MORPHO-MOLECULAR CHARACTERIZATION OF JACKFRUIT (*Artocarpus heterophyllus* Lam.) ACCESSIONS

by

ASWINI A.

(2013-12-104)

THESIS

Submitted in partial fulfilment of the
requirements for the degree of

MASTER OF SCIENCE IN HORTICULTURE

Faculty of Agriculture
Kerala Agricultural University

DEPARTMENT OF POMOLOGY AND FLORICULTURE
COLLEGE OF HORTICULTURE
VELLANIKKARA, THRISSUR – 680 656
KERALA, INDIA

2015

DECLARATION

I, hereby declare that the thesis entitled **"Morpho-molecular characterization of jackfruit (*Artocarpus heterophyllus* Lam.) accessions"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

Vellanikkara, **Aswini A.**

(2013-12-104)

CERTIFICATE

Certified that the thesis entitled **"Morpho-molecular characterization of jackfruit (*Artocarpus heterophyllus* Lam.) accessions"** is a record of research work done independently by **Ms. Aswini A. (2013-12-104)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, associateship or fellowship to her.

Vellanikkara

Dr. K. Lila Mathew

(Chairman, Advisory Committee)
Professor (Horticulture)
Department of Pomology and Floriculture
College of Horticulture
Vellanikkara

CERTIFICATE

We, the undersigned members of the advisory committee of **Ms. Aswini A. (2012-11-144)** a candidate for the degree of **Master of Science in Horticulture**, with major field in Horticulture, agree that the thesis entitled **"Morpho-molecular characterization of jackfruit (*Artocarpus heterophyllus* Lam.) accessions"** may be submitted by Ms. Aswini A. (2013-12-104), in partial fulfilment of the requirement for the degree.

Dr. K. Lila Mathew
(Chairman, Advisory Committee)
Professor
Department of Pomology and Floriculture
College of Horticulture Vellanikkara

Dr. T. Radha
(Member, Advisory Committee)
Professor and Head
Department of Pomology and Floriculture
College of Horticulture, Vellanikkara

Dr. A. K. Babylatha
(Member, Advisory Committee)
Professor
Pineapple Research Centre
Vellanikkara

Dr. P. S. Abida
(Member, Advisory Committee)
Associate Professor
Centre for Plant Biotechnology and Molecular Biology
College of Horticulture, Vellanikkara

EXTERNAL EXAMINER

ACKNOWLEDGEMENTS

It is with great respect and devotion, I place on record my deep sense of gratitude and indebtedness to my chairperson ***Dr. K. Lila Mathew****, Professor (Horticulture), for her sustained and valuable guidance, constructive suggestions, unfailing patience, friendly approach, constant support and encouragement during the conduct of this research work and preparation of the thesis. I gratefully remember her knowledge and wisdom which nurtured this research project in right direction without which fulfillment of this endeavor would not have been possible.*

No words can truly represent my profound gratitude and indebtedness to ***Dr.T. Radha****, Professor and Head, Department of Pomology and Floriculture member of my Advisory Committee for her unstinted support and guidance in the conduct of field experiments, constructive criticism, valuable suggestions and critical scrutiny of the manuscript.*

I am deeply indebted to ***Dr. P. S. Abida,*** *Associate Professor CPBMB and member of my Advisory Committee for her unbounded support, critical and valuable suggestions.*

I am deeply obliged to ***Dr. A. K. Babylatha,*** *Professor, Pineapple Research Centre, Vellanikkara and member of my Advisory Committee for the generous and timely help she has always accorded to me during the course of this study.*

I am extremely delighted to place on record my profound sense of gratitude to ***Dr. S. Krishnan****, Professor, Department of Agricultural Statistics, for his support, critical comments and valuable advice during the preparation of this manuscript.*

I consider it as a privilege to express my sincere thanks to ***Dr. Rajeena*** *Professor and Head, KVK, Sadanandapuram for her support and help during thesis work.*

My sincere thanks to Department of Pomology and floriculture for the valuable help and advice rendered during the course of my study.

I am thankful to ***Dr. Sheela*** *Professor and head, Department of Processing technology for sincere help during chemical analysis.*

I wish to express my sincere gratitude to Miss Jeeshma, Farm officer, COH Vellanikkara and all labourers at COH vellanikkara.

Words fall short as I place on record my indebtedness to my seniors, classmates, juniors and friends for their prompt help and cooperation for the entire period of study.

Special thanks to Mr. Aravind, students computer club, COH, for rendering necessary help whenever needed.

Words can't express my soulful gratitude to my parents, Aswin and Amritha for their selfless sacrifice, boundless patience and unflagging interest throughout the period of my course.

Finally I bow my head before ***THE ALMIGHTY*** *whose blessings enabled me to undertake this venture successfully.*

Place: Vellanikkara **Aswini A.**

Date: 4/08/2015

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Dedicated to my parents and grandparents

Introduction

1. INTRODUCTION

Jackfruit (*Artocarpus heterophyllus* L.) bearing world's largest fruit belongs to the family Moraceae. It is indigenous to the rainforests of Western Ghats of India (Rowe-Dutton, 1985). India is the largest producer of jackfruit in the World (Haq, 2006; APAARI, 2012). It is grown in states like Kerala, Karnataka, Tamil Nadu, Andhra Pradesh, Maharashtra, Assam etc. It is also cultivated in Thailand, Malaysia, Indonesia, Philippines, Cambodia, Vietnam and African countries. In some African countries, jackfruit is regarded as staple food and known as poor man's fruit.

Jackfruit is an invariable component of the homesteads of Kerala and also grown as a shade tree in coffee plantations. The estimated area of this fruit crop in Kerala is 89702 ha and the production is about 28 lakh tonnes. Jack tree flowers during October to February and majority of the female and male inflorescence (catkins) appears on the main trunk and primary branches. The fruit takes about 120 - 140 days for complete development. There are two types of jackfruit *i.e.* soft and firm flesh types according to the texture of the flakes. The fruit consist of four parts *viz.,* (a) bulb (37 - 40 per cent) derived from the fleshy perianth constitutes the edible portion (b) perigones (18 - 20 per cent) the unfertilized (or) aborted flowers (c) rind (20 - 22 per cent) and (d) seed (20 - 23 per cent).

Jack bulbs are rich source of carbohydrate (16 - 20 per cent), total soluble solids (29° brix), carotene (500 - 580 IU) and pectin (1.5 - 6.0 per cent).The bulbs are used both in unripe and ripe stages. Apart from the table purpose, the ripe bulbs can be used for making canned products, nectar, preserves, jam, jelly, squash, fruit bar and candy. Mature unripe green jack bulbs (100 - 120 days old) are used for making pickles, chips and *papad*. In Kerala, tender fruits of about 60 days old are commonly used as vegetable. Seeds are rich source of starch and also forms popular ingredient in many culinary preparations. It can be relished when boiled or roasted. Tree has got good timber values as it is rarely attacked by white ants. It had been reported that jack fruit could be very useful in the treatment of the AIDS. An extract of jack fruit called 'Jacaline' was seen to have inhibited the

growth of HIV infection *in vitro*. Jacaline is inactive on lymphocytes which are already infected but has proved its might by protecting the healthy ones. Hot water extract of leaves improve the glucose tolerance level of diabetic persons. Lectine, an important class of natural protein plays a commendable role in cancer treatment since it can be used in the prediction of malignant transformation of normal to cancer cells. In Ayurveda, it has been used for curing inflammation, constipation, skin disease and wound-healing. Due to its nutritional and economical value and food security, efforts have been made to promote its cultivation. Internationally, efforts have been made to promote jackfruit as an underutilized crop especially in countries plagued by malnutrition and economic depression.

Being an indigenous and cross pollinated crop and propagated through seeds, there exists lot of variability in this tree. Several studies were conducted to explore the genetic variability in jackfruit in India and also in Kerala (Hossain, 1996; Anand, 1998; Muthulakshmi, 2003; Mathew *et al.,* 2003; Azad, 2007; Jagadeesh *et al.,* 2007; Shyamalamma *et al*., 2008; Ullal and Haque, 2008 and Krishnan *et al*., 2015).

Variability studies were conducted in jackfruit in Kerala Agricultural University and the selected accessions were maintained in college orchard, College of Horticulture and research stations. Detailed evaluation of these accessions is very much essential for identifying trait specific types. Hence the present study is taken up with the objective to characterise the selected accessions of jackfruit based on the morphological and molecular analysis to facilitate future breeding programme.

Review of literature

2. REVIEW OF LITERATURE

In this chapter, relevant literature based on the objectives of the study are reviewed and presented in the order of variability in jackfruit, growth and development, flowering, fruit characters, fruit quality, product diversification and molecular characterization.

2.1 Variability in jackfruit

Jack fruit has innumerable types (or) forms regarding the fruit characteristics. The types differ widely among themselves in bearing and density of spines on the rind, bearing, size, shape, quality, and period of maturity. There is wide variation in its sweetness, acidity, flavour and taste (Mitra, 1998).

Among 672 jackfruit trees studied, Mitra (1998) observed wide variability in yield (14 to 325 fruits/plant), fruit weight (2.1 to 10.2 kg), fruit shape (oblong, roundish and conical), skin colour (greenish, light brown, dark brown, yellow and yellow with brown), number of tubercles in skin (5 to 27/ cm^2), pulp colour (yellow whitish, reddish yellow and pinkish yellow), number of segments (34 to 380 per fruit), number of stones (32 to 362 per fruit), texture of pulp (soft , moderately soft and hard), pulp weight (361 to 3648 g) per fruit, total soluble solids (15.4 to 29.6 °Brix), total sugars (12.9 to 26.6 %) and acidity (0.10 to 0.31%).

Studies were conducted by Singh and Srivastava (2000) on genetic variability of jackfruit (*Artocarpus heterophyllus*) germplasm collected from eastern Uttar Pradesh, where jackfruit grows wild. Among the populations sampled, 18 were identified as superior clones, showing variation for fruit shape, weight, length and circumference, rind thickness, skin and pulp colour, fibre length, number of bulbs per fruit, bulb weight, length and width, cylinder percentage, total soluble solids, total sugars, acidity, total minerals, seed weight,

length, width, shape and colour, bearing habit (some bore fruit twice a year), yield (12-400 fruits/tree) and fruit maturity.

Mitra and Maity (2002) evaluated 1460 jackfruit trees in West Bengal and identified thirty-five superior clones. Wide variability in yield (15-1450 fruits/tree), fruit weight (1.22-17.30 kg), fruit shape, peel colour, flake colour, number of flakes (30-380/fruit), number of seeds (30-365/fruit), texture of flakes, flake weight, total soluble solids (9.1-28.0%), total sugar (7.6-23.6%), and fruit acidity (0.10-0.33%) were observed among the genotypes. The growth, bearing (twice a year in some types) and maturity (June-September) of fruits also showed variations among the genotypes.

Maiti *et al.,* (2003) observed that the leaf size and yield per tree varied due to high genotypic and phenotypic factors than that of low genotypic and phenotypic variance for leaf length and breadth. Yield per tree showed highest genotypic and phenotypic variance while the highest estimated heritability was noted for leaf length. A higher range of values were also reflected on coefficient of variation, which was highest for yield per tree. It was also noted that yield per tree had maximum genetic advance as percentage of mean. Among the physical characters of fruits, the highest magnitude of genotypic and phenotypic variance and genetic advance were observed for fruit weight.

Muthulaskshmi (2003) conducted study in genetic diversity and canopy management in jack fruit (*Artocarpus heterophyllus* Lam.) and reported variability in vegetative, floral, fruiting and biochemical characters. Variation was noticed with respect to tree vigour, canopy shape, tree growth habit, branching density and branching pattern. Variation was noticed with respect to fruit shape, junction of stalk attachment, fruit rind colour, shape of spines, intensity of latex exudation and flake shape. Wide variation was noticed in terms of biometric characters of fruit. There were no significant differences between soft and firm

fleshed types in terms of morphological, anatomical and biochemical characters studied.

Sharma *et al.,* (2005) observed that ten genotypes of jackfruit showed significant variation for all the characters studied. High magnitudes of genotypic and phenotypic coefficients of variation were observed for weight of bulbs without seed per fruit, weight of bulbs with seed per fruit, average fruit weight, number of bulbs per fruit, number of fruits per tree, test weight and ascorbic acid content. High heritability coupled with high genetic advance were recorded for average fruit weight, number of bulbs per fruit, weight of bulbs without seed per fruit, test weight and fruit yield per tree, indicating that these characters are highly heritable and likely to provide high selection response.

Ninety-five jackfruit types selected from Western Ghats of India, by Jagadeesh *et al.,* (2007) revealed that majority of selections (91), irrespective of their ecogeographic area, were grouped in one cluster and the remaining 4 types were solitary with one selection in each cluster. Inter cluster distance was maximum between clusters D and E (525.8) and minimum inter cluster divergence was observed between clusters B and C (106.1). Cluster means for all economically important characters were not found to be highest in any one cluster indicating the vast diversity on account of indigenous and cross- pollinated nature of the crop. The maximum relative contribution to the total divergence was by number of seeds per fruit and TSS: Acid ratio indicating the ample amount of variability in these traits and hence the selection process for crop improvement in jackfruit should deem these characters.

2.2 Growth and development of jackfruit

Fortnightly observations were made on shoot length and diameter, node number and leaf number in young and mature trees for one year. Growth continued throughout the year with distinct flushes during July to September and March to May. The main period of bud emergence was June to October, and to a lesser degree January and February (Sinha and Singh, 1971).

The leaves varied in length from 5.0 to 25.0 cm and in width from 3.5 to 12 cm. The shape varied from obovate – elliptic to elliptic (CSIR, 1992).

Bhanu *et al.,* (2006) evaluated ten clones of jackfruit at monthly intervals for changes in their physical and chemical attributes during fruit growth and development. Among them the clone NSP-1 recorded highest fruit length (38.56 cm), fruit girth (80.80 cm), bulb length (6.75 cm), bulb weight (44.30 g), TSS (8.79%), ascorbic acid (26.19 mg/100 g pulp) acidity (0.20%) and sugars (5.23%) after 150 days of fruit set. Out of the ten clones evaluated four clones *viz.,* NSP-1, GKVK-1, AF-1 and MV were identified as outstanding for quality attributes.

Wide variability in jackfruit leaves were reported by Radha and Mathew (2007). They also reported that both genetic and phenotypic elements have a role in determining various leaf characters. Irregular leaf shapes are seen in younger plants. While in aged plants, elliptic/ obtuse leaf blade shapes, obtuse leaf apex and oblique leaf base shapes were observed.

Singh *et al.,* (2010) evaluated twenty genotypes of jackfruit for differentiating cracking and non-cracking types. Based on overall performance with respect to vegetative growth, yield and quality parameters, jackfruit cracking are suggested more to be a varietal character and contains less pectin when compared with the non-cracking genotypes.

Kunhamu (2011) reported that jackfruit enjoys a prominent position in tropical agroforestry primarily on account of its multiple benefits such as food, fodder, fuelwood and timber values. Jackfruit, largest among the fruits, has high demand world over due to its nutritive value and taste. Jackfruit tree also yield durable timber with excellent strength properties. Fast growth, shade tolerance and amenability to tree management practices such as lopping, pruning, thinning etc. are some of the factors that qualifies jackfruit tree as a useful component for integration in multitier agroforestry systems such as homegardens. Furthermore, it contributes to ecosystem services such as C-sequestration, litter dynamics, nutrient cycling and micro- site enrichment.

'Red Flesh Jackfruit' is a new dry-bulb cultivar selected from natural seedlings of Thailand jackfruit (ZeHuai *et al.,* 2012). The variety has the following characteristics: early fruiting and lower fruiting location, flowering year round but mainly from March to October. The fruit development period is 110 to 135 days. Its fruit is oblong, with an average weight of 10.3 kg. The fruits have thick and less latex bulbs. The flake is orange red, crisp and with sweet aroma. The total soluble solids (TSS) content of flake is 18.87 %.

2.3 Flowering in jackfruit

The occurrence of two flowering season in jackfruit was reported by Sambamoorthy and Ramalingam (1954).

Shankar and Singh (1965) reported that the thirty-year-old trees started flowering about 1 month earlier than 10 - year-old trees. Flowers opened about 10 days later when all the leaves on the fruit stalk were removed. The ratio of male to female flowers was 4: 1 in young trees, and 2: 1 in old trees.

In the jackfruit varieties Khaja and Kanpur Local, the average time for flower development was 41 days, emergence of the flower buds occurring in late October and early November. The majority of buds opened at 06.00 h, but

anthesis occurred throughout the day until 18.00 h. Anther emergence occurred between 09.00 and 11.00 h and dehiscence was completed by 15.00-17.00 h after 3-5 days (Sinha, 1975).

Investigations on the floral characters of Varikka and Koozha types of jackfruit were conducted by Joseph and Kumaran (1996) on fourteen mature trees. There was no significant difference between Varikka and Koozha types in respect of any of the characters studied. The pattern of male and female catkin production was found to differ, the former occurred from October to February while the latter was confined to only 3 months starting from late November to February. In a male catkin, anthesis started by 06.00 h and continued up to 18.00 h in a day. This pattern continued for 5-7 days in a catkin. Anther dehiscence occurred between 18.00 h and 19.00 h on the day of its emergence. The sequence of emergence of stigma on the female catkin was highly erratic and continued for 3-4 weeks. Complete fading away of the stigma occurred in 21-35 days after anthesis started. The chief agent of pollination was found to be wind although a certain amount of insect pollination cannot be ruled out.

Ten genotypes of jackfruit, collected from various locations in Uttar Pradesh and Uttaranchal were evaluated. High heritability coupled with high genetic advance were recorded for average fruit weight, number of bulbs per fruit, weight of bulbs without seed per fruit, fruit weight and fruit yield per tree, indicating that these characters are highly heritable and likely to provide high selection response (Sharma *et al.,* 2005).

Fruit yield per tree showed significant and positive association at the phenotypic and genotypic level with average fruit, which had highly significant positive association with fruit length, weight of bulbs with seed per fruit and weight of bulbs without seed per fruit. Thus, these characters are considered as important components of fruit yield per tree in jackfruit. Path analysis revealed that number of fruits per tree and number of bulbs per fruit, followed by average

fruit weight, exhibited the most important direct effect on fruit yield per tree (Sharma *et al.,* 2006).

Das (2010) observed that, jackfruit (*Artocarpus heterophyllus*) grown in upper plains and hills of India, has unique flowering features and having the coefficient of correlation between trunk leaves and flowers is almost unity (r=0.99). Jackfruit trees, however, grown under environmental stress or having damaged trunk yields reduced number of trunk leaves and flowers. Flowering bio-molecules are synthesised in trunk and in matured stems. Only flowering leaves from trunk and from matured stems help in translocation of flowering bio-molecules and flower bearings.

Pushpakumara (2011) reported that jackfruit (*Artocarpus heterophyllus* Lam.) is a monoecious species with separate female and male inflorescences. Female inflorescence consists of 5,695±52 female flowers. Fruit of the species is a compound fruit technically called as syncarp which consist individual fruitlets. Based on morphological differences nine and six phenological stages of development of female and male inflorescences, respectively are described. Flowering and fruiting in *A. heterophyllus* is seasonal with major and minor flowering and fruiting phases. Stigma of individual flower is receptive to pollen for a period of 5 days whereas female inflorescence remains receptive for a period of 15 days. Flowering shows complete synchrony of the female flowering phase with the male phase. It is a highly outcrossing species with self-compatiblilty and facultative agamospermy.

Jackfruit exhibits wide variation in terms of vegetative, flowering, fruiting and quality characters. Based on the firmness of flesh, cultivated types are of two general groups - soft flesh and firm flesh in which many local varieties exist. The heterogenous nature of the seedling population offers tremendous potential for selection of superior types suited for commercial cultivation (Menon and Peter, 2011).

2.4 Fruit characters

Cultivated Jackfruits are broadly classified into two groups, one with firm flesh and the other with soft flesh. The soft pulp group is locally known as pazham, ghula, vela, koozha, ghila, tsjakepa, or koppa. The mature pericarp of this group comparatively smaller in size. The juice is either thin or thick; colour varies from pale yellow to dark or golden yellow. Pulp is generally mushy or soft and of varying quality ranging from sweet to insipid. The seeds are comparatively larger. The hard pulp group is locally known as varikka, varcha, kujja, korcha, or berka. The pulp is crisp and highly flavoured and therefore relished. The juice is scanty and the seeds are comparatively smaller (Singh *et al.,* 1967*).*

Srinivasan (1970) described a variety namely "Muttam Varikka" which produced fruits of average weight of 7.0. kg with 46 cm length and 23 cm width.

Hussain and Haque (1977) compared jackfruits from different. Studies showed that average fruit weight ranged from 3.24 to 7.39 kg, the weight of pulp and seed was 0.57 and 0.39 kg, respectively, in the smallest fruit and 2.70 and 1.01 kg, respectively in the largest fruit. Rind colour ranged from yellow and pale green to brown.

Bhore *et al.,* (1980) identified a highly promising jackfruit type in Ajra village of Kolhapur district of Maharastra which is high yielding and highly pulpy containing more protein, fat, mineral matter and carbohydrate than local jackfruit. The fruits are small and weighing between one and 3 kg and uniform in size and shape.

Jackfruit types like 'Varikka', 'Koozha', 'Navarikka', 'Rudrakshachakka' or 'Thamarachakka' and other wild forms have been collected from Wayanad plateau in the Western Ghats of Kerala (NBPGR, 1986). Three types of jackfruits namely 'Rasdar', 'Khajwa' and 'Sugandhi' were identified through survey in the plains of Eastern Uttar Pradesh (NBPGR, 1988).

Berry and Kalra (1988) reported that the average fruit weight varied from 3.24 to 17.39 kg.

A comparative study was carried out on yellow-bulb, light yellow bulb and orange yellow bulb types jackfruits. The light – yellow types had the highest seed weight (7.66 g), seed length (3.23cm) , seed breadth (2.10cm) and average total weight of seeds per fruit (913.21 g). The yellow types had the highest seeds per fruit (124.6) and the highest pulp to seed ratio (4.24) (Guruprasad and Thimmaraju, 1989).

Several subgroups are recognised in jackfruit depending upon the taste, shape and size of fruits. One of these is Rudrakshi, a small fruited type, with smooth and less spiny rind and a less fleshy perianth than the common jack. Certain old trees in Assam showed a tendency to produce fruits during off seasons and designated as *baro-mahia*or *baro-mosha.* Ceylon jack or Singapore jack a recent introduction in South India, is an early maturing variety and comes to bearing in about 18 months under favourable environmental condition in low elevation but may take more time at higher elevation. It generally matures in November to February. Fruit is a hard- fleshed varikka. In Assam, soft pulp group is divided into six types, namely, V_1, V_2, V_3, V_4,V_5 and V_6 and hard pulp groups into two varieties, namely, V_7 and V_8. The fruit number per tree ranged up to 500 annually and fruit weight up to 40 kg (CSIR, 1992).

From the various genotypes collected in course of surveys of jackfruit growing regions, particularly in Eastern Uttar Pradesh, from November 1989 to August 1990, Kumar and Singh (1996) grouped the genotypes into nine categories based on fruit morphology. They observed wide variation in number, shape, colour, size and rind thickness of fruits. Average fruit weight ranged from 12.0 to 20.5 per cent and ascorbic acid content varied from 23.8 to 32.9 mg 100 g^{-1}. The best genotype was considered to be AC.7, with moderate yield large fruits (more than 15 kg) and bulbs (about 20 g), small cylinders, high pulp/cylinder ratio and average fruit quality.

A survey was conducted during 1995-1996 in the lower Brahmaputra valley zone of Assam to study the fruiting behaviour, yield and physico-chemical character of local jackfruit germplasm. Significant variation was observed in yield and chemical composition of the different genotypes. Fruit yield (60 fruits/tree) and TSS (^{o} brix) values were highest in KJF 3, while the lowest acid content (6 per cent) was recorded in KJF 12 (Sharma *et al.,* 1997).

Mitra and Mani (2000) conducted a survey to identify and collected superior genotypes of jackfruit from eastern parts of India. The individual fruit weight varied between 2.10-10.22 kg. The trees showed yield potential from 16 to 325 fruits per tree per year. Some identified types (TSS >25°Brix and total sugar >20%) were found suitable to use as table fruit while others were found to bear thrice a year and were suitable to use as a vegetable. Types 5 and 15 had very high juice content, suitable for processing, and types 6, 20 and 28 were extremely drought tolerant.

The genetic variability, heritability, genetic advance, and genotypic and phenotypic variability of the physicochemical characteristics of 44 jackfruit genotypes, collected from different agroclimatic zones of West Bengal, India, were studied. The results showed that leaf size and yield per tree varied due to high genotypic and phenotypic factors than that of low genotypic and phenotypic variance for leaf length and breadth. Yield per tree showed maximum genotypic and phenotypic variance while the highest estimated value of heritability was noted for leaf length. A higher range of values were also reflected on coefficient of variation, which was highest for yield per tree. Among the physical characters of fruits, the highest magnitude of genotypic and phenotypic variance and genetic advance were observed for fruit weight (Maiti *et al.,* 2003).

Rai *et al.,* (2003) evaluated of 21 genotypes of jackfruit from Bihar, West Bengal and Uttar Pradesh, India. Genotypes varied in their tree morphological characters, bearing behaviour, fruit and flake characters, maturity period and yield potential. Based on the overall performance with respect to the bearing potential, maturity period, fruit and flake characters, genotypes HPJS-5/8 and HPJS-3/10 were promising for table purposes, while HPJS-4/5 and HPJS-2/6 were suitable for culinary purposes. These genotypes have been recommended for release by the Institute Varietal Release Committee. Genotypes HPJS-3/10, HPJS-5/8, HPJS-8/9, HPJS-9/5 and HPJS-11/9 have also been identified for pleasant aroma in the ripe flakes.

The genetic divergences among the thirty-three off-season cultivars of jackfruit were estimated by Nazrul *et al.,* (2005). The genotypes were grouped into eight clusters. The cluster IV comprised twelve genotypes followed by cluster V with six genotypes. Highest intercluster distance (260.972) was observed between the cluster I and VI and least between cluster IV and VIII (48.996). Cluster VIII had highest (50.891) intercluster value. The characters like fruit weight, fruit diameter, rind weight, seed weight and edible portion in both clusters exhibited important components of divergence. The genotypes of the cluster I and cluster VI were the best choice for improvement

Reddy *et al*., (2004) evaluated ten open pollinated fruits of jackfruit collected from elite clones of South Karnataka, India. Among the quantitative traits, highest variability was observed for the characters such as fruit weight, fruit shape, carpel number, carpel colour and carpel size. Different accessions were identified for these fruit characters. Of the qualitative characters studied, TSS recorded more variability in the clones identified and ranged from 24.8-40.5° brix. The highest TSS (40.5° brix) and lowest acidity (0.18%) were observed in Acc. No. 18 and Acc. No. 7, respectively. The reducing sugar was highest in Acc. No. 15 (8.62%).

Jagadeesh *et al.,* (2005) studied natural variability with respect to physicochemical qualities existing among the elite jackfruit selections of Shimoga district in Western Ghats of Karnataka, India. A great deal of variation was observed in terms of physicochemical qualities among fruits of 31 jackfruit trees of seedling origin. Upon consideration of the desirable physicochemical and organoleptic characters, eight promising types were identified (SMG-3, SMG-15, SMG-20, SMG-22, SMG-24, SMG-25, SMG-26 and SMG-28).

Sharma *et al*., (2006) assessed various quantitative traits in 10 genotypes of jackfruit. Fruit yield per tree showed significant and positive association at the phenotypic and genotypic level with average fruit, which had highly significant positive association with fruit length, weight of bulbs with seed per fruit and weight of bulbs without seed per fruit. Thus, these characters are considered as important components of fruit yield per tree in jackfruit. Path analysis revealed that number of fruits per tree and number of bulbs per fruit, followed by average fruit weight, exhibited the most important direct effect on fruit yield per tree.

Maiti (2010) found that genotypic and phenotypic correlation were positively significant between fruit weight of edible part (0.980 and 0.977), fruit and rind weight (0.976 and 0.971), and number of stones and flakes (0.999 and 0.999). The path coefficient analysis indicated that weight of edible part had positive direct effect on fruit weight both at genotypic (0.459) and phenotypic (0.451) levels. Hence, at the time of selection of jackfruit genotypes, one has to put emphasis on the characters like weight of edible part, rind weight, flake and stone numbers.

In jackfruit trees (*Artocarpus heterophyllus* Lam), Varikka and Koozha are the two ecotypes found in all areas which differ only in the flake texture. The crop is propagated mainly through seed and there is variability in fruit quality attributes (Prasannakumariamma and Kumaran, 2011).

There are two types of jackfruit: firm flesh type and soft flesh type and in the north India the later type is predominantly found (Alila and Sanyal, 2011).

Wangchu *et al.,* (2013) observed that the characters like weight of fresh flakes without seed, weight of fresh flakes with seed, stalk length, fruit yield per tree, rachis diameter, rachis length, fruit length, shelf life, number of flakes per kg of fruit, flake width, number of seeds per kg of fruit, vitamin C, TSS/acid ratio and sugar/acid ratio could be used as selection criteria for development of effective and productive plant types in jackfruit.

Ibrahim *et al*., (2013) studied the morphological characters, fruit characters and nutritional food value of different jackfruit cultivars. The characters recorded (%) and their values (range) were pulp (38.60-47.37%), percentage of rind (15.67-20.00%), percentage of skin (14.86-23.68%), percentage of seed (09.46-19.33%), moisture content (63.39-76.62%), TSS (18.80-27.37%), total sugar (11.84-17.01%), vitamin C content (17.82-31.55 mg/100 g) and acidity (0.037-0.075% as citric acid).

2.5 Fruit quality

Muthulaskshmi (2003) conducted study in genetic diversity in jack fruit (*Artocarpus heterophyllus* Lam.) Significant variation was noticed with respect to biochemical characters of fruit like total sugar (8.16 to 19.30%); reducing sugar (1.63 to 5.23%), non-reducing sugar (5.96 to 14.98%), total soluble solids (14.63 to 33.00 ^{o}Brix), total acidity (0.69 to 4.95%) and sugar acid ratio (2.32 to 20.81%).

Jagadeesh *et al.,* (2007) reported physio-chemical parameters of 34 jackfruit types surveyed and selected in the hilly zone of Karnataka to determine their suitability for chips. Flake thickness, bulb length, TSS, total sugars and reducing sugars exhibited a considerable amount of variation. Those jackfruit

selections found organoleptically superior in the present study for chips making (SRS-26, SRS-3, UKY-5 and SRS-4) had a range for reducing sugars from 0.87 (SRS-26) to 2.17% (SRS-4). Starch content and dry matter determined the yield of processed products. Although, these parameters expressed a lower level of variation among the selections, the high chips yielding selection SRS-3 (56.00%) was associated with highest dry matter content (27.50%). It also had higher scores for overall acceptability along with other accessions, *i.e.* SRS-26 and SRS-4 in terms of organolyptic evaluation.

Jagadeesha *et al.,* (2010) reported that significant variation in physical characters of fruit was observed among the 30 jackfruit selections surveyed and studied in this zone. A high coefficient of variation for cylinder mass (74.00%), fruit mass (62.84%), rind mass (56.39%); for bulb parameters such as flake mass (74.79%), bulb mass (71.17%) and single bulb mass (50.11%); and seed number (65.82%) and seed mass (75.25%) in seed related traits. The results are useful to select Jackfruit clones for crop improvement.

2.6 Product diversification

Kabir *et al.,* (2008) reported that hot- pickle from green jackfruit and sweet- pickle from ripe jackfruit can be prepared and ripe jackfruit bulb can also be preserved for future use which is encourageous for us in the establishment of cottage industries efforts of which are as yet quite inadequate.

Valavi *et al.,* (2011) reported that the canned products have an exotic flavour and are quite likeable. There is scope for developing canning of the fruit on a commercial scale. The outer rind is rich in pectin and can be used for preparing pectin. A good jelly can also be prepared out of the peel. Jackfruit is a seasonal tropical fruit, consumed and preserved in various forms. Drying of the fruit bulbs to make fruit leathers is a convenient method of marketing the fruit as confectionery and yields a product that is stable for more than two months at room

temperature. Jackfruit seed is of high nutritive value can be used as a vegetable or ground into flour which is rich in starch content. Ground as a flour, jackfruit seeds can be stored for a long time and can be used as an alternative to the present cereal-based food products.

Sensory evaluation of the product chapathies developed from seed flour indicates that chapathies made out of 50 per cent seed flour and 50 per cent wheat flour (w/w) were quite acceptable for human consumption. Where as chapathies prepared from higher per cent of seed flour and less of wheat flour (75%: 25%) were found to be poor in texture, flavour, colour and consistency and were notprefered for consumption. Sensory evaluation of macula vada prepared from fresh jackfruit seeds were found to be very good with respect to taste, flavour, texture and colour indicating its acceptability for human consumption (Munishamanna *et al.,* 2010).

Studies were conducted to process the jackfruit bulbs into powder and develop some value- added products, *i.e.* biscuits, muffins (cupcake) and pakoda, from the bulb flour. Mature and healthy semi-ripe or ripe jackfruit bulbs were used for flour processing. The flour was then subjected to biochemical analysis (moisture, protein, fat, fibre and ash). Results showed that the jackfruit bulb flour contained 5.2% moisture, 1.05% protein, 0.2% fat, 3.67% ash and 1.8 mg fibre. Furthermore, value added products, such as biscuits, muffins (cupcake) and pakoda have been developed from jackfruit bulb flour (Munishamanna *et al.,* 2012).

Seeds of jackfruit are abundant and contain high amounts of starch. They are discarded during the fruit processing or consumption and can be an alternative source of starch. The starch was extracted from the jackfruit seeds and characterised to chemical, morphological and functional properties. Soft and hard jackfruit seeds showed starch content of 92.8% and 94.5%, respectively. The

results suggest that the Brazilian jackfruit seed starch could be used in food products (Madruga *et al.,* 2014).

2.7 Molecular characterization

Twenty-six jackfruit accessions, one interspecific hybrid, champedak, and one breadfruit accession were analyzed using amplified fragment length polymorphic (AFLP) markers to determine the degree of genetic diversity within the Fairchild Tropical Garden (FTG) germplasm collection. Cluster analysis and principal component analysis (PCA) grouped all of the jackfruit accessions with south-east Asian origins into one major cluster with little support for groupings within the cluster. The Indian accessions were grouped in a different cluster, as did the hybrid and the breadfruit accession. The AFLP marker based analysis indicates that limited genetic diversity exists within this collection. These observations are in agreement with the phenotypic evaluation and suggest that new accessions be obtained from the center of origin for the species (Schnell *et al.,* 2001).

ChunHai *et al.,* (2009) conducted genetic diversity studies in 76 accessions of jackfruit (*Artocarpus heterophyllus* Lam.). Among 477 bands produced by 24 ISSR primers, 427 were polymorphic (accounted for 89.52%). The average PIC (polymorphism information content) was 0.23. These 76 jackfruit accessions could be discriminated by the 24 ISSR primers. Genetic distance analysis revealed that, low genetic diversity existed in the jackfruit germplasm studied, and the genetic similarity coefficient ranged from 0.626 to 0.945, with an average of 0.775. Cluster analysis showed that 4 groups could be clustered at a genetic distance coefficient of 0.752. The results indicated that, 2 accessions from Tropical Plant Garden, WJ2 and GSYWJ1, were genetically different from other accessions. Accessions of soft flesh type and firm flesh type could not be discriminated. Accessions collected from different sources could form independent clusters, while accessions collected from different areas of Leizhou Peninsula could not form independent clusters.

The genetic diversity and genetic relatedness of 50 jackfruit accessions were studied using amplified fragment length polymorphism markers. Cluster analysis and principal component analysis grouped all jackfruit genotypes into three major clusters. Cluster I included the genotypes grown in a jackfruit region of Karnataka, called Tamaka, with very dry conditions; cluster II contained the genotypes collected (Shyamalamma *et al.,* 2008)

The morphological characterization when collated with DNA profiles of eighteen accessions of jackfruit showed that Tenvarike, which is a divergent accession, had desirable fruit characters like low latex exudation and low flake fiber content. Thus molecular marker data together with morphological parameters could be effectively utilized for identifying trait specific germplasm to establish working collections in crop improvement programmes (Sane *et al.,* 2009).

Ying-zhi *et al.,* (2010) genetic diversity of 50 jackfruit accessions from three provinces in China were analyzed based on amplified fragment length polymorphic (AFLP) markers. A total of 320 unambiguous bands were produced by eight primer combinations, and 65 (20.3%) of them were polymorphic. Genetic similarity coefficients ranged from 0 to 0.9841, with an average of 0.5000, indicating a moderate genetic diversity in this collection. The dendrogram derived by unweighted pair group method with arithmetic mean algorithm (UPGMA) analysis revealed five groups, and no correlation between genetic relationship and geographical origin were found. Accessions of soft and firm flesh type were not clustered into distinct groups; neither could yearly bearing once, or twice fruit accessions.

High quality of DNA isolated in five varieties of jackfruit *viz.,* TCJ4, TCJ2, FH10, FH4, and NC2. Amplification of jackfruit DNA for RAPD analysis using OPC7-GTCCGACGACGA was analyzed. The PCR reaction mixture was found optimum to produce intense and reproducible banding patterns in jackfruit.

The dendrogram based on Euclidean distance was constructed using the computer package 'STATISTICA'. This dendrogram indicated a moderate diversity among the five jack fruit varieties. Three major clusters were identified, one cluster with 2 varieties. The individuals in a cluster share common phylogenetic characteristics (Gopalsamy *et al.,* 2012).

Krishnan *et al.,* (2015) conducted a survey in Kuttanad region to find out promising jack types during 2010-12 and selected six superior trees based on physico-chemical characters and organoleptic properties. This study was undertaken to realize the genetic relationship among these jackfruit selections during 2012-2014, using RAPD technique. Out of the thirty RAPD primers used for the analysis only ten produced maximum reproducible polymorphic bands (OPA-1, OPA-2, OPA-4, OPA9, OPC7, OPD19, OPN-05, OPM- 16, OPG-03 and OPG-10). The primer OPA-1 gave the highest number of bands and OPN-05 recorded least.

2.8 Molecular characterization in other fruit crops

Anju *et al.,* 2008 screened forty six mango cultivars using RAPD and ISSR markers. Nine decamer oligonucleotides and 11 inter- simple sequence repeats yielded 110 and 160 discrete fragments, respectively. RAPD primers yielded 14 monomorphic bands and 96 displayed polymorphism. Per cent polymorphism generated by these primers was 87.3%. OPA 19, OPA 20 and OPC 6 were highly polymorphic primers. Overall polymorphism detected by ISSR was 79.38%, 14.5 bands per primer. ISSR 5 yielded 14 polymorphic bands and 7 monomorphic bands. UPGMA tree constructed on RAPD data on the basis of Jaccard's coefficient clustered the accessions into 3 groups, one comprising majority of north Indian varieties and other having eastern Indian and third cluster comprising accessions from both the regions. UPGMA clustering of ISSR data could not arrange the cultivars as per geographic separation.

Singh *et al.,* (2009) studied genetic diversity of five commercially important mango cultivars of India, comprising three landraces (‘Banganapalli’, ‘Dashehri’, and ‘Langra’) and two recently-bred cultivars (‘Amrapali’ and ‘Mallika’) using morphological and molecular inter simple sequence repeat (ISSR) markers. Morphological analysis based on 17 fruit characters detected prominent variation in the landraces ‘Banganapalli’, ‘Langra’, and ‘Dashehri’ and some variation in the cultivar ‘Mallika’. Using ten ISSR repeat primers, intracultivar variation was detected among replicates of ‘Banganapalli’, ‘Langra’, and ‘Mallika’, while replicates of ‘Amrapali’ and ‘Dashehri’ showed no variation.

Singh and Bhat, (2009) analyzed 241 mango landraces and commercial cultivars from 15 different regions of India for microsatellite variability. Eighteen primer pairs selected for high polymorphism were used for the analysis. A total of 103 alleles with an average of 5.78 alleles per primer pair were scored in the cultivars analyzed. The pair-wise similarity coefficients for the cultivars ranged from 0.024 to 0.808 with an average of 0.258 indicating presence of high genetic diversity among the cultivars analyzed.

An assessment of genetic diversity studies was undertaken by Samal *et al.,* (2012) to understand the level and pattern of diversity in 65 mango (*Mangifera indica* L.) genotypes of India including 20 commercial cultivars, 18 hybrids, 25 local genotypes and two exotic cultivars based on qualitative and quantitative fruit characters as well as RAPD and ISSR profiles. Fifteen RAPD primers yielded 27 monomorphic and 129 polymorphic bands with per cent polymorphism averaging 82.7%. Of a total 70 ISSR bands generated from eight ISSR primers, 60 bands (85.71%) were found to be polymorphic. Cumulative band data from these two methods precisely arranged accessions into eight clusters which correspond well with their pedigree relationship. UPGMA dendrograms had drawn using RAPD, ISSR and cumulative data showed highly similar grouping of genotypes on the basis of their parental origin. No clear-cut geographical separation was revealed

among East, West, North and South Indian mango cultivars by neither of these molecular markers nor their combinations.

Materials and methods

3 MATERIALS AND METHODS

The present investigation on 'Morpho-molecular characterization of jackfruit (*Artocarpus heterophyllus* L.) accessions' was conducted at College of Horticulture, Vellanikkara, Kerala from August 2013 to June 2015. The main objective was to characterise the selected accessions of jackfruit based on morphological and molecular analysis. The materials used and methodology adopted for the studies are described in this chapter.

3.1 Experimental site

The present experiments were conducted for the period from August 2013 to June 2015. In an ICAR adhoc scheme on variability studies conducted in jackfruit in College of Horticulture, Kerala Agricultural University (KAU) Vellanikkara, about eighty good accessions were identified. Their seedling progenies were planted and maintained in the college orchard and Pineapple Research Centre, Vellanikkara. Among these twenty types/accessions of jackfruit maintained in the orchard of Dept. of Pomology and Floriculture, College of Horticulture, K.A.U. Vellanikkara, Thrissur and in the Pineapple Research Centre, Vellanikkara along with Muttam Varikka, Thamarachakka and Sindoor varieties were utilised for the studies. Accessions 1 to 10 belong the soft fleshed types (Koozha) and accessions 11 to 20 belong to the firm fleshed typed (Varikka).

3.1.1 Location

The College of Horticulture, Vellanikkara where the experiment was conducted lies at a latitude of 10^{o} 31' N and longitude of 76^{o} 3' E. The area lies 22.25 m above MSL and enjoys the typical warm humid tropical climate of Kerala.The College is situated in the main campus of the Kerala Agricultural University, Vellanikkara, Thrissur, and Kerala.

3.1.2 Climate

The climate is tropical humid climate. The climatological data during the period of investigation are given in Appendix I.

3.2 Morphological characterization

Tree characters, inflorescence characters and fruit characterswere recorded. Mature fruits were collected. Standard descriptors prescribed by IPGRI (2000) were used as the guideline to describe the vegetative, inflorescence and fruit characters of twenty accessions (10 soft fleshed and 10 firm fleshed) and three varieties *viz.,* Sindoor, Muttom Varikka and Thamarachakka. Fruit samples were collected and analysed for quality traits like TSS, reducing sugars and β carotene. Sensory evaluation of the fruits was also carried out.

3.2.1 Tree characters

3.2.1.1 Tree age

Approximate age of the tree was noted from the basic records maintained in the college/ stations.

3.2.1.2 Tree height (m)

Height of the tree was recorded from the ground level to the top of the tree with multimeter

3.2.1.3 Trunk girth (cm)

Trunk girth was recorded from50 cm above the ground level of the trees.

3.2.1.4 Crown shape

Crown shape of the trees of different accessions were recorded and classified into seven groups namely pyramidal, broadly pyramidal, spherical, oblong, semi-circular, elliptical and irregular (Fig.1).

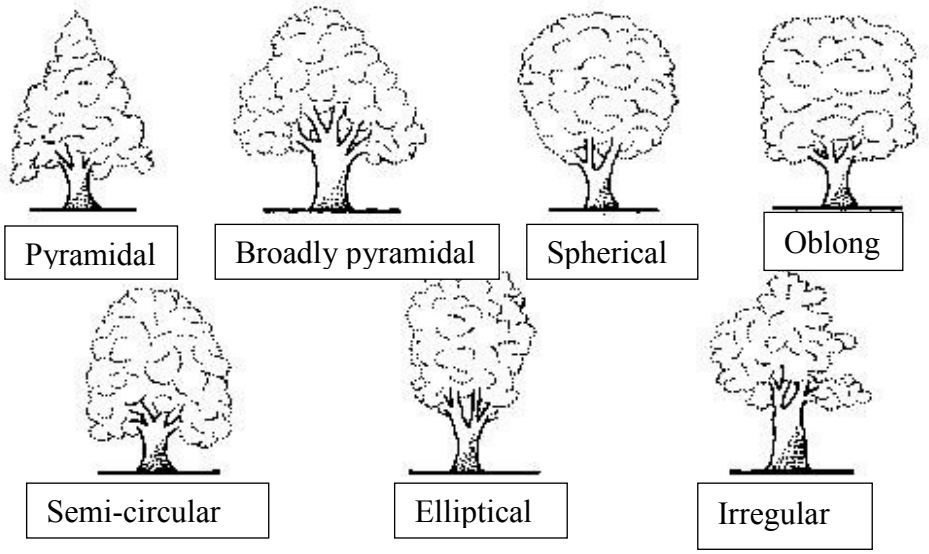


Fig. 1 Crown shape

3.2.1.5 Branching pattern

Branching pattern of the trees were recorded and were classified into five groups namely erect, opposite, verticillate, horizontal and irregular (Fig.2)

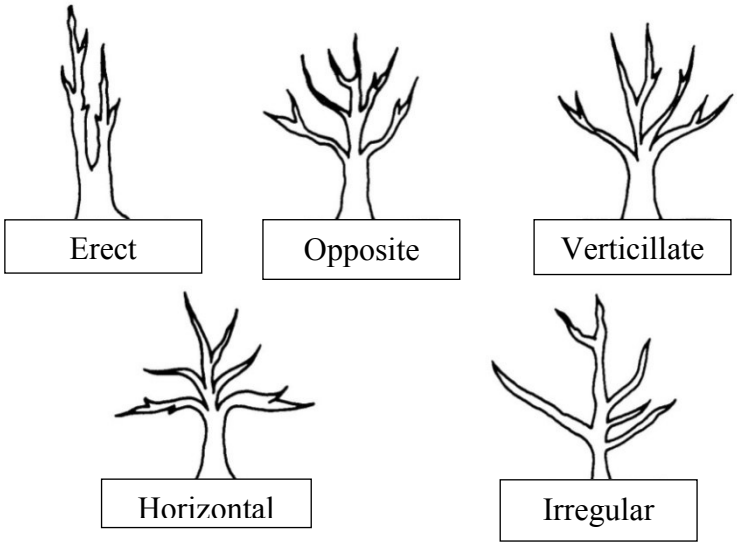


Fig. 2 Branching pattern

3.2.1.6 Leaf blade shape

Leaf blade shapes of the trees was recorded and were classified into six groups namely obovate, elliptic, broadly elliptic, narrowly elliptic, oblong and lyrate (wavy) (Fig.3).

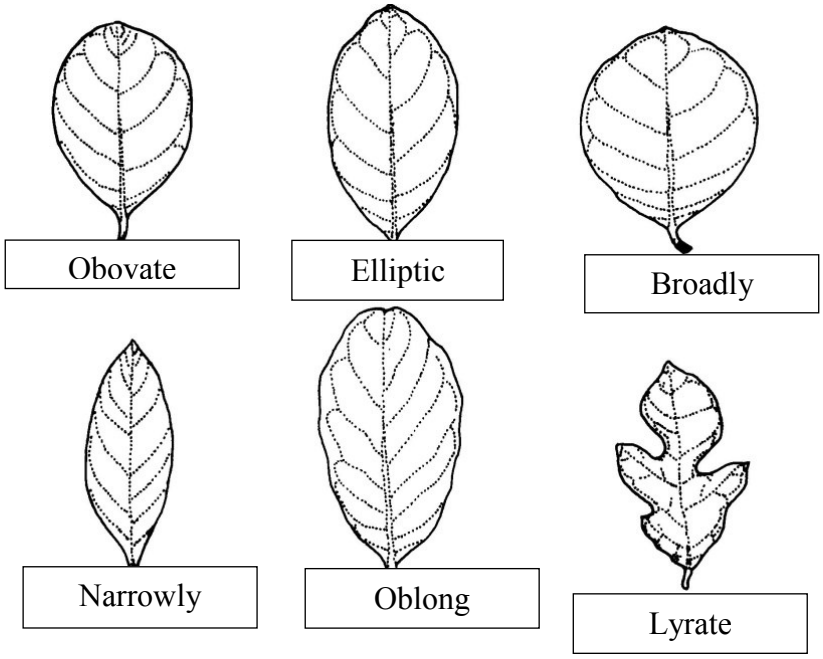


Fig. 3 Leaf blade shape

3.2.1.7 Leaf apex shape

Leaf apexes of the trees were recorded and were classified into four groups namely acute, acuminate, retuse and obtuse (Fig.4).

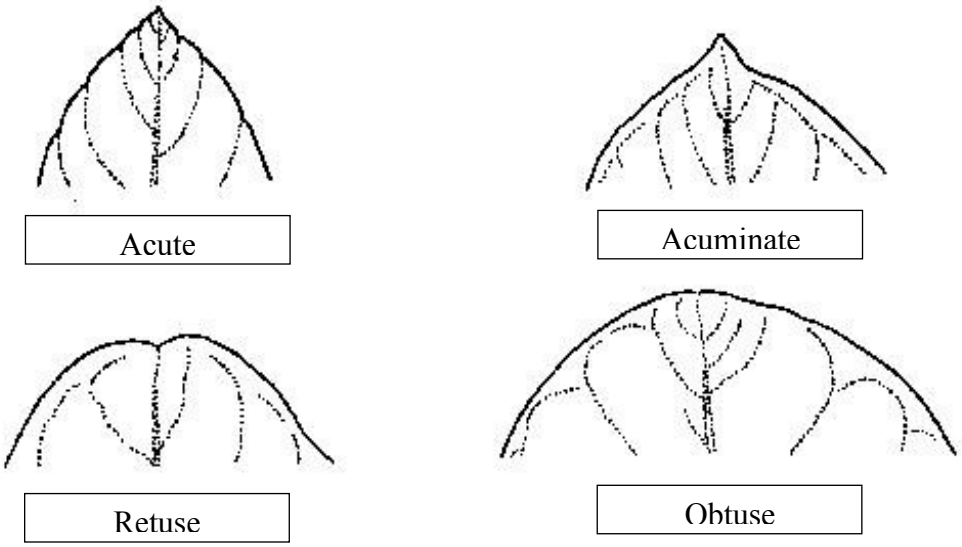


Fig.4 Leaf apex

3.2.1.8 Leaf base shapes

Leaf base shapes of the trees were recorded and were classified into four groups namely oblique, rounded, cuneate and shortly attenuate (Fig.5).

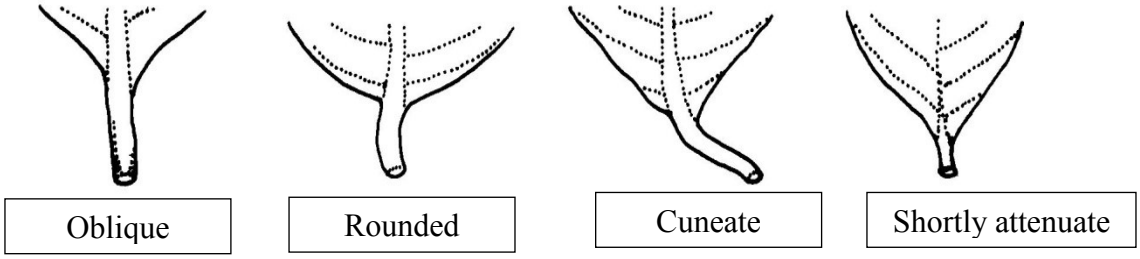


Fig. 5 Leaf base shapes

3.2.1.9 Leaf length (cm)

Average length of twenty fully expanded representative leaves of each trees from the base to the tip of the leaf blade were taken and recorded.

3.2.1.10 Leaf breadth (cm)

Average breadth of 20 fully expanded representative leaves of each trees at the widest point were taken and recorded.

3.2.2 Inflorescence characters

3.2.2.1 Time of flowering

Time of flowering was recorded in each accession.

3.2.2.2 Female inflorescence density

Female inflorescence density was recorded as sparse, intermediate and dense.

3.2.2.3 Female inflorescence position

Female inflorescence positions were recorded and classified into four categories namely mainly on trunk, mainly on trunk and primary branches, mainly on trunk, primary and secondary branches and on the whole stem including

primary, secondary and tertiary branches.

3.2.2.4 Male inflorescence position

Male inflorescence positions were recorded and classified into five categories namely mainly on tertiary branches, mainly on secondary branches, mainly on primary branches, mainly on trunk and all positions equally.

3.2.2.5 Bearing habit

Bearing habit was recorded and classified into regular and alternate years.

3.2.2.6 Secondary flowering

Apart from the regular flowering season, if any accessions shown a secondary flowering was also noted.

3.2.3 Fruit characters

3.2.3.1 Fruiting season

Time of fruiting was recorded in each accession.

3.2.3.2 Fruit clustering habit

Fruit clustering habit was recorded and classified into solitary and clusters.

3.2.3.3 Fruit number

Approximate number of fruits per tree was counted and recorded.

3.2.3.4 Fruit shape

Fruit shapes were observed and classified into six groups namely obloid, spheroid, ellipsoid, clavate, oblong and irregular (Fig.6).

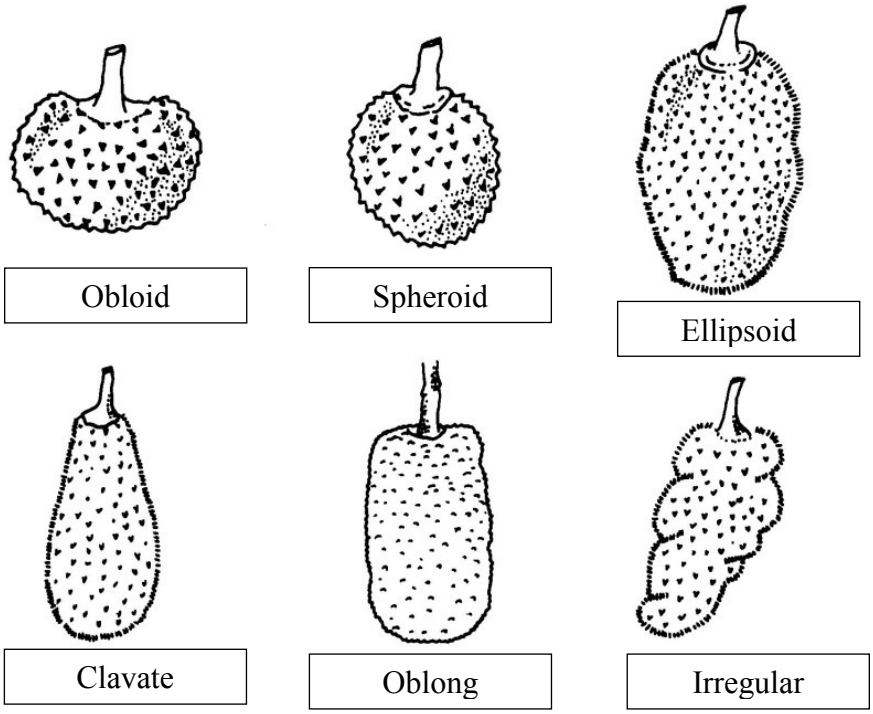


Fig. 6 Fruit shapes

3.2.3.5 Fruit surface

Fruit surface was observed and classified to smooth and spiny.

3.2.3.6 Fruit weight (kg)

Ten mature fruits of variable sizes from selected germplasm were collected to find out the mean weight of fruits. Fruit was weighed after ripening. The weight was taken by electronic balance and expressed in kilogram (kg).

3.2.3.7 Fruit yield

Approximate yield per trees were recorded as weight of the fruit.

3.2.3.8 Shelf life (Days)

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

3.2.3.9 Latex exudation

Latex exudation was determined at the time of detaching mature fruits and fully developed leaves and was classified as low, medium and high.

3.2.3.10 Rind colour

Rind colour was observed at the time of fruit maturity and classified into four groups namely green, greenish yellow, yellow and reddish yellow

3.2.3.11 Rind thickness (cm*)*

An average rind thickness of 10 fruits was recorded.

3.2.3.12 Core length (cm)

Average core length of 10 fruits was recorded

3.2.3.13 Number of flakes(bulbs) per kg of fruit

The total number of bulbs per fruit was counted to find out the average number of bulbs per fruit.

3.2.3.14 Weight of flake with seed (g)

Average weight of 20 flakes was recorded.

3.2.3.15 Weight of flake without seed (g)

Average weight of 20 flakes was recorded.

3.2.3.16 Flesh thickness (mm)

Average thickness of 20 flakes was recorded with vernier calipers.

3.2.3.17 Bulb diameter (cm)

Average diameter at the widest point of 20 bulbs was recorded.

3.2.3.18 Bulb shape

Bulb shapes were observed and were classified into seven groups namely spheroid, cordate, twisted, obovate, rectangular, oblong with curved tip and irregular (Fig.7).

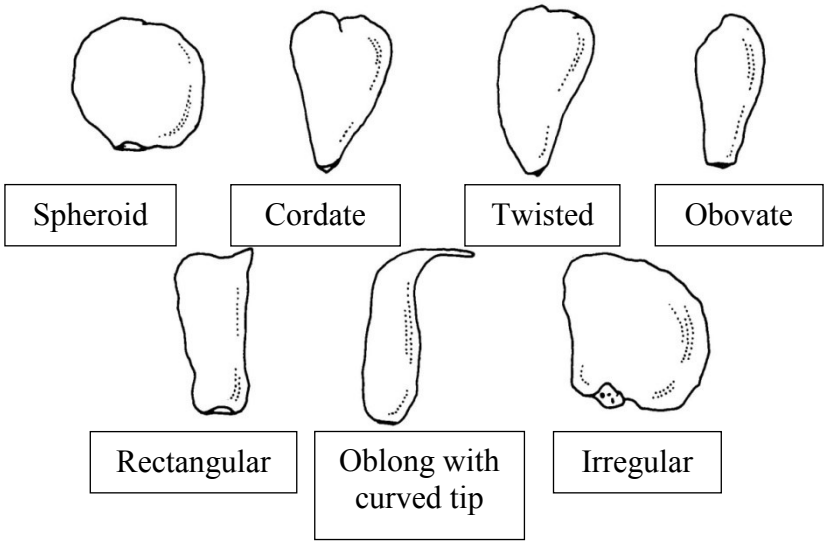


Fig. 7 Bulb (flake) shapes

3.2.3.19 Pulp flavour

Assessed at the time of opening ripe fruit and were grouped as weak, intermediate and strong

3.2.3.20 Pulp colour

Colours of the pulp was recorded at the ripened stage and were classified into six groups namely coppery red, deep yellow, yellow, light yellow, creamy white and white.

3.2.3.21 Pulp consistency

Pulp consistency was observed based on the viscosity and classified as slimy, soft, medium and firm.

3.2.3.22 Number of seeds

Number of seeds per fruit was recorded.

3.2.3.23 100- seed weight (g)

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

3.2.3.24 Rind, flake and seed ratio

This was calculated by dividing the weight of rind and flakes divided by the weight of seeds in each fruit.

3.2.4 Fruit quality parameters

3.2.4.1 Sensory evaluation

Taste, flavour, colour, texture, sweetness and appearance were recorded.

3.2.4.1.1. Selection of judges

A series of sensory evaluation were carried out using hedonic scale at laboratory level to select a panel of ten judges between the age group of 18-40 years as suggested by Jellinek (1985).

3.2.4.1.2. Preparation of score card

Score card including the quality attributes like taste, flavour, colour, texture, sweetness and appearance was prepared for sensory evaluation of jackfruits. Each of the above mentioned qualities was assessed by a nine point hedonic scale. Total score was calculated separately using the average of above mentioned quality attributes. The score card used for the evaluation of fruits is given in Appendix II.

3.2.4.1.3. Organoleptic evaluation

Organoleptic evaluation of fruits was carried out using the score card by a panel of ten selected judges. Hedonic rating scale method measures the level of liking of any product based on a test which relays on the people's ability to

communicate their feelings of like or dislike. Hedonic ratings were converted to rank scores and rank analysis was done by Kendall's coefficient of concordance.

3.2.4.2 Biochemical analysis

3.2.4.2.1 Moisture

Moisture content of the sample is estimated by heating the sample in an oven to a constant weight at 100 ^{0}C for overnight or 130 ^{o}C for 2 hours in an oven (Ranganna, 1997).

$$\text{Moisture in percentage} = \frac{\text{Initial weight of moisture cup + sample} - \text{Final weight of moisture cup + sample after drying}}{\text{Weight of sample}} \times 100$$

3.2.4.2.2 TSS

TSS (^{0}Brix reading) of jackfruit pulp was recorded with the help of digital refractometer.

3.2.4.2.3 Reducing sugar

Reducing sugars were determined by adopting the method given by Lane and Eynon (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.

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

3.2.4.2.4 Total sugar

For the estimation of total sugars, 50 ml of the clarified solution (filtrate of reducing sugars) was boiled gently after adding citric acid and water. It was neutralized using NaOH and volume made up to 250 ml and 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).

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

3.2.4.2.5 Non-reducing sugar

Percentage non-reducing sugar = Percentage total sugar - Percentage reducing sugar

3.2.4.2.6 β carotene

β carotene was estimated by AOAC (1975) method as described below. 10g of jackfruit flakes were taken in 150ml conical flask and 40 ml water saturated butanol (WSB) was added. The contents of the flask were mixed vigorously for 1 minute and kept overnight (16-18 h) at room temperature under dark for complete extraction of β carotene. Next day, the contents were shaken again and filtered completely through the Whatman no.1 filter paper in to a 100 ml volumetric flask. The optical density of the clear filtrate was measured at 440 nm using spectrophotometer. Pure WSB was used as blank. The β carotene content was calculated from calibration curve from known amount of β carotene as discussed below and expressed as parts per million (ppm). Standard solution of β carotene (Sigma) was prepared in WSB at the concentration 0f 5µg/ml.WSB is prepared by mixing n-butanol with distilled water in 8:2 ratios. Calibration curve is made from known amounts of pure β carotene from 0.25 µg/ml which are prepared after suitable dilutions of original stock with WSB in calibrated 10 ml volumetric flasks (from 0.5 ml to 3 ml of standard solution in 10 ml). Absorbance of each dilution is measured and a calibration curve is established. β carotene content of unknown samples is calculated from standard curve.

3.2.4.2.7 Total carotenoids

Total carotenoids (mg/100g) were determined by the method of Ranganna (1997) using acetone and petroleum ether as extracting solvents and measuring the absorbance at 452 nm.

3.2.4.2 Molecular characterization

3.2.4.2.1 DNA isolation

Tender emerging leaves were collected early in the morning from individual plants. The collected leaves were quickly covered in aluminum foils and transported to the laboratory in ice box. The surface was cleaned by washing with sterile water and wiping with 70 per cent ethanol and stored at -80 ^{o}C till being used. CTAB method developed by Doyle and Doyle (1987) was used for the extraction of genomic DNA.

Reagents used are,

I. CTAB buffer (2X):
   - 2 per cent CTAB (w/v)
   - 100mM Tris base (pH8)
   - 20mM EDTA (pH8)
   - 1.4M NaCl
   - 1 per cent polyvinyl pyrrolidin (PVP)
   - 0.2 per cent 2-mercaptoethanol

II. 10 per cent CTAB solution:
   - 10 per cent CTAB (w/v)
   - 0.7M NaCl.

III. TE buffer:
   -10mM Tris (pH8)
   -1mM EDTA (reagent 1 and 3 autoclaved and stored at room temperature)

IV. Wash buffer
   - 76% Ethyl alcohol
   - 10 mM Ammonium acetate

V. Chloroform: isoamyl alcohol (24:1 v/v)
VI. Chilled isopropanol
VII. Ethanol 70 per cent and 100 per cent
VIII. Sterile distilled water

Reagent I and III autoclaved and stored at room temperature.

Procedure

- Preheat 5-7.5 ml of CTAB isolation buffer (2 X) in 50 ml Oakridge centrifuge tube to 60 ºC in a water bath.
- Grind 0.5-1.0 g fresh leaf tissue with a pinch of polyvinyl pyrrolidin (soluble) and 50µl of β- mercapto ethanol in 60 ºC CTAB isolation buffer in a preheated mortar and pestle.
- Incubate sample at 60 ºC for 30 (15-60) minutes with optional occasional gentle swirling.
- Equal volume of chloroform-isoamyl alcohol (24:1) mixture was added to the tube, mixed gentle by inversion and centrifuged (Kubota 6500) at 12000 rpm for 20 min at room temperature.
- The content gets separated in to three distinct phases.

  Aqueous top layer - DNA with small quantity of RNA
  Middle layer - Protein and fine particles
  Lower layer - Chloroform, pigments and cell debris

- Transferred the top aqueous layer to a sterile centrifuge tube and equal volume of chloroform: isoamyl alcohol (24:1) was added and mixed by inversion.
- Centrifuged at 12,000 rpm for 20 min at room temperature.
- Transferred the aqueous phase into a clean centrifuge tube and added 0.6 volume (3 ml) of chilled isopropanol and mixed by gentle inversions till the DNA precipitated. These tubes were kept at -20 ºC for half an hour for complete precipitation.
- After the expiry of time, centrifuged at 12,000 rpm for 15 min at 4 ºC and the supernatant was gently poured off.

- The DNA pellet was washed with 10-20 ml of wash buffer with centrifugation at 1000 rpm for 5 min.
- Then remove the supernatant carefully and again wash with 70% ethanol and spun tubes for 5 min at 10,000 rpm and ethanol was decanted.
- The pellet was air dried, dissolved in 50µl sterile distilled water or in TE buffer and stored at -20 ºC.

3.2.4.2.2 Purification of DNA

The DNA contained RNA as contaminant and was purified by RNase treatment.

Reagents

1. Chilled isopropanol
2. 70 per cent ethanol
3. TE buffer
4. Chloroform: Isoamyl alcohol (24:1, v/v)
5. One per cent RNase

The RNase A from Sigma, USA was used for the present study. One per cent solution was prepared by dissolving RNase in TE buffer at 100 ^{0}C for 15 minutes. The solution was cooled to room temperature, dispensed into aliquots and stored at -20 ^{0}C.

RNase solution (5 µl) was added to 100 µl DNA sample and incubated at 37 ^{0}C in dry bath (Genei, Thermocon) for one hour. Then added equal volume of chloroform: isoamyl alcohol (24: 1) and centrifuged at 10000Xg for 20 min at 4 ^{0}C. The upper aqueous phase transferred to another tube. Repeated above step and finally precipitated the DNA from the aqueous phase with 0.6 ml volume of chilled isopropanol. The mixture was then incubated at -20 ^{0}C for 30 min and centrifuged at 10000 rpm for 15 min at 4 ^{0}C. The pellet of DNA was washed with 70 per cent ethanol. The pellet was air dried and dissolved in 50 to 100µl autoclaved distilled water. Electrophoresis was carried out 0.8 per cent agarose gel at constant voltage of 100V to test the quality and to find whether there was any shearing during RNase treatment.

3.2.4.2.3 Assessing the quality of DNA by electrophoresis

The quality of isolated DNA was evaluated through agarose gel electrophoresis (Sambrook *et al*., 1989).

Cleaned the work area, swabbed gel casting tray and comb with 70 per cent ethanol. The open end of gel casting tray was sealed with a cello tape and kept on a horizontal surface. The comb was placed desirably. Agarose (0.8 per cent) was weighed and dissolved in TAE buffer (1X) by boiling in micro wave oven until the agarose melted completely and solution became clear. Agarose solution was allowed to cool to about 42 to 45 ^{0}C and added ethidium bromide (0.5 µg/ml) and mixed well. Dissolved agarose was poured on to the tray. The gel was allowed to set for 30 min. The comb and tape (used for sealing the tray) were removed carefully. The tray was kept in the electrophoresis tank with well side directed towards the cathode. 1X TAE buffer was added to the tank. Then DNA sample (5 µl) along with tracking dye (1 µl) was loaded into the wells using a micropipette carefully. Suitable molecular weight marker (λ DNA + *Hind* III double digest) was loaded in one lane. After closing the tank, the anode and cathode ends were connected to the power pack and the gel was run at a constant voltage (100V) and current (50 A). The power was turned off when the tracking dye reached 2/3rd length of the gel.

Then the gel was taken from the electrophoresis unit and viewed under UV transilluminator for presence of DNA. The fluoresces under UV light due to ethidium bromide dye. The quality of DNA was judged by clarity and intactness of DNA band. The images was documented and saved in gel documentation system.

3.2.4.2.4 Gel documentation

The image was documented in gel documentation system (BIO-RAD). The gel profile was examined for intactness, clarity of DNA band, presence of contamination such as RNA and proteins.

3.2.4.2.5 Assessing the quality and quantity of DNA by NanoDrop^R method

The quality and quantity of genomic DNA was estimated using NanoDrop^R ND-1000 spectrophometer (NanoDrop Technologies Inc., USA). Before taking sample readings, the instrument was set to zero by taking 1µl autoclaved distilled water as blank. One micro litre of nucleic acid sample was measured at a wavelength of 260 nm and 280 nm and OD_{260}/OD_{280} ratios were recorded to assess the purity of DNA. A ratio of 1.8 to 2.0 for OD_{260}/OD_{280} indicated good quality of DNA. The quantity of DNA in the pure sample was calculated using the formula OD_{260}= 1 is equivalent to 40 µg double stranded DNA/µl sample.

1OD at 260 nm = 40 µg DNA/ml

Therefore $OD_{260} \times 40$ gives the quantity of DNA in µg/ml.

Procedure for quantity detection using Nanodrop

- Connected the Nanodrop spectrophotometer to the System and open the operating software ND-100.
- Selected the option Nucleic acid.
- With the sampling arm open, pipetted 1µl distilled water onto the lower measurement pedestal.
- Closed the sampling arm and initiated a spectral measurement using the operating software on the PC.
- The sample column is automatically drawn between the upper and lower measurement pedestals and the spectral measurement is made.
- Set the reading to zero with sample blank.
- 1µl sample was pipette on to measurement pedestal and select measure.
- When the measurement was complete, opened the sampling arm and wiped the sample from both the upper and lower pedestals using a soft laboratory wipe.
- Simple wiping prevents sample carryover in successive measurements for samples varying by more than 1000 fold in concentration.

3.2.4.2.6 ISSR (Inter Simple Sequence Repeat) analysis

The good quality genomic DNA (40 ng/µl) isolated from jackfruit leaf samples were subjected to ISSR analysis. ISSR primers with good resolving power were used for further amplification of DNA. The primers for assay were selected after an initial screening.

PCR amplification was performed in a 20 µl reaction mixture and the composition of the reaction mixture consisted of,

a) Genomic DNA (40 ng) - 2.0 µl
b) 10XTaq assay buffer A with $MgCl_2$ - 3.8µl
c) dNTP mix (10 mM each) - 1.8µl
d) Taq DNA polymerase (3U) - 0.4 µl
e) Primer (10 pM) - 2.0µl
f) Autoclaved distilled water - 10.0µl

Total volume - 20.0 µl

The amplification was carried out with the following programme

94 ^{0}C for 2 minutes	-	Initial denaturation	
94 ^{0}C for 30 seconds	-	Denaturation	35 cycles
43 ^{0}C to 63 ^{0}Cfor 1 minutes	-	Primer annealing	
72 ^{0}C for 2 minutes	-	Primer extension	
72 ^{0}C for 10 minutes	-	Final extension	

4 ºC for infinity to hold the sample

3.2.4.2.7 Screening of ISSR primers and analysis

Fifty primers were screened for ISSR analysis and are listed in table below. And out of 50 screened primers, 10 primers were selected based on their good amplification power.

The amplified products were run on 2 per cent agarose gel using 1X TAE buffer stained with ethidium bromide along with marker (100-bp DNA ladder). The profile was visualized under UV (312 nm) transilluminator and documented by using gel documentation system (BIO-RAD Imaging system, USA) for further

analysis. The documented ISSR profiles were carefully examined for amplification of DNA. The numbers of monomorphic and polymorphic bands were recorded for further analysis.

Primers screened for ISSR analysis

Sl. No	Primer	Nucleotide Sequence
1	UBC 811	5'GAGAGAGAGAGAGAGAC3'
2	UBC 813	5'CTCTCTCTCTCTCTCTT3'
3	UBC 814	5'CTCTCTCTCTCTCTCTA3'
4	UBC 815	5'CTCTCTCTCTCTCTCTG3'
5	UBC 834	5'AGAGAGAGAGAGAGAGYT3'
6	UBC 835	5'AGAGAGAGAGAGAGAGYC3'
7	UBC 836	5'AGAGAGAGAGAGAGAGYA3'
8	UBC 840	5'GAGAGAGAGAGAGAGAYT3'
9	UBC 844	5'CTCTCTCTCTCTCTCTRC3'
10	UBC 890	5'VHVGTGTGTGTGTGTGT3'
11	UBC 866	5'CTCCTCCTCCTCCTCCTC3'
12	1UBC 807	5'AGAGAGAGAGAGAGAGT3'
13	UBC 843	5'CTCTCTCTCTCTCTCTRA3'
14	UBC 812	5'GAGAGAGAGAGAGAGAA3'
15	UBC 820	5'GTGTGTGTGTGTGTGTC3'
16	UBC 854	5'TCTCTCTCTCTCTCTCRG3'
17	UBC 845	5'CTCTCTCTCTCTCTCTRG3'
18	UBC 817	5'CACACACACACACACAA3'
19	UBC 826	5'ACACACACACACACACC3'
20	UBC 818	5'CACACACACACACACAG3'
21	ISSR 04	5'ACACACACACACACACC3'
22	ISSR 05	5'CTCTCTCTCTCTCTTG3'
23	ISSR 06	5'GAGAGAGAGAGAGAGAC3'
24	ISSR 07	5'CTCTCTCTCTCTCTTG3'
25	ISSR 08	5'GAGAGAGAGAGAGAGAT3'
26	ISSR 09	5'CTCTCTCTCTCTCTCTCG3'
27	ISSR 10	5'ACACACACACACACACG3'
28	ISSR 15	5'TCCTCCTCCTCCTCC3'
29	2UBC 808	5'AGAGAGAGAGAGAGAGC3'
30	3UBC 809	5'AGAGAGAGAGAGAGAGG3'
31	UBC 868	5'GAAGAAGAAGAAGAAGA3'
32	UBC 895	5'AGAGTTGGTAGCTCTTGATC3'
33	UBC 899	5'CATGGTGTTGGTCATTGTTCCA3'
34	UBC 880	5'GGAGAGGAGAGGAGA3'
35	UBC 892	5'TAGATCTGATATCTGAATTCCC3'

36	UBC 855	5'ACACACACACACACYT3'
37	UBC 858	5'TGTGTGTGTGTGTGTGRT3'
38	UBC 864	5'ATGATGATGATGATGATG3'
39	(ACTG)4	5'ACTGACTGACTGACTG3'
40	UBC 873	5'GACAGACAGACAGACA3'
41	(GACAC)4	5'GACACGACACGACACGACAC3'
42	(TC)10G	5'TCTCTCTCTCTCTCTCTCTCG3'
43	(CT)10A	5'CTCTCTCTCTCTCTCTCTCTA3'
44	(CT)10G	5'CTCTCTCTCTCTCTCTCTCTG3'
45	UBC 841	5'GAGAGAGAGAGAGAGATYC3'
46	UBC 830	5'TGTGTGTGTGTGTGTGG3'
47	UBC 900	5' ACTTCCCCACAGGTTAACACA3'
48	UBC 825	5'ACACACACACACACACT3'
49	UBC S2	5'CTCTCTCTCGTGTGTGTG3'
50	4UBC 810	5'GAGAGAGAGAGAGAGAT3'

3.2.4.2.8 Analysis of molecular data

Scoring of bands in agarose gel was done with the Quantity one software (BIO-RAD) in the Gel Doc imagination system. 100 - bp ladder was used as molecular weight size marker for each gel along with DNA samples. Jaccard's coefficient of similarity was measured and a dendrogram based on similarity coefficient was generated by using Unweighed Pair Group Method with Arithmetic means (UPGMA). Only the distinct and well resolved fragments were scored. The resulting data were analysed using the software package NTsys (Rohlf, 2005).

3.2.4.3 Statistical analysis of data

Data based on 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. For sensory evaluation hedonic ratings were converted to rank scores and rank analysis was done by Kendall's coefficient of concordance.

Results

4. RESULTS

The results of the study pertaining to the "Morpho-molecular characterization of jackfruit (*Artocarpus heterophyllus* Lam.) accessions " are presented in this chapter. Twenty accessions (10 soft fleshed and 10 firm fleshed) and three varieties *viz.,* Sindoor, Muttom Varikka and Thamarachakka were characterized and the results are presented under the heads, morphological characters namely tree characters, inflorescence characters, fruit characters, fruit quality characters and molecular characters. Morphological characters were recorded based on IPGRI descriptor. Data were subjected to multivariate analysis utilizing cluster analysis using NTsys software.

4.1 Morphological characters

Various observations on morphological characters *viz.*, tree characters, inflorescence characters, fruit characters, fruit quality parameters like sensory evaluation and biochemical characters were recorded, analysed and the results are presented in Tables 1a to 13.

4.1.1 Tree characters

The data depicting tree characters are presented in (Tables 1a and 1b). At the similarity coefficient status of 30 per cent, grouping of accessions was done which resulted in 6 non-overlapping clusters. Cluster wise listing of accessions according to tree characters are listed in (Table 2). Cluster IV had highest number of accessions (six) and cluster III had the least number of accession (one).

4.1.2 Age of the tree

Most of the trees were of the age group 25 years except Sindoor (12 years) (Tables 1a and 1b).

4.1.3 Tree height

The tree height of the accessions/ varieties ranged from 4.50 m to 18.00 m (Plate 1 to 6). The accessions Acc 2 and Acc 4 recorded the lowest plant height of 4.50 m each and the highest plant height was recorded in the accession Acc 10 (Tables 1a and 1b).

The cluster means for the tree height (6.47 ± 2.54 m), (6.50 m), (7.25 ± 1.17 m), (8.88 ± 3.38 m), (10.00 ± 4.87 m) and (14.25 ± 3.57 m) were recorded in clusters II, III, IV, VI, I and V respectively (Table 3). Cluster II recorded the lowest value of 6.47 ± 2.54 m and Cluster V recorded the highest value of 14.25 ± 3.57 m (Table 3).

4.1.4 Trunk girth

Trunk girth of the accessions/ varieties ranged from 76.00 cm to 270 cm. Acc 4 recorded the lowest trunk girth of 76.00 cm and the accession Acc 16 recorded the highest trunk girth of 270.00 cm (Tables 1a and 1b).

The cluster means for the trunk girth (151.67 ± 45.86 cm), (152.38 ± 38.81 cm), (164.60 ± 81.70 cm), (167.00 ± 65.34 cm), (173.75 ± 2.50 cm) and (190.00 cm) were recorded in cluster IV, VI, I, II, V and III respectively. Cluster IV recorded the lowest value of 151.67 ± 45.86 cm and cluster III recorded the highest value of 190.00 cm (Table 3).

4.1.5 Crown shape

Different crown shapes like pyramidal, broadly pyramidal, spherical, oblong, semi-circular, elliptical and regular shapes were noticed among the accessions/ varieties, of these broadly pyramidal crown shapes were more common in accession/varieties Acc 2, Acc 9, Acc 14, Acc 17, Sindoor and Thamarachakka (Tables 1a and 1b).

Cluster I included trees with irregular crown shape. Cluster II had trees with broadly pyramidal and spherical crown shape. Cluster III included trees with

oblong crown shape while Cluster IV had trees with pyramidal, semi-circular and elliptical crown shapes. Elliptical, broadly pyramidal and semi-circular crown shapes were seen in Cluster V. Cluster VI included trees with broadly pyramidal and irregular crown shape (Table 3).

4.1.6 Branching pattern

Different branching patterns like erect, opposite, verticillate, horizontal, and irregular patterns were noticed among the accessions/ varieties, of these erect branching pattern were more common among the accessions Acc 3, Acc 4, Acc 5, Acc 10, Acc 11, Acc 16 and Muttom Varikka (Tables 1a and 1b).

Results showed that Cluster I included trees with erect and irregular branching pattern. In Cluster II trees with erect and verticillate branching pattern are included. Cluster III included trees with only opposite branching pattern while Cluster IV had trees with erect and opposite branching patterns. Cluster V had trees with erect, verticillate, horizontal and irregular branching patterns whereas trees of Cluster VI showed trees with verticillate, horizontal and irregular branching patterns (Table 3).

4.1.7 Leaf blade shape

Wide variation was noticed among the accessions/ varieties with respect to leaf characters like leaf blade shape, leaf apex shape and leaf base shape (Tables 1a and 1b).

Cluster I had trees with elliptic and narrow leaf blade shape. Trees in Cluster II had elliptic, broad and narrow shapes. Trees in Cluster III recorded oblong shape. Cluster IV and V had trees with elliptic shape. Cluster VI included trees with obovate leaf blade shape (Table 3).

4.1.8 Leaf apex

Accessions/ varieties had varied leaf apex shapes like acute, acuminate, retuse and obtuse shapes (Tables 1a and 1b). Cluster I included trees with acute,

acuminate, retuse and obtuse leaf apex while Cluster II and IVhad trees with acute and obtuse leaf apex. Trees with acuminate leaf apex was observed in Clusters III and V while Cluster VI included trees with acuminate and obtuse leaf apex (Table 3).

4.1.9 Leaf base shape

Cluster I, Cluster II and Cluster III included trees with oblique leaf base shape.Cluster IV included trees with oblique, cuneate and shortly attenuate shape. Cluster V had trees with cuneate and shortly attenuate shapes and Cluster VI included trees with rounded, oblique and shortly attenuate shapes (Table 3).

4.1.10 Leaf length

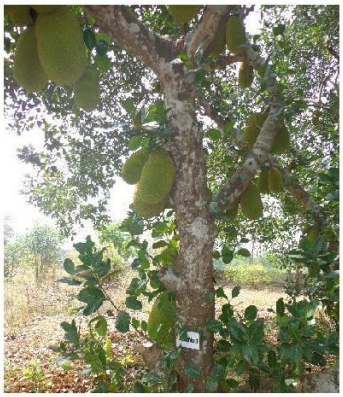
The leaf length of the accessions ranged from 12.34 cm to 18.02 cm. Accession 8 recorded the lowest leaf length of 12.34 cm and Acc 11 recorded the highest value of 18.02 cm (Tables 1a and 1b).

The cluster means of the leaf length recorded were (14.45 ± 1.74 cm), (15.42 ± 1.85 cm), (15.54 ± 2.45 cm), (15.63 ± 1.60 cm), (16.76 ± 1.48 cm) and (18.45 cm) for cluster I,V, II, VI, IVand III respectively. Cluster I recorded the lowest (14.45 ± 1.74 cm) and Cluster III recorded the highest mean values (18.45 cm) for this parameter (Table 3).

4.1.11 Leaf breadth

The leaf breadth of the accession ranged from 6.37 cm to 10.17 cm. Thamarachakka. Thamarchakka recorded the lowest value of 6.37 cm and Acc 1 recorded the highest leaf breadth of 10.17 cm (Tables 1a and 1b).

The cluster means of the leaf breadth recorded in Cluster II, V, IV, I, VI and III were 7.53 ± 1.34 cm, 7.80 ± 0.57 cm, 8.30 ± 0.81 cm, 8.60 ± 1.31 cm, 8.76 ± 0.49 cm and 9.93 cm. Cluster II recorded the lowest value of 7.53 ± 1.34 cm and Cluster III recorded the highest value of 9.93 cm (Table 3).



Accession no. 1

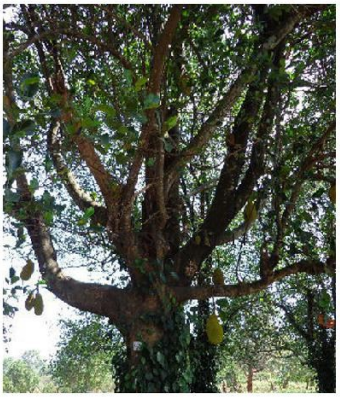
Accession no. 2

Accession no. 3

Accession no. 4

Plate 1. General view of jackfruit accessions

Accession no. 5

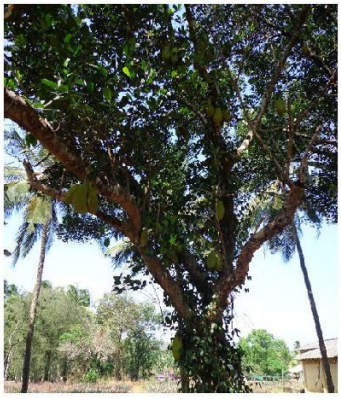


Accession no. 6

Accession no. 7

Accession no. 8

Plate 2. General view of jackfruit accessions



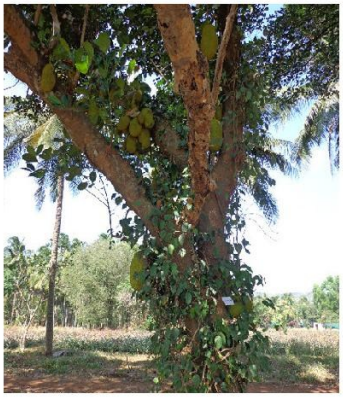
Accession no. 9

Accession no. 10

Accession no. 11

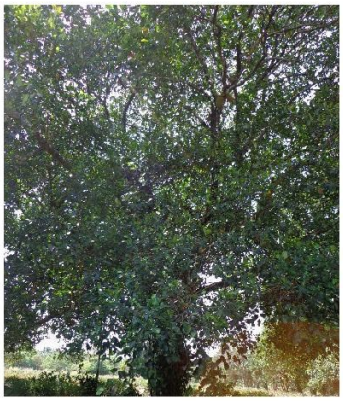
Accession no. 12

Plate 3. General view of jackfruit accessions



Accession no. 13

Accession no. 14



AAccession no. 15

Accession no. 16

Plate 4. General view of jackfruit accessions

Accession no. 17

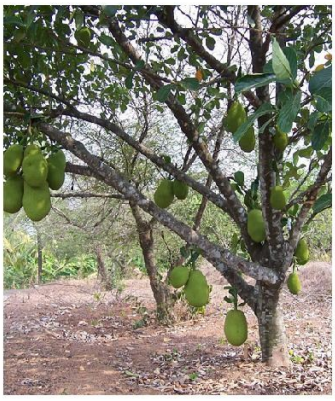
Accession no. 18

Accession no. 19

Accession no. 20

Plate 5. General view of jackfruit accessions

Muttom Varikka



Sindoor

Thamarachakka

Plate 6. General view of jackfruit varieties

Table 1a.Tree characters of accessions (1 to 11)

Tree characters	Tree characters of accessions (1 to 11)										
	ACC1	**ACC2**	**ACC3**	**ACC4**	**ACC5**	**ACC6**	**ACC7**	**ACC8**	**ACC9**	**ACC10**	**ACC11**
Age of the tree (years)	25	25	25	25	25	25	25	25	25	25	25
Tree height(m)	6.00	4.50	5.00	4.50	6.00	6.50	9.50	13.50	11.00	18.00	7.50
Trunk girth (cm)	117.00	109.50	94.00	76.00	136.00	190.00	160.00	130.00	180.00	175.00	115.00
Crown shape	Irregular	Broadly pyramidal	Spherical	Irregular	Pyramidal	Oblong	Elliptical	Irregular	Broadly pyramidal	Elliptical	Pyramidal
Branching pattern	Irregular	Verticillate	Erect	Erect	Erect	Opposite	Irregular	Irregular	Verticillate	Erect	Erect
Leaf bladeshape	Elliptic	Obovate	Broadly ellpitic	Elliptic	Elliptic	Narrowly elliptic	Elliptic	Oblong	Obovate	Elliptic	Elliptic
Leaf apex	Acuminate	Acuminate	Obtuse	Acuminate	Acute	Acuminate	Acuminate	Retuse	Obtuse	Acuminate	Obtuse
leaf baseshape	Oblique	Shortly attenuate	Oblique	Oblique	Oblique	Oblique	Shortly attenuate	Oblique	Rounded	Shortly attenuate	Cuneate
Leaf length(cm)	12.79	13.85	12.90	15.32	16.65	18.45	12.79	12.34	16.8	17.12	18.02
Leaf breadth (cm)	10.17	8.32	7.22	9.63	8.10	9.93	7.26	7.28	8.49	8.14	7.70

Table 1b. Tree characters of accessions (12 to 20), Sindoor (S), MuttomVarikka (MV), Thamarachakka (TC)

character	Tree characters of accessions (12 to 20), Sindoor (S), MuttomVarikka (MV), Thamarachakka (TC)											
	ACC12	**ACC13**	**ACC14**	**ACC15**	**ACC16**	**ACC17**	**ACC18**	**ACC19**	**ACC20**	**S**	**MV**	**TC**
Age of the tree	25	25	25	25	25	25	25	25	25	12	25	25
Tree height (m)	8.00	7.00	5.00	6.00	10.00	15.50	14.00	16.00	12.00	8.00	9.00	9.40
Trunk girth (cm)	142.00	157.00	220.00	240.00	270.00	190.00	170.00	230.00	190.00	130.00	120.00	187.00
Crown shape	Pyramidal	Pyramidal	Broadly pyramidal	Semi-circular	Irregular	Broadly pyramidal	Semi-circular	Irregular	Irregular	Broadly pyramidal	Elliptical	Broadly pyramidal
Branching pattern	Erect	Opposite	Verticillate	Opposite	Erect	Horizontal	Verticillate	Irregular	Irregular	Horizontal	Erect	Verticillate
Leaf blade shape	Elliptic	Elliptic	Elliptic	Elliptic	Narrowly elliptic	Elliptic	Elliptic	Elliptic	Obovate	Obovate	Elliptic	Narrowly elliptic
Leaf apex	Obtuse	Obtuse	Obtuse	Obtuse	Acute	Acuminate	Acuminate	Obtuse	Obtuse	Obtuse	Acute	Acute
leaf base shape	Cuneate	Cuneate	Oblique	Shortly attenuate	Oblique	Shortly attenuate	Rounded	Oblique	Rounded	Oblique	Cuneate	Oblique
Leaf length (cm)	17.66	17.85	17.74	14.08	15.89	15.82	15.96	15.91	17.15	14.72	16.33	16.00
Leaf breadth (cm)	8.49	8.41	8.99	7.40	7.32	7.39	8.42	8.61	9.43	8.79	9.72	6.37

Fig 8. Dendrogram of tree characters

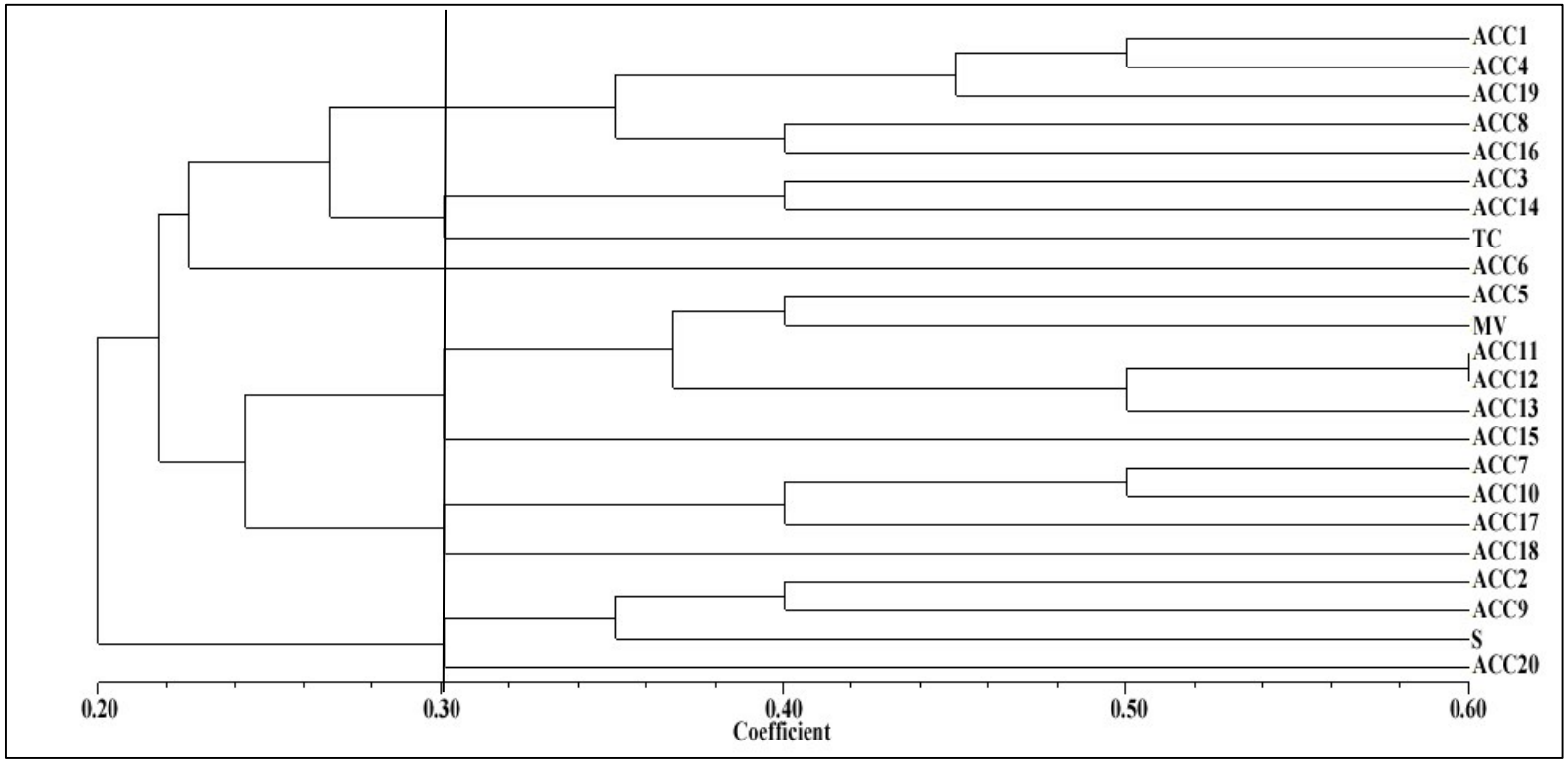


Table 2.Cluster wise listing of accessions according to tree characters

Clusters					
I	**II**	**III**	**IV**	**V**	**VI**
Acc 1	Acc 3	Acc 6	Acc 5	Acc 7	Acc 2
Acc 4	Acc 14		MV	Acc 10	Acc 9
Acc 19	TC		Acc 11	Acc 17	Sindoor
Acc 8			Acc 12	Acc 18	Acc 20
Acc 16			Acc 13		
			Acc 15		

Table 3.Cluster wise summary statistics of tree characters

Characters	**Clusters**					
	I	**II**	**III**	**IV**	**V**	**VI**
Age of the tree	25.00	25.00	25.00	25.00	25.00	21.75± 6.50
Tree height (m)	10.00± 4.87	6.47±2.54	6.50	7.25± 1.17	14.25± 3.57	8.88± 3.38
Trunk girth (cm)	164.60± 81.70	167.00±65.34	190.00	151.67± 45.86	173.75± 2.50	152.38± 38.81
Crown shape	Irregular	Broadly pyramidal, Spherical	Oblong	Pyramidal, Semi-circular, Elliptical	Elliptical, Broadly pyramidal, Semi-circular	Broadly Pyramidal, Irregular
Branching pattern	Erect, Irregular	Erect, Verticillate	Opposite	Erect, Opposite	Erect, Verticillate, Horizontal, Irregular	Verticillate, Horizontal, Irregular
Leaf blade shape	Elliptic, Narrowly elliptic	Elliptic, Broadly elliptic Narrowly elliptic	Oblong	Elliptic	Elliptic	Obovate
Leaf apex	Acute, Acuminate, Retuse, Obtuse	Acute, Obtuse	Acuminat e	Acute, Obtuse	Acuminate	Acuminate, Obtuse
Leaf base shape	Oblique	Oblique	Oblique	Oblique Cuneate, Shortly attenuate	Shortly attenuate, Rounded	Shortly attenuate, Rounded, Oblique
Leaf length (cm)	14.45± 1.74	15.54± 2.45	18.45	16.76± 1.48	15.42± 1.85	15.63± 1.60
Leaf breadth (cm)	8.60± 1.31	7.53± 1.34	9.93	8.30± 0.81	7.80± 0.57	8.76± 0.49

4.2 Inflorescence characters

The data depicting the inflorescence characters are presented in Tables 4a and 4b.The accessions were grouped at the similarity coefficient status of 75 per cent which resulted in five non-overlapping clusters.

Cluster wise listing of accessions according to inflorescence charactersare listed in Table 5. Cluster I had highest number of accessions (seven) and cluster II and cluster IV had the lowest number of accessions (three).

4.2.1 Time of flowering

According to the time of flowering, the accessions/ varieties studied could be grouped into two namely the one which flowered during October and the other group which flowered during September. The time of flowering of different accessions are presented in the (Tables 4a and 4b).

In Cluster I, the trees observed flowering during 1st and 2nd week of September. In Cluster II, flowering was observed in 3rd and 4th week of October. Cluster III included the trees that flowered during 3rd and 4th week of September. Cluster IV included trees that flowered during 2nd week of September and October and Cluster V shown flowering during 3rd and 4th week of October (Table 6).

4.2.2 Female inflorescence density

Different female inflorescence densities like dense, intermediate and sparse were noticed among the accessions/ varieties. Among this dense inflorescence density was common. Accession 1, Acc 2, Acc 7, Acc 8, Acc 14, Acc17, Acc18, Acc19, Acc20 and Thamarachakka had dense female inflorescence densities (Tables 4a and 4b).

Female inflorescence densities of different clusters are presented in table 6. In Cluster I the trees were recorded with sparse, intermediate and dense female inflorescence density. Cluster II had trees with dense female inflorescence density

only.Cluster III and V included trees with dense and sparse female inflorescence density while in Cluster IV trees with only intermediate female inflorescence density was observed (Table 6).

4.2.3 Female inflorescence positions

Regarding the position of female flowers, majority of the accessions had female flowers on trunk, primary and secondary branches. Accession 2, Acc 7, Acc 10, Acc 11, Acc 20, Sindoor, Muttom Varikka, and Thamarachakka had female flowers on trunk, primary and secondary branches (Tables 4a and 4b).

Female inflorescence position was mainly on trunk, primary and secondary branches in Clusters I, II and III. However female inflorescence position was on the whole stem including primary, secondary and tertiary branches in clusters IV and V (Table 6).

4.2.4 Male inflorescence positions

Male inflorescence positions were of two types namely, mainly on primary branches and all positions equally. Of these majority of the accessions had male inflorescence on all positions equally (Tables 4a and 4b).

Cluster I and II included trees with male inflorescence positions mainly on primary branches. In Cluster III, IV and V male inflorescence positions were seen mainly on all positions equally (Table 6).

4.2.5 Bearing habit

Regarding bearing habit, all the accessions had regular bearing tendency and no secondary flowering were observed among the accessions/varieties. In all the clusters regular bearing habit was noticed (Table 6).

4.2.6 Secondary flowering

No secondary flowering was noticed in the trees coming under different clusters (Table 6).

Table 4a.Inflorescence characters of accessions (1 to 11)

Inflorescence characters	Inflorescence characters of accessions (1 to 11)										
	ACC1	**ACC2**	**ACC3**	**ACC4**	**ACC5**	**ACC6**	**ACC7**	**ACC8**	**ACC9**	**ACC10**	**ACC11**
Time of flowering	2nd week of September	2nd week of September	2nd week of September	2nd week of September	2nd week of September	2nd week of September	2nd week of September	2nd week of September	3rd week of September	3rdweek of September	2ndweek of October
Female inflorescence density	Dense	Dense	Intermediate	Sparse	Intermediate	Intermediate	Dense	Dense	Intermediate	Sparse	Sparse
Female inflorescence position	Mainly on trunk and 1^0 branches	Mainly on trunk 1^0 and 2^0 branches	Mainly on trunk and 1^0 branches	Mainly on trunk and 1^0 branches	Mainly on trunk and 1^0 branches	On the whole stem including 1^0, 2^0 and 3^0 branches	Mainly on trunk 1^0 and 2^0 branches	Mainly on trunk and 1^0 branches	On the whole stem including 1^0, 2^0 and 3^0 branches	Mainly on trunk 1^0 and 2^0 branches	Mainly on trunk 1^0 and 2^0 branches
Male inflorescence position	Mainly on 1^0 branches	Mainly on 1^0 branches	Mainly on 1^0 branches	Mainly on 1^0 branches	Mainly on 1^0 branches	All positions equally	All positions equally	Mainly on 1^0 branches	All positions equally	All positions equally	All positions equally
Bearing habit	Regular	Regular	Regular	Regular	Regular	Regular	Regular	Regular	Regular	Regular	Regular
Secondary flowering	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent

Table 4b.Inflorescence characters of accessions (12 to 20), Sindoor (S), MuttomVarikka (MV), Thamarachakka (TC)

Inflorescence characters	Inflorescence characters of accessions (12 to 20), Sindoor (S), MuttomVarikka (MV), Thamarachakka (TC)											
	ACC12	**ACC13**	**ACC14**	**ACC15**	**ACC16**	**ACC17**	**ACC18**	**ACC19**	**ACC20**	**S**	**MV**	**TC**
Time of flowering	3rdweek of October	3rdweek of October	3rdweek of October	2ndweek of October	2ndweek of October	3rdweek of October	3rdweek of October	3rdweek of October	3rdweek of October	3rdweek of September	3rdweek of September	2ndweek of September
Female inflorescence density	Sparse	Sparse	Dense	Intermediate	Sparse	Dense	Dense	Dense	Dense	Sparse	Sparse	Dense
Female inflorescence position	On the whole stem including 1^0, 2^0 and 3^0 branches	Mainly on trunk and 1^0 branches	Mainly on trunk and 1^0 branches	On the whole stem including 1^0, 2^0 and 3^0 branches	On the whole stem including 1^0, 2^0 and 3^0 branches	Mainly on trunk and 1^0 branches	Mainly on trunk and 1^0 branches	On the whole stem including 1^0, 2^0 and 3^0 branches	Mainly on trunk 1^0 and 2^0 branches	Mainly on trunk 1^0 and 2^0 branches	Mainly on trunk 1^0 and 2^0 branches	Mainly on trunk and 1^0 branches
Male inflorescence position	All positions equally	All positions equally	All positions equally	All positions equally	All positions equally	Mainly on 1^0 branches	Mainly on 1^0 branches	All positions equally	Mainly on 1^0 branches	Mainly on 1^0 branches	Mainly on 1^0 branches	Mainly on 1^0 branches
Bearing habit	Regular	Regular	Regular	Regular	Regular	Regular	Regular	Regular	Regular	Regular	Regular	Regular
Secondary flowering	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent

Fig 9. Dendrogram of inflorescence characters

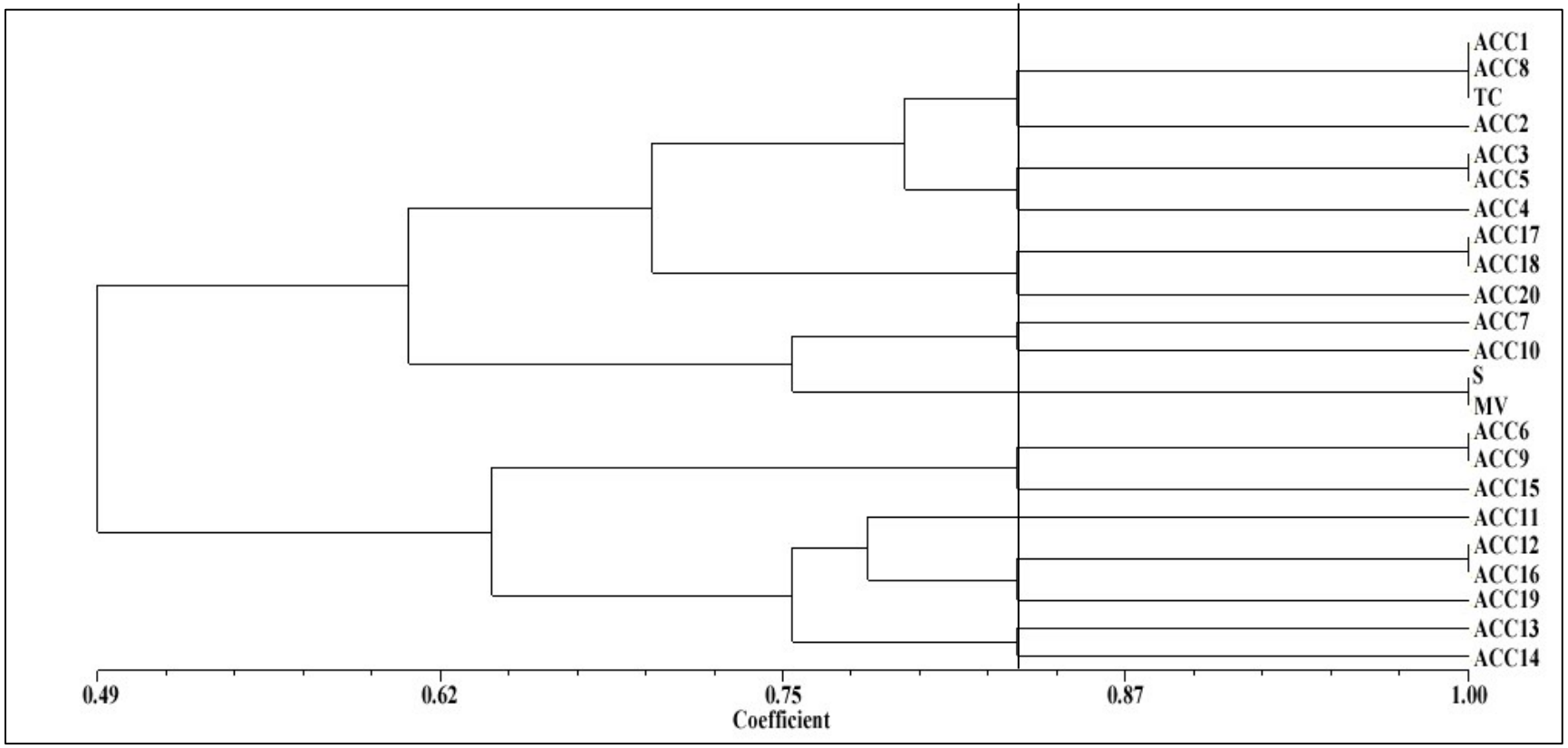


Table 5.Cluster wise listing of accessions according to inflorescence characters

Clusters				
I	**II**	**III**	**IV**	**V**
Acc 1	Acc 17	Acc 7	Acc 6	Acc 11
Acc 8	Acc 18	Acc 10	Acc 9	Acc 12
TC	Acc 20	Sindoor	Acc 15	Acc 16
Acc 2		MV		Acc 19
Acc 3				Acc 13
Acc 5				Acc 14
Acc 4				

Table 6. Cluster wise summary statistics of inflorescence characters

Characters	**Clusters**				
	I	**II**	**III**	**IV**	**V**
Time of flowering	1st and 2nd Week of September	3rd and 4th week of October	3rd and 4th Week of September	2nd Week of September and October	3rd and 4th week of October
Female inflorescence density	Sparse, Intermediate, Dense	Dense	Dense, Sparse	Intermediate	Dense, Sparse
Female inflorescence position	Mainly on trunk, primary and secondary branches	Mainly on trunk, primary and secondary branches	Mainly on trunk, primary and secondary branches	On the whole stem including primary, secondary and tertiary branches	On the whole stem including primary, secondary and tertiary branches
Male inflorescence position	Mainly on primary branches	Mainly on primary branches	All positions equally	All positions equally	All positions equally
Bearing habit	Regular	Regular	Regular	Regular	Regular
Secondary flowering	Absent	Absent	Absent	Absent	Absent

4.3 Fruit characters

Various observations on fruit characters are presented in Tables 7a and 7b. At the similarity coefficient status of 26 per cent, grouping of accessions was done which resulted in 5 non - overlapping clusters.

Cluster wise listing of accessions according to fruit characters are listed in Table 8. Cluster IV had maximum number of accessions (10) and cluster V had the least number of accession (1).

4.3.1 Fruiting season

All firm fleshed types had a fruiting period from January to March and all the soft fleshed types had fruiting during February and extended to April-May (Tables 7a and 7b).

All accessions in the clusters I, II, III and V started fruiting during the month of January to March and fruiting started on February and extended to May in cluster IV (Tables 9a and 9b).

4.3.2 Fruit clustering habit

Two types of fruit clustering habits were observed among the accessions/ varieties namely solitary and cluster. Majority of the accessions had cluster bearing habit. Acc 1, Acc 2, Acc 5, Acc 6, Acc 7, Acc 8, Acc 11, Acc 13, Acc 14, Acc 15, Acc 17, Acc 18, Acc 19, Acc 20, Sindoor, Muttomvarikka and Thamarachakka had cluster fruit bearing habit (Tables 7a and 7b).

Cluster I, III and IV had solitary and cluster fruit bearing habit. In Cluster II and V most of the trees had only cluster bearing habit (Table 9a and 9b).

4.3.3 Fruit number

Number of fruits of the accessions ranged from 21 to 135. Acc 1 recorded the least number of 21 fruits and Acc 14 recorded the highest number of 135 fruits (Tables 7a and 7b).

The cluster mean value for number of fruits was recorded as cluster V (25.00), cluster I (29.00 ± 8.49), cluster II (31.50 ± 8.47), cluster III (34.33 ± 4.89) and cluster IV (63.40 ± 38.05). Cluster V recorded the minimum mean value (25.00) for fruit number and cluster V recorded the maximum value (63.40 ± 38.05) (Tables 9a and 9b).

4.3.4 Fruit shape

Different fruit shapes were noticed among the accessions *viz.,* ellipsoid, clavate, oblong, irregular and obloid (Plate 7 to 10). Of these ellipsoid fruit shape was observed among majority of the accessions/ varieties. All the accessions except Acc 8, Acc 14, Muttom Varikka and Thamarchakka had ellipsoid fruit shape (Tables 7a and 7b). Ellipsoid and clavate fruit shapes were observed in Cluster I whereas Cluster II had only ellipsoid fruit shape. In Cluster III and IV the fruit shape noted was ellipsoid and oblong. Obloid fruit shape was observed in Cluster V(Tables 9a and 9b).

4.3.5 Fruit surface

Spiny and smooth fruit surface was observed among the accessions/ varieties. All the accessions and varieties had spiny fruit surface except Thamarachakka with smooth surface (Tables 7a and 7b). Spiny fruit surface was observed in Cluster I, II, III and IV. However smooth fruit surface was observed only in Cluster V (Tables 9a and 9b).

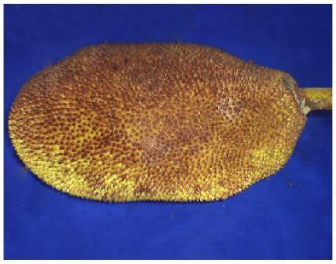
4.3.6 Fruit weight

Wide variability was noticed among the accessions/ varieties studied with respect to fruit weight. It varied from 1.65 to 20.00 kg. Thamarachakka recorded the lowest fruit weight of 1.65 kg and Acc 7 recorded the highest fruit weight of 20.00 kg (Tables 7a and 7b).The cluster mean for the fruit weight ranged from 1.65 to 15.50 ± 7.78 kg. The clusters V, IV, III, I and II recorded the fruit weight of 1.65 kg, 8.09 ± 2.11 kg, 10.23 ± 2.45 kg, 12.00 ± 3.03 kg and 15.50 ± 7.78 kg respectively (Tables 9a and 9b).

Accession no. 1

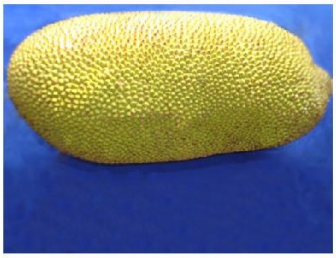
Accession no. 2

Accession no. 3



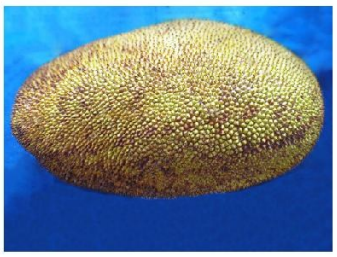
Accession no. 4

Accession no. 5



Accession no. 6

Plate 7. Fruit shapes of jackfruit accessions



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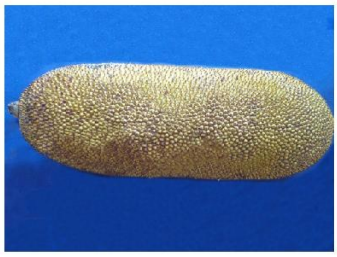
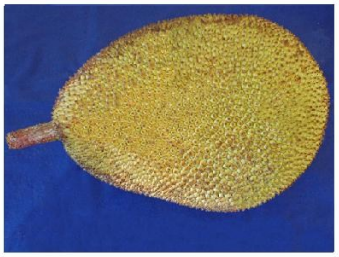


Accession no. 8

Accession no. 9

Accession no. 10



Accession no. 11

Accession no. 12

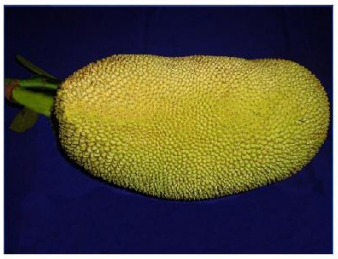
Plate 8. Fruit shapes of jackfruit accessions

Accession no. 13

Accession no. 14

Accession no. 15

Accession no. 16



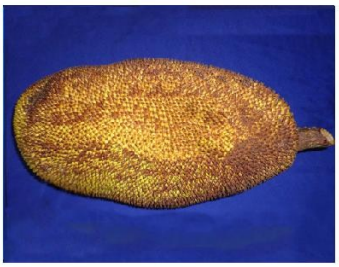
Accession no. 17

Accession no. 18

Plate 9. Fruit shapes of jackfruit accession

Accession no. 19

Accession no. 20



Muttom Varikka

Sindoor

Thamarachakka

Plate 10. Fruit shapes of jackfruit accessions/ varieties

4.3.7 Fruit yield

Wide variability was noticed in the fruit yield of jackfruits. It varied from 41.25 kg /plant to 1593 kg/ plant. Thamarachakka recorded the lowest yield of 41.25 kg/plant and Acc 14 recorded the highest value of 1593 kg/plant (Tables 7a and 7b).

The cluster means for the fruit yield ranged from 42.25 kg to 536.74 ± 421.56 kg. The cluster V, I, III, II and IV recorded the fruit yield of 41.25 kg, 334.25 ± 57.30 kg, 343.32 ± 60.10 kg, 490.50 ± 325.27 kg and 536.74 ± 421.56. Cluster V recorded the least fruit yield of 42.25 and Cluster IV recorded the highest value of 536.74 ± 421.56 kg per plant (Tables 9a and 9b).

4.3.8 Shelf life

Shelf life of the fruit varied from 3 to 5 days. Majority of the accessions had shelf life of 4 days (Tables 7a and 7b).

Cluster I and IV consisted of fruits with shelf life of 4 days whereas Cluster II, III and V recorded fruit with shelf life of 5 days (Tables 9a and 9b).

4.3.9 Latex exudation

Latex exudation was noticed as high, medium and low among the accessions/varieties (Tables 7a and 7b).

Cluster I recorded fruits with medium latex exudation whereas Cluster II recorded fruits with high latex exudation. Cluster III consisted of fruits with low, medium and high latex exudation. Cluster IV had fruits with medium and high latex exudation and low latex exudation was recorded in Cluster V (Tables 9a and 9b).

4.3.10 Rind colour

Rind colour varied from green to greenish yellow. Of these greenish yellow was observed in majority of the accessions/varieties (Tables 7a and 7b).

The fruits produced in trees of Cluster I and V had green rind colour whereas Clusters II, III and IV included fruits with green and greenish yellow rind colour (Tables 9a and 9b).

4.3.11 Rind thickness

Rind thickness of the fruits varied from 0.30 cm to 2.90 cm. Accession 11 recorded the lowest rind thickness of 0.30 cm and Sindoor recorded the highest rind thickness of 2.90 cm (Tables 7a and 7b).

The cluster mean for the rind thickness ranged from 0.5 cm to 1.62 ± 2.80 cm. Clusters V, II, IV, I and III recorded the rind thickness of 0.5 cm, 1.25 ± 0.21 cm,1.26 ± 0.69 cm, 1.53 ± 0.92 cm and 1.62 ± 2.80 cm respectively. Cluster V recorded the lowest value of 0.5 cm and cluster III recorded the highest value of 1.62 ± 2.80 cm for this parameter (Tables 9a and 9b).

4.3.12 Core length

Core length of the accessions/varieties varied from 10.20 cm to 50.50 cm (Plate 11 to 14). Thamarachakka recorded the least core length of 10.20 cm whereas Acc 7 recorded the highest core length of 50.50 cm (Tables 7a and 7b).

The cluster mean for core length ranged from 10.20 cm to 48.75 ± 2.47 cm. The clusters V, IV, III, I and II recorded the core length of 10.20 cm, 23.50 ± 3.24 cm, 34.84 ± 8.93 cm, 36.00 ± 9.13 cm and 48.75 ± 2.47 cm respectively. Cluster V recorded the lowest cluster mean values of 10.20 cm and highest value of 48.75 ± 2.47 cm in cluster II (Tables 9a and 9b).

4.3.13 Core thickness

Core thickness of the accessions varied from 2.50 to 13.90 cm. Muttom Varikka recorded the minimum core thickness of 2.50 cm whereas Acc 7 recorded the maximum core thickness of 13.90 cm (Tables 7a and 7b).

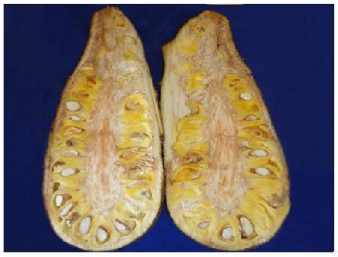
The cluster means for the core thickness ranged from 4.50 cm to 9.95 ± 4.53 cm. The clusters V, III, I, IV and II recorded the core thickness of 4.50 cm, 5.72 ±

Accession no. 1

Accession no. 2

Accession no. 3

Accession no. 4



Accession no. 5

Accession no. 6

Plate 11. Longitudinal section of jackfruit accessions

Accession no. 7

Accession no. 8

Accession no. 9

Accession no. 10

Accession no. 11

Accession no. 12

Plate 12. Longitudinal section of jackfruit accessions

Accession no. 13

Accession no. 14

Accession no. 15

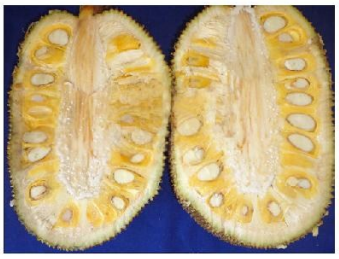
Accession no. 16

Accession no. 17

Accession no. 18

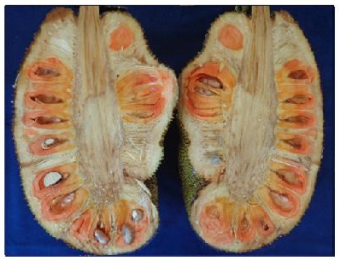
Plate 13. Longitudinal section of jackfruit accessions

Accession no. 19



Accession no. 20

Muttom Varikka



Sindoor

Thamarachakka

Plate 14. Longitudinal section of jackfruit accessions/ varieties

2.44 cm, 7.13 ± 1.55 cm, 7.20 ± 1.03 cm and 9.95 ± 4.53 cm respectively. Cluster V recorded the lowest cluster mean value of 4.40 cm and the highest value of 9.95 ± 4.53 cm was recorded in cluster II (Tables 9a and 9b).

4.3.14 Number of flakes (bulbs) per kg of the fruit

Number of flakes (bulbs) per kg of fruit varied from 12.61 to 71.15. Accession 4 recorded the lowest number of 12.61 where as Acc 9 recorded the highest number of 74.15 (Tables 7a and 7b).The cluster mean number of flakes (bulbs) per kg of the fruit ranged from 21.85 ± 7.92 to 35.18 ± 21.80. The clusters II, I, IV, V and III recorded number of flakes (bulbs) per kg of the fruit as 21.85 ± 7.92 , 22.61 ± 7.08 , 25.54 ± 8.88 , 26.67 and 35.18 ± 21.80 were recorded in cluster II, cluster I, cluster IV, cluster V and cluster III respectively. Cluster II recorded the lowest mean value for number of flakes (bulbs) per kg of the fruit as 21.85 ± 7.92 and cluster III recorded the maximum of 35.18 ± 21.80 (Tables 9a and 9b).

4.3.15 Weight of flake with seed

Weight of the flake with seed varied from 16.69 g to 34.64 g. Thamarachakka recorded the lowest weight of 16.69 g whereas Acc 5 recorded the highest weight of 34.64 g (Tables 7a and 7b).The cluster means for the weight of the flake with seed ranged from 16.69 g to 31.53 ± 2.92 g. The clusters V, IV, II, III and I recorded weight of the flake with seed as 16.69 g, 28.23 ± 2.55 g, 28.44 ± 2.35 g, 27.32 ± 2.54 g and 31.53 ± 2.92 grespectively. Cluster I recorded the highest value and cluster V recorded the lowest value (Tables 9a and 9b).

4.3.16 Weight of flake without seed

Weight of the flake without seed varied from 10.79 g to 28.81 g. Thamarachakka recorded the lowest weight of 10.79 g and Acc 5 recorded the highest weight of 28.81 g (Tables 7a and 7b).The cluster means for the weight of the flake without seed ranged from 10.79 g to 26.67 ± 1.81 g. The clusters V, III, II, IV and I recorded the values as 10.79 g, 23.05 ± 2.30 g, 24.43 ± 1.71 g, 24.71

± 2.43 g and 26.67 ± 1.81 g respectively. Cluster I recorded the lowest value of 10.79 g for weight of the flake without seed and cluster V recorded the highest value of 26.67 ± 1.81 g (Tables 9a and 9b).

4.3.17 Flesh thickness

Flesh thickness of the accessions/varieties varied from 1.26 mm to 7.8 mm. Accession 18 recorded the lowest thickness of 1.26 mm and Acc 10 recorded the highest thickness of 7.8 mm (Tables 7a and 7b).The cluster means for the flesh thickness ranged from 1.30 mm to 4.40 ± 2.36 mm. The clusters V, IV, II, I and III recorded the flesh thickness of 1.30 mm, 2.20 ± 0.91 mm, 2.50 ± 1.01 mm, 3.70 ± 1.91 mm and 4.40 ± 2.36 mm respectively. Cluster V recorded the lowest cluster mean value of 1.28 mm for flesh thickness and cluster III recorded the highest value of 4.40 ± 2.36 mm (Tables 9a and 9b).

4.3.18 Flake (bulb) length

Length of the flake varied from 4.17 cm to 7.53 cm. Thamarachakka recorded the lowest length of 4.17 cm and Acc 1 recorded the highest length of 7.53 cm (Tables 7a and 7b).The cluster means for the bulb length ranged from 4.17 cm to 6.58 ± 0.77 cm. The clusters V, IV, II, III and I recorded the bulb length of 4.17 cm, 5.49 ± 0.81 cm, 5.67 ± 0.09 cm, 6.07 ± 1.03 cm and 6.58 ± 0.77 cm respectively. Cluster V recorded the lowest cluster mean values of 4.17 for bulb length and cluster I recorded the highest 6.58 ± 0.77 (Tables 9a and 9b).

4.3.19 Bulb diameter

Bulb diameter of the accessions/ varieties varied from 6.08 cm to 10.11 cm. Thamarachakka recorded the lowest bulb diameter of 6.80 cm and Acc 5 recorded the highest diameter of 10.11 cm (Tables 7a and 7b).

The cluster means for the weight of the bulb diameter ranged from 6.10 cm to 8.60 ± 0.62 cm. The clusters V, II, IV, III and I recorded the bulb diameter of 6.10 cm, 7.80 ± 0.72 cm, 7.80 ± 1.34 cm, 8.20 ± 1.28 cm and 8.60 ± 0.62 cm

respectively. Cluster V recorded the lowest cluster mean value of 6.10 cm for bulb diameter and cluster I recorded the highest of 8.60 ± 0.62 cm (Tables 9a and 9b).

4.3.20 Bulb shape

Wide variability was noticed among the accessions/varieties with respect to bulb shape (Plate 15 to 17). Different bulb shapes *viz.,* spheroid, twisted, and rectangular shapes were observed among the accessions and varieties (Tables 7a and 7b). Cluster I, III and IV exhibited fruits with spheroid, twisted and rectangular bulb shapes. Cluster II had fruits with twisted and rectangular bulb shape and spheroid shape was noticed in Cluster V (Tables 9a and 9b).

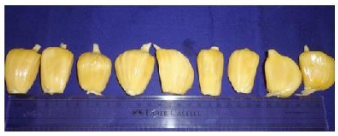
4.3.21 Pulp flavour

Strong and intermediate pulp flavour was observed in different accessions/varieties whereas strong pulp flavour was found in majority of the accessions/varieties. Strong pulp flavour was noticed in all accessions except Acc 1, Acc 3, Acc 5, Acc 6, Acc 7 and Acc 8 (Tables 7a and 7b).In Cluster I fruits with intermediate pulp flavour was included. In Cluster II intermediate and strong pulp flavour was observed where as Clusters III, IV and V contained fruits with strong flavoured pulp (Tables 9a and 9b).

4.3.22 Pulp colour

Pulp colour of the fruit varied from creamy white, yellow, deep yellow and coppery red. Among these deep yellow colour pulp was more common among the accessions/varieties. Deep yellow pulp colour was observed in all accessions except Acc 1, Acc 2, Acc 3, Acc 4, Acc 5, Acc 7, Acc and Sindoor (Tables 7a and 7b).Deep yellow and yellow pulp colour was observed in Cluster I. Cluster II, IV and V exhibited fruits with yellow pulp colour. Fruits with Coppery red, deep yellow and yellow pulp colour were recorded in Cluster III (Tables 9a and 9b).

Accession no. 1



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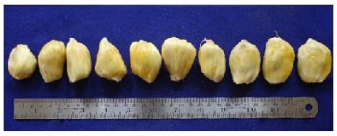
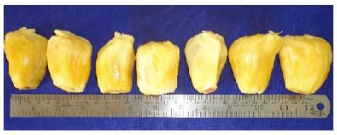


Accession no. 3

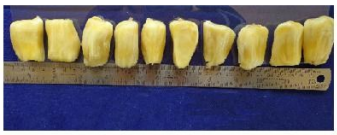
Accession no. 4



Accession no. 5

Accession no. 6

Accession no. 7



Accession no. 8

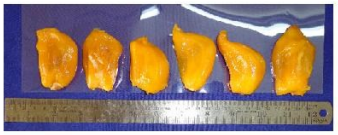
Plate 15. Flake shapes of jackfruit acessions

Accession no. 9

Accession no. 10

Accession no. 11

Accession no. 12



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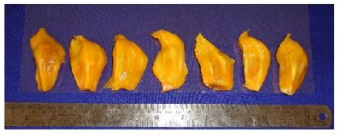
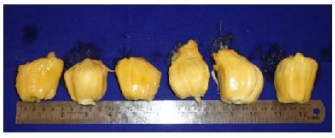


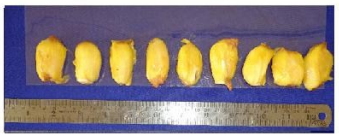
Accession no. 14

Accession no. 15



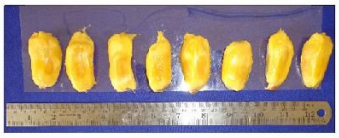
Accession no. 16

Plate 16. Flake shapes of jackfruit acessions



Accession no. 17

Accession no. 18



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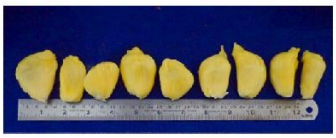

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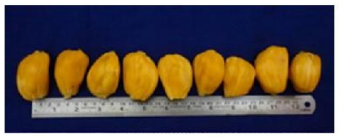
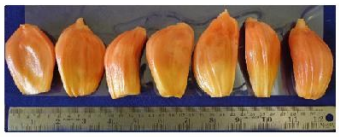
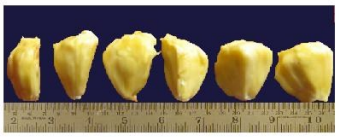


Mutton Varikka



Sindoor



Thamarachakka

Plate 17. Flake shapes of jackfruit acessions/ varieties

4.3.23 Pulp consistency

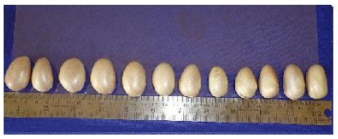
Medium, firm, soft and slimy pulp consistency was noticed in different accessions/varieties. Whereas medium pulp consistency were observed among the majority of the accessions (Tables 7a and 7b).Medium and firm pulp consistency was observed in Clusters I, II and III. Fruits with slimy and soft pulp consistency were noticed in Cluster IV whereas the fruit pulp was with medium consistency in Cluster V (Table 9a and 9b).

4.3.24 Number of seeds

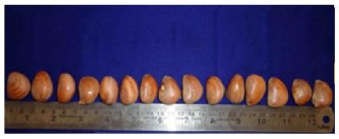
Number of seeds per fruit varied from 44 to 482 (Plate 18 to 20). Thamarachakka recorded the least number of 44 seeds and Acc 9 recorded the highest number of 482 seeds (Tables 7a and 7b).The cluster means for the number of seeds ranged from 44.00 to 369.00 ± 55.15. The clusters V, IV, I, III and II recorded the number of seeds as 44.00 , 195.80 ± 50.50 , 261.38 ± 58.86 ,338.20 ± 156.86 and 369.00 ± 55.15 respectively. Cluster V recorded the lowest value of 44.00 for number of seeds and cluster II recorded the highest value of 369.00 ± 55.15 (Tables 9a and 9b).

4.3.25 100-seed weight

100 seed weight varied from 240 to 800. Thamarachakka recorded the least weight of 240 g and Acc 3, 4, 5 recorded the highest weight of 800 g (Tables 7a and 7b).The cluster means for 100-seed weight ranged from 240.00 g to 687.50 ± 103.08 g. The clusters V, III, II, IV and I recorded the values of 240.00 g, 606.70 ± 126.91 g, 650.00 ± 70.71 g, 665.20 ± 87.22 g and 687.50 ± 103.08 g respectively. Cluster V recorded 240 g and cluster I had the highest value of 687.50 ± 103.08 g (Tables 9a and 9b).

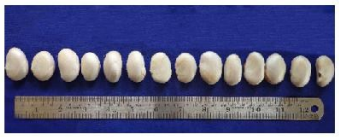


Accession no. 1



Accession no. 2

Accession no. 3



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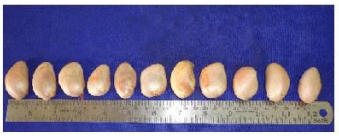


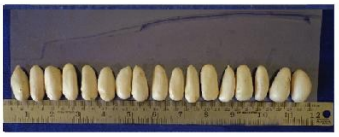
Accession no. 5

Accession no. 6

Accession no. 7

Accession no. 8

Plate 18. Seeds of jackfruit acessions



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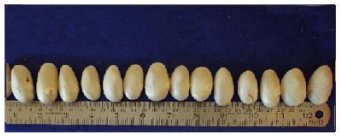
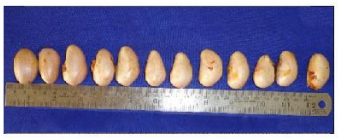
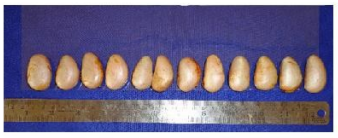


Accession no. 10

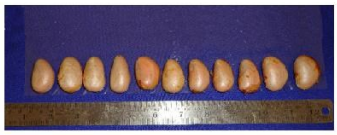


Accession no. 11

Accession no. 12

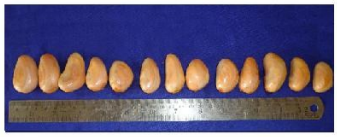


Accession no. 13



Accession no. 14

Accession no. 15

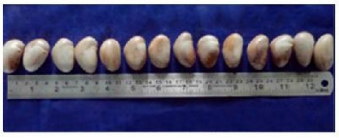


Accession no. 16

Plate 19. Seeds of jackfruit acessions

Accession no. 17

Accession no. 18



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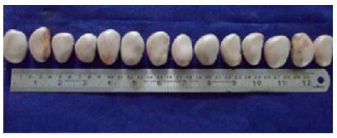
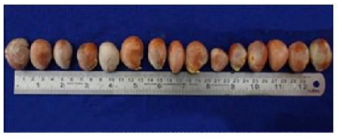
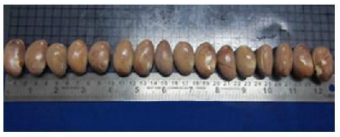


Accession no. 20



Muttom Varikka



Sindoor

Thamarachakka

Plate 20. Seeds of jackfruit acessions/ varieties

Fruit characters	Table 7a. Fruit characters of the accessions 1 to 11										
	ACC1	**ACC2**	**ACC3**	**ACC4**	**ACC5**	**ACC6**	**ACC7**	**ACC8**	**ACC9**	**ACC10**	**ACC11**
Fruiting season	Jan - March	Jan - March	Jan - March	Jan - March	Jan - March	Jan - March	Jan - March	Jan - March	Jan - March	Jan - March	Feb - May
Fruit clustering habit	Clusters	Clusters	Solitary	Solitary	Clusters	Clusters	Clusters	Clusters	Solitary	Solitary	Clusters
Fruit number	21.00	31.00	27.00	36.00	20.00	41.00	32.00	27.00	43.00	33.00	54.00
Fruit shape	Ellipsoid	Ellipsoid	Ellipsoid	Ellipsoid	Ellipsoid	Ellipsoid	Ellipsoid	Clavate	Ellipsoid	Ellipsoid	Ellipsoid
Fruit surface	Spiny	Spiny	Spiny	Spiny	Spiny	Spiny	Spiny	Spiny	Spiny	Spiny	Spiny
Fruit weight (kg)	16.50	11.00	11.00	11.50	9.00	10.00	20.00	10.50	6.50	12.00	7.50
Fruit yield (kg/plant)	346.50	341.00	297.00	414.00	180.00	410.00	640.00	283.50	279.50	396.00	405.00
Shelf life (days)	4	5	5	5	4	4	4	4	4	5	3
Latex exudation	Medium	High	Medium	High	High	Medium	High	Medium	High	Medium	High
Rind colour	Green	Green	Green	Greenish yellow	Greenish yellow	Green	Greenish yellow	Green	Greenish yellow	Greenish yellow	Greenish yellow
Rind thickness (cm)	2.00	1.30	2.50	2.00	0.90	0.40	1.20	1.20	1.50	0.50	0.30
Core length (cm)	32.00	47.00	44.00	40.00	47.00	43.00	50.50	25.00	31.00	34.00	26.00
Core thickness (cm)	8.00	6.00	5.00	5.00	7.50	8.50	13.90	7.00	5.00	10.00	7.00
Number of flakes per kg of fruit	17.09	37.55	18.64	12.61	27.44	32.80	16.25	21.90	74.15	35.67	24.67
Weight of flake with seed (g)	33.91	25.58	33.55	29.75	34.64	27.58	31.31	31.08	24.29	30.94	31.41
Length of flake	7.53	4.81	6.53	6.02	6.66	5.65	6.54	6.62	5.08	6.33	6.06
Weight of flake without seed (g)	27.08	22.47	28.5	25.21	28.81	24.18	26.38	26.93	22.28	26.12	27.345
Flesh thickness (mm)	6.51	1.55	3.06	4.62	4.90	2.50	3.47	2.61	4.80	7.8	1.305
Bulb diameter (cm)	9.35	7.285	8.71	8.315	10.11	8.505	8.215	7.855	6.375	7.97	8.635
Bulb shape	Spheroid	Twisted	Spheroid	Spheroid	Twisted	Rectangular	Rectangular	Twisted	Twisted	Rectangular	Twisted
Pulp flavour	Intermediate	Strong	Intermediate	Strong	Intermediate	Intermediate	Intermediate	Intermediate	Strong	Strong	Strong
Pulp colour	Yellow	Yellow	Yellow	Yellow	Creamy white	Deep yellow	Yellow	Deep yellow	Deep yellow	Deep yellow	Deep yellow
Pulp consistency	Medium	Medium	Medium	Firm	Firm	Firm	Firm	Medium	Medium	Firm	Soft
Number of seeds	282	413	205	145	247	328	325	230	482	428	185
100 seed weight (g)	750	600	800	800	800	600	700	600	400	600	750
Rind, flake and seed ratio	6.75	3.65	7.31	5.67	6.00	4.41	6.82	4.67	3.46	5.30	4.60

Fruit characters	Table 7b. Fruit characters of accessions (12 to 20), Sindoor (S), MuttomVarikka (MV), Thamarachakka (TC)											
	ACC12	**ACC13**	**ACC14**	**ACC15**	**ACC16**	**ACC17**	**ACC18**	**ACC19**	**ACC20**	**S**	**MV**	**TC**
Fruiting season	Feb - May	Feb - May	Feb - March	Feb - May	Feb - April	Feb - March	Feb - May	Feb -May	Feb - April	Jan - March	Jan - March	Jan - March
Fruit clustering habit	Solitary	Clusters	Clusters	Clusters	Solitary	Clusters	Clusters	Clusters	Clusters	Clusters	Clusters	Clusters
Fruit number	47.00	59.00	135.00	22.00	21.00	79.00	108.00	83.00	26.00	29.00	34.00	25.00
Fruit shape	Ellipsoid	Ellipsoid	Oblong	Ellipsoid	Ellipsoid	Ellipsoid	Ellipsoid	Ellipsoid	Ellipsoid	Ellipsoid	Irregular	Obloid
Fruit surface	Spiny	Spiny	Spiny	Spiny	Spiny	Spiny	Spiny	Spiny	Spiny	Spiny	Spiny	Smooth
Fruit weight (kg)	9.0	10.50	11.80	9.80	6.00	7.50	6.00	7.25	5.50	12.50	7.85	1.65
Fruit yield (kg/plant)	423.00	619.50	1593	215.60	126.00	592.50	648.00	601.75	143.00	362.50	266.90	41.25
Shelf life (days)	4	3	3	3	3	4	4	4	4	5	5	5
Latex exudation	Medium	Medium	Medium	Medium	High	High	High	Medium	Medium	High	Medium	Medium
Rind colour	Greenish yellow	Greenish yellow	Greenish yellow	Greenish yellow	Greenish yellow	Greenish yellow	Green	Greenish yellow	Greenish Yellow	Greenish yellow	Greenish yellow	Green
Rind thickness (cm)	0.30	0.50	0.90	1.80	1.80	1.50	1.70	1.80	2.00	2.90	1.50	0.50
Core length (cm)	22.00	25.00	31.00	22.00	20.00	21.00	24.00	21.00	23.00	20.50	36.50	10.20
Core thickness (cm)	8.00	8.00	7.00	8.00	6.00	8.00	8.00	7.00	5.00	5.80	2.50	4.50
Number of flakes per kg of fruit	21.44	18.57	16.61	19.90	27.17	18.13	35.00	44.83	29.09	34.40	16.69	26.67
Weight of flake with seed (g)	31.04	31.63	29.52	27.89	27.60	25.20	24.65	26.77	26.57	26.96	26.39	16.69
Length of flake	6.63	6.30	6.13	5.64	5.29	4.65	4.21	5.38	4.60	7.63	6.58	4.17
Weight of flake without seed (g)	27.33	28.14	26.84	23.10	23.75	22.01	21.10	23.14	22.56	22.50	19.73	10.79
Flesh thickness (mm)	2.44	1.48	2.78	1.61	3.90	1.33	1.26	3.11	1.95	2.35	6.39	1.28
Bulb diameter (cm)	8.80	8.63	7.80	7.39	7.96	6.85	7.13	7.04	7.45	8.93	10.01	6.08
Bulb shape	Twisted	Twisted	Rectangular	Spheroid	Twisted	Spheroid	Twisted	Twisted	Twisted	Twisted	Twisted	Spheroid
Pulp flavour	Strong	Strong	Strong	Strong	Strong	Strong	Strong	Strong	Strong	Strong	Strong	Strong
Pulp colour	Deep yellow	Deep yellow	Deep yellow	Deep yellow	Deep yellow	Deep yellow	Deep yellow	Deep yellow	Deep yellow	Coppery red	Deep yellow	Deep yellow
Pulp consistency	Soft	Soft	Slimy	Slimy	Slimy	Soft	Slimy	Soft	Slimy	Medium	Firm	Medium
Number of seeds	193	195	196	195	163	136	210	325	160	430	131	44
100 seed weight (g)	750	750	670	600	760	600	500	622	650	620	620	240
Rind, flake and seed ratio	7.00	5.40	5.84	4.60	3.00	3.46	4.25	4.48	3.95	5.28	2.91	2.30

Fig 10. Dendrogram of fruit characters

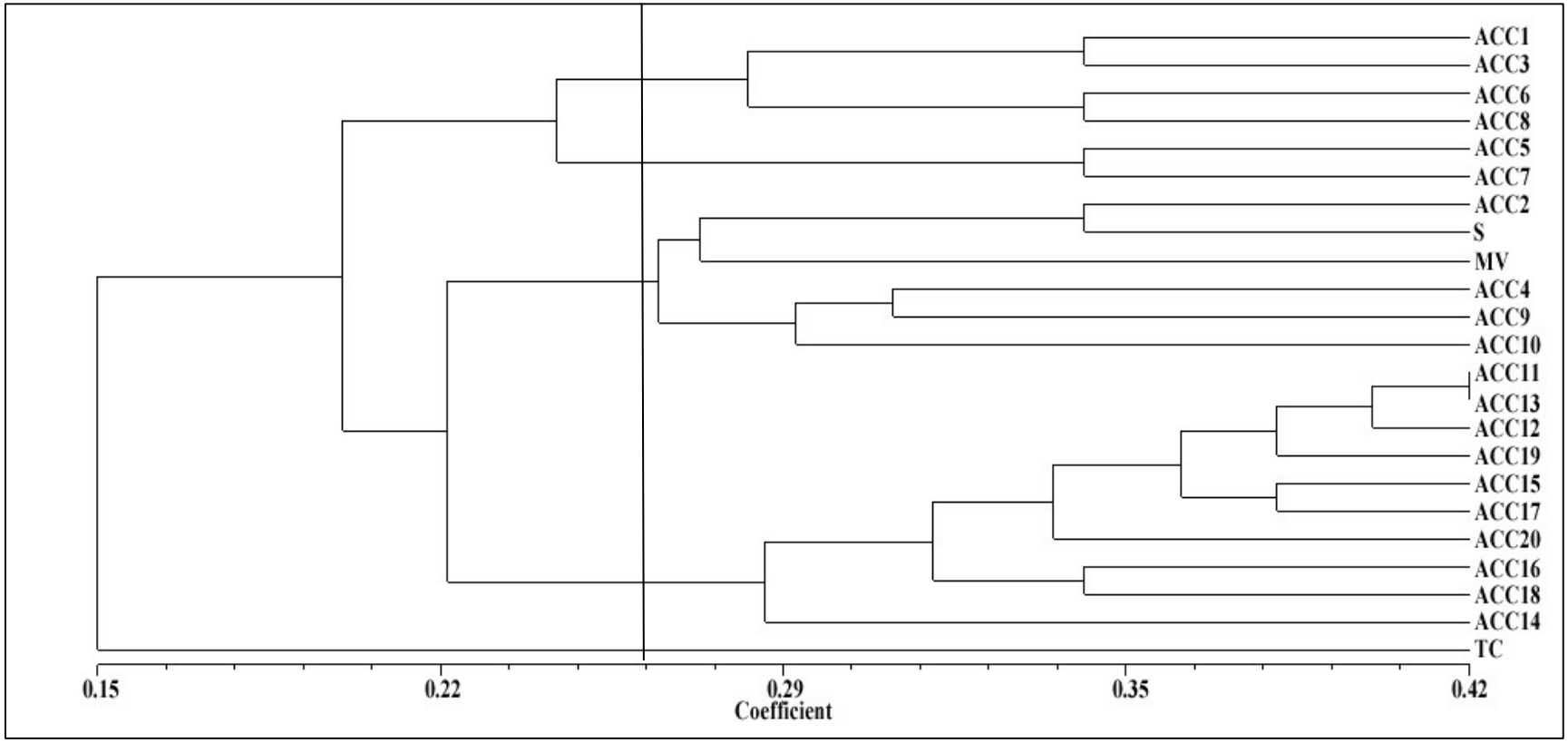


Table 8.Cluster wise listing of accessions according to fruit characters

Clusters				
I	**II**	**III**	**IV**	**V**
Acc 1	Acc 5	Acc 2	Acc 11	TC
Acc 3	Acc 7	Sindoor	Acc 13	
Acc 6		MV	Acc 12	
Acc 8		Acc 4	Acc 19	
		Acc 9	Acc 15	
		Acc 10	Acc 17	
			Acc 20	
			Acc 16	
			Acc 18	
			Acc 14	

Table 9a.Clusterwise summary statistics of fruit characters

Characters	**Clusters**				
	I	**II**	**III**	**IV**	**V**
Fruiting season	Jan-March	Jan-March	Jan-March	Feb-May	Jan-March
Fruit clustering habit	Solitary, Clusters	Clusters	Solitary, Clusters	Solitary, Clusters	Clusters
Fruit number	29.00 ± 8.49	31.50 ± 8.47	34.33 ± 4.89	63.40 ± 38.05	25.00
Fruit shape	Ellipsoid, Clavate	Ellipsoid	Ellipsoid, Oblong	Ellipsoid, Oblong	Obloid
Fruit surface	Spiny	Spiny	Spiny	Spiny	Smooth
Fruit weight (kg)	12.00± 3.03	15.50 ± 7.78	10.23± 2.45	8.09 ± 2.11	1.65
Fruit yield (kg/plant)	334.25 ± 57.30	490.50 ± 325.27	343.32 ± 60.10	536.74 ± 421.56	41.25
Shelf life (Days)	4	5	5	4	5
Latex exudation	Medium	High	Low, Medium, High	Medium, High	Low
Rind colour	Green	Green, Greenish yellow	Green, Greenish yellow	Green, Greenish yellow	Green
Rind thickness (cm)	1.53 ± 0.92	1.25 ± 0.21	1.62 ± 2.80	1.26 ± 0.69	0.50
Core length (cm)	36.00 ± 9.13	48.75 ± 2.47	34.84 ± 8.93	23.50 ± 3.24	10.20
Core thickness (cm)	7.13 ± 1.55	9.95 ± 4.53	5.72 ± 2.44	7.20 ± 1.03	4.50

Table 9b.Cluster wise summary statistics of fruit characters

Characters	Clusters				
	I	II	III	IV	V
Number of flakes per kg of fruit	22.61 ± 7.08	21.85 ± 7.92	35.18 ± 21.80	25.54 ± 8.88	26.67
Weight of flake with seed (g)	31.53 ± 2.92	28.44± 2.35	27.32 ± 2.54	28.23 ± 2.55	16.69
Length of flake (bulb)	6.58± 0.77	5.67± 0.09	6.07± 1.03	5.49 ± 0.81	4.17
Weight of flake without seed (g)	26.67 ± 1.81	24.43 ± 1.71	23.05 ± 2.30	24.71 ± 2.43	10.79
Flesh thickness (mm)	3.70 ± 1.91	2.50 ± 1.01	4.40 ± 2.36	2.20 ±0.91	1.30
Bulb diameter (cm)	8.60 ± 0.62	7.80 ± 1.34	8.20 ± 1.28	7.80 ± 0.72	6.10
Bulb shape	Spheroid, Twisted, Rectangular	Twisted, Rectangular	Spheroid, Twisted, Rectangular	Spheroid, Twisted, Rectangular	Spheroid
Pulp flavour	Intermediate	Intermediate, Strong	Strong	Strong	Strong
Pulp colour	Yellow, Deep yellow	Yellow	Coppery red, Deep yellow, Yellow	Deep yellow	Deep yellow
Pulp consistency	Medium, Firm	Medium, Firm	Medium, Firm	Slimy, Soft	Medium
Number of seeds	261.30 ± 58.86	369.00 ± 55.15	338.20 ±156.86	195.80 ± 50.50	44.00
100 seed weight (g)	687.50± 103.08	650.00 ± 70.71	606.70 ± 126.91	665.20 ± 87.22	240.00
Rind, flake and seed ratio	5.79 ± 1.46	6.41 ± 0.58	4.37 ± 1.17	4.66 ± 1.17	2.30

4.3.26 Rind, flake and seed ratio

Rind, flake and seed ratio varied from 2.30 to 7.31. Thamarachakka recorded the lowest ratio of 2.30 and Acc 3 recorded the highest ratio of 7.31 (Tables 7a and 7b).Rind, flake and seed ratio ranged from 2.30 to 6.41 ± 0.58. The Clusters V, III, IV, I and II recorded values of 2.30, 4.37 ± 1.17, 4.66 ± 1.17, 5.79 ± 1.46 and 6.41 ± 0.58 respectively. Cluster V recorded the lowest ratio of 2.30 for this and cluster II showed the highest value of 6.41 ± 0.58 (Tables 9a and 9b).

4.4 Fruit quality parameters

4.4.1 Sensory evaluation

In jackfruit, colour, sweetness, taste, flavour, appearance and texture contribute to the fruit quality. Hence for quality assessment, sensory evaluation was carried out on a nine point Hedonic scale using score card for seven attributes namely appearance, sweetness, colour, texture, flavour and taste. Each character was scored on the scale and ranking was given based on Kendall's coefficient of concordance. Sensory evaluation was conducted using ripe fruits and the ranking on the sensory evaluations are given in Table 10. Among the twenty accessions and three varieties, the highest rank for appearance was given for Acc 5, followed by Acc 3 and Sindoor. For colour highest rank was given for Sindoor followed by Acc 1 and Acc 5. Accession 5 was given the highest rank for flavour followed by Acc 1 and Sindoor. Accession 1 recorded highest rank for sweetness followed by Acc 3 and Acc 5. Accession 1 also recorded highest rank for taste followed by Sindoor and Acc 5. Accession 3 was given highest rank for texture followed by Acc 5 and Acc 9.

4.4.2 Biochemical analysis

Results of the observations recorded on biochemical characters are presented in Tables 11a and 11b. At the similarity coefficient status of 7%, grouping ofaccessions was done which resulted in 14 non – overlapping clusters.

Sensory evaluation of jackfruit accessions/ varieties by Kendall's coefficient of concordance											
APPEARNCE		COLOUR		FLAVOUR		SWEETNESS		TASTE		TEXTURE	
	Rank Mean		Rank mean		Rank Mean		Rank Mean		Rank Mean		Rank Mean
Acc 5	21.05	**Sindoor**	20.15	**Acc5**	20.7	**Acc1**	18.55	**Acc1**	20.90	**Acc3**	21.45
Acc3	20.80	**Acc1**	20.10	**Acc1**	20.55	**Acc3**	17.90	**Sindoor**	20.75	**Acc5**	20.60
Sindoor	20.20	**Acc5**	17.35	**Sindoor**	19.65	**Acc5**	17.10	**Acc5**	18.85	**Acc9**	19.95
Acc2	19.70	**Acc2**	14.45	**Acc3**	18.65	**Sindoor**	16.40	**Acc3**	18.8	**Acc2**	19.05
Acc9	19.15	**Acc3**	14.40	**Acc2**	18.5	**TC**	16.10	**Acc2**	18.6	**Sindoor**	18.75
Acc1	18.75	**Acc9**	14.30	**Acc9**	17.2	**Acc10**	14.45	**Acc9**	17.55	**Acc1**	17.50
MV	16.90	**MV**	14.05	**Acc10**	17.2	**Acc2**	13.95	**Acc10**	17.25	**Acc7**	17.05
Acc7	16.05	**Acc11**	13.35	**MV**	15.6	**Acc20**	13.95	**MV**	17.20	**Acc10**	16.10
Acc10	15.35	**Acc17**	13.05	**Acc7**	12.75	**Acc15**	13.10	**Acc7**	14.80	**MV**	15.60
TC	13.90	**Acc19**	13.05	**Acc4**	12.65	**Acc12**	12.90	**TC**	13.85	**Acc8**	14.95
Acc6	12.55	**Acc14**	12.00	**Acc6**	11.5	**Acc18**	12.25	**Acc4**	13.10	**TC**	13.70
Acc4	11.85	**Acc12**	11.65	**TC**	11.2	**Acc17**	11.85	**Acc6**	13.05	**Acc6**	13.40
Acc8	11.60	**Acc18**	10.75	**Acc8**	11.00	**Acc11**	11.85	**Acc8**	12.00	**Acc4**	12.15
Acc13	7.35	**Acc10**	10.65	**Acc14**	9.30	**Acc16**	11.60	**Acc12**	7.20	**Acc19**	6.45
Acc15	6.75	**Acc16**	9.65	**Acc15**	7.70	**MV**	11.10	**Acc19**	6.80	**Acc13**	6.40
Acc14	6.35	**Acc15**	9.55	**Acc11**	7.60	**Acc19**	10.95	**Acc15**	6.55	**Acc16**	5.90
Acc20	6.30	**Acc20**	9.45	**Acc13**	7.15	**Acc14**	10.45	**Acc13**	6.50	**Acc12**	5.60
Acc16	5.95	**Acc7**	9.35	**Acc17**	7.00	**Acc13**	9.70	**Acc20**	6.40	**Acc11**	5.40
Acc12	5.60	**Acc13**	8.80	**Acc20**	6.80	**Acc6**	9.20	**Acc11**	5.85	**Acc18**	5.40
Acc18	5.15	**Acc6**	8.45	**Acc12**	6.65	**Acc7**	8.60	**Acc14**	5.75	**Acc14**	5.30
Acc11	5.00	**Acc4**	8.25	**Acc18**	5.75	**Acc4**	5.50	**Acc17**	5.40	**Acc17**	5.25
Acc17	5.00	**TC**	7.85	**Acc16**	5.6	**Acc9**	5.45	**Acc16**	5.20	**Acc15**	5.15
Acc19	4.70	**Acc8**	5.35	**Acc19**	5.30	**Acc8**	3.10	**Acc18**	3.65	**Acc20**	4.90

Cluster wise listing of accessions according to inflorescence characters are listed in Table 12. Cluster III and XII had the highest number of accessions (3) and Clusters II, V, VIII, IX, X, XI and XIII had the lowest number of accession (1).

4.4.2.1 Moisture

Moisture content of the accession /varieties varied from 29 to 74 per cent. Accession 9 recorded the least moisture of 29 per cent whereas Acc 17 recorded the highest moisture of 74 per cent (Tables 11a and 11b).

The cluster means for moisture ranged from 29.00 to 74.00 per cent. Cluster VIII recorded the lowest value of 29.00 per cent and Cluster XIII recorded the highest value of 74.00 per cent (Table 13).

4.4.2.2 TSS

T.S.S of the accessions/varieties ranged from 20.30 to 33.80 ^{o}Brix. Accession 15 recorded the lowest TSS of 20.30 ^{0}Brix and Thamarachakka recorded the highest value of 32 ^{o}Brix (Tables 11a and 11b).

The cluster means for TSS ranged from 20.60 to 33.80 0 Brix. Cluster V recorded the lowest TSS and cluster II recorded the highest TSS (Table 13).

4.4.2.3 Total sugars

Total sugar of the accessions/varieties ranged from 15.66 to 22.72 per cent. Acc 16 recorded the lowest value of 15.86 per cent and Acc 19 recorded the highest value of 22.72 per cent (Tables 11a and 11b).

The cluster means for total sugar ranged from 15.66 to 22.48 per cent. The Clusters VIII, X, V, VII, XIV, XII, III, XII, IV, IX, I, XI, VI and II recorded the total sugars of 15.66, 15.94, 16.32, 16.64 ± 1.10, 16.80 ± 0.80, 17.61, 17.84 ± 1.78, 18.22 ± 0.66, 18.45 ± 0.54, 19.59, 19.97, 20.84, 21.81 ± 1.29 and 22.48 per cent respectively (Table 13).

4.4.2.4 Reducing sugar

Reducing sugar of the accessions/ varieties ranged from 6.61 to 13.16 per cent. Acc 17 recorded the lowest value of 6.61 per cent and Acc 4 recorded the highest value of 13.16 per cent (Tables 11a and 11b).

The cluster means for reducing sugar ranged from 6.61 (Cluster XIII) to 11.01 ± 1.43 per cent (Cluster I). The clusters XIII, V, VIII, VII, XIV, IX, XII, VI, II, XI, X, III, IV and I recorded the reducing sugar of 6.61, 7.14, 7.18, 7.35, 7.62, 7.86, 8.58 ± 1.04, 8.62, 9.19, 10.51, 10.78, 10.84 ± 0.05, 10.86 ± 3.25 and 11.01 ± 1.43 per cent respectively (Table 13).

4.4.2.5 Non-reducing sugars

Non reducing sugar of the different accessions/varieties ranged from 5.16 to 13.29 per cent. Accession 8 recorded the lowest value of 5.16 % and Thamarachakka recorded the highest value of 13.29 per cent (Tables 11a and 11b).

The cluster means for non-reducing sugars ranged from 5.16 (Cluster X) to 13.29 % (Cluster II). The clusters X, III, IV, VIII, I, XIV, V, VII, XII, XI, XIII, V, VI and II recorded the non-reducing sugar of 5.16, 7.00 ± 1.73, 7.59 ± 2.70, 8.48, 8.96 ± 1.43, 9.12 ± 0.80, 9.18, 9.29 ± 1.10, 9.64 ± 0.80, 10.33, 11.00, 11.73, 13.19 ± 1.29 and 13.29 per cent respectively (Table 13).

4.4.2.7 β-carotene

β-carotene of different accessions /varieties ranged from 0.75 mg/100 g to 12.94 mg/100 g. Acc 10 recorded the lowest value whereas Muttom Varikka recorded the highest value of 12.94 mg/100 g (Tables 11a and 11b).

The cluster means for β-carotene ranged from 0.09 (Cluster V) to 7.27± 8.03 mg/100g (Cluster XIV). The clusters V, II, XIII, XII, X, I, III, VIII, IV, IX, VI, XI, VIII and XIV recorded the value of 0.09, 0.46, 0.79, 0.95 ± 1.19, 1.07, 1.69±0.86, 2.99 ± 2.69, 3.71, 3.72 ±2.43, 4.11, 4.49 ± 1.06, 4.68, 6.30 ± 0.43 and 7.27 ± 8.03 mg/100g respectively (Table 13).

Table 11a. Biochemical characters of accessions(1 to 12)

Characters	ACC1	ACC2	ACC3	ACC4	ACC5	ACC6	ACC7	ACC8	ACC9	ACC10	ACC11	ACC12
Moisture (%)	65.00	62.00	66.00	56.00	50.00	61.00	44.00	49.00	29.00	45.00	56.00	57.00
TSS (°Brix)	31.30	29.00	30.00	28.00	28.00	28.70	32.00	21.10	27.00	31.50	31.20	26.80
Total sugar (%)	19.97	18.12	19.97	18.83	19.47	18.6	20.84	15.94	19.59	18.6	18.06	17.36
Reducing sugar (%)	12.02	10.87	10.00	13.16	10.87	8.17	10.51	10.78	7.86	9.77	8.56	7.62
Non reducing sugar (%)	7.95	7.25	9.97	5.67	8.60	10.43	10.33	5.16	11.73	8.83	9.50	9.74
β carotene (mg/100g)	1.08	1.84	2.30	2.00	6.06	0.99	4.68	1.07	4.11	0.75	5.44	1.59
Carotenoids (mg/100g)	1.75	3.45	0.79	0.90	3.48	0.47	0.10	1.09	0.66	0.26	1.97	5.62

Table 11b. Biochemical characters of accessions(13 to 20), Sindoor (S), MuttomVarikka (MV), Thamarachakka (TC)

Characters	ACC13	ACC14	ACC15	ACC16	ACC17	ACC18	ACC19	ACC20	S	MV	TC
Moisture (%)	53.00	58.00	41.00	32.00	74.00	50.00	67.00	73.00	56.00	64.00	53.00
TSS (°Brix)	28.70	31.90	20.30	24.50	21.00	20.60	29.00	25.50	28.00	25.00	33.8
Total sugar (%)	17.46	20.90	17.41	15.66	17.61	16.32	22.72	15.86	17.40	16.23	22.48
Reducing sugar (%)	7.81	8.62	7.35	7.18	6.61	7.14	8.62	7.35	7.44	7.62	9.19
Non- reducing sugar (%)	9.65	12.28	10.06	8.48	11.00	9.18	14.10	8.51	9.96	8.61	13.29
β carotene (mg/100g)	1.12	5.24	5.99	3.71	0.79	0.09	3.74	6.6	2.71	12.94	0.46
Carotenoids (mg/100g)	1.22	2.76	1.49	1.50	0.98	0.38	2.29	1.67	3.50	2.60	0.43

Fig 11. Dendrogram of biochemical characters

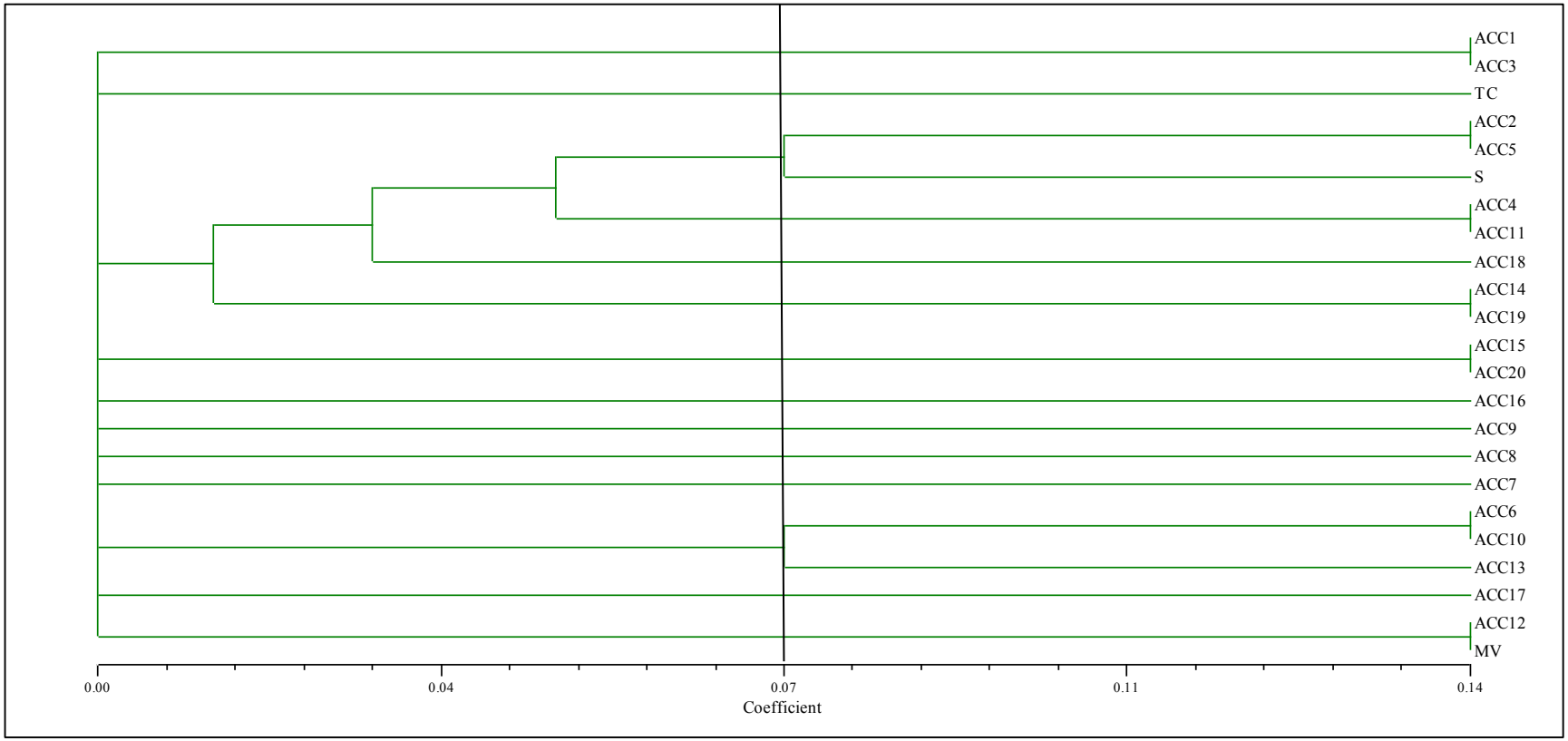


Table 12.Cluster wise listing of accessions according to the biochemical characters

Clusters													
I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**	**XIII**	**XIV**
Acc 1	TC	Acc 2	Acc 4	Acc 18	Acc 14	Acc 15	Acc 16	Acc 9	Acc 8	Acc 7	Acc 6	Acc 17	Acc 12
Acc 3		Acc 5	Acc 11		Acc 19	Acc 20					Acc 10		MV
		S									Acc 13		

Table 13.Clusterwise summary statistics of biochemical characters

Characters	Clusters													
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV
Moisture (%)	65.50 ± 0.71	53.00	53.67 ± 7.23	56.00	50.00	62.50 ± 6.36	57.00 ± 22.63	32.00	29.00	49.00	44.00	53.00 ± 8.00	74.00	60.50 ± 4.95
TSS (°Brix)	30.65 ± 0.92	33.80	26.03 ± 4.30	29.60 ± 2.26	20.60	30.45 ± 2.05	22.90 ± 3.68	24.50	27.00	21.10	32.00	29.63 ± 1.62	21.00	25.90 ± 1.28
Total sugar (%)	19.97	22.48	17.84 ± 1.78	18.45 ± 0.54	16.32	21.81 ± 1.29	16.64 ± 1.10	15.66	19.59	15.94	20.84	18.22 ± 0.66	17.61	16.80 ± 0.80
Reducing sugar (%)	11.01 ± 1.43	9.19	10.84 ± 0.05	10.86 ± 3.25	7.14	8.62	7.35	7.18	7.86	10.78	10.51	8.58 ± 1.04	6.61	7.62
Non reducing sugar (%)	8.96 ± 1.43	13.29	7.00 ± 1.73	7.59 ± 2.70	9.18	13.19 ± 1.29	9.29 ± 1.10	8.48	11.73	5.16	10.33	9.64 ± 0.80	11.00	9.12 ± 0.80
β carotene (mg/100g)	1.69 ± 0.86	0.46	2.99 ± 2.69	3.72 ± 2.43	0.09	4.49 ± 1.06	6.30 ± 0.43	3.71	4.11	1.07	4.68	0.95 ± 1.19	0.79	7.27 ± 8.03
Carotenoids (mg/100g)	1.27 ± 0.68	0.43	2.67 ± 1.37	1.44 ± 0.76	0.38	2.53 ± 0.33	1.58 ± 1.23	1.50	0.66	1.09	0.10	0.65 ± 0.50	0.98	4.11 ± 2.14

4.4.2.7 Total carotenoids

Carotenoids ranged from 0.1 to 5.62 mg/100 g. Accession 7 recorded the lowest carotenoids of 0.1 mg/100g where as Acc 12 recorded the highest value of 5.62 mg/100 g (Tables 11a and 11b).

The cluster means for total carotenoids ranged from 0.10 (Cluster XI) to 4.11 ± 2.14 mg/100g (Cluster XIV). The clusters XI, V, II, XII, IX, XIII, X, I, IV, VIII, VII, VI, III and XIV recorded the value of 0.10, 0.38, 0.43, 0.65 ± 0.50, 0.66, 0.98, 1.09, 1.27 ± 0.68, 1.44 ± 0.76, 1.50, 1.58 ± 1.23, 2.53 ± 0.33, 2.67 ± 1.37 and 4.11 ± 2.14 mg/100g respectively (Table 13).

4.5 Molecular characterization

The results of molecular characterization of twenty accessions and 3 varieties (Sindoor, Muttom Varikka and Thamarachakka of jackfruits was carried out using Inter Simple Sequence Repeats (ISSR). The results of the experiments are furnished below.

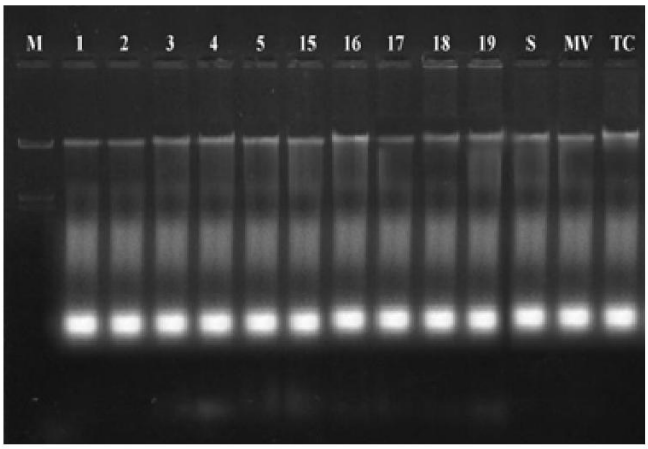
4.5.1 Isolation, purification and quantification of DNA

As reported in many other crops young leaves were selected as the ideal part for extraction of genomic DNA. The leaves were collected in the morning (6 to 7 am) from the trees. Young tender, pale green leaves (1g) yielded good quality DNA in sufficient quantity.

Genomic DNA isolated through Doyle and Doyle (1990) was not pure and had RNA contamination (Plate 1a). RNase treatment and further precipitation gave sufficient quantity of good quality DNA from leaf sample. The agarose gel electrophoresis indicated clear discrete band without RNA contamination (Plate 1b) and spectrophotometric analysis gave ratio of UV absorbance (A 260/280) between 1.8 and 2.0. Quality and quantity of DNA isolated through the Doyle and Doyle method for jackfruits are depicted in Plate 21 and Table14.

Table 14.Quality and quantity of DNA isolated from jackfruit genotypes by Nano Drop spectrophotometer

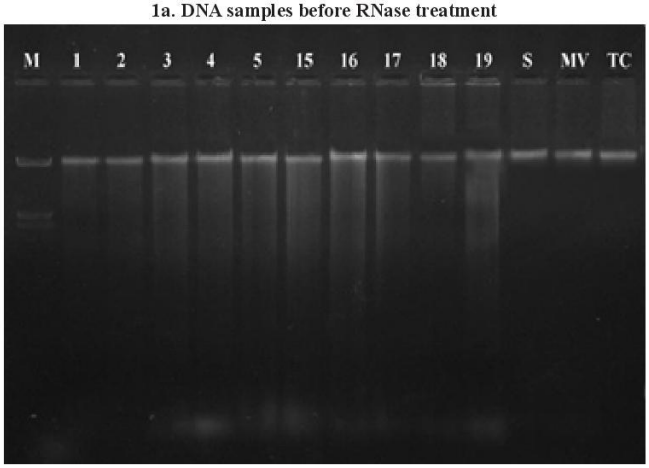
Accessions/ Varieties	UV absorbance at 260 nm (A_{260})	UV absorbance at 280 nm (A_{280})	A_{260}/A_{280}	Quantity(ng/µl)
Acc. 1	2.072	1.129	1.84	1981.80
Acc. 2	12.855	6.505	1.98	642.74
Acc. 3	3.897	1.959	1.99	194.83
Acc. 4	3.837	1.950	1.97	191.84
Acc. 5	9.375	4.703	1.99	468.73
Acc. 6	7.835	4.061	1.93	391.75
Acc. 7	9.006	4.617	1.95	450.30
Acc. 8	9.202	4.621	1.99	460.10
Acc. 9	10.833	5.685	1.91	541.66
Acc. 10	10.419	5.399	1.93	520.95
Acc. 11	9.865	5.070	1.95	493.24
Acc. 12	9.045	4.829	1.87	452.26
Acc. 13	2.586	1.348	1.92	132.02
Acc. 14	1.567	0.789	1.96	178.33
Acc. 15	4.343	2.308	1.88	345.76
Acc. 16	5.529	2.833	1.95	786.98
Acc. 17	17.498	8.604	2.03	874.89
Acc. 18	10.294	5.000	2.06	917.50
Acc. 19	16.607	8.231	2.02	118.89
Acc. 20	6.676	3.267	2.04	149.49
S	4.956	2.588	1.82	372.82
MV	0.640	0.354	1.81	256.81
TC	0.889	0.478	1.86	139.53



M: Molecular weight marker λ DNA (Hind III digest) Lane 1 to 19,S,MV and TC jack fruit DNA samples

1-Acc 1, 2-Acc 2, 3-Acc 3, 4-Acc 4, 5-Acc 5, 15-Acc 15, 16-Acc 16, 17-Acc 17, 18-Acc 18, 19-Acc 19, S-Sindoor, MV-Muttom Varikka and TC-Thamarachakka

1a. DNA samples before RNase treatment



M: Molecular weight marker λ DNA (Hind III digest) Lane 1 to 19,S,MV and TC jack fruit DNA samples

1b. DNA samples after RNase treatment

Plate 21. Isolation of DNA and its purification

4.5.2 Molecular Marker Analysis

The protocols for marker assays for ISSR are validated with bulked DNA of jackfruit varieties. Different primers were screened with the genomic DNA of 10 accessions and 3 varieties utilizing the validated protocols.

4.5.3 Inter Simple Sequence Repeat (ISSR) analysis

4.5.4 Primer screening for ISSR assay

The good quality genomic DNA isolated from jackfruit accessions were subjected to the ISSR assay. Fifty ISSR primers used for amplification of the genomic DNA with thermal settings mentioned earlier gave different amplification pattern (Plate 22 and Table 15) for the bulked DNA. From the amplified primers, 10 were selected for their reproducibility and polymorphism and used in the study and details are provided in Table16.

4.5.5 Amplification with selected ISSR primers

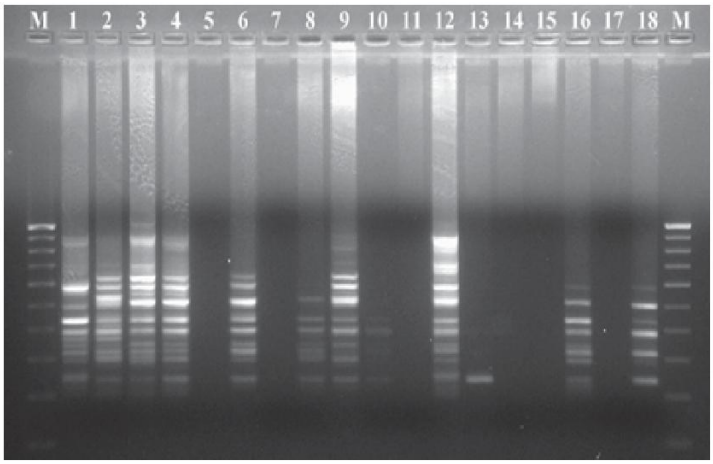
Characterization was done with 10 primers (Plate 23 and 24) so as to generate the ISSR data (Table 17). The details of amplification with 10 primers are as follows.

(1) **UBC 807**

The agarose gel profile for 23 genotypes of jackfruit with primer UBC 807 (Plate 23). The primer generated a total of nine clear, distinct and reproducible loci out of which four were polymorphic (Plate 23). The polymorphism was **44.45 per cent** and size of amplicons ranged from 400-1000 bps.

(2) **UBC 809**

The agarose gel profile for 23 genotypes of jackfruit with primer UBC 809 (Plate 23). The primer generated a total of ten clear, distinct and reproducible loci out of which eight were polymorphic (Plate 23). The polymorphism was **80.00 per cent** and size of amplicons ranged from 300-1000 bps.



M: Marker (100bp) ladder, 1-18: Amplification pattern with different ISSR primer

1-18: UBC 834, UBC 840, UBC 866, UBC 807, UBC 818, UBC 812, UBC 808, UBC 809, UBC 855, UBC 858, UBC 845, (TC) 10 G, UBC 817, UBC 818, UBC 810, UBC 825, UBC 880, UBC 826

Plate 22. Screening of ISSR primers for amplification of jackfruit genomic DNA

Table 15.Details of amplification with 50 primers screened for ISSR assay in jackfruit genotypes

Sl. No.	Amplification pattern				Remarks
	Primer	No. of bands	Types of bands		
			Distinct	Faint	
1	UBC 811	1	1	0	-
2	UBC 813	1	1	0	-
3	UBC 814	2	1	1	-
4	UBC 815	0	0	0	-
5	UBC 834	13	7	6	Selected
6	UBC 835	0	0	0	-
7	UBC 836	2	1	1	-
8	UBC 840	14	6	8	Selected
9	UBC 844	3	1	2	-
10	UBC 890	0	0	0	-
11	UBC 866	13	8	5	Selected
12	UBC 807	8	6	2	Selected
13	UBC 843	0	0	0	-
14	UBC 812	13	8	5	Selected
15	UBC 820	5	5	0	-
16	UBC 854	4	0	4	-
17	UBC 845	0	0	0	-
18	UBC 817	0	0	0	-
19	UBC 826	0	0	0	-
20	UBC 818	0	0	0	-
21	ISSR 04	0	0	0	-
22	ISSR 05	0	0	0	-
23	ISSR 06	0	0	0	-
24	ISSR 07	2	2	0	-
25	ISSR 08	2	0	2	-
26	ISSR 09	4	4	0	-
27	ISSR 10	2	1	1	-
28	ISSR 15	4	2	2	-
29	UBC 808	4	0	4	-
30	UBC 809	10	8	2	Selected
31	UBC 868	11	5	6	-
32	UBC 895	2	1	1	-
33	UBC 899	3	2	1	-
34	UBC 880	0	0	0	-
35	UBC 892	0	0	0	-
36	UBC 855	11	6	5	Selected
37	UBC 858	14	6	8	Selected
38	UBC 864	7	3	4	-
39	(ACTG)4	5	5	0	-
40	UBC 873	3	1	2	-
41	(GACAC)4	0	0	0	-
42	(TC)10G	14	10	4	Selected
43	(CT)10A	1	1	0	-
44	(CT)10G	2	1	1	-
45	UBC 841	14	5	9	Selected
46	UBC 830	0	0	0	-
47	UBC 900	0	0	0	-
48	UBC 825	0	0	0	-
49	UBC S2	0	0	0	-
50	UBC 810	0	0	0	-

Table 16. Details of ISSR primers selected for molecular assay

Sl. No.	Primer	Annealing temperature (^{0}C)	Nucleotide sequence (5'-3')
1	UBC 807	45	5'AGAGAGAGAGAGAGAGT3'
2	UBC 809	47	5'AGAGAGAGAGAGAGAGG3'
3	UBC 812	45	5'GAGAGAGAGAGAGAGAA3'
4	UBC 841	51	5'GAGAGAGAGAGAGAGATYC3'
5	UBC 855	49	5'ACACACACACACACACYT3'
6	UBC 858	49	5'TGTGTGTGTGTGTGTGRT3'
7	UBC 866	60	5'CTCCTCCTCCTCCTCCTC3'
8	UBC 834	44	5'AGAGAGAGAGAGAGAGYT3'
9	UBC 840	45	5'GAGAGAGAGAGAGAGAYT3'
10	TC10G	59	5'TCTCTCTCTCTCTCTCTCTCG3'

(3) **UBC 812**

The agarose gel profile for 23 genotypes of jackfruit with primer UBC 812 (Plate 23). The primer generated a total of nine clear, distinct and reproducible loci out of which five were polymorphic (Plate 23). The polymorphism was **55.56 per cent** and size of amplicons ranged from 300-1000 bps.

(4) **UBC 841**

The agarose gel profile for 23 genotypes of jackfruit with primer UBC 841 (Plate 23). The primer generated a total of 11 clear, distinct and reproducible loci out of which 9 were polymorphic (Plate 23). The polymorphism was **81.82 per cent** and size of amplicons ranged from 200-1000 bps.

(5)**UBC 855**

The agarose gel profile for 23 genotypes of jackfruit with primer UBC 855 (Plate 23). The primer generated a total of nine clear, distinct and reproducible loci out of which four were polymorphic (Plate 23). The polymorphism was **44.45 per cent** and size of amplicons ranged from 200-1000 bps.

(6)**UBC 858**

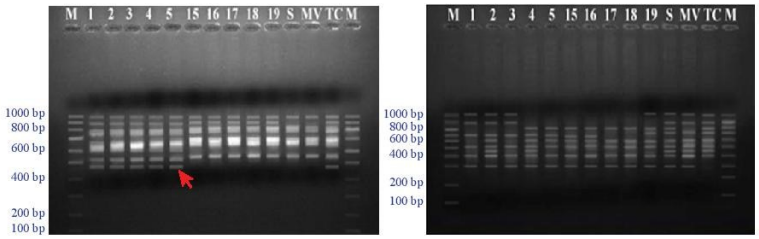
The agarose gel profile for 23 genotypes of jackfruit with primer UBC 858 (Plate 23). The primer generated a total of seven clear, distinct and reproducible loci out of which 2 were polymorphic (Plate 23). The polymorphism was **28.57 per cent** and size of amplicons ranged from 400-1000bps

(7)**UBC 866**

The agarose gel profile for 23 genotypes of jackfruit with primer UBC 866 (Plate 24). The primer generated a total of eight clear, distinct and reproducible loci out of which three were polymorphic (Plate 24). The

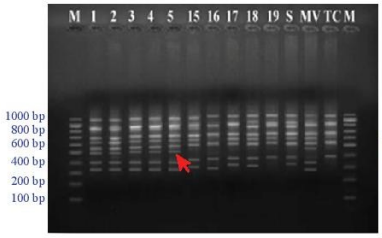
17. Details of amplification with selected primers for ISSR assay in jackfruit genotypes

Sl.No	Primer	Total number of amplicons	No. of monomorphic amplicons	No. of polymorphic amplicons	Polymorphism (%)	Size of the amplicons from range (bp)
1	UBC 807	9	5	4	44.45	400-1000
2	UBC 809	10	2	8	80.00	300-1000
3	UBC 812	9	4	5	55.56	300- 1000
4	UBC 841	11	2	9	81.82	200-1000
5	UBC 855	9	5	4	44.45	200 -1000
6	UBC 858	7	5	2	28.57	400- 1000
7	UBC 866	8	5	3	37.50	400-1000
8	UBC 834	9	5	4	44.45	200-1000
9	UBC 840	8	4	4	50.00	200-1000
10	TC10G	6	1	5	83.34	200-1000
Total		86	38	48	550.14	
Average		8.6	3.8	4.8	55.01	

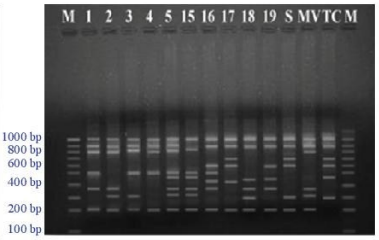


UBC 807

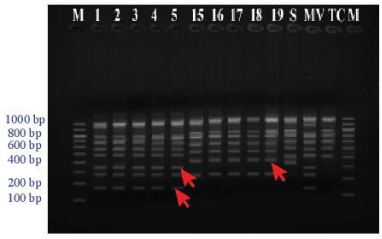
UBC 809



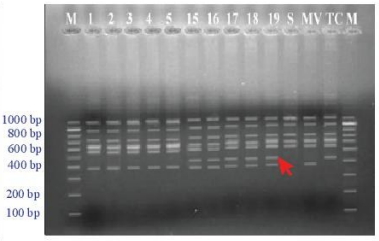
UBC 812



UBC 841



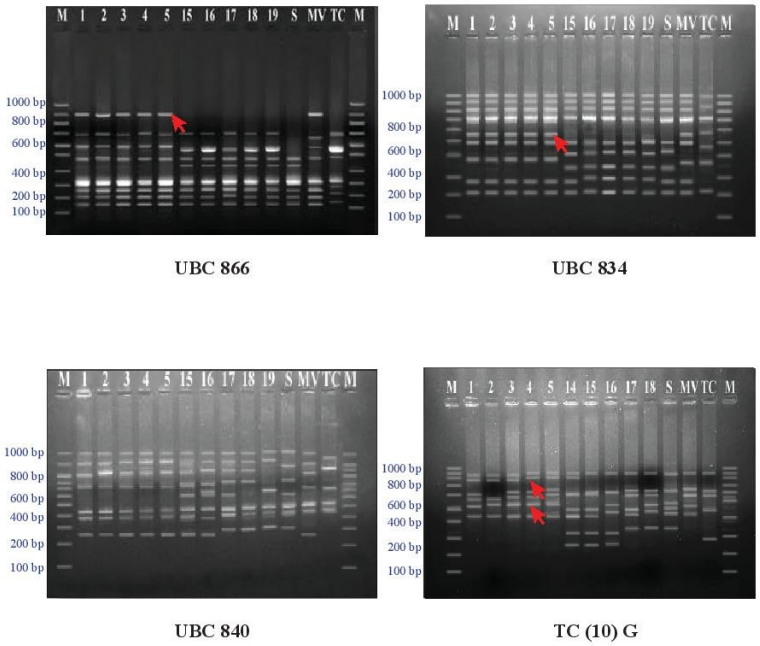
UBC 855



UBC 858

1-Acc 1, 2-Acc 2, 3-Acc 3, 4-Acc 4, 5-Acc 5, 15-Acc 15, 16-Acc 16, 17-Acc 17, 18-Acc 18, 19-Acc 19, S-Sindoor, MV-Muttom Varikka and TC-Thamarachakka

Plate 23. Amplification patterns of jackfruit genotypes with ISSR primers- UBC 807, UBC 809, UBC 812, UBC 841, UBC 855 and UBC858



1-Acc 1, 2-Acc 2, 3-Acc 3, 4-Acc 4, 5-Acc 5, 15-Acc 15, 16-Acc 16, 17-Acc 17, 18-Acc 18, 19-Acc 19, S-Sindoor, MV-Muttom Varikka and TC-Thamarachakka

Plate 24. Amplification patterns of jackfruit genotypes with ISSR primers- UBC 866, UBC 834, UBC 840 and TC (10) G

polymorphism was **37.50 per cent** and size of amplicons ranged from 400-1000 bps.

(8)**UBC 834**

The agarose gel profile for 23 genotypes of jackfruit with primer UBC 834 (Plate 24). The primer generated a total of nine clear, distinct and reproducible loci out of which four were polymorphic (Plate 24). The polymorphism was **44.45 per cent** and size of amplicons ranged from 200-1000 bps.

(9)**UBC 840**

The agarose gel profile for 23 genotypes of jackfruit with primer 840 (Plate 24). The primer generated a total of eight clear, distinct and reproducible loci out of which four were polymorphic (Plate 24). The polymorphism was **50.00 per cent** and size of amplicons ranged from 200-1000 bps.

(10) **TC(10)G**

The agarose gel profile for 23 genotypes of jackfruit with primer TC(10)G (Plate 24). The primer generated a total of six clear, distinct and reproducible loci out of which were five polymorphic (Plate 24). The polymorphism was **83.34 per cent** and size of amplicons ranged from 200-1000 bps.

4.5.6 ISSR data analysis

Reproducible, well resolved fragments/ bands were scored for presence (1) and absence (0). The total number of bands observed among 23 genotypes on ISSR analysis with 10 primers was 86. The number of scorable bands produced per primer ranged from 6 to 11. The total number of polymorphic bands and the percentage of polymorphism were 48 and 55.01 per cent, respectively.

Fig 12. Dendrogram of molecular characters

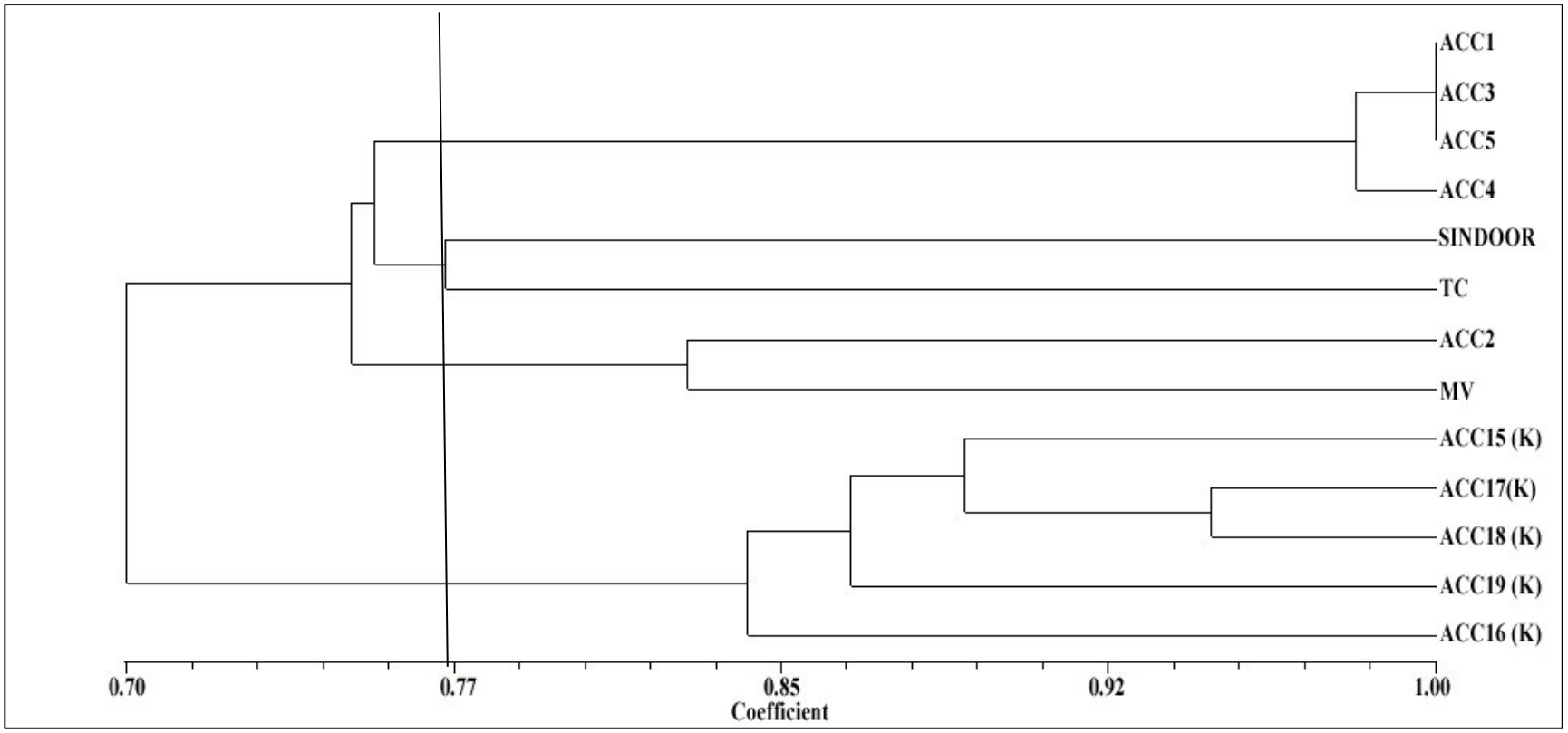


Table 18. Cluster wise listing of accessions according to molecular characterization

Clusters				
I	**II**	**III**	**IV**	**V**
Acc. 1	Sindoor	Thamarachakka	Acc. 2	Acc. 15
Acc. 3			Muttom Varikka	Acc. 16
Acc. 4				Acc. 17
Acc. 5				Acc. 18
				Acc. 19

Dendrogram for ISSR (Fig.5) cluster analysis was generated by the unweighed pair group method with arithmetic mean (UPGMA) using the software package NTsys pc version 2.02i (Rohlf, 1993). Jaccard's similarity coefficient ranged from 70 to 100. Five main clusters were formed at 77 % similarity. The first cluster grouped 4 accessions (Acc 1, Acc 3, Acc 5, Acc 4) (Table 18). The second cluster consists of Sindoor. Third cluster consists of Thamarachakka, fourth cluster consists of Acc 2 and Muttom Varikka and the fifth cluster consists of 5 accessions (Acc 15, Acc 17, Acc 18, Acc 19, Acc 16). Dendrogram generated using NTsys is given in Figure 5.

Discussion

5. DISCUSSION

Jackfruit is a tetraploid fruit crop and propagated through seed. Wide genetic variability is reported in this fruit plant. Surveys were conducted by Kerala Agricultural University to explore the variability and the seedling progenies of selected accessions were planted in the orchards. From thisgermplasm ten accessions each in hard and soft fleshed types were identified and utilized for further characterization in the present study along with the varieties of Sindoor, MuttomVarikka and Thamarachakka.

The results of the study pertaining to the "Morpho-molecular characterization of jackfruit (*Artocarpusheterophyllus* Lam.) accessions"are discussed under five captions namely tree characters, inflorescence characters, fruit characters, fruit quality parameters and molecular characterization.

5.1. Morphological characters

5.1.1. Tree characters

Most of the trees were the age group 25 years except Sindoor (12 years), The cluster means for the tree height ranged from (6.47 ± 2.54 m) to (14.25 ± 3.57 m) The cluster means for the trunk girth ranged from (151.67 ± 45.86 cm) to (190.00 cm). The tree characters namely height and girth is influenced by age of the plant, nutritional and climatic factors.

Different crown shapes like pyramidal, broadly pyramidal, spherical, oblong, semi-circular, elliptical and regular shapes were noticed among the accessions/varieties.The study revealed that Cluster I had trees with irregular crown shape. Cluster II had trees with broadly pyramidal and spherical crown shape. Cluster III included trees with oblong crown shape while Cluster IV had trees with pyramidal, semi-circular and elliptical crown shapes. Elliptical, broadly pyramidal and semi-circular crown shapes were seen in Cluster V. Cluster VI included trees with broadly pyramidal and irregular crown shape. Crown shape

and branching pattern are mainly decided by genetic make-up but still environmental parameters and shade also play a role (Muthulakshmi, 2003).

Different branching patterns like erect, opposite, verticillate, horizontal, and irregular patterns were noticed among the accessions/varieties. Results showed that Cluster I included trees with erect and irregular branching pattern. In Cluster II trees with erect and verticillate branching pattern are included. Cluster III included trees with only opposite branching pattern while Cluster IV had trees with erect and opposite branching patterns. Cluster V had trees with erect, verticillate, horizontal and irregular branching patterns whereas trees of Cluster VI showed trees with verticillate, horizontal and irregular branching patterns.

Wide variation was noticed among the accessions/varieties with respect to leafcharacters like leaf blade shape, leaf apex shape and leaf base shape.Different leaf blade shapes like elliptic, narrow, broad, oblong and obovate shapes were noticed, among these elliptic leaf blade shape was common in all clusters except Cluster III. Accessions/varieties had varied leaf apex shapes like acute, acuminate, retuse and obtuse shapes. Among these obtuse leaf apex shape was noticed in all clusters except Cluster III and IV. This was in accordance with the findings of CSIR (1992) andMuthulakshmi (2003) in jackfruit.Leaf base shape like oblique, cuneate and short shapes were noticed, among these oblique leaf base shape was common in all clusters except Cluster V.

Wide variation was noticed in all accessions/varieties in leaf characters. The cluster means of the leaf length recorded ranged from (14.45 ± 1.74 cm) to (18.45 cm). Cluster I recorded the lowest (14.45 ± 1.74 cm) and Cluster III recorded the highest mean values (18.45 cm) for this parameter (Table 3).The cluster means of the leaf breadth ranged from 7.53 ± 1.64 cm to 9.93 cm. Cluster II recorded the lowest value of 7.53 ± 1.64 cm and Cluster III recorded the highest value of 9.93 cm. Both genetic and phenotypic elements have a role in determining various leaf characters. Irregular leaf shapes are seen in younger plants. While in aged plants

elliptic/obtuse leaf blade shapes, obtuse leaf apex and oblique leaf base shapes were noted (CSIR, 1992; Muthulakshmi, 2003; Radha and Mathew, 2007).

5.1.2. Inflorescence characters

Observations on inflorescence characters *viz.,*time of flowering, female inflorescence density, female inflorescence positions, male inflorescence positions, bearing habit, secondary flowering were recorded.

According to the time of flowering, the accessions/varieties studied could be grouped into two namely the one which flowered during September and the other group which started flowering during October.Accession 1 to Acc 10 flowered during the month of September which belongs to the firm flesh type whereas Acc 11 to Acc 20 flowered on October which belongs to soft flesh type. The varieties Thamarachakka, Sindoor and MuttomVarikkaflowered on September. However, Muthulakshmi (2003) observed 3 flowering seasons in jackfruit. In accessions one to ten, the flowering period extended from September to October/ November while in soft fleshed types the flowering period was from October to January. From this study, it is noted that hard fleshed types flowered early when compared to soft fleshed types. The occurrence of two flowering seasons per year was mentioned by Sambamoorthy (1954) and three flowering seasons by Muthulakshmi (2003).Joesph and Kumaran(1996) reported that hard fleshed and soft fleshed varieties did not differ in flowering season, fruit set and fruit drop.

In Cluster I, the trees were recorded with sparse, intermediate and dense female inflorescence density. Cluster II had trees with dense female inflorescence densityonly.Cluster III and V included trees withdense and sparsefemale inflorescence density while in Cluster IV trees with only intermediate female inflorescence density was observed (Table 6).Female inflorescence position was mainly on trunk, primary and secondary branches in Clusters I, II and III. However female inflorescence position was on the whole stem including primary, secondary and tertiary branches in clusters IV and V.Cluster I and II included trees with male inflorescence positions mainly on primary branches. In Cluster III,

IV and V male inflorescence positions were seen mainly on all positions equally. Regarding bearing habit, all the accessions had regular bearing tendency and no secondary flowering were observed among the accessions/varieties.

5.1.3. Fruit characters

Various observations on fruit characters include fruiting season, fruit clustering habit, fruit number, shape, surface, fruit weight, fruit yield, shelf life, latex exudation, rind colour and thickness, core length and thickness, number of flakes (bulbs) per kg of the fruit, weight of flake, flesh thickness, bulb diameter, shape, pulp flavour, colour and consistency, number of seeds, 100-seed weight and rind, flake and seed ratio are studied.

All firm fleshed types of fruits had fruiting during January - March and all the soft fleshed types had fruiting during February– May.Cluster I, III and IV had solitary and cluster fruit bearing habit. In Cluster II and V most of the trees had only cluster bearing habit.

Different fruit shapes were noticed among the accessions *viz*., ellipsoid, clavate, oblong, irregular and obloid. Of these ellipsoid fruit shape was observed among majority of the accessions/ varieties. Ellipsoid and clavate fruit shapes were observed in Cluster I whereas Cluster II had only ellipsoid fruit shape. In Cluster III and IV the fruit shape noted was ellipsoid and oblong. Obloid fruit shape was observed in Cluster V. Similar observations were made by Muthulakshmi (2003). Mitra (1998) reported the existence of variability in fruit shape namely conical, oblong and round. Variation in fruit shape was also reported by Kumar and Singh (1996).

Spiny and smooth fruit surface was observed among the accessions/varieties. All the accessions and varieties had spiny fruit surface except Thamarachakka with smooth surface. Fruits with sharp pointed spines are less desirable since in such fruits rainwater gets stagnated paving way for entry inside the fruits leading to quality loss and fruit damage. The most desirable spine shape

is flat spines. In these fruits, rainwater does not stagnate over it and hence there may not be loss of quality and easy for handling. Mitra (1998) and Muthulakshmi (2003) observed variation in spine density in jackfruit.

Two characters determining the yield of a crop is the fruit number and weight. Wide variability was noticed among the accessions/varieties and between cluster means for these two characters. Fruit number was least for Cluster V and it was highest in Cluster IV comprising of soft fleshed types (Fig. 13). Accession wise fruit number ranged from 10 to 108 and cluster mean values from 25 to 63.40 ± 38.05. Thamarachakka registered the lowest number of fruits (cluster wise) and Acc 4 recorded the highest. With respect to the fruit weight, Thamarachakka registered the lowest (1.65 kg) and Acc 7 gave the highest value (20 kg).

Cluster mean for the fruit weight ranged from 1.65 kg to 15.50 ± 7.78 kg. Accession 20 (5.50 kg), Acc 18 (6.00 kg), Acc 16 (6.00 kg), Acc 9 (6.50 kg), Acc 19 (7.25 kg), Acc 17 (9.50 kg), Acc 11 (7.50 kg), MuttomVarikka (7.85 kg) were preferred for household purposes and the fruit weight varied from 5.50 kg to 7.85 kg. Accession 5 (10.00 kg), Acc 12 (9.00 kg), Acc 15 (9.80 kg), Acc 6 (10.00 kg), Acc 8 (10.50 kg), Acc 13 (10.50 kg), Acc 2 (11 kg), Acc 3 (11.00 kg), Acc 4 (11.50 kg), Acc 14 (11.80 kg), Acc 10 (12.00 kg), Sindoor (12.50 kg), Acc 1 (16.50 kg) and Acc 7 (20.00 kg) were preferred for industrial purposes also as the fruit weight varied from 10.00 kg to 20.00 kg. Muthulakshmi (2003) reported that medium sized fruits ranging from 5-8 kg are generally preferred for household consumption but for commercial purposes like chips making bigger sized fruits are preferred since cutting and removing of flakes may be made easier and quicker.

Variability noticed in fruit number and fruit weight also reflected in the yield of jackfruit accessions. Individual yield varied from 41.25 to 1593.00 kg and the cluster mean value ranged from 41.25 kg to 536.74 ± 421.56 kg. When we compare the cluster wise fruit yield, the varieties Sindoor and MuttomVarikka, produced medium yield (Cluster III) and the other accessions in the cluster are

Acc 2, Acc 4, Acc 9 and Acc 10.Soft fleshed accessions were grouped in Cluster IV recorded the highest yield (Fig. 14). Genetic variability in the fruit and yield characters were also reported by several workers in jackfruit (Mitra and Mani, 2000; Muthulakshmi, 2003 and Mathew *et al.,* 2003).

Jackfruit has a storage life of three to ten days depending on the stage of maturity, ambient temperature and relative humidity. Jackfruit flake is not normally stored in cold storage. In the present study, the shelf life of the ripe fruits varied from three to five days. Cluster I and IV consisted of fruits with shelf life of 4 days whereas Cluster II, III and V recorded fruits with shelf life of 5 days (Tables 9a and 9b).

Latex exudation was noticed as high, medium and low among the accessions/varieties. Cluster I recorded fruits with medium latex exudation whereas Cluster II recorded fruits with high latex exudation. Cluster III consisted of fruits with medium and high latex exudation. Cluster IV had fruits with low, medium and high latex exudation and medium latex exudation was recorded in Cluster V. The varieties Sindoor, MuttomVarikka and accession 2, 3, 4, 10 and Thamarachakka showed high shelf life compared to other accessions. There is an indication that in accessions with medium and high latex content shelf life is more compared to Accessions with low latex levels. Occurrence of gumless jackfruit is reported by Reddy *et al.,* (2004). Storage life of ripe fruit of gumless jackfruit is only one or two days. Extraction of flakes/bulbs becomes difficult in case of high latex content fruits whereas in gumless jackfruits are available where the above problem can be nullified.

Rind colour varied from green to greenish yellow. The fruits produced in trees of Cluster I and V had green rind colour whereas Clusters II, III and IV included fruits with green and greenish yellow rind colour (Tables 9a and 9b). The cluster meanfortherind thickness ranged from 0.5 cm to 1.62 ± 2.80cm. A positive

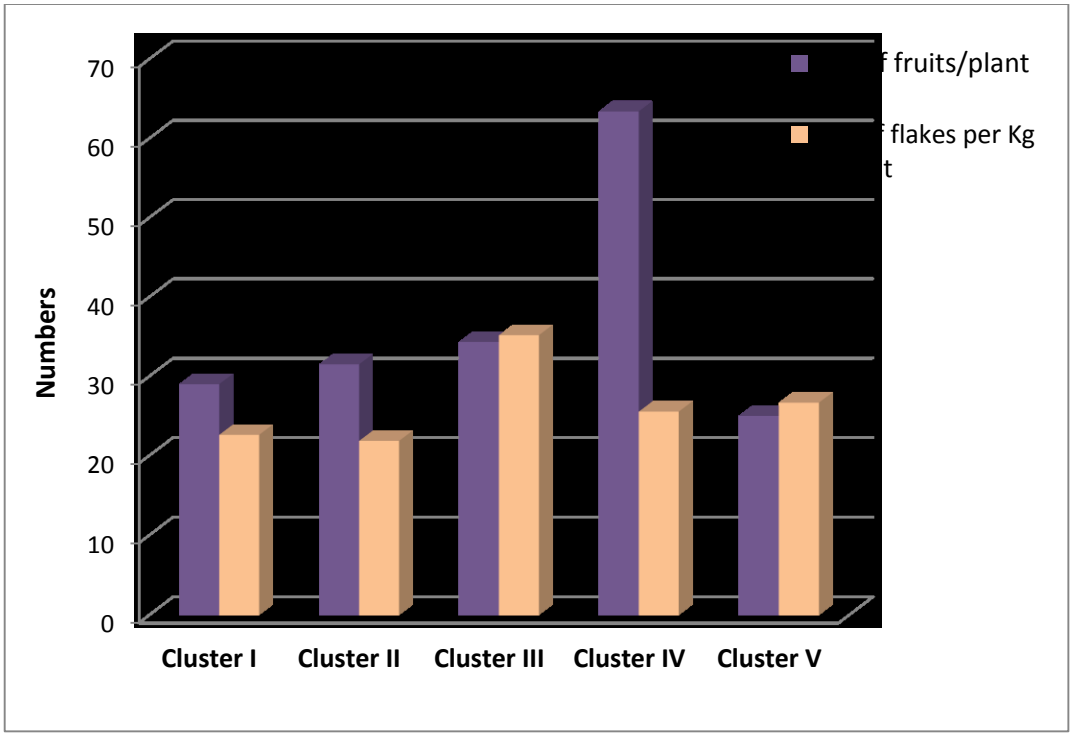


Fig.13 No. of fruits/ plant and no. of flakes per kg of fruit in different clusters

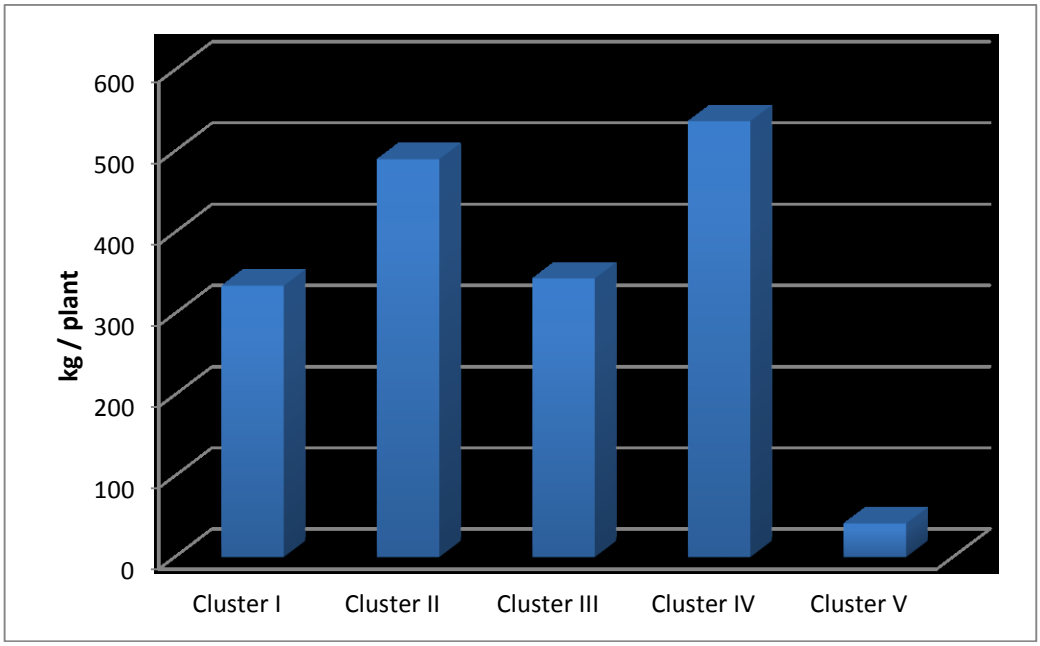


Fig.14 Yield per plant in different clusters

correlation between rind thickness and storage life was reported in jackfruit by Muthulakshmi (2003). The cluster mean for core length ranged from 10.20 cm to 48.75 ± 2.47 cm. The cluster means for the core thickness ranged from 4.50 cm to 9.95 ± 4.53 cm.

Diversity was observed in various flake (bulb) characters. The cluster mean for number of flakes (bulbs) per kg of the fruit ranged from 21.85 ± 7.92 to 35.18 ± 21.80. Cluster V had lowest numbers whereas Cluster IV had highest numbers (Fig. 13).Number of flakes (bulbs) in a jackfruit is determined by number of seed set. Low seed set resulted in the production of less number of flakes and more number of aborted flakes. In this study also number of flakes/kg of fruit are less in fruits with low seeds except in Thamarachakka.

The cluster means for the weight of the flake with seed ranged from 16.69 g to 31.53 ± 2.92 g. The cluster means for the weight of the flake without seed ranged from 10.79 g to 26.67 ± 1.81 g. The cluster means for the flesh thickness ranged from 1.30 mm to 4.40 ± 2.36 mm. Medium to low thickness flakes are suitable for chips making compared to thick flesh. The cluster means for the bulb length ranged from 4.17 cm to 6.58 ± 0.77 cm. The cluster means for the bulb diameter ranged from 6.10 cm to 8.60 ± 0.62 cm.

Muthulakshmi (2003) and Haq (2006) reported the variability in different flake (bulb) characters. The cluster mean for number of flakes per kg of fruit is more in Cluster III while weight of the flakes with and without seed is high in accessions coming under the Cluster I. Length and thickness of flake (flesh) is more in accessions coming under Cluster I and Cluster III respectively.

Wide variability was noticed among the accessions/varieties with respect to bulb shape. Clusters I, III and IV exhibited fruits with spheroid, twisted and rectangular bulb shapes. Cluster II had fruits with twisted and rectangular bulb shape and spheroid shape was noticed in Cluster V. In Cluster I,fruits with intermediate pulp flavour were included. In Cluster II intermediate and strong pulp flavour was observed whereas Clusters III, IV and V contained fruits with

strong flavoured pulp. Deep yellow and yellow flake colour was observed in Cluster I. Cluster II, IV and V exhibited fruits with yellow flake colour. Fruits with coppery red, deep yellow and yellow flake colour were recorded in Cluster III.Coppery red colour of the flesh is the peculiarity of the variety Sindoor which has got acceptance.

Medium and firm flake consistency was observed in Clusters I, II and III. Fruits with slimy and soft flake consistency were noticed in Cluster IV whereas the flake was with medium consistency in Cluster V (Table 9a and 9b).MuttomVarikka showed firm consistency of flakes. Hard fleshed varieties exhibited firm or medium firm consistency. Medium flakeconsistency was observed in Sindoor and Thamarachakka. Soft fleshed varieties usually exhibited soft or slimy type flakes.

The cluster means for the number of seeds ranged from 44.00 to 369.00 ± 55.15. The cluster means for 100-seed weight ranged from 240.00 g to 687.50 ± 103.08 g. Rind, flake and seed ratio ranged from 2.30 to 6.41 ± 0.58.

The results showed a wide diversity in morphological traits especially in the fruit characters. Hence as per the specific needs further selection can be done.

5.1.4. Fruit quality parameters

5.1.4.1.Sensory evaluation

Sensory qualities are very important from the consumer's point of view. It depends on quality parameters like colour, taste, texture, flavour, appearance, and sweetness.

Among the twenty accessions and three varieties, the highest rank for appearance was given for Acc 5, followed by Acc 3 and Sindoor. For colour highest rank was given for Sindoor followed by Acc 1 and Acc 5.Accession 5

was given the highest rank for flavour followed by Acc 1 and Sindoor. Accession 1 recorded highest rank for sweetness followed by Acc 3 and Acc 5. Accession 1 also recorded highest rank for taste followed by Sindoor and Acc 5. Accession3 was given highest rank for texture followed by Acc5 and Acc 9. Ranking was given based on Kendall's coefficient of concordance. From the sensory evaluation Acc 1, Acc 3 and Acc 5 were found to be promising types which had qualities and acceptance as that of varieties like Sindoor and MuttomVarikka. The results also indicated that the accession 1 to 10 and the varieties Sindoor, MuttomVarikka and Thamarachakka having firm flesh are highly preferred over the soft fleshed types (Acc 11 to Acc 20) . The cultivated jackfruits are broadly classified into 2 groups, one with the firm flesh and the other with soft flesh, for dessert purpose people prefer hard fleshed types as reported by Singh *et al*.(1967).

5.1.4. 2.Biochemical analysis

Various observations on the biochemical analysis includes moisture, TSS, reducing and non-reducing sugars and β-carotene were recorded.

The cluster means for moisture ranged from 29.00 to 74.00 per cent. The cluster means for TSS ranged from 20.60 to 33.80°Brix (Fig. 15). The cluster means for total sugar ranged from 15.66 (Cluster VIII) to 22.48 per cent(Cluster II) (Fig. 16). The cluster means for β-carotene ranged from 0.09 (Cluster V) to 7.27± 8.03 mg/100g (Cluster XIV) (Fig. 17). The cluster means for totalcarotenoids ranged from 0.10 (Cluster XI) to 4.11 ± 2.14 mg/100g (Cluster XIV) (Table 13).

Wide genetic variability was observed in biochemical traits as the accessions were grouped into fourteen clusters. Such type of variations in the biochemical characters were reported by Reddy *et al*.(2004) and Jagadeesh*et al.*(2007). They have studied the physio-chemical characteristics of jackfruit clones from South Karnataka and Western Ghats respectively.

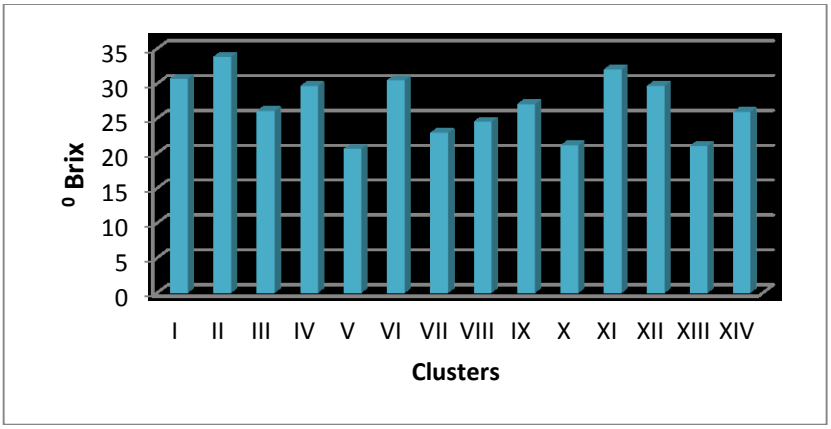


Fig. 15 Total sugar content of fruits in different clusters

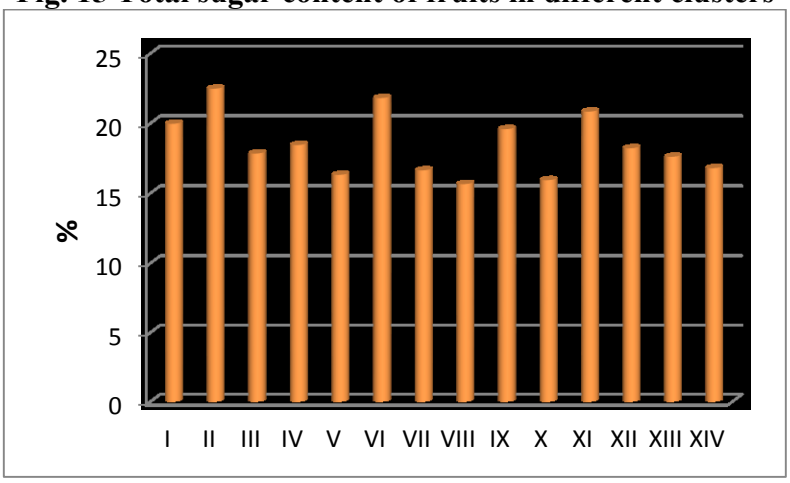


Fig. 16 Total sugar content of fruits in different clusters

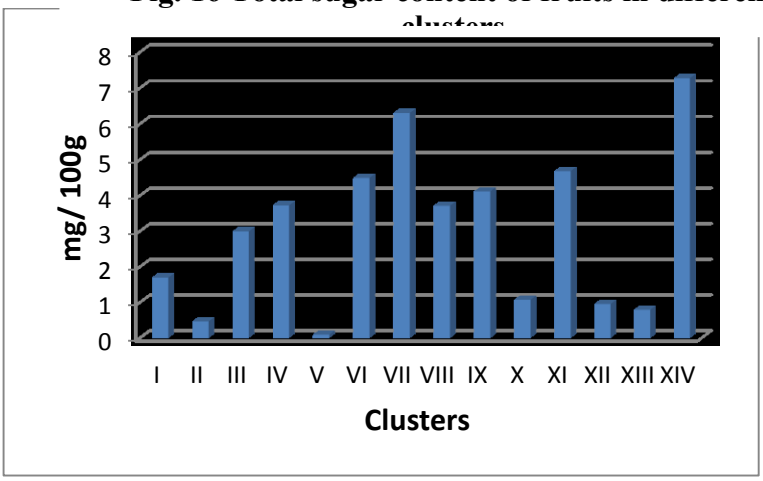


Fig.17 β carotene content of fruits in different clusters

5.2. Molecular characterization

5.2.1. Isolation, purification and analysis of DNA

Genomic DNA was extracted from five firm fleshed and five soft fleshed typesof jackfruits. DNA isolation through the CTAB method (Doyle and Doyle, 1987) attempted with RNasetreatment with β-mercaptoethanol was given for removing the colour of DNA due to polyphenols. The chloroform:isoamyl alcohol (24:1) treatment was given three times and the DNA was washed with ammonium acetate. With RNase treatment and further precipitation gave sufficient quantity of good quality DNA from leaf sample. The agarose gel electrophoresis had shown clear and discrete band with no RNA contamination (Plate 21) and spectrophotometric analysis gave the acceptable ratio of UV absorbance (A_{260}/A_{280}) between 1.8 and 2.06.

5.2.2. DNA amplification conditions for ISSR assay

DNA sampleswere diluted to a final concentration of 40 ng/µl before PCR amplification using selected 10 ISSR primers from 50 primers screened for ISSR assays. PCR amplification was performed in a 20 µl reaction mixture and the composition of the reaction mixture consisted of(40 ng) Genomic DNA 2.0 µl, 10X Taq assay buffer A3.8 µl with $MgCl_2$, dNTP mix (10 mM each) 1.8 µl,Taq DNA polymerase (3U)0.4 µl, Primer (10 pM) 2.0 µl and autoclaved distilled water 10.0 µl. The amplification was carried out with the following programme with an initial denaturation temperature of 94 ^{0} C for 2 minutes followed by 35 cycles of 30 second denaturation at 94 ^{o} C, 1 minute annealing at 43 ^{0}C to 63 ^{O}C and 2 minute extension at 72 ^{O}C with a final extension of 72 ^{O}C for 10 minutes using thermal cycler.

5.2.3. Screening of ISSR primers

Fifty primers, belonging to series UBC and ISSR were screened for ISSR analysis using good quality genomic DNA of five firm fleshed and five soft fleshed accessions and varieties namely Sindoor, MuttomVarikka and

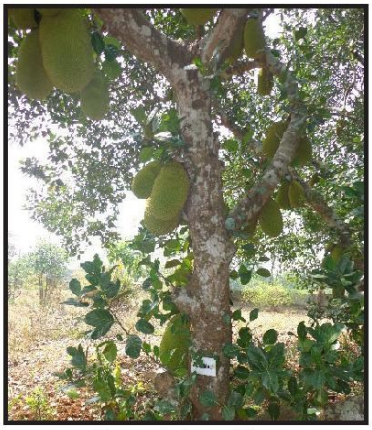
Thamarachakka. Out of 50 screened primers, 10 primers were selected based on their reproducibility and polymorphism for ISSR analysis.

5.2.4. Characterization using ISSR

In the present ISSR assay, total numbers of markers observed among the accessions and varieties with ten ISSR primers were 86 with average of 8.6 bands per primer. And out of them 48 were polymorphic which gave a percentage of polymorphism of 55.01 per cent with an average of 4.8 polymorphic bands per primer.ChunHai*et al.* (2009) evaluated 76 accessions of jackfruit using 24 ISSR primers and found 477 bands out of which 427 bands were polymorphic accounting to 89.52 per centpolymorphism.

Dendrogram for ISSR (Fig.5) cluster analysis was generated by the unweighed pair group method with arithmetic mean (UPGMA) using the software package NTsys pc version 2.02i (Rohlf, 2005). Jaccard's similarity coefficient ranged from 70 to 100. Five main clusters were formed at 77 per centsimilarity. The first cluster grouped 4 accessions (Acc 1, Acc 3, Acc 5, Acc4). The second cluster consists of Sindoor. Third cluster consist of Thamarachakka, fourth cluster consist of Acc 2 and MuttomVarikka and the fifth cluster consist of 5 accessions (Acc 15, Acc 17, Acc 18, Acc 19, Acc 16). Dendrogram generated using NTsys is given in figure 5. First cluster included the firm fleshed jackfruit accessions whereas Cluster V included all the soft fleshed jackfruit accessions. Thus molecular data could be effectively utilized in identifying soft fleshed and firm fleshed accessions from a germplasm. Contrary to this, Ying-zhi*etal.* (2010)reported that soft and firm fleshed types were not clustered into distinct groups while characterizing 50 accessions of jackfruits with AFLP markers. Characterization using ISSR markers in this study also gave 55 per cent polymorphism which shows the existence of a good amount of genetic variability.

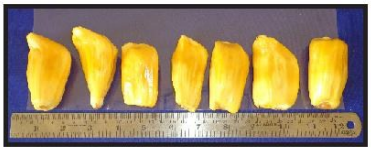
Genetic diversity of plants aredetermined by their morphological characteristics. But these traits are influenced by environmental factors and many of the qualitative characters which are of polygenic inheritance and expressed



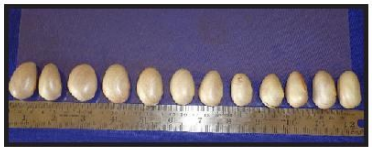
General view of tree

Fruit

Longitudinal section of the fruit



Flakes



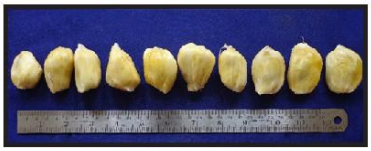
Seeds

Plate 25. Tree and fruit characters of Accession no. 1

General view of tree

Fruit

Longitudinal section of the fruit



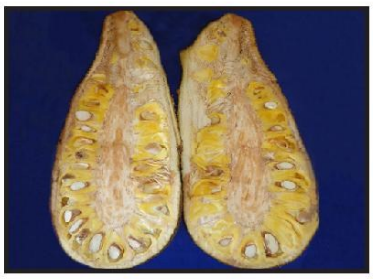
Flakes

Seeds

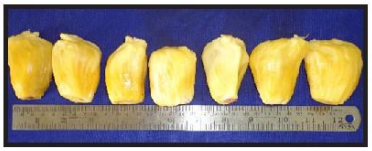
Plate 26. Tree and fruit characters of Accession no. 3

General view of tree

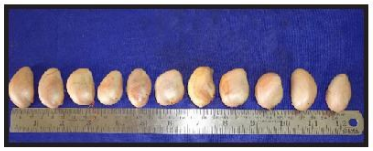
Fruit



Longitudinal section of the fruit



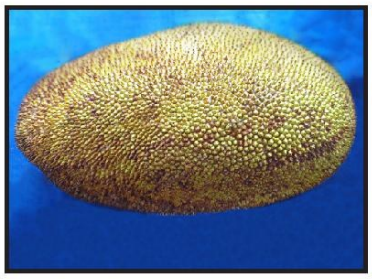
Flakes



Seeds

Plate 27. Tree and fruit characters of Accession no. 5

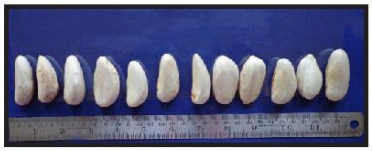
General view of tree



Fruit

Longitudinal section of the fruit

Flakes



Seeds

Plate 28. Tree and fruit characters of Accession no. 7

General view of tree

Fruit

Longitudinal section of the fruit

Flakes

Seeds

Plate 29. Tree and fruit characters of Accession no. 10

General view of tree

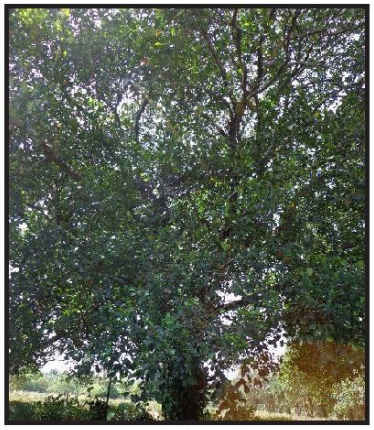
Fruit

Longitudinal section of the fruit

Flakes

Seeds

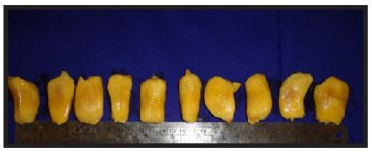
Plate 30. Tree and fruit characters of Accession no. 14



General view of tree

Fruit

Longitudinal section of the fruit



Flakes

Seeds

Plate 31. Tree and fruit characters of Accession no. 15

only after flowering or fruiting. Hence such types of characterization are not cent per cent reliable and also time consuming. In this context biochemical markers can be employed for a more accurate assessment. Scientists used isozymes and molecular markers to measure the genetic diversity and genetic relatedness in jackfruit (Schnell *et al.,* 2001 and Azad *et al.,* 2007). Jagadeesh*et al.*(2007) and Shyamalamma*et al.* (2008) carried out evaluation of jackfruit accessions using AFLP markers. They reported modest variation in the germplasm as the polymorphism is 20-22 per cent.

Thus in the present investigation, evaluation and characterization of twenty accessions and three varieties namely Sindoor, MuttomVarikka and Thamarachakka have been made to understand the extent of genetic diversity and similarity with the help of morphological, biochemical and molecular characters for identifying superior types for further selection.Sindoor and MuttomVarikka are the two firm fleshed varieties widely accepted in Kerala and suited for homestead cultivation. The morphological and fruit quantity and quality parameters of accessions 1, 3, 5, 7, 10, 14 and 15 are comparable with the above varieties (Plate 25 to 31). But for specific purposes, desirable traits are to be employed for selection. Further studies are also required to confirm these results.Molecular markers- ISSR markers could be successfully employed in determining the texture of the jackfruit flakes (firm/soft flesh types) and also for knowing the genetic relatedness.

Summary

6. SUMMARY

The study entitled 'Morpho-molecular characterization of jackfruit (*Artocarpus heterophyllus* L.) accessions' was carried out at College of Horticulture, Vellanikkara, Kerala from August 2013 to June 2015. The main objective of the study was to characterise the selected accessions/varieties of jackfruit based on morphological and molecular analysis. Twenty types/accessions of jackfruit maintained in the College orchard and in the Pineapple Research Centre, Vellanikkara along with the Muttam Varikka, Thamarachakka and Sindoor varieties were used for the study. Standard descriptors prescribed by IPGRI were used as the guideline to describe the morphological characterization. Fruit samples were analysed for quality traits and sensory evaluation. For molecular characterization was carried out with selected accessions. Total genomic DNA was isolated from young jackfruit leaves using standard procedure and subjected to ISSR molecular assays.

The salient findings of the study are as follows:

Most of the trees were of the age group 25 years except Sindoor (12 years). The cluster means for the tree height ranged from 6.47 ± 2.54 m to 14.25 ± 3.57 m . The cluster means for the trunk girth ranged from 151.67 ± 45.86 cm to 190.00 cm. Different crown shapes like pyramidal, broadly pyramidal, spherical, oblong, semi-circular, elliptical and regular shapes were noticed among the accessions/varieties. Different branching patterns like erect, opposite, verticillate, horizontal and irregular patterns were noticed among the accessions/varieties. Wide variation was noticed among the accessions/varieties with respect to leaf characters like leaf blade shape, leaf apex shape and leaf base shape. The cluster means of the leaf length recorded ranged from 14.45 ± 1.74 cm to 18.45 cm. The cluster means of the leaf breadth ranged from 7.53 ± 1.64 cm to 9.93 cm.

According to the time of flowering, the accessions/varieties studied could be grouped into two namely the one which flowered during September and the other

group which started flowering during October. Accession 1 to Acc 10 flowered during the month of September which belongs to the firm flesh type whereas Acc 11 to Acc 20 flowered on October which belongs to soft flesh type. The varieties Thamarachakka, Sindoor and Muttom Varikka flowered on September.

Wide variation was noticed in female inflorescence densities and male and female inflorescence positions of different clusters. Regarding bearing habit, all the accessions had regular bearing tendency and no secondary flowering were observed among the accessions/varieties.

All firm fleshed types of fruits had fruiting during January - March and all the soft fleshed types had fruiting during February – May. Cluster I, III and IV had solitary and cluster fruit bearing habit. In Cluster II and V most of the trees had only cluster bearing habit. Different fruit shapes were noticed among the accessions *viz*., ellipsoid, clavate, oblong, irregular and obloid. Spiny and smooth fruit surface was observed among the accessions/varieties. All the accessions and varieties had spiny fruit surface except Thamarachakka with smooth surface.

Wide variability was noticed among the accessions/varieties and between cluster means for fruit number and weight. Accession wise fruit number ranged from 10 to 108 and cluster mean values from 25 to 63.40 ± 38.05. Thamarachakka registered the lowest number of fruits (clusterwise) and Acc 4 recorded the highest. With respect to the fruit weight, Thamarachakka registered the lowest (1.65 kg) and Acc 7 gave the highest value (20 kg). Accession 20 (5.50 kg), Acc 18 (6.00 kg), Acc 16 (6.00 kg), Acc 9 (6.50 kg), Acc 19 (7.25 kg), Acc 17 (9.50 kg), Acc 11 (7.50 kg), Muttom Varikka (7.85 kg) were preferred for household purposes and the fruit weight varied from 5.50 kg to 7.85 kg. Accession 5 (10.00 kg), Acc 12 (9.00 kg), Acc 15 (9.80 kg), Acc 6 (10.00 kg), Acc 8 (10.50 kg), Acc 13 (10.50 kg), Acc 2 (11 kg), Acc 3 (11.00 kg), Acc 4 (11.50 kg), Acc 14 (11.80 kg), Acc 10 (12.00 kg), Sindoor (12.50 kg), Acc 1 (16.50 kg) and Acc 7 (20.00 kg) were preferred for industrial purposes also as the fruit weight varied from 10.00 kg to 20.00 kg.

Fruit yield varied from 41.25 kg to 1593.00 kg and the cluster mean value ranged from 41.25 kg to 536.74 ± 421.56 kg. When we compare the cluster wise fruit yield, the varieties Sindoor and Muttom Varikka produced medium yield (Cluster III) and the other accessions in the cluster are Acc 2, Acc 4, Acc 9 and Acc 10. Soft fleshed accessions were grouped in Cluster IV and recorded higher yield.

Shelf life of the ripe fruits varied from three to five days. Cluster I and IV consisted of fruits with shelf life of 4 days whereas Cluster II, III and V recorded fruit with shelf life of 5 days.

Cluster I recorded fruits with medium latex exudation whereas Cluster II recorded fruits with high latex exudation. Cluster III consisted of fruits with medium and high latex exudation. Cluster IV had fruits with low, medium and high latex exudation and medium latex exudation was recorded in Cluster V.

Rind colour varied from green to greenish yellow. The fruits produced in trees of Cluster I and V had green rind colour whereas Clusters II, III and IV included fruits with green and greenish yellow rind colour.

The cluster mean for the rind thickness ranged from 0.5 cm to 1.62 ± 2.80 cm. The cluster mean for core length ranged from 10.20 cm to 48.75 ± 2.47 cm. The cluster means for the core thickness ranged from 4.50 cm to 9.95 ± 4.53 cm.

The cluster mean for number of flakes (bulbs) per kg of the fruit ranged from 21.85 ± 7.92 to 35.18 ± 21.80. Number of flakes (bulbs) in a jackfruit is determined by number of seed set. The cluster means for the weight of the flake with seed ranged from 16.69 g to 31.53 ± 2.92 g. The cluster means for the weight of the flake without seed ranged from 10.79 g to 26.67 ± 1.81 g. The cluster means for the flesh thickness ranged from 1.30 mm to 4.40 ± 2.36 mm. The cluster means for the weight of the bulb length ranged from 4.17 cm to 6.58 ± 0.77 cm. The cluster means for the bulb diameter ranged from 6.10 cm to 8.60 ± 0.62 cm.

The cluster mean for number of flakes per kg of fruit is more in Cluster III while weight of the flakes with and without seed is high in accessions coming under the Cluster I. Length and thickness of flake (flesh) is more in accession coming under Cluster I and Cluster III respectively.

Cluster I, III and IV exhibited fruits with spheroid, twisted and rectangular bulb shapes. Cluster II had fruits with twisted and rectangular bulb shape and spheroid shape was noticed in Cluster V.

In Cluster I fruits with intermediate pulp flavour were included. In Cluster II intermediate and strong pulp flavour was observed whereas Clusters III, IV and V contained fruits with strong flavoured pulp.

Deep yellow and yellow flake colour was observed in Cluster I. Cluster II, IV and V exhibited fruits with yellow flake colour. Fruits with coppery red, deep yellow and yellow flake colour were recorded in Cluster III. Coppery red colour of the flesh is the peculiarity of the variety Sindoor which has got acceptance.

Medium and firm flake consistency was observed in Clusters I, II and III. Fruits with slimy and soft flake consistency were noticed in Cluster IV whereas the flake was with medium consistency in Cluster V. Muttom Varikka showed firm consistency of flakes. Hard fleshed varieties exhibited firm or medium firm consistency. Medium flakes were observed in Sindoor and Thamarachakka. Soft fleshed varieties usually exhibited soft or slimy type flakes.

The cluster means for the number of seeds ranged from 44.00 to 369.00 ± 55.15. The cluster means for 100-seed weight ranged from 240.00 g to 687.50 ± 103.08 g. Rind, flake and seed ratio ranged from 2.30 to 6.41 ± 0.58. The results showed that a wide diversity in morphological traits especially in the fruit characters. Hence as per the specific needs further selection can be done.

From the sensory evaluation Acc 1, Acc 3 and Acc 5 were found to be promising types which had qualities and acceptance as that of varieties like

Sindoor and Muttom Varikka. The results also indicated that the accession 1 to 10 and the varieties Sindoor, Muttom Varikka and Thamarachakka having firm flesh are highly preferred over the soft fleshed types (Acc 11 to Acc 20).

The cluster means for moisture ranged from 29.00 per cent to 74.00 per cent. The cluster means for TSS ranged from 20.60 to 33.80° Brix. The cluster means for total sugar ranged from 15.66 per cent (Cluster VIII) to 22.48 per cent (Cluster II). The cluster means for β-carotene ranged from 0.09 (Cluster V) to 7.27± 8.03 mg/100 g (Cluster XIV). The cluster means for total carotenoids ranged from 0.10 (Cluster XI) to 4.11 ± 2.14 mg/100 g (Cluster XIV).

Five jackfruit genotypes each in firm and soft fleshed categories were utilized for molecular characterization. Dendrogram was generated for ISSR cluster analysis and five main clusters were formed at 77 % similarity. The first cluster grouped 4 accessions (Acc 1, Acc 3, Acc 5, Acc 4). The second cluster consists of Sindoor. Third cluster consist of Thamarachakka, fourth cluster consist of Acc 2 and Muttom Varikka and the fifth cluster consist of 5 accessions (Acc 15, Acc 17, Acc 18, Acc 19, Acc 16). First cluster included the frim fleshed jackfruit accessions whereas Cluster V included all the soft fleshed jackfruit accessions. Thus molecular data could be effectively utilized in identifying soft fleshed and firm fleshed accessions from a germplasm. ISSR markers could be successfully employed in determining the texture of the jackfruit flakes (firm/soft flesh types) and also for knowing the genetic relatedness.

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MORPHO-MOLECULAR CHARACTERIZATION OF JACKFRUIT (*Artocarpusheterophyllus* Lam.) ACCESSIONS

by

ASWINI A.

(2013-12-104)

ABSTRACT OF THE THESIS

Submitted in partial fulfilment of the
requirements for the degree of

MASTER OF SCIENCE IN HORTICULTURE

Faculty of Agriculture
Kerala Agricultural University

DEPARTMENT OF POMOLOGY AND FLORICULTURE
COLLEGE OF HORTICULTURE
VELLANIKKARA, THRISSUR – 680 656
KERALA, INDIA

2015

ABSTRACT

India is the largest producer of jackfruit in the world (APAARI, 2012). A wide range of genetic and morphological variation has been reported in jackfruit (Ullah and Haque, 2008). In Kerala also rich genetic diversity is reported (Muthulakshmi, 2003; Amma and Kumaran, 2011). Hence it is essential to characterize the accessions at morphological and molecular levels for knowing their identity, genetic relatedness and for exploitation in future breeding programmes.

The study on 'Morpho-molecular characterization of jackfruit (*Artocarpusheterophyllus* L.) accessions' was carried out at College of Horticulture, Vellanikkara, Kerala from August 2013 to June 2015. The main objective of the study was to characterise the selected accessions/varieties of jackfruit based on morphological and molecular analysis. Twenty types/accessions of jack fruit maintained in the College orchard and in the Pineapple Research Centre, Vellanikkara along with the MuttomVarikka,Sindoorand Thamarachakkavarieties were used for the study. All the accessions/varieties were studied for morphological, physico-chemical and organoleptic properties. Molecular characterization of the selected accessions/varieties was carried out using standard procedure and subjected to ISSR techniques.

All the accessions/varieties showed variability in tree characters,inflorescence characters, fruit characters and fruit quality. At the similarity coefficient status of 30 percent, grouping of accessions was done based on tree characters,which resulted in 6 non-overlapping clusters.Tree characters *viz.,*tree height (4.50 m to 18.00 m), trunk girth (76.00 cm to 270.00 cm), crown shape (pyramidal, broadly pyramidal, spherical, oblong, semi-circular, elliptical and irregular), branching pattern (erect, opposite, verticillate, horizontal and irregular), leaf blade shape (obovate, elliptic, broadly elliptic, narrowly elliptic, oblong and lyrate (wavy)), leaf apex (acute, acuminate, retuse and obtuse) , leaf base shape

(oblique, rounded, cuneate and shortly attenuate) , leaf length (12.34 cm to 18.02 cm) and breadth (6.37 cm to 9.43 cm) were observed.

The accessions were grouped at the similarity coefficient status of 75per cent based on inflorescence characters, which resulted in 5 non-overlapping clusters.Time of flowering, female inflorescence density, female and male inflorescence positions, bearing habit (regular) and secondary flowering (no secondary flowering) were recorded.

At the similarity coefficient status of 26 per cent, grouping of accessions was done based on fruit characters, which resulted in 5 non - overlapping clusters. Variation was observed with respect to fruiting season, fruit clustering habit, fruit number (21 to 135) , shape, surface, fruit weight (1.65 kg to 20.00 kg), fruit yield (41.25 kg/ plant to 1593 kg/ plant), shelf life (3 to 5 days), latex exudation, rind colour and thickness, core length (10.20 cm to 50.50 cm) and thickness (2.50 cm to 13.90 cm), number of flakes (bulbs) per kg of the fruit (12.61 to 71.15), weight of flake (16.69g to 33.91g), flesh thickness (1.26 mm to 7.8 mm), bulb diameter (6.08 cm to 10.11 cm), shape, pulp flavour, colour and consistency, number of seeds (44 to 482), 100-seed weight (240g to 800g) and rind, flake and seed ratio (2.30 to 7.31).

Sensory evaluation *viz.,*taste, flavour, colour, texture, sweetness and appearance were recorded on basis of 9 point hedonic scale. At the similarity coefficient status of 7 per cent, grouping of accessions was done based on biochemical characters, which resulted in 14 non - overlapping clusters.The percentage of moisture (29 to 74 %), TSS (20.30 ^{0} Brix to 33.80 ^{o} Brix), reducing sugars (6.61 to 13.16 %) and non-reducing sugars (5.16 to 13.29 %) and β carotene (0.99 to 12.94 mg/100g) were estimated.

In molecular characterization five main clusters were formed at 77 per cent similarity. The first cluster grouped four accessions (Acc. 1, Acc. 3, Acc. 5, Acc. 4). The second cluster consists of Sindoor. Third cluster consists of Thamarachakka, fourth cluster consists of Acc. 2 and Muttom Varikka and the

fifth cluster consist of five accessions (Acc. 15, Acc. 17, Acc. 18, Acc. 19, and Acc. 16). First cluster included the firm fleshed jackfruit accessions whereas Cluster V included all the soft fleshed accessions.

Thus in the present investigation, evaluation and characterization of twenty accessions and three varieties namely Sindoor, MuttomVarikka and Thamarachakka have been made to understand the extent of genetic diversity and similarity with the help of morphological, biochemical and molecular characters for identifying superior types for further selection. Sindoor and MuttomVarikka are the two firm fleshed varieties widely accepted in Kerala and suited for homestead cultivation. The morphological and fruit quantity and quality parameters of accessions 1, 3, 5, 7, 10, 14 and 15 are compared with the above varieties. But for specific purposes, desirable traits are to be employed for selection. Further studies are also required to confirm the results. Molecular markers- ISSR markers could be successfully employed in determining the texture of the jackfruit flakes (firm/soft flesh types) and also for knowing the genetic relatedness.

Appendices

Appendix – I

Weather data 2014-2015 - Vellanikkara

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
	Mean maximum temperature (0 C)												
2014	32.9	34.7	36.7	35.3	33.2	30.9	29.5	29.5	31.3	31.9	31.6	31.9	32.5
2015	32.5	34.3	35.8	34.0	32.9								
Mean minimum temperature (0C)													
2014	23.0	22.9	24.2	25.7	24.2	24.4	23.1	23.2	23.3	23.7	23.2	22.5	23.6
2015	22.1	23.0	24.9	24.6	24.7								
Mean relative humidity morning (%)													
2014	66	75	76	89	90	95	95	97	95	93	84	78	86
2015	75	73	83	89	92								
Mean relative humidity evening (%)													
2014	36	37	34	57	64	76	80	76	69	68	60	53	59
2015	41	37	44	64	68								
Mean relative humidity(%)													
2014	51	56	55	73	77	85	87	87	82	81	72	65	73
2015	58	55	63	77	80								
Rainfall (mm)													
2014	0.0	0.0	0.0	61.0	323.6	469.8	768	599.8	215.1	224.6	85.3	9.6	2756.8 (total)
2015	0.0	0.0	72	162.2	259.0								
Rainy days													
2014	0	0	0	4	5	21	26	22	13	15	5	1	112(total)

2015	0	0	2	8	12								
Total evaporation (mm)													
2014	171.3	145.0	191.5	130.8	107.5	88.7	77.6	90.2	92.8	86.1	96.9	112.1	115.9
2015	135.4	157.4	151.6	106.9	95.8								
Mean evapotranspiration (mm)													
2014	277.6	240.8	264.2	192.4	182.0	90.1	49.3	81.3	172.6	135.2	151.9	188.5	168.8
2015	271.5	246.7	248.6	203.8	156.4								
Sunshine (hrs)													
2014	277.6	240.8	264.2	192.4	182.0	90.1	49.3	81.3	172.6	135.2	151.9	188.5	168.8
2015	271.5	246.7	248.6	203.8	156.4								
Mean sunshine (hrs)													
2014	9.0	8.6	8.5	6.4	5.9	3.0	1.6	2.6	5.8	4.4	5.1	6.1	5.6
2015	8.8	8.8	8.0	6.8	5.0								
Mean wind speed (km/hr)													
2014	6.9	4.5	3.9	2.3	2.5	2.2	2.1	1.9	2.2	2.2	3.7	5.4	3.3
2015	5.6	5.8	3.3	2.4	1.7								

Appendix – II

Score card for organoleptic evaluation

Name of the judge:
Date:

Characteristics	Scores				
	Acc 1	Acc 2	Acc 3	Acc 4	Acc 5
Appearance					
Colour					
Flavour					
Texture					
Sweetness					
Taste					

9 point Hedonic scale

Like extremely	9
Like very much	8
Like moderately	7
Like slightly	6
Neither like or dislike	5
Dislike slightly	4
Dislike moderately	3
Dislike very much	2
Dislike extremely	1

Signature