are green when immature and various shades of red when mature. The skin has sharp protuberances in some cultivars, but is smooth in others. The fruits normally contain one chestnut brown to dark-brown, ovoid to oblong seed, 1.0–3.3 cm long and 0.6–1.2 cm wide. In some cultivars, a high proportion of seeds may be abortive. The abortive seeds are small and shrivelled and are known as 'chicken tongues'. Fruit with abortive seeds are preferred and often attract a high price, for

although they are somewhat smaller than fruit with normal seeds, they usually contain a higher proportion of flesh.

2.7 Nutrition

Nutrients are the important sources for growth, yield and quality of fruit. Roy *et al.* (1984) reported that yield was positively correlated with leaf nitrogen content. Kotur and Singh (1993) conducted an experiment to standardize litchi leaf-sampling technique in China reported N (1.91-1.59%), P (0.12-0.08%), K (0.81-0.56%), S (0.13-0.10%), Zn (20-15 μg/g), Cu (2G-14 /μg) and Mo (2.32-1.82 μ/g) in September flush sampled at one month interval from 6-year-old healthy trees.

Menzel *et al.* (1992) studied leaves sampling of litchi in subtropical Queensland over three years and suggested that major nutrients such as nitrogen, phosphorus and potassium reached a maximum at flowering, and then declined during fruit development while minor nutrients such as calcium, magnesium, iron, copper, boron and manganese were at a minimum at flowering, and then increased.

High nitrogen reduced flowering while low nitrogen promoted flowering in tissue but critical level of nitrogen is very much essential to encourage the reproductive shoot as well as fruit set in spring. Significant increase in flower bud induction was recorded by the treatment with ethrel which also reduced the vegetative flush (Wada and Shinozaki, 1985; Chen and Ku, 1988).

Yanping *et al.* (1996) suggested that maximum amount of nitrogen and the less of potassium was required in earlier stage of litchi fruit growth and development. However, in the later stage potassium requirement of litchi fruit growth was more to nitrogen. They also reported physiological fruit drop in the earlier stage were closely related to nitrogen for the first and potassium for the second, but the opposite in the later stage, fruit nutritional state maintain the lowest level during the peroid of embryo abortion, to be related directly with the middle stage fruit drop.

Li *et al.* (2001) reported that nitrogen fertilizing significantly increased nitrogen concentrations in the soil and in the leaves and found that concentrations of leaf nitrogen were in the range of 1.1 to 2.4 per cent for 'Brewster' and 1.1 to 2.7 per cent for 'Mauritius'. Trees received with high rates of nitrogen showed an increased frequency and intensity of vegetative flushing and less flowering.

The study carried out by Mandala *et al.* (2014) to measure the effect etherel and cincturing for induction of flowering in 'Bombai' litchi. The result showed that plants treated with ethrel (2 ml/L) had the highest C/N ratio both in leaves (6.58) and shoots (12.04) before flowering. They also recorded the average leaf nitrogen content varied between 1.71 and 1.80 per cent.

Mallik and Singh (1965) found no relationship between leaf phosphorus and nutrient supply. Menzel (2002) found that leaf potassium concentrations was below 0.80% in many of litchi orchards in South-east Asia and Australia. Deng *et al.* (1994) reported that potassium affects photosynthesis of litchi.

Low boron concentrations in litchi exhibited small fruit with a low pulp recovery. However, high boron concentrations are generally required for satisfactory fruit set in plants but deficiencies reduced flowering and pollination, whereas vegetative growth was often unaffected (Dutt, 1962; Hanson and Breen, 1985).

Li and Huang (1995) found strong correlation between cracking and total calcium concentration in different tissues of skin and found less calcium concentration on cracked fruits. Further studies by Huang *et al.* (2001) showed that the concentration of the nutrient in the cell wall as pectin-bound calcium was higher in the skin of the resistant cultivar 'Wai Chee' ('Huaizhi') than in the skin of the susceptible cultivar 'No Mai Chee' ('Nuomici').

Hossain *et al.* (2014) conducted a study in Bangladesh on two litchi varieties *viz.*, China-3 and Mongolbari, to examine the effects of foliar application of different nutrient solutions on fruit setting, cracking and quality. China-3

exhibited maximum of total soluble solids (21.23 ^{0}B), total sugar (14.20 %), reducing sugar (10.58 %), pulp pH (4.54) and sugar/acid ratio (52.66). While variety Mongolbari showed the maximum non-reducing sugar (3.66 %), vitamin C (30.32 mg/100 g) and titratable acidity (0.58 %) content.

Nath *et al.* (2012) showed pruning of litchi branches at 40 cm and spray of borax @ 1.0% or 0.5% resulted in the yield of 26.77 kg/plant and 26.43 kg/plant respectively.

2.8 Fruit quality

Singh and Singh (1954) reported 0.20 to 0.64 per cent titrable acidity in Indian cultivars. Among organic acids malic acid is the predominant which accounts for 80 per cent of total acid present in the various litchi cultivars (Mathew and Pushpa, 1964; Chan and Kowk, 1974).

Physical changes during fruit development of litchi fruits were recorded in plateau region of Ranchi by Singh *et al.* (1999). During early growth, Kasba was significantly superior in fruit weight whereas Purbi was the best in case of volume while at maturity period, Kasba showed highest fruit weight (18.07 g) which was at par with Purbi (17.99 g). The fruit volume was maximum in Purbi (16.30 ml) being at par with Kasba. The specific gravity was highest (1.18) in Kasba followed by Deshi (1.14). The colour of the fruits were reddish with bottom yellowish in Purbi while it was light reddish in other cultivars.

Chaudhary *et al.* (2004) investigated on effect of bee pollination, open pollination and self-pollination on the fruit morpho-physiological characters of litchi. All the characters varied very closely but the fruits obtained from the bee pollinated trees were significantly bigger than those obtained from the self-pollinated and open pollinated trees.

Bhattacharjee *et al.* (2001) conducted correlation study in litchi variety Muzaffarpur, Early Bedana and Early Large Red which showed positive

correlations with weight of peel and total soluble solids content. In contrast, a significant and negative correlation between total soluble solids and peel weight was recorded in Bombai whereas the total sugar content of fruit pulp in all the cultivars exhibited a negative correlation with weight of peel.

Dwivedi *et al.* (2000) studied fruit traits in litchi cultivars in Nadia. Globose fruit shape found in cultivars Bedana and Naffarpal while oval or oblong shape was found in Deshi, Early Large Red, Early Muzaffarpur, Mclean, Muzaffarpur and Rose Scented but Bombai fruits were heartshaped. Peel colour was mostly red or brown. Fruits of Bedana and Elachi were very sweet, while those of Kasba, Mclean and Rose Scented were less sweet.

Studies on physico-chemical characters of litchi by Ranjan *et al.* (2002), under Bihar plateau condition showed that the highest fruit weight (23.89 g) was recorded in Kasba and volume (22.10 C.C.), stone weight (5 g) and pulp weight (15.45 g), whereas Early Bedana recorded the highest pulp:stone ratio (9.48). Fruits of Early Bedana recorded the highest juice content (69.04 %), juice per rag (8.31 per cent) and total soluble solids TSS/acidity ratio (38.72), whereas fruits of Deshi recorded the highest acidity (0.71 %).

Sahay and Kumar (2007) conducted an experiment to study the fruiting behaviour of different litchi cultivars. Variety Kasba recorded maximum fruit length of 3.96 cm followed by Purbi (3.86 cm) and minimum in Bedana (2.05 cm) while fruit breadth was found maximum in Lal Bombai (3.75 cm) whereas minimum in Bedana (2.2 cm). China exhibited highest TSS/acid ratio (72.92) followed by Purbi (63.90) whereas Green (25.44) possessed significantly least TSS/acid ratio under Bihar conditions.

Singh *et al.* (2010) evaluated litchi varieties grown in Bihar for fruit quality and yield. The highest fruit weight of 21 g was recorded in variety Shahi. The minimum skin percentage was recorded in Mandraji and maximum in Kasba. Late Bedana fruits had markedly higher aril percentage while those of Kasba had

the least percentage. Total soluble solid content of juice was maximum in Shahi and minimum in Kasba. Shahi fruits had minimum acid content while both Shahi and China showed higher TSS/acid ratio.

Nath *et al.* (2012) conducted an investigation on physico-chemical properties at Ranchi using different rates of pruning and chemical spray. Results revealed that spraying of borax @ 0.5 per cent or 1.0 per cent increased TSS (17.42 0Brix), ascorbic acid (51.82 mg/100g fresh fruit), total sugar (15.33 per cent) and reducing sugar content (11.10 per cent) of litchi fruits but decreased the acidity percentage.

Singh and Nath (2015) identified important clones (i) for higher fruit weight clones *viz.*, A26, A11, and A15 showed better performance, resulting 22.29 g 21.75 g and 21.21 g of fruit weight respectively, (ii) for high TSS clones *viz.*, T9 (20.88 °Brix), A23 (20.16 °Brix) and T5 (19.88 °Brix) performed well (iii) for small seeds (A26 (1.18g/seed), A25 (1.37g/seed) and A27 (1.95g/seed) and (iv) for high pulp percentage A26 (72.96%), T15 (69.83%) and T14 (68.63%) were performed better.

2.9 Fruit physiology

Litchi follows sigmoidal growth curve. In the initial stage the seed and the pericarp development is simultaneous, followed by aril growth. The same growth pattern can be seen over the different genotypes except late maturing cultivars where the initial slow growth phase is prolonged (Huang and Xu, 1983; Paull *et al.*, 1984).

Differences in the ratio of the sugars are the result of differences in invertase activities, stages of maturity and cultivars. Water-soluble pectin and total pectin have also been shown to increase during ripening, whereas acid soluble pectin declines (Singh and Abidi, 1986). Titratable acidity and total identified acid decreases during development and pH increases (Paull *et al.*, 1984). At maturity malic acid accounts for 80% of the titratable acids while citric,

succinic, levulinic, glutaric, malonic and lactic acids account for the remaining 20% (Chan and Kwok, 1974; Paull *et al.*, 1984)

Litchi fruits having edible aril surrounded by an anthocyanin rich pericarp. During maturity the colour of the pericarp changes from green to reddish pink with decreasing chlorophyll content and increasing anthocyanin synthesis (Underhill and Crichtley, 1992).

Perira *et al.* (2006) indicated two distinct phases of fruit growth, first phase was characterized by peel and seed growth and the second phase was characterized by aril growth. Fruit weight, aril weight, and aril:seed ratio, TSS:acid ratio and total sugar content increased whereas seed weight decreased as the fruits approached maturity. Titratable acidity and vitamin C content of fruits increased during early stages of fruit development but decreased towards maturity.

Physico-chemical changes during fruit development of litchi cultivar Rose Scented indicated that the initial phase of fruit growth i.e. 40 days after full bloom was mainly contributed by peel and seed growth and the later phase of growth until maturity is contributed to rapid pulp growth (Singh *et al.*, 2013).

Singh *et al.* (2013) with the advancement of age there is increase in fruit size, fruit weight, peel weight and specific gravity but peel thickness showed declining trend in litchi fruits. Seed size and seed weight showed increase until appearance of pulp, then showed a declining trend. Simultaneous occurrence of chlorophyll degradation and anthocyanin synthesis led to the development of red colour at maturity. Pulp pH, total soluble solids, total soluble solids to acid ratio and ascorbic acid increased, while titratable acidity decreased with advancement of maturity.

2.10 Maturity index

In practice, maturity is usually assessed on fruit color and flavour but colour is the most commonly used harvest index. However, the relationship between the pericarp colour and fruit maturity varies with cultivar, region of cultivation and cultural practices.

Batten (1989) suggested that TA and TSS/TA ratio were both good indicators of flavour but TSS (degree Brix) was not a reliable maturity index.

Underhill and Wong (1990) recommended a TSS/TA ratio of 30-40 is optimum stage of maturity. Fruit with a TSS/TA ratio of greater than 80:1 are considered to be over mature and most cultivars lose flavour if they are harvested when over mature.

Badiyala (1993) investigated maturity standards for 'Muzaffarpur' litchi and concluded the TSS/acidity ratio was greatest in fruit harvested 78 days after fruit set and the optimum harvest date was 73-78 days after anthesis.

2.11 Yield

An average number of 4000 to 5000 fruits yielding 80 to 150 kg per tree in Uttar Pradesh. Minimum yield of 60 kg was reorded from harly Seedless cultivar and Calcultia Late cultivar gave a maximum yield of 130 kg (Vyas, 1938).

On an average 80-150 kg fruits were recorded in a full grown tree under Punjab conditions (Nijjar, 1972). Jawanda and Singh (1977) observed 60-130 kg fruit/tree among different cultivars grown at Gurdaspur in Punjab.

Ray *et al.* (1985) in Bihar recorded significant difference in the yield potential of five cultivars *viz.*, Rose Scented, Shahi, China, Purbi and Bedana. Highest yield (115.24 kg/tree) recorded in Rose scented followed by Shahi (102.64 kg/tree) while China yielded 82.16 kg/tree. Purbi and Bedana recorded the yield of 87.96 kg/tree and 79.44 kg respectively.

Menzel and Simpson (1986) recorded yield/tree in cultivar Bengal (28.5 kg), Jaiso (24.5 kg), Wai chee (21.3 kg) and Gee Kee (6.5 kg) under Australian conditions.

2.12 Post harvest studies

The major factors reducing the storage life and marketability of litchi are pathological decay and pericarp browning. Low temperature storage has been used to reduce pathological decay but has a limited role in reducing pericarp browning. Pericarp browning is induced by desiccation, and consequently methods to reduce desiccation help retain red color.

Swarts and Anderson (1980) reported that litchi can be stored for up to 30 days at 0-1°C which are used for export of litchi fruit from South Africa. Kadam and Deshpande (1995) recommended temperatures of 5°C for two weeks of storage and temperatures of 7°C for 3-4 weeks of storage. Bhullar *et al.* (1983) reported that the storage life of the litchi can be extended with the use of fungicides.

Controlled atmospheres of 5 per cent O_2 and 3-5 per cent CO_2 prolonged storage life and quality of the fruit and reduced pericarp browning and polyphenol oxidase activity. Modified atmosphere packaging is used to a limited extent (Chen *et al.*, 1982; Kader, 1994).

Tongdee *et al.* (1982) reported chilling damage to benomyl-treated fruit packed in punnets and wrapped in PVC film, after 30 days at 0 and 5°C.

2.13 Physiological disorder

Pericarp browning is the major postharvest problem of litchis. Browning of litchi fruit was rapid and decay was prevalent after 2-3 days at 20°C. Paull and Chen (1987) found that temperatures of 2°C resulted in slower pericarp browning and decay than 22°C. Joubert and van Lelyveld (1975) found that the mesocarp cells were the first to turn brown, followed by the epicarp and endocarp.

The structure of litchi pericarp favours water loss and there is no water conducting tissue between aril and pericarp, thus there is no way for the pericarp to absorb water from the pulp to replenish. After water loss exceeds a certain extent, the pericarp turns brown (Chen *et al.*, 2001).

Underhill and Critchley (1995) observed pericarp browning initially on the protuberances of the pericarp. Later this extended over the entire surface of the pericarp, mainly in the epicarp and upper layers of the mesocarp.

2.14 Pests and diseases

Erophyid mite (*Aceria litchi*) is distributed all over the litchi growing areas of India (Puttarudriah and Basavanna, 1959). Both nymphs and adults attack on leaves. Apart from leaves infestation mites also caused malformation of inflorescence (Das and Choudhary, 1958).

Kumar *et al.* (2013) identified green looper (*Thalassodes pilaria*) on litchi trees in Bihar during surveys of farmer fields also noticed that larvae of *T. pilaria* fed on tender foliage and resembled a green stick similar to the midrib of leaves or thin shoots that served as a camouflage for the pest.

Kumar *et al.* (2014) identified three new insect pests in litchi *viz.*, red weevil (*Apoderus blandus*), semilooper (*Anisodes illepidaria*) and bagworm (*Eumeta crameri*) and one disease *viz.*, leaf and twig blight (*Colletotrichum gloeosporioides* and *Gloeosporium* sp.) during the surveys of litchi orchards in Bihar. Red weevils were dominant around the year except extreme cool and hot weather months, while bagworms from November to February and semiloopers were prevalent from September to February. Red weevil and semilooper damaged young leaves whereas bagworm preferred older leaves. The incidence of leaf and twig blight disease was damaged leaf from 28.1 to 66.3 per cent.

In changing climate scenario the new emerging plants *viz.*, litchi looper (*Perixera illepidaria*), litchi bug (*Tessaratoma javanica* Thunberg), bag worm

(*Eumeta camera* Westwood), red weevil (*Apoderus blandus*) are becoming major threat to litchi production in India. Litchi looper (*Perixera illepidaria*) has been identified from July to December with peak activity in September-October attacks tender leaves in mass and defoliate the new shoots. Litchi bug (*Tessaratoma javanica*) identified in cool regions of Jharkhand, Bihar, Uttar Pradesh, Punjab, Himachal Pradesh and Jammu and Kashmir. Both adult and nymph suck sap from tender parts of leaves, growing buds, fruit stalks and tender branches. While bag worm (*Eumeta camera*) larvae infested older leaves and bark. Red weevil (*Apoderus blandus*) are active feeder on litchi leaves, shoot and flower, sometimes irregular nibbles and consume the entire leaf leaving only midrib (Kuldeep and Nath, 2015).

Red rust (Sharma *et al.,* 1972) and leaf spot (Tandon *et al.,* 1952; Prasad, 1962) are the important fungal diseases reported in litchi.

Anthracnose is one of the common post harvest diseases affecting litchi (Johnson, 1989). It is caused by *Colletotrichum gloeosporioides*, although *C. acutatum* plays a minor role in Australia (Johnson *et al.*, 2002).

MATERIALS AND METHODS

3. MATERIALS AND METHODS

1. MATERIALS

The study entitled "Morpho-physiological characterization of litchi (*Litchi chinensis* Sonn.) in Wayanad" was carried out during 2015-2016 at Wayanad district (Plate 1), of Kerala under the Department of Pomology and floriculture, College of Horticulture, Vellanikkara. The details of the materials used and methods adopted during the course of the investigation are given below.

2. LOCATION

The Wayanad region lies between 11° 60' North latitude and 76° 08' East longitude at an altitude of 1000 m above mean sea level and enjoys mild sub-tropical climate. Thirty two collections of litchi from different location of Wayanad formed the material for the study. The litchi collections maintained in the Regional Agricultural Research Station (RARS) Ambalvayal and farmers fields in Wayanad district used for the study.

3. OBSERVATIONS

Observations were recorded from individual plant. The observations on tree characters, floral characters, fruit characters, quality attributes recorded as per descriptor prescribed by IPGRI, (2002) for litchi.

3.1 Observations on tree character

The following tree characters were observed and recorded.

3.1.1 Age of the tree

Age of the tree was recorded from the registers maintained in the RARS Ambalwayal and the details collected from farmers.

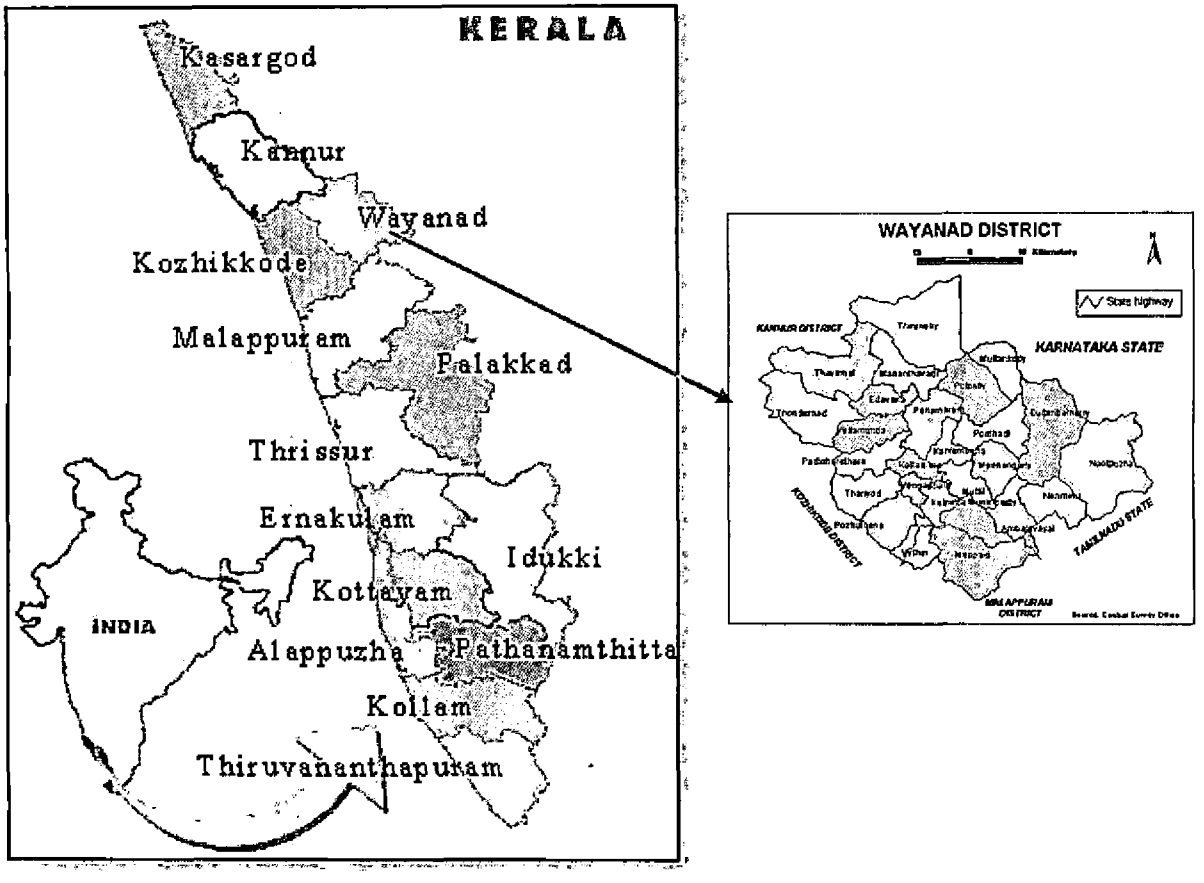


Plate 1. Location map

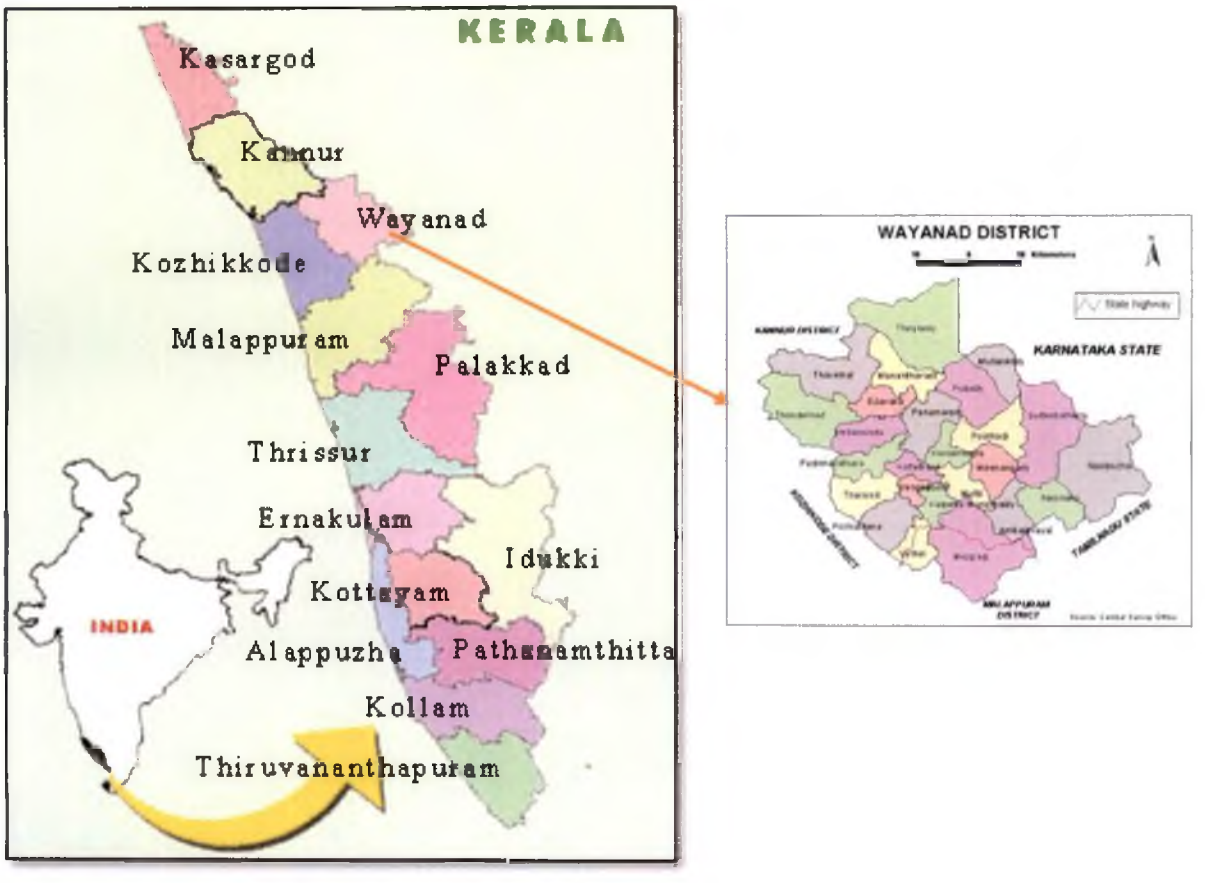


Plate 1. Location map

Plate 2. Mr. Kuruvilla Joseph, pioneer in litchi cultivation

3.1.2 Tree height

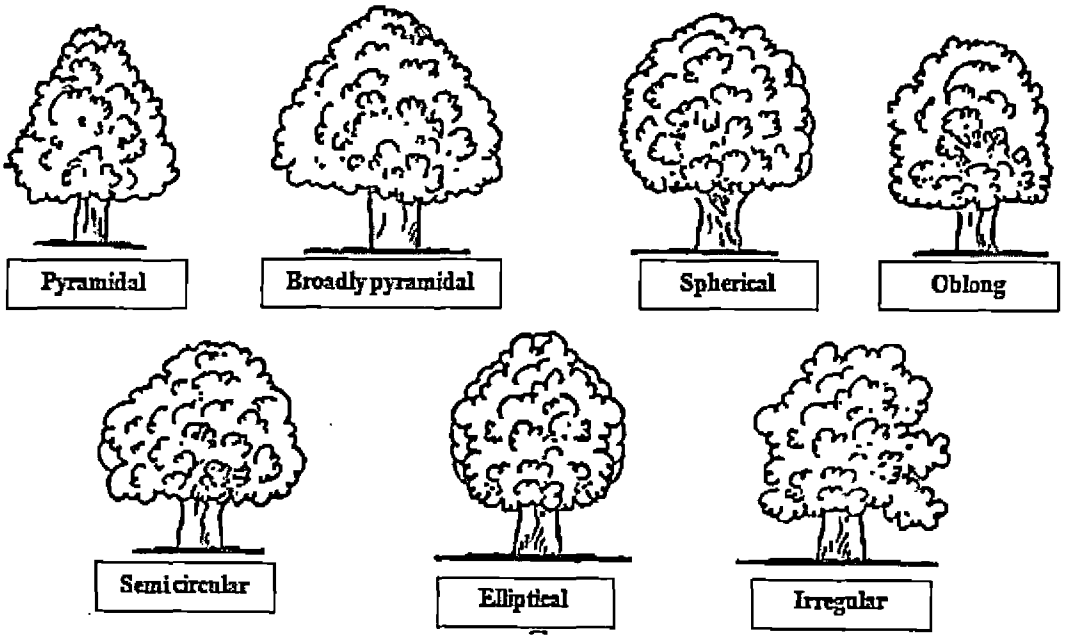
Height of the each tree was measured from ground level to top of tree by using the instrument haga altmeter and measuring tape and expressed in meter (m).

3.1.3 Trunk girth

Girth of the tree was measured at 50 cm above the ground and expressed in (cm).

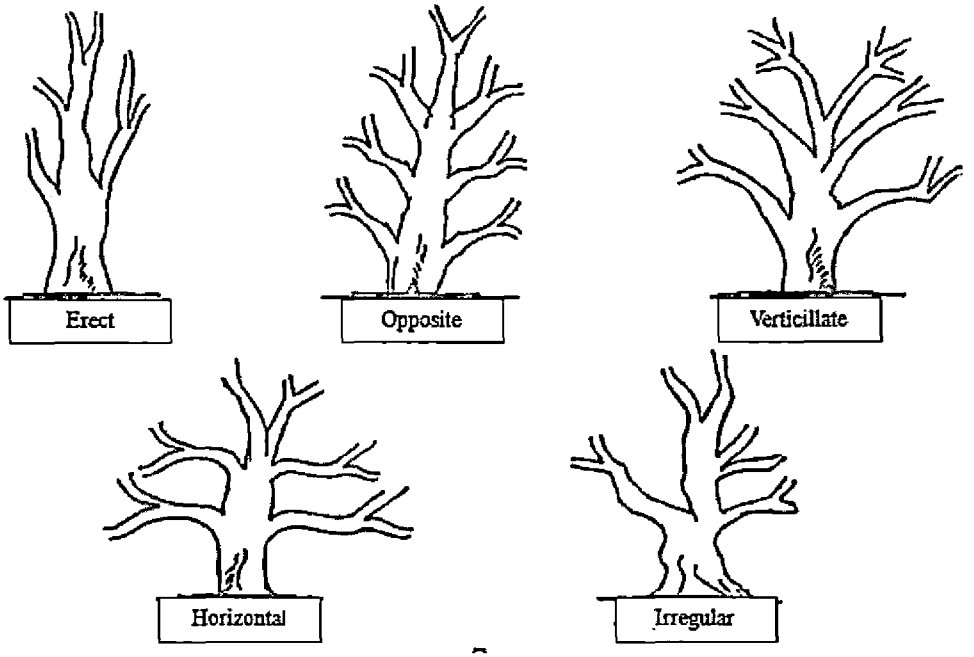
3.1.4 Crown shape

Crown shape of the trees observed and classified into seven groups namely pyramidal, broadly pyramidal, spherical, oblong, semi-circular, elliptical and irregular.



3.1.5 Branching pattern

Branching pattern of the trees were observed and were classified into five groups namely erect, opposite, verticillate, horizontal and irregular.



3.1.6 Leaf length

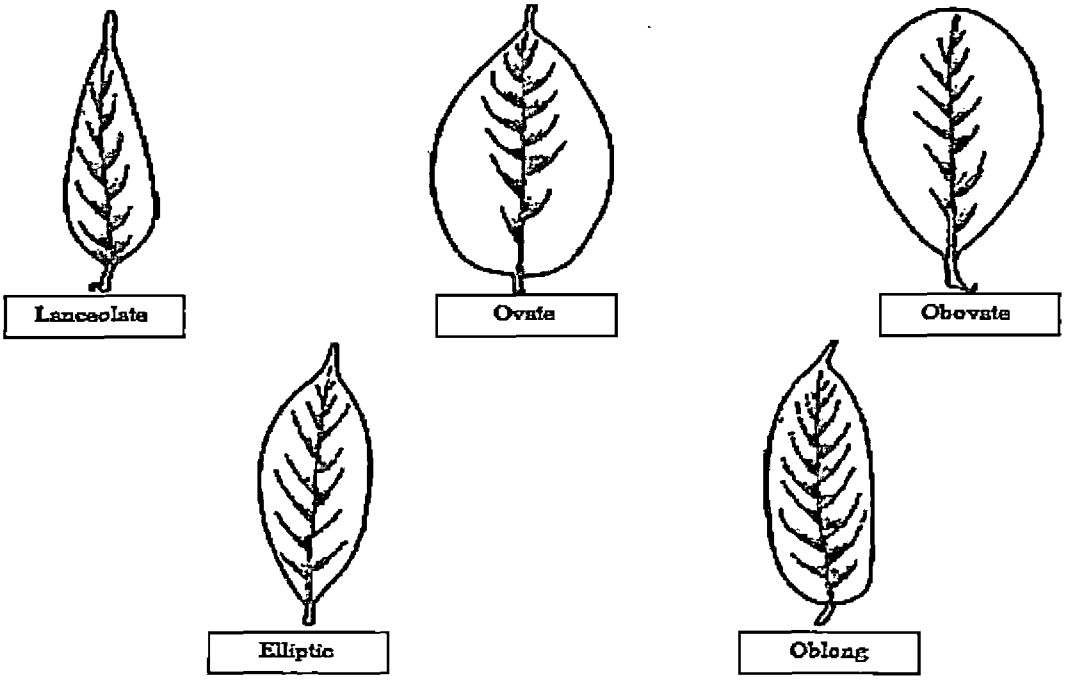
Average of 20 fully expanded representative leaves measured from the base to the tip of the leaf blade and expressed in centimeter (cm).

3.1.7 Leaf width

Recorded on same 20 leavesused for measurement of leaf length, measured at widest point and average expressed in centimeter (cm).

3.1.8 Leaf blade shape

Recorded on same 20 leaves used for measurement of leaf length and classified into sixgroups namely lanceolate, ovate, obovate, elliptic and oblong.



3.1.9 Leaf colour

The colour of the matured litchi leaf was evaluated at adaxial side and were categorized into light green, green, dark green, pinkish green. Colour of newly emerged leaf was also observed and classified into light green, yellowish green, green, light purple, purple, pinkish green, reddish brown

3.1.10 Shoot length

The shoot length was determined by selecting randomly in the tagged current season shoots from each collections and the shoot length was measured from the base of primary leaf to collar region and mean shoot length was expressed in centimeter.

3.1.11 Internodal length

The internodal length between two successive nodes was measured and the average is expressed in centimeters.

3.2. Observations on inflorescence characters

The following inflorescence character was observed and recorded at the time of bloom period.

3.2.1 Flower composition in the inflorescence

The average of ten number of flower inflorescences were recorded, presence of male flowers, pseudo-hermaphrodite flowers and functional hermaphrodite flowers were observed.

3.2.2 Position of inflorescence

The position of inflorescence was observed and classified as terminal, axillary, and both.

3.2.3 Length of inflorescence

The average of ten inflorescences length were measured from the base to tip of the inflorescence.

3.2.4 Width of inflorescence

The average of ten inflorescences width were measured from the widest point of the inflorescence.

3.3 Observations on phenological characters

3.3.1 Time of flushing

Recorded when plant gives new extension growth.

3.3.2 Flowering season

The flowering season was observed when 50 per cent panicles have opened the flower and recorded during winter (August-September) and summer (February-March).

3.3.3 Duration of flowering

Four flowering panicles per tree, one in each direction, were tagged at random before flowering. The panicles were tagged in all the collections, as and when emerged, depending on the time of flowering in each collection. The tagged panicles were used for recording of date from the day of first flower opening to the day of last flower opening in each panicle.

3.3.4 Time taken to flowering to fruit maturity

Total number of days from flowering to fruit maturity was calculated.

3.3.5 Number of days from fruit set to fruit maturity

Total number of days from fruit set to fruit maturity was calculated.

3.4. Observations on physiological parameters

3.4.1 Chlorophyll content

Chlorophyll content of the matured leaf sample was measured with the SPAD 502 chlorophyll meter (Minolta, Japan). Chlorophyll concentration of leaves was estimated using acetone method at 652 nm. Relationship between SPAD values and chlorophyll concentration was formulated as described by Netto *et al.* (2002). Finally total chlorophyll content was calculated using equation **-0.536+0.038*X** where, X is SPAD value. (R^2=0.53) SE=.0963769

3.4.2 Cell sap pH

pH of cell sap of leaf sample was measured directly by an instrument pH meter.

3.4.3 Sugars (Carbohydrates)

Sugar estimation of plant sample was estimated by Anthrone method and absorbance was measured at 630 nm using spectrophotometer (Sadasivam and Manickam, 1996)

3.4.4 C/N ratio estimation

3.4.4.1 Carbon content

Carbon content of the leaf sample was analysed by using elemental analyser (Model: multi EA 4000) (Sato *et al.*, 2014).

3.4.4.2 Nitrogen content

N content was determined by semi micro kjeldahl method (Bremmer, 1965).

3.4.4.3 C/N ratio calculation

C/N ratio was calculated by dividing value of C by value of N for each sample.

3.5. Observations on fruit characters

The observations on fruit characters were taken from well-developed 20 fruits at harvest time selected at random and mean value was recorded.

3.5.1 Fruit bearing habit

Fruit bearing habit was and classified into regular, alternate years and irregular recorded from the basic information collected from growers where trees bearing studied three or more consecutive years.

3.5.2 Fruit bearing intensity

Fruit bearing intensity was recorded and classified into poor, medium and heavy based on the average data of number of fruit set per inflorescence.

3.5.3 Fruit clustering habit

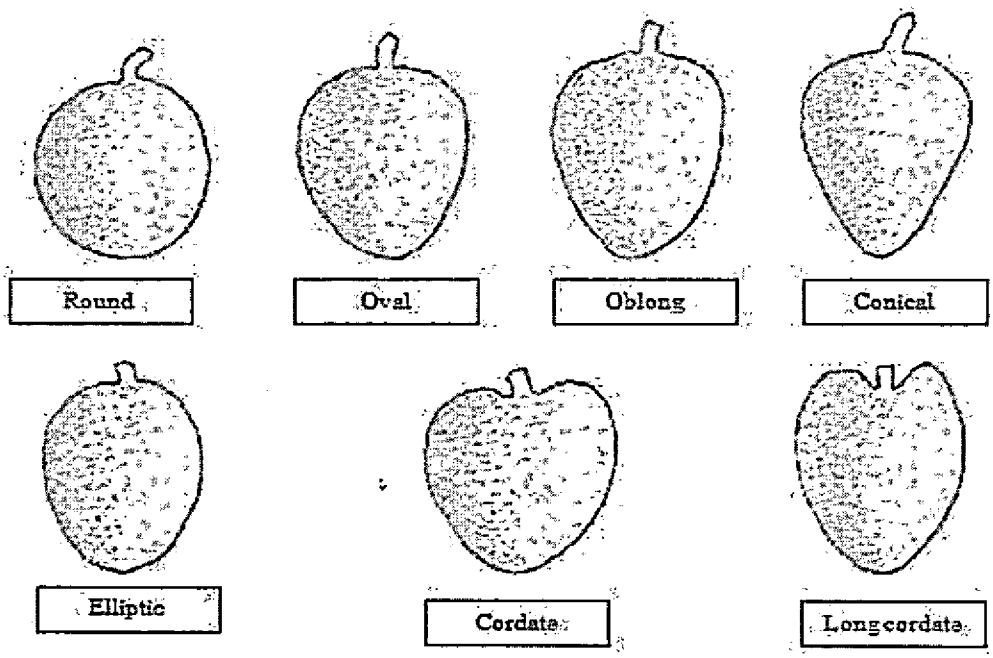
The fruit clustering habit was observed and expressed as solitary or clusters.

3.5.4 Number of fruits per cluster/inflorescence

Number of fruits per cluster was recorded as average randomly selected clusters.

3.5.5 Fruit shape

Fruit shapes were observed and classified into namely round, oval, oblong, conical, elliptic, cordate, long cordate.



3.5.6 Fruit length

Length of ten randomly selected fruits was measured using vernier caliper and average was expressed in cm.

3.5.7 Fruit diameter

Recorded on same fruits used for measuring the fruit length. Diameter measured at the widest point using vernier calipers and average was expressed in cm.

3.5.8 Fruit weight

Weight of ten randomly selected matured fruits was taken using electric balance and average is expressed in g.

3.5.9 Cracking/splitting of fruit skin

Collections were observed for cracking or splitting of fruit skin and degree of cracking described as not prone to cracking, prone to cracking, highly prone to cracking.

3.5.10 Fruit skin thickness

Fruit skin thickness was observed and classified as thin, medium, thick and very thick.

3.5.11 Mature fruit colour

Fruit colour was recorded at maturity and classified as green, greenish yellow, greenish red, pinkish red, crimson, red, reddish yellow, dark red, purple red, rosy red, deep orange, deep pink.

3.5.12 Fruit attractiveness

Fruit attractiveness was recorded based on combined assessment of shape, size, and appearance and classified as poor, intermediate, good and excellent.

3.5.13 Shelf life

Number of days fruit remain in good condition under storage at room temperature was recorded.

3.5.14 Weight of aril

Weight of ten aril was measured using electrical balance and average was expressed in g.

3.5.15 Aril thickness

Aril thickness was measured using vernier caliper expressed in mm and classified as thin, medium, and thick.

3.5.16 Aril texture

Recorded on fully ripe fruits and classified as soft (succulent/fleshy), firm, coarse, fibrous, melting, leathery, crisp and extremely crisp.

3.5.17 Aril quality

Based on aril quality collections were classified into insipid, acid, bitter, sweet types.

3.5.18 Aril colour

Aril colour was recorded at the ripe stage and classified as white, dull, white, creamy white, creamy yellow, yellow, pearl white, waxy white, waxy yellow.

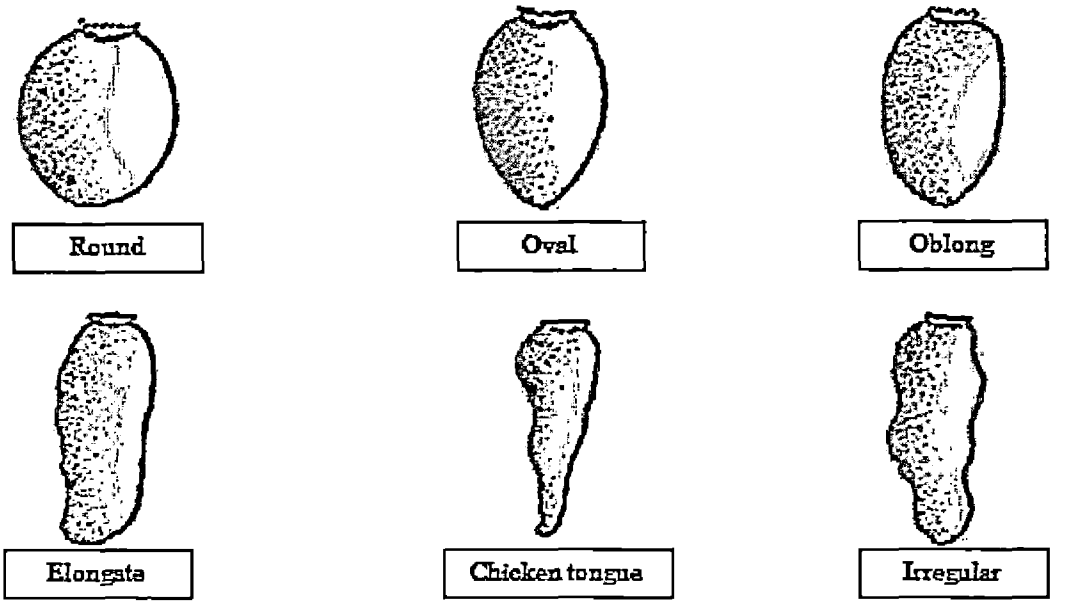
3.6. Observations on seed characters

1. Seed weight (100 seeds)

Weight of 100 seeds from fruits of different collections was recorded.

3.6.2 Seed shape

Seed shape was recorded and classified as round, oval, oblong, elongate, chicken tongue, and irregular.



3.6.3 Seed coat colour

Seed coat colour was recorded and classified as off white, creamish, dull brown, brown, brown and dark brown.

3.7. Observations on Quality attributes

3.7.1 Total sugar

The fruit sample was crushed in a grinder and filtered through No. 4 Whatman paper. For the estimation of total sugars, 50 ml of the clarified solution was boiled gently after adding citric acid and water. It was neutralized using NaOH and volume made up to 250 ml. the made up solution was titrated against a mixture of Fehling's solution A and B and total sugars was expressed as percentage (Ranganna, 1997).

$$\text{Total sugars (\%)} = \frac{\text{Titre value x 0.1 x Volume made up x 0.064x 100}}{\text{Volume of the sample x Weight of the sample}}$$

3.7.2 Total Soluble Sugar (TSS)

TSS was measured/recorded directly using a hand refractometer and expressed in degree B (°Brix).

3.7.3 Acidity

The acidity was estimated by titrating a known weight/volume of the sample against 0.1N NaOH solution using phenolphthalein as an indicator for all the samples. The acidity was calculated and expressed as per cent citric acid (AOAC, 1975).

3.7.4 TSS/acid ratio

TSS/acid ratio was found by dividing values of TSS by values of acid content.

3.7.5 Reducing sugar

Reducing sugars was estimated using Lane and Eynon method (Ranganna, 1997). The fruit sample was crushed in a grinder and filtered through No.4 Whatman paper. An aliquot of 25 ml filtered juice was transferred to a 250 ml volumetric flask, mixed with distilled water and neutralized with NaOH. Solution was clarified with neutral lead acetate. Excess lead acetate was removed by adding potassium oxalate and volume was made up to 250 ml. The solution was filtered and aliquot of the filtrate was titrated against a mixture of Fehling's solution A and B using methylene blue as indicator and the reducing sugar was expressed as percentage.

$$\text{Reducing sugars (\%)} = \frac{0.05 \times \text{Volume made up} \times 100}{\text{Titre value} \times \text{Weight of the sample}}$$

3.7.6 Non-reducing sugar

Non-reducing sugar = Percentage total sugar - Percentage reducing sugar and was expressed as percentage.

3.8 Sensory evaluation

Fruit samples of different collections were subjected to organoleptic evaluation by a ten panel of ten judges. They were briefed about sample before evaluation. The fruit samples of different collections were randomly coded and presented.. The test panelists were asked to rate the fruit sample presented to them on nine point hedonic scale. Score card including the quality attributes appearance, colour, flavour, taste, texture and overall acceptibility was prepared for sensory evaluation of litchi fruit. The score card used for the evaluation of fruits was given in Appendix I.

3.9 Statistical analysis

The data pertaining to the morphological and biochemical characters were compared with Jaccard's similarity coefficients and was clustered by the Unweighed Pair Group Average Method (UPGAM) devised by Sneath and Sokal (1973) using NTSYS pc 2.02 software. Similarity matrix was computed and the dendrogram was constructed accordingly. Principle Component Analysis was done using MINI TAB software 17.1. The data pertaining to organoleptic evaluation were analysed using statistical software SPSS- K related.

3.10 Pest and disease incidence

Constant caution and monitoring of the experimental area was exercised to check the incidence of pests and diseases were observed and recorded during the study period.

3.11 Meteorological observations

Temperature, relative humidity, light intensity, rainfall, sun shine hour, soil temperature, evapotranspiration, wind speed were recorded from RARS Ambalavayal Wayanad (Appendix II to IV).

RESULTS

4. RESULTS

The results of the study pertaining to the "Morpho-physiological characterization of litchi (*Litchi chinensis* Sonn.) in Wayanad" are presented in this chapter. Thirty two collections were characterized and the results are presented under the heads, tree characters, inflorescence characters, phenological characters, physiological characters, fruit characters, seed characters and quality characters. All tree characters were recorded based on IPGRI descriptor. Data were subjected to multivariate analysis utilizing cluster analysis using NTSYS software and Principal component analysis.

4.1 Tree characters

Various observations on tree characters *viz.*, tree age, height, trunk girth, crown shape, branching pattern, leaf length, leaf width, leaf blade shape, leaf colour, shoot length and internodal length were recorded, analysed and the descriptive statistics of minima, maxima, range, average, standard deviations, standard error mean and coefficients of variation (CV) are presented in the Tables 1a, 1b and 2.

4.1.1 Age of the tree

Extensive variability was observed with respect to age of the tree. Tree age ranged from 5 to 79 years and displayed high coefficients of variation (CV) of 74.21 per cent. The maximum tree age was recorded in Collections *viz.*, Coll. 20, Coll. 21, Coll. 22, Coll. 24 and Coll. 25 (79 years) which was followed by Coll. 15, Coll. 16, Coll. 17, Coll. 18 and Coll. 19 (49 years). Coll. 1, Coll.2 and Coll. 12 comes in the age group of 31-40 years. While Coll. 7, Coll. 12 lies in the range of 21-30 years age. There were thirteen collections *viz.*, Coll. 3, Coll. 4, Coll. 6, Coll. 8, Coll. 9, Coll. 10, Coll. 11, Coll. 13. Coll. 14, Coll. 23, Coll. 30, Coll. 31 and Coll. 32 lies in the range of age group from 11-20 years. The Coll. 24, Coll. 28 and Coll. 29 are below ten years of age. Among all the trees Coll. 28 recorded minimum age of 5 years (Tables 1a, 1b and 2).

4.1.2 Tree height

Tree height exhibited 57.87 per cent of CV. The height of the trees ranged from 3.00 m to 19.00 m. The maximum tree height of 19 m was recorded in Coll. 25, which was followed by Coll. 24 (18.5 m), Coll. 22 (18.2 m), Coll. 21(18 m) and Coll. 20 (17.8 m). The collections *viz.,* Coll. 1, Coll. 2, Coll. 12, Coll. 15, Coll. 16, Coll. 17, Coll. 18 and Coll. 19 lies in the range of 12-16 m height. The Coll. 3, Coll. 4, Coll. 5, Coll. 6, Coll. 8, Coll. 9, Coll. 10, Coll. 11, Coll. 13, Coll. 14, Coll. 23, Coll. 26, Coll. 27, Coll. 28 Coll.29, Coll. 30, Coll. 31 and Coll. 32 recorded less than 10 m. Minimum tree height of 3 m was recorded in Coll. 28 (Tables1a, 1b and 2).

4.1.3 Trunk girth

Co-efficient of variation of 74.1 per cent was observed in tree trunk girth and it ranged from 28.00 cm to 540 cm. Mean trunk girth recorded was 148.71 cm. The Coll. 24 recorded the highest trunk girth of 540 cm which was followed by Coll. 21 (384 cm), Coll. 16 (256 cm), Coll. 17 (250 cm), Coll. 22 (242 cm), Coll. 18 (241 cm), Coll. 15 (240 cm) and Coll. 19 (210 cm) whereas Coll. 1, Coll. 2, Coll. 3, Coll. 6, Coll. 7, Coll. 12, Coll. 20, Coll. 23, Coll. 25 and Coll. 32 recorded a trunk girth between range of 100 cm to 200 cm. Minimum trunk girth of 28 cm was recorded in Coll. 28 (Tables1a, 1b and 2).

4.1.4 Leaf length

The leaf length of the collections ranged from 12 cm to 16.8 cm. Leaf length displayed low CV of 8.67 per cent. The average leaf length of 13.75 cm was recorded among the trees evaluated. Maximum leaf length was recorded in Coll. 2 (16.8 cm). The Coll. 1, Coll. 3, Coll. 4, Coll. 6, Coll. 7, Coll. 15, Coll. 16, Coll. 17, Coll. 18, Coll. 19, Coll. 20, Coll. 21, Coll. 24 and Coll. 25 recorded leaf length above average. The Coll. 5, Coll. 8, Coll. 9, Coll.10, Coll. 11, Coll. 12, Coll. 13, Coll. 14, Coll. 22, Coll. 23, Coll. 26, Coll. 27, Coll. 28, Coll. 29, Coll. 30 Coll. 31 and Coll. 32 recorded leaf length below average. Minimum leaf length was recorded in Coll. 8 (Tables1a, 1b and 2).

4.1.5 Leaf width

The leaf width of the litchi trees ranged from 1.8 cm to 5.2 cm which displayed CV of 14.27 per cent. Average leaf width of 3.8 cm recorded among collections. Maximum leaf width of 5.2 cm was recorded in Coll. 6. The Coll. 1, Coll. 2, Coll. 3, Coll. 4, Coll. 7, Coll. 12, Coll. 14, Coll. 15, Coll. 16, Coll. 17, Coll. 18, Coll. 19, Coll. 20, Coll. 21, Coll. 24, Coll. 25 and Coll. 26 recorded leaf width above average. The Coll. 5, Coll. 9, Coll. 10, Coll. 11, Coll. 13, Coll. 22, Coll. 23, Coll. 27, Coll. 28, Coll. 29, Coll. 30, Coll. 31 and Coll. 32 recorded leaf width below average.

4.1.6 Shoot length

The shoot length was ranged from 15 cm to 26 cm which displayed a CV of 12.77 per cent. The average shoot length of 21.6 cm was recorded in collections. Maximum shoot length was recorded in Coll. 23 (26 cm) and Coll. 14 (26 cm) which was followed by Coll. 3 (25 cm), Coll. 24 (25 cm) and Coll. 26 (25 cm). The Coll. 4, Coll. 8, Coll. 9, Coll. 12, Coll. 13, Coll. 15, Coll. 16, Coll. 17, Coll. 19, Coll. 20 and Coll. 25 recorded shoot length above average. Coll. 28 recorded minimum shoot length of 15 cm. (Tables1a, 1b and 2).

4.1.7 Internodal length

The internodal length of the collections ranged from 2.8 cm to 5.2 cm. The co-efficient of variation was 17.66 per cent. Average internodal length was 3.87 cm. Maximum internodal length of 5.2 cm was recorded in Coll. 24 which was followed by Coll. 25 (4.8 cm), Coll. 20 (4.8 cm), Coll. 27 (4.6 cm), Coll.14 (4.5 cm) and Coll. 6 (4.5 cm). Minimum internodal length of 2.8 cm recorded in Coll. 28 (Tables1a, 1b and 2).

4.1.8 Crown shape

Different crown shapes like pyramidal, broadly pyramidal, spherical, oblong, semi-circular, elliptical and irregular shapes were noticed among the collections, of these semicircular crown shape was more common. The Coll. 1,

Coll. 2, Coll. 6, Coll. 7, Coll. 8, Coll. 13, Coll. 20, Coll. 21, Coll. 22, Coll. 28 and Coll. 30 recorded semicircular crown shape. Oblong crown shape was noticed in Coll. 3, Coll. 5, Coll. 15, Coll. 16, Coll. 17, Coll. 18, Coll. 19, Coll. 27, Coll. 31 and Coll. 32. Spherical crown shape was observed in Coll. 4, Coll. 9, Coll. 10, Coll. 11, Coll. 12, Coll. 14, Coll. 23, Coll. 24 and Coll. 25. Broadly pyramidal crown shape and irregular crown shape was observed in Coll. 26 and Coll. 29 respectively (Tables1a, 1b and 2).

4.1.9 Branching pattern

Different branching patterns like erect, opposite, verticillate, horizontal, and irregular patterns were noticed among the collections. Verticillate branching pattern was more common among the collections *viz.*, Coll. 1, Coll. 3, Coll. 4, Coll. 5, Coll. 9, Coll. 10, Coll. 11, Coll. 12, Coll. 15, Coll. 16, Coll. 17, Coll. 18, Coll. 19, Coll. 21, Coll. 22, Coll. 23 Coll. 24, Coll. 26, Coll. 30, Coll. 31 and Coll. 32. Horizontal branching pattern was noticed in Coll. 6, Coll. 8, Coll. 13, Coll. 14 and Coll. 28. While irregular branching pattern was observed in Coll. 2, Coll. 7, Coll. 20 and Coll. 25. Erect branching pattern noticed only in collection Coll. 27 (Tables1a, 1b and 2).

4.1.10 Leaf blade shape

Elliptic blade shape was noticed in all the plants except Coll. 5, where lanceolate leaf blade shape was observed (Tables 4.1a and 4.1b).

4.1.11 Leaf colour

Leaf colour of both young and matured leaf were observed and presented in table (Tables1a, 1b and 2).

4.1.11.1 Young leaf colour

Newly emerged young leaves showed variations in leaf colours. Pinkish green colour was observed in Coll. 1, Coll. 2, Coll. 3, Coll. 4, Coll. 5 Coll. 7, Coll. 8, Coll. 9, Coll. 12, Coll. 13, Coll. 15, Coll. 16, Coll. 17, Coll. 18, Coll. 19,

Table 1a. Tree characters of litchi grown in Wayanad

Collections	Tree age (years)	Tree height (m)	Trunk girth (cm)	Leaf length (cm)	Leaf width (cm)	Shoot length (cm)	Internodal length (cm)	Crown shape	Branching pattern	Leaf blade shape	Leaf colour	
											Young	Mature
Coil. 1	40	14.5	156	16.5	5	21	3.4	Semi circular	Verticillate	Elliptic	Pinkish green	Green
Coll. 2	40	15.8	133	16.8	4.8	20	3.4	Semi circular	Irregular	Elliptic	Pinkish green	Green
Coll. 3	20	5.1	110	14.2	4.2	25	4.1	Oblong	Verticillate	Elliptic	Pinkish green	Dark green
Coll. 4	20	6.1	94	14.6	4.3	24	3.5	Spherical	Verticillate	Elliptic	Pinkish green	Green
Coll. 5	10	4.8	55	13.5	3.2	21	3.5	Oblong	Verticillate	Lanceolate	Pinkish green	Dark green
Coll. 6	20	5.5	120	14.5	5.2	21	3.5	Semi circular	Horizontal	Elliptic	Light green	Dark green
Coll. 7	30	10.0	150	16.2	4.7	18	3.0	Semi circular	Irregular	Elliptic	Pinkish green	Green
Coll. 8	20	5.3	74	12.0	3.8	23	3.2	Semi circular	Horizontal	Elliptic	Pinkish green	Green
Coll. 9	20	5.8	84	12.5	3.6	22.5	3.1	Spherical	Verticillate	Elliptic	Pinkish green	Green
Coll. 10	12	5.9	81	13.2	3.7	18	3.6	Spherical	Verticillate	Elliptic	Yellowish green	Green
Coll. 11	12	4.8	30	12.5	3.6	16	2.8	Spherical	Verticillate	Elliptic	Light green	Green
Coll. 12	35	13.1	166	12.6	3.9	24	3.2	Spherical	Verticillate	Elliptic	Pinkish green	Dark green
Coll. 13	12	5.1	55	13.7	3.6	22	3.5	Semi circular	Horizontal	Elliptic	Pinkish green	Green
Coll. 14	12	4.8	88	13.3	4.2	26	4.5	Spherical	Horizontal	Elliptic	Light green	Dark green
Coll. 15	49	12.8	240	13.8	4.2	22	4.0	Oblong	Verticillate	Elliptic	Pinkish green	Green
Coll. 16	49	13.2	256	14.1	3.9	24	4.5	Oblong	Verticillate	Elliptic	Pinkish green	Green

Table 1b. Tree characters of litchi grown in Wayanad

Collections	Tree age (years)	Tree height (m)	Trunk girth (cm)	Leaf length (cm)	Leaf width (cm)	Shoot length (cm)	Internodal length (cm)	Crown shape	Branching pattern	Leaf blade shape	Leaf colour	
											Young	Mature
Coll. 17	49	14.0	250	14.2	4.1	24	4.4	Oblong	Verticillate	Elliptic	Pinkish green	Green
Coll. 18	49	14.5	241	14	4.0	21	3.9	Oblong	Verticillate	Elliptic	Pinkish green	Green
Coll. 19	49	13.5	210	13.9	3.9	22	3.8	Oblong	Verticillate	Elliptic	Pinkish green	Green
Coll. 20	79	17.8	185	14.3	4.6	22	4.8	Semicircular	Irregular	Elliptic	Pinkish green	Green
Coll. 21	79	18.0	384	14.5	4.5	21	4.5	Semicircular	Verticillate	Elliptic	Pinkish green	Green
Coll. 22	79	18.2	242	13.6	3.7	20	4.0	Semicircular	Verticillate	Elliptic	Pinkish green	Green
Coll. 23	20	5.2	178	12.5	3.6	26	5.0	Spherical	Verticillate	Elliptic	Pinkish green	Green
Coll. 24	79	18.5	540	14.5	4.7	25	5.2	Spherical	Verticillate	Elliptic	Pinkish green	Dark green
Coll. 25	79	19.0	196	14.3	4.5	24	4.8	Spherical	Irregular	Elliptic	Pinkish green	Dark green
Coll. 26	6	3.2	45	12.4	3.9	25	5.0	Broadly Pyramid	Verticillate	Elliptic	Pinkish green	Dark green
Coll. 27	25	5.9	50	12.2	3.4	21	4.6	Oblong	Erect	Elliptic	Yellowish green	Dark green
Coll. 28	5	3.0	28	12.1	3.0	15	2.8	Semicircular	Horizontal	Elliptic	Yellowish green	Light green
Coll. 29	8	3.4	38	12.8	3.1	18	3.0	Irregular	Irregular	Elliptic	Pinkish green	Green
Coll. 30	15	4.7	90	13.6	3.2	21	3.7	semicircular	Verticillate	Elliptic	Pinkish green	Dark green
Coll. 31	15	4.8	70	13.5	3.5	19	3.8	oblong	Verticillate	Elliptic	Pinkish green	Green
Coll. 32	15	6.8	120	13.6	3.5	20	4.0	oblong	Verticillate	Elliptic	Yellowish green	Green

Table 2. Descriptive statistics for quantitative traits of tree morphology

Descriptives	Tree age (Years)	Tree height (m)	Trunk girth (cm)	Leaf length (cm)	Leaf width (cm)	Shoot length (cm)	Internodal length (cm)
Maximum value	79	19	540	16.8	5.2	26	5.2
Minimum value	5	3	28	12	3	15	2.8
Range	74	16	512	4.8	2.2	11	2.4
Average	32.875	9.478	148.717	13.75	3.978	21.603	3.871
Standard Deviation	24.399	5.48	110.338	1.199	0.569	2.762	0.682
Standard Error of Mean	4.318	0.961	19.5	0.218	0.102	0.481	0.121
Co-efficient of Variation	74.211	57.873	74.182	8.672	14.273	12.772	17.664

Coll. 20, Coll. 21, Coll. 22, Coll. 23, Coll. 24, Coll. 25 Coll. 26, Coll. 29, Coll. 30 and Coll. 31. Light green colour was observed in Coll. 6, Coll. 11, and Coll. 14. While yellowish green leaf was noticed in Coll. 10, Coll. 27, Coll. 28 and Coll. 32 (Tables 1a, 1b and 2).

4.1.11.2 Mature leaf colour

Green, light green and dark green colours were noticed in mature leaves. The Coll. 1, Coll. 2 Coll. 4, Coll. 7, Coll. 8, Coll. 9, Coll. 10, Coll. 11, Coll. 13, Coll. 15, Coll. 16, Coll. 17, Coll. 18, Coll. 19, Coll. 20, Coll. 21, Coll. 22, Coll. 23, Coll. 29, Coll. 31 and Coll. 32 showed green leaf colour. Dark green leaves were observed in Coll. 3, Coll. 5, Coll. 6, Coll. 12, Coll. 14, Coll. 24, Coll. 25, Coll. 26, Coll. 27 and Coll. 30. Light green leaves were observed only in Coll. 28 (Tables1a, 1b and 2).

4.2 Inflorescence characters

Among the 32 collections evaluated only 28 collections were flowered during the study period. The data depicting the inflorescence characters of 28 collections are presented in Table 3 to 6.

4.2.1 Flowering season

Flowering was observed in the month of August to September and erratic flowering was also observed during February to March. The Coll. 1, Coll. 2, Coll. 3, Coll. 4, Coll. 7, Coll. 8, Coll. 9, Coll. 10, Coll. 11, Coll. 12, Coll. 13, Coll. 14, Coll. 15, Coll. 16, Coll. 17, Coll. 18, Coll. 19, Coll. 20, Coll. 21, Coll. 22, Coll. 23, Coll. 28, Coll. 29, Coll. 30, Coll. 31 and Coll. 32 exhibited flowering during August to September. Apart from August to September flowering, erratic flower during February to March was observed in the Coll. 2, Coll. 3, Coll. 10, Coll. 11 and Coll. 13. The Coll. 5 and Coll. 6 were flowered only in February to March (Table 5).

4.2.2 Flower composition in inflorescence

Three basic types of flower *viz.*, male or staminate flowers (Type 1, male), hermaphrodite female flower (Type 2, female) and hermaphrodite male flower (Type 3, male) were observed in all the collections (Table 3).

4.2.3 Position of inflorescence

Terminal position of the inflorescence was observed in all the collections (Table 3).

4.2.4 Length of inflorescence

The length of inflorescence ranged from 15.1 cm to 38 cm and displayed 25.2 per cent of CV. Average inflorescence length of 25.65 cm was recorded in the collections. Maximum inflorescence length of 38 cm was recorded in Coll. 9 which was followed by Coll. 22 (37.1), Coll. 12 (35.5 cm), Coll. 31 (33 cm), Coll. 1 (32.2 cm) and Coll. 4 (31.5 cm). The Coll. 2, Coll. 3, Coll. 7, Coll. 13, Coll. 14, Coll. 28, Coll. 30 and Coll. 32 had inflorescence length above average. The Coll. 8, Coll. 10, Coll. 11, Coll. 14, Coll. 15, Coll. 16, Coll. 17, Coll. 18, Coll. 19, Coll. 20, Coll. 23 and Coll. 28 recorded inflorescence length below average. Minimum inflorescence length of 15.1 cm recorded in Coll. 17 (Table 3 and 6).

The plants flowered during February to March recorded the maximum length of 26.5 cm in Coll. 11 followed by Coll. 13 (24.2 cm). Minimum length of 15.2 cm was recorded in Coll. 10. The Coll. 5 and Coll. 6 which flowered only during February to March had inflorescence length of 23.3 cm and 20.6 cm respectively (Table 3 and 6).

4.2.5 Width of inflorescence

The width of inflorescence of the collections ranged from 9.4 cm to 19.3 cm and displayed CV of 19.04 per cent. Average inflorescence width of 13.5 cm was recorded in the collections. Maximum inflorescence width was recorded in Coll. 9 (19.3 cm) which was followed by Coll. 2 (18.2 cm), Coll. 22 (18.1 cm), Coll. 11 (17.3 cm), Coll. 7 (15.5 cm) and Coll. 31 (15.1 cm). Other collections

were recorded width of less than 15 cm. Minimum inflorescence width of 9.4 cm was recorded in Coll. 17 (Table 3 and 6).

The plants flowered during February to March recorded the maximum width of 26.5 cm in Coll. 11 followed by Coll. 2 (15.1 cm). Minimum width of 11.2 cm was recorded in Coll. 3. The Coll. 5 and Coll. 6 which flowered only during February to March had inflorescence width of 9.8 cm and 14.5 cm respectively (Table 3 and 6).

4.3 Phenological characters

The phenological characters were evaluated and observed at the time of flushing, duration of flowering, time taken to flowering to maturity and fruit set to maturity were recorded, analysed and the descriptive statistics of minima, maxima, range, average, standard deviations, standard error mean and coefficients of variation (CV) are presented in the Tables 3 to 6.

4.3.1 Time of flushing

Different cycles of flushing were observed in litchi (Table 5). Flushing initiated from July onwards. One cycle of flushing observed in most of the collections. Flushing observed in the month of August recorded in Coll. 1, Coll. 2, Coll. 10, Coll. 12, Coll. 15, Coll. 16, Coll. 17, Coll. 18, Coll. 19, Coll. 20, Coll. 21, Coll. 23, Coll. 27, Coll. 30, Coll. 31, and Coll. 32. The Coll. 24, Coll. 25 and Coll. 28 were flushed during September. The Coll. 11 flushed during the month of February.

Two cycles of flushing during July and November months were observed in Coll. 8, Coll. 9 and Coll. 22. During August and September flushing was observed in Coll. 4, and Coll. 7 whereas Coll. 26 flushed during August and November. The Coll. 13 flushed during month of August as and February. The Coll. 3, Coll. 5, Coll. 14 and Coll. 29 had flushing during September and February. The Coll. 6 flushed during the months of November and February.

4.3.2 Duration of flowering

The duration of flowering varied from 12 days to 35 days. Average flowering duration taken was 25.6 days. The Coll. 11 and Coll. 28 recorded minimum duration of 12 days for flowering and Coll. 7 recorded maximum duration 35 days, followed by Coll. 30 (34 days), Coll. 4 (34 days), Coll. 10 (33 days) and Coll. 16 (33 days).

The duration of flowering also varied in months of February to March flowering. Minimum duration of flowering was recorded in Coll. 10 (12 days) and maximum in Coll. 11 (34 days) followed by Coll. 6 (29 days) and Coll. 5 (28 days) (Table 4 and 6).

4.3.3 Time taken to flowering to fruit maturity

Time taken to flowering to fruit maturity ranged from 71 days to 94 days. The lowest days from flowering to fruit maturity of 71 days was recorded in Coll. 4 and maximum duration of 94 days was observed in Coll. 30. Average number of days taken from flowering to fruit maturity was 87.05 days. The CV of flowering to fruit maturity was 7.38 per cent. The number of days taken to flowering to fruit set of the collections Coll. 1, Coll. 4, Coll. 7, Coll. 10, Coll. 12, Coll. 20, Coll. 31 and Coll. 32 were less than average number of days taken for flowering to fruit maturity (87.05 days). The Coll.2, Coll. 3, Coll. 9, Coll. 15, Coll. 16, Coll. 17, Coll. 18, Coll. 19, Coll. 21, Coll. 22 and Coll. 30 were recorded more than average number of days (87.05 days) for flowering to fruit maturity (Table 4 and 6).

In the Coll. 5, Coll. 6, Coll. 11 and Coll. 13 flowering and fruiting were observed during February to March. Maximum duration of flowering to fruit maturity (85 days) in Coll. 11 and minimum duration of 78 days was observed in Coll. 6 and Coll. 13.

Table 3. Inflorescence characters of litchi grown in Wayanad

Collections	Flowering season	Flower composition in inflorescence	Position of inflorescence	Inflorescence length (cm)		Inflorescence width (cm)	
				Aug - Sept	Feb - Mar	Aug - Sept	Feb- Mar
Coll. 1	August to September	Type 1, Type 2, Type 3	Terminal	32.2		14.1	
Coll. 2	August to September and February to March	Type 1, Type 2, Type 3	Terminal	29.3	20.2	18.2	15.1
Coll. 3	August to September and February to March	Type 1, Type 2, Type 3	Terminal	27	23.1	13.2	11.2
Coll. 4	August to September	Type 1, Type 2, Type 3	Terminal	31.5	-	12.5	-
Coll. 5	February to March	Type 1, Type 2, Type 3	Terminal	-	20.6		9.8
Coll. 6	February to March	Type 1, Type 2, Type 3	Terminal	-	23.3		14.5
Coll. 7	August to September	Type 1, Type 2, Type 3	Terminal	29.5	-	15.5	-
Coll. 8	August to September	Type 1, Type 2, Type 3	Terminal	25.1	-	12.5	-
Coll. 9	August to September	Type 1, Type 2, Type 3	Terminal	38	-	19.3	-
Coll. 10	August to September and February to March	Type 1, Type 2, Type 3	Terminal	21.2	15.2	12.2	11.1
Coll. 11	August to September and February to March	Type 1, Type 2, Type 3	Terminal	16.2	26.5	17.3	17.3
Coll. 12	August to September	Type 1, Type 2, Type 3	Terminal	35.5	-	13.5	-
Coll. 13	August to September and February to March	Type 1, Type 2, Type 3	Terminal	29.3	24.2	14.1	13.1
Coll. 14	August to September	Type 1, Type 2, Type 3	Terminal	28.7	-	10.6	-
Coll. 15	August to September	Type 1, Type 2, Type 3	Terminal	16.5	-	12.2	-
Coll. 16	August to September	Type 1, Type 2, Type 3	Terminal	17.2	-	14.7	-
Coll. 17	August to September	Type 1, Type 2, Type 3	Terminal	15.1	-	9.4	-
Coll. 18	August to September	Type 1, Type 2, Type 3	Terminal	16.4	-	11.5	-
Coll. 19	August to September	Type 1, Type 2, Type 3	Terminal	17.5	-	12.6	-
Coll. 20	August to September	Type 1, Type 2, Type 3	Terminal	21.8	-	13.3	-
Coll. 21	August to September	Type 1, Type 2, Type 3	Terminal	22.2	-	14.7	-
Coll. 22	August to September	Type 1, Type 2, Type 3	Terminal	37.1	-	18.1	-
Coll. 23	August to September	Type 1, Type 2, Type 3	Terminal	18.8	-	9.8	-
Coll. 28	August to September	Type 1, Type 2, Type 3	Terminal	28.4	-	10.3	-
Coll. 29	August to September	Type 1, Type 2, Type 3	Terminal	22.3	-	14.2	-
Coll. 30	August to September	Type 1, Type 2, Type 3	Terminal	28.2	-	12.1	-
Coll. 31	August to September	Type 1, Type 2, Type 3	Terminal	33	-	15.1	-
Coll. 32	August to September	Type 1, Type 2, Type 3	Terminal	26	-	12.8	-

Type 1= male or staminate flowers, Type 2= hermaphrodite female flower, Type 3= hermaphrodite male flower

Table 4. Phenological characters of litchi grown in Wayanad

Collections	Flowering duration (days)		Flowering to fruit maturity (days)		Fruit set to fruit maturity (days)	
	Aug - Sept	Feb - Mar	Aug - Sept	Feb - Mar	Aug - Sept	Feb - Mar
Coll. 1	18	-	85		62	
Coll. 2	32	15	91	No fruit set	75	
Coll. 3	31	22	90	No fruit set	72	
Coll. 4	34	-	71	-	59	-
Coll. 5	No flowering	28	--	82	--	63
Coll. 6	No flowering	29	--	78	--	61
Coll. 7	35	-	72	-	60	-
Coll. 8	21	-	No fruit set	-	--	-
Coll. 9	25	-	92	-	62	-
Coll. 10	33	12	82	No fruit set	58	-
Coll. 11	12	34	--	85	--	64
Coll. 12	27	-	84	-	63	-
Coll. 13	28	27	92	78	60	58
Coll. 14	15	-	No fruit set	-	--	-
Coll. 15	32	-	93	-	65	-
Coll. 16	33	-	91	-	66	-
Coll. 17	26	-	90	-	64	-
Coll. 18	22	-	92	-	69	-
Coll. 19	30	-	88	-	68	-
Coll. 20	31	-	85	-	70	-
Coll. 21	32	-	88	-	71	-
Coll. 22	23	-	92	-	61	-
Coll. 23	16	-	No fruit set	-	--	-
Coll. 24	No flowering	-	--	-	--	-
Coll. 25	No flowering	-	--	-	--	-
Coll. 26	No flowering	-	--	-	--	-
Coll. 27	No flowering	-	--	-	--	-
Coll. 28	12	-	No fruit set	-	--	-
Coll. 29	14	-	No fruit set	-	--	-
Coll. 30	34	-	94	-	61	-
Coll. 31	27	-	82	-	65	
Coll. 32	24	-	87	-	61	-

Table 5. Time of flushing in litchi grown in Wayanad

Time of flushing (Months)	Collections
August	Coll. 1, Coll. 2, Coll. 10, Coll. 12, Coll. 15, Coll. 16, Coll. 17, Coll. 18, Coll. 19, Coll. 20, Coll. 21, Coll. 23, Coll. 27, Coll. 30, Coll. 31, Coll. 32
September	Coll. 24, Coll. 25, Coll. 28
February	Coll. 11
July and November	Coll. 8, Coll. 9, Coll. 22
August and September	Coll. 4, Coll. 7
August and November	Coll. 26
August and February	Coll. 13
September and February	Coll. 3, Coll. 5, Coll. 14, Coll. 29
November and February	Coll. 6

Table 6. Descriptive statistics for quantitative flower traits

Descriptives	Inflorescence length (cm)	Inflorescence width (cm)	Flowering duration (days)	Flowering to fruit maturity (days)	Fruit set to fruit maturity (days)
Number of collections	28	28	26	20	20
Maximum value	38	19.3	35	94	75
Minimum value	15.1	9.4	12	71	58
Range	22.9	9.9	23	23	17
Average	25.65	13.505	25.658	87.05	64.6
Standard Deviation	6.479	2.578	7.373	6.425	4.806
Standard Error of Mean	1.225	0.48	1.444	1.432	1.075
Co-efficient of Variation	25.268	19.047	28.743	7.387	7.431

4.3.4 Days from fruit set to maturity

The number of days taken from fruit set to maturity varied from 58 days to 75 days. The minimum days from fruit set to fruit maturity (58 days) was observed in Coll. 10 and maximum days (75 days) observed in Coll. 2. Average days taken for fruit set to maturity was 64.6 days. The Coll. 2, Coll. 3, Coll. 15, Coll. 16, Coll. 18, Coll. 19, Coll. 20, Coll. 21 and Coll. 31 recorded more days when compared to mean value of 64.6 days. The Coll. 1, Coll. 4, Coll. 7, Coll. 9, Coll. 10, Coll. 12, Coll. 13, Coll. 17, Coll. 22, Coll. 30 and Coll. 32 recorded less number of days for fruit set to maturity when compared to the mean value.

Among the plants flowered during February to March, Coll. 11 recorded maximum (64 days) days from fruit set to maturity while Coll. 13 recorded 58 days to mature after fruit set (Table 4 and 6).

4.4 Physiological parameters

The data depicting the physiological parameters were recorded, analysed and the descriptive statistics of minima, maxima, range, average, standard deviations, standard error mean and coefficients of variation (CV) are presented in Table 7 and 8.

4.4.1 Chlorophyll content

Chlorophyll content of collections ranged from 1.07 mg/g to 1.87 mg/g and displayed a CV of 13.88 per cent. The maximum chlorophyll content was recorded in Coll. 24 (1.87 mg/g) which was followed by Coll. 25 (1.84 mg/g) and Coll. 22 (1.79 mg/g), Coll. 16 (1.79 mg/g), Coll. 6 (1.74 mg/g) and Coll. 9 (1.73mg/g). Minimum chlorophyll content of 1.07 mg/g was recorded in Coll. 11 and Coll. 28 (Table 7 and 8).

4.4.2 Cell sap pH

Cell sap of pH of the collections ranged from 5.12 to 5.96. Average value of cell sap pH was 5.43 among the collections and displayed CV of 2.86 per cent. The maximum cell sap pH of 5.96 was recorded in Coll. 2, followed by Coll. 20

Table 7. Physiological characters of litchi grown in Wayanad

Collections	Chlorophyll (mg/g)	Cell sap pH	Carbohydrates (g/100g)	Nitrogen (%)	C/N ratio
Coll. 1	1.29	5.29	5.92	1.31	6.27
Coll. 2	1.67	5.96	10.86	1.82	7.09
Coll. 3	1.59	5.51	8.04	1.82	5.55
Coll. 4	1.2	5.4	5.76	1.31	5.73
Coll. 5	1.52	5.42	4.49	1.56	5.64
Coll. 6	1.74	5.43	4.97	1.72	4.81
Coll. 7	1.61	5.32	8.04	1.79	6.48
Coll. 8	1.21	5.42	13.48	1.8	4.61
Coll. 9	1.73	5.61	11.24	1.62	6.97
Coll. 10	1.44	5.12	10.5	1.56	7.23
Coll. 11	1.14	5.24	5.27	1.09	8.44
Coll. 12	1.67	5.4	8.71	1.82	6.48
Coll. 13	1.53	5.51	9.64	1.63	6.67
Coll. 14	1.63	5.39	7.33	2.1	4.33
Coll. 15	1.68	5.31	10.6	1.61	6.65
Coll. 16	1.79	5.38	9.45	1.64	6.67
Coll. 17	1.61	5.49	8.84	1.59	5.79
Coll. 18	1.53	5.42	7.13	1.99	4.96
Coll. 19	1.55	5.4	7.13	1.65	5.4
Coll. 20	1.56	5.62	7.46	1.9	5.39
Coll. 21	1.71	5.56	7.55	2.01	4.52
Coll. 22	1.79	5.52	9.73	1.54	6.93
Coll. 23	1.4	5.44	3.87	2.1	4.04
Coll. 24	1.87	5.59	4.79	2.31	4.32
Coll. 25	1.84	5.61	6.26	2.14	3.83
Coll. 26	1.26	5.4	4.55	1.8	4.72
Coll. 27	1.72	5.3	8.73	1.9	4.3
Coll. 28	1.07	5.24	3.79	1.2	5.75
Coll. 29	1.25	5.24	4.99	1.42	5.27
Coll. 30	1.45	5.42	7.76	1.83	5.24
Coll. 31	1.49	5.4	7.11	2.09	5.8
Coll. 32	1.54	5.6	9.12	1.86	6.93

Table 8. Descriptive statistics for physiological characters

Descriptives	Chlorophyll (mg/g)	Cell sap pH	Carbohydrates (g/100g)	Nitrogen (%)	C/N ratio
Maximum value	1.87	5.96	13.48	2.31	8.44
Minimum value	1.07	5.12	3.79	1.09	3.83
Range	0.8	0.84	9.69	1.22	4.61
Average	1.537	5.432	7.591	1.733	5.718
Standard Deviation	0.219	0.158	2.391	0.288	1.117
Standard Error of Mean	0.036	0.025	0.425	0.049	0.193
Co-efficient of Variation	13.881	2.868	31.541	16.292	19.446

(5.62), Coll. 9 (5.61) and Coll. 25 (5.61). Minimum cell sap pH of 5.12 was recorded in Coll.10 (Table 7 and 8).

4.4.3 Carbohydrates

Carbohydrate content of leaves ranged from 3.79 g/100g to 13.48 g/100g. The average carbohydrate content of 7.59 g/100g was recorded among the collections. The CV of 31.51 per cent was displayed among the collections. The highest carbohydrate content was recorded in Coll. 8 (13.48 g/100g) followed by Coll. 9 (11.24 g/100g), Coll. 2 (10.86 g/100g), Coll. 10 (g/100g) and Coll.15 (10.6 g/100g). Lowest carbohydrate content of 3.79 g/100g was recorded in Coll. 28 (Table 7 and 8).

4.4.4 Nitrogen content

Nitrogen content of leaves ranged from 1.09 per cent to 2.31 per cent. Mean nitrogen content of 1.73 per cent was recorded in the collections. The CV of nitrogen content was 16.2 per cent. The highest nitrogen content was recorded in Coll. 24 (2.31 %), followed by Coll. 25 (2.14 %), Coll. 14 (2.14 %), Coll. 23 (2.1 %) and Coll. 31 (2.09 %). Minimum nitrogen content of 1.09 per cent was recorded in Coll.11 (Table 7 and 8).

4.4.5 C/N ratio

The C/N ratio of the collections ranged from 3.83 and 8.44 with a mean value of 5.71. The CV of the C/N ratio of the collections was 19.44 per cent. The highest C/N ratio was recorded in Coll. 11 (8.44), followed by Coll. 10 (7.23), Coll. 2 (7.09) and Coll. 32 (6.93). Lowest C/N ratio of 3.83 was recorded in Coll. 25 (Table 7 and 8).

4.5 Fruit characters

Only 20 collections exhibited fruiting, and data depicting the fruit characters are presented in Tables 9 to 12.

4.5.1 Fruit bearing habit

Regular and alternate bearing habit were noticed among the collections. Regular bearing habit was noticed in Coll. 1, Coll. 2, Coll. 3, Coll. 4, Coll. 7, Coll. 9, Coll. 10, Coll. 13, Coll. 30, Coll. 31 and Coll. 32. Alternate bearing was noticed in Coll. 12, Coll. 15, Coll. 16, Coll. 17, Coll. 18, Coll. 19, Coll. 20, Coll. 21, and Coll. 22 (Table 9).

4.5.2 Fruit bearing intensity

Poor and medium bearing intensity was noticed among collections. Poor bearing intensity was noticed in Coll. 1, Coll. 3, Coll. 4, Coll. 16, Coll. 17, Coll. 18, Coll. 19, Coll. 20, Coll. 21 and Coll. 30. Medium bearing intensity was noticed in Coll. 2, Coll. 7, Coll. 9, Coll. 10, Coll. 12, Coll. 13, Coll. 15, Coll. 22, Coll. 31 and Coll. 32 (Table 9).

4.5.3 Fruit clustering habit

Clustering fruit habit was observed in all the collections (Table 9).

4.5.4 Fruit shape

Oblong, oval, elliptic fruit shapes were noticed among the collections. Elliptic shape was common among the collections *viz.*, Coll. 4, Coll. 13, Coll. 17, Coll. 18, Coll. 19, Coll. 20, Coll. 21, Coll. 30, Coll. 31 and Coll. 32. Oblong fruit shape was noticed in Coll. 1, Coll. 3, Coll. 7, Coll. 9 and Coll. 10. Both oval and oblong shaped fruits were observed in Coll. 2 and Coll. 21. Oval and elliptic shaped fruits were noticed in Coll. 12 and Coll. 16. Oblong and elliptic shaped fruits were observed in Coll. 15 (Table 9).

4.5.5 Cracking/splitting of fruit skin

Cracking/splitting of fruit skin was observed in Coll. 2, Coll. 9, Coll. 10, Coll. 12, Coll. 13, Coll. 15, Coll. 16, Coll. 17, Coll. 18, Coll. 20, Coll. 22, Coll. 30, Coll. 31 and Coll. 32 whereas, Coll. 1, Coll. 3, Coll. 4, Coll. 7, Coll. 19 and Coll. 21 had no incidence of cracking/splitting of the fruit skin (Table 9).

4.5.6 Fruit skin thickness

Fruit skin thickness was classified as thin, medium and thick skinned. Thin skinned fruits were recorded in Coll. 2 and Coll. 9. Medium skin thickness was observed in Coll. 1, Coll. 4, Coll. 10, Coll. 12, Coll. 13, Coll. 15, Coll. 16, Coll. 17, Coll. 18, Coll. 19, Coll. 20, Coll. 21, Coll. 22, Coll. 30, Coll. 31 and Coll. 32. Thick skinned fruits were noticed in Coll. 3 and Coll. 7 (Table 9).

4.5.7 Mature fruit colour

Mature fruit colour varied as pinkish red and greenish yellow. Greenish yellow colour was observed in Coll. 12, Coll. 15, Coll. 16, Coll. 17 and Coll. 18. Pinkish red colour was observed in Coll. 1, Coll. 2, Coll. 3, Coll. 4, Coll. 7, Coll. 9, Coll. 10, Coll. 13, Coll. 19, Coll. 20, Coll. 21, Coll. 22, Coll. 30, Coll. 31 and Coll. 32 (Table 9).

4.5.8 Fruit attractiveness

Excellent fruit attractiveness was recorded the in the Coll.2. Fruit attractiveness was good in Coll. 1, Coll. 3, Coll. 4, Coll. 7, Coll. 9, Coll. 10, Coll. 13, Coll. 20, Coll. 21, Coll. 22, and Coll. 32. Intermediate type fruits were observed in Coll.12, Coll.15, Coll.16, Coll.17, Coll.18, Coll.19, Coll.30 and Coll.31 (Table 9).

4.5.9 Aril thickness

Aril thickness of the fruit classified as thin, medium and thick. Coll. 2, Coll. 9, Coll. 10, Coll. 13, and Coll. 21 had thick aril fruit. Coll. 1, Coll. 3, Coll. 4, Coll. 7, Coll. 12, Coll. 15, Coll. 16, Coll. 20, Coll.22 and Coll.32 recorded medium aril thickness. The Coll.17, Coll.18, Coll.19, Coll.30 and Coll.31 had thin aril thickness (Table 9).

4.5.10 Aril texture

Firm textured aril was recorded in all the collections (Table 9).

4.5.11 Aril quality

Sweet type aril was recorded in Coll. 1, Coll. 2, Coll. 3, Coll. 7, Coll. 9, Coll. 10, Coll. 12, Coll. 13, Coll. 15, Coll. 19, Coll. 20, Coll. 21, Coll. 22, Coll. 31 and Coll. 32. Sour type aril was recorded in Coll. 4, Coll. 16, Coll. 17, Coll. 18, Coll. 19 and Coll. 30 (Table 9).

4.5.12 Aril colour

Aril colour of creamy white was noticed among all the collections (Table 9).

4.5.13 Fruit length

Length of fruit varied from 2.8 cm and 3.8 cm. Average fruit length was 3.31 cm with CV of 8.87 per cent. Maximum fruit length of 3.8 cm was recorded in Coll. 13 followed by Coll. 2 (3.7 cm), Coll. 15 (3.7 cm), Coll. 10 (3.7 cm), Coll. 4 (3.6 cm), Coll. 1 (3.5 cm), Coll. 19 (3.5 cm), Coll. 3 (3.4 cm), Coll. 7 (3.4 cm), Coll. 12 (3.3 cm), Coll. 9 (3.2 cm), Coll. 20 (3.2 cm), Coll. 22 (3.2 cm), Coll. 16 (3.1 cm), Coll. 32 (3.1 cm), Coll. 17 (3 cm), Coll. 18 (3 cm), Coll. 21 (3 cm), Coll. 31 (3 cm) and Coll. 30 (2.8 cm) (Table 10 and 12).

4.5.14 Fruit diameter

Fruit diameter ranged from 2.1 cm to 3.2 cm with mean fruit diameter of 2.59 cm. The CV of fruit diameter was 11.76 per cent. Coll. 10 recorded maximum fruit diameter of 3.2 cm which was followed by Coll. 15 (3.1 cm), Coll. 2 (3.1 cm), Coll. 19 (2.9 cm), Coll. 16 (2.8 cm), Coll. 13 (2.7 cm), Coll. 20 (2.7 cm), Coll. 1 (2.6 cm), Coll. 17 (2.6 cm), Coll. 4 (2.5 cm). Coll. 9 (2.5 cm), Coll. 18 (2.5 cm), Coll. 22 (2.5 cm), Coll. 32 (2.5 cm), Coll. 7 (2.4 cm), Coll. 12 (2.4 cm), Coll. 21 (2.4 cm), Coll. 30 (2.3 cm), Coll. 3 (2.1 cm) and Coll. 31 (2.1 cm) (Table 10 and 12).

4.5.15 Fruit weight

Fruit weight ranged from 16.9 g to 25.8 g. Average fruit weight of 20.6 g was recorded with a CV of 13.4 %. Highest fruit weight of 25.8 g was recorded in Coll. 10 followed by Coll.13 (25.6 g), Coll.2 (23.9 g), Coll. 9 (23.2 g), Coll. 22

(22.9 g), Coll. 15 (22.8 g), Coll. 7 (22.5 g), Coll. 12 (21.8 g), Coll. 32 (21.1 g), Coll. 3 (19.8 g), Coll. 1 (19.6 g), Coll. 16 (19.3 g), Coll. 19 (19.2 g), Coll. 17 (19.1 g), Coll. 31 (19.1 g), Coll. 4 (18.9 g), Coll. 20 (17.8 g), Coll. 21 (18 g), Coll. 18 (17.2 g) and Coll. 30 (16.9 g) (Table 10 and 12).

4.5.16 Number of fruits per cluster/inflorescence

Number of fruits per cluster/inflorescence was ranging from 6 to 18. Average number of fruits per cluster/inflorescence was 10.85. CV of number of fruits/cluster was 39.7 per cent. Maximum number of fruits/cluster (18) were observed in Coll. 2 and Coll. 13, followed by Coll. 9 (17), Coll. 10 (16), Coll. 7 (15) Coll. 22 (15) and 32 (14). Remaining collections recorded less than 10 fruits per cluster. Minimum number of fruits/cluster (6) were recorded in Coll.1 and Coll. 18 (Table 10 and 12).

4.5.17 Yield/plant

Yield/plant ranged from 1 to 30 kg. Average yield of collections recorded was 12.6 kg/plant with a CV of 78.13 per cent. Highest yield of 30 kg was recorded in Coll. 10, followed by Coll.13 (28.4 kg), Coll.32 (25 kg), Coll. 2 (22.9 kg), Coll. 12 (21 kg), Coll. 9 (20.6 kg), Coll. 15 (18 kg), Coll. 22 (18 kg), Coll. 7 (17.6 kg), Coll. 15 (15 kg), Coll. 16 (10 kg), Coll. 31 (8 kg), Coll. 17 (5 kg), Coll. 30 (5 kg), Coll. 3 (2.5 kg), Coll. 4 (2.1 kg), Coll. 19 (2 kg), Coll. 20 (2 kg) and Coll. 21 (2 kg). Lowest yield of 1 kg per plant was recorded in Coll.1 (Table 10 and 12).

4.5.18 Shelf life

The shelf life of the fruit varied from 3 and 4 days in an ambient condition. The Coll. 1, Coll. 7, Coll. 10, Coll. 13 and Coll. 31 had shelf life of 4 days. The Coll. 2, Coll. 4, Coll. 12 and Coll. 20 recorded a shelf life of 3.5 days each. The Coll. 3, Coll. 9, Coll. 15, Coll. 16, Coll. 17, Coll. 18, Coll. 19, Coll. 21, Coll. 22 and Coll. 32 recorded shelf life of 3 days (Table 10 and 12).

4.5.19 Weight of aril

Aril weight ranged from 12.10 g to 17.10 g. Average aril weight was 14.26 g with CV of 10.1 per cent. Maximum aril weight recorded in Coll. 2 (17.10 g) followed by Coll.10 (16.8 g), Coll. 13 (16.5 g), Coll. 9 (15.5 g), Coll. 7 (15.2 g), Coll. 15 (15.2 g), Coll. 32 (15.2 g), Coll. 22 (14.3 g), Coll. 4 (14.1 g), Coll. 16 (14.1 g), Coll. 17 (13.8), Coll. 3 (13.6 g), Coll. 12 (13.5 g), Coll. 30 (13.5 g), Coll. 1 (13.4), Coll. 17 (13.2 g), Coll. 21 (13.2), Coll. 19 (12.5 g), Coll. 31 (12.4 g) and Coll. 20 (12.10 g) (Table 10 and 12).

4.6 Seed characters

The data depicting the seed characters are presented in Tables 11.

4.6.1 Seed weight (100 seeds)

Seed weight of 100 seeds ranged from 210 g to 297 g, with a CV of 8.9 per cent. Maximum seed weight was recorded in Coll. 15 (297 g) followed by Coll. 13 (296 g), Coll. 32 (295 g), Coll. 22 (285 g), Coll. 9 (284 g), Coll. 31 (281 g), Coll. 12 (275 g), Coll. 16 (272 g), Coll. 7 (270 g), Coll. 10 (270 g), Coll. 4 (265 g), Coll. 3 (256 g), Coll. 30 (256 g), Coll. 19 (254 g), Coll. 18 (249 g), Coll. 20 (243 g), Coll. 21 (240 g), Coll. 1 (236 g) and Coll. 2 (210 g) (Table 11 and 12).

4.6.2 Seed shape

Seed shape of fruits were varied as oblong, chicken tongue, oval and irregular shapes. Oblong and chicken tongue shaped seeds were observed in Coll. 2, Coll. 15, Coll. 17, Coll. 21 and Coll. 30. Oblong shaped seeds were observed in Coll. 1, Coll. 3, Coll. 4, Coll. 7, Coll. 9, Coll. 10, Coll. 12, Coll. 13, Coll. 16, Coll. 18, Coll. 31 and Coll. 32. Oblong and oval shaped seeds were observed in Coll.20. Irregular and oblong shaped seeds were observed in Coll. 19, Coll. 22.

4.6.3 Seed colour

Brown seed colour was noticed among all collections (Table 11)

Table 9. Qualitative characters of litchi fruits grown in Wayanad

Collections	Bearing habit	Bearing intensity	Clustering habit	Fruit shape	Cracking of fruit skin	Fruit skin thickness	Mature fruit colour	Fruit attractiveness	Texture	Aril quality	Aril thickness	Aril colour
Coll. 1	Regular	Poor	Cluster	Oblong	Not prone	Medium	Pinkish red	Good	Firm	Sweet	Medium	Creamy white
Coll. 2	Regular	Medium	Cluster	Oval & oblong	Prone	Thin	Pinkish red	Excellent	Firm	Sweet	Thick	Creamy white
Coll. 3	Regular	Poor	Cluster	Oblong	Not prone	Thick	Pinkish red	Good	Firm	Sweet	Medium	Creamy white
Coll.4	Regular	Poor	Cluster	Elliptic	Not prone	Medium	Pinkish red	Good	Firm	Sour	Medium	Creamy white
Coll. 7	Regular	Medium	Cluster	Oblong	Not prone	Thick	Pinkish red	Good	Firm	Sweet	Medium	Creamy white
Coll. 9	Regular	Medium	Cluster	Oblong	Prone	Thin	Pinkish red	Good	Firm	Sweet	Thick	Creamy white
Coll. 10	Regular	Medium	Cluster	Oblong	Prone	Medium	Pinkish red	Good	Firm	Sweet	Thick	Creamy white
Coll. 12	Alternate	Medium	Cluster	Oval & elliptic	Prone	Medium	Greenish yellow	Intermediate	Firm	Sweet	Thick	Creamy white
Coll. 13	Regular	Medium	Cluster	Elliptic	Prone	Medium	Pinkish red	Good	Firm	Sweet	Medium	Creamy white
Coll. 15	Alternate	Medium	Cluster	Oblong & elliptic	Prone	Medium	Greenish yellow	Intermediate	Firm	Sweet	Thick	Creamy white
Coll. 16	Alternate	Poor	Cluster	Elliptic & oval	Prone	Medium	Greenish yellow	Intermediate	Firm	Sour	Medium	Creamy white
Coll. 17	Alternate	Poor	Cluster	Elliptic	Prone	Medium	Greenish yellow	Intermediate	Firm	Sour	Thin	Creamy white
Coll. 18	Alternate	Poor	Cluster	Elliptic	Prone	Medium	Greenish yellow	Intermediate	Firm	Sour	Thin	Creamy white
Coll. 19	Alternate	Poor	Cluster	Elliptic	Not prone	Medium	Pinkish red	Intermediate	Firm	Sour	Thin	Creamy white
Coll. 20	Alternate	Poor	Cluster	Elliptic	Prone	Medium	Pinkish red	Good	Firm	Sweet	Medium	Creamy white
Coll. 21	Alternate	Poor	Cluster	Elliptic	Not prone	Medium	Pinkish red	Good	Firm	Sweet	Thick	Creamy white
Coll. 22	Alternate	Medium	Cluster	Oblong & oval	Prone	Medium	Pinkish red	Good	Firm	Sweet	Medium	Creamy white
Coll. 30	Regular	Poor	Cluster	Elliptic	Prone	Medium	Pinkish red	Intermediate	Firm	Sour	Thin	Creamy white
Coll. 31	Regular	Medium	Cluster	Elliptic	Prone	Medium	Pinkish red	Intermediate	Firm	Sweet	Thin	Creamy white
Coll. 32	Regular	Medium	Cluster	Elliptic	Prone	Medium	Pinkish red	Good	Firm	Sweet	Medium	Creamy white

Table 10. Quantitative characters of litchi fruits grown in Wayanad

Collections	Fruit length (cm)	Fruit diameter (cm)	Fruit weight (g)	Number of Fruits/cluster	Yield (kg/ plant)	Aril weight (g)	Shelf life (days)
Coll. 1	3.5	2.6	18.6	6	1.0	13.4	4
Coll. 2	3.7	3.1	23.9	18	22.9	17.1	3.5
Coll. 3	3.4	2.1	19.8	6	2.5	13.6	3
Coll.4	3.6	2.5	18.9	7	2.1	14.1	3.5
Coll. 7	3.4	2.4	22.5	15	17.6	15.2	4
Coll. 9	3.2	2.5	23.2	17	20.6	15.5	3
Coll. 10	3.7	3.2	25.8	16	30.0	16.8	4
Coll. 12	3.3	2.4	21.8	11	21.0	13.5	3.5
Coll. 13	3.8	2.7	25.6	18	28.4	16.5	4
Coll. 15	3.7	3.1	22.8	9	18.0	15.2	3
Coll. 16	3.1	2.8	19.3	10	12.0	14.1	3
Coll. 17	3.0	2.6	19.1	9	10.0	13.2	3
Coll. 18	3.0	2.5	17.2	6	5.0	13.8	3
Coll. 19	3.5	2.9	19.2	7	2.0	12.5	3
Coll. 20	3.2	2.7	17.8	7	2.0	12.1	3.5
Coll. 21	3.0	2.4	18	7	2.0	13.2	3
Coll. 22	3.2	2.5	22.9	15	18.0	14.3	3
Coll. 30	2.8	2.3	16.9	10	5.0	13.5	3
Coll. 31	3.0	2.1	19.1	9	8.0	12.4	4
Coll. 32	3.1	2.5	21.1	14	25.0	15.2	3

Table 11. Seed characters of litchi grown in Wayanad

Collections	Seed weight (100 seeds) (g)	Seed shape	Seed coat colour
Coll. 1	236	Oblong	Brown
Coll. 2	210	Oblong & chicken tongue	Brown
Coll. 3	256	Oblong	Brown
Coll.4	265	Oblong	Brown
Coll. 7	270	Oblong	Brown
Coll. 9	284	Oblong	Brown
Coll. 10	270	Oblong	Brown
Coll. 12	275	Oblong	Brown
Coll. 13	296	Oblong	Brown
Coll. 15	297	Oblong & chicken tongue	Brown
Coll. 16	272	Oblong	Brown
Coll. 17	235	Oblong & chicken tongue	Brown
Coll. 18	249	Oblong	Brown
Coll. 19	254	Irregular	Brown
Coll. 20	243	Oblong & oval	Brown
Coll. 21	240	Oblong & chicken tongue	Brown
Coll. 22	285	Oblong/oval	Brown
Coll. 30	256	Oblong &chicken tongue	Brown
Coll. 31	281	Oblong	Brown
Coll. 32	295	Oblong	Brown

Table 12. Descriptive statistics for quantitative traits of litchi fruits

Descriptives	Fruit length (cm)	Fruit diameter (cm)	Fruit weight (g)	Fruits/cluster (number)	Yield (kg/plant)	Shelf life (days)	Aril weight (g)	Aril thickness (mm)	Seed weight (100 seeds) (g)
Maximum value	3.8	3.2	25.8	18	30	4	17.1	7	297
Minimum value	2.8	2.1	16.9	6	1	3	12.1	4	210
Range	1	1.1	8.9	12	29	1	5	3	87
Average	3.31	2.595	20.675	10.85	12.655	3.35	14.26	5.21	263.45
Standard Deviation	0.296	0.301	2.716	4.305	9.882	0.432	1.441	0.842	23.47
Standard Error of Mean	0.066	0.062	0.601	0.962	2.21	0.096	0.325	0.183	5.242
Co-efficient of Variation	8.875	11.761	13.154	39.702	78.13	12.9	10.149	16.168	8.901

4.7 Quality attributes

The data depicting the quality attributes of the fruits are presented in Tables 4.7.

4.7.1 Total sugar

Total sugar content of the 20 collections were ranged from 10.18 to 15.50 per cent. Average total sugar content was 12.18 per cent with a CV of 9.6 per cent. Coll. 15 recorded the maximum value of 15.50 per cent followed by Coll. 13 (13.3 %), Coll. 12 (13.2 %), Coll. 32 (12.6 %), Coll. 9 (12.5 %), Coll. 22 (12.5 %), Coll. 20 (12.4 %), Coll. 3 (12.3 %), Coll. 17 (12.26 %), Coll. 4 (12.1 %), Coll. 21 (12.1 %), Coll. 18 (12.01 %), Coll. 31 (11.9 %). Coll. 16 (11.6 %), Coll. 30 (11.30 %) Coll. 7 (11.1 %), Coll. 19 (11.1 %), Coll. 1 (10.6 %) and Coll. 10 (10.2 %). Minimum value of 10.18 per cent was recorded in Coll. 2 (Tables 4.7).

4.7.2 Total soluble solids

Total soluble solids varied from 15.10 ^{0}B to 19.6 ^{0}B. The TSS displayed a CV of 6.23 per cent and average TSS of 17.46 ^{0}B among the collections. Coll.2 recorded maximum value of 19.6 ^{0}B which was followed by 13 (19.2 ^{0}B), Coll. 10 (19 ^{0}B), Coll. 20 (18.5 ^{0}B), Coll. 22 (18.5 ^{0}B), Coll. 9 (18.3 ^{0}B), Coll. 1 (18^{0}B), Coll. 32 (17.8 ^{0}B), Coll. 7 (17.5 ^{0}B), Coll. 4 (17.3 ^{0}B), Coll. 21 (17.3 ^{0}B), Coll. 3 (17.2 ^{0}B), Coll. 19 (17.1 ^{0}B), Coll. 15 (16.9 ^{0}B), Coll. 12 (16.8 ^{0}B), Coll. 16 (16.7 ^{0}B), Coll. 17 (16.5 ^{0}B), Coll. 18 (16.5 ^{0}B), Coll. 31 (16.10 ^{0}B) and Coll. 30 (15.5 ^{0}B).

4.7.3 Acidity

Acidity of the fruits ranged from 0.38 per cent to 1.18 per cent. Average acidity of fruits was 0.77 per cent with a CV of 22.8 per cent. The Coll. 30 recorded the maximum acidity of 1.18 per cent followed by Coll. 19 (1.02 %), Coll. 21 (0.95), Coll. 20 (0.91), Coll. 16 (0.9 %), Coll. 18 (0.87), Coll. 31 (0.86 %), Coll. 17 (0.82 %), Coll. 3 (0.8 %), Coll. 9 (0.8 %), Coll. 22 (0.8 %), Coll. 12 (0.75 %), Coll. 15 (0.73 %), Coll. 13 (0.71 %), Coll. 4 (0.7 %), Coll. 10 (0.62 %), Coll. 1 (0.61 %), Coll. 7 (0.6 %), Coll. 32 (0.57 %) and Coll.2 (0.38 %).

4.7.4 TSS/Acidity ratio

TSS/Acidity was ranged from 12.8 to 51.58. Average value of the TSS/Acidity was 24.03 with a CV of 33.9 per cent. The Coll. 2 recorded maximum ratio of 51.58 followed by Coll. 32 (31.23), Coll. 10 (30.65), Coll. 1 (29.51), Coll. 7 (29.17), Coll.13 (27.04), Coll. 4 (24.71), Coll. 15 (23.15), Coll. 22 (23.11), Coll. 9 (22.88), Coll. 12 (22.4), Coll. 3 (21.5), Coll. 17 (20.12), Coll. 18 (19.31), Coll. 20 (19.23), Coll. 31 (18.72), Coll.16 (18.56), Coll. 21 (18.21), Coll. 19 (16.76) and Coll. 30 (12.8).

4.7.5 Reducing sugar

The reducing sugar content of the fruits was ranged from 5.8 per cent to 8.8 per cent. Average reducing sugar content was 7.34 per cent with a CV of 10.8 per cent. The Coll. 15 recorded the maximum value of 8.8 per cent which was followed by Coll. 32 (8.6 %), Coll. 4 (8.2 %), Coll. 13 (7.95 %), Coll. 12 (7.9 %), Coll. 31 (7.90 %), Coll. 10 (7.8 %), Coll. 22 (7.69 %), Coll. 17 (7.60 %), Coll. 30 (7.4 %), Coll. 3 (7.2 %), Coll. 1 (7.1 %), Coll. 7 (7.1 %), Coll. 16 (7.1 %), Coll. 18 (6.9 %), Coll. 2 (6.8 %), Coll. 21 (6.8 %), Coll. 9 (6.2 %), Coll. 19 (6.1 %) and Coll. 20 (5.8 %).

4.7.6 Non reducing sugar

Non reducing sugar of fruits ranged from 3.38 per cent to 6.7 per cent. Average non-reducing sugar recorded was 4.84 per cent with a CV of 22.33 per cent. The Coll. 15 recorded the maximum value of 6.7 per cent followed by Coll. 20 (6.60 %), Coll. 9 (6.30 %), Coll. 13 (5.35 %), Coll. 12 (5.3 %), Coll. 21 (5.3 %), Coll. 18 (5.11 %), Coll. 3 (5.1 %), Coll. 19 (5.0 %), Coll. 22 (4.81 %), Coll. 17 (4.66 %), Coll. 16 (4.5 %), Coll. 7 (4 .0 %), Coll. 31 (4.0 %), Coll. 32 (4 %), Coll. 4 (3.9 %), Coll. 30 (3.9 %), Coll. 1 (3.5 %), Coll. 2 (3.38 %), and Coll. 10 (2.4 %).

Table 13. Fruit quality characters of litchi fruit

Collections	Total sugar (%)	TSS (°B)	Acidity (%)	TSS/Acidity	Reducing sugar (%)	Non-reducing sugar (%)
Coll. 1	10.60	18.00	0.61	29.51	7.10	3.50
Coll. 2	10.18	19.60	0.38	51.58	6.80	3.38
Coll. 3	12.30	17.20	0.80	21.50	7.20	5.10
Coll.4	12.10	17.30	0.70	24.71	8.20	3.90
Coll. 7	11.10	17.50	0.60	29.17	7.10	4.00
Coll. 9	12.50	18.30	0.80	22.88	6.20	6.30
Coll. 10	10.20	19.00	0.62	30.65	7.80	2.40
Coll. 12	13.20	16.80	0.75	22.40	7.90	5.30
Coll. 13	13.30	19.20	0.71	27.04	7.95	5.35
Coll. 15	15.50	16.90	0.73	23.15	8.80	6.70
Coll. 16	11.60	16.70	0.90	18.56	7.10	4.50
Coll. 17	12.26	16.50	0.82	20.12	7.60	4.66
Coll. 18	12.01	16.80	0.87	19.31	6.90	5.11
Coll. 19	11.10	17.10	1.02	16.76	6.10	5.00
Coll. 20	12.40	17.50	0.91	19.23	5.80	6.60
Coll. 21	12.10	17.30	0.95	18.21	6.80	5.30
Coll. 22	12.50	18.50	0.80	23.13	7.69	4.81
Coll. 30	11.30	15.10	1.18	12.80	7.40	3.90
Coll. 31	11.90	16.10	0.86	18.72	7.90	4.00
Coll. 32	12.60	17.80	0.57	31.23	8.60	4.00

Table 14. Descriptive statistics for quality traits of litchi fruits

Descriptives	Total sugar (%)	TSS	Acidity (%)	TSS/Acidity ratio	Reducing sugar (%)	Non reducing sugar (%)
Maximum value	15.5	19.6	1.18	51.58	8.8	6.7
Minimum value	10.18	15.1	0.38	12.8	5.8	3.38
Range	5.32	4.5	0.8	38.78	3	3.32
Total	243.75	349.2	15.58	480.66	146.94	96.81
Average	12.185	17.46	0.779	24.033	7.347	4.845
Standard Deviation	1.182	1.088	0.178	8.159	0.79	1.082
Variance	1.399	1.186	0.036	66.53	0.637	1.16
Standard Error of Mean	0.269	0.244	0.037	1.829	0.17	0.247
Co-efficient of Variation	9.681	6.234	22.827	33.944	10.831	22.33

4.7.7 Sensory evaluation

The attributes of litchi fruits *viz.,* fruit appearance, colour, texture, flavour, taste and over all acceptability were considered for quality assessment and sensory evaluation of matured fruits was carried out on a nine point hedonic scale using score card for five attributes. Score 1 is lowest which indicates dislike extremely and highest score 9 is indicating like extremely.

Among the twenty collections, the highest mean rank for appearance was recorded by Coll. 2 (17.7) followed by Coll. 10 (16), Coll. 32 (15.6), Coll. 20 (15.15), Coll. 7 (14.5). The highest mean rank for colour recorded by Coll. 20 (13.9) followed by Coll. 2 (13.85), Coll. 22 (13.7), Coll. 13 (13.35), and Coll. 7 (13.1). Highest mean rank for flavour was recorded by Coll. 2 (19.55) followed by Coll. 7 (16.15), Coll. 9 (13.25), and Coll. 32 (13.1). For taste, the highest mean rank was recorded by Coll. 2 (19.9), Coll. 1 (16.55), Coll. 32 (15.7), Coll. 7 (14.55), and Coll. 15 (14.55). Highest mean rank for overall acceptability recorded by Coll. 2 (19.35), Coll. 1 (16.3), Coll. 10 (15.9), Coll. 15 (14.5), Coll. 22 (13.75) and Coll. 13 (13.15) (Table 15).

4.8 Pest and disease incidence

There was incidence of pests and diseases during the period of study. Incidence of mites, lepidopteran defoliators and coleopteran defoliators were observed. Incidence of vertebrate pests like monkey, bats and squirrel were also observed.

Incidence of red rust and anthracnose diseases were noticed among the collections.

Table 15. Mean ranks of sensory evaluation of litchi fruits

Appearance	Mean rank	Colour	Mean rank	Flavour	Mean rank	Taste	Mean rank	Overall acceptability	Mean rank
Coll. 2	17.7	Coll. 20	13.9	Coll. 2	19.55	Coll. 2	19.9	Coll. 2	19.35
Coll. 10	16	Coll. 2	13.85	Coll. 7	16.15	Coll. 1	16.55	Coll. 1	16.3
Coll. 32	15.6	Coll. 22	13.7	Coll. 9	13.5	Coll. 32	15.7	Coll. 10	15.9
Coll. 20	15.15	Coll. 13	13.35	Coll. 15	13.25	Coll. 7	14.55	Coll. 15	14.5
Coll. 7	14.5	Coll. 7	13.1	Coll. 32	13.1	Coll. 15	14.55	Coll. 22	13.75
Coll. 13	13.5	Coll. 32	12.95	Coll. 13	13.05	Coll. 9	13.15	Coll. 13	13.15
Coll. 22	12.95	Coll.4	12.45	Coll. 22	12.45	Coll. 13	13.1	Coll. 3	12.65
Coll. 9	11.4	Coll. 10	12.35	Coll. 20	12.2	Coll. 10	12.6	Coll. 32	12.6
Coll. 1	10.95	Coll. 19	11.7	Coll. 21	12.2	Coll. 22	12.15	Coll. 7	12.45
Coll. 15	10.75	Coll. 9	11.4	Coll. 1	10.8	Coll. 3	11.9	Coll. 9	11.55
Coll. 31	10.1	Coll. 1	10.45	Coll. 10	9.65	Coll. 12	11.75	Coll. 20	11.35
Coll. 3	9.55	Coll. 17	10.25	Coll. 17	9.65	Coll. 20	10.7	Coll. 21	11.35
Coll. 12	9.4	Coll. 15	9.7	Coll. 31	9.45	Coll. 21	10.7	Coll. 12	10
Coll. 21	8.8	Coll. 3	9.15	Coll. 12	8.85	Coll. 16	6.85	Coll. 31	7.6
Coll. 16	8.5	Coll. 31	9.05	Coll. 19	7.45	Coll. 31	5.95	Coll.4	6.75
Coll. 19	6.85	Coll. 16	8.05	Coll. 3	7.4	Coll. 18	4.65	Coll. 30	4.7
Coll. 30	5.05	Coll. 21	6.7	Coll. 16	7.3	Coll. 30	4.35	Coll. 16	4.6
Coll. 17	4.9	Coll. 18	6.5	Coll. 18	5.65	Coll. 17	4.25	Coll. 18	4.3
Coll.4	4.75	Coll. 30	5.75	Coll. 30	5.35	Coll.4	3.7	Coll. 19	3.9
Coll. 18	3.6	Coll. 12	5.65	Coll.4	3	Coll. 19	2.95	Coll. 17	3.25
Kendall's W test	0.086	0.104		0.05		0.124		0.033	

4.9 Qualitative evaluation

Wide variability was present among the qualitative characters of collections. Fourteen qualitative characters were variable among the collections. However, characters *viz.*, flower composition in inflorescence, position of inflorescence, fruit clustering habit, aril colour, aril texture and seed coat colour were non-variable parameters. Hence, these characters were not included for further analysis. The percentage frequency of each characters were calculated and presented in Table 16 a, 16b and 16c.

4.9.1 Tree and leaf characters

Among the tree characters variability was observed in crown shape, branching pattern, and leaf blade shape, colour of both young and mature leaves (Table 16a).

Five types of crown shapes *viz.*, semicircular, oblong, spherical, irregular and broadly pyramid were observed among the collections. Semicircular crown shape (34.37 %) was common, followed by oblong (31.25 %), spherical (25.12 %), irregular (3.12 %) and broadly pyramidal shape (3.12 %).

Branching pattern of the collections showed verticillate type (65.62 %) followed by horizontal type (15.62 %) and irregular type (15.62 %) and erect type (3. 12 %).

The mature leaf shape had a predominance of elliptic shape (96.87 %) while single collection recorded lanceolate shape (3.12 %).

The frequency of mature leaf colour was 65.62 per cent green, 31.25 per cent dark green and 3.12 per cent light green whereas in young leaf 78.12 per cent pinkish green 12.5 per cent yellowish green and 9.37 per cent light green.

Table 16 a. Frequency distribution of tree and leaf characters of litchi

Sl. No.		Character	Expression	Frequency (%)
1		Crown Shape	Semicircular	34.37
			Oblong	31.25
			Spherical	25.12
			Irregular	3.12
			Broadly Pyramid	3.12
2		Branching Pattern	Verticillate	65.62
			Horizontal	15.62
			Irregular	15.62
			Erect	3.12
3		Leaf Blade Shape	Elliptic	96.87
			Lanceolate	3.12
4	a	Mature leaf colour	Green	65.62
			Light Green	3.12
			Dark Green	31.25
	b	Young leaf colour	Pinkish Green	78.12
			Light Green	9.37
			Yellowish Green	12.50

Table 16b. Frequency distribution of time of flushing and flowering season of litchi

Sl. No.	Character	Expression	Frequency (%)
1	Time of flushing	August	50
		September	9.37
		February	3.12
		July and November	9.37
		August and September	6.25
		August and November	3.12
		August and February	3.12
		September and February	12.5
		November and February	3.12
2	Flowering season (28 collection)	August- September	75
		February-March	7.14
		Both seasons	17.85

4.9.2 Time of flushing and flowering season

Wide variability in flushing time and flowering season were noticed in the collections (Table 16b). The frequency of flushing were August (50 %), September (9.37 %) and February (3.12 %). Two time flushing was also observed and frequency of flushing were July and November (6.25 %), August and November (3.12 %), August and February (3.12 %), September and February (12.5 %) and November and February (3.12 %).

Only 28 trees were flowered during the period of study (Table 16b). Among the collections, 75 per cent were flowered during the month of August to September and 7.14 per cent during February to March. Both the seasons flowering (17.5 %) were also noticed in the collections.

4.9.3 Fruit characters

Out of 32 collections, only 20 collections were fruited during period of the study. The frequency distribution of 20 collections are presented in the table 16 c.

Regarding the fruit bearing habit, 55 per cent plants were regular bearing habit and 45 per cent plants were alternate bearing habit.

Fifty per cent of the collections were poor fruit bearing intensity and fifty per cent medium fruit bearing intensity.

Three types of fruit shape were observed *viz.*, oblong, elliptic and oval. Frequency of fruits shapes were elliptic (47.60 %), oblong (19.04 %), oval (4.7 %). Both oval and oblong (9.52 %); oval and elliptic (9.52 %); elliptic and oval (4.7 %).

Regarding cracking of fruit skin, 70 per cent of the fruits were prone to cracking and 30 per cent were not prone to cracking among the collections.

Thin (10 %), medium (80 %) and thick (%) fruit skin were noticed among the collections.

Table 16c. Frequency distribution of fruit characters of litchi

Sl. No.	Character	Expression	Frequency (%)
1	Fruit bearing habit	Regular	55.00
		Alternate	45.00
2	Fruit bearing intensity	Poor	50.00
		Medium	50.00
3	Fruit shape	Oblong	19.04
		Elliptic	47.60
		Oval	4.70
		Oval and oblong	9.52
		Oval and elliptic	9.52
		Elliptic and oval	4.70
4	Cracking/splitting of fruit skin	Prone	70.00
		Not Prone	30.00
5	Fruit skin thickness	Thin	10.00
		Medium	80.00
		Thick	10.00
6	Mature fruit colour	Greenish yellow	25.00
		Pinkish red	75.00
7	Fruit attractiveness	Intermediate	40.00
		Good	55.00
		Excellent	5.00
8	Aril thickness	Thin	25.00
		Medium	50.00
		Thick	25.00
9	Aril quality	Bitter	30.00
		Sweet	70.00
10	Seed shape	Oblong	60.00
		Oblong and Oval	10.00
		Oblong and Chicken Tongue	25.00
		Irregular	5.00

Two types of fruit colours were noticed among the collections and 75 per cent of fruits were pinkish red and 25 per cent fruits were greenish yellow in colour.

Fruit attractiveness was classified into good, intermediate and excellent based on the combined assessment of shape, size and appearance of fruits. Among the collections 55 per cent were good, 40 per cent intermediate type and 5 per cent were excellent.

Ari thickness of fruits were classified into thin, medium and thick. Among the collections, 25 per cent of the trees were thick aril, 50 per cent medium thick aril and 25 per cent thin aril.

Frequency distribution of quality of aril, 70 per cent of the collections were sweet type and 30 per cent were bitter type fruits.

The seed shapes of the collections were oblong (60 %), oblong & oval seeds (10 %); oblong and chicken tongue (25 %) and irregular shape (5 %) (Table 16c).

4.10 Clustering based on qualitative characters

Agglomerative hierarchical clustering was performed based on the Jacquard's similarity coefficient using UPGMA method. Fourteen qualitative characters *viz.*, crown shape, branching pattern, mature and young leaf colour, bearing habit, bearing intensity, fruit shape, skin cracking, skin thickness, fruit colour, fruit attractiveness, aril thickness, aril quality and seed shape were considered and dendrogram was formulated.

Twenty fruit bearing collections were used in formulating dendrogram. Five clusters could be framed at 66 per cent similarity level (Fig.1). The details of the each cluster are presented in Table 17.

Cluster I composed of semicircular, oblong and spherical crown shapes, verticillate and irregular branching pattern, green and dark green matured leaves,

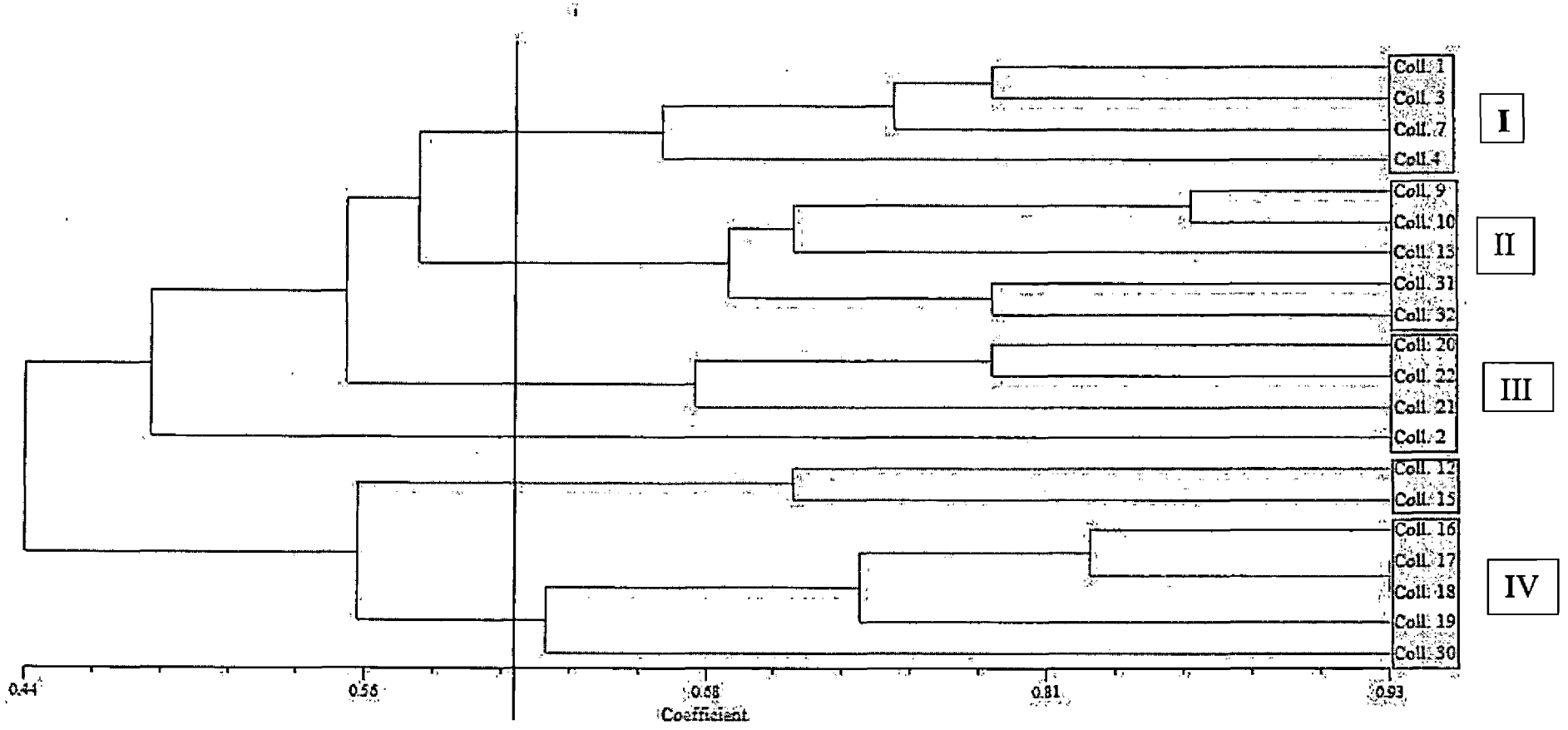


Fig. 1 Dendrogram of qualitative characteristics of litchi grown in Wayanad

pinkish young leaves, bearing habit was regular, intensity of bearing was poor and medium, fruit shapes were elliptic and oblong, fruit colour was pinkish red, attractiveness of the fruits were good, skin was not prone to cracking, thickness of skin was medium and thick, aril thickness was medium, quality of aril was sweet as well as sour types and shape of the seeds was oblong.

Cluster II comprised of crown shapes of semicircular, oblong and spherical. Verticillate and horizontal branching pattern, green coloured matured leaves, pinkish green and yellowish green coloured young leaves, bearing habit was regular, intensity of bearing was medium, fruit shapes were elliptic and oblong, fruit colour was pinkish red, attractiveness of the fruits were good and inter mediate, skin was prone to cracking, thickness of skin was thin and medium, aril thickness was thin, medium, and thick, quality of aril was sweet types and shape of the seeds was oblong.

Cluster III displayed only semicircular crown shape, verticillate and irregular branching pattern, green coloured matured leaves, pinkish green young leaves, bearing habit was both regular and alternate, intensity of bearing was poor and medium, fruit shapes were elliptic, oval and oblong, fruit colour was pinkish red, attractiveness of the fruits were good and excellent, skin cracking was observed in Coll. 2 and Coll. 22. The Coll. 20 and Coll. 21 were not prone to cracking. Thickness of skin was thick and medium, aril thickness was thick and medium, quality of aril was sweet types and shape of the seeds were oblong, oblong/chicken tongue and irregular.

Cluster IV displayed spherical and oblong crown shapes, verticillate branching pattern, green and dark green coloured matured leaves, pinkish green young leaves, bearing habit was alternate, intensity of bearing was medium, fruit shapes were oval and elliptic, oblong and elliptic. Fruit colour was greenish yellow, attractiveness of the fruits were intermediate and fruit skin was prone to cracking. Thickness of skin was medium, aril thickness was medium, quality of aril was sweet types and shape of the seeds were oblong, oblong/chicken tongue.

Table17. Cluster analysis of qualitative characters using dendrogram

Clusters	I	II	III	IV	V
Collections	Coll. 1, Coll. 3, Coll. 4, Coll. 7	Coll. 9, Coll. 10, Coll. 13, Coll. 31, Coll. 32	Coll. 2, Coll. 20, Coll. 21, Coll. 22	Coll. 12, Coll. 15	Coll. 16, Coll. 17, Coll. 18, Coll. 19, Coll. 30
Crown shape	Semicircular, oblong, spherical	Semicircular, oblong, spherical	Semicircular	Spherical, oblong	Oblong and semicircular
Branching Pattern	Verticillate, irregular	Verticillate, horizontal	Verticillate, irregular	Verticillate	Verticillate
Mature leaf colour	Green, dark green	Green	Green	Green, dark green	Green, dark green
Young leaf colour	Pinkish green	Pinkish green, yellowish green	Pinkish green	Pinkish green	Pinkish green
Bearing habit	Regular	Regular	Alternate, regular	Alternate	Alternate, regular
Bearing intensity	Poor, medium	Medium	Poor, medium	Medium	Poor
Fruit shape	Oblong, elliptic	Oblong, elliptic	Elliptic, oval & oblong	Oval & elliptic, oblong& elliptic	Elliptic & oval, elliptic
Fruit colour	Pinkish red	Pinkish red	Pinkish red	Greenish yellow,	Greenish yellow, pinkish red
Attractiveness	Good	Good, intermediate	Good, excellent	Intermediate	Intermediate
Skin cracking	Not prone	Prone	Prone, not prone	Prone	Prone, not prone
Skin thickness	Medium and thick	Thin, medium	Thick, medium	Medium	Medium
Aril thickness	Medium	Medium, thick and thin	Thick, medium	Medium	Medium, thin
Aril quality	Sweet and sour	Sweet	Sweet	Sweet	Sour
Seed shape	Oblong	Oblong	Oblong/oval, oblong/chicken tongue	Oblong, oblong/chicken tongue	Oblong, oblong/chicken tongue, irregular

Cluster V had oblong and semicircular crown shapes, verticillate branching pattern, green and dark green coloured matured leaves, pinkish green young leaves, bearing habit was alternate as well as regular, intensity of bearing was poor, fruit shapes were oval & elliptic, oblong & elliptic. Fruit colour was greenish yellow and pinkish green, attractiveness of the fruits were intermediate, skin crack present in Coll. 16. Coll. 17 and Coll. 30. The Coll. 18 and Coll. 19 were resistant to cracking. Thickness of skin was medium while aril thickness was medium and thin, quality of aril was sour and shape of the seeds was oblong, oblong/chicken tongue and irregular.

4.11 Principal component analysis

Principal component analysis (PCA) is essentially a data reduction technique wherein the original variables are subjected to a linear transformation, resulting in principal components (PCs) and the number of PCs to be retained are based on Kaiser's criterion (Eigenvalue >1) (Kaiser, 1958).

4.11.1 Tree morphological traits

The Scree plot of PCA (Fig. 2a) shows that the first two components had eigenvalues >1. The first two main PCs extracted from the complicated components, the total cumulative variance of these two factors amounted 77.3 per cent.

The Cluster analysis was attempted through the plot of the collections based on the first two PCs in which PC 1 accounted for 55.8 per cent and PC 2 had 21.4 per cent (Table 18 a).

The PC1 was contributed by age and its associate traits like height and girth with PC loadings of 0.459, 0.460 and 0.444 respectively, whereas PC2 contributed by leaf length, shoot length and internodal length with PC loadings of 0.508, -0.568 and -0.563 respectively. The traits, which contributed more positively to PC 1 were age of tree, height and girth. PC2 contributed more positively to leaf length while shoot length and internodal length were negatively contributed.

From the PC loading plot it could be inferred that the characters like tree age, height and girth were linked together. It is evident that the angle between the above three characters are extremely acute in nature which infers that they are positively associated. Likewise shoot length and internodal length were also closely associated (Fig. 2).

4.11.1.1 Clustering of morphological traits

Based on the first two components of the PC analysis clustering pattern was made. Out of 32 collections 9 clusters could be framed (Fig. 2c). Cluster VI

Table 18 a. Principal component analysis of morphological characters of litchi

Variables	Components						
	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Age of tree	**0.459**	0.025	0.386	0.077	-0.371	0.019	-0.704
Height	**0.46**	0.145	0.317	0.148	-0.342	0.251	0.682
Girth	**0.444**	-0.082	0.278	0.176	0.803	-0.205	0.029
Leaf length	0.309	**0.508**	-0.397	-0.331	0.237	0.55	-0.144
Leaf width	0.375	0.272	-0.52	0.09	-0.195	-0.682	0.064
Shoot length	0.228	**-0.568**	-0.493	0.508	-0.034	0.346	-0.058
Internodal length	0.304	**-0.563**	-0.053	-0.752	-0.068	-0.087	0.101
Eigenvalue	3.9077	1.5004	0.8928	0.2805	0.2083	0.187	0.0233
Proportion	0.558	0.214	0.128	0.04	0.03	0.027	0.003
Cumulative	0.558	0.773	0.9	0.94	0.97	0.997	1

Table 18 b. Cluster wise distribution of litchi collections based on morphological characters

Clusters	Cluster size	Collections
I	3	Coll. 20, Coll. 21, Coll. 25
II	5	Coll. 15, Coll. 16, Coll. 17, Coll. 19, Coll. 22
III	3	Coll. 1, Coll. 2, Coll. 7
IV	1	Col. 6
V	3	Coll. 3, Coll. 4, Coll. 12
VI	8	Coll. 5, Coll. 8, Coll. 9, Coll. 10, Coll. 13, Coll. 31, Coll. 30, Coll. 32
VII	3	Coll. 11, Coll. 28, Coll. 29
VIII	4	Coll.14 Coll.23 Coll.26 Coll.27
IX	1	Coll.24

Table 18 c. Mean performance of clusters based on morphological characters

Clusters	Age (years)	Height (m)	Girth (cm)	Leaf length (cm)	Leaf width	Shoot length (cm)	Internodal length (cm)
I	**79.00**	18.40	274.00	14.13	4.23	21.67	4.43
II	54.00	14.37	239.83	13.93	3.97	22.17	4.10
III	36.67	13.43	146.33	**16.50**	4.83	19.67	3.27
IV	20.00	5.50	120.00	14.50	**5.20**	21.00	3.50
V	25.00	8.10	123.33	13.80	4.13	24.33	3.60
VI	14.88	5.40	78.63	13.20	3.51	20.81	3.55
VII	**8.33**	**3.73**	**32.00**	**12.47**	**3.23**	**16.33**	**2.87**
VIII	15.75	4.78	90.25	12.60	3.78	24.50	4.78
IX	**79.00**	**18.50**	**540.00**	14.50	4.70	**25.00**	**5.20**

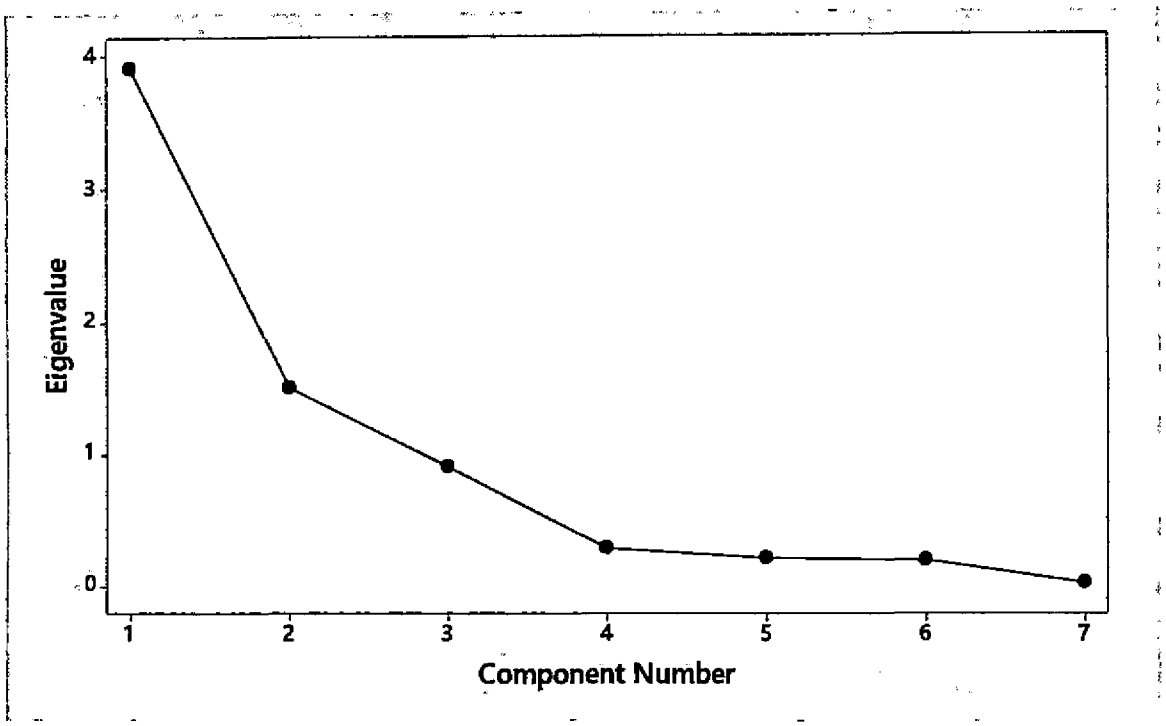


Fig. 2a Scree plot showing eigenvalues in response to number of components for estimated variables of litchi

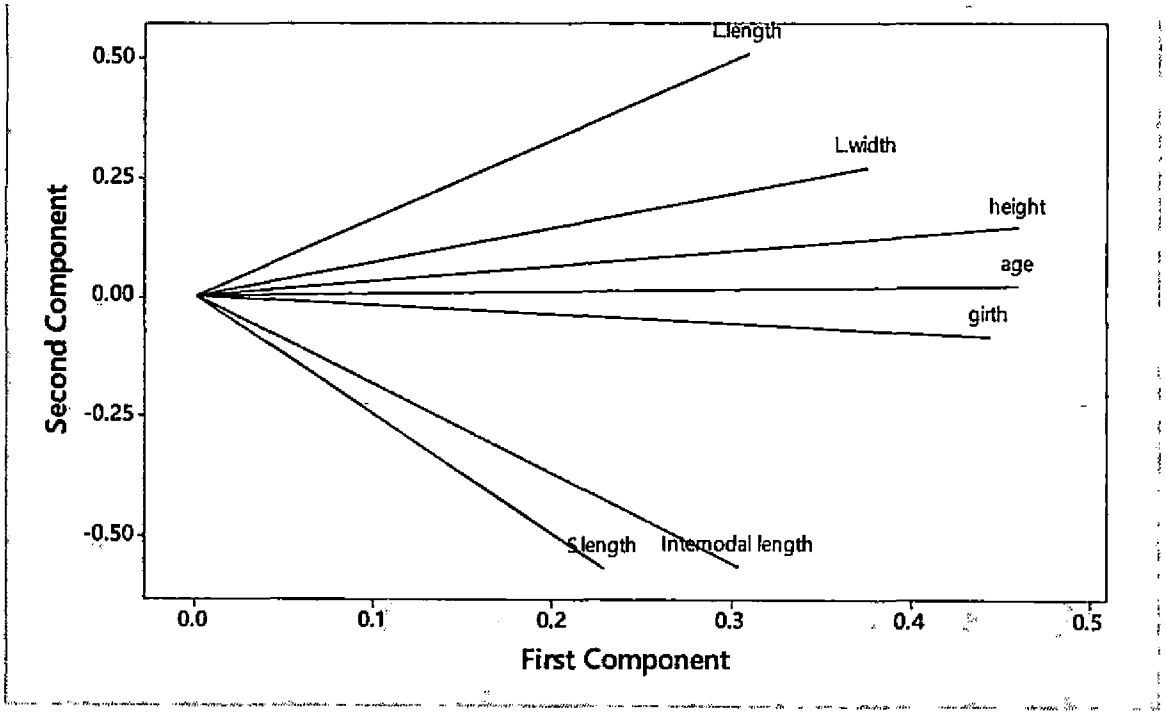


Fig. 2b Plot of first two PCs showing relation among the various morphological trits of litchi

L. length=Leaf length, L. width=Leaf width, S. length=Shoot length

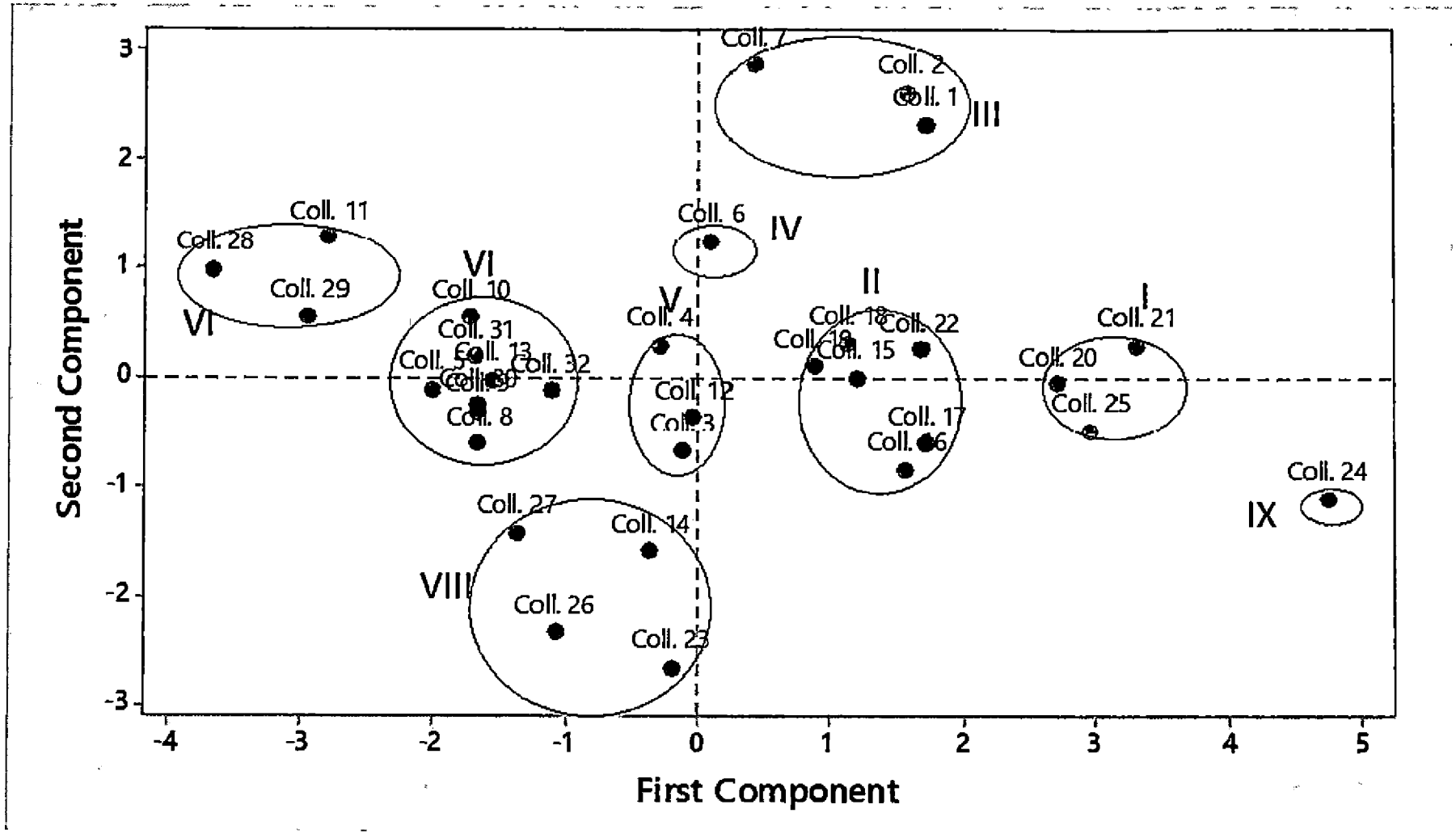


Fig. 2c Clustering of litchi collections of based on morphological traits from first two principal components

had maximum collections and cluster IX composed of single collection. The mean performance of the clusters depicts that, Coll. 24 alone formed cluster IX, mainly attributing to highest value in almost all characters like age of the tree, girth, shoot length and internodal length, whereas cluster VII is attributed by minimum readings in all the morphological characters (Table 18c). Cluster I also attributed to maximum age of the tree. Maximum leaf length and maximum leaf width is attributed by the Clusters III and Cluster IV respectively.

4.11.2 Floral traits

The scree plot of PCA shows that the first two eigenvalues corresponds to the maximum percentage of the variation in the data set (Fig. 3a). The first two PCs extracted from 5 components, the total cumulative variance of these two factors amounted 86.4 per cent and components had eigenvalues >1. Other PCs had eigenvalues <1. PC1 and PC2 which made the largest contribution with eigenvalues of 2.80, 1.51 and contributed 56.1 per cent and 30.3 per cent of total variability respectively (Table 19a).

The PC1 composed of flowering duration, days from flowering to fruit maturity and fruit set to maturity with PC loadings of 0.521, 0.576 and 0.582 respectively which contributed positively. PC2 was contributed by inflorescence length and width with PC loadings of 0.724 and 0.649 and contributed more positively (Table 19a).

The first two components explained major variance and were plotted to observe the relationship between flower traits of litchi. From the PC loading plot it could be inferred that there is a strong association between days from flowering to fruit maturity and fruit set to maturity as indicated by angle between vectors is extremely acute in nature (Fig. 3b). Flowering duration also had positive association with days from flowering to fruit maturity and fruit set to maturity. Inflorescence width and inflorescence length also had close linkage showing acute angle between vectors. Flowering duration and inflorescence length mutually near perpendicular vectors which means no linkage between these characters.

Table 19a. Principal component analysis of flower traits of litchi

Variables	Components				
	PC1	PC2	PC3	PC4	PC5
Inflorescence length	0.075	**0.724**	-0.679	-0.097	-0.012
Inflorescence width	0.23	**0.649**	0.724	-0.044	0.015
Flowering duration	**0.521**	-0.199	-0.038	-0.827	0.062
Flowering to fruit maturity	**0.576**	-0.081	-0.098	0.438	0.679
Fruit set to fruit maturity	**0.582**	-0.091	-0.068	0.337	-0.732
Eigenvalue	2.8062	1.5157	0.406	0.2596	0.0126
Proportion	0.561	0.303	0.081	0.052	0.003
Cumulative	0.561	0.864	0.946	0.997	1

Table 19b. Cluster wise distribution of litchi collections based on flower traits

Clusters	Size	Collections
I	8	Coll. 1, Coll. 2, Coll. 4, Coll. 7, Coll. 12, Coll. 13, Coll. 31, Coll. 32
II	2	Coll. 9, Coll. 22
III	6	Coll. 8, Coll. 11, Coll. 14, Coll. 23, Coll. 28, Coll. 29
IV	2	Coll. 17, Coll. 18
V	8	Coll. 3, Coll. 10, Coll. 15, Coll. 16, Coll. 19, Coll. 20, Coll. 21, Coll. 30

Table 19c. Mean performance of clusters based on flower traits

Clusters	Size	Inflorescence length (cm)	Inflorescence width (cm)	Flowering duration (days)	Flowering to fruit maturity (days)	Fruit set to fruit maturity (days)
I	8	30.79	14.48	28.13	83.00	63.13
II	2	**37.55**	**18.70**	24.00	**92.00**	61.50
III	6	24.97	12.45	**15.00**	**0.00**	**0.00**
IV	2	**15.75**	**10.45**	24.00	91.00	**66.50**
V	8	21.45	13.13	**32.00**	88.88	66.38

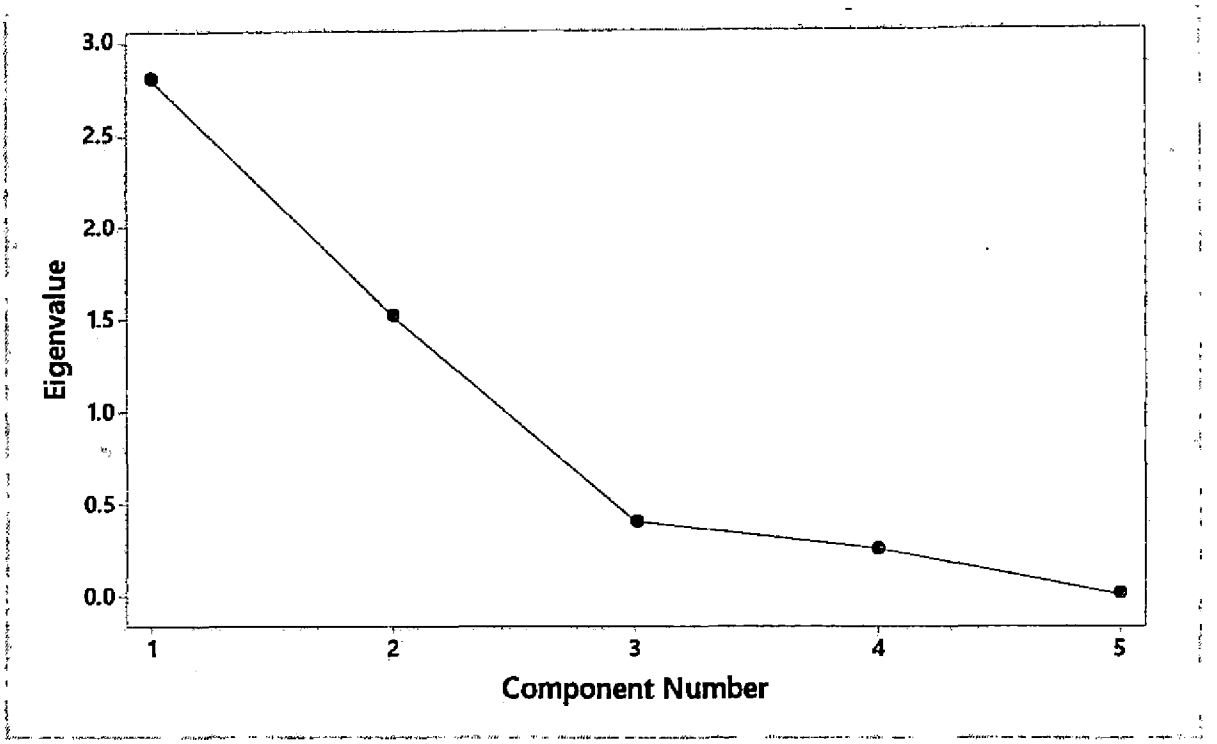


Fig. 3a Scree plot showing eigenvalues in response to number of components for estimated variables of litchi

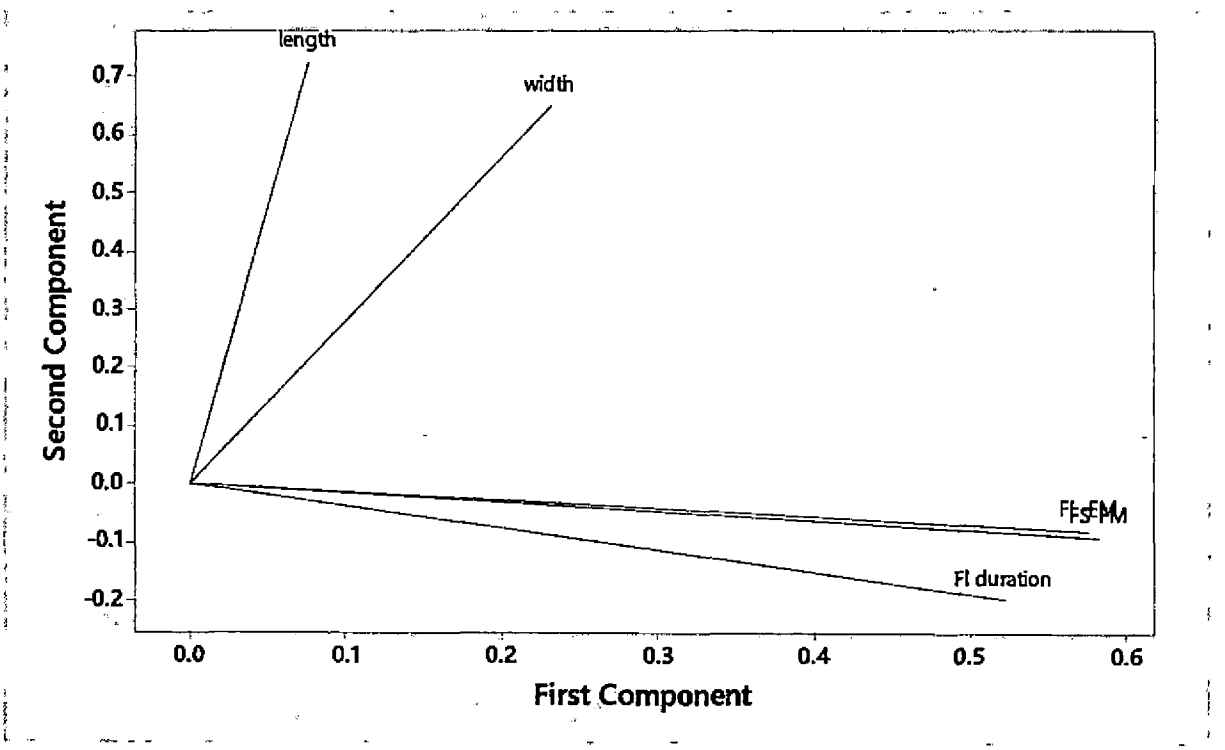


Figure 3b Plot of first two PCs showing relation among the flower traits of litchi

length=Inflorescence length, width=Inflorescence width, Fl-FM=Flowering to fruit maturity, FS-FM=Fruit set to fruit maturity, Fl duration=Flowering duration

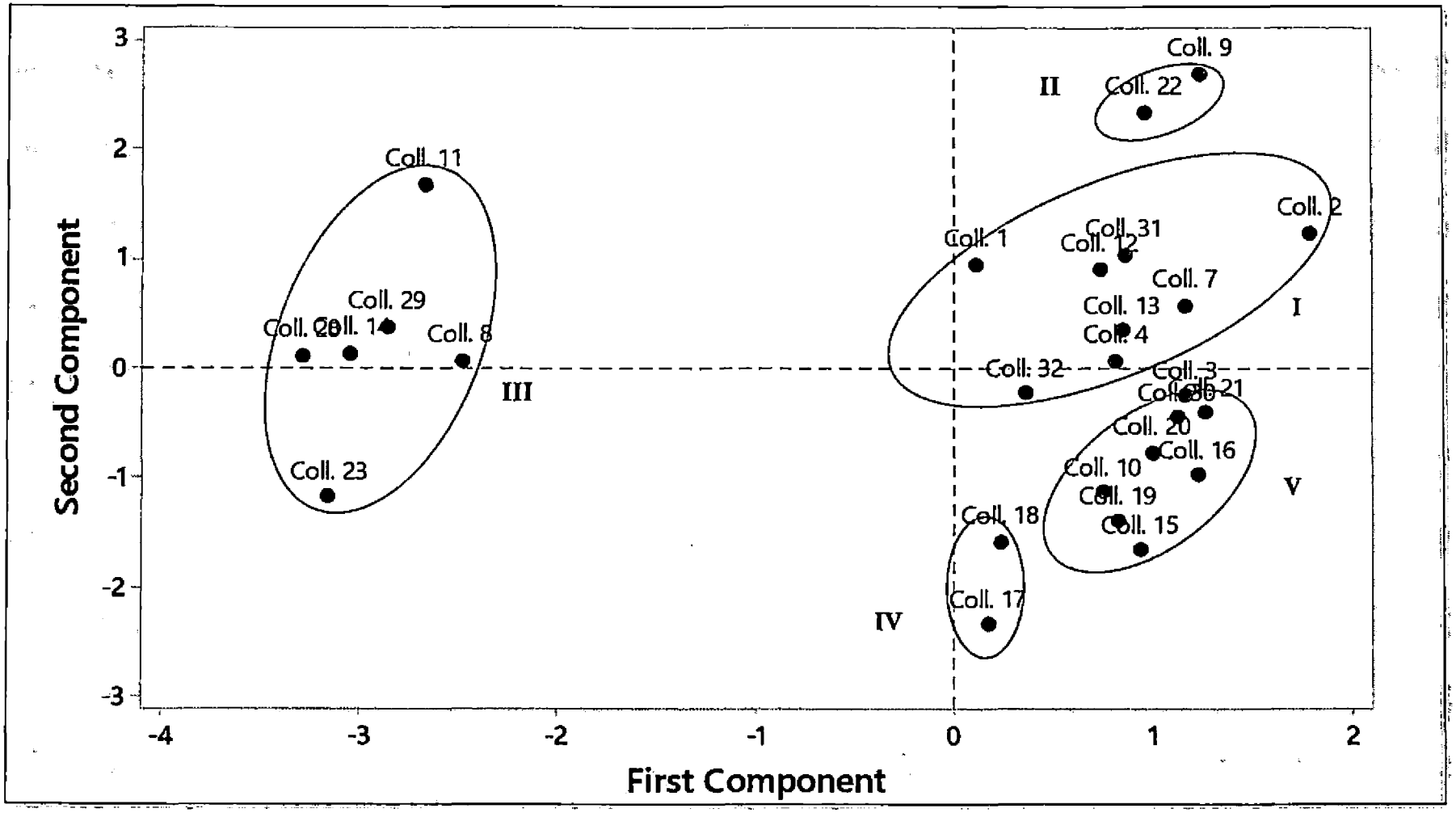


Fig. 2c Clustering of litchi collections of based on flower traits from first two principal components

4.11.2.1 Clustering of floral traits

Based on the first two components of the PC analysis clustering pattern was made. Out of 26 collections 5 clusters could be framed (Fig. 3c). Cluster I and cluster V were composed of maximum number of collections and cluster II and IV composed of two collections each (Table 19b).

The mean performance of the clusters depicts that, cluster II recorded maximum inflorescence length, inflorescence width and days from flowering to fruit maturity. Cluster V recorded maximum flowering duration. While cluster IV recorded maximum days from fruit set to fruit maturity and minimum inflorescence length and width. Cluster III recorded minimum flowering duration and zero days from flowering to maturity since there was no fruit set had been occurred (Table 19c).

4.11.3 Physiological traits

The scree plot of PCA shows that the first two eigenvalues corresponds to the maximum percentage of the total variation in the data set (Fig. 4a). The first two main PCs extracted from five components, the total cumulative variance of these two factors amounted 75.6 per cent and had eigenvalues >1 and other PCs had eigenvalues <1. PC1 and PC2 which made the largest contribution with eigenvalues 2.25 and 1.52 and contributed 45.1 per cent and 30.5 per cent of total variability respectively (Table 20a).

The PC1 associated to chlorophyll content, pH of cell sap, nitrogen with PC loadings of 0.534, 0.478 and 0.594. PC2 was correlated by carbohydrates and C/N ratio with PC loadings of -0.665 and -0.634 respectively. The factors which contributed more positively to PC1 were tchlorophyll content, pH of cell sap and nitrogen content. PC2 associated to carbohydrates and C/N ratio and contributed negatively (Table 20a).

From the PC loading plot it is recorded that there is a strong association between cell sap pH and chlorophyll content as indicated by small acute angle

Table 20a. Principal component analysis of physiological variables of litchi collections

Variable	PC1	PC2	PC3	PC4	PC5
Chlorophyll	**0.534**	-0.227	0.134	0.75	-0.289
Cell sap pH	**0.478**	-0.241	-0.768	-0.327	-0.132
Carbohydrates	0.154	**-0.665**	0.534	-0.47	-0.167
C/N ratio	-0.332	**-0.634**	-0.24	0.311	0.578
Nitrogen	**0.594**	0.216	0.224	-0.115	0.733
Eigenvalue	2.254	1.5252	0.5859	0.4517	0.1832
Proportion	0.451	0.305	0.117	0.09	0.037
Cumulative	0.451	0.756	0.873	0.963	1

Table 20b. Cluster wise distribution of litchi collections based on physiological characters

Clusters	Cluster Size	Collections
I	2	Coll. 24, Coll. 25
II	11	Coll. 3, Coll.5, Coll. 6, Coll. 14, Coll. 18, Coll. 19, Coll. 20, Coll. 21, Coll. 27, Coll. 30, Coll. 31
III	2	Coll. 23, Coll. 26
IV	4	Coll. 1, Coll. 4, Coll. 28, Coll. 29
V	1	Coll. 11
VI	1	Coll. 10
VII	10	Coll. 7, Coll. 8, Coll. 9, Coll. 12, Coll.13, Coll. 15, Coll. 16, Coll. 17, Coll. 22, Coll. 32
VIII	1	Coll.2

Table 20c. Mean performance of clusters based on physiological characters

Cluster	Chlorophyll (mg/g)	Cell sap pH	Carbohydrates (g/100g)	Nitrogen (%)	C/N ratio
I	**1.86**	5.60	5.53	**2.23**	**4.08**
II	1.59	5.44	7.06	1.87	5.09
III	1.33	5.42	**4.21**	1.95	4.38
IV	1.20	5.29	5.12	1.31	5.76
V	**1.14**	5.24	5.27	**1.09**	**8.44**
VI	1.44	**5.12**	10.50	1.56	7.23
VII	1.62	5.46	9.89	1.69	6.42
VIII	1.67	**5.96**	**10.86**	1.82	7.09

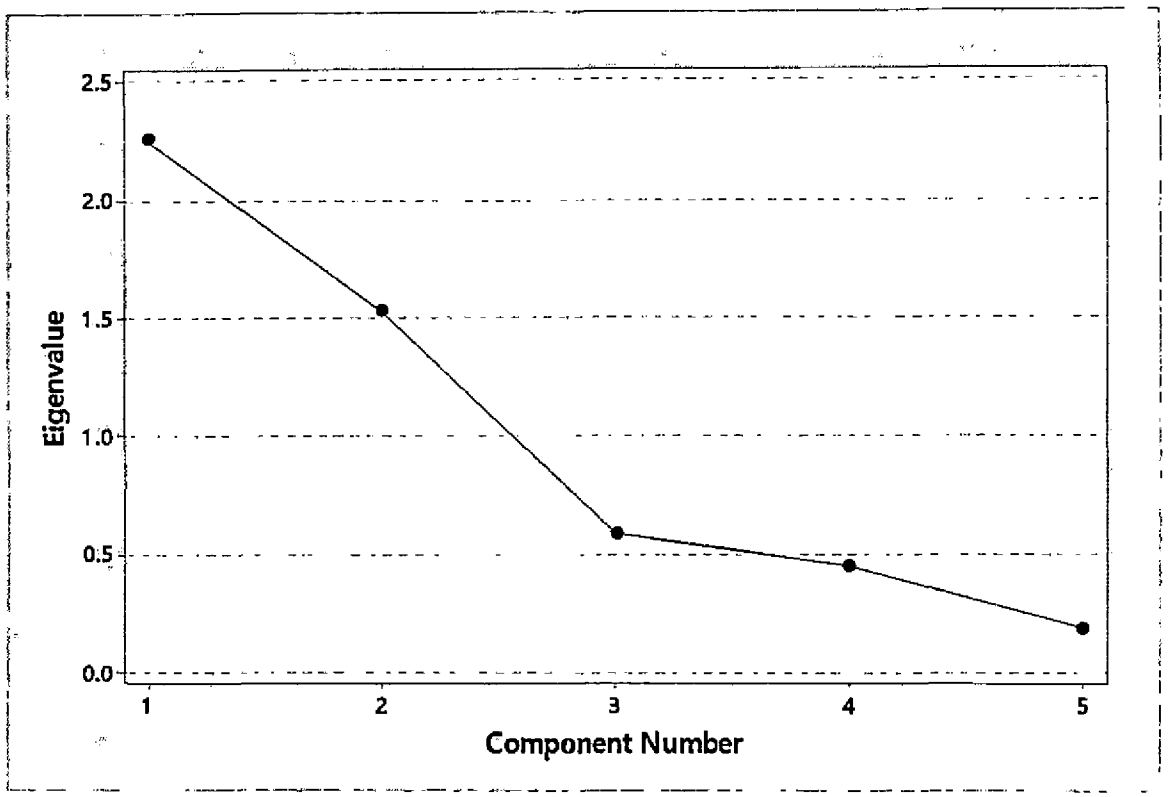


Fig. 4a Scree plot showing eigenvalues in response to number of components for estimated variables of litchi

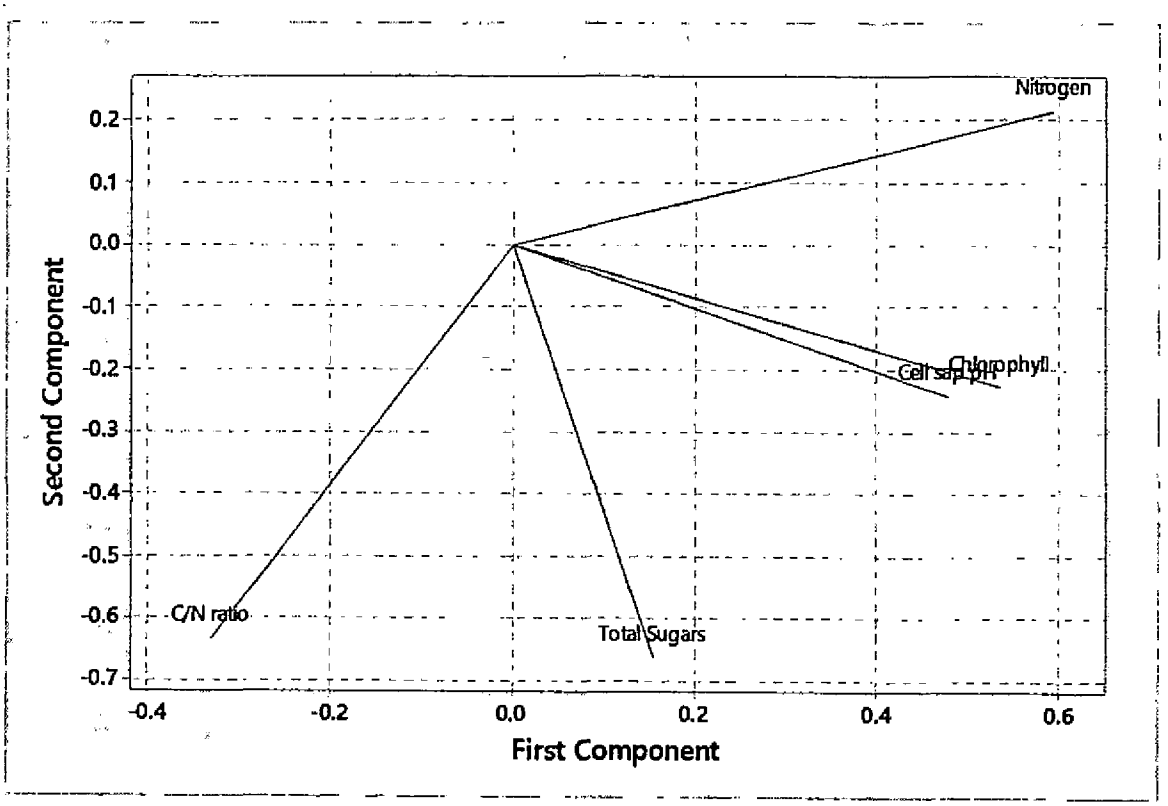


Fig. 4b Plot of first two PCA's showing relation among the various physiological traits

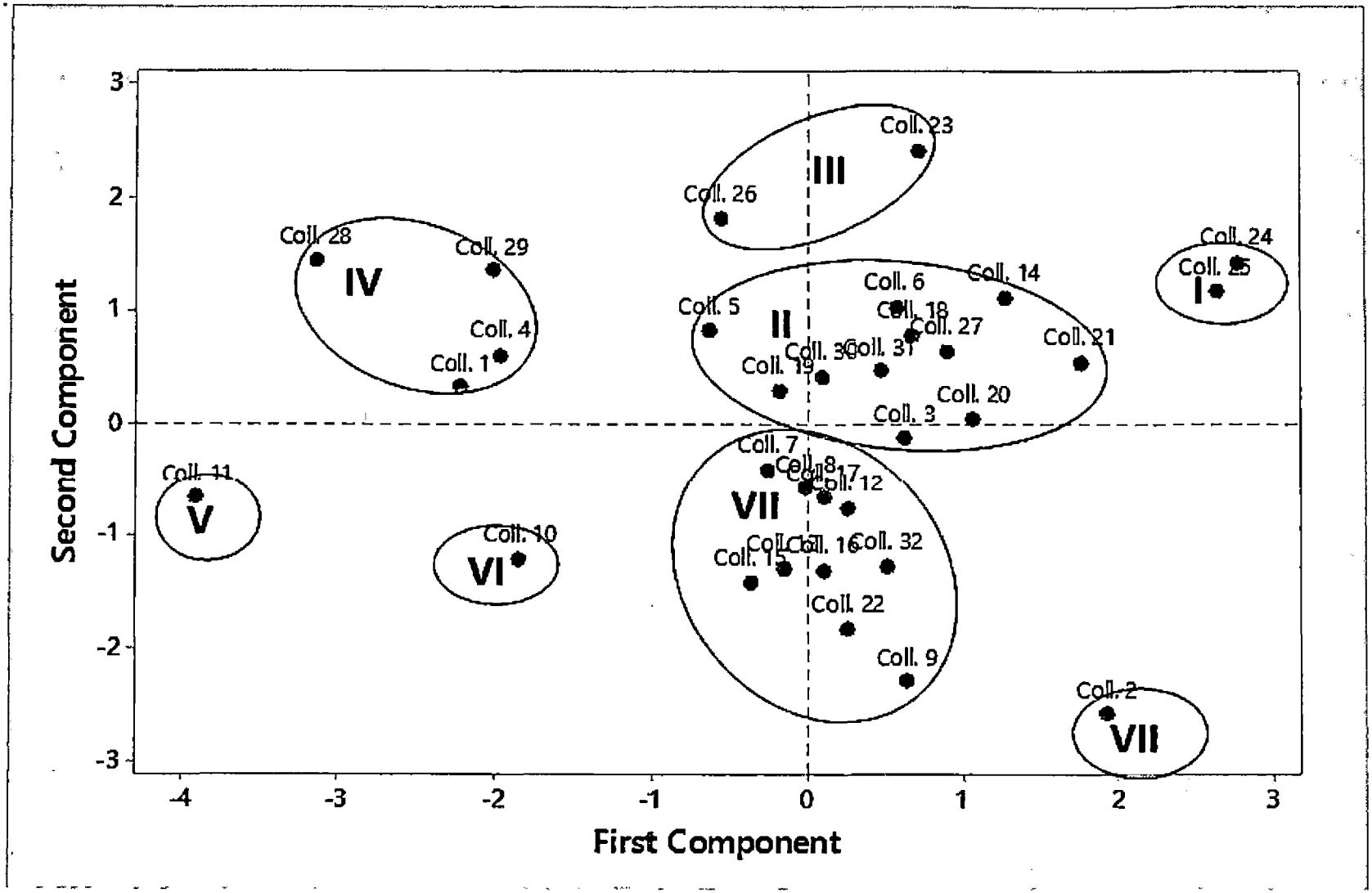


Fig. 4c Clustering of litchi collections based on physiological characters from first two principal components

between the two vectors, also there is positive linkage between nitrogen and chlorophyll content. Nitrogen and C/N ratio had negative association (Fig. 4b).

4.11.3.1 Clustering of physiological traits

Based on the first two components of the PC analysis clustering pattern was made. Out of 32 collections 8 clusters were framed (Fig. 4c). Cluster II and VII composed of maximum number of collections, followed by cluster IV. Cluster V, VI and VIII composed of single collection each (Table 20b).

The mean performance of the clusters depicts that, cluster I recorded maximum chlorophyll and nitrogen content in contrast low C/N ratio was recorded (Table 20c). Cluster VIII recorded maximum cell sap pH and carbohydrates. Maximum C/N ratio was recorded in cluster V but nitrogen and chlorophyll content were minimum.

4.11.4 Fruit characters

The scree plot of PCA shows that the first two eigenvalues corresponds to the large percentage of the total variation in the data set (Fig. 5a). The first two main PCs extracted from 9 components, the total cumulative variance of these two factors amounted 71.9 per cent and had eigenvalue >1.

The PCA grouped the fruit characters of litchi fruit into nine main components in which first 2 PCs accounted for maximum variability with eigenvalues >1 and other PCs had eigenvalues <1. PC1 and PC2 which made the largest contribution with eigenvalues 5.01 and 1.45 respectively. PC1 contributed 55.1 per cent and PC2 had 16.2 per cent of total variability (Table 21a).

The PC1 composed of characters such as fruits/cluster, yield, fruit weight, aril weight and aril thickness with PC loadings of 0.386, 0.399, 0.430, 0.411 and 0.341 respectively. PC2 was contributed by fruit diameter, fruit length and seed weight (100 seeds) with PC loadings of -0.368, -0.404 and 0.654 respectively. PC3 more associated to shelf life with PC loadings of 0.854. The factors which contributed more positively to PC1 were fruits/cluster, yield, fruit weight, aril

Table 21a. Principal component analysis of fruit characters of litchi

Variables	Components					
	PC1	PC2	PC3	PC4	PC5	PC6
Fruits/cluster	**0.386**	0.238	-0.091	-0.382	-0.19	0.004
Yield	**0.399**	0.293	-0.089	-0.061	-0.285	-0.035
Fruit length	0.317	**-0.368**	0.239	0.457	0.354	0.389
Fruit diameter	0.263	**-0.404**	-0.359	0.47	-0.497	-0.365
Fruit weight	**0.43**	0.114	0.037	0.052	0.058	0.11
Shelf life	0.180	-0.182	0.854	-0.15	-0.33	-0.183
Aril weight	**0.411**	0.012	-0.163	-0.125	0.017	0.503
Aril thickness	**0.341**	-0.292	-0.111	-0.337	0.581	-0.559
Seed weight (100 seeds)	0.143	**0.654**	0.17	0.516	0.246	-0.321
Eigenvalue	5.0184	1.4547	0.9841	0.7258	0.4010	0.1971
Proportion	0.558	0.162	0.109	0.081	0.045	0.022
Cumulative	0.558	0.719	0.829	0.909	0.954	0.976

Table 21b: Cluster wise distribution of litchi collections based on fruit characters

Clusters	Cluster Size	Collections
I	2	Coll. 10, Coll. 13
II	3	Coll. 7, Coll. 9, Coll. 15
III	4	Coll. 12, Coll. 16, Coll. 22, Coll. 32
IV	2	Col. 30, Coll. 31
V	3	Coll. 3, Coll. 17, Coll. 18
VI	5	Coll. 1, Coll. 4, Coll. 19, Coll. 20, Coll. 21
VII	1	Coll.2

Table 21. Mean performance clusters based on fruit characters

Clusters	Size	Fruits/ cluster	Yield (kg/plant)	Fruit length (cm)	Fruit diameter (cm)	Fruit weight (g)	Shelf life (days)	Aril weight (g)	Aril thickness (g)	Seed weight (100 seeds) (g)
I	2.00	17.00	**29.20**	**3.75**	2.95	**25.70**	4.00	16.65	7.35	283.00
II	3.00	13.67	18.73	3.43	2.67	22.83	3.33	15.30	6.40	**283.67**
III	4.00	12.50	19.00	3.18	2.55	21.28	**3.13**	14.28	6.00	281.75
IV	2.00	9.50	6.50	**2.90**	**2.20**	**18.00**	3.50	**12.95**	5.00	268.50
V	3.00	7.00	5.83	3.13	2.40	18.70	3.00	13.53	5.50	246.67
VI	5.00	**6.80**	**1.82**	3.36	2.62	18.50	3.40	13.06	6.22	247.60
VII	1.00	18.00	22.90	3.70	**3.10**	23.90	3.50	**17.10**	**8.00**	**210.00**

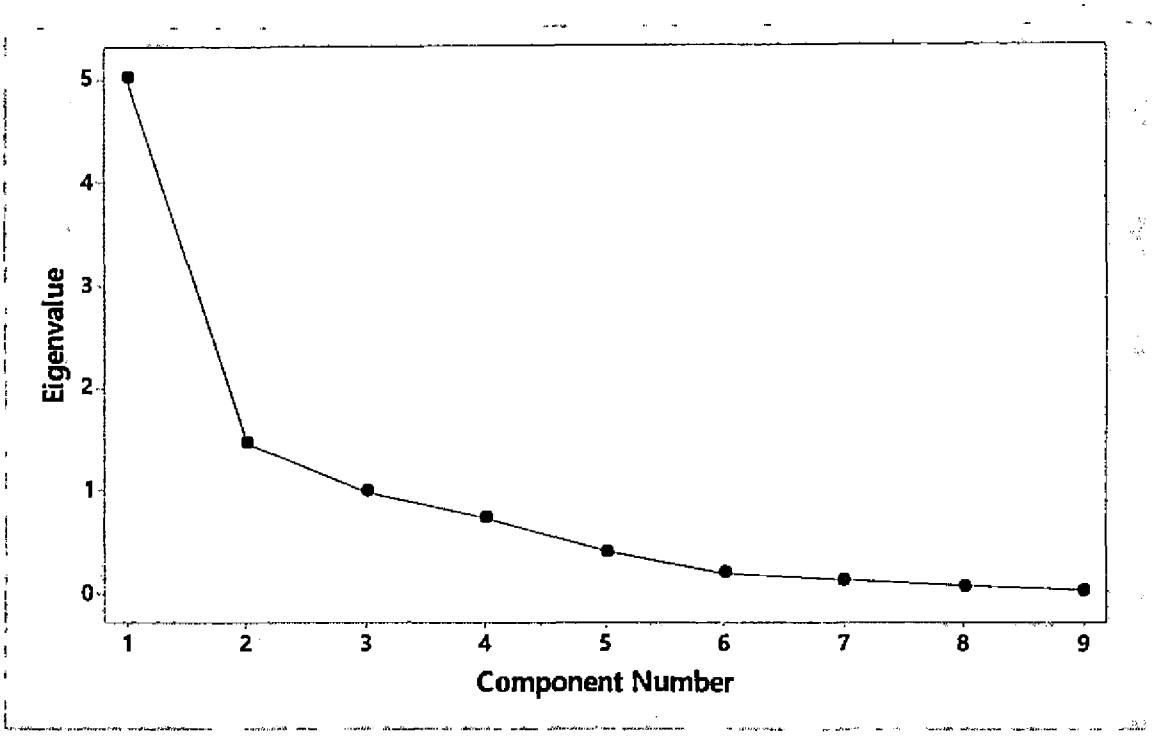


Fig. 5a Scree plot showing eigenvalues in response to number of components for estimated variables of litchi

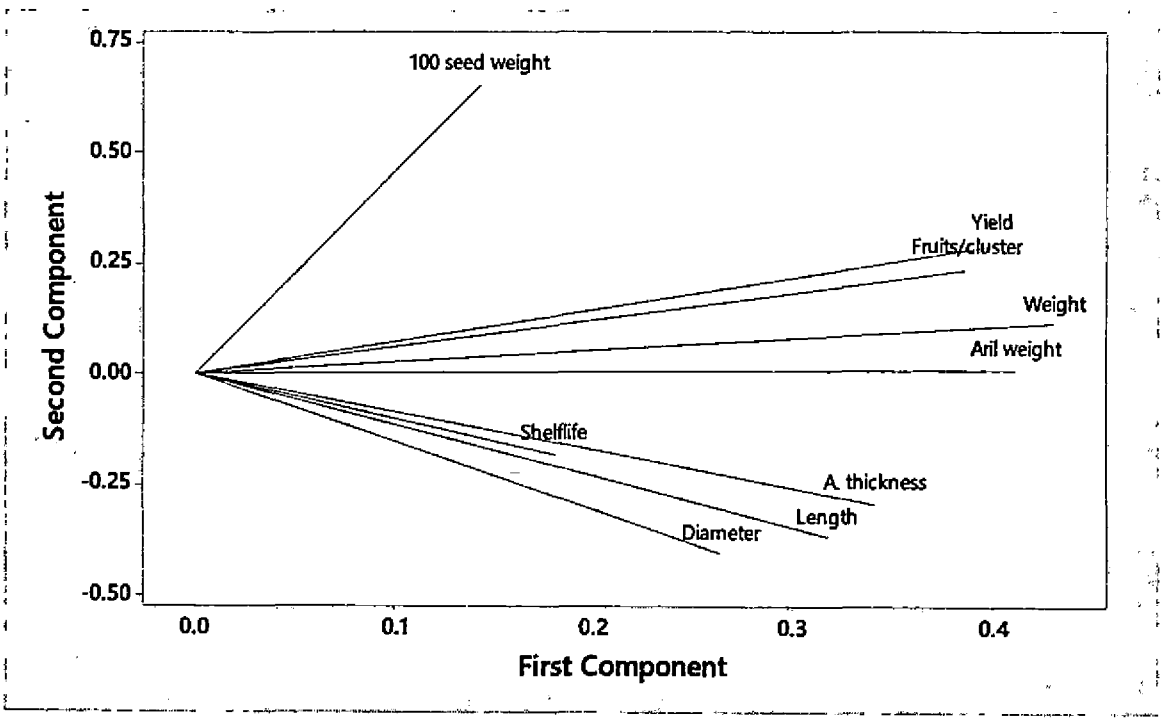


Fig. 5b Plot of first two PCA's showing relation among the various quality traits of litchi

Diameter=Fruit diameter, Length=Fruit length, A.thickness= Aril thickness

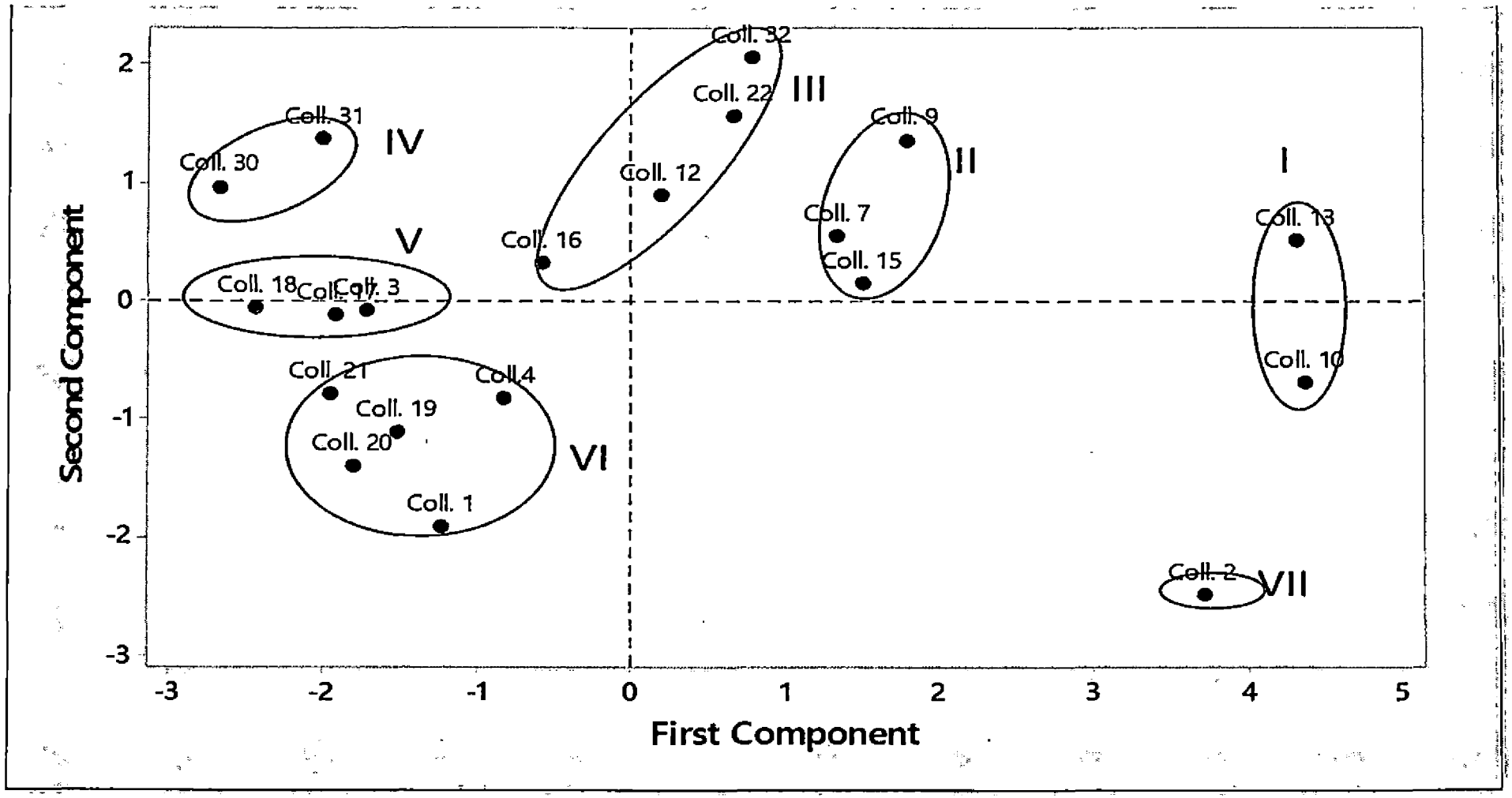


Fig. 5c Clustering of 20 collections of litchi based on fruit characters from first two principal components

weight and aril thickness. Seed weight (100 seeds) was positively contributed while fruit length, fruit diameter were contributed negatively in PC2 (Table 21a).

From the PC loading plot it could be inferred that there is a strong association between yield and fruits/cluster; fruit weight and aril weight; aril thickness, shelf life, fruit length, and fruit diameter as indicated by extremely acute angle between the vectors (Fig. 5b).

4.11.4.1 Clustering of fruit characters

Based on the first two components of the PC analysis clustering pattern was made. Out of 20 collections 7 clusters were formed (Fig. 5c). Cluster VI composed of maximum number of collections and cluster VII composed of single collection (Table 21b).

The mean performance of the clusters depicts that, cluster I recorded higher yield, fruit length, fruit weight and shelf life (Table 21c). Cluster II recorded maximum 100 seed weight, cluster VII recorded maximum fruits/cluster, fruit diameter, aril weight and aril thickness. While minimum fruit length, fruit diameter, fruit weight, aril weight and aril thickness were recorded in cluster IV. Fruits/cluster and yield was minimum in cluster VI.

4.11.5 Fruit quality characters

The scree plot of PCA shows that the first three eigenvalues corresponds to the larger percentage of the total variation in the data set (Fig. 6a). The first three main PCs extracted, the total cumulative variance of these three factors amounted 95.5 per cent and components had eigenvalues >1.

The PCA grouped the quality characters of litchi fruit into six main components in which first 3 PCs accounted for maximum variability with eigenvalues >1 and other PCA had eigenvalues <1. PC1, PC2, PC3 which made the largest contribution with eigenvalues 3.02, 1.56, 1.14 respectively and contributed 50.4 per cent, 26.1 per cent and 19 per cent of total variability respectively (Table 22a).

The PC1 composed of TSS, acidity, TSS/acidity ratio with PC loadings of 0.444, -0.514 and -0.544. PC2 was contributed by total sugar and reducing sugar with PC loadings of 0.672 and 0.577 respectively. PC3 was more associated to non-reducing sugar with PC loadings of -0.592. The factors which contributed more positively to PC1 were TSS and TSS/acidity but acidity was negatively contributed. Total sugar and reducing sugar were contributed positively in PC2. Non-reducing sugar was negatively contributed in PC 3 (Table 22a).

To observe the relationship between quality traits of litchi fruit an attempt was made to plot the first two components which contributed major variance. From the PC loading plot it is recorded that there is a strong association between TSS and TSS/ acidity ratio as indicated by extremely acute angle between the two vectors; which is also seen in total sugar and non-reducing sugar with acute angle between the two traits of vectors (Fig. 6b). TSS and total sugar; reducing sugar and non-reducing sugar had mutually near perpendicular vectors. There was a negative correlation between acidity and TSS; acidity and TSS/acidity ratio as indicated by the angle of approximately 180^0.

4.11.5.1 Clustering of fruit quality

Based on the first two components of the PC analysis clustering pattern was made. Out of 20 collections, 7 clusters were formed (Fig. 6c). Cluster IV composed of maximum number of collections and cluster II and cluster VII composed of single collection each (Table 22b).

The mean performance of the clusters depicts that, cluster II recorded maximum total sugar, reducing sugar and non-reducing sugar. Cluster V recorded minimum TSS, TSS/acidity ratio and reducing sugar and also recorded maximum acidity. Cluster VII is attributed maximum TSS and TSS/acidity ratio while minimum total sugar, acidity and non-reducing sugar was recorded (Table 22c).

Table 22a. Principal component analysis of quality variables of litchi collections

Variables	Components					
	PC1	PC2	PC3	PC4	PC5	PC6
Total sugar	-0:302	**0.672**	-0.119	0.023	0.083	-0.66
TSS	**0.444**	0.144	-0.472	-0.748	-0.02	0
Acidity	**-0.514**	-0.293	0.056	-0.415	0.689	0
TSS/Acidity	**0.544**	0.12	-0.128	0.408	0.712	0
RS	0.072	**0.577**	0.627	-0.244	0.101	0.445
Non-reducing sugar	-0.383	0.308	-0.592	0.205	0.017	0.605
Eigenvalue	3.0224	1.568	1.1403	0.2113	0.058	0
Proportion	0.504	0.261	0.19	0.035	0.01	0
Cumulative	0.504	0.765	0.955	0.99	1	1

Table 22b. Cluster wise distribution of litchi collections based on quality traits of litchi fruits

Clusters	Size	Collections
I	4.00	Coll.4 Coll.13 Coll.22 Coll.32
II	1.00	Coll.15
III	2.00	Coll.12 Coll.16
IV	7.00	Coll.3 Col.9 Coll.17 Coll.18 Coll.20 Coll.21 Coll.31
V	2.00	Coll.19 Coll.30
VI	3.00	Coll.1 Coll.7 Coll.10
VII	1.00	Coll.2

Table 22c. Mean performance of clusters based on fruit quality traits

Cluster	Cluster Size	Total sugar	TSS	Acidity	TSS/Acidity	Reducing sugar	Non reducing sugar
I	4.00	12.63	18.20	0.70	26.53	8.11	4.52
II	1.00	**15.50**	16.90	0.73	23.15	**8.80**	**6.70**
III	2.00	13.40	16.75	0.83	20.48	7.50	5.90
IV	7.00	12.04	17.24	0.83	21.29	6.84	5.20
V	2.00	11.20	**16.10**	**1.10**	**14.78**	**6.75**	4.45
VI	3.00	10.97	18.17	0.61	29.77	7.33	3.63
VII	1.00	**10.18**	**19.60**	**0.38**	**51.58**	6.80	**3.38**

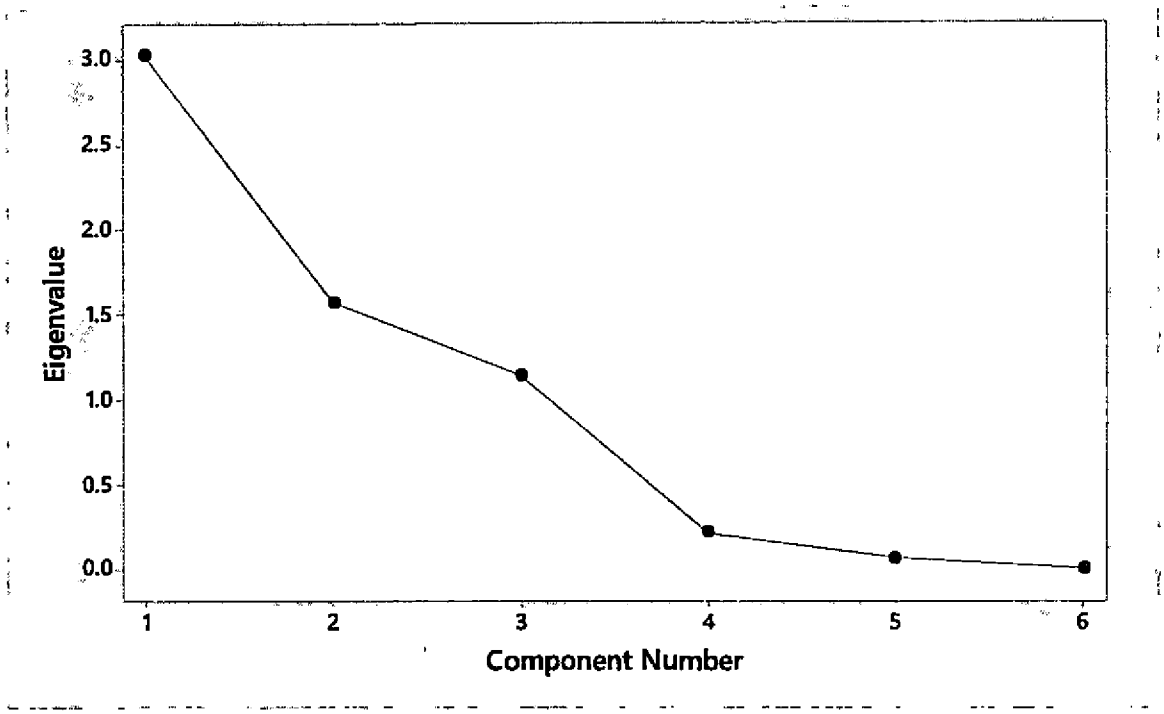


Figure 6a Scree plot showing eigenvalues in response to number of components for estimated variables of litchi

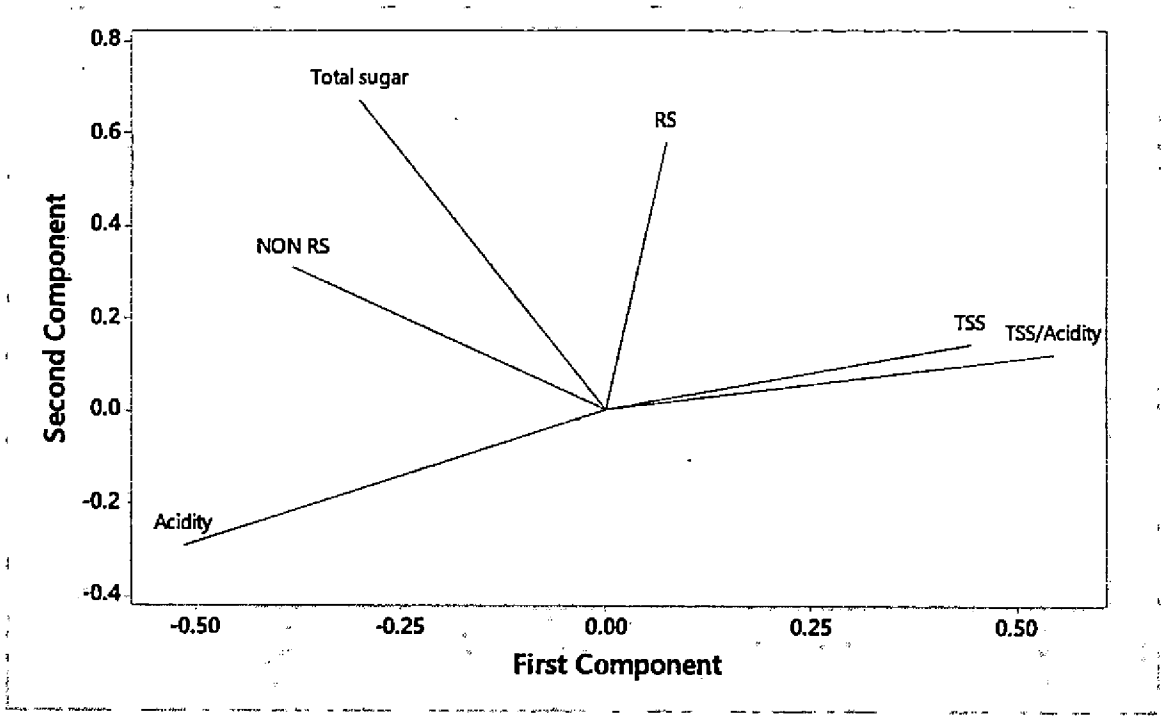


Figure 6b Plot of first two PCA's showing relation among the various quality traits of litchi

RS=Reducing sugar, NON RS= Non reducing sugar

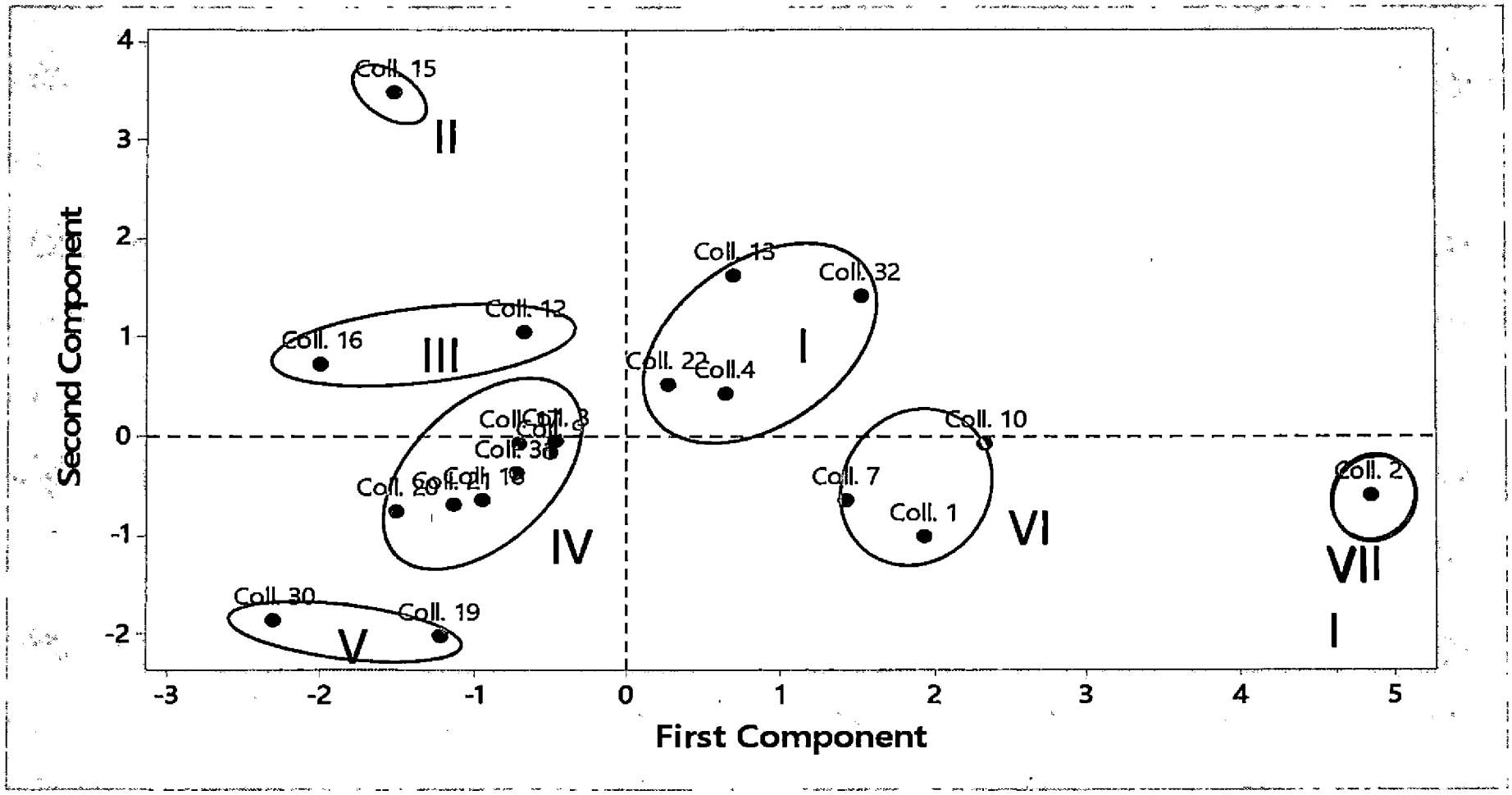


Fig. 6c Clustering of 32 collections of litchi based on 6 quality characters from first two principal components

DISCUSSION

5. DISCUSSION

Litchi (*Litchi chinensis* Sonn.) is an important subtropical fruit species that originated in Southern China. Now it has been widely cultivated in many countries with tropical and subtropical climates for its sweet flesh, pleasant fragrance and high nutritional value (Menzel, 2002). India is the second largest producer of litchi in the world after china. Cultivation of litchi varies within state. In India, litchi maturity commences second week of May (Tripura) to last week of June (Himachal Pradesh) (Singh *et al.*, 2012).

The possibilities of production of litchi fruits during November–January do exist in few selected areas of Southern India which can make its fruit available during off season. In Kerala, the crop performance under the humid tropic Wayanad region is also found to be highly promising in off season as evident from the observation at Regional Agricultural Research Station Ambalavayal, Wayanad and in the nearby farmer's field.

In the present study, a basic work on characterisation was done using thirty two collections from RARS Ambalavayal and farmer's field in Wayanad region of Kerala. The collections were evaluated to study the flowering and fruit set pattern in litchi and the related morpho-physiological parameters under the Wayanad situations of Kerala. The results pertaining to the present study are discussed in this chapter:

5.1.1. Morphological characters

Extensive variability was observed with respect to age of the tree. Tree age ranged from 5 to 79 years and displayed high coefficients of variation (CV) of 74.21 per cent. The height of the trees ranged from 3.00 m to 19.00 m and displayed 57.87 per cent of CV. Co-efficient of variation of 74.1 per cent was observed in tree trunk girth and it ranged from 28.00 cm to 540 cm. The height as well as girth of the tree are positively influenced by the age of the plant. Litchi is an evergreen fruit tree that grows up to the height of 15 m if left unpruned and up to 30 m under favourable

conditions (Cronje, 2010). According to Singh *et al.* (2012) well-managed orchard will be commercially productive for a period of 50 years.

The leaf length of the collections ranged from 12 cm to 16.8 cm. Leaf length displayed low CV of 8.67 per cent. The leaf width of the litchi trees ranged from 1.8 cm to 5.2 cm which displayed a CV of 14.27 per cent. The leaf size and shape are important varietal characters and is also used for cultivar identification (Singh *et al.*, 1999). Khurshid *et al.* (2004) reported significant difference in characteristics of leaf length and leaf width of four litchi cultivars. Madhou *et al.* (2010) also noticed major morphological differences in leaflet size and number of leaflets among 34 litchi accessions in Mauritius.

The shoot length ranged from 15 cm to 26 cm which displayed a CV of 12.77 per cent. The internodal length of the collections ranged from 2.8 cm to 5.2 cm. The co-efficient of variation was 17.66 per cent. Similar trend was also observed with regard to shoot length and internodal length in litchi (Ather 2001). Duration and interval of shoot growth are strongly related to environmental conditions (Batten and Lahav, 1994). Temperature also has a strong influence on shoot development, with high temperatures conducive to vegetative growth (Cobin, 1954).

Wide variation was noticed with respect to crown shape in litchi. Different crown shapes *viz.*, pyramidal, broadly pyramidal, spherical, oblong, semi-circular, elliptical and irregular shapes were noticed among the collections (Plate 3). However, most prominent among these includes semicircular (34.37 per cent) followed by oblong (31.25 per cent), spherical (25.12 per cent), irregular (3.12 per cent) and broadly pyramidal shape (3.12 per cent). The crown structure of a tree solely depends on branching pattern and crotch angles. The difference in shape might be also due to the genotypes and their interaction with the prevailing climatic conditions of the area. Crown shape and canopy size are important factors that influence productivity and quality production of various fruit crops which helps in net assimilation rate and flowering (Nath *et al.*, 2014). Tree crown shape also

Semicircular

Oblong

Spherical

Broadly pyramid

Irregular

Plate 3. Crown shapes of litchi collections

influence light penetration (Kellomaki *et al.,* 1985) and canopy microclimate including temperature, vapour pressure deficit and wind speed (Gary, 1974).

Branches are the skeletal structures of the tree. The nature of branching is an important factor which decides the population density for utilizing the horizontal as well as vertical space. Different branching patterns *viz.,* erect, opposite, verticillate, horizontal, and irregular were noticed among the collections (Plate 4). Verticillate branching pattern dominated by 65.62 per cent followed by horizontal type (15.62 %) and irregular type (15.62 %), erect type (3. 12 %).

The mature leaf shape had a predominance of elliptic shape (96.87 %) while single collection recorded lanceolate shape (3.12 %) (Plate 5).

The leaf colour of the young flush varies from pinkish green, greenish yellow and light green (Plate 6) whereas matured leaf colour was green, light green and dark green. The frequency of mature leaf colour was 65.62 per cent green, 31.25 per cent dark green and 3.12 per cent light green whereas in young leaf 78.12 per cent pinkish green, 12.5 per cent yellowish green and 9.37 per cent light green. Nakasone and Paull (1998) reported that colour of young emerging flushes range from pale green to pinkish to a copperish red in colour. The foliage colour is a genetic trait that may be used for identification of cultivars. The litchi cultivars can be distinguished on the basis of colour of flush and season of flushing (Singh *et al.* 1999). Khurshid *et al.* (2004) also reported reddish brown flush colour in Gola and Bombay cultivars while Calcutti cultivar had brownish red and Bedana cultivar had dark pink flush colour. The slight variation could also be due to prevailing environmental conditions *i.e.* sunlight, temperature, humidity, rainfall *etc.*

5.1.2 Principal component analysis of morphological characters

To know the extent of contribution of each variable towards the total variation PCA was performed. Quantitative parameters *viz.,* tree age, tree height, trunk girth, leaf length, leaf width, shoot length and internodal length were taken in PC analysis. PCA revealed wide morphological variations in the collections. It was observed that most of the variables were integrated by PC1 and PC2. PC1 was

Verticillate

Erect

Horizontal

Irregular

Plate 4. Branching pattern of litchi collections

Lanceolate leaf shape

Elliptic leaf shape

Vegetative shoots

Plate 5. Litchi leaves and shoots

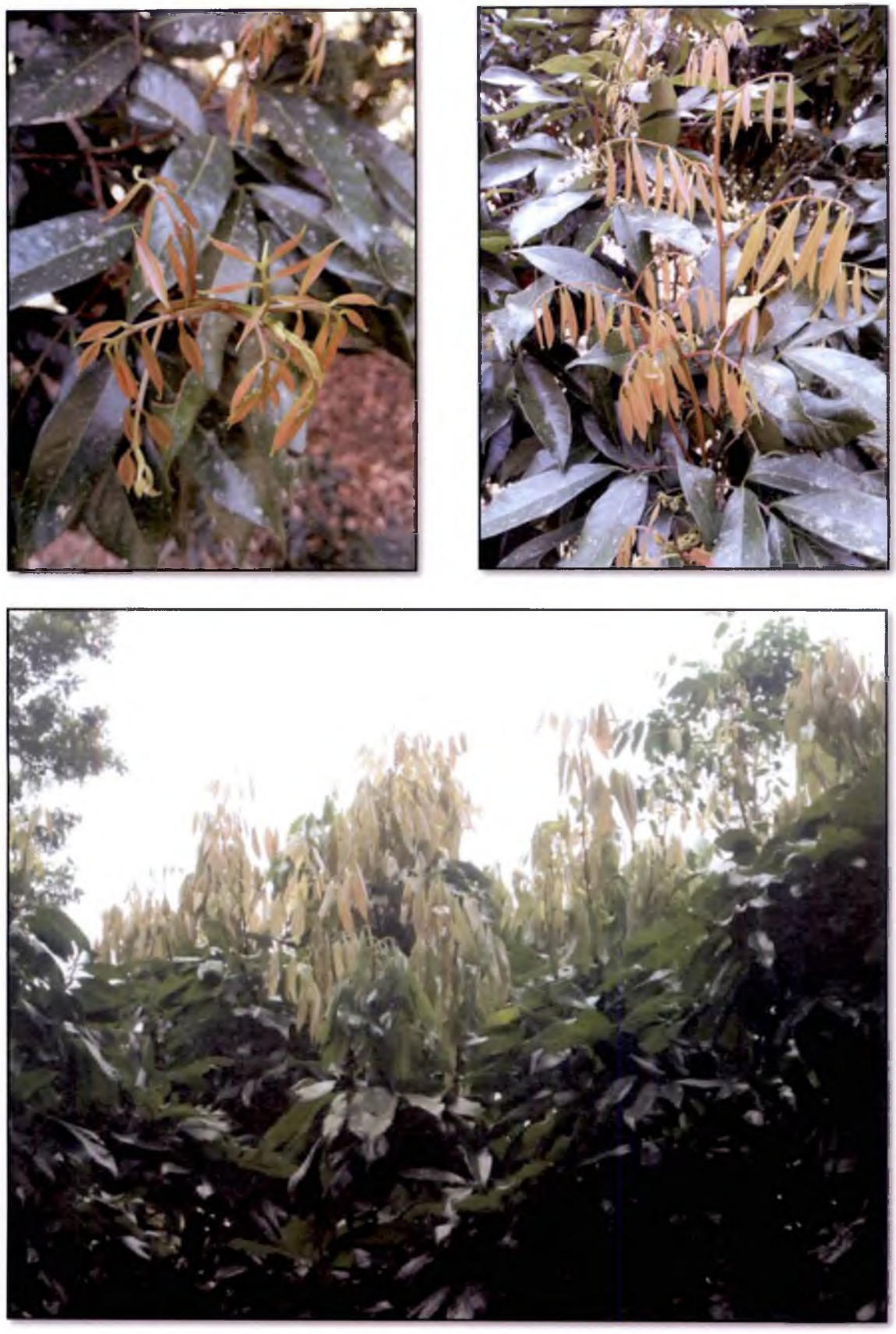


Plate 6. New flush in litchi

contributed by age, height and trunk girth whereas, PC2 composed of leaf length and shoot characters. The results were in accordance with the findings of Wu *et al.* (2016), that leaf characters including leaf length, leaf interval, ratio of leaf length to width and petiole length contributed more to the total variance. Perusal of PC loading plot indicates that age of tree, tree height and trunk girth were closely linked.

Clustering of collections resulted in the formation of nine different clusters. Among the clusters formed, cluster VII comprising of three collections (Coll. 11, Coll. 28 and Coll. 29) showed minimum value for all the morphological traits while cluster IX consisting of single collection (Coll. 24) recorded maximum value for all the traits except leaf length and leaf width. It implies that most of the morphological traits including tree height and trunk girth are influenced by age of the plant.

5.2 Inflorescence characters

Flowering was observed in the months of August to September and erratic flowering was also observed during February to March. Only 28 trees were flowered during the period of study (Plate 7). Among the collections, 75 per cent were flowered during the month of August to September, 7.14 per cent during February to March and 17.85 per cent in both the seasons. Sharma and Roy (1987) observed that flower emergence in litchi under Bihar condition started from second week of March to third week of April. However, with milder summer and winter, litchi blooms twice a year under Bangalore conditions (Firminger, 1947). February-march flowering is considered as erratic flowering in South India. The flowering period may varies with the genotype and environmental conditions.

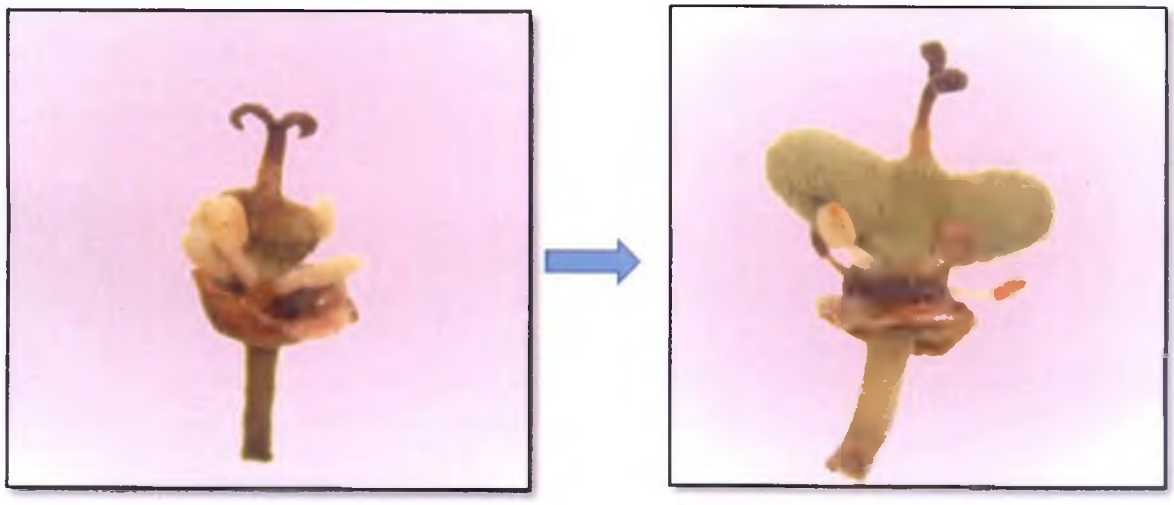
Three basic types of flowers *viz.*, male or staminate flowers (Type 1, male), hermaphrodite female flower (Type 2, female) and hermaphrodite male flower (Type 3, male) were observed in all the collections (Plate 8). Terminal position of the inflorescence was observed in all collections.

The length of inflorescence ranged from 15.1 cm to 38 cm and displayed 25.2 per cent of CV. The width of inflorescence of the collections ranged from 9.4 cm to 19.3 cm and displayed CV of 19.04 per cent. Tree with longer inflorescence

Plate 7. Bloomed litchi tree

Male or staminate flower

Hermaphrodite male flower



Hermaphrodite female flower

Plate 8. Flower types in litchi

resulted in increased width of inflorescence which were parallel to results of Sahay (2001). However, during February-March, flowering size of the inflorescence was small compared to the normal season of flowering. The variation in inflorescence size may be due to the difference in climatic conditions prevailing during the season. As indicated by Chen and Cheng (1996) largest inflorescences were produced early in the season under lower temperatures. In litchi, the temperature requirements for inflorescence induction, inflorescence development and anthesis are different (Chen *et al.*, 2016). According to Menzel (1983) low temperature favours inflorescence induction. Under low temperature inflorescence were longer and under higher temperatures, inflorescence were shorter Chen *et al.* (2013).

Flushing initiated from July onwards and distribution of flushing recorded in August (50 %), September (9.37 %) and February (3.12 %). Two time flushing was also observed and distribution of flushing recorded in July and November (6.25 %), August and November (3.12 %), August and February (3.12 %), September and February (12.5 %) and November and February (3.12 %). Kanwar and Nijjar (1985) observed abundant flushing in early rains and summer under North Indian conditions. Shukla and Bajpai (1974) recorded two distinct flushes in February to April and July to October. Under normal conditions, litchi trees produce two to three batches of vegetative flushes each year (Wei *et al.*, 2013). Menzel and Simpson (1994) inferred that the flush development is strongly influenced by temperature. Each flush, after it is initiated, grows for sometimes, stops and breaks out again till growth finally ceases (Popenoe, 1920).

5.3 Phenological characters

The duration of flowering which varied from 12 days to 35 days and displayed a CV of 28.7 per cent. Sharma and Roy (1987) reported that cultivar China and Bedana had flowering duration of 27 and 38 days respectively under Bihar condition.

Time taken for flowering to fruit maturity ranged from 71 days to 94 days. The CV of flowering to fruit maturity was 7.38 per cent. The number of days taken

from fruit set to maturity varied from 58 days to 75 days (Plate 9) and displayed CV of 7.4 per cent. According to Sahay (2001) the late maturing variety Kasba and Late Bedana took 68.67 and 66.83 days respectively to mature while early maturing varieties Deshi and Green took 56.17 and 56.50 days respectively to maturity. Intermediate varieties Purbi and China took 62.17 and 63.17 days respectively to mature. Hence the variations in flowering to maturity may be due to the genetic makeup of the cultivars as well as environmental conditions prevailing in the region.

5.3.1 PCA for floral characters

PC analysis was performed using both phenological and inflorescence characters *viz.*, inflorescence length, inflorescence width, flowering duration, days from flowering to fruit maturity and days from fruit set to fruit maturity. PC1 and PC2 accounted 86.4 per cent of total variation. PC1 related to flowering duration, days from flowering to fruit maturity and fruit set to maturity while PC2 composed of inflorescence length and width. Loading plot of first 2 PCs revealed a strong association between days from flowering to fruit maturity and fruit set to maturity. Inflorescence width and inflorescence length were also positively correlated.

Clustering resulted in formation of five clusters. Cluster II comprised of two collections (Coll. 9 and Coll. 22) reported maximum inflorescence length and width and also taken more number of days to reach maturity from flowering. While cluster III exhibited minimum flowering duration and there was no fruit set because of flower drop.

5.4 Physiological parameters

The chlorophyll concentration of the leaf determines the photosynthetic activity of the plant. In the present study, the chlorophyll content of mature leaves varied from 1.07 to 1.87 mg/g and displayed a CV of 13.88 per cent. Sukhvibul *et al.* (2014) reported that chlorophyll content varied from 2.0-2.8 mg/g in leaves and slight variation in chlorophyll content of leaves during annual growth and pre-flowering period does not affect the floral differentiation.

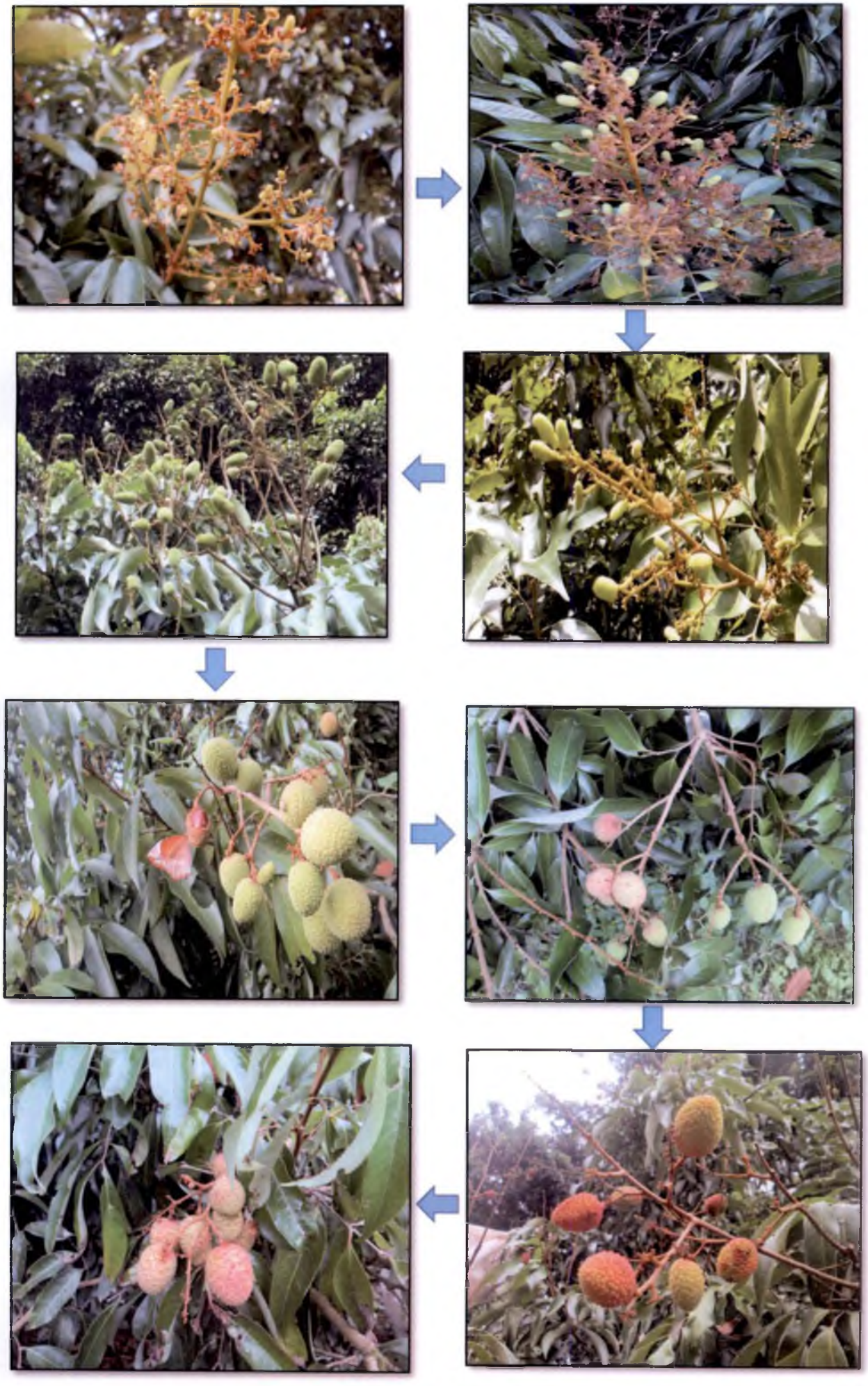


Plate 9. Development of fruit from fruit set to fruit maturity

The cell sap pH of leaves varied from 5.12 to 5.96 and displayed CV of 2.86 per cent.

Carbohydrate content of leaves estimated before flowering varied from 3.79 g/100g to 13.48 g/100g. The CV of 31.51 per cent was displayed among the collections. The carbohydrate content was not necessary for flower initiation in litchi. The results were in conformity with the observations of Menzel *et al.* (1995) in litchi. Prasad *et al.* (2010) found that the maximum carbohydrate content was 8.94 per cent in variety CHL- 5 and minimum was 1.32 per cent in Rose scented variety.

Nitrogen content of leaves varied from 1.09 per cent to 2.31 per cent. The CV of nitrogen content was 16.2 per cent. Li *et al.,* (2001) observed that in Florida nitrogen concentration of leaf varied from 1.1 to 2.4 per cent in cultivar Brewister and 1.5 - 2.4 per cent in Mauririus. Mandal *et al.* (2014) reported that average leaf nitrogen content of litchi varied from 1.71-1.80 per cent in West Bengal.

Carbon/nitrogen (C/N) ratio varied from 3.83 to 8.44. The CV of the C/N ratio of the collections were 19.44 per cent. Mandal *et al.* (2014) observed that in litchi leaf C/N ratio varied from 4.53 to 5.15, 5.46 to 6.02, 5.67 to 6.67, 5.94 to 7.18 and 6.48 to 7.86 during the months of September, October, November, December and January, respectively.

5.4.1 PCA of physiological characters

The PCA grouped the physiological characters of litchi into five main components in which PC1 and PC2 explained 43.2 per cent and 23.6 per cent of total variability respectively. PC1 comprised of total chlorophyll, pH of cell sap, total nitrogen and C/N ratio. PC2 was contributed by total carbohydrates. Loading plot indicates the strong association between cell sap pH and chlorophyll content while total nitrogen and C/N ratio shown negative correlation. Chlorophyll and nitrogen content of leaves were also positively correlated. It may be due to nitrogen, which is one of the important component of chemical structure of chlorophyll molecule. It is also revealed that darker green leaves had higher chlorophyll content. Similar results was also reported by Fu *et al.* (2013).

Clustering of physiological parameters based on first two PCs resulted in eight clusters. The mean performance of cluster IV consisting single collection (Coll.11) which recorded minimum chlorophyll content and cell sap pH but recorded maximum nitrogen. While Cluster III recorded maximum chlorophyll content. Cluster VI attributed maximum C/N ratio and minimum total nitrogen whereas cluster VII attributed maximum carbohydrates. Maximum cell sap pH was noticed in cluster IX.

5.5 Fruit and yield characters

Out of 32 collections, only 20 collections were fruited during the period of study. Regarding the fruit bearing habit, 55 per cent of the plants were regular bearing habit and 45 per cent plants were alternate bearing habit. In India, poor and irregular bearing are the major problems in litchi growing areas. The bearing habit of the tree is mainly influenced by the genetic makeup of cultivar. Management practices like irrigation, nutrition and environmental conditions and soil type are also responsible for the cause of irregular or alternate bearing in litchi. Regularity of the tree may be maintained by adopting good management practices. Application of manures and fertilizers at later stage, high frequency and heavy irrigation just before the panicle emergence and flowering period are considered to be good management practices (Singh *et al.*, 2012).

Fifty per cent collections recorded medium fruit bearing intensity (15-25 fruits/m^2) while other 50 per cent recorded poor fruit bearing intensity (<15 fruits/m^2). The erratic rain fall during the fruiting period may be resulted in fruit drop and leads to medium and poor fruit bearing intensity (Appendix IV). Clustering fruit habit was observed in all the collections.

Three types of fruit shape were observed *viz.*, oblong, elliptic and oval. Frequency of fruit shapes were elliptic (47.60 %), oblong (19.04 %), oval (4.7 %). oval and oblong (9.52 %); oval and elliptic (9.52 %); elliptic and oblong (4.7 %) (Plate 10). Khurasid *et al.* (2014) observed that variation in fruit shape in litchi may be due to the genetic makeup of cultivar.

Elliptic fruit shape

Oval fruit shape

Oblong fruit shape

Fruit cluster

Plate 10. Variation in fruit colour and shape

Cross section of fruit

Creamy white aril

Fruit skin

Seed surrounded by aril

Plate 11. Parts of litchi fruit

Cracking/splitting of fruit skin is one of the major problems in commercial litchi producing areas of the country (Plate 12). In the present study, the fruit skin thickness varied as thin, medium and thick skin. Eighty per cent of collections had medium skinned fruits. Among the collections most of the trees were prone to cracking while collection with thick skinned fruits (Coll. 1, Coll. 3, Coll. 4, Coll. 7, Coll. 19 and Coll. 21) were free from cracking. Kanwar and Nijjar (1984), Sharma and Ray (1987); Chandel and Sharma, (1992) reported that high temperatures or drought during fruit growth were associated with abnormal skin development and increased cracking. High intensity of sunlight in summer also causes skin cracking in litchi fruits (Kanwar *et al.*, 1972 and Shrestha, 1981). Poor orchard management, mechanical injuries and micro-nutrient deficiencies resulted in fruit cracking of litchi (Singh *et al.*, 2012).

Mature fruit colour varied as pinkish red and greenish yellow where 75 per cent of fruits were pinkish red and 25 per cent fruits were greenish yellow in colour (Plate 10). Variation in fruit colour also reported by Froneman (1999); Wong (1999) and Yuan and Zhu (2001) in litchi.

Fruit attractiveness was classified into good, intermediate and excellent based on the combined assessment of shape, size and appearance of fruits. Among the collections 55 per cent were good, 40 per cent intermediate type and 5 per cent were excellent. Excellent fruits were recorded the in Coll.2. Fruit attractiveness was good in Coll. 1, Coll. 3, Coll. 4, Coll. 7, Coll. 9, Coll. 10, Coll. 13, Coll. 20, Coll. 21, Coll. 22, and Coll. 32.

Aril thickness of the fruit classified as thin, medium and thick. 25 per cent of the collections were thick aril fruits, 50 per cent medium thick aril and 25 per cent were thin aril. Coll. 2, Coll. 9, Coll. 10, Coll. 13, and Coll. 21 had thick aril fruit. All the collections had firm aril texture.

Seventy per cent of the collections were sweet type and 30 per cent were sour type fruits. Sweet type aril was recorded in Coll. 1, Coll. 2, Coll. 3, Coll. 7,

Cracking/splitting of fruit

Pericarp browning

Copper deficiency

Plate 12. Physiological disorders and nutrient deficiency in litchi

Coll. 9, Coll. 10, Coll. 12, Coll. 13, Coll. 15, Coll. 19, Coll. 20, Coll. 21, Coll. 22, Coll. 31 and Coll. 32. Aril colour was creamy white for all the fruits (Plate 11).

Length of fruit varied from 2.8 cm and 3.8 cm. Average fruit length was 3.31 cm with a CV of 8.87 per cent. Maximum fruit length of 3.8 cm was recorded in Coll. 13 followed by Coll. 2 (3.7 cm), Coll. 15 (3.7 cm), Coll. 10 (3.7 cm), Coll. 4 (3.6 cm), Coll. 1 (3.5 cm) and Coll. 19 (3.5 cm). Fruit diameter ranged from 2.1 cm to 3.2 cm with mean fruit diameter of 2.59 cm. The CV of fruit diameter was 11.76 per cent. The Coll. 10 recorded maximum fruit diameter of 3.2 cm which was followed by Coll. 15 (3.1 cm), Coll. 2 (3.1 cm), Coll. 19 (2.9 cm), Coll. 16 (2.8 cm) and Coll. 13 (2.7 cm). Fruit weight ranged from 16.9 g to 25.8 g. Average fruit weight was 20.6 and CV was 13.4 per cent. Highest fruit weight of 25.8 g was recorded in Coll. 10 followed by Coll. 13 (25.6 g) and Coll. 2 (23.9 g). The Coll. 2, Coll. 13, Coll. 10 showed better performance with respect to length, breadth and fruit weight. According to Singh *et al.* (1999) fruit size is reported to be a genetic characteristic of the cultivars.

Number of fruits per cluster/inflorescence was ranging from 6 to 18. CV of number of fruits/cluster was 39.7 per cent. Maximum number of fruits/cluster (18) were observed in Coll. 2 and Coll. 13, followed by Coll. 9 (17) and Coll. 10 (16). Variation in number of fruits/cluster was reported Kumar *et al.* (1981) in litchi.

Yield/plant ranged from 1 to 30 kg. Average yield/plant was 12.6 kg with a CV of 78.13 per cent. Highest yield of 30 kg/plant was recorded in Coll. 10, followed by Coll. 13 (28.4 kg), Coll. 32 (25 kg), Coll. 2 (22.9 kg), Coll. 12 (21 kg) and Coll. 9 (20.6 kg). According to Senthilkumar *et al.* (2015) yield of litchi ranged from 0-45 kg/plant in Coorg regions of Karnataka. Yield of the tree depends on many factors that includes nutritional factors (Singh *et al.*, 2012), management practices, climate and locality of tree (Roy and Mishra, 1982; Syamala *et al.*, 1983 and Lal and Kumar, 1997). Huang *et al.* (1992) reported a strong correlation between yield of the tree and crown or canopy.

The shelf life of the fruits varied from 3 and 4 days in an ambient condition. The Coll. 1, Coll. 7, Coll. 10, Coll. 13 and Coll. 31 had shelf life of 4 days. After 4 days fruit loses its bright colour and pericarp turns into brown colour (Plate 12).

Aril weight ranged from 12.10 g to 17.10 g. Average aril weight was 14.26 g with a CV of 10.1 per cent. Maximum aril weight recorded in Coll. 2 (17.10 g) followed by Coll. 10 (16.8 g) and Coll. 13 (16.5 g).

Seed weight of 100 seeds ranged from 210 g to 297 g with a CV of 8.9 per cent. Seed shape of fruits were varied as oblong (60 %), oblong & oval seeds (10 %); oblong and chicken tongue (25 %) and irregular shape (5 %). The fruits which contained more percentage of chicken tongue had a lower value for 100 seed weight.

5.5.1 PCA of fruit and yield characters

PC analysis of fruit and yield characters *viz.*, fruit length, diameter, weight, number of fruits/cluster, yield, aril weight, aril thickness and seed weight (100 seeds) revealed that first two PCs explains the 71.9 per cent of total variance. PC1 explained about fruits/cluster, yield, fruit weight, aril weight and aril thickness while PC2 composed of fruit diameter, fruit length and seed weight of 100 seeds (Plate 13).

With regards to association between the characters loading plot explained that there is a strong association between yield and number of fruits/cluster; fruit weight and aril weight; aril thickness, shelf life, fruit length, and fruit diameter as indicated by extremely acute angle between the vectors but no relation found between seed weight of 100 seeds and fruit diameter. Results infers that the yield was depend upon the number of fruits/cluster and fruit weight. Furthermore, fruit weight and aril weight were also interrelated.

Clustering based on first two PCs divides into seven clusters. The mean performance of the clusters explains that cluster I recorded maximum yield, fruit length, fruit weight and shelf life. Hence, collections 10 and 13 under cluster I found to be promising with respect to yield. However, Cluster VII comprised single collection 2 also performed better with high amount of aril weight, fruit diameter

Oblong

Oval

Chicken tongue

Irregular

Plate 13. Variation in seed shape

and minimum seed weight. The collection in the cluster IV performed poorly with respect to yield attributes.

5.6 Fruit quality characters

Total sugar content of the 20 collections were ranged from 10.18 to 15.50 per cent. Average total sugar content was 12.18 per cent with a CV of 9.6 per cent. The Coll. 15 recorded the maximum total sugar content 15.50 per cent followed by Coll. 13 (13.3 %), Coll. 12 (13.2 %), Coll. 32 (12.6 %), Coll. 9 (12.5 %) and Coll. 22 (12.5 %). Singh & Singh (1995) reported that sugar content ranged from 6.74-20.6 per cent in litchi fruit. The major sugars present in litchi are sucrose, fructose and glucose (Jiang *et al.,* 2006). Sugar content varied between different cultivars (Wang *et al.* 2006).

Total soluble solids (TSS) varied from 15.10 ^{0}B to 19.6 ^{0}B. The TSS displayed a CV of 6.23 per cent and average TSS content of fruits was 17.46 ^{0}B. The Coll. 2 recorded maximum TSS content of 19.6 ^{0}B which was followed by Coll. 13 (19.2 ^{0}B) and Coll. 10 (19 ^{0}B). The variation in TSS content of fruits were also reported by Waseem *et al.* (2002) and Islam *et al.* (2013) in litchi.

Acidity of fruits ranged from 0.38 to 1.18 per cent and displayed CV of 22.82 per cent. The lowest acidity of 0.38 per cent was recorded in Coll. 2, followed by Coll. 32 (0.57 %), Coll. 7 (0.6 %), Coll. 1 (0.61 %), and Coll. 10 (0.62 %). Acidity of fruits is also considered as one of the important quality traits of the fruits which decreases with maturity.

TSS/Acidity was ranged from 12.8 to 51.58. Average value of the TSS/Acidity was 24.03 with a CV of 33.9 per cent. The Coll. 2 recorded maximum ratio of 51.58 followed by Coll. 32 (31.23) and Coll. 10 (30.65). Batten (1989) and Underhill and Wong (1990) observed that TSS/acid ratio was highly correlated with the litchi taste than TSS. According to Batten (1989); Underhill and Wong (1990); Finger *et al.* (1997); Revathy and Narasimham (1997) and Pesis *et al.* (2002) the recommended TSS/acidity ratios varied from 15 to 65 for different producing areas of litchi.

Plate 14. Harvesting and top view of litchi tree

5.6.1 PCA of fruit quality characters

The reducing sugar content of the fruits was ranged from 5.8 per cent to 8.8 per cent. Average reducing sugar content was 7.34 per cent with a CV of 10.8 per cent. Non-reducing sugar of fruits ranged from 3.38 per cent to 6.7 per cent. Average non-reducing sugar recorded was 4.84 per cent with a CV of 22.33 per cent.

The first three main PCs explained the total cumulative variance of 95.5 per cent. The PC1 composed of TSS, acidity, TSS/acidity ratio. PC2 was contributed by total sugar and reducing sugar. PC3 explains reducing and non-reducing sugars. Positive correlation were observed in TSS and TSS/acidity ratio; total and non-reducing sugars. Negative correlation was observed in acidity and TSS; acidity and TSS/acidity ratio.

Based on the first two PCs clustering pattern was made. Out of 20 collections, 7 clusters were formed. Cluster IV composed of maximum number of collections and cluster II and VII composed of single collection. The mean performance of the clusters depicts that, the cluster II registered maximum total sugar, reducing sugar and non reducing sugar. The cluster IV registered highest acidity and lowest TSS, TSS/acidity ratio and reducing sugar. The highest TSS/acidity ratio was recorded by cluster VII.

5.7 Sensory evaluation

Organoleptic rating or sensory evaluation is essential to assess the consumer's acceptability of fruits, because it regulates the marketability of fruits. It depends on texture, colour, taste and flavour of fruits. The marketability of fruits decreases with the advancement of the storage period. The contributing factors to the marketability such as general appearance, taste and flavour are much influenced by changes in colour, texture, shrinkage of fruits and enzymatic activities within the fruits.

Among the collections evaluated for sensory/organoleptic rating of fruits, the Coll. 2 recorded highest mean rank in appearance of fruits followed by Coll. 10

(16) and Coll. 32 (15.6). The Coll. 22, Coll. 2 and Coll. 13 recorded highest mean ranks of 13.9, 13.85 and 13.7 respectively for fruit colour. Fruits with best flavour was observed in Coll. 2 (19.55) which was followed by Coll. 7 (16.75) and Coll. 9 (13.25). Aril taste was sweet in Coll. 2 (19.9) which was followed by Coll. 1 (16.25) and Coll. 32 (15.7). The Coll. 2 ranks top (19.35) with respect to overall acceptability which was followed by Coll. 1 (16.3), Coll. 10 (15.9) and Coll. 15 (14.5), Coll. 22 (13.75) and Coll. 13 (13.15).

5.8 Pests and diseases incidence

5.8.1 Pests

Mites, lepidopteran, coleopteran pests were noticed during the period of study.

Mild incidence of eriophyid mite (*Aceria litchi*) was observed in most of the litchi trees resulted in curling and crinkling of both young and old leaves and showed hair like velvetty growth on leaves which later turned into chocolate brown colour (Plate 15a)

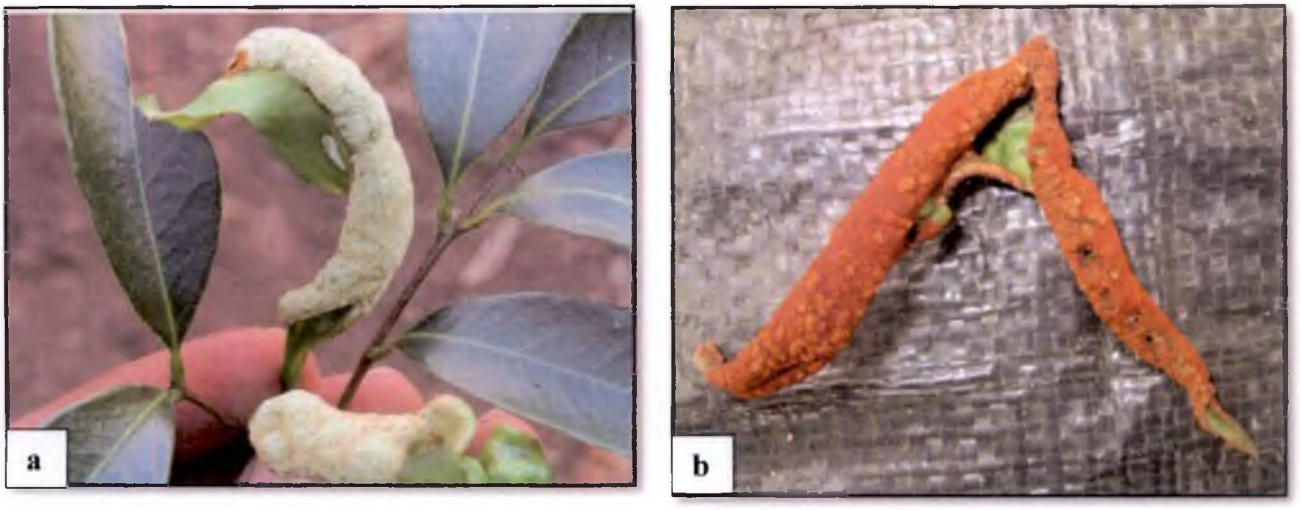
Four lepidopteran defoliators were observed. Out of these one type caused damage by rolling of tender leaves and feeding from inside (Plate 15a). Other three were seen feeding on the leaf lamina which are yet to be ascertained (Plate 15b)

Two coleopteran pests *viz.*, ash weevil and chrysomelid beetle (yet to be ascertained) caused defoliation by making holes and notches (Plate 15b)

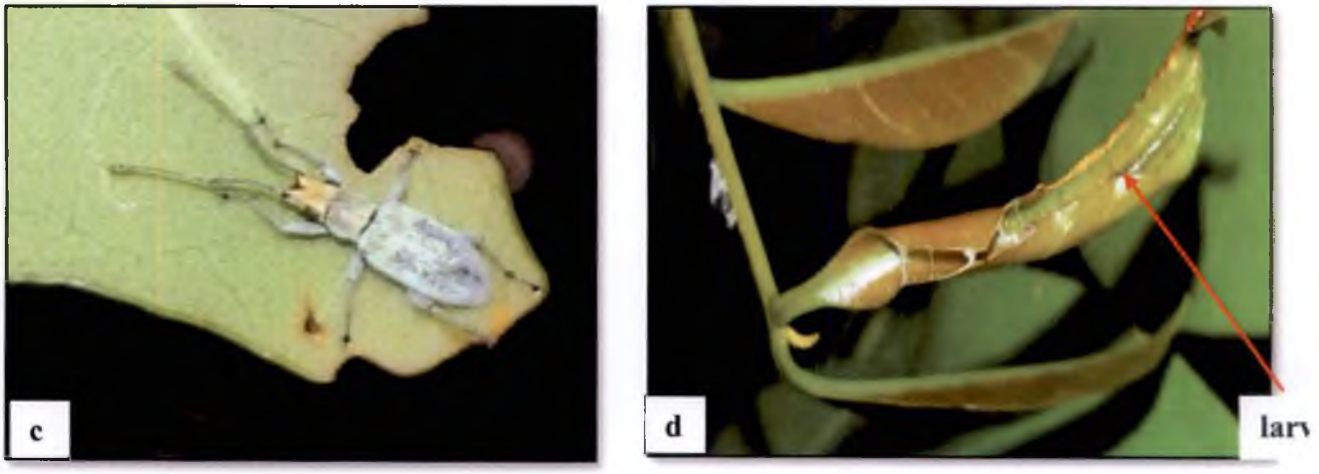
Apart from these pests vertebrate pests like monkey, bats, birds and squirrels were found eating and damaging the fruits causing economic loss to farmers. In order to protect from these vertebrates farmers are covering the whole tree with net at the time of fruit maturity (Plate 17)

5.8.1.2 Diseases

Two diseases observed during the study period were red rust and anthracnose (Plate 16)



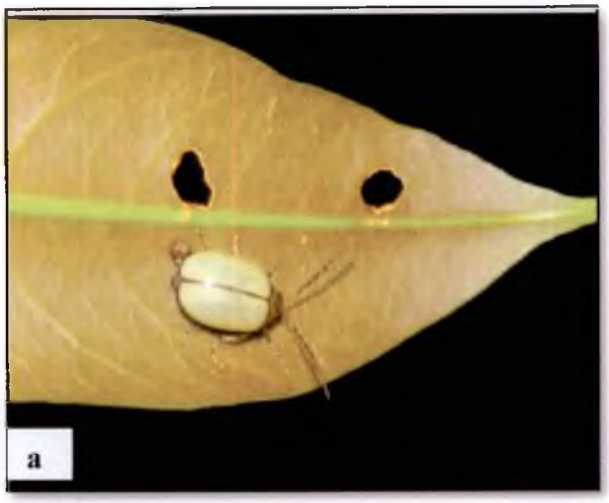
Eriophyid Mite (*Aceria litchi*) attack on a. young leaves, b. old leaves



c. Ash weevil (*Myllocerus* sp.) feeding on litchi leaves

d. Leaf roller (*Pletupelpus aprobola*) feeding litchi leaf

Plate 15a. Pests of litchi grown in Wayanad



Insects (a, b, c, d) associated with litchi as defoliators (identity to be ascertained)

Plate 15b. Pests of litchi grown in Wayanad

Red rust (*Cephaleuros virescens*)

Anthracnose (*Colletotrichum gloeosporioides)*

Plate 16. Diseases of litchi

Plate 17. Litchi tree covered with net

Mild incidence of red rust (*Cephaleuros virescens*) disease was noticed on leaves. Symptoms were circular to semicircular spots on the leaves and orange yellow to pink velvety coating on the spots on formation of sporangia of the algae.

Anthracnose (*Colletotrichum gloeosporioides*) was observed on the fruits by forming circular dark-brown to black sunken lesions on mature fruits.

5.9 Influence of weather parameters on growth of litchi in Wayanad

Low temperature is a prerequisite for floral bud development and flower initiation in litchi. In Wayanad, the minimum temperature from June to July is below 20°C which trigger the development of reproductive bud and initiation of panicles leading to flowering in August to September (Fig. 7). Menzel and Simpson (1995) observed threshold temperature of 20°C is suitable for floral induction of a litchi cultivars. Young (1961) inferred that cool nights of temperature 10°C or less stimulates shoot initiation and floral induction in litchi.

High rainfall above 500 mm in the month of June (Fig. 8), resulted in higher soil moisture and low soil temperature (below 20°C) that may resulted in induction flower. Menzel (2001) opined that low root temperature of 12.5°C stimulates flower induction and increases flowering in litchi.

5.10 Promising collections

In the present investigation, wide variability with respect to morphological, floral, fruit and quality attributes were noticed in the litchi collections in Wayanad.

Based on the fruit traits, yield and quality attributes of the three collections *viz.*, Coll. 2, Coll. 10 and Coll. 13 (Plate 18) were found to be promising among the total 32 collections. These collections were comparable with the popular litchi variety Shahi grown in Coorg regions. The data collected from CHES (Central Horticultural experimental Station), Chettalli revealed a fruit weight of 15.25 g, fruit length of 3.13 cm, fruit diameter of 2.87 cm, yield of 25.87 kg/plant, TSS of 19.00 ° B and acidity of 0.6 per cent in litchi variety Shahi (Senthilkumar *et al.*, 2015).

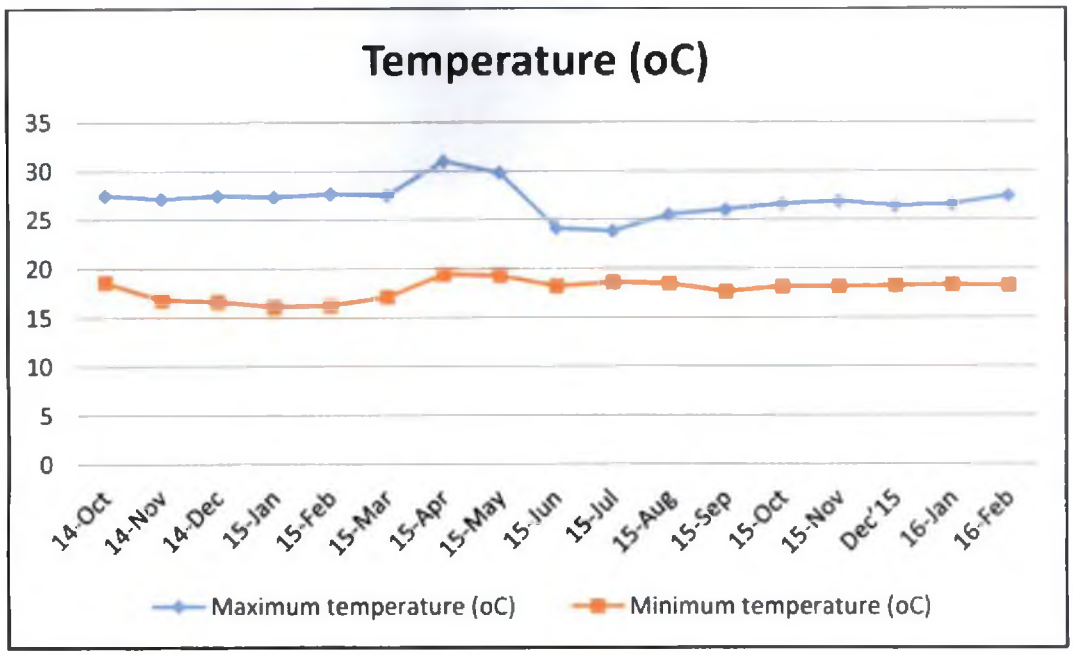


Fig. 7 Temperature variation in Wayanad from October 2014 to February 2016

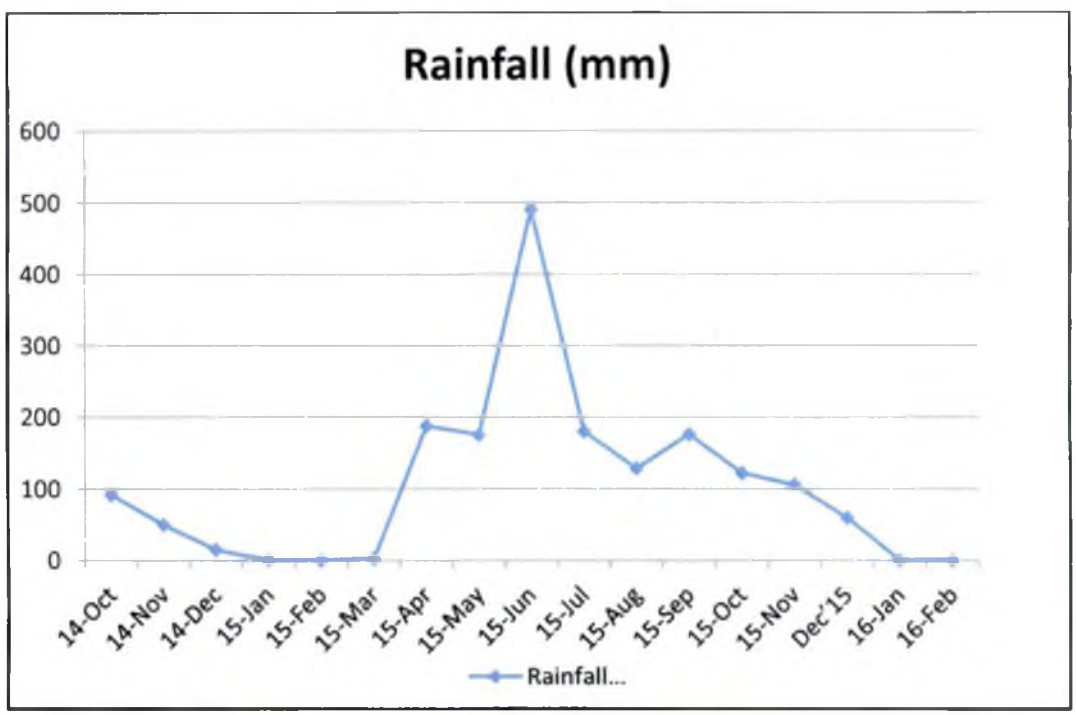


Fig. 8 Rainfall distribution pattern in Wayanad from October 2014 to February 2016

Hence, these selections (Coll. 2, Coll. 10 and Coll. 13) can be utilized for future breeding programmes. These collections need to be evaluated further to ascertain the yield and suitable parameters. Further studies are required to standardize the management practices including the eco-physiological aspects of litchi for Kerala conditions as this fruit crop is fetching a premium price in the market because of its off season production.

Plate 18. Promising litchi collections

SUMMARY

6. SUMMARY

The study entitled 'Morpho-physiological characterization of litchi (*Litchi chinensis* Sonn.) in Wayanad' was carried out in the Department of Pomology and Floriculture, College of Horticulture, Vellanikkara, Kerala during the year 2015 to 2016. The main objective was to study the flowering and fruit set pattern in litchi and the related morpho-physiological parameters under Wayanad situations of Kerala. Thirty two bearing trees selected from the collections of litchi maintained in the Regional Agricultural Research Station, Ambalavayal and farmer's fields in Wayanad. Trees were evaluated for tree characters, phenological characters and physiological parameters. Floral characters were recorded at the time of flowering. Mature fruits were collected for recording fruit characters, seed characters, quality attributes and sensory evaluation. The salient findings of the study are summarized below:

Wide variability was observed with respect to age of the trees. Tree age varied from 5 to 79 years and displayed high coefficients of variation (CV) of 74.21 per cent. The height of the trees ranged from 3.00 m to 19.00 m and displayed a CV of 57.87 per cent. Tree trunk girth ranged from 28.00 cm to 540 cm with a CV of 74.1 per cent.

Leaf length ranged from 12 cm to 16.8 cm with a CV of 8.67 per cent. Leaf width was 5.2 to 3 cm with a CV of 14.27 per cent. Shoot length ranged from 15 cm to 26 cm which displayed a CV of 12.77 per cent. The internodal length of the collections ranged from 2.8 cm to 5.2 cm with a CV of 17.66 per cent.

Broadly pyramidal, spherical, oblong, semi-circular and irregular crown shapes were observed. The predominant shapes were semicircular (34.37 %), oblong (31.25 %) and spherical (25.12 %).

Erect, opposite, verticillate, horizontal and irregular branching patterns were noticed. The prominent branching pattern was verticillate (65.62 %).

Elliptic leaf blade shape (96.87 %) was predominant. Pinkish green colour (78.12 %) was predominant in young leaves. Matured leaves had green (65.62 %), dark green (31.25 %) and light green (3.12 %) colours.

The principal component analysis (PCA) of tree characters revealed that the first two principal components (PCs) accounted for 77.3 per cent of the total variation. The clustering of the collections based on first two PCs resulted in the formation of 9 clusters.

Only 26 collections flowered during the period. Seventy five percent of the collections flowered during August to September whereas, 7.14 per cent flowered during February to March. Both the season flowering were noticed in 17.85 per cent collections.

Flowering duration varied from 12-35 days. Inflorescence length ranged from 38 cm (Coll. 9) to 15.1 cm (Coll. 17) and inflorescence width ranged from 19.3 cm (Coll. 2) to 9.4 cm (Coll. 17).

Days taken from flowering to fruit maturity varied from 71 (Coll. 4) to 94 days (Coll. 30). Days from fruit set to maturity varied from 58 (Coll. 10) to 75 days (Coll. 2).

PCA of flower traits revealed that the first two PCs explained 86.4 per cent of total variation. Clustering of collections based on first two PCs resulted in formation of 5 clusters.

Chlorophyll content of leaves varied from 1.07 to 1.87 mg/g and displayed a CV of 13.88 per cent. Cell sap pH of leaves varied from 5.12 to 5.96 with a CV of 2.86 per cent. Carbohydrate content of leaves varied from 3.79 g/100g (Coll. 28) to 13.48 g/100g (Coll. 8) with a CV of 31.51 per cent.

Nitrogen content of leaves varied from 1.09 per cent (Coll. 24) to 2.31 per cent (Coll. 11) and displayed a CV of 16.2 per cent. Carbon/Nitrogen (C/N) ratio varied from 3.83 to 8.44 and displayed a CV of 19.44 per cent.

PCA of physiological parameters explained 75.6 per cent of the total variation by the first two PCs. Clustering based on first two PCs resulted in 8 clusters.

Only 20 collections were set fruits during the period. Among these, fifty per cent collections recorded medium fruit bearing intensity (15-25 fruits/m^2) while other 50 per cent recorded poor fruit bearing intensity (<15 fruits/m^2). Clustering fruit habit was observed in all the collections.

Fruits shape varied as elliptic (47.60 %), oblong (19.04 %), oval (4.7 %). oval and oblong (9.52 %); oval and elliptic (9.52 %) and elliptic and oblong (4.7 %).

Fruit skin thickness classified as thin, medium and thick skin. Eighty per cent of collections had medium skinned fruits. Most of the trees were prone to fruit cracking while collection with thick skinned fruits (Coll. 1, Coll. 3, Coll. 4, Coll. 7, Coll. 19 and Coll. 21) were free from fruit cracking.

Fruit colour varied as pinkish red (75 %) and greenish yellow (25 %). Among the collections, 5 per cent of the collections were excellent in fruit attractiveness. Excellent fruits were recorded the in Coll. 2.

Aril thickness of the fruits classified as thin (25 %), medium (50 %) and thick (25 %). Thick aril fruits were recorded in Coll. 2, Coll. 9, Coll. 10, Coll. 13 and Coll. 21. Seventy per cent of the collections were sweet types and 30 per cent were sour type fruits.

Length of fruits varied from 2.8 cm and 3.8 cm. Average fruit length was 3.31 cm with a CV of 8.87 per cent. Fruit diameter ranged from 2.1 cm to 3.2 cm with mean fruit diameter of 2.59 cm and displayed a CV of 11.76 per cent.

Aril weight varied from 12.1g to 17.1g. Maximum aril weight was recorded in Coll. 2, Coll. 9, Coll. 10 and Coll. 13. Texture of aril was found firm in all collections but quality differed as sweet and sour types.

Number of fruits per cluster ranged from 6 to 18 with a CV of 39.7 per cent. Yield/plant ranged from 1 to 30 kg. Average yield/plant was 12.6 kg with a CV of

78.13 per cent. Highest yield of 30 kg/plant was recorded in Coll. 10, followed by Coll. 13 (28.4 kg), Coll. 32 (25 kg) and Coll. 2 (22.9 kg).

The shelf life of the fruit varied from 3 and 4 days in ambient condition. The Coll. 1, Coll. 7, Coll. 10, Coll. 13 and Coll. 31 had shelf life of 4 days.

Seed weight (100 seeds) ranged from 210 g to 297 g with a CV of 8.9 per cent. Seed shape of fruits were varied as oblong (60 %), oblong and oval seeds (10 %), oblong and chicken tongue (25 %) and irregular shape (5 %). Brown seed colour was common in all collections.

PC analysis of fruit and yield characters revealed that first two PCs explains the 71.9 per cent of total variance. Clustering based on first two PCs divides into seven clusters.

Total sugar content of the fruits were ranged from 10.18 to 15.50 per cent with a CV of 9.6 per cent. Total soluble solids (TSS) of the fruits were varied from15.10 ^{0}B to 19.6 ^{0}B. TSS displayed a CV of 6.23 per cent. The Coll. 2 recorded maximum TSS content of 19.6 ^{0}B which was followed by Coll. 13 (19.2 ^{0}B) and Coll. 10 (19 ^{0}B).

Acidity of fruits ranged from 0.38 to 1.18 per cent and displayed CV of 22.82 per cent. The lowest acidity of 0.38 per cent was recorded in Coll. 2, followed by Coll. 32 (0.57 %) and Coll. 7 (0.6 %)

Reducing sugar was ranged from 5.8 per cent (Coll. 20) to 8.6 per cent (Coll. 32) and non-reducing sugar ranged from per cent 3.38 (Coll. 2) to 6.7 per cent (Coll. 15) in fruits.

PCA of quality characters explained that the first two PCs associated for 75.6 percent of the total variation. The clustering of the collections based on first two PCs resulted in formation of 7 clusters.

Sensory evaluation based on nine point hedonic scale, Coll. 2 was found to be promising because of its higher mean ranks for flavour and taste.

Dendrogram of qualitative characters resulted in formation of 4 non-overlapping clusters at similarity level of 66 per cent.

Mild incidence of mites, lepidopteran and coleopteran pests and red rust and anthracnose diseases were noticed during the period of study.

In the present investigation, Coll. 2, Coll. 10 and Coll. 13 were identified as superior types based on fruit size, weight, yield, quality and sensory parameters. Hence, these selections can be utilized for future breeding programmes.

REFERENCES

REFERENCES

Abrol, D. P. 1999. Pollination importance value of bees. *Insect Environ.* 5:140-141.

Aguas, A. A., García, P. E., Ruiz, R. O. and Trinidad, S. A. 2014. Fruit quality of lychee (*Litchi chinensis* Sonn.) produced in Veracruz State, México. Sociedad Mexicana de Fitogenética, Chapingo, Mexico. 37(4): 373-380.

Ali, A. G. and Lovatt, C.J. 1995. Relationship of polyamines to low-temperature stress- induced flowering of the 'Washington' navel orange (*Citrus sinensis* L. Osbeck). *J. Hortic. Sci.* 70: 491-498.

AOAC, 1975. *Official Methods of Analysis.* Association of Official Agricultural Chemistis, Washington D.C.12th Edn.

Ather, M. 2001. Response of litchi (*L chinensis*) to paclobutrazol. PhD thesis, G.B Pant University Uttaranchal.

Badiyala, S. D. 1993. Maturity standards for Muzaffarpur litchi fruits. *South Indian Hortic.* 41: 223-224.

Batten, D. J. and Lahav, E. 1981. The effect of temperature on growth and nutrient uptake in three litchi cultivars. Research Report Tropical Fruit Research Station, Alstonville, N.S.W., Australia. 37-38.

Batten, D. J. and Lahav, E. 1994. Base temperatures for growth processes of lychee, a recurrently flushing tree, are similar but optima differ. *Aust. J. Plant Physiol.* 21: 589-602.

Batten, D.J. and McConchie, C.A. 1992. Pollination in lychee. In: *Proc. of the Third National Lychee Seminar.* Australian Lychee Growers' Association, Bundaberg, Australia, pp. 23–28.

Batten, D. J. and McConchie, C. A. 1995. Floral induction in growing buds of lychee (*Litchi chinensis*) and mango (*Mangifera indica*). *Aus. J. Plant Physiol.* 22: 783–791.

Batten, D. J., 1989. Maturity criteria for litchis (lychees). *Food Qual. Prefer.* 1:149-155.

Bhattacharjee, S., Das, B. C. and Hasan, M. A. 2001. Studies on the morphology of fruit growth in litchi and their correlative relationship with fruit quality. Agricultural Society of India, Calcutta, India, *Indian Agriculturist,* 45(½):121-129.

Bhullar, J. S., Dhillon, B. S. and Randhawa, J. S. 1983. Extending the postharvest life of litchi cultivar Seedless Late. *J. Res. Punjab Agric. Univ.* 20: 467-470.

BiYan, Z., HouBin, C., ChiHua, X., WeiQiang, L., Ning, L., ZhiQun, H. and Si, Z. 2010. Flowering of' Sanyuehong' litchi with treatments of different temperature regimes. *Acta Hortic. Sinica*, 37(7):1041-1046.

Bremner, J. M. 1965. Total nitrogen. In: C.A. Black (Ed.), Methods of Soil Analysis, Part 2, *Am. Soc. Agron.* Madison, 1149-1178.

Budathoki, K. 2002. Lychee production in Nepal. In: Papademetriou, M. K. and Dent, F. J. (eds), *Lychee Production in the Asia-Pacific Region.* Food and Agricultural Organization of the United Nations, Bangkok, Thailand, pp. 81–93.

Chan, H. T and Kwok, S. C. M. 1974. Non volatiles in lychee. *J. Food Sci.* 39:792-793.

Chandel, J. S. and Sharma, N. K. 1992. Extent of fruit cracking in litchi and its control measures in Kangra Valley of Himachal Pradesh. *South Indian Hortic.* 40: 74–78.

Chaubey, D. K., Chattopadhyay, T. K., Singh, B. and Das, U. 2001. Correlation studies among plant and fruit characters in litchi (*Litchi chinensis* Sonn.). *Envir. and Ecol.* 19(4): 973-977.

Chaudhary, D. K., Singh, B., Singh, A. K. and Singh, P. P. 2004. Influence of bee pollination on morpho-physiological characters on litchi fruit. *J. Res. Birsa Agric. Univ.* 16(1): 139-141.

Chen, H. B., and Huang, H. B. 2005. Low Temperature Requirements for Floral induction in Lychee. In: (Eds.). Chomchalow, N. and Sukhvibul, N. *Proc. 2nd Int. Symp. on Lychee, Longan, Rambutan & Other Sapindaceae plants Acta Hortic.* 195-202.

Chen, I. Z. and Cheng, C. Y. 1996. Effect of root temperature on flowering, root growth and leaf mineral nutrients and carbohydrate content of mango (*Mangifera indica* L.). *J. Taiwan Soc. Hortic. Sci.* 42: 131–141.

Chen, P.A., Roan, S.F., Lee, C.L. and Chen, I.Z., 2013. The effect of temperature during inflorescence development to flowering and inflorescence length on yield of 'Yu Her Pau' litchi. *Sci. Hortic.* 159: 186–189.

Chen, Po-An., Roan, Su-Feng., Lee, Chin-Lung. and Chen, Iou-Zen. 2016. Temperature model of litchi flowering from induction to anthesis. *Sci. Hortic.* 205: 106–111.

Chen, W. S. and Ku, M. L. 1988. Ethephon and kinetin reduce shoot length and increase flower bud formation in lychee. *Hortic. Sci.* 23(6):1078.

Chen, W. X., Su, M. X. and Lee, P. M., 1982. A study of controlled atmosphere storage of litchi. *J. South China Agric. Univ.* 3: 54-61.

Chen, W., Wu, Z., Ji, Z. and Su, M. 2001. Postharvest research and handling of litchi in China: a review. *Acta Hortic.* 558:321–329.

Cobin, M., 1954. The lychee in Florida. Bull. *Fla. Agric. Exp. Stn.* 546: 1–35.

Cronje, R. B. 2010. Litchi phenology and botanical aspects. In: deVilliers, E. A., Joubert, P.H. (Eds.), The Cultivation of Litchi. Nelspruit, South Africa, ARC-Institute for Tropical and Subtropical Crops, pp. 8–22.

Das, B., Nath, V. and Dey, P. 2004. Investigations on flushing and panicle emergence in litchi under subhumid sub-tropical plateau region of eastern India. *Indian J. Hortic.* 61(1):51-55.

Das, C. S. and Choudhary, K.R. 1958. Floral biology of litchi (*Litchi chinensis* Sonn.) *South Indian Hortic.* 6: 17-22.

Davenport, T. L. 2000. Processes influencing floral initiation and bloom: the role of phytohormones in a conceptual flowering model. *Hortic. Tech.* 10(4):733-739.

Deng, X. M., Han, Z. H. and Li, S. H. 1999. Fruit Tree Biology. Higher Education Press, Beijing, China. 141 p.

Deng, Y. C., Ni, Y. Y. and Chen, N. R. 1994. Studies on the effects of potassium on photosynthesis and respiration of litchi. *J. South China Agric. Univ.* 15:80–84.

Du, T. A. P. and Swart, D. J. 1995. Pollination and fruit set in Bengal litchi during the 1993 flowering season at Politsi: second report. *Yearbook of the South African Litchi Growers Association,* 7: 31-32.

Dutt, A. K. 1962. Response of litchi to minor elements in laterite soils. *Fertilizer News.* 7:24-26.

Dwivedi, A. K. and Jha, K. K. 2000. Morphological characters of fruits in litchi (*Litchi chinensis* Sonn.). *J. Res., Birsa Agric.l Univ.* 12(1): 119-120.

Finger, F. L., Vieira, G. and Ledsham, L. R. 1997. Maturity standard and pericarp browning of litchi fruit. *R. Bras. Fisiol. Veg.* 9:15-18.

Firminger, W. K. 1947. *Manual of gardening in India.* Thaker Spink and Company, Calcutta.

Froneman, S., 1999. Two new litchi cultivars released: new litchi cultivars will lengthen the South African production season, *Neltropika Bull.* 305: 3–6.

Fu, X., Zhou, L., Huang, J., Mo, W., Zhang, J., Li, J., Wang, H. and Huang, X. 2013. Relating photosynthetic performance to leaf greenness in litchi: A comparison among genotypes. *Sci. Hortic.* 152: 16–25.

Galán Saúco, V., Fernández Galván, D., and Delgado, H. P. M. 2001. Behavior of different litchi cultivars in Canary Islands. *(Eds.)* Huang, H. and Menzel, C. *Ist Int. Symp. on Litchi & Longan. Acta Hortic.* 558p.

Gary, H. L. 1974. The vertical distribution of needles and branchwood in thinned and unthinned 80-year-old lodgepole pine. *Northwest Sci.* 52: 303-309.

Gosh, B., Biswas, B., Mitra S. K. and Bose, T. K. 1988. Physico-chemical composition of some promising cultivars of litchi adapted in West Bengal. *Indian Food Packer.* 42(1): 34-37.

Groff, G. W. 1921. *The Lychee and Lungan.* Orange Judd Company, New York, 188 p.

Hai, V. M. and Dung, N. V. 2002. Lychee production in Viet Nam. In: Papademetriou, M.K. and Dent, F.J. (eds) *Lychee Production in the Asia-Pacific Region.* Food and Agricultural Organization of the United Nations, Bangkok, Thailand, 114–119.

Hanson, E. J. and Breen, P. J. 1985. Effects of fall boron sprays and environmental factors on fruit set and boron accumulation in 'Italian' prune flowers. *J. Am. Soc. Hortic. Sci.* 110: 389–392

Haq, I. U. and Rab, A. 2012. Characterization of physico-chemical attributes of litchi fruit and its relation with fruit skin cracking. *J. Animal & Plant Sci.* 22(1): 142-147.

Hossain, M. M., Hossain, M. S., and Islam, M. M. 2014. Fruit setting, cracking and quality of litchi (*Litchi chinensis* Sonn.) as influenced by foliar spray of different nutrient solutions during fruit growth and development. *J. Agric. Tech.* 10(3):717-731.

Huang, H. and Xu, J., 1983. The developmental patterns of fruit tissues and their correlative relationships in *Litchi chinensis* Sonn. *Sci. Hortic.* 19: 335-342.

Huang, X. M., Li, J. G., Wang, H.C., Huang, H. B. and Gao, F. F. 2001. The relationship between fruit cracking and calcium in litchi pericarp. *Acta Hortic.* 558: 209–211.

Huang, Y.H., Su, J.F. and Wang, Z.X. 1992. Discussion on the relationship between longan tree structure and yield. *Fujian Agric. Sci. and Technol.* 1: 17–18.

IPGRI. 2002. Descriptors for Litchi (*Litchi chinensis*). International Plant Genetic Resources Institute, Rome, Italy, 58p.

Islam, M. S., Ibrahim M., Rahman, M. A., Uddin, M. A. and Biswas, S. K. 2003. *Pakistan J. Biol. Sci.* 6: 70-72.

Jawanda, J. S. and Singh, S. 1977. Fruit yield, ripening time and fruit quality of litchi cultivars grown in Punjab. *Punjab Hortic. J.*. 17(3): 122-125.

Jiang, Y. M., Wang, Y., Song, L., Liu, H., Lichter, A., Kerdchoechuen, O., Joyce, D. C. and Shi, J. 2006. Postharvest characteristics and handling of litchi fruit - An overview. *Aust. J. Exp. Agric.* 46: 1541-1556.

Johnson, G. I. 1989. Lychee disease control. In: Campbell, T. and Sing, N. (eds) Proceedings of second National Lychee Seminar. Australian Lychee Growers' Association, Cairns, Queensland, Australia, pp. 90-93.

Johnson, G. I., Cooke, A. W. and Sardsud, U. 2002. Postharvest disease control in lychee. *Acta Hortic.* 575: 705–715.

Joubert, A. J. 1985. *Litchi chinensis*. In: Halevy, A.H. (ed.) *Handbook of Flowering*. CRC Press, Boca Raton, Florida, 204–210.

Joubert, A. J. and van Lelyveld, L. J. 1975. An investigation of preharvest browning of litchi peel. *Phytophylactica,* 7: 9-14.

Kadam, S. S. and Deshpande, S. S., 1995. Lychee. In: D. K. Salunkhe, D. K. and Kadam, S.S. (Eds). Handbook of Fruit Science and Technology. Marcel Dekker, New York, NY, pp. 435-443.

Kader, A. A. 1994. Modified and controlled atmosphere storage of tropical fruits. In: (Eds). Champ, B.R., Highley, E. and Johnson, G.I. ACIAR *Proc. Postharvest Handling of Tropical Fruit,* 50: 239-249.

Kaiser, H. F. 1958. The varimax criterion for analytic rotation in factor analysis. *Psychometrika.* 23:187-200.

Kanwar, J. S. and Nijjar, G. S. 1984. Comparative evaluation of fruit growth in relation to cracking of fruits in some litchi cultivars. *Punjab Hortic. J.* 24:79-82.

Kanwar, J. S. and Nijjar, G. S. 1985. Litchi cultivation in Punjab-problems and prospects. *Punjab Hortic. J.* 15:9-13.

Kanwar, J. S., Rajpoot. M. S. and Bajwa, M. S. 1972. Sun burning and skin cracking in some varieties of litchi and factors affecting them. *Indian. J. Agric. Sci.* 42:772-775.

Kellomaki, S., Oker-Bloom, P. and Kuuluvainen, T. 1985. The effect of crown and canopy structure on light interception and distribution in a tree stand. In: P.M.A. Tigerstedt, P. Puttonen and V. Kiski (eds.), *Crop Physiology of Forest Trees.* Departmaent of Plant Breeding, Helsinki. 107-115.

Khurshid, S., Ahmad, I., Anjum, M. A. 2004. Genetic diversity in different morphological characteristics of litchi (*Litchi chinensis* Sonn). *Int. J. Agric. Biol.* 6 (6):1062–1065.

Kitroo, R. and Abrol, D. P. (1996). Studies on pollen carrying capacity and pollination efficiency of honey bees visiting litchi flowers. *Indian Bee J.* 58: 55–57.

Kotur, S. C. and Singh, H. P. 1993. Leaf-sampling technique in litchi (*Litchi chinensis* Sonn.). *Indian J. Agric. Sci.* 63: 632–638.

Kuldeep, S. and Nath. V. 2015. Keeping emerging pests under changing climate at bay. 2015. *Indian Hortic.* 61:28-30.

Kumar, R. 2014. Effect of Climate Change and Climate Variable Conditions on Litchi (*Litchi chinensis* Sonn.) Productivity and Quality. In: Cronje, R. (Ed.) *Proc. Fourth Int. Symp. on Lychee, Longan and Other Sapindaceae Fruits. Acta Hortic.* 145-154.

Kumar, R., Chaudhury, O.P. and Lenin, J.K. 1996. Studies on pollination of litchi (*Nephilium litchi* Camb.) in Dehradunn. *Indian Bee J.* 58: 9-12.

Kumar, S., Kumar, R., Sharma, R. S., Hoda, M.N and Singh, U.P 1981. Effect of growth regulators on litchi (*Litchi chinensis* Sonn.). *Indian J. Hortic.* 38(3 & 4):191-194.

Kumar, V., Kumar, A., Nath, V. and Kumar, R. 2014. New Threats of Insect Pests and Disease in Litchi (*Litchi chinensis* Sonn.) in India. In : Cronge R. (Ed.), *Proc. Fourth Int. Symp. Lychee, Longan and Other Sapindaceae Fruits. Acta Hortic.* 417-424.

Kumar, V., Rami reddy, P. V. and Ajit Kumar, D. A. 2013. Report on the occurrence and biology of Thalassodes pilaria Guenée (Lepidoptera: Geometridae) on litchi (*Litchi chinensis* Sonn.) in Bihar, India. *Pest manag. Hortic. Ecosystems.* 19(2): 245-247.

Lal, R. L. and Kumar, G. 1997. Effect of irrigation frequencies on yield and Quality of litchi fruits cv Rose Scented. *Indian J. Hortic.* 54(1): 30-33.

Leenhouts, P.W. 1978. Systematic notes on the Sapindaceae-Nephelieae. Blumea 24: 395–403.

Li, J. G. and Huang, H. B. 1995. Physio-chemical properties and peel morphology in relation to fruit cracking susceptibility in litchi. *J. South China Agric. Univ.*16: 84–89.

Li, Y. C., Davenport, T. L., Rao, R. and Zheng, Q. 2001. Nitrogen, flowering and production of lychee in Florida. In : Huang, H. and Menzel, C. (Eds.), *Proc. First Int. Symp. on Lychee, Longan and Other Sapindaceae Fruits. Acta Hortic.* 221-224.

Madhou, M., Bahorun, T. and Hormaza, J. I. 2010. Phenotypic and molecular diversity of litchi cultivars in Mauritius. *Fruits,* 65(3): 141-152.

Mallik, P. C. and Singh, D. L. 1965. Hunger signs in litchi (*Litchi chinensis* Sonn.). *Indian Agriculturist,* 9:127–132.

Mandala, D., Sarkar, A. and Ghosh, B. 2014. Induction of Flowering by Use of Chemicals and Cincturing in 'Bombai'. In : Cronge R. (Ed.), *Proc. Fourth Int. Symp. on Lychee, Longan and Other Sapindaceae Fruits. Acta Hortic.* 265-272.

Mathew, A. B. and Pushpa, M. C. 1964. Organic acids and carbohydrates of litchi. *J. Food Sci. Technol.* 1:71-72.

Menzel, C. M. 1983. The control of floral initiation in lychee: a review. *Scientia. Hortic.* 21:201-215.

Menzel, C. M. 1991. *Litchi chinensis* Sonn. In: Verheij, E.W.M. and Coronel, R.E. (eds) *Plant Resources of South-East Asia No. 2: Edible Fruits and Nuts.* Pudoc, Wageningen, The Netherlands, 191–195.

Menzel, C. M. 2001. The physiology of growth and cropping in lychee. In: Huang, H. and Menzel, C. Proc. of Ist Int. Symp. On litchi and longan. *Acta Hortic.* 175-184.

Menzel, C. M. 2002 The Lychee Crop in Asia and the Pacific. Food and Agricultural Organization of the United Nations, Bangkok, Thailand, 108 p.

Menzel, C. M. and Simpson, D. R. 1986. Description and performance of major lychee cultivars in subtropical Queensland. *Queensland Agric. J.* 112: 125-136.

Menzel, C. M. and Simpson, D. R. 1988. Effect of temperature on growth and flowering of litchi (Litchi chinensis Sonn.) cultivars. *J. Hortic. Sci.* 63: 349-360.

Menzel, C. M. and Simpson, D. R. 1995. Temperatures above 20°C reduce flowering in lychee (*Litchi chinensis* Sonn.). *J. Hortic. Sci.* 70: 981-987.

Menzel, C. M., 1984. The pattern and control of reproductive development in lychee: A Review. *Sci. Hortic.* 22: 333-45.

Menzel, C. M., Carseldine, M. L., Haydon, G. F. and Simpson, D. R. 1992. A review of existing and proposed new leaf nutrient standards for lychee. *Sci. Hortic.* 49:33-53.

Menzel, C. M., Olesen, T., McConchie, C., Wiltshire, N., Diczbalis, Y. and Wicks, C. 2000. *Lychee, longan and rambutan: optimizing canopy management.* Rural Industries Research and Development Corporation, Canberra, Australia, 92 p.

Menzel, C. M., Rasmussen, T.S. and Simpson, D. R. 1995. Carbohydrate reserves in lychee trees (*Litchi chinensis* Sonn.). *J. Hortic. Sci.* 70:245-255.

Menzel, C. M., Watson, B.J. and Simpson, D. R. 1988. The lychee in Australia. *Queensland Agricultural Journal* 114: 19-27.

Menzel, C. M., Watson, B.J. and Simpson, D. R. 1989. Longan: a place in Queensland's horticulture. *Queensland Agric. J.* 115: 251–265.

Menzel, C. M. and Simpson, D. R. 1994. Lychee. In: Schaffer, B., Anderson, P.C. (Eds.), Handbook of Environmental Physiology of Fruit Crops. Vol. 2. Subtropical and Tropical Crops. CRC Press, Boca Raton, Fla, pp. 123–145.

Merrill, E. D. 1923. *An Enumeration of Philippine Flowering Plants.* Bureau of Printing, Manila, Philippines, 67 pp.

Milne, D. L. (1999) Lychee production and research in Southern Africa. In: Menzel, C.M, Waite, G. and Bronson, R. (eds) *Proceedings of the Fifth National Lychee Conference.* Australian Lychee Growers' Association, Twin Waters, Queensland, 25–31 pp.

Nakasone, H. Y. and Paull, R. E. 1998. *Tropical Fruits.* CAB International, Wallingford, Oxon, UK. 173–207.

Nakata, S. and Watanabe, Y. 1966. Effects of photoperiod, and night temperature on flowering of *Litchi chinensis. Botanical Gazette* 127:146–152.

Nath, S., Kumar, M., Ojha, R. K. and Jha, K. K. 2012. Yield and physico-chemical properties of litchi fruits as affected by different rates of pruning and chemical spray. *Progressive Hortic.* 44(1): 166-169.

Nath, V., Thakrea M., Pandey, S. D., Kumar, A. and Kuma, R. 2014. Canopy architecture for high density litchi (*Litchi chinensis* Sonn.) Plantings. In: Cronje, R. (ed.), *Proc. Fourth Int. Symp. on Lychee, Longan and Other Sapindaceae Fruits. Acta Hortic.* 287-294.

Nath. V., Kumar, A., Pandey S.D. and Tripathi, P.C. 2015. Litchi in winter season-a way forward. *Indian Hortic.* 59:26-27.

Netto A. T., Campostrini, E, Oliveira, J. G. and Yamanishi, O. K. 2002. Portable chlorophyll meter for the quantification of photosynthetic pigments, nitrogen and the possible use for assessment of the photochemical process in *Carica papaya* L. *Braz J. Plant Physiol* 14:203–210.

NHB [National Horticulture Board], 2015. Second Advance Estimate of Area and Production of Horticulture Crops (2013 - 14).

Nijjar, G. S. 1972. *Litchi cultivation* Punjab Agricultural University, Ludhiyana.

NRC [National Research Centre], 2015. *Vision -2050.* National Research Centre on Litchi by National Research Centre on Litchi, Muzaffarpur, 29p.

Olesen, T., Menzel, C. M., Wiltshire, N. and McConchie, C. A. 2002. Flowering and shoot elongation of lychee in Eastern Australia. *J. Agric. Res.* 53(8): 977-983.

Osuna, E. T., Valenzuela, R. G., Muy, R. M., Gardea, B. A. A. and Vllarreal, R. M. 2008. Sex expression and flower anatomy of litchi (*Litchi chinensis* Sonn.). Revista Fitotecnia Mexicana, 31(1): 51-56.

Pandey, R. M. and Sharma, H. C. 1989. The litchi. Indian Council of Agricultural Research, New Delhi , 80p.

Paull, R.E. and Chen, N.J. 1987. Effect of storage temperature and wrapping on quality characteristics of litchi fruit. *Scientia. Hortic.* 33:223–236.

Paull, R.E., Chen, N.J., Deputy, J., Huang, H., Cheng, G. and Gao, F. 1984. Litchi growth and compositional changes during fruit development. *J. Am. Soc. Hortic. Sci.* 109: 817-821.

Pereira, L. S. and Mitra, S. K. 2006. Studies on fruit growth and development of litchi cultivars. *Orissa J. Hortic.* 34(1): 17p.

Pesis, E., Dvir, O., Feygenberg, O., Ben Arie, R., Ackerman, M., Lichter, A. 2002. Production of acetaldehyde and ethanol during maturation and modified atmosphere storage of litchi fruit. *Postharvest Biol. Technol.* 26, 157–165.

Popenoe, W. 1920. The Litchi. Manual of Tropical and Subtropical Fruits. McMillan Company, New York, 312-325.

Prasad, S. S. 1962. The new leaf spot diseases *Nephelium litchi* Comb. *Indian Phytopathology*. 31:293.

Prasad, A., Das, B. and Gerard, M. 2010. Differentiation of litchi genotypes based on leaf biochemical parameters: a feasibility study. *Biospectra.* 5 (1):105-110.

Puttarudriah, M. and Basavanno, C. 1959. A preliminary account of phytophagous mite of Mysore. *Proceedings of Ist All-India Congress of Zoology* 2:530-539.

Qiu, Y. P., Yuana, P. Y., Zhang, B.Y., Li, Z. Q., Dai, H. F. and Liu, X. Y. 2014. Study of fruit characteristics and tree nutritional differences for different

flowering periods in 'Feizixiao' litchi. In : Cronge R. (Ed.), *Proc. Fourth Int. Symp. on Lychee, Longan and Other Sapindaceae Fruits. Acta Hortic.* 233-236.

Ranganna, S. 1997. Handbook of analysis and quality control for fruits and vegetable products (2 nd Ed.) Tata Mc Grow Hill Publishing Pvt. Ltd., New Delhi, pp. 3-621.

Ranjan, R., Kumar, A. and Singh, C. 2002. Studies on physicochemical characters of some promising cultivars of litchi (*Litchi chinensis* Sonn.) under Bihar plateau condition. *Orissa J. Hortic.* 30(2): 60-62.

Ray, P. K., Sharma, S. B. and Mishra. K. A. 1984. Important litchi cultivars of Bihar. *Indian J. Hortic.* 41:61-21.

Ray. P. K. Mishra, K. A. and Sharma, S. B. 1985. Yield and bearing consistency of some commercial litchi cultivars. *Indian J. Hortic.* 42:218-222.

Roy, R. N, Rao, D. P. and Mukherjee, S. K. 1984. Orchard efficiency analysis of litchi. *Indian J. Hortic.* 41:16-25.

Revathy, J., Narasimham, P., 1997. Litchi (*Litchi chinensis* Sonn.) fruit: influence of pre- and post-harvest factors on storage life and quality for export trade—a critical appraisal. *J. Food Sci. Tech.* 34: 1-19.

Robbertse, P. J., Fivaz, J. and Menzel, C. M. 1995. The structure of the litchi inflorescence in relation to the position and sex of the flowers. Yearbook South African Litchi Growers' Association. 7: 21-25.

Roy, P. K. and Mishra, K. A. 1982. The commercial varieties of litchi. *Litchi visheshank, Gandak Command Kshetra Vikas Abhikaran,* Muzzaffarpur, Bihar: 25 p.

Sadasivam, S. and Manickam, A. 1996. *Biochemical Methods.* (2nd Ed.). (Reprint, 2005). New Age International (P) Ltd., New Delhi, 256 p.

Sahay 2001. Bearing behaviour and quality characters of some litchi (*Litchi chinensis* Sonn.) cultivars. Ph.D thesis, Rajendra Agricultural University Bihar.

Sahay, S. and Kumar, N. 2007. Physio-chemical characteristics of some litchi (*Litchi chinensis* Sonn.) cultivars. *Haryana J. Hortic. Sci.* 6(3 & 4): 264.

Sarkar, T. K. and Bandyopadhyay, A. 1989. Flowering behavior of some important litchi Litchi chinensis varieties of the Gangetic Plains of West Bengal. *Environ. Ecol.* 7(1): 189-192.

Sato, J. H., Celio, de, Figueiredo, C., Marchao, R. L., Madari, B. E., Celino, L. E., Busato, J. G., and de Souza, D. M. 2014. Metods of soil organic carbon determination in Brazilian Savannah soils. *Sci Agric.* 71(4):302-308.

Senthil Kumar, R., Kishor Kumar, M., Sankar, V. Karankaran, G., Tripathi, P. C., Sethvil, and Ravishankar. 2015. Performance of litchi cultivars under high altitude and high rainfall areas of Western Ghats. In: Senthil Kumar, R., Sankar, V, and Karankaran, G. (eds.), Souvenir: Awareness programme on off-season litchi cultivation in South India (December 10, 2015). pp. 20-21.

Sharma, S.B. and Roy, P. K. 1987. Flowering and fruiting behaviour of some litchi Cultivars. *Harayana J. Hortic. Sci.* 16:168-174.

Sharma, V. K., Srivastava, A. K. and Chohan, J. S. 1972. A new host record for parasitic alga *Cephaleurous virescens* Kunze. *Sci. and Culture.* 38(i):39-40.

Shreshtha, G. K. 1981. Effect of Ethephon on fruit cracking of lychee (*Litchi chinensis* Sonn.). *Hortic. Sci.* 16: 498p.

Shukla. R. K. and Bajpai. P. N. 1974. Studies on vegetative growth in litchi (*Litchi chinensis* Sonn.). *Indian J. Hortic.* 31: 148-153.

Siddiqui, A. B. S. B. M. 2002. Lychee production in Bangladesh. In: Papademetriou, M.K. and Dent, F.J. (eds.), *Lychee Production in the Asia-Pacific Region.*

Food and Agricultural Organization of the United Nations, Bangkok, Thailand, 28- 40.

Singh, A. and Abidi, A.B., 1986. Level of carbohydrate fractions and ascorbic acid during ripening and storage of litchi (Litchi chinensis Sonn.) cultivars. *Indian J. Agric. Chem.*, 19:197-202

Singh, A. and Nath, V. 2015. Variability in fruit physico-chemical characteristics of litchi (*Litchi chinensis*) in Tripura and Asom. *Indian. J. Agric. Sci.* 85 (2): 261- 265.

Singh, A. K., Ranju Kumari, and Ray, P. K. 2010. Evaluation of litchi varieties grown in Bihar for fruit quality and yield. *Environ. And Ecol.* 28(1): 216-219.

Singh, A., Mishra, D. S., Kumar, R. and Kumar, P. 2013. Physico-chemical changes in litchi cultivar Rose Scented during fruit development and maturation. *Indian J. Hortic.* 70 (3): 328-332.

Singh, G., Nath, V., Pandey, S. D., Ray, P. K. and Singh, H. S. 2012. *The Litchi* Food and agriculture Organization of the United Nations, New Delhi, 214p.

Singh, H. P. and Babita, S. 2002. Lychee production in India. In: Papademetriou, M. K. and Dent, F. J. (eds) *Lychee Production in the Asia- Pacific Region.* Food and Agricultural Organization of the United Nations, Bangkok, Thailand, 55- 67 p.

Singh, K., Chowdhary, B. M., Shankar, R. and Jain, B. P. 1999. Studies on the physiological changes in litchi fruits during growth and development under Ranchi condition. *Prog. Horic.* 31: 151- 155.

Singh, L. B. and Singh, U. P. 1954. *The Litchi.* Lucknow Superintendent of Printing and Stationary, Uttar Pradesh, India, 87 p.

Singh, P. and Singh, I. S. 1995. Physico-chemical changes during fruit development in litchi (*Litchi chinensis* Sonn.). *Mysore J. Agric. Sci.* 29: 252- 255.

Singh, R. and Chopra, S.K. 1998. Flower visitors of litchi (*Litchi chinensis* Sonn.) and their role in pollination and fruit production. *Pest Manag. and Econ. Zool.* 6:1- 5.

Singh, R. D. 1977. Morphological changes during development of litchi fruits (*Litchi chinensis* Sonn.) cultivar. 'Early Large Red' Agriculture and *Agro-Indian. J.* 10:31-33.

Sneath, P. H. and Sokal, R. R. 1973. *Numerical Taxonomy.* Freeman, San Francisco, 573p.

Sotto, R.C. 2002. Lychee production in the Philippines. In: Papademetriou, M.K. and Dent, F.J. (eds.), *Lychee Production in the Asia- Pacific Region.* Food and Agricultural Organization of the United Nations, Bangkok, Thailand, pp. 94–105.

Stern, R. A. and Gazit, S. 1996. Lychee pollination by the honey bee. *J. Am. Soc. Hortic. Sci.* 121: 152–157.

Stern, R. A. and Gazit, S. 1998. Pollen viability in lychee. *J. Am. Soc. Hortic. Sci.* 123:41–46.

Stern, R. A. and Gazit, S. 2003. The reproductive biology of the lychee. *Hortic. Rev.* 28: 393–453.

Sukhvibul, N., Dasananda, M. and Vorapitiruangsri, S. 2014. Growth, Flowering and Fruit Development of Lowland Litchi Cultivars. In: Chomchalow, N. *et al.* (eds.), *Proc. Int. Symp. on Tropical and Subtropical Fruits. Acta Hortic.*163-170.

Swarts, D.H. and Anderson, T., 1980. Chemical control of mould growth on litchis during storage and sea shipment. *Subtropica,* 1(10):13-15.

Syamal, M. M., Mishra, K. A., Singh, K. P. and B. K. Singh. 1983. Physio- chemical composition of litchi varieties of Bihar. *Indian Food Packer.* 37(4): 80.

Tandon, R. N., Singh, B. and Grewal J. S. 1952. Leaf spot disease of litchi (*Nephelium litchi* Comb.) *Proc. National Acad. Sci. India.* Section B, 21:21-28.

Tindall, H.D. 1994. Sapindaceous fruits: Botany and Horticulture. *Hortic. Rev.* 16: 143-196.

Tongdee, S. C., Scott, K.J. and McGlasson, W.B. 1982. Packaging and storage of litchi fruit. CSIRO *Food Res. Qual.* 42: 25-28.

Tripathy, P. C., Karunakaran, G., Sankar, V and Senthilkumsr R. 2015. Scope and off-season litchi cultivation in Western Ghats. Sovenir: In: Senthil Kumar, R., Sankar, V, and Karankaran, G. (eds.), *Souvenir:* Awareness programme on off-season litchi cultivation in South India (December 10, 2015). pp. 16-20.

Ullah, M. A., Mannan, M. A. and Islam, M. S. 2001. Studies on growth, flowering, yield potential and fruit characteristics of fifteen litchi cultivars. *Bangladesh J. Training and Development.* 14(1/2): 49-56.

Underhill S. J. R. and Critchley, C. 1995. Cellular localisation of polyphenol oxidase and peroxidase activity in *Litchi chinensis* Sonn. pericarp. *Aust. J. Plant Physiol.* 22: 627-632.

Underhill, S. J. R. and Critchley, C. 1992. The physiology and anatomy changes of lychee (*Litchi chinensis* Sonn) pericarp during fruit development. *Aust. J. Exp. Agri.* 34: 115-122

Underhill, S.J.R. and Wong, L.S. 1990. A maturity standard for lychee (*Litchi chinensis* Sonn). *Acta Hortic.* 16:245-251.

Vyas, N. D. 1938. *The litchi.* U. P Department of Agiculture Bulletin, 12:1-10.

Wada, K. and Shinozaki, Y. 1985. Flowering response in relation to C and N contents of Pharbisnil plant cultured in nitrogen-poor media. *Plant Cell Physiol.* 26:525-535.

Wang, H. C., Huang, H. B., Huang, X. M. and Hu, Z. Q. 2006. Sugar and acid compositions in the arils of *Litchi chinensis* Sonn.: cultivar differences and evidence for the absence of succinic acid. *J. Hort. Sci. Biotech.* 81:57-62.

Waseem, K., A. Ghafoor and S. U. Rahman .2002. Effect of Fruit Orientation on the Quality of Litchi (*Litchi chinenesis* Sonn) under the Agro-Climatic Conditions of Dera Ismail Khan– Pakistan, *Int. J. Agric. & Biol.* 4: 503-505.

Wei, Z. Zhangb, H. N., Lia, W. C., Xiea, J. H., Wanga, Y. C., Liua, L. Q., Shia, S. Y. 2013. Phenological growth stages of lychee (*Litchi chinensis* Sonn.) using the extended BBCH-scale. *Sci. Hortic.*161: 273-277.

Wong, D. X. 1999. Introduction of several promising litchi varieties. *China Fruits,* 4: 55

Wu, J, Zhanga C., Chena, J., Caia, C., Wang, L., Fua,,D. and Oua, L. 2016. Morphological diversity within litchi (*Litchi chinensis* Sonn.) based on leaf and branch traits. *Sci. Hortic.* 207:21-27.

Wu, S.X. 1998. *Encyclopedia of China Fruits: Litchi.* China Forestry Press, Beijing, China, 221 p.

Yang, H. F., Kim, H. J., Chen, H. B. M. D., and Rahman Jillur. 2014. Carbohydrate accumulated and flowering-related gene expression levels at different developmental stages of terminal shoots in *Litchi chinensis*. *Hortic. Sci.* 49(11): 1381-1391.

Yanping, Q., Zhanwei, Z., Biqing, W., Peiyuan, Y. and Xu, X. 2014. Nutritional Component Fluctuation in Leaves and Fruits of Litchi (*Litchi Chinensis* Sonn. Cv. Nuomici) During the Period of Fruit Development and Its Relation with Fruit-drop. In: Cronge R. (Ed.), *Proceedings of Fourth Int. Symposium on Lychee, Longan and Other Sapindaceae Fruits. Acta Hort.* 1029p.

Young, T.W. 1970. Some climatic effects on flowering and fruiting of Brewster lychee in Florida. *Proc. Ann. Meeting Florida State, Hort. Soc.* 83:362-367.

Young, T.W. and Harkness, R. W. 1961. Flowering and fruiting behaviour of 'Brewster' Lychees in Florida. *Proc. Florida State Hortic. Soc.* 74: 358-63.

Yuan, P. and Zhu, L. 2001. Preliminary report on trails of four high quality late litchi varieties. *South China Fruits.* 30: 22

Zhang, Z. W. 1997. China, the native home of litchi. In: Zhang, Z. W., Yuan, P. Y., Wang, B. Q., Qiu, Y. P. and Li, J. S. (eds) *Litchi: Pictorial Narration of Cultivation.* Pomology Research Institute, Guangdong, *Acad. Agric. Sci.* China, 12–17.

APPENDICES

APPENDIX - I

Score card for sensory evaluation of litchi collections

Name of the judge:

Characteristics	Score						
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7
Appearance							
Colour							
Flavour							
Taste							
Overall acceptability							

Date:

9 point Hedonic scale

Like extremely	9
Like very much	8
Like moderately	7
Like slightly	6
Neither like nor dislike	5
Dislike slightly	4
Dislike moderately	3
Dislike very much	2
Dislike extremely	1

Signature:

APPENDIX - II

Weather parameters of Wayanad district for the period 2014 October to 2016 April

Month	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity (%)	Rainfall (mm)	Evapotranspiration (mm)	Wind speed (km/h)	Sun shine hours	Light intensity (lux)
2014								
October	27.5	18.57	81.59	92	-	-	-	
November	27.15	16.79	76.65	50	-	-	-	
December	27.47	16.6	81.32	15	-	-	-	
2015								
January	27.34	16.1	83.31	0.4	3.02	1.90	7.15	57416
February	27.65	16.23	78.23	0.00	4.53	2.89	7.56	58857
March	27.5	17.1	79.21	2.2	4.28	2.44	6.10	72021
April	31.00	19.38	77.67	187.2	2.84	1.82	6.56	75784
May	29.81	19.24	78.54	175.0	3.78	2.08	5.52	63547
June	24.08	18.17	83.61	490.0	3.50	2.54	3.27	35478
July	23.81	18.57	80.14	180.0	3.63	2.31	3.42	36478
August	25.50	18.44	81.28	128.4	1.74	3.54	5.20	48575
September	26.03	17.61	79.32	176.0	2.15	3.42	6.10	58476
October	26.60	18.12	79.26	122.2	2.50	5.27	6.24	59578
November	26.86	18.14	81.12	106.0	2.70	3.21	5.21	52475
December	26.40	18.20	80.43	59.8	3.01	5.15	4.60	45488
2016								
January	26.56	18.31	80.13	0.00	3.50	2.93	6.85	57548
February	27.43	18.23	79.13	0.00	4.00	2.95	7.18	68547
March	28.21	18.30	77.71	0.00	4.40	11.4	6.83	63245
April	28.81	18.13	78.12	0.00	4.50	2.5	5.18	78545

APPENDIX - III

Soil temperature of Wayanad for the year 2015

Months	Minimum soil temperature			Maximum soil temperature		
	5 cm	10 cm	20 cm	5 cm	10 cm	20 cm
January	19.42	20.92	22	35.17	29.5	27.75
February	20.95	22.26	23.32	41.95	35.89	29.79
March	22.95	24.12	25.02	40.45	35.67	28.72
April	22.68	23.52	24.43	34.77	31.12	28.46
May	22.26	23.05	23.91	32.42	30.52	27.4
June	18.2	19.2	19.8	23.6	22.12	24.5
July	21.75	22.23	23.71	28.17	27.09	27.4
August	21.94	23.03	24.32	31.34	28.76	28.51
September	21.2	22.31	22.8	27.5	28.7	29.31
October	20.52	21.45	21.98	26.54	29.82	31.2
November	20.93	21.74	22.53	28.28	26.96	26.03
December	19.66	21.02	21.4	30.68	27.45	27.19

APPENDIX - IV

Daily Rainfall data from May 2015 to December

May	RF	June	RF	July	RF	Aug	RF	Sept	RF	Oct	RF	Nov	RF	Dec	RF
01	000.6	01	000.6	01	000.0	01	000.0	01	001.0	01	009.8	01	000.0	01	000.0
02	000.0	02	000.0	02	000.0	02	000.0	02	000.0	02	000.4	02	037.6	02	000.0
03	023.6	03	018.4	03	008.6	03	000.0	03	000.0	03	000.2	03	000.0	03	012.4
04	000.0	04	016.0	04	000.4	04	013.2	04	001.0	04	000.8	04	001.6	04	000.0
05	004.4	05	012.4	05	001.2	05	000.0	05	005.8	05	006.6	05	014.4	05	000.0
06	007.8	06	003.6	06	000.0	06	003.2	06	005.2	06	014.0	06	009.0	06	000.0
07	010.2	07	000.0	07	000.0	07	004.6	07	013.4	07	007.2	07	000.2	07	000.0
08	006.4	08	001.6	08	005.4	08	003.2	08	046.8	08	008.0	08	002.0	08	000.0
09	009.0	09	005.2	09	003.4	09	001.4	09	002.6	09	004.6	09	000.0	09	000.0
10	004.8	10	004.2	10	011.4	10	001.6	10	001.8	10	006.0	10	005.4	10	000.0
11	007.0	11	000.0	11	009.2	11	016.6	11	002.6	11	001.6	11	001.4	11	000.0
12	003.0	12	000.0	12	007.0	12	010.4	12	000.0	12	000.0	12	002.2	12	000.0
13	023.6	13	005.2	13	004.0	13	012.4	13	000.0	13	003.6	13	010.2	13	002.0
14	005.2	14	012.4	14	000.0	14	013.2	14	000.0	14	002.2	14	000.0	14	000.0
15	005.0	15	000.0	15	006.0	15	006.2	15	000.0	15	000.0	15	000.0	15	041.8
16	015.6	16	005.2	16	002.6	16	000.0	16	004.0	16	000.0	16	002.2	16	003.6

Cont... **Daily Rainfall data from May 2015 to December**

17	011.2	17	024.6	17	009.2	17	003.2	17	002.2	17	000.0	17	000.0	17	000.0
18	027.8	18	005.4	18	016.8	18	011.2	18	000.0	18	000.0	18	000.0	18	000.0
19	000.4	19	011.5	19	038.6	19	014.0	19	000.8	19	000.0	19	006.4	19	000.0
20	001.6	20	033.9	20	008.0	20	001.6	20	000.0	20	000.0	20	005.0	20	000.0
21	000.0	21	021.2	21	004.0	21	001.0	21	000.8	21	003.4	21	000.0	21	000.0
22	000.0	22	037.6	22	002.2	22	006.0	22	000.0	22	000.0	22	000.0	22	000.0
23	000.0	23	045.0	23	019.8	23	001.4	23	000.0	23	000.0	23	000.6	23	000.0
24	000.0	24	062.6	24	010.8	24	000.0	24	000.0	24	000.0	24	000.0	24	000.0
25	001.0	25	040.2	25	000.4	25	000.8	25	005.4	25	000.0	25	001.2	25	000.0
26	000.0	26	063.0	26	004.6	26	000.0	26	000.0	26	000.0	26	000.0	26	000.0
27	000.0	27	047.4	27	001.0	27	000.0	27	001.0	27	000.0	27	000.0	27	000.0
28	000.0	28	001.4	28	003.4	28	003.2	28	056.6	28	014.2	28	006.6	28	000.0
29	000.0	29	001.8	29	001.0	29	000.0	29	008.0	29	035.2	29	000.0	29	000.0
30	006.8	30	009.6	30	000.6	30	000.0	30	017.0	30	000.2	30	000.0	30	000.0
31	000.0	31		31	000.4	31	000.0	31		31	004.2	31		31	000.0
Total	**175.0**	Total	**490.0**	Total	**180.0**	Total	**128.4**	Total	**176.0**	Total	**122.2**	Total	**106.0**	Total	**001.9**

APPENDIX - V

Threshold values fixed for fruit attributes

Quality attributes	Values/score	Expression
Bearing intensity	<15 fruits/m^2	Poor
	15-25 fruits/m^2	Medium
	>25 fruits/m^2	Heavy
Skin thickness	<1 mm	Thin
	1-2 mm	Medium
	>2mm	Thick
Fruit attractiveness	9-10	Excellent
	7-9	Good
	<7	Intermediate
Aril thickness	<6 mm	Thin
	6-7 mm	Medium
	>7 mm	Thick

ABSTRACT

MORPHO-PHYSIOLOGICAL CHARACTERIZATION OF LITCHI (*Litchi chinensis* Sonn.) IN WAYANAD

By

SANJAY D. CHAVARADAR

2014-12-131

ABSTRACT

Submitted in partial fulfilment of the requirement for the degree of

Master of Science in Horticulture

Faculty of Agriculture

Kerala Agricultural University, Thrissur

DEPARTMENT OF POMOLOGY AND FLORICULTURE

COLLEGE OF HORTICULTURE

VELLANIKKARA, THRISSUR-680 656

KERALA, INDIA

2016

ABSTRACT

Litchi (*Litchi chinensis* Sonn.) is an important subtropical fruit crop of family Sapindaceae. Unlike in Northern India, it is grown as an off season crop in southern parts of the country due to which there is ample scope for commercialisation. Assessment of existing variability is a pre-requisite for taking up successful crop improvement programmes in the future. Thus, the present investigation entitled "Morpho-physiological characterization of litchi (*Litchi chinensis* Sonn.) in Wayanad" was taken up with the main objective of studying the flowering and fruit set pattern in litchi and the related morpho-physiological parameters under Wayanad situations of Kerala.

A total of 32 collections maintained at farmers' fields as well as RARS, Ambalavayal in Wayanad were evaluated. All the characters studied were found to be widely variable. Variation in tree characters include age (5-79 years), height (3 to 19 m), trunk girth (28 to 540 cm), crown shape (semi-circular, oblong, spherical, broadly pyramidal, and irregular), branching pattern (erect, opposite, verticillate, horizontal, and irregular), leaf blade shape (elliptic and lanceolate), leaf length (12 to 16.80 cm) and breadth (1.8 to 5.2 cm), young leaf colour (pinkish green, greenish yellow and light green), matured leaf colour (green, light green and dark green), shoot length (15 cm - 26 cm) and internodal length (2.8 cm – 5.2 cm). Principal component analysis (PCA) performed on the basis of tree characters revealed that the first two principal components (PCs) accounted for 77.3 per cent of the total variation with contributing characters such as tree age, height, trunk girth, leaf length, shoot length and internodal length. The clustering of the collections based on the PCA plot resulted in the formation of 9 clusters.

Regarding flowering, only 26 collections flowered and flowering lasted for 12-35 days. Seventy five percent of the collections flowered in August to September whereas, 7.14 percent flowered in February to March. Flowering both in August to September and February to March was seen in 17.85 per cent of the collections. Days taken from flowering to fruit maturity ranged from 71 (Coll. 4) to 94 days (Coll. 30) while days from fruit set to maturity varied from 58 (Coll.10) to 75 days (Coll.2).

PCA of phenological and inflorescence characters revealed that the first two PCs explained 86.4 per cent of total variation. Clustering of collections based on the above PCA resulted in formation of 5 clusters.

The fruit varied in length, width and weight as 2.8 to 3.8 cm, 2.1 to 3.2 cm and 16.9 to 25.8 g, respectively. Majority of the collections had medium skinned fruits (80 %) and matured fruits were pinkish red to greenish yellow in colour. Aril weight ranged from 12.1 to 17.1 g, where 50 per cent of collections had medium, while, 25 per cent of each collections had thin and thick arils with seed weight (100 seeds) ranging from 210 to 297 g. The collections evaluated consisted of regular bearers (55 %) and alternate bearers (45 %) and the yield was recorded as ranging from one to 30 kg/plant. The fruits could be stored for 3 to 4 days. The first two components explained 71.9 per cent of variation. Clustering based on first two PCs grouped the collections into 7 distinct clusters.

Physiological parameters, *viz.*, chlorophyll (1.07 to 1.87 mg/g), cell sap pH (5.12 to 5.96), total carbohydrates (3.79 to 13.48 %) and C/N ratio (3.83 to 8.44) were recorded. The results of PCA read 75.6 percent of the total variation by the first two PCs. Clustering of physiological parameters based on first two PCs resulted in 8 clusters.

Quality parameters *viz.*, total sugar (10.18 to 15.50 %), TSS (15.10 to 19.6 ^{0}B), acidity (0.38 to 1.18 %) and the TSS/acidity ratio (12.8 to 51.58) were recorded. The first three main PCs explained a total cumulative variance of 95.5 per cent. Based on the first two PCs, 7 clusters were formed. In the sensory evaluation based on nine point hedonic scale, Coll. 2 was found to be promising because of its flavour and taste.

In the present investigation, Coll. 2, Coll. 10 and Coll. 13 were identified as superior types based on fruit size, weight, yield, quality and sensory parameters. Thus, these collections need to be evaluated to ascertain the stability under different regions which can be exploited in order to secure premium price for the crop. Further, studies are required to standardize the management practices including the eco physiological aspects of litchi for Kerala and promoting cultivation of this crop.