MORPHOMETRIC EVALUATION AND PROPAGATION STUDIES IN TAMARIND (*Tamarindus indica* L.)

By

SHANKARPRASAD K S

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THESIS

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DEPARTMENT OF PLANTATION CROPS AND SPICES

COLLEGE OF HORTICULTURE

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DECLARATION

I hereby declare that the thesis entitled "Morphometric evaluation and propagation studies in tamarind (*Tamarindus indica* L.)" is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

Date: 26-07-2019

Place: Vellanikkara

SHANKARPRASAD K. S.

(2017-12-024)

CERTIFICATE

Certified that the thesis entitled **"Morphometric evaluation and propagation studies in tamarind (*Tamarindus indica* L.)"** is a record of work done independently by Mr. Shankarprasad K. S. under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

Date:
Place: Vellanikkara

Dr. Jalaja S. Menon
(Chairman, Advisory Committee)
Professor and Head i/c
Cashew Research Station,
Madakkathara

CERTIFICATE

We, the undersigned members of the advisory committee of Mr. Shankarprasad K. S. **(2017-12-024)**, a candidate for the degree of **Master of Science in Horticulture**, with major field in **Plantation Crops and spices**, agree that the thesis entitled **"Morphometric evaluation and propagation studies in tamarind (*Tamarindus indica* L.)"** may be submitted by Mr. Shankarprasad K. S., in partial fulfillment of the requirement for the degree.

Dr. Jalaja S Menon
(Chairman, Advisory Committee)
Assistant Professor and Head i/c
Cashew Research Station
Madakkathara

Dr. V S Sujatha
(Member, Advisory Committee)
Professor & Head,
Dept. of Plantation Crops and Spices
College of Horticulture, Vellanikkara

Dr. Lisamma Joseph
(Member, Advisory Committee)
Professor
Dept. of Plantation Crops and Spices
College of Horticulture, Vellanikkara

Dr. Jiji Joseph
(Member, Advisory Committee)
Professor and Head
Dept. of Plant Breeding and Genetics
College of Horticulture, Vellanikkara

(External Examiner)

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AFFECTIONATELY DEDICATED

TO

MOTHER EARTH

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Introduction

I. INTRODUCTION

Tamarind (*Tamarindus indica* L.) is a hardy evergreen monotypic cross pollinated tree. It comes under family Caesalpinaceae, the sub family of Leguminosae with a chromosome number of 2n =24 (Purseglove, 1981). The tree has spice value for its peculiar acidic pulp, which is a chief souring agent in variety of dishes in India and in many other countries. Tree is a common component of avenue planting, home gardens and farm lands in warmer and drier regions of Central and South India. The seeds have many industrial uses. Owing to the booming demand for its pulp, seeds and climate smart value, commercial plantations are mushrooming in large scale mainly in the arid and semi-arid zones.

Salim *et al.* (1998) documented geographical distribution of tamarind and declared Tropical Africa as its native. The oldest documentation available on tamarind is from Brahmasamhita scriptures, which is believed to be written between 1200-200 BCE. Its cultivation around 400 BCE was documented in Egypt.

The word tamarind has its root in Arabic word "Tamar-u'l-Hind" meaning 'Date of India'. Tamarind is known by different names across the country. Puli in Malayalam and Tamil, Hunase in Kannada, Amalika in Sanskrit, Chinta in Telugu, Chinch in Marathi, Imli in Hindi are the few vernacular names for tamarind.

Tamarind is a highly out crossing species due to its unique floral adaptations like herkogamy, protogyny and very low level of self compatability promotes out crossing under natural conditions. Pollinator limitation is the biggest problem faced during flowering season which results in poor fruit set of maximum 1-2 per cent. Due to outcrossing behaviour and predominant wild seedling progeny, broad range of diversity is available in its growing regions. Availability of inter population and intra population variability provides ample opportunity for exploiting their commercial and scientific significance.

Tamarind has become naturalised in most of the tropical and subtropical countries. In India it is mainly distributed in warmer and drier tropics and subtropics.The state of Kerala also blessed with very good diversity of tamarind. Land races such as Valanpuli, Thenpuli and Madhurapuli are popular among the people of Kerala. Despite being the third largest state in terms of area (11,000 ha) and production (38,300 MT) of tamarind

(NHB, 2017), the variability of tamarind trees of Kerala has not been systematically studied so far. It was also encountered that most of the popular varieties of other states are not performing well in the agroclimatic situations of Kerala. So there is a need to identify promising traits attributing to yield and quality which will help in future to identify suitable genotypes for homesteads if proper vegetative propagation method is standardized.

This investigation on the variability of morphological characters of tamarind cultivars will form a baseline for germplasm collection, cultivar selection and future breeding programmes, meanwhile the propagation studies will help to screen the best method to multiply and conserve existing local elite genotypes.

Review of literature

II. REVIEW OF LITERATURE

Tamarind is a multipurpose tree distributed widely across tropical and subtropical parts of world. Tamarind grows in more than 50 countries in Africa, Asia and Central America. Sour type is most commonly grown all over the world and sweet types are mainly produced in Thailand (Palgrave, 1988; Yahia and Salih, 2011). Tamarind is believed to be originated from different regions of world according to different authors like tropical Africa (Palgrave, 1988; Van den Bilcke *et al.*, 2013), India (Morton, 1987), Madagascar (Von Maydell, 1986).

2.1 Importance

2.1.1 Importance of tamarind tree

Tamarind can tolerate five to six months of drought conditions (Rao *et al.*, 2015) but successptible to frost (Mascarenhas *et al.,* 1987). Tamarind usually harvested in dry season hence a boon for farmers of arid regions to get income during lean period of field crops (Jambulingam and Fernandes, 1986).

In many countries tamarind is still consumed as food, medicine and has immense value in cultural, social, environmental amelioration, waste and degraded land management in arid regions and forms an income generation source for livelihood of poor. Major constraints towards cultivation included limited land holdings, long gestation period of seedling progenies and low monetary value for fruits and wood (Bhatnagar *et al.,* 2013; Ebifa-Othieno *et al.,* 2017).

Realizing the need for germplasm collection in this underutilized crop, IIHR, Bengaluru had initiated its germplasm collection, evaluation and conservation a long back. Currently collections were stood at 278 which were collected from different regions across the country. Among them, 64 accessions were collected from Bastar, Narayanpur and Kondagoan regions of Chattisgarh, other 62 were selected from Adilabad and Mehbubnagar regions of Telangana, 57 germplasms were gathered from various parts of Korapet and Rayagada regions of state of Odisha, other thirty accessions from Ratlam of Madhya Pradesh, from Maharashtra 15 genotypes were selected and from Mizoram 50 germplasms were collected and evaluated (ICAR-IIHR, 2018).

2.1.2 Importance of tamarind leaf

Tamarind is a potential and viable resource vegetable of excellent nutrition (Narina and Catanzaro, 2018). Total leaf protein content was 8.7-15.6 per cent. Tamarind is an excellent source of folates, iron, potassium, calcium, magnesium and Vitamin C. Hence it is good for rural people especially woman and children to fight malnutrition (Hamacek *et* al., 2013; Sajib *et al.,* 2014).

Tamarind leaves have vast array of medicinal properties and possess antibacterial and antimicrobial property (Mehr and Dash, 2013). In traditional medicines it is mainly used to treat bleeding piles, dysuria and union of fractured bones (Sharma *et al.,* 2007; Kumar *et al.,* 2014). The leaves and flowers are used to make curries, salads, stews, chutneys and soups in tropical countries, especially in times of drought and scarcity (Bhadoriya et al., 2011).

Lima *et al.* (2017) reported that tamarind leaf extracts has broad spectrum antibacterial activity and has immense potential for developing new classes of antibiotics which could be useful for treating infectious diseases and chemotherapy treatment.

2.1.3 Importance of tamarind fruit and its components

Each and every part of tamarind has its own value and has great industrial significance. Tamarind fruit components such as seed gum, seed polysaccharide, seed powder, seed coat, Tamarind Kernel Powder (TKP), kernel oil, Tamarind Seed Powder (TSP), decorticated tamarind seed meal are known for wide range of applications. These products are majorly used as thickener, binder, stabilizer, extender, antioxidative component in food processsing, emulsifying agent, gelatinizing agent, pharmaceutical excipient, adhesives, carriers of nutrients, tamarind seed starch edible films for meat packaging, vinegar, cosmetics, tamarind pulp powders, bioethanol (Kumar and Bhattacharya, 2008; Singh *et al*., 2011; Balaji *et al.,* 2013; Rakhavan *et al.,* 2016; Padiyar *et al.,* 2016; Taha *et al.,* 2016).

Tamarind fruits are rich in nutrients and could be used effectively to ensure food security in developing countries where tamarind natural population exists (Adeola, and Aworh, 2012). Value added products such as jams, squashes, blended squashes, RTS (Ready To Serve) beverages preparation protocols have been standardised and these processed products have great potential in Indian food markets as the trend is shifting

towards healthy beverages and nutraceuticals (Niketa *et al.,* 2015; Khan *et al.,* 2017; Manjula *et al.,* 2017)

Pulp is preserved with either sugar or salt, and is a major ingredient of curries and chutneys, leaves and flowers are also used in preparation of various dishes (Palgrave, 2002). Khanzada (2008) isolated thirty-two different fatty acids from tamarind pulp along with essential elements *viz.,* Arsenic, Calcium, Cadmium, Copper, Iron, Sodium, Manganese, Magnesium, Potassium, Phosphorus, Lead, and Zinc. Pulp accumulated more copper whereas potassium was comparatively less.

Tamarind forms important component in traditional medicines. There is a vast scope for exploring ethnobotanical knowledge of this crop. Tribal people of Tamil Nadu prepare formulations using dried tamarind fruits to treat diarrhoea and local people in Rajasthan make formulations out of tamarind pulp and take orally to treat eye infections (Muthu *et al.,* 2006; Sharma *et al.,* 2007).

Water extract of tamarind pulp is having antibiotic property equivalent to that of commonly used antibiotic gentamicin (Doughari, 2006). Phenolic content of the sweet type tamarind seed extract was superior in antioxidant property than synthetic antioxidant Butylated Hydroxyl Toluene (BHT) and is a potential sources of natural antioxidants for the future food industry (Reis *et al.,* 2016).

Tamarind seed polysaccharide is a best alternative to commercial pectin (Mohamed *et al.,* 2015). Tamarind kernel powder is used extensively as sizing material in textiles, bookbinding, cardboard and plywood manufacturing, and in weighing and size compositions in the leather industry (Mascarenhas *et al.,* 1987; Rao and Mathew, 2012).

Tamarind seed contains golden yellow coloured oil which is having industrial demand for making illuminants and varnishes (El-Siddig *et al.,* 2006). Normally pulses are deficient in sulphur containing amino acids but tamarind seeds are comparatively rich in sulphur containing amino acids (Pugalenthi *et al.,* 2004).

Tannins were extracted from tamarind seed coat and used as a natural mordant for three different fabrics viz. cotton, wool and silk along with 0.5-1 per cent metal mordant copper sulphate and dyed with natural dyes. The fabrics which were mordanted and dyed resulted in greater antibacterial activity up to 20 washes (Prabhu and Teli, 2014).

Tamarind shell powder is an excellent adsorbent for the removal of dyes from wastewater effluents and can be used for the adsorption of methylene blue and amaranth

dyes (Naidu *et al.,* 2012). Tamarind shell has a calorific value of 16.3 MJ/kg with combustion efficiency of around 99 per cent. Hence it can be used as raw material for production of briquettes. (Rao *et al.,* 2015).

2.2 Variability and characterization

Characterization of tamarind for morphological and genetic characters are pivotal for breeding, commercialization and germplasm conservation to avoid genetic erosion (Algabal *et al.,* 2010; Fandohan *et al.,* 2011; Adeola and Aworh, 2012; Sharma *et al.,* 2015; Nasution and Yapwattanaphun, 2016). Wide range of variability was observed in tamarind for tree characters such as growth habit, vigour, yield, fruit characters, flower characters and leaf characters. Presence of diversity in tamarind population can be attributed to its allogamous nature (Gangaprasad *et al.,* 2013).

2.2.1 Tree characters

Tamarind is a medium to large sized, semi-deciduous tree with dense crown, growing up to 20-25m height, with round crown and branches drooping and it can be seen distributed in wide range of soil and climatic conditions (Jambulingam and Fernandes, 1986; Rao *et al.*, 2015). Bark colour vary from greyish brown to greyish black and possess scaly and rough appearance (Palgrave, 2002). Tamarind GBH (girth at breast height) varied from 38.33cm to 50.83cm at the age of 14 years (Kakkar and Nagaraj, 2011).

Dwarf statured trees favours easy harvesting which can be exploited for high density planting. Rao and Subramanyam (2010) studied growth habit of clones of different varieties. Among the selected varieties, N-1, V-112, H-77, V-2, Pratistan and JK-1 were dwarf genotypes as their plant height was below 3.76 m at 9 years' age whereas V-59, V-29 were vigorous genotypes with height more than 4.8m at the same age. They also observed seasonal variation in growth rate among the genotypes.

Saraladevi *et al.* (2010) reported that the canopy spread of the tamarind tree exhibited highest correlation with girth (0.61) whereas tree height (0.21) was less correlated. Tree height exhibited higher correlation with tree girth (0.46) compared to canopy spread (0.21).

Avinash (2018) reported considerable variation in the quantitative and qualitative characters in populations of clove in clove growing belts of Kerala and Tamil Nadu. Bivariate analysis revealed significant association of canopy shape with branching pattern, colour of young leaf with petal colour and size of bud with leaf colour. Koko *et*

al. (2013) reported presence of very high positively significant correlation between trunk circumference and pod yields (r = 0.77) of the cocoa plant.

2.2.2 Leaf characters

Leaves are paripinnate, alternate and fine hairs are present on rachis. Leaves usually contain 10- 18 pairs of leaflets in opposite direction. Terminal pair of leaflets are less conspicuous and smaller, pointing along the direction of rachis. Leaflet apex vary from round to almost square shape. Stipules are present and fall in the early stages of leaf growth (Palgrave, 2002). A peculiar characters of leaf is at night the leaflets fold up and as the sun comes they open. Leaf shedding occurs during dry season as an escape mechanism to skip drought period (Jambulingam and Fernandes, 1986).

Siddiqui *et al.,* (1994) studied foliar characters of *Terminalia tomentosa and Terminalia arjuna* and reported leaf characters are genetically controlled. Leaf characters like leaf area, leaf weight, stomatal length, leaf length, leaf breadth had significant positive association with each other and had direct effect on fruit yield

2.2.3 Flowering characters

Flowering occurs on both current season and old season wood. Upto 100 flowers can be seen in a single inflorescence. Phenological parameters were found to vary between clones. Flowers possess entomophilous adaptations for favouring open pollination with fruit setting upto 1 - 2 %. Tamarind prefers outcrossing with very little selfing and apomixis not observed. Pollen exhibit less sterility and long term storage of pollen is possible (Nagarajan *et al.,* 1997).

Co-existence of both cross-pollination and self-pollination can be seen in tamarind but post zygotic embryo abortion and partial self-incompatability makes it predominantly a cross pollinated species (Diallo *et al.,* 2008). But Bajpai *et al.* (1968) recorded 84 per cent and 85.50 per cent of fruit set by hand self-pollination and hand cross pollination respectively.

Climatic zones exert a significant influence on flowering and fruiting in tamarind. Flowering in general initiates by the end of the dry period when hygrometry shows rising trend and lasts for about two to three months. Fruiting begins during the peak of rainy season. Pods take six to eight months to ripe which coincides with dry season (Fandohan *et al.,* 2015).

In Raichur district of Karnataka, flowering was observed during the last week of March to mid-June. A significant influence of longitude and day and night temperature on flowering was noticed while comparing flowering in eastern India. Around 25 days were required for completion of flowering in a single panicle. The anther dehiscence took place between 09.00 a.m. and 11.00 a.m. (Chavan *et al.*, 1999; El-Siddig *el al.,* 2006). Bajpai *et al.* (1968) recorded maximum anther dehiscence between 8:30 am to 9:30 am at Khanpur. Anthesis of flowers normally take 7-8 hours to complete but in some flowers it took as much as 32 hours for complete opening of flowers after initiation of anthesis. Maximum anthesis took place in the early morning between 4:30 am to 5:30 am.

A wide range of variability was observed for pedicel length, flower length, flower spread, petal length, petal breadth, filament length, sepal length, sepal breadth, number of sepals, number of petals, anther length, anther breadth, anthers per flower, stamen length, pistil length, stigma diameter, ovary length, ovary breadth, style length, style diameter, bud length and bud breadth at flower opening (Singh *et al.,* 2008). Observed differences among the floral traits might be due to the variations in genetic makeup of genotypes (Singh *et al.,* 2007).

Number of fruits per unit area (1 sq. ft.) of the tree canopy of 12-year-old trees varied from 5 (NTI-79) to 11.40 (NTI-14). Variety DTS-1 recorded 11 fruits per unit area (Hanamashetti *et al.,* 2002).

Patil (2004) reported positively significant correlation (0.662) between yield per tree and crown size of trees. Path co-efficient analysis revealed that pod weight had positive and highest direct effect on yield per tree (1.232).

Positional effect was noticed for fruit set and development in tamarind. Monoclonal plantation with single high yielding genotype was highly associated with risk of complete fruiting failure due to remarkably lowest compatibility with its own pollen (partial or complete self incompatability) and in natural condition herkogamy prevents selfing and strongly promotes cross breeding system, thus inclusion of five or more different clones in clonal orchards of tamarind along with honey bee rearing improves fruit set and returns (Nagarajan *et al.,* 1998).

2.2.4 Flower characters

Flowers are zygomorphic and irregular. Flower buds are covered by one caducous bract and two boat shaped caducous bracteoles. Flowers contain four sepals, five petals

of which two lower petals are miniature in size and remaining upper three are well developed, prominent petals are ovate, pale yellow with red streaks and very attractive. Eight stamens which are fused at the base and free at the top as three fertile stamens and remaining stamens are underdeveloped and termed as staminodes. Ovary is hypogynous. Flowers open in acropetal succession along the panicle (Bajpai *et al.,* 1968; Thimmaraju *et al.,* 1977; Palgrave, 2002).

Flower bud takes 20 days to develop from its initiation. Peak anthesis was observed at 6.30 a.m. and peak anther dehiscence at 10:30 a.m. (Thimmaraju *et al.,* 1977). Flowers are protogynous in nature but maximum receptivity was observed on the day of anthesis and the next day. Unavailability of enough number of pollen grains at receptive stage results in low fruit set (1.30%) and only 0.844 per cent flowers reached maturity (Bajpai *et al.,*1968).

Raju *et al.* (1979) reported presence of floral abnormality and variability in tamarind for number of sepals (3-4), number of petals (2-5), number of stamens (2-6), length of filament, length of pistil and number of pistils per flower (1-2).

Nagarajan *et al.* (1998) recorded colour dimorphism in fruits which could be used as morphological markers. Green and pink coloured fruits were noticed. Flowers of pink fruit producing clone had pink anthers, pink filaments and pink styles which resulted in greater insect activity around the tree.

Chavan (1999) reported wide variability for mean flower weight ranging from 85 mg to 186 mg. which in turn denotes nectar content of flowers to attract pollinators. It was evident from the previous studies that greater the floral size and display, greater will be the attractions for pollinators which in turn increases fruit set and yield.

2.2.5 Fruit characters

Tamarind took nearly 280 days after anthesis to reach harvesting stage and this period included fruit growth, maturation and ripening. Ripening follows a simple sigmoidal growth curve. Physiological maturity of fruit attains between 270 and 280 days after anthesis, which coincided with natural detachment of fruit from tree and seeds maturation took 277 days after anthesis (de Oliveira Gurjão, 2006).

Fruit is a rusty brown coloured indehiscent semi curved pod of length 10-18 cm, seeds are packed in the sticky pulp inside the brittle shell of pod (Palgrave, 2002). A mature tree gives an average yield of 100-500 kg pods annually with 40-50 per cent pulp

recovery. Variation in annual yield and a bumper yield once in three years was observed in Tamil Nadu (Jambulingam and Fernandes, 1986).

In general tamarind pods contain 1–12 seeds but the Indian pods are usually longer and contain 6–12 seeds. A wide range of variability was observed for pod weight (9.5 - 83.7 g), pulp weight (4.8 - 51.2 g), seed weight (2.4 - 12.2 g), shell weight (2.3 - 18.1 g), pod length (9.0 - 25.5 cm) and pod width (1.8 - 5.5 cm). Higher heritability estimates and higher genetic advance were observed for traits such as shell weight, pod weight, pulp weight, and vein weight which indicates greater possibility of progress by mere selection procedures (Divakara *et al.,* 2012).

Pulp yield is around 30-50 per cent of the whole fruit weight. Shell and fibre together accounts for 11-30 per cent and seed contributes 25-40 per cent of fruit weight (Shankaracharya, 1998; Rao *et al.*, 2015).

Wide variability was observed for traits such as average number of branches per tree, average stem girth, average plant height, branching habit, new flush colour, plant stature, leaf colour, stem colour (Rao and Subramanyam, 2010)

Pooja *et al.,* (2018) identified existence of significant positive association of pod weight with pulp weight, pod width and pod length. Tania *et al.,* (2018) reported variation in tamarind varieties with respect to ripening period. Variety Vantoor, Urigam and PKM-1 took 261, 301 and 326 days respectively to reach harvesting stage after fruit set.

2.2.6 Biochemical properties of fruit

Fruit pulp contains 8-18 per cent tartaric acid (as potassium bitartarate) and reducing sugars are present upto 25-45 per cent of which glucose and fructose are in ratio 70:30 (Shankaracharya, 1998; Rao and Mathew, 2012). Tadas *et al.,* (2015) recorded TSS in the range of 32.40 to 53.70 ^{O}Brix and tartaric acid in the range of 9.92 to 17.04 per cent among the 25 genotypes evaluated at Akola.

Wide variability was present with respect to tartaric acid content, sugar content and proportion of glucose and fructose at tree level. The sweetness of the pulp was negatively correlated with tartaric acid percentage. Interestingly none of the nutritional traits were correlated with any of the morphological traits (Van den Bilcke *et al.*, 2014).

The chemical properties of pulp like TSS, proteins, carbohydrates, fats and total ash content followed an increasing trend after drying but the titratable acidity of pulp decreased with decreasing moisture content during drying of the fruits and the color of

pulp turned darker, redder and yellower than the initial colour (Sinha *et al.,* 2012). Tartaric acid content of fruits varied from tree to tree and year to year and observed tarataric acid range during the year 2000 was 9.90-16.76 per cent (Hanamashetti *et al.,* 2002).

The morphological differences of *Garcinia gummigutta trees* have been manifested in chemical constitution of the fruits as well (Shameer *et al.,* 2016).

Vikram (2016) observed wide variability in nutmeg population of Kerala. All the quantitative parameters except shelling percentage exhibited significant variation. Biochemical constituents of fruits also exhibited higher variability among the accessions.

Fifty-six accessions of Malabar tamarind were collected by NBPGR, Thrissur. Immense variability was observed for morphological characters like canopy shape, branching pattern of tree, fruit colour, shape and size but variation in biochemical characters were limited. Hence the selection of trees with higher value for fruit weight, rind thickness, total acidity, (-) HCA, crude protein coupled with low values of moisture, total phenol, crude fat and crude fibre became impossible (Abraham *et al.,* 2006).

2.3 Identification of elite trees

Shivanandam (1983) recommended selection of trees producing curved pod, bulged fruits which are best in terms of weights of pod, pulp weight, seed weight, seed size and pulp recovery for the purpose of yield improvement. These characters were also recommended by Osorio *et al.* (2018).

Correlation analysis done by Mayavel *et al.* (2018a) revealed that the length of inflorescence, number of flowers per inflorescence, number of fruits per inflorescence, length and breadth of fruits, fruit weight, pulp weight showed positive and significant association with tree yield. Consideration of these yield attributing characters for improvement programme for selecting genotypes is recommended by several authors (Divakara, 2008; Divakara *et al.,* 2012; Nasution and Yapwattanaphun, 2016; Bhogave *et al.,* 2018; Pooja *et al.,* 2018; Mayavel *et al.,* 2018b) Understanding the relationship between fruit and flower parameters and yield helps in increasing efficiency of selecting elite genotypes of seedling origin.

Divergence study done by Divakara *et al.* (2012) on 35 genotypes of tamarind, grouped them into two broad clusters, one cluster with 9 genotypes had good combination

of all desirable characters and which can be directly utilized in breeding programmes for further improvement.

Algabal *et al.* (2010) reported that pod length, pod weight, husk weight and pulp weight had high heritability along with high per cent mean for genetic advance which could be considered as prime characters for improvement by mere selection.

Singh *et al.* (2008) reported positively significant association of pedicel length, panicle length, flower length, pistil length, ovary length and perfect flowers per panicle with observed average fruit yield per plant. Thus, important floral traits can be observed for their positive behaviour while selecting superior genotypes.

Genotypes with superior traits combination are marked as plus trees for further study and mass multiplication purposes (Singh and Nandini, 2011).

Fruit characters and yield are influenced by climate and soil characteristics. It should be considered during domestication process and planting trees in any region different from the existing region. So taming of existing superior genotypes is of great importance (Van den Bilcke *et al.*, 2014)

Vikram (2016) developed crop descriptors for evaluation and characterization of nutmeg with 51 qualitative and 38 quantitative parameters and descriptor states for each characters. Based on the results, a key for identification of elite trees was formulated

Ayala-Silva *et al.,* (2016) analysed the diversity of tamarind germplasms which were being maintained at Subtropical Horticultural Research Station, Miami, Florida, USA using Principal Component Analysis. Data on 13 tamarind accessions 18 quantitative characters were used for analysis. Seventy-two per cent of the variability was captured under first three principal components and three broad clusters A, B and C were made by cluster analysis to know the extent of similarity between genotypes.

Kidaha *et al.* (2019) conducted PCA to analyse the diversity and to know the correlation between various characters. Seventy-six per cent of the total variation was explained by first five principle components. Eleven traits contributed positively to PC1 and PC2. Eight traits contributed positively to PC3 where as PC4 and PC5 had six positively contributed traits each. Three clusters were represented the correlation among the characters. Length of pod, weight of pod, weight of seed and pulp weight formed a single cluster which represented highly positive correlation.

Taking all the 15 characters into consideration, yield/tree (kg) expressed significant and positive relationship with length of inflorescence (cm), number of flowers/inflorescence, number of fruits/inflorescence, fruit length (cm), fruit breadth (cm), fruit weight (g), pulp weight (g) and anthocyanin content (mg/litre). Hence it might be inferred that these traits could be considered as most important yield contributing traits in red tamarind

2.4 Propagation study

Tamarind is a cross pollinated species hence seed propagation commonly result in heterozygous and variable population. Vegetative propagation is crucial for conservation of elite germplasms and their mass multiplication to produce true to type plants. Different methods are followed with varying rate of success percentage.

Successful propagation method in tamarind include grafting (veneer, softwood, side, approach, cleft), budding (patch, modified ring method, shield), layering (air layering, mound layering), stem cutting and to a lesser extent by micropropagation. Micropropagation of tamarind gave around 39-56 per cent survival of plants developed from mature and young shoot nodal explants on MS medium (Farooq and Farooq, 2003).

2.4.1 Softwood grafting

Six months old seedlings of uniform growth and scions of 10 cm were used for soft wood grafting. Scions were freshly defoliated before grafting. Grafting was done at 15 cm height and obtained 68 per cent success during the month of April. The average number of new shoots produced per graft was 3.22 and the average sprout length was 15.95 (Purushotham and Narasimharao, 1990). Tamarind propagation carried out under black shade net condition performed better (Soares *et al.*, 2017).

Praveenakumar *et al.* (2019) conducted softwood grafting of tamarind in Bangaluru over four months (February to May) under different types of protected structures and outdoor growing conditions. The survival rate was highest in the month of March (96.68 %) under low cost polyhouse condition.

Singh and Singh (2007) conducted soft-wood grafting (cleft method) at CHES, Godhra, Gujarat at monthly interval and highest graft success was obtained in grafts of May, followed by April. Based on the results they recommended April-May as best time for multiplication of elite tamarind genotypes in the same agroclimatic region.

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Agasimani *et al.* (2019) conducted propagation study at Arabhavi (Karnataka) recommended grafting on six month old rootstocks as it showed higher graft success (70.39%), grafts survivability (70.95%) and took less number of days to sprout (12.52). They also observed maximum graft height (37.31 cm), graft diameter (7.92 mm), length of sprouts (19.02 cm) for six-month old rootstock. Month of April and May was recommended for maximum graft success.

After 90 days after grafting (DAG) October grafts produced highest number of average sprouts (4.62), while the December grafts developed lowest number of sprouts (3.02). Average number of sprouts produced grafts of August (3.54), September (4.19) and January (3.56) are statistically on par with each other. Similarly, Highest sprout length (6.12 cm) was recorded in August followed by September (5.43 cm) and January (4.21 cm). The vigorous growth of sprouts developed in August and September grafts may be due to the higher relative humidity and reduced transpiration which boosted vegetative growth (Kumar *et al*., 2003)

Age of rootstock influence grafting success and higher success could be achieved in softwood grafting by using seven (60.00%), eight (80.00%) and nine (73.33%) month old seedlings as rootstocks (Patil, 2004).

In a study conducted at College of Horticulture, Sindhudurg, Maharashtra, defoliation of scion eight days prior to grafting gave maximum shoot growth, highest sprouting percentage and maximum graft survival percentage than defoliation four days prior to grafting and defoliation on the day of grafting (Mane and Nalage, 2017).

2.4.2 Veneer grafting

Purushotham and Narasimharao (1990) obtained 49 per cent success during April for veneer grafting done on six months old seedlings of uniform growth and scions of 10cm. Freshly defoliated scions were grafted at 08 cm height and the stock above the graft union was cut immediately after grafting and fastened tightly using 200-gauge polythene tape. On an average three sprouts produced per graft and the average sprout length was 16.69 cm.

2.4.3 Approach grafting

Approach grafting or inarching is a proven method for successful propagation of tamarind. But it's a tedious and time consuming method compared to grafting and budding. It requires greater care by regular watering.

The success percentage of approach grafting ranged from 83.00 (October) to 96.67 (June). Overall the higher per cent of success was obtained in approach grafting compared to softwood grafting and air layering done during the same period. Highest survival per cent obtained in the June (96.67%) followed by July, August and lowest survival recorded in October (83%) (Patil, 2004). Swaminath and Ravindran (1989) obtained upto 95 percent success in tamarind inarching.

2.4.4 Patch budding

Patch budding was carried out at monthly interval. Early sprouting was noticed in August (22 days) followed by July (23 Days) and June (24.25 days). Buds took maximum duration for sprouting during February (32 days). Budded plants of August showed highest success rate and survival followed by July (Singh and Singh 2007).

Patel (2016) studied effect of different combinations of growing environment and budding seasons and came to conclusion that low polythene tunnel growing condition with patch budding preferably July and August months were best for mass multiplication of tamarind.

Pathak (1991) conducted propagation studies at Narendra Deva University of Agriculture and Technology, Faizabad, Uttar Pradesh. Nine month old seedlings are used as rootstocks and performed patch budding and modified ring budding. Patch-budding recorded highest success (96%) followed by modified ring budding (94% success).

Lalaji (2001) obtained highest sprouting of 51.66 per cent for patch budding and recommended carrying of propagation during mid-April to mid-June and mid-October for better success. He also reported that there was complete failure in patch budding done during January, February, March and December.

2.4.5 Air layering

Rooting percent and survival in air layers of tamarind can be improved by using coconut powder substrate along with 1000ppm IBA treatment or sphagnum moss substrate along with 500ppm IBA (Ferreira, *et al.,* 2017).

Highest rooting was observed when the air layers which were treated with IBA 1000 ppm during May and same treatment gave no rooting during January. The survival rate was ranged between 16.66 to 64.28 per cent (Patil, 2004).

Materials and methods

III. MATERIALS AND METHODS

The study was conducted at Department of Plantation Crops and Spices, College of Horticulture, Kerala Agricultural University, Vellanikkara during 2017-2019.

3.1 Location and climatic condition

Main campus of Kerala Agricultural University is situated at 10.54^0 N latitude and 76.28^0 E longitude. It comes under Western Tropical Plains of Agro Climatic Zone-XII. Thrissur belong to sub-agro climatic zone 'Coastal Midland Region' (Annamalai, 2006). This zone enjoys tropical humid climate with around 3000 mm annual rainfall and this location is at a distance of around 25 km from sea.

3.2 Meteorological data

Meteorological data of minimum and maximum temperature, relative humidity, rainfall, sunshine hours recorded during the study period from 2017-2019 has been represented in Appendix-I.

Experiment I: Morphological characterization of tamarind accessions

3.3 Study Materials

The materials for morphological studies were selected from the bearing tamarind trees located in the main campus of KAU. Survey was conducted in the main campus of KAU and located 17 yielding trees and positional coordinates of the trees (Table 1a) were recorded using GPS device (Model: Garmin Etrex 30x) and were also marked on Google Map Satellite view images (Plate 1a & 1b) and identified as accessions as follows:

1. KTI-1	2. KTI-4	3. KTI-9
4. KTI-10	5. KTI-11	6. KTI-13
7. KTI-14	8. KTI-15	9. KTI-16
10. KTI-17	11. KTI-2	12. KTI-3
13. KTI-5	14. KTI-6	15. KTI-7
16. KTI-8	17. KTI-12	

3.4 Evaluation of accessions:

3.4.1 Trees character

Table 1a: Passport data of selected tamarind accessions

Accession number	Latitude	Longitude	Country of origin and state	Collection site	Landmark
KTI-1	N 10° 33' 06.98"	E 076° 17' 02.45"	India, Kerala	KAU main campus, Thrissur	Fruit Science Department-Orchard
KTI-2	N 10° 33' 08.00"	E 076° 17' 03.40"	India, Kerala	KAU main campus, Thrissur	Gokhale block of Department of Plantation Crops and Spices
KTI-3	N 10° 33' 07.90"	E 076° 17' 01.39"	India, Kerala	KAU main campus, Thrissur	Fruit Science Department-Orchard
KTI-4	N 10° 33' 07.64"	E 076° 17' 00.60"	India, Kerala	KAU main campus, Thrissur	Fruit Science Department-Orchard
KTI-5	N 10° 33' 07.53"	E 076° 17' 00.02"	India, Kerala	KAU main campus, Thrissur	Fruit Science Department-Orchard
KTI-6	N 10° 32' 56.64"	E 076° 17' 06.17"	India, Kerala	KAU main campus, Thrissur	KAU canteen
KTI-7	N 10° 32' 56.95"	E 076° 17' 06.13"	India, Kerala	KAU main campus, Thrissur	KAU canteen
KTI-8	N 10° 33' 13.18"	E 076° 17' 25.32"	India, Kerala	KAU main campus, Thrissur	Fruit Science Department-Mango orchard
KTI-9	N 10° 33' 14.86"	E 076° 17' 27.28"	India, Kerala	KAU main campus, Thrissur	Fruit Science Department-Mango orchard
KTI-10	N 10° 32' 38.37"	E 076° 17' 05.96"	India, Kerala	KAU main campus, Thrissur	Central library
KTI-11	N 10° 32' 50.88"	E 076° 17' 31.26"	India, Kerala	KAU main campus, Thrissur	KAU staff quarters road
KTI-12	N 10° 32' 54.66"	E 076° 17' 35.61"	India, Kerala	KAU main campus, Thrissur	KAU staff quarters
KTI-13	N 10° 32' 53.22"	E 076° 17' 38.08"	India, Kerala	KAU main campus, Thrissur	KAU staff quarters
KTI-14	N 10° 32' 50.74"	E 076° 17' 35.85"	India, Kerala	KAU main campus, Thrissur	KAU staff quarters
KTI-15	N 10° 32' 46.79"	E 076° 17' 19.31"	India, Kerala	KAU main campus, Thrissur	KAU staff quarters road
KTI-16	N 10° 32' 46.92"	E 076° 17' 20.19"	India, Kerala	KAU main campus, Thrissur	KAU staff quarters road
KTI-17	N 10° 32' 49.02"	E 076° 17' 26.76"	India, Kerala	KAU main campus, Thrissur	KAU staff quarters road

Plate 1a: Google map satellite view based location of accessions

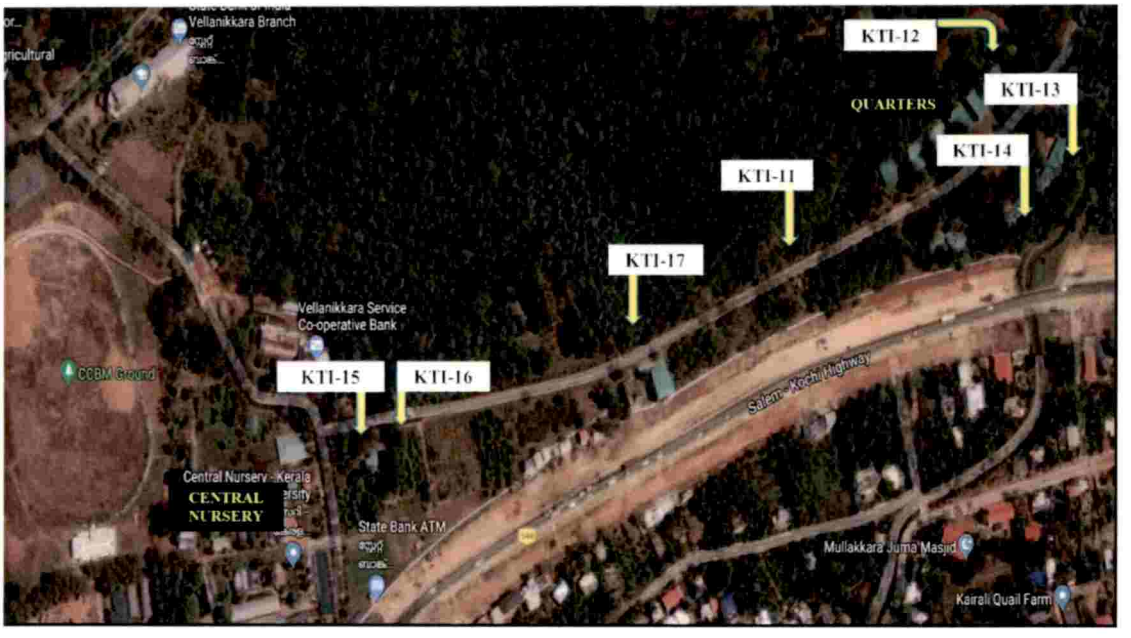

Plate 1b: Google map satellite view based location of accessions and GPS device

3.4.1.1 Tree girth

Girth of the tree trunk was measured at 1.40 m height from the ground level using measuring tape and expressed in meter (m).

3.4.1.2 Bearing habit

Bearing habit of trees were recorded for two consecutive years. Based on bearing, trees were classified as regular bearers and irregular bearers.

3.4.2 Leaf characters

3.4.2.1 Number of leaflets

Total number of leaflets per leaf was recorded from 10 randomly selected matured leaves from the mid portion of the branches.

3.4.2.2 Leaf area

Leaf area of 10 leaves from each tree was measured using Area Meter (Brand: LI-COR, model: LI-3100). Matured leaves were freshly collected from the middle portion of the randomly selected shoots of each accession and leaf area was expressed in square centimetre (cm^2).

3.4.2 Flowering characters

3.4.3.1 Season of flowering

Initiation of flowering on the tree was recorded based on the visual appearance of first few inflorescences on the tree. The trees were observed at weekly interval from 2nd week of February up to May last week. Accessions were categorised into 3 groups based on season of flowering as early (flowering before April month), mid (flowering during April month) and late (flowering after April month).

3.4.3.2 Number of inflorescence per node

Total number of inflorescence emerged from each node was recorded from randomly selected 30 inflorescences from each tree.

3.4.3.3 Panicle length (cm)

Total length of the panicle was measured at the end of flowering season and represented in centimetre.

3.4.4 Flower characters:

Observations were made on 30 randomly selected flowers from four directions of each tree during Mar 2018 to May 2019.

3.4.4.1 Qualitative characters:

The accessions were characterized based on floral characters (Table 1b) according to classes given by Singh (2010). Observations were recorded during peak flowering period.

Table 1b: Characters, their classes and scores used for classification.

Characteristics	Classes
Bract colour	Pale green
	Pale yellow
	Yellow
	Pale pink
	Pink
	Deep pink
Bracteole colour	Pale green
	Yellow
	Pink
Corolla colour	Pale yellow with red streak
	Yellow with red streak
	Orange yellow with red streak
	Orange red with red streak
Sepal colour	Lemon chiffon
	Pale yellow
	Yellow
	Gold
Filament colour	Green without streaks
	Green with streaks

3.4.4.2 Quantitative characters:

Observations were made on 10 randomly selected fresh flowers from four different directions of each tree during peak flowering period. Floral part measurements were done using Digital Vernier callipers and mean value was recorded.

3.4.4.2.1 Corolla spread (cm)

Fully opened flower was measured. Width from tip to tip of two opposite petals was recorded.

3.4.4.2.2 Pedicle length (cm)

Measurement of pedicel length was done after detaching them from the freshly harvested flower.

3.4.4.2.3 Petal length (cm)

Length of the petals of each flower was measured and the average was calculated.

3.4.4.2.4 Petal width (cm)

Width of the petals of each flower was measured and mean was recorded.

3.4.4.2.5 Filament length (cm)

Measurement of filament length was done after detaching them from the freshly collected flowers and the mean value was recorded.

3.4.4.2.6 Sepal length (cm)

Length of all the sepals of each flower was measured from tip to base of sepal and the mean value was recorded.

3.4.4.2.7 Sepal width (cm)

Width of all sepals of each flower was measured and the mean value was recorded.

3.4.4.2.8 Ovary length (cm)

Length of the ovary of each flower was measured and average value was recorded.

3.4.4.2.9 Pistil Length (cm)

Length of the pistil was recorded and the mean value was recorded.

3.4.4.2.10 Number of stamens

Total number of stamens present in each flower was recorded and the mean value was recorded.

3.4.4.2.11 Number of staminodes

Staminodes are sterile stamens which develops along with stamens, total number of staminodes present in each flower was recorded.

3.4.4.2.12 Flower weight (g)

Total weight of 10 randomly selected flowers from four different directions of each tree was recorded and expressed in grams.

3.4.5 Fruit characters:

Observations were recorded during 2018-19. For pod characters, observations were made on 30 randomly selected pods from four different directions of each tree. Mean values were recorded for each character for each accession.

3.4.5.1 Quantitative characters

3.4.5.1.1 Pod length (cm)

Pod length was measured from stalk end of the fruit to the tip of the fruit using thread and 30 cm scale.

3.4.5.1.2 Pod girth (cm)

Girth of the pod was measured at the mid portion of the pod using thread and 30 cm scale.

3.4.5.1.3 Fruit weight (g)

Weight of each pod was recorded and average weight was expressed in gram.

3.4.5.1.4 Shell weight (g)

Outer cover was separated from fruit and weighed. Average weight was recorded.

3.4.5.1.5 Fibre weight (g)

Fibres of each fruit was weighed and average value was recorded.

3.4.5.1.6 Pulp weight (g)

Weight of the pulp of each individual fruit was recorded and mean was derived.

3.4.5.1.7 Seed weight (g)

Weight of the seeds in each fruit was recorded and average weight of seed was expressed in gram.

3.4.5.1.8 Seed number

Total number of seeds present in each fruit was recorded and average value was recorded as number of seed per fruit for each accession.

3.4.5.1.9 Number of pods per unit area of canopy

Total number of fruit present in one sq. ft. area of the canopy is counted randomly on eight directions and expressed as number of fruits per unit area.

3.4.5.1.10 Pulp: Shell ratio

For each tree, pulp: shell ratio was calculated by dividing corresponding values of average pulp weight by average shell weight.

3.4.5.1.11 Pulp: Seed ratio

For each accession, pulp: seed ratio was calculated by dividing mean pulp weight of the accession by its mean seed weight.

3.4.5.1.12 Pulp content (%)

Pulp content was calculated by using the following formula for each accession.

$$\text{Pulp content (\%)} = \frac{\text{Average pulp weight}}{\text{Average fruit weight}} \times 100$$

3.4.5.1.13 Shell content (%)

Shell content per fruit was calculated by using the following formula for each accession.

$$\text{Shell content (\%)} = \frac{\text{Average shell weight}}{\text{Average fruit weight}} \times 100$$

3.4.5.1.14 Fibre content (%)

Fibre content per fruit was calculated by using the following formula for each accession.

$$\text{Fibre content (\%)} = \frac{\text{Average fibre weight}}{\text{Average fruit weight}} \times 100$$

3.4.5.1.15 Seed content (%)

Seed content per fruit was calculated by using the following formula for each accession.

$$\text{Shell content (\%)} = \frac{\text{Average seed weight}}{\text{Average fruit weight}} \times 100$$

3.4.5.2 Fruit biochemical characters

3.4.5.2.1 Titratable acidity

Titratable acidity was estimated as per standard procedure given by Sadasivam and Manickam (1996) and expressed as per cent of tartaric acid.

Procedure: Forty gram of pulp was taken in a beaker and water was added. The sample was boiled for one hour and water lost during boiling was replaced by adding

distilled water and mixed thoroughly. Cooled sample was transferred to volumetric flask and made up to 100 ml.

From this sample, 2 ml was transferred to conical flask containing 20 ml distilled water. Few drops of phenolphthalein indicator were added and titrated against 0.1N NaOH solution till the appearance of light pink colour which represents end point, corresponding titre value was recorded and titratable acidity was calculated using following formula.

$$\text{Total acid (\%)} = \frac{\text{Titre} \times \text{Normality of alkali} \times \text{Volume made up} \times \text{Equivalent weight of acid} \times 100}{\text{Weight of the sample taken} \times 1000}$$

3.4.5.2.2 Total Soluble Solids (TSS)

TSS was estimated using hand refractometer (FSSAI, 2016), 40 g of the pulp was taken and 150 ml of distilled water was added to it in a 250 ml beaker. The sample was boiled gently for 30 minutes with intermittent stirring using a glass rod. Then the sample was cooled for 20 min and mixed thoroughly. Cooled sample was weighed and then filtered through a fluted filter paper or a Buchner funnel into a dry vessel. Refractometer reading of filtrate was recorded. TSS of the original sample was calculated using following formula and expressed in ^{o}brix to one decimal place.

$$\text{TSS of original sample } (^{o}\text{brix}) = \frac{P \times m_1}{m_0}$$

Where,

P is the refractometer reading (^{o}brix)

m_0 is the mass of the sample before dilution (g)

m_1 is the mass of the sample after dilution (g)

3.4.5.2.3 Ascorbic Acid

Ascorbic acid was estimated using standard procedure given by Sadasivam and Manickam (1996) and ascorbic acid content of the pulp was expressed in mg/100g of the pulp weight.

Table 2: Descriptors for characterization

Characteristics	States	Stage/time of recording observation
Growth habit	Spreading	During vegetative phase
	Semi spreading	
	Upright	
Type of foliage	Sparse	During vegetative phase
	dense	
New flush colour	Reddish green	During flushing season after dormancy period
	Reddish brown	
Inflorescence (panicle) length (cm)	Low (<10.0)	End of flowering season
	Medium (10.0 to 12.0)	
	High (>12.0)	
Matured fruit colour	Brown	Mature fruits during harvesting
	Reddish brown	
	Grey	
Mature pod shape	Curved	Mature fruits during harvesting
	Semi curved	
	Straight	
Mature pod weight (g)	Low (<15.0)	Mature fruits during harvesting
	Medium (15.0 to 25.0)	
	High (>25.0)	
Mature pod length (cm)	Short (<10.0)	Mature fruits during harvesting
	Medium (10.0 to 15.0)	
	Long (>15.0)	
Mature fruit pulp colour	Brown	Mature fruits during harvesting
	Reddish brown	
Pulp TSS at ripe stage	Low (<60 ^{O}B)	Mature fruits during harvesting
	Medium(60-70 ^{O}B)	
	High (>70 ^{O}B)	
Titratable Acidity (%)	Low (<8.0)	Mature fruits during harvesting
	Medium (8.0-10.0)	
	High (>10.0)	
Seed weight/pod	Low (<5.0 g)	Mature fruits during harvesting
	Medium (5.0-6.0 g)	
	High (>6.0 g)	
Ripening period	Early (255 days)	Mature fruits during harvesting
	Medium (270 days)	
	Late (280 days)	

(PPVFRA, 2017)

3.4.6 Statistical analysis

Seventeen accessions were grouped into clusters based on yield attributing characters *viz.,* pod length, pod girth, fruit weight, pulp weight, seed weight, number of seed per fruit, number of fruit per unit area and pulp content. Multivariate clustering of accessions was carried out using score plot of Principal Component Analysis (PCA). Minitab version 18.1 software was employed for generating PCA score plot. Correlation among fruit and flower characters were analysed using IBM SPSS statistics software. Descriptive statistics *viz.,* mean, Standard Deviation (SD), Coefficient of Variation (CV) were estimated.

Experiment 2. Evaluation of vegetative propagation techniques

This study was conducted in the nursery block of department of Plantation Crops and Spices, COH, KAU, Thrissur during 2018-19.

3.5 Design of the experiment

Design : CRD

Treatments :
1. Veneer grafting
2. Wedge grafting
3. Approach grafting
4. Patch budding
5. Air layering

Seasons :
1. March-April
2. June-July
3. September-October
4. December-January

Replications : 4

No. of plants per replication : 10

Number of plants/treatment/season : 40

For grafting and budding, one-year-old seedlings of uniform growth and pencil thickness were used as rootstocks. Scion sticks of approx. 10-12 cm with 3-5 buds were used for softwood grafting and veneer grafting.

3.6 Methods of vegetative propagation

3.6.1 Veneer grafting

Scion shoots were collected from tamarind plus trees present in the KAU main campus. Scion shoots were defoliated prior to grafting. During the season of March, scion shoots were defoliated naturally. Rootstock was prepared by giving a slant cut of 5 cm and an oblique cut was made at the base of first cut (Plate 2b). A piece of bark along with wood was removed from the cut made on the stock. Similar cut was given on the scion base and then fitted into the rootstock such that their cambial layers' touch each other and tied together with 150-gauge polythene strip. Rootstock was cut few centimeters above the graft union immediately after grafting and covered with a wet polythene hood till the sprout emerge from the scion. The wrapped polythene tape was removed three months after successful union.

3.6.2 Wedge grafting

Wedge grafting is also known as softwood grafting (Plate 2a). Scion shoots were collected from the plus trees present in the KAU main campus. Scion shoots were defoliated prior to grafting. During the season of March, scion shoots were defoliated naturally. Rootstocks were decapitated at 15-20 cm height and a split was made at center to a depth of 5 cm. Base of the scion was given wedge cut of 5 cm and inserted in the split of the rootstock and firmly wrapped together with 150-gauge polythene tape. Grafts were covered with wet polythene hood till the sprout emerge from the scion. The wrapped polythene tape was removed three months after successful union.

3.6.3 Approach grafting

Rootstock was brought near to the desirable mother plant and shoot of similar thickness was selected on mother tree. On rootstock, at about 10-15 cm height a thin slice of bark of length 6-8 cm was removed and a similar cut was given to scion shoot without detaching from mother tree. Both the stock and scion are brought together and cut surface were joined together and wrapped firmly with polythene tape (wire). They were detached from mother plant after three months by giving two successive cuts on scion shoot below graft union (Plate 2a).

3.6.4 Patch budding

For patch budding, previous season shoots with unsprouted, dormant, well swollen buds were selected from selected trees. Bud woods were collected freshly during

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each budding season and defoliated by leaving the petiole intact with the bud. On stock plant a rectangular shaped patch of bark was removed and patch of bud along with petiole similar to size of removed bark was placed on rootstock. They are firmly wrapped with 150-gauge polythene strip immediately. After 21 days, the tape was removed and the stock plant was bent back just above the bud union and removed successively after sprouting of the bud (Plate 2b).

3.6.5 Air layering

Shoots of desirable mother plants were girdled and rooting hormone IBA at 1000 ppm was swabbed on the upper end of the girdled portion. Moist sphagnum moss was wrapped around the cut using transparent polythene sheet and tied tightly on both ends by jute thread (Plate 2a). They were detached from the mother plant after three months by giving two successive cuts at weekly interval at 2-3 cm below the girdled portion.

3.7 Aftercare of plants

Grafting and budding activities were carried out in mist chamber and sprouted plants were transferred to shade house one month after grafting and budding. Approach grafted and air layered plants were transferred to shade-house after their detachment from the mother plant after three months. Budded and grafted plants were watered regularly and need based application of plant protection chemicals like wettable Sulphur @2g/l for powdery mildew control and carbendazim @2g/l for fungal rot were taken up to maintain health and vigour of the plants.

3.8 Propagation observations

Observations were taken periodically on both grafted and budded plants for following parameters:

3.8.1 Time taken for sprouting

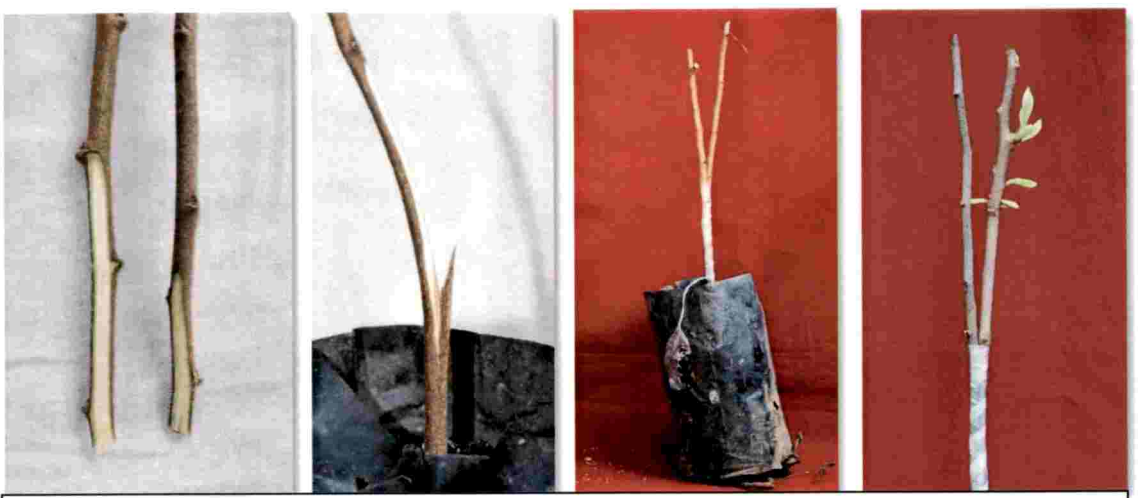
Number of days taken for the appearance of first green coloured sprout on the scion/bud after grafting/budding was recorded for each treatment and average value was calculated.

Air layering

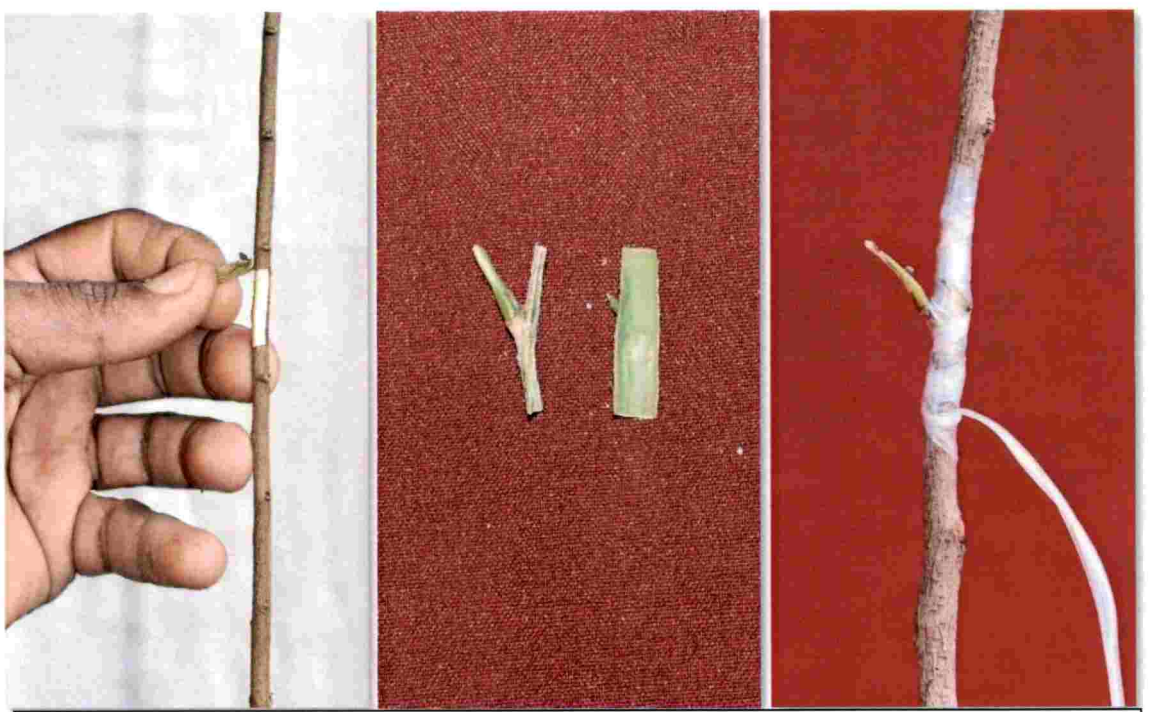
Approach grafting

Softwood grafting

Plate 2a: Vegetative propagation of tamarind



Veneer grafting



Patch budding

Plate 2b: Vegetative propagation of tamarind

3.8.2 Success percentage

Number of successful grafts/budded plants were recorded on 30th, 45th, 60th and 90th day after grafting for each treatment. Success percentage at 30th, 45th and 60th day were expressed as establishment percentage and recorded only for detached method of grafting and budding whereas success percentage at 90th day was recorded for all the evaluated vegetative propagation methods.

3.8.3 Length of shoot

Length of all the sprouts was measured on 45th and 60th day after grafting/budding and average shoot length was calculated for each plant in detached method of grafting *viz.*, softwood grafting, veneer grafting and patch budding.

3.8.4 Number of branches

Total number of newly formed branches present on the grafted scion/budded plant were recorded on 90th day of grafting in detached method of grafting and patch budding.

3.9 Statistical analysis

Factorial-CRD design was employed for analysis of variance. Main factors effects and interaction effects of season of propagation and method of propagation on success percentage and performance of grafts were analysed.

Results and Discussion

IV. RESULTS AND DISCUSSION

The present study entitled "Morphometric evaluation and propagation studies in tamarind (*Tamarindus indica* L.)" Was carried out at the Department of Plantation Crops and Spices, College of Horticulture, Kerala Agricultural University, Thrissur, during 2017-2019.

Tamarind accessions of seedling origin available in the main campus of Kerala Agricultural University were selected for the study.

A survey was conducted in the campus to identify healthy bearing trees which were not undergone any training, pruning, trimming or any major tree surgery to ensure that the trees were grown in full freedom and expressing its actual tree structure solely under the influence of nature.

At the end of the survey 17 accessions were found suitable for the present study and each tree was marked and the accession number was allotted for further study. Locations of the selected 17 trees were marked on google satellite view map and GPS coordinates were recorded for generating passport data.

As the trees are scattered all over the campus in the unprotected area, it was difficult to record total fruit yield per tree. Hence yield per unit area of the canopy was estimated using number of fruits and fruit weight and pulp weight.

4.1 EVALUATION AND MORPHOLOGICAL CHARACTERIZATION OF TAMARIND OF ACCESSIONS

Characterization helps to distinguish accessions within a species, facilitates easy and quick discrimination among different phenotypes. It allows one to have a clear knowledge about the composition of the collected germplasm and their genetic diversity.

Morphological descriptors are employed to describe the phenotype of accessions. Descriptive traits like flower colour can be expressed in numeric value by using a standard colour chart. The descriptive traits may vary from species to species.

Due to unavailability of full-fledged descriptors for tamarind, a compilation of suitable descriptors from previous studies (Patil, 2004; Singh, 2010) and descriptors published by the Protection of Plant Varieties and Farmer's Rights Authority, New Delhi (PPVFRA, 2017) was made and referred during the study.

4.1.1 Trees character

4.1.1.1 Tree girth

Considerable difference was observed for tree girth (Table 3a, Plate 3) and accession KTI-9 recorded highest tree girth (3.16 m) followed by KTI-1 and KTI-17 each having 2.62 m girth. The minimum tree girth was observed in accession KTI-10 (1.00 m).

Age of the tree and growth rate influence tree girth to a larger extent. Rao and Subramanyam (2010) evaluated 15 genotypes and the girth varied from 59.4 to 62.1 cm among the genotypes of nine year age. The difference in the tree girth in the present study might be due to differences in the age of the trees.

4.1.1.2 Bearing habit

Trees were grouped into regular and irregular bearers based on observations of two consecutive years. Ten out of 17 accessions were regular bearers (Table 3b).

In tamarind, the irregular bearing is not an uncommon phenomenon. Irregular bearing, alternate bearing, non-bearing and the bumper harvest once in three years are frequently noticed in tamarind trees (Jambulingam and Fernandes, 1986; Mayavel *et al.* 2018b). Regular bearers are the preferred ones with respect to crop improvement programmes. In the present study, accession KTI-2,3,5,6,7,8 and 12 were irregular bearers and such genotypes should be excluded while selecting trees for crop improvement activities and mass multiplication.

4.1.1.3 Growth habit

Three types of growth habit observed in experimental population (Table 3b, Plate 4). Upright (47.06%) and semi-spreading types (41.17%) were predominantly found followed by spreading type (11.77%).

Type of growth is very important to decide the space requirements and suitability of the accession to high-density plantation. Rao and Subramanyam (2010) observed variation in plant stature and growth habit. They categorized tree grwoth pattern as erect, semi-erect, semi drooping and drooping. Algabal *et al.* (2012) and Kidaha (2019) reported two types of growth habit *viz.*, orthotropic and plagiotropic which were similar to an upright and spreading type respectively. Plants with upright growth habit are generally preferred for high density planting.

Plate 3: Tree girth measurement

Plate 4: Branching pattern

Plate 5: New flush colour

Table 3a: Tree girth and leaf characters

Accession	Tree girth (m)	Number of leaflets	Leaf area (sq. cm)
KTI-1	2.62	25.67	13.34
KTI-2	1.30	26.00	11.71
KTI-3	1.25	24.33	14.23
KTI-4	1.20	28.00	16.59
KTI-5	1.27	31.00	17.21
KTI-6	1.65	30.33	13.26
KTI-7	1.05	29.67	14.37
KTI-8	1.35	29.33	11.09
KTI-9	3.16	31.00	9.32
KTI-10	1.00	32.00	12.62
KTI-11	1.78	29.00	13.83
KTI-12	1.58	28.67	9.54
KTI-13	1.57	29.67	14.04
KTI-14	2.10	28.67	6.47
KTI-15	2.62	24.00	10.66
KTI-16	1.50	27.33	8.56
KTI-17	1.70	27.00	7.03
Mean±SE	1.69±0.15	28.33±0.57	11.99±0.75
SD	0.61	2.33	3.09
CV	35.95	8.24	25.80

Table 3b: Tree, leaf and inflorescence characters

Accession	Bearing habit	Growth habit	Type of foliage	New flush colour	Inflorescence length (cm)	Season of flowering
KTI-1	Regular	Upright	Dense	Reddish green	Medium	April 4th week
KTI-2	Irregular	Upright	Sparse	Green	High	April 3rd week
KTI-3	Irregular	Upright	Sparse	Green	Low	April 3rd week
KTI-4	Regular	Upright	Dense	Green	Medium	April 3rd week
KTI-5	Irregular	Upright	Dense	Green	Medium	April 3rd week
KTI-6	Irregular	Semi-spreading	Dense	Green	Low	May 2nd week
KTI-7	Irregular	Upright	Sparse	Green	High	April 4th week
KTI-8	Irregular	Upright	Dense	Green	Low	May 1st week
KTI-9	Regular	Semi-spreading	Dense	Reddish green	High	April 2nd week
KTI-10	Regular	Spreading	Dense	Green	High	April 1st week
KTI-11	Regular	Semi-spreading	Dense	Reddish green	High	April 4th week
KTI-12	Irregular	Semi-spreading	Dense	Reddish green	Low	April 3rd week
KTI-13	Regular	Semi-spreading	Sparse	Green	High	March 4th week
KTI-14	Regular	Semi-spreading	Dense	Green	High	April 2nd week
KTI-15	Regular	Semi-spreading	Dense	Reddish brown	High	April 4th week
KTI-16	Regular	Upright	Dense	Green	High	April 3rd week
KTI-17	Regular	Spreading	Dense	Green	High	April 4th week

Table 3c: Distribution of tree, leaf and panicle characters among the selected tamarind accessions

Character	States	Frequency (%)
Bearing habit	Regular	58.82
	Irregular	41.18
Growth pattern	Spreading	11.77
	Semi-spreading	41.17
	Upright	47.06
Type of foliage	Sparse	23.53
	Dense	76.47
New flush colour	Green	70.59
	Reddish green	23.53
	Reddish brown	05.88
Inflorescence length	Low	23.53
	Medium	17.65
	High	58.82
Season of flowering	Early	05.88
	Mid	82.35
	Late	11.77

4.1.2 Leaf characters

Leaf characters of evaluated accessions are presented in table 3a, 3b and 3c.

4.1.2.1 Number of leaflets

Accession KTI-10 (32 leaflets) recorded highest number of leaflets per leaf and the lowest was recorded in accession KTI-15 (24 leaflets). Variations observed in number of leaflets per leaf might be due to the genetic makeup of the trees.

4.1.2.2 Leaf area

Leaf area recorded the highest value in accession KTI-5 (17.21 cm^2) followed by accession KTI-4 (16.59 cm^2). The lowest leaf area was recorded in accession KTI-14 (6.47 cm^2). Variations observed among the accessions for leaf area of a single compound leaf might be due to the genetic makeup of the tree which controls growth and vigour of tree and foliage.

4.1.2.3 Type of foliage

Predominant foliage type was dense (76.47%) followed by sparse (23.53%). Singh (2010) in Nallur tamarind heritage site recorded similar variability in foliage density.

4.1.2.4 New flush colour

New flush colour varied from green, reddish green to reddish brown (Plate 5). Green was the predominant type (70.59%) among the selected accessions. KTI-15 was the only tree with reddish brown coloured new flush. Rao and Subramanyam (2010) also noticed similar variation for new flush colour in tamarind population of Andhra Pradesh.

4.1.3 Flowering characters

Data on flowering characters of selected accessions are presented in table 3b and table 3c.

4.1.3.1 Season of flowering

In different accessions, the flowering initiation was observed from last week of March to the second week of May. The earliest to flower was KTI-13 (last week of March) and KTI-6 was the last tree to start flowering (second week of May). Season of flowering was classified into three categories *viz.*, early (flowering before April), mid (April flowering) and late (flowering May onwards). Mid-season flowering was noticed predominantly among the accessions (82.35%), followed by late (11.77%) and early

flowering types (5.88%). KTI-13 was the only early type while KTI-6 and KTI-8 were the only two late types. All remaining accessions were mid flowering types.

Chavan *et al.* (1999) also observed flowering from last week of March which extended till the first week of June in Raichur condition (Karnataka). Usha and Singh (1996) suggested selection of mid and late flowering types as they had higher chance of cross-pollination due to prolonged flowering duration.

4.1.3.2 Number of inflorescence per node

The average number of inflorescence per node was ranged from 1.00 (KTI-2, KTI-3, KTI-5, KTI-8, KTI-14) to 1.13 (KTI-17). Data on number of inflorescence per node is given in table 5.

This variation might be due to variation in growth and division of inflorescence meristem which is controlled by hormonal changes in the meristem region. Tamarind inflorescence is a branched raceme but in this study 490 out of 510 inflorescences were simple raceme type. In case of two panicles per node, the branches of the inflorescence were differentiated from each other at the base of the inflorescence, hence it was considered as separate inflorescences.

4.1.3.3 Panicle length

The average panicle length (Table 5) was ranged from 7.8 cm (KTI-6) to 23 cm (KTI-17). Based on the length, the panicle was grouped into low, medium and high (Table 3c). The majority of the accessions expressed high length panicle (58.82%), the second largest group was low length (23.53%) and least number of accessions showed medium length panicle (17.65%).

Chavan *et al.* (1999) observed differences in inflorescence length, which ranged from 4 cm to 16 cm with 12-43 buds per inflorescence. Nagarajan *et al.* (1997) studied variability in length of inflorescence and reported higher fruit set in genotypes having long inflorescences and longer floral duration.

4.1.4 Flower characters

Typical tamarind flower parts are represented in plate 6.

4.1.4.1 Qualitative characters

Flowers were observed for five different qualitative characters *viz.,* bract colour, bracteole colour, corolla colour, sepal colour and filament colour. Data on floral

characters are represented in table 4a and 4b. Characters like bract colour and bracteole colour were found to be highly variable among the accessions than the other characters.

4.1.4.1.1 Bract colour

Wide variability was noticed for bract colour among the accessions (Plate 7). Five colours were noticed during the study *viz.*, dark pink, pink, pale pink, pale yellow and pale green. Among the selected accession 29.41 % of the trees had pale pink bracts and 29.41 % of the trees had pale green bracts followed by dark pink (23.53%), pale yellow (11.77%) and pink (5.88%).

4.1.4.1.2 Bracteole colour

The majority of accessions produced pink bracteoles (52.94%) followed by pale green (23.53%) and yellow (23.53%). Bracteole colour is presented in plate 7.

4.1.4.1.3 Corolla colour

The corolla colour of accessions was predominantly pale yellow with red streaks (88.23%) followed by yellow with red streaks (11.77%). Corolla colour is presented in plate 8.

4.1.4.1.4 Sepal colour

Only two types of sepal colours were noticed among the selected accessions (Plate 8). The lemon chiffon coloured sepal (76.47%) was prominent followed by pale yellow (23.53%) coloured sepal.

4.1.4.1.5 Filament colour

The predominant filament colour noticed among the accession was green with dark streaks (88.24%) followed by green without dark streaks (11.76%).

Presence of wide variability in floral qualitative traits has been recorded earlier in many temperate trees and very rarely in tropical trees. But tamarind, a tropical tree expressed a wide range of colouration in different floral parts which could be effectively used as a morphological marker for tree identification and for progeny testing programmes (Singh, 2010).

4.1.4.2 Quantitative characters:

Data on quantitative characters of flower are presented in table 5 (Plate 9).

4.1.4.2.1 Corolla Spread

The average corolla spread ranged from 2.17 cm (KTI-6) to 3.27 cm (KTI-7). KTI-17 recorded second highest value of 3.06 cm.

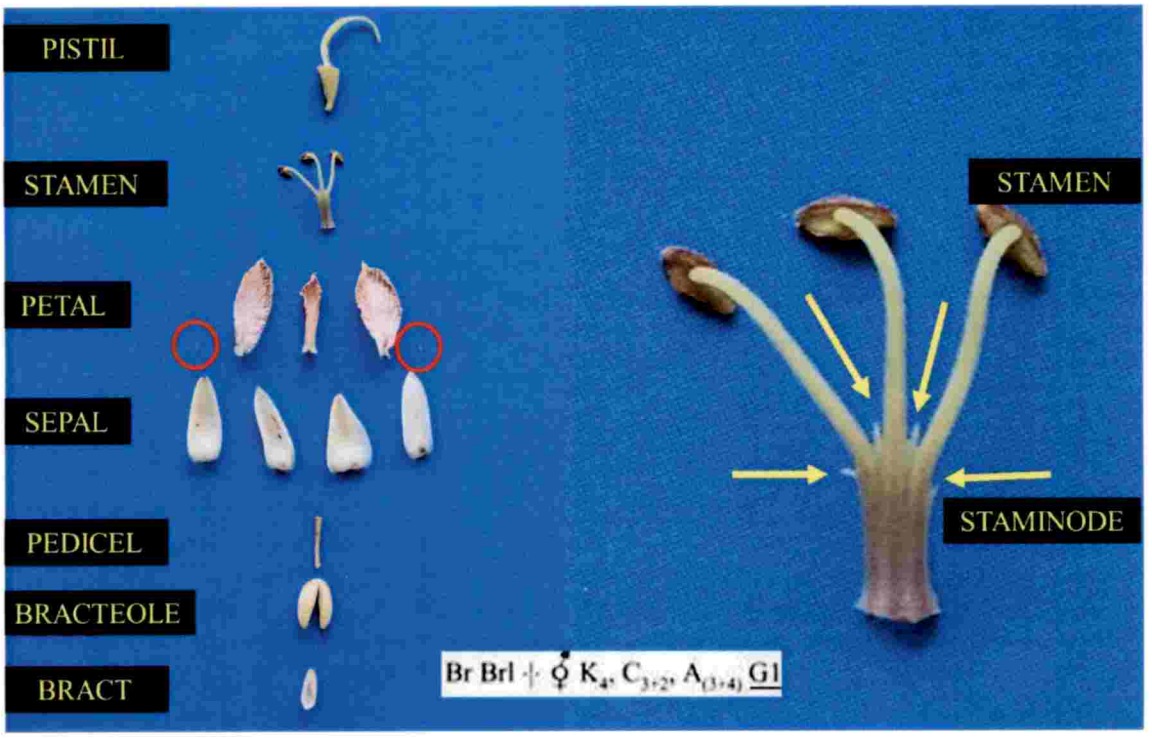


Plate 6: Dissected flower and flower parts

Pale green bract and yellow bracteole

Deep pink bracteole and pink bracteole

Plate 7: Flower bract and bracteole colour

Lemon chiffon
Pale yellow with red streak

Pale yellow
Yellow with red streak

Plate 8: Corolla and sepal colour

Table 4a: Qualitative characters of flowers

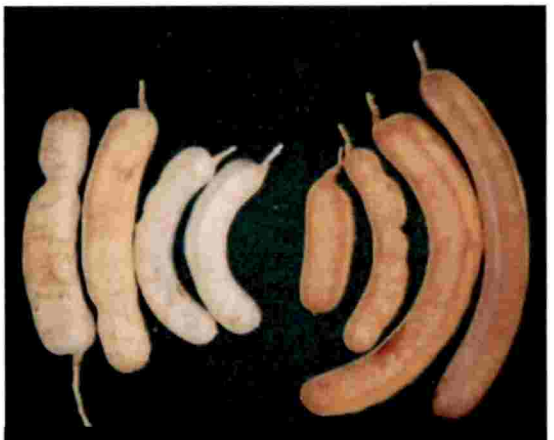
Accession	Bract colour	Bracteole colour	Corolla colour	Sepal colour	Filament colour
KTI-1	Dark pink	Pink	Pale yellow with red streak	Lemon chiffon	Green with dark streak
KTI-2	Pale pink	Pink	Pale yellow with red streak	Lemon chiffon	Green with dark streak
KTI-3	Pale green	Pale green	Pale yellow with red streak	Lemon chiffon	Green with dark streak
KTI-4	Pink	Pink	Pale yellow with red streak	Lemon chiffon	Green with dark streak
KTI-5	Pale yellow	Yellow	Pale yellow with red streak	Lemon chiffon	Green without dark streak
KTI-6	Pale pink	Pale green	Pale yellow with red streak	Lemon chiffon	Green with dark streak
KTI-7	Pale pink	Pink	Pale yellow with red streak	Lemon chiffon	Green with dark streak
KTI-8	Pale green	Yellow	Pale yellow with red streak	Lemon chiffon	Green with dark streak
KTI-9	Pale pink	Pink	Pale yellow with red streak	Pale yellow	Green with dark streak
KTI-10	Pale green	Yellow	Pale yellow with red streak	Pale yellow	Green without dark streak
KTI-11	Dark pink	Pink	Yellow with red streak	Pale yellow	Green with dark streak
KTI-12	Deep pink	Pink	Pale yellow with red streak	Lemon chiffon	Green with dark streak
KTI-13	Pale green	Pale green	Yellow with red streak	Pale yellow	Green with dark streak
KTI-14	Pale pink	Pink	Pale yellow with red streak	Lemon chiffon	Green with dark streak
KTI-15	Dark pink	Pink	Pale yellow with red streak	Lemon chiffon	Green with dark streak
KTI-16	Pale green	Pale green	Pale yellow with red streak	Lemon chiffon	Green with dark streak
KTI-17	Pale yellow	Yellow	Pale yellow with red streak	Lemon chiffon	Green with dark streak

Table 4b: Distribution of flower character among the selected tamarind accessions

Character	States	Frequency (%)
Bract colour	Pale green	29.41
	Pale yellow	11.77
	Yellow	00.00
	Pale pink	29.41
	Pink	05.88
	Dark pink	23.53
Bracteole colour	Pale green	23.53
	Yellow	23.53
	Pink	52.94
Sepal colour	Lemon chiffon	76.47
	Pale yellow	23.53
	Yellow	00.00
	Gold	00.00
Corolla colour	Pale yellow with red streak	88.23
	Yellow with red streak	11.77
	Orange yellow with red streak	00.00
	Orange red with red streak	00.00
Filament colour	Green without streaks	11.76
	Green with streaks	88.24

Floral measurements

Pulp colour



Mature fruit (pod) colour

Plate 9: Flower and fruit observations

Chavan (1999) reported association of larger flower spread with higher flower weight and higher nectar content coupled with a large floral display which attracted more pollinators and resulted in higher fruit set.

4.1.4.2.2 Pedicel length

The average pedicel length was having a range of 0.54 cm (KTI-3) to 1.23 cm (KTI-10).

4.1.4.2.3 Petal length

The length of petal varied from 1.30 cm (KTI-12) to 1.65 cm (KTI-9).

4.1.4.2.4 Petal width

The width of petal ranged from 0.55 cm (KTI-1) to 0.88 cm (KTI-12) cm.

4.1.4.2.5 Filament length

KTI-2 recorded longest filament (1.59 cm) and KTI-12 recorded shortest filament (1.26 cm).

4.1.4.2.6 Sepal length

Highest sepal length was observed in KTI-7 (1.58 cm). KTI-12 recorded lowest (1.09 cm).

4.1.4.2.7 Sepal width

KTI-7 recorded widest sepal (0.65 cm) and KTI-13 recorded least width of sepal (0.48 cm).

4.1.4.2.8 Ovary length

Length of the ovary was recorded highest in KTI-3 (1.31 cm) and the shortest was KTI-7 (0.69 cm).

Nagarajan *et al.* (1998) also reported variation in length of ovary (0.61-0.67 cm) and style length under Coimbatore conditions.

4.1.4.2.9 Pistil Length

Longest pistil was about 1.94 cm (KTI-16) and the shortest was observed in KTI-7 (1.05 cm).

Variation in pistil length (1.04-1.13 cm) was also reported by Nagarajan *et al.* (1998) under Coimbatore conditions. The variation in pistil length might be due to variation in ovary length.

Table 5: Quantitative characters of flowers and inflorescence

Accession	Corolla spread (cm)	Pedicel length (cm)	Petal length (cm)	Petal breadth (cm)	Filament length (cm)	Sepal length (cm)	Sepal breadth (cm)	Ovary length (cm)	Pistil length (cm)	Number of stamens	Number of staminodes	Panicle length (cm)	Number of inflorescence per node	Flower weight (g)
KTI-1	2.56	0.80	1.38	0.55	1.28	1.17	0.51	0.76	1.40	3	4	11.1	1.03	1.28
KTI-2	2.61	0.94	1.53	0.78	1.59	1.41	0.60	1.04	1.75	3	2	18.3	1.00	1.71
KTI-3	2.44	0.54	1.41	0.67	1.35	1.40	0.60	1.31	1.74	3	2.7	8.9	1.00	1.79
KTI-4	2.66	0.87	1.49	0.65	1.32	1.44	0.55	1.05	1.81	3	4	10.8	1.03	1.63
KTI-5	2.38	0.94	1.52	0.67	1.38	1.47	0.54	1.03	1.78	3	3.2	11.3	1.00	1.73
KTI-6	2.14	0.65	1.35	0.65	1.31	1.21	0.58	0.91	1.54	3	4	7.8	1.00	1.37
KTI-7	3.27	1.07	1.58	0.63	1.42	1.58	0.65	0.69	1.05	3	4	14.6	1.03	1.78
KTI-8	2.67	0.63	1.36	0.62	1.34	1.09	0.50	0.76	1.45	3	4	7.9	1.00	1.39
KTI-9	2.81	1.15	1.65	0.80	1.45	1.53	0.55	1.13	1.86	2.5	4.5	14.9	1.03	1.65
KTI-10	2.52	1.23	1.46	0.68	1.44	1.43	0.58	1.04	1.81	3	4	15.9	1.07	1.41
KTI-11	2.33	0.92	1.46	0.69	1.47	1.22	0.52	1.05	1.81	3	4	12.1	1.07	1.64
KTI-12	2.30	0.69	1.30	0.88	1.26	1.09	0.52	0.97	1.62	3	3	9.8	1.07	1.09
KTI-13	2.67	1.06	1.53	0.62	1.39	1.37	0.48	1.08	1.75	3	4	26.3	1.07	1.50
KTI-14	2.71	0.94	1.44	0.69	1.44	1.29	0.53	0.70	1.14	3	4	18.8	1.00	1.34
KTI-15	2.38	0.97	1.45	0.69	1.35	1.21	0.50	0.98	1.73	3	4	25	1.07	1.37
KTI-16	2.69	0.97	1.61	0.76	1.50	1.42	0.56	1.22	1.94	3	4	28.9	1.07	1.41
KTI-17	3.06	0.81	1.52	0.68	1.36	1.39	0.58	1.10	1.71	3	4	32.00	1.13	1.79
Mean ±SE	2.60 ±0.07	0.89 ±0.05	1.47 ±0.02	0.69 ±0.02	1.39 ±0.02	1.34 ±0.04	0.55 ±0.01	0.99 ±0.04	1.64 ±0.06	2.97 ±0.03	3.73 ±0.15	16.14 ±1.85	1.04 ±0.01	1.52 ±0.05
SD	0.28	0.19	0.09	0.08	0.09	0.15	0.04	0.18	0.25	0.12	0.63	7.65	0.04	0.21
CV	10.68	21.14	6.43	11.52	6.17	11.09	8.17	17.13	15.19	4.08	16.87	47.37	3.63	13.69

4.1.4.2.10 No of stamens

The average number of stamens was three in all the accessions except KTI-9 which had recorded 2.5 stamens.

4.1.4.2.11 No of staminodes

Total number of staminodes ranged from 2 (KTI-2) to 4.5 (KTI-9). The variation in the number of staminodes and number of stamens was due to floral abnormalities occurred during growth and development of floral primordia and subsequent flower development (Raju *et al.,* 1979).

4.1.4.2.12 Flower weight (g)

Accession KTI-17 (1.787 g) recorded highest flower weight followed by KTI-3 (1.785 g). Least floral weight was recorded in KTI-12 (1.093 g).

The data on floral weights were on par with the fresh flower weights obtained by Chavan (1999), who mentioned lesser variations in dry flower weight was due to nectar content and size of the fresh flower. Trees with large flowers and higher flower weight increased the floral display which attracted more pollinators and resulted in higher fruit set and yield.

Singh, *et al.* (2008) who opined that variations in quantitative characters of flowers might be genetically controlled and vary from genotype to genotype due to its highly cross-pollinated nature. The present study also revealed the presence of immense variability of floral characters in tamarind populations of KAU. These floral characteristics can be used as markers in crop improvement programmes.

4.1.5 Fruit characters:

Quantitative characters of fruits and qualitative characters which were recorded from visual observations of the accessions and qualitative characters generated using quantitative data and visual observation of the accessions according to DUS descriptors (Table 2) developed by PPVFRA (2017) are presented in this section (Table 6).

4.1.5.1 Quantitative characters

4.1.5.1.1 Pod length

The average pod length was highest in accession KTI-16 (19.22 cm), followed by accession KTI-10 (17.09 cm) and shortest pods were recorded in accession KTI- 4 (9.79 cm). Accession KTI-16 had fruit length in the range of 7-23 cm.

Table 6: Quantitative characters of fruits

Accession	Pod length (cm)	Pod girth (cm)	Fruit wt. (g)	Shell wt. (g)	Fibre wt. (g)	Pulp wt. (g)	Seed wt. (g)	Number of seed per fruit	Number of fruits per unit area	Pulp: Shell Ratio	Pulp content (%)	Rind content (%)	Fibre content (%)	Seed content (%)	Pulp : Seed ratio
KTI-1	10.84	7.17	17.19	3.38	0.58	7.16	6.08	7.63	7.33	2.12	41.67	19.67	3.39	35.36	1.18
KTI-2	10.86	7.14	16.68	3.39	0.63	7.77	5.59	6.10	8.17	2.30	46.61	20.31	3.81	33.53	1.39
KTI-3	14.28	7.15	18.62	4.45	0.83	8.26	5.78	6.70	7.17	1.86	44.38	23.89	4.44	31.05	1.43
KTI-4	9.79	7.04	21.69	4.97	0.88	9.55	6.71	7.70	7.00	1.92	44.05	22.92	4.06	30.94	1.42
KTI-5	10.68	6.67	19.99	4.06	0.64	7.52	6.79	5.63	8.83	1.85	37.59	20.28	3.19	33.99	1.11
KTI-6	11.62	6.34	15.62	2.98	0.28	5.43	6.04	7.73	9.83	1.82	34.79	19.07	1.79	38.66	0.90
KTI-7	10.60	6.96	13.17	3.28	0.22	6.47	3.41	5.80	5.67	1.97	49.09	24.89	1.69	25.90	1.90
KTI-8	12.61	8.06	21.78	4.53	0.41	9.50	8.49	6.97	3.17	2.10	43.61	20.78	1.86	38.99	1.12
KTI-9	11.73	7.09	19.14	4.40	0.56	7.58	6.62	6.27	3.67	1.72	39.61	22.99	2.90	34.56	1.15
KTI-10	17.09	7.53	26.60	6.89	1.55	10.66	7.48	6.47	5.33	1.55	40.08	25.89	5.81	28.11	1.43
KTI-11	11.14	7.57	14.58	3.18	0.33	5.90	4.94	5.80	5.17	1.86	40.44	21.78	2.28	33.86	1.19
KTI-12	10.74	6.24	11.28	2.94	0.19	4.14	4.26	5.97	6.33	1.41	36.70	26.02	1.69	37.74	0.97
KTI-13	13.31	8.29	18.95	3.67	0.62	9.14	5.30	4.43	9.67	2.49	48.27	19.37	3.25	27.98	1.72
KTI-14	12.40	6.64	16.35	3.28	0.38	7.17	5.46	5.33	5.00	2.18	43.82	20.06	2.31	33.38	1.31
KTI-15	12.38	6.52	15.07	3.18	0.30	5.46	6.26	7.67	3.83	1.72	36.24	21.10	1.98	41.54	0.87
KTI-16	19.22	7.09	23.64	4.93	0.59	10.15	8.75	8.93	2.83	2.06	42.94	20.84	2.50	37.02	1.16
KTI-17	13.17	8.40	19.43	3.92	0.69	8.87	6.23	5.77	9.33	2.26	45.63	20.19	3.55	32.08	1.42
Mean ±SE	12.50 ±0.59	7.17 ±0.15	18.22 ±0.94	3.97 ±0.24	0.57 ±0.08	7.69 ±0.44	6.13 ±0.32	6.52 ±0.27	6.37 ±0.56	1.95 ±0.06	42.09 ±1.02	21.77 ±0.54	2.97 ±0.28	33.80 ±1.03	1.27 ±0.07
SD	2.46	0.63	3.88	1.01	0.32	1.83	1.35	1.12	2.30	0.28	4.22	2.26	1.14	4.24	0.27
CV	19.67	8.84	21.30	25.38	57.07	23.76	22.04	17.21	36.02	14.19	10.03	10.38	38.38	12.53	21.35

4.1.5.1.2 Pod girth

The highest pod girth was recorded in accession KTI-17 (8.40 cm) and accession KTI-12 recorded least pod girth of 6.24 cm

4.1.5.1.3 Fruit (pod) weight

The average fruit weight was significantly high in accession KTI-10 (26.60 g), followed by KTI-16 (23.64 g). Accession KTI-12 recorded the lowest pod weight of 11.28 g. The individual fruit weight for accession KTI-10 was in the range of 8-54 g.

Rao and Subramanyam (2010) reported greater variability for pod weight in Ananthpur (AP). Accession V-2 recorded 32.8 g fruit weight. Similar variability for pod weight also reported by many other authors (Hanamashetti *et al.,* 2002; Ankushrao, 2010; Singh and Nandini, 2011; Rao and Mathew, 2012; Tadas *et al.,* 2015; Ayala-Silva *et al.,* 2016; Kidaha *et al.,* 2019).

4.1.5.1.4 Shell weight per pod

Shell weight of the selected accessions ranged from 2.94 g per pod in KTI-12 to 6.89 g per pod in KTI-10.

4.1.5.1.5 Fibre weight per pod

The weight of the fibres ranged from 0.19-1.55 g per pod. Highest fibre weight was recorded in KTI-10 and the least weight was recorded in KTI-12.

4.1.5.1.6 Pulp weight per pod

Accession KTI-10 recorded highest pulp weight of 10.66 g, followed by KTI-16 (10.15 g) which is significantly different. Lowest pulp weight was recorded in KTI-12 (4.14 g).

4.1.5.1.7 Seed weight per pod

KTI-16 recorded highest seed weight of 8.75 g per pod and KTI-7 recorded lowest seed weight of 3.41 g per pod with individual seed weight of approx. 0.59 g.

4.1.5.1.8 Seed number

Total number of seeds per fruit ranged from 4.43 (KTI-13) to 8.93 (KTI-16).

4.1.5.1.9 Number of pods per unit area of the canopy

The number of fruits per unit area of the canopy ranged from 2.83 (KTI-16) to 9.83 (KTI-6). The number of fruits per unit area from KTI-6 (9.83), KTI-13 (9.67 fruits) and KTI-17 (9.33 fruits) were also on par with KTI-16.

Hanamashetti *et al.* (2002) recorded variation in number of fruits per unit area (1 sq. ft.) of the tree canopy of 12-year-old trees, which varied from 5 (NTI-79) to 11.40 (NTI-14). Variety DTS-1 recorded 11 fruits per unit area.

Number of fruits per unit area of the canopy depends on the number of inflorescence per unit area which is an inherited character and also influenced by fruit set percentage. Generally, in open pollinated condition up to 1-2% fruit set is observed. Variation in the number of fruit set among the genotypes indicates variation in the extent of pollination (Nagarajan *et al.,* 1998) and limitation of pollinators in the respective region.

In the present study, the length of inflorescence (32 cm), flower weight (1.79 g for 10 flowers) were high in KTI-17 along with a wider corolla spread (3.06 cm) which might have resulted in collection of more nectar and attracted more pollinators to set more fruit per unit area in KTI-17 (9.33).

4.1.5.1.10 Pulp: Shell ratio

Highest pulp shell ratio was observed in KTI-13 (2.49: 1) and least was observed in KTI-12 (1.41: 1).

4.1.5.1.11 Pulp: Seed ratio

Highest pulp seed ratio was recorded in accession KTI-7 (1.9) followed by KTI-13 (1.72). Least pulp seed ratio was recorded by KTI-15 (0.87).

Ankushrao (2010) observed similar variation for pulp: seed ratio for local tamarind trees of the Parbhani (Maharashtra). These variations were due to changes in pulp weight and seed weight, which depends on the genetic makeup of the tree. Trees with higher pulp: seed ratio are recommended for selection and improvement.

4.1.5.1.12 Pulp content (%)

The average pulp content of the fruits ranged from 34.79 per cent (KTI-6) to 49.09 per cent (KTI-7).

In a similar study done by Prabhushankar *et al.* (2010), the pulp content was ranged from 23 to 64 per cent among the 15 elite clones of tamarind including PKM-1 (51%) and Urigam (64 %).

Pulp content of fruit differed among the accessions. From the data, it was declared that variation in pulp content was due to the differences in pulp weight and weight of non-pulp components of the pod. Similar variability in pulp content was observed by Tadas *et*

al. (2015) who reported that the difference in pulp content might be due to its genetic makeup.

4.1.5.1.13 Shell content (%)

The average shell content ranged from 19.07 per cent (KTI-6) to 26.02 per cent (KTI-12).

4.1.5.1.14 Fibre content (%)

KTI-12 recorded lowest fibre content of 1.69 per cent and the highest fibre content was recorded in KTI-10 (5.81%).

4.1.5.1.15 Seed content (%)

Seed content of the fruit ranged from 25.90 per cent in accession KTI-7 to 41.54 per cent in accession KTI-15. The seed weight per pod was also lowest in KTI-7 (3.41 g).

The results were on par with the findings of Rao and Mathew, (2012). They reported that the pulp content generally ranged from 30 to 50 per cent of the weight of fruit, the fibre along with shell contributes around 11 to 30 per cent of fruit weight and the seed weight contributes about 25 to 40 per cent of the pod weight.

Shukla (2006) observed similar variability for pod weight and opined that variation in pod weight among the accessions might be due to differences in the number of seeds per fruit, unit seed weight, pulp content of fruit and shell weight which are highly variable among the tree.

Genetic composition of tree is responsible for variability in fruit characters. Variability for pod quantitative characters such as pod length, pod girth, fruit weight, fibre weight, shell weight, seed weight, pulp content, seed content etc., were also recorded by Shankaracharya (1998), Divakara *et al.* (2012), Rao *et al.* (2015) and several others (Hanamashetti *et al.*, 2002; Ankushrao, 2010; Prabhushankar *et al.*, 2010; Singh and Nandini, 2011; Rao and Mathew, 2012; Tadas *et al.*, 2015; Ayala-Silva *et al.*, 2016; Kidaha *et al.*, 2019).

4.1.5.2 Fruit biochemical characters

Data on tartaric acid content, ascorbic acid content and TSS of selected accessions are presented in table 7.

4.1.5.2.1 Titratable acidity

The titratable acidity of the pulp (as the equivalent weight of tartaric acid) ranged 7.79% (KTI-9) to 21.94% (KTI-12) among the accessions.

Table 7: Biochemical characters of fruits

Accession	Tartaric acid (%)	TSS (^{O}Brix)	Vit C (mg/100g)
KTI-1	8.54^{j}	64^{abcd}	12.07^{cde}
KTI-2	8.54^{j}	65^{abc}	11.53e
KTI-3	10.97^{h}	70^{a}	11.81^{e}
KTI-4	11.81^{fg}	57^{ef}	11.17^{e}
KTI-5	8.03^{k}	58^{b}	11.53^{e}
KTI-6	12.47^{e}	61^{cdef}	12.07^{cde}
KTI-7	13.32^{d}	63^{bcde}	12.19^{cde}
KTI-8	13.60^{d}	63^{bcde}	12.38^{bcde}
KTI-9	7.79^{k}	61^{cdef}	13.53^{bcd}
KTI-10	12.10^{f}	65^{abc}	13.72^{bc}
KTI-11	16.41^{b}	59^{cdef}	11.71^{e}
KTI-12	21.94^{a}	55^{f}	13.91^{b}
KTI-13	11.91^{f}	58^{def}	12.57^{bcde}
KTI-14	10.60^{i}	64^{abcd}	11.53^{e}
KTI-15	14.44^{c}	63^{bcde}	18.76^{a}
KTI-16	11.54^{e}	64^{abcd}	12.00^{b}
KTI-17	12.60^{e}	58^{bcde}	18.91^{a}
Mean±SE	12.15±0.83	62.24±0.96	13.02±0.56
SD	3.44	3.95	2.33
CV	28.33	6.34	17.86

A similar range of tartaric acid content (9.92-17.04%) was also reported by Tadas *et al.* (2015). Prabhushankar *et al.* (2010) evaluated 15 elite clones of tamarind including PKM-1 and Urigam and recorded a titratable acidity range of 7.66 to 18.01 per cent. The differences observed in titratable acidity might be due to variation in sugar content of the pulp, which is inherited property of genotype as reported by Pooja *et al.* (2018).

4.1.5.2.2 Total Soluble Solids (TSS)

Among the selected accessions, TSS content of pulp ranged from 55 ^{O}Brix (KTI-12) to 70 ^{O}Brix (KTI-3).

Tadas *et al.* (2015) observed TSS content of pulp in the range of 32.40-53.70 ^{O}Brix among different genotypes evaluated at Akola (Maharashtra) and difference were mainly due to variation in sugar content of the pulp which is genotype dependent (Pooja *et al.*, 2018).

4.1.5.2.3 Ascorbic Acid

Among the accessions, the ascorbic acid content was ranged from 11.17 (KTI-4) mg to 18.91 mg (KTI-17).

Pooja *et al.* (2018) reported variation in the ascorbic acid content (4.28-12.85 mg/100g) of pulp among the different genotypes was due to genotypic variation in the synthesis of ascorbic acid precursor glucose-6-phosphate during the growth and development of fruits. In the present study, KTI-15 and KTI-17 were identified as plus genotypes with respect to high ascorbic acid content.

4.1.5.3 Fruit qualitative characters

Fruit qualitative characters and their distribution frequency are presented in table 8a and table 8b respectively.

4.1.5.3.1 Matured fruit colour

The reddish brown pod (Plate 9) was more common (70.59%) followed by grey pods (29.41%). Age of the tree and the environment were reported to be the known factors influencing pod colour (Kidaha *et al.*, 2019). Ayala-Silva *et al.*, (2016) noticed two types of pod colour *viz.*, greyish brown and brown during germplasms evaluation in Florida. In the present study also similar colour variations were observed for mature fruit colour.

4.1.5.3.2 Mature pod shape

The majority of the accessions were having pods of semi curved shape (52.94%) followed by curved pods (35.29%) and straight pods (11.77%).

Table 8a: Qualitative characters of fruits

Accession	Matured fruit colour	Mature pod weight (g)	Mature pod length (cm)	Fruit shape	Pulp colour	Pulp TSS at ripe stage	Titratable Acidity	Seed weight and pod	Ripening period
KTI-1	Reddish brown	Medium	Medium	Straight	Brown	Medium	Medium	High	Early
KTI-2	Grey	Medium	Medium	Curved	Brown	Medium	Medium	Medium	Medium
KTI-3	Reddish brown	Medium	Medium	Curved	Reddish brown	Medium	High	Medium	Medium
KTI-4	Reddish brown	Medium	Short	Semi curved	Reddish brown	Low	High	High	Medium
KTI-5	Reddish brown	Medium	Medium	Semi curved	Brown	Low	Medium	High	Medium
KTI-6	Grey	Medium	Medium	Curved	Brown	Medium	High	High	Medium
KTI-7	Reddish brown	Low	Medium	Semi curved	Brown	Medium	High	Low	Medium
KTI-8	Grey	Medium	Medium	Semi curved	Brown	Medium	High	High	Medium
KTI-9	Reddish brown	Medium	Medium	Curved	Reddish brown	Medium	Low	High	Medium
KTI-10	Reddish brown	High	Long	Semi curved	Reddish brown	Medium	High	High	Late
KTI-11	Reddish brown	Low	Medium	Semi curved	Reddish brown	Low	High	Low	Medium
KTI-12	Reddish brown	Low	Medium	Curved	Brown	Low	Low	Low	Medium
KTI-13	Grey	Medium	Medium	Semi curved	Reddish brown	Low	High	Medium	Late
KTI-14	Grey	Medium	Medium	Straight	Brown	Medium	High	Medium	Medium
KTI-15	Reddish brown	Medium	Medium	Semi curved	Brown	Medium	High	High	Medium
KTI-16	Reddish brown	Medium	Long	Semi curved	Reddish brown	Medium	High	High	Medium
KTI-17	Reddish brown	Medium	Medium	Curved	Brown	Low	High	High	Late

Table 8b: Distribution of fruit character among the selected tamarind accessions

Character	States	Frequency (%)
Matured fruit colour	Brown	00.00
	Reddish brown	70.59
	Grey	29.41
Mature pod weight	Low	17.65
	Medium	76.47
	High	05.88
Mature pod length	Short	05.88
	Medium	82.35
	Long	11.77
Fruit shape	Curved	35.29
	Semi curved	52.94
	Straight	11.77
Pulp colour	Brown	58.82
	Reddish brown	41.18
Seed weight/pod	Low	17.65
	Medium	23.53
	High	58.82
Ripening period	Early	05.88
	Medium	76.47
	Late	17.65
Pulp TSS at ripe stage	Low	35.29
	Medium	64.71
	high	00.00
Titratable Acidity	Low	11.77
	Medium	17.64
	High	70.59

The genetic makeup of tree controls seed shape and number of seeds per fruit which were major factors determining the shape of the fruit (Kidaha *et al.*, 2019). In this study also similar observations were made and pods with very few seeds (1-3) were almost straight and more seeded pods were either curved or semi curved in most of the accessions except KTI-1 and KTI-14 which were having straight pods with 5-7 number of seeds.

Within an accession pod shape varied from fruit to fruit and observed straight, semi curved and curved fruits in different regions of the canopy. The predominant shape of fruit observed on tree was recorded as fruit shape of respective accession (Algabal *et al.*, 2012).

4.1.5.3.3 Mature pod weight

Three categories of pod weight were made *viz.*, low, medium and high. The majority of the accessions came under group medium (76.47%) followed by low (17.65%) and high (5.88%). KTI-10 was the only accession with high pod weight with average pod weight of 26.60 g.

4.1.5.3.4 Mature pod length

Three categories of pod length were made *viz.*, short, medium and long. The majority of the selected accessions were grouped under medium (82.35%) followed by long (11.77%) and short fruits (5.88%).

4.1.5.3.5 Mature fruit pulp colour

Two types of pulp colour were observed (Plate 9) among the accessions *viz.*, brown colour pulp (58.82%) and reddish brown colour pulp (41.18%).

Shankaracharya (1998) identified leucoanthocyanidin as pigment responsible for brown pulp colour. The pulp colour variation observed during the present study were similar to the observations made by Ayala-Silva *et al.* (2016) in Florida who also recorded brown and reddish brown colour pulp where as Algabal *et al.* (2012) reported accessions with brown and light brown colour pulp.

4.1.5.3.6 Pulp TSS at ripe stage

The pulp TSS range was divided into three categories *viz.*, low (<60 ^{0}B), medium (60-70 ^{0}B) and high (>70 ^{0}B). None of the accessions had high TSS and the majority of the accessions came under the medium TSS category (64.71%) followed by low TSS category (35.29%). There was no tree reported to contain high TSS. Tamarind trees of

arid regions facing water scarcity accumulates more dry matter than moisture. This contributes to higher TSS (Tadas *et al.,* 2015) compared to trees grown in tropical humid climate.

4.1.5.3.7 Titratable acidity

Based on the titratable acidity value, accessions were classified into low, medium and high. The bulk of the accessions came under class high (70.59%) followed by medium (17.64%) and low (11.77%).

4.1.5.3.8 Seed weight per pod

Three categories were made based on seed weight *viz.,* low, medium and high. Most of the accessions were placed under group high (58.82%) followed by medium (23.53%) and low seed weight (17.65%) categories.

4.1.5.3.9 Ripening period

Based on the time taken for fruits to ripe, three categories were made *viz.,* early, medium and late. Most of the accessions were of medium duration (76.47%) followed by late (17.65%) and early (5.88%).

Tania *et al.* (2018) also observed variation in ripening period which varies significantly among genotypes of seedling origin.

4.1.6 Principal component analysis

Quantitative characters such as pod length, pod girth, fruit weight, pulp weight, seed weight, number of seeds per fruit, number of fruits per unit area and pulp content were considered for multivariate statistical analysis. Each tree was considered as separate genotype and due to unavailability of replication of trees, Principal component analysis was carried out for the purpose of clustering the accessions.

Principal component analysis results showed that first three components captured 83.4 per cent of the total variability while first two components accounted 72.9 per cent (Table 10). Eigen vectors of Principal component-1 (PC1) and Principal component-2 (PC2) along with component loadings of eight characters were presented in table 9. The bulk of the variability was accounted by PC1 (45.6%) and was positively correlated with all the variable characters except number of fruits per unit area which is negatively correlated. Pod length, fruit weight, pulp weight, seed weight were the major characters under PC1 whereas pulp content, number of seeds per fruit, number of fruits per unit area and pod girth were major characters under PC2.

Table 9: Eigenvectors of Principal Component Analysis for yield contributing characters of tamarind.

Variable	PC1	PC2
Pod length	0.402	-0.106
Pod girth	0.283	0.474
Fruit weight	0.492	0.009
Pulp weight	0.484	0.210
Seed weight	0.447	-0.252
Number of seed	0.190	-0.508
Number of fruits per unit area	-0.170	0.333
Pulp content	0.128	0.537

Table 10: Eigen analysis of the Correlation Matrix

	PC1	PC2
Eigenvalue	3.6500	2.1841
Proportion	0.456	0.273
Cumulative	0.456	0.729

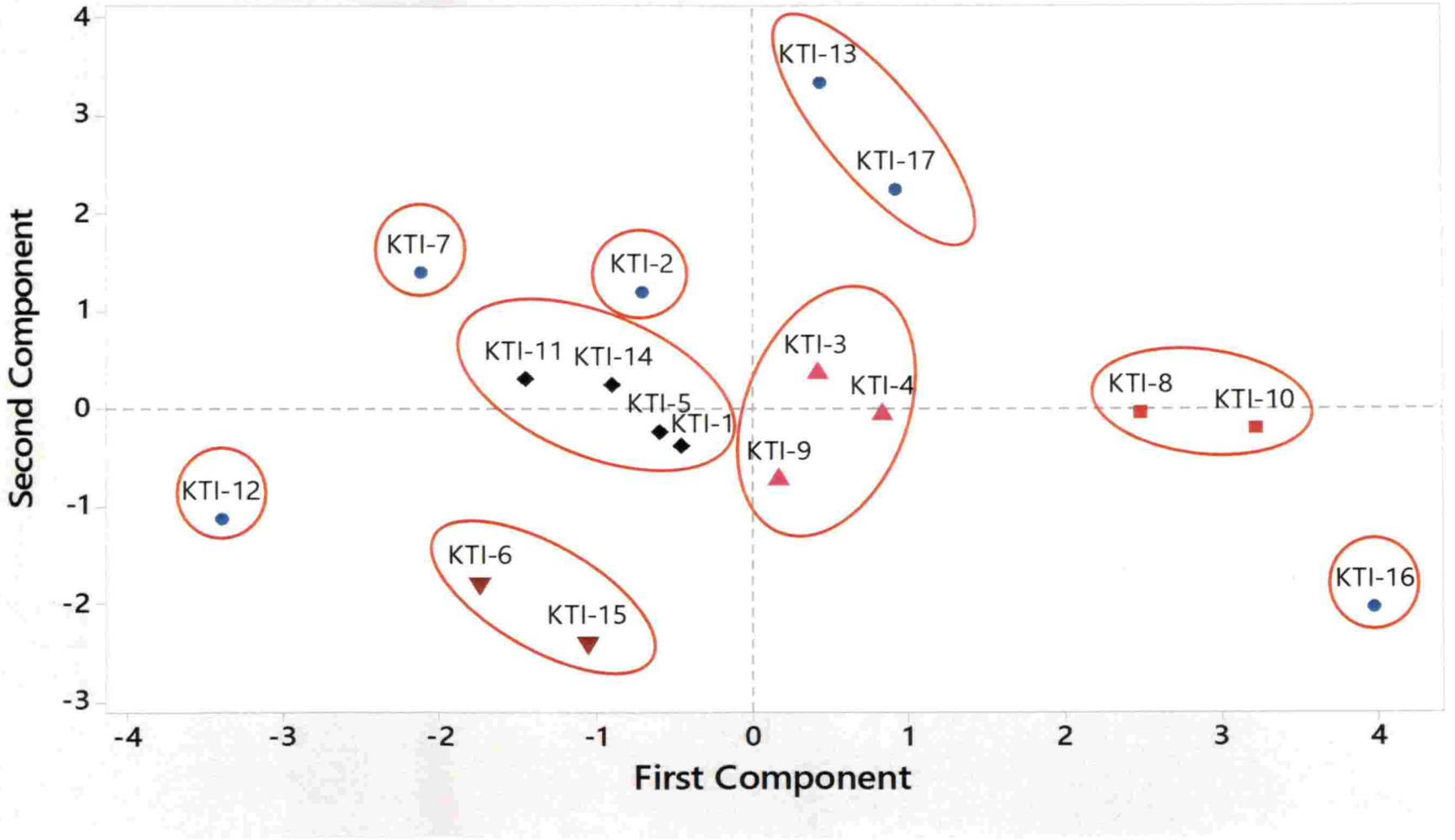


Fig 1a: Score plot of characters for first two principal components

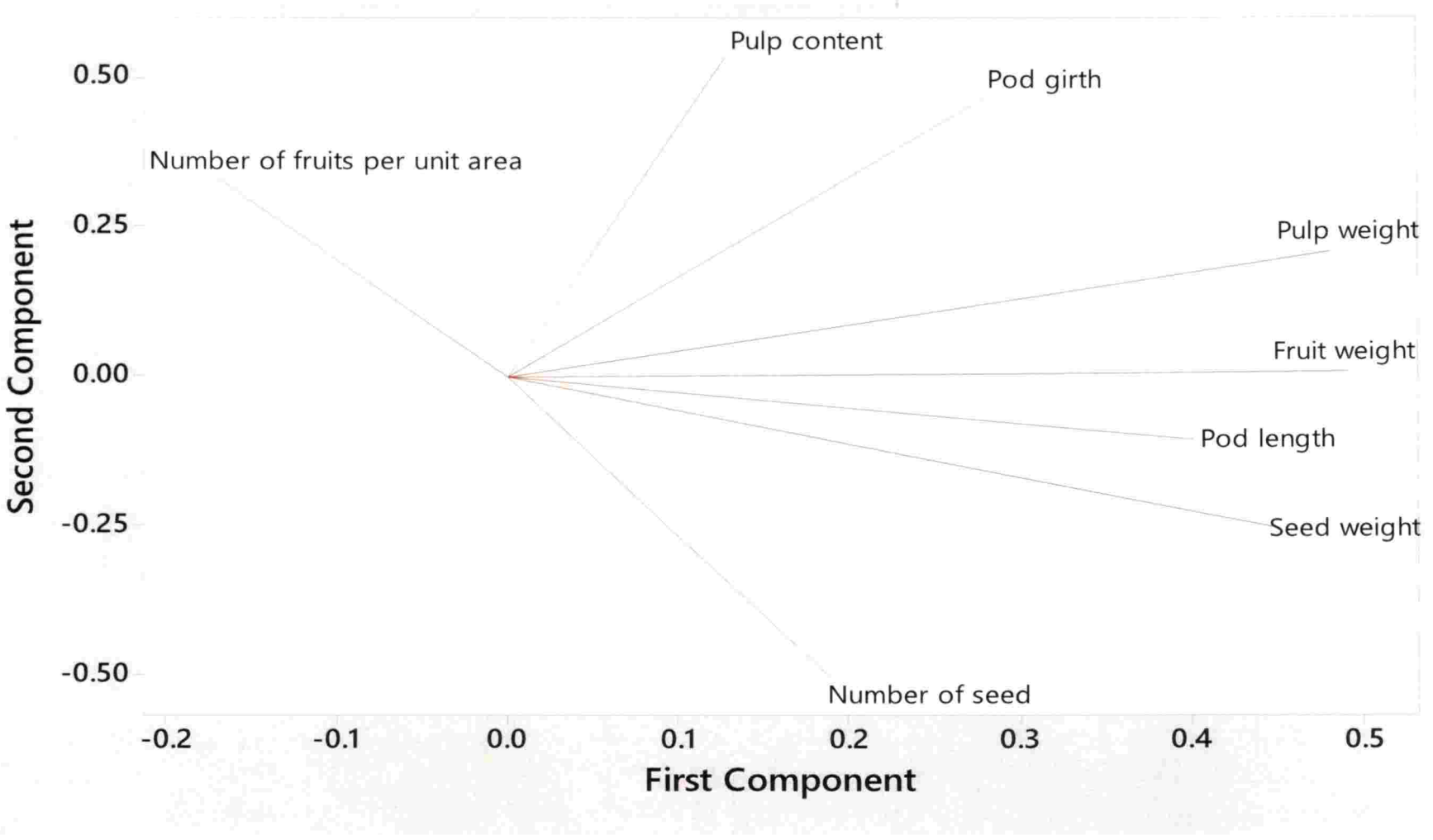


Fig 1b: Loading plot of characters for first two principal components

Table 11: Perceived characters of clusters

		1	2	3	4	5	6	7	8	9
Cluster	**Members**	**Pod length**	**Pod girth**	**Fruit weight**	**Pulp weight**	**Seed weight**	**Number of seed**	**Number of fruits per unit area**	**Pulp content**	**Fruit yield per unit area of canopy (column 3X7)**
Cluster-I	KTI-12	10.74	6.24	11.28	4.14	4.26	5.97	6.33	36.70	71.40
Cluster-II	KTI-7	10.60	6.96	13.17	6.47	3.41	5.80	5.67	49.09	74.67
Cluster-III	KTI-2	10.86	7.14	16.68	7.77	5.59	6.10	8.17	46.61	136.28
Cluster-IV	KTI-11, KTI-14, KTI-5, KTI-1	11.27	7.01	17.03	6.94	5.82	6.10	6.58	40.88	112.06
Cluster-V	KTI-6, KTI-15	12.00	6.43	15.34	5.45	6.15	7.70	6.83	35.52	104.77
Cluster-VI	KTI-3, KTI-4, KTI-9	11.93	7.09	19.82	8.47	6.37	6.89	5.94	42.68	117.73
Cluster-VII	KTI-17, KTI-13	13.24	8.345	19.19	9.005	5.765	5.1	9.5	46.95	182.31
Cluster-VIII	KTI-8, KTI-10	14.85	7.80	24.19	10.08	7.99	6.72	4.25	41.84	102.81
Cluster-IX	KTI-16	19.22	7.09	23.64	10.15	8.75	8.93	2.83	42.94	66.90

Score plot and loading plot based on first two principal components and a scree plot was also generated to determine the extent of variability under different principal components.

Based on the score plot, the accessions were grouped into nine clusters and the same was represented in the score plot (Fig. 1a). Newly formed clusters and their members and the perceived characters of the new groups were represented in the table 11. Cluster IV had 4 accessions, Cluster VI had 3 accession while Cluster V, VII and VIII had 2 accession each. The remaining clusters had single accession each. Accession KTI-12 belongs to Cluster I, KTI-7 belongs to Cluster II, KTI-2 belongs to Cluster III, KTI-16 belongs to Cluster IX. Cluster IV had 4 members *viz.*, KTI-11, KTI-14, KTI-5 and KTI-1 while Cluster VI contain 3 members *viz.*, KTI-3, KTI-4 and KTI-9. KTI-6 and KTI-15 were members of Cluster V whereas KTI-8 and KTI-10 were members of Cluster VIII. Accession KTI-17 and KTI-13 belongs to Cluster VII.

Quantitative data of the clusters were generated based on the data of respective members. Pulp yield per unit area of tree canopy was estimated using data of number of fruits per unit area and average fruit weight of fruits. Cluster VII recorded highest fruit yield per unit area (182.31 g). KTI-17 and KTI-13 which were members of Cluster VII are marked as plus trees.

The relationship between the characters were analysed based on the loading plot of the first two principal component scores. As 72.9 per cent of the total variation was captured within first two principal components itself, it is more reliable to justify the linkage based on the loading plot.

Only productive and yield attributing quantitative characters were utilized for analysis. Linkage analysis revealed a highly positive correlation between pod length and seed weight, pod length and fruit weight. The fruit weight and pulp weight were positively correlated. Seed weight had positive correlation with fruit weight. Pulp content and pod girth were positively correlated to a lesser extent. Similarly pod length and pulp weight were positively correlated to much lesser extent. Number of fruits per unit area and number of seeds per fruit were negatively correlated. Number of fruits per unit area and pulp content were independent of each other. Similarly pulp content and number of seeds per fruit were also independent and pulp content and fruit weight also independent. Pod length and pod girth were also independent of each other. Pod girth was found to be independent of the number of seeds per fruit.

Ayala-Silva *et al.,* (2016) analysed the diversity of tamarind germplasms which were being maintained at the Subtropical Horticultural Research Station, Miami, Florida, USA using Principal Component Analysis. Thirteen tamarind accessions were analysed based on 18 quantitative characters. Seventy-two per cent of the variability was captured under first three principal components and three broad clusters A, B and C were made by cluster analysis to know the extent of similarity between genotypes. Similar clustering and correlation studies in tamarind were done recently by Kidaha *et al.* (2019) in Kenya using PCA. Based on PCA he reported number of seeds per fruit, length of the fruit, weight of fruit, weight of seed per pod and pulp weight were highly correlated. Similar results were also obtained in the current study.

4.1.7 Correlation

A correlation study was conducted between major fruit and flower characters. The characters used for correlation included pod length, pod girth, fruit weight, seed weight, pulp weight, number of seeds per fruit, fruits per unit area (1 ft^2), pulp content, pedicel length, petal length, petal breadth, filament length, sepal length, sepal breadth, ovary length, pistil length, panicle length and flower weight (Table 12).

Pod length exhibited a highly significant positive correlation with fruit weight. Pod girth exhibited strong positive and significant correlation with pulp weight. Fruit weight recorded highly positive and most significant correlation with pulp weight and seed weight. Pulp weight and seed weight were positively and highly significantly correlated.

A strongly positive and significant correlation was observed between pulp content and corolla spread. Petal length expressed a significant and highly positive correlation with pedicel length and filament length. Petal length was highly positively and significantly correlated with sepal length, filament length and corolla spread.

Highly positive and significant correlation was noticed between sepal length and sepal breadth. Weight of the flower was found to be highly significantly and highly positively correlated with sepal length. Ovary length expressed strongly significant and highly positive correlation between pistil length.

Pod length expressed positive and significant correlation with pulp weight and seed weight. Pod girth recorded positively significant correlation with pulp content.

Table 12: Correlation coefficients among fruit and flower characters in tamarind accessions

	Pod length	Pod girth	Fruit weight	Pulp weight	Seed weight	Seed number	Fruits per unit area	Pulp content	Pedicel length	Petal length	Petal breadth	Filament length	Sepal length	Sepal breadth	Ovary length	Pistil length	Panicle length	Flower weight
Pod girth	0.27																	
Fruit weight	0.64 **	0.46																
Pulp weight	0.60 *	0.64 **	0.93 **															
Seed weight	0.58 *	0.24	0.83 **	0.68 **														
Seed number	0.31	-0.31	0.28	0.12	0.57 *													
Fruits per unit area	-0.34	0.10	-0.16	-0.10	-0.35	-0.36												
Pulp content	0.07	0.60 *	0.13	0.49	-0.18	-0.35	0.10											
Pedicel length	0.21	0.11	0.27	0.26	0.00	-0.25	-0.23	0.15										
Petal length	0.22	0.23	0.30	0.39	0.11	-0.12	-0.15	0.42	0.72 **									
Petal breadth	0.10	-0.35	-0.19	-0.26	-0.07	-0.04	-0.26	-0.28	0.10	0.15								
Filament length	0.31	0.17	0.21	0.30	0.10	-0.15	-0.24	0.37	0.57 *	0.67 **	0.29							
Sepal length	0.15	0.10	0.33	0.41	-0.04	-0.17	0.09	0.44	0.59 *	0.84 **	0.03	0.50 *						
Sepal breadth	0.09	-0.10	0.01	0.09	-0.23	0.04	0.14	0.31	0.07	0.32	0.10	0.31	0.62 **					
Ovary length	0.44	0.18	0.36	0.32	0.28	0.12	0.10	-0.06	0.01	0.32	0.39	0.22	0.34	0.09				
Pistil length	0.35	0.18	0.46	0.33	0.46	0.21	0.02	-0.26	0.14	0.26	0.38	0.21	0.16	-0.17	0.88 **			
Panicle length	0.46	0.41	0.19	0.30	0.13	-0.09	0.01	0.33	0.40	0.52 *	0.11	0.35	0.26	-0.02	0.27	0.23		
Flower weight	-0.13	0.35	0.14	0.28	-0.12	-0.28	0.26	0.49 *	0.15	0.60 *	-0.14	0.40	0.74 **	0.55 *	0.37	0.17	0.14	
Corolla spread	0.04	0.44	0.11	0.37	-0.11	-0.24	-0.14	0.76 **	0.37	0.61 **	-0.14	0.27	0.56 *	0.42	-0.21	-0.36	0.44	0.45

*: Significant at 5% **: Significant at 1%

Similarly flower weight also expressed significantly positive correlation with pulp content. Seed number and seed weight were significantly and positively correlated. Pedicel length expressed positive and significant correlation with filament length and sepal length. Petal length was positively and significantly correlated with panicle length and flower weight. Sepal length expressed moderately positive and significant correlation. Sepal length recorded positive and significant correlation with corolla spread. Sepal breadth and flower weight expressed a positive and significant correlation between them.

The results of the present study were in agreement with the results obtained by previous studies for various fruit and flower characters conducted by various authors (Bhogave *et al.,* 2018; Mayavel *et al.,* 2018a; Pooja *et al.,* 2018; Kidaha *et al.,* 2019).

4.1.8 Ideotype for selection of tamarind genotypes

An ideotype is a genotype with a set of desirable combination of selected characters. The development of universal ideotype for a crop is difficult due to differences in end users and growing conditions (El-Siddig *et al.,* 2006; Devi, 2016; Mayavel *et al.,* 2018b) and tree with following characters are ideal for pulp oriented industry.

- Precocious in bearing (from 4^{th} or 5^{th} year onwards)
- More number of fruits per unit area of canopy
- Round and dense canopy
- Regularity in bearing
- Early flowering and longer flowering period
- Longer fruiting season and high fruit set
- Fleshy and heavy long pods with high pulp recovery
- Longer vegetative terminal shoot
- Quality pulp (highly acidic pulp or low acidic and sweet pulp, depending on market profitability)
- Resistance to pest (Major pests: tamarind fruits borer-*Cryptophlebia ombrodelta* Lower, groundnut beetle-*Caryedon serratus* Oliver and tamarind weevil-*Sitophilus linearis* Herbst).
- Resistance to diseases (Powdery mildew).
- High yield (600-800 kg fruits/tree/year from yield stabilized tree)

Key flower characters for genotype selection

Present study revealed considerable association fruit characters with floral traits such as flower weight and corolla spread with pulp content of fruits. During collection of germplasms and genotype evaluation, the efficiency of selection can be enhanced by screening for wider corolla spread and higher flower weight along with ideotype characters.

4.2 EVALUATION OF VEGETATIVE PROPAGATION TECHNIQUES

4.2.1 Time taken for sprouting

Number of days taken for the appearance of first green coloured sprout on the scion/bud after grafting/budding was recorded only in detached method of propagation *viz.,* veneer grafting, softwood grafting and patch budding as the bud wood or scions were completely devoid of leaves during grafting hence the newly formed sprouts can be recorded.

Irrespective of season of propagation, there was a significant difference in time taken for sprouting in grafting and budding methods (Table 13 and Fig. 2). Time taken for sprouting was lowest for softwood grafting (4.5 days) but it was 9.3 days for veneer grafting. Patch budded plants failed to sprout in all the seasons, hence they were excluded from further statistical analysis.

When the time taken for sprouting was evaluated in four season irrespective of propagation method, comparatively more number of days were taken to sprout during September-October and grafts took least time to sprout during March-April. Softwood grafts took least days to sprout during March-April whereas veneer grafts took least days to sprout during June-July. Softwood grafts took maximum number of days to sprout during June-July (5.38 days) whereas veneer grafts took maximum days to sprout during September-October (11.5 days).

Temperature of 32°C favours callusing in grafts resulting in successful graft union, above 32°C causes tissue injury and tissue death occurs at 40°C, as soon as tissue dies, the mould start colonizing the union, which can be seen within the first few days after grafting (Shippy, 1930).

Higher temperature prevailing during the March-April might be the reason for early sprouting which helped for faster establishment of vascular connection across the graft union as reported by Agasimani *et al.,* (2019). Singh and Singh (2007) also reported that tamarind softwood grafts took less days (24-27 days) to sprout during March, April and May months.

Time taken for bud sprouting increases as the temperature starts increase and humidity starts to drop (Singh, and Srivastava, 1962). Lalaji (2001) recommended softwood grafting of tamarind between leaf fall and new growth for Rahuri condition which was quite opposite to normal propagation season of major tropical crops like

Table 13: Time taken for sprouting

Season	Propagation method		Season mean
	Softwood grafting	Veneer grafting	
March-April	3.325	8.975	6.15
June-July	5.375	7.875	6.63
Sept-Oct	4.875	11.5	8.19
Dec-Jan	4.433	8.858	6.65
Methods mean	4.50^{a}	9.30^{b}	

Factors	C.D.	SE(m)	F-Calculated
Season (S)	N/A	0.744	1.42^{NS}
Propagation method (P)	1.545	0.526	41.61**
Factor(S X P)	N/A	1.052	1.43^{NS}

*: Significant at 5% ; **: Significant at 1%

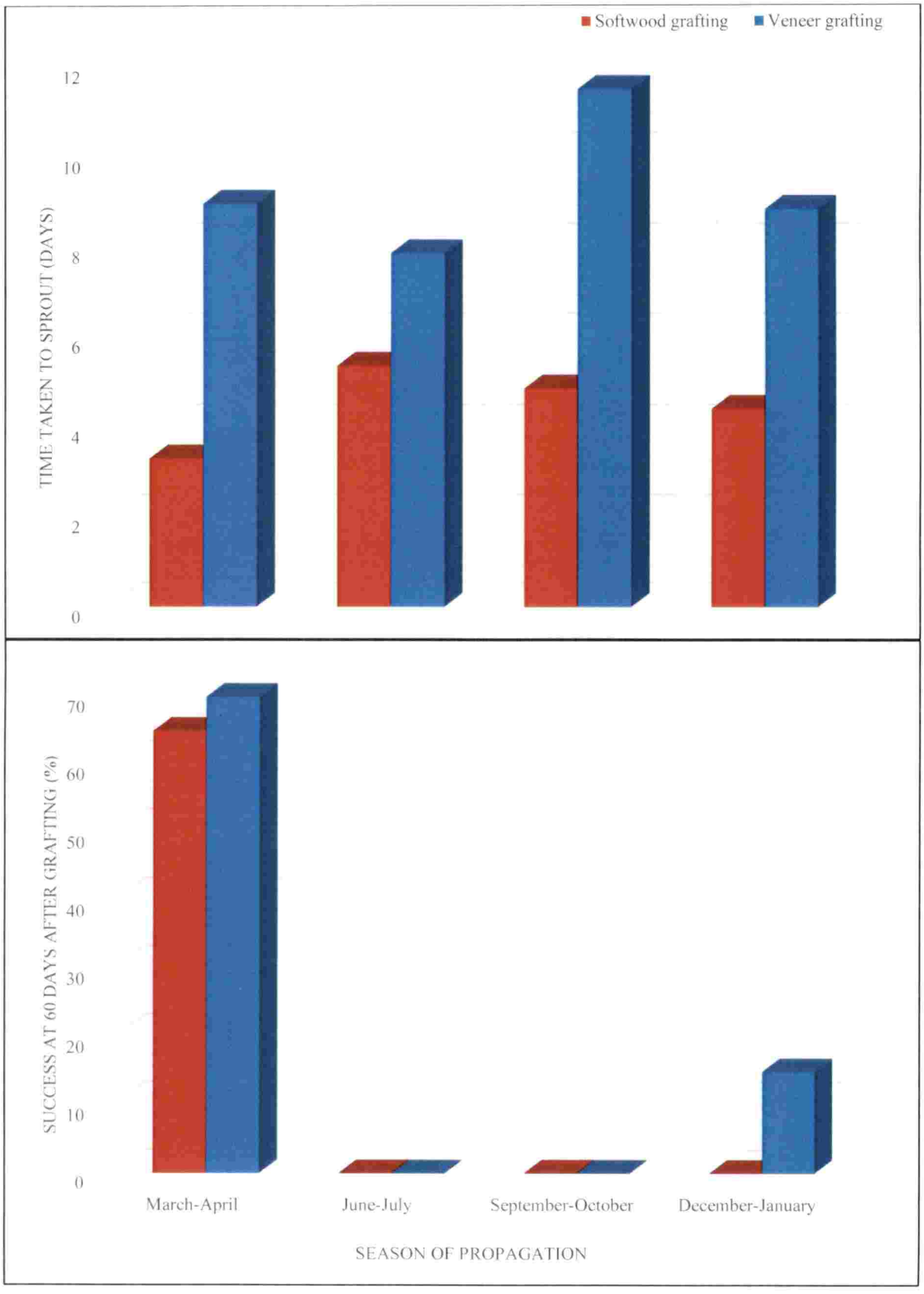


Fig 2: Time taken for sprouting and success percentage of grafting methods

mango and sapota. Similarly, Salve (1994) also recommended summer season for tamarind propagation for Rahuri condition (MH). This recommendation also holds good with respect to present study.

In the present study, patch budding was completely failed as there was no sprouting even after three months of budding. Complete failure of patch budding was reported earlier by Singh and Singh (2007) who reported complete failure of patch budded tamarind plants prepared in different months at Central Horticultural Experiment Station, Godhra. In case of softwood grafting also they reported complete failure in the grafts prepared during the month of December, January and February.

4.2.2 Success percentage

The number of grafted/budded plants established after 30 days, 45 days and 60 days were recorded. The patch budding method was complete failure and there was no sprouting in all the months in spite of bud take. Hence, only softwood grafting and veneer grafting were considered and patch budding was omitted from further statistical analysis (Table 14 and Fig. 2). Propagation unit and successful grafts are presented in plate 10 and plate 11.

4.2.2.1 Success percentage at 30 days

At 30 days after grafting, the initial success percentage was recorded. There was significant difference for success percentage in different seasons. Irrespective of the propagation method followed, March-April recorded highest establishment (73.75%) followed by December-January (7.50%). In the grafts prepared during June-July and September-October even though there was sprouting, none of the grafts established after 30 days. A significant difference in establishment per cent was recorded for propagation methods. Veneer grafting recorded highest establishment (23.13%) whereas softwood grafting recorded 17.50 per cent establishment irrespective of the season. The softwood grafting recorded highest establishment (70%) in the grafting done in the month of March-April. None of the plants were established in softwood grafts prepared during June-July, September-October and December-January months even after successful sprouting in all the months.

4.2.2.2 Success percentage at 45 days

At 45th day after grafting, the establishment percentage remained same as that at 30th day in both softwood grafting and veneer grafting.

Table 14: Success at 30, 45 and 60 days after grafting

Season	Propagation method						Season mean		
	Softwood grafting			Veneer grafting					
	30 D	45 D	60 D	30 D	45 D	60 D	30 D	45 D	60 D
March-April	70	70	65	77.5	77.5	70	73.75	73.75	67.5
June-July	0	0	0	0	0	0	0	0	0
September-October	0	0	0	0	0	0	0	0	0
December-January	0	0	0	15	15	15	7.5	7.5	7.5
Methods mean	17.5	17.5	16.25	23.13	23.13	21.25			

Factors	C.D.			SE(m)			F-Calculated		
	30 D	45 D	60 D	30 D	45 D	60 D	30 D	45 D	60 D
Season (S)	7.264	7.264	7.34	2.474	2.474	2.5	209.43**	209.43**	171**
Propagation method (P)	5.136	5.136	N/A	1.749	1.749	1.768	5.17*	5.17*	4^{NS}
Factor(S X P)	N/A	N/A	N/A	3.499	3.499	3.536	2.11^{NS}	2.11^{NS}	2^{NS}

*: Significant at 5% ; **: Significant at 1%

4.2.2.3 Success percentage at 60 days

A slight variation was observed in the establishment percentage after 60th day compared to 45th day of grafting.

The difference between establishment percentage due to propagation methods irrespective of the season was non-significant and difference in establishment percentage due to interaction effects of season and propagation method (S x P) were also non-significant. Influence of season on establishment was highly significant irrespective of the method. Grafts prepared during March-April recorded highest establishment (67.5%) followed by December-January grafts (7.5%). The establishment percentage of March-April prepared softwood graft was reduced from 70 per cent at 30th day of grafting to 65 per cent at 60th day of grafting. A similar reduction in establishment percentage was recorded in veneer grafting which reduced from 77.50 per cent at 30 days after grafting to 70 per cent at 60 days after grafting.

4.2.3 Length of shoot

4.2.3.1 Length of shoot at 45 days after grafting (per graft)

The differences in shoot length due to method of propagation was highly significant. Veneer grafting recorded maximum shoot length (3.38 cm) compared to softwood grafting (1.43 cm).

The differences in shoot length due to season of grafting was highly significant. Maximum shoot length was recorded in grafts made during March-April (5.81 cm) followed by December-January grafts (3.82 cm). Both of these seasons were significantly different from each other in terms of shoot length (Table 15).

The interaction of the season and propagation method had a highly significant influence on shoot length. Maximum shoot length was recorded in combination of veneer grafting method and December-January grafting season (7.63 cm). Shoot length of softwood grafts (5.73 cm) and veneer grafts (5.90 cm) produced during March-April were on par with each other.

The shoot length was recorded zero for the softwood grafts produced during June-July, September-October, December-January and veneer grafts produced during June-July and September-October as the grafts recorded zero success during these seasons.

Table 15: Length of shoot at 45 and 60 days after grafting

Season	Propagation method				Season mean	
	Softwood grafting		Veneer grafting			
	45 D	60 D	45 D	60 D	45 D	60 D
March-April	7.26	5.73	6.55	5.9	6.91[a]	5.81[a]
June-July	0	0	0	0	0	0
Sept-Oct	0	0	0	0	0	0
Dec-Jan	0	0	8.93	7.63	4.46[a]	3.82[b]
Methods mean	1.82[b]	1.43[b]	3.87[a]	3.38[a]		

Factors	C.D.		SE(m)		F-Calculated	
	45 D	60 D	45 D	60 D	45 D	60 D
Season (S)	2.502	1.87	0.852	0.636	16.21**	20.76**
Propagation method (P)	1.769	1.32	0.603	0.45	5.82*	9.40**
Factor(S X P)	3.538	2.64	1.205	0.899	7.27**	8.88**

*: Significant at 5% ; **: Significant at 1%

4.2.3.2 Length of shoot at 60 days after grafting (per graft)

The differences in shoot length due to propagation method was highly significant. Maximum shoot length was recorded in veneer grafting (3.87 cm) whereas softwood grafting recorded lowest shoot length (1.82 cm).

The influence of grafting season on the shoot length of grafts was significantly high (Table 15). March-April season grafts recorded highest shoot length (6.91 cm) which was on par with shoot length of December-January grafts (4.46 cm). There was no success in both veneer grafting produced during June-July and September-October and softwood grafting carried out during June-July, September-October and December-January.

Shoot length was highly and significantly influenced by interaction effect of season and propagation method. Maximum shoot length was recorded for veneer grafting carried out during December-January (8.93 cm) which is at par with shoot lengths of softwood graft produced during March-April (7.26 cm) and veneer graft prepared during March-April (6.55 cm).

Similar marginal difference for shoot length of softwood grafts and veneer grafts prepared during April was reported by Purushotham and Narasimharao (1990). Agasimani *et al.,* (2019) reported 5.54 cm to 19.02 cm shoot length in softwood grafts after 90 days.

Veneer grafts recorded more shoot length in December-January (8.93 cm) than March-April (6.55 cm) which might be due to lesser number of shoots in December-January grafts (2.13) compared to March-April veneer grafts (4.45). Due to lesser number of branches the shoot growth was vigorous compared to grafts with more branches.

Kumar *et al.* (2003) obtained longer sprouts in softwood grafts of August, September and January months in Dharwad who opined that increased shoot length might be due to increased vegetative growth and reduced transpiration as a result of higher RH.

4.2.4 Number of branches (per graft)

The observations on number branches produced by grafts were recorded on 90th day after grafting (Table 16 and Fig. 3).

The data indicate that differences in the number of branches were not significantly influenced by the method of grafting. Veneer grafts recorded maximum number of branches (1.64) which is slightly greater than the number of branches produced by softwood grafts (1.25).

Table 16: Number of branches at 90 days after grafting

Season	Propagation method		Season mean
	Softwood grafting	Veneer grafting	
March-April	4.99	4.45	4.72
June-July	0	0	0
Sept-Oct	0	0	0
Dec-Jan	0	2.13	1.06
Methods mean	1.25	1.64	

Factors	C.D.	SE(m)	F-Calculated
Season (S)	0.688	**0.234**	91.42**
Propagation method (P)	N/A	**0.166**	2.85^{NS}
Factor(S X P)	0.972	**0.331**	6.36**

*: Significant at 5% **: Significant at 1%

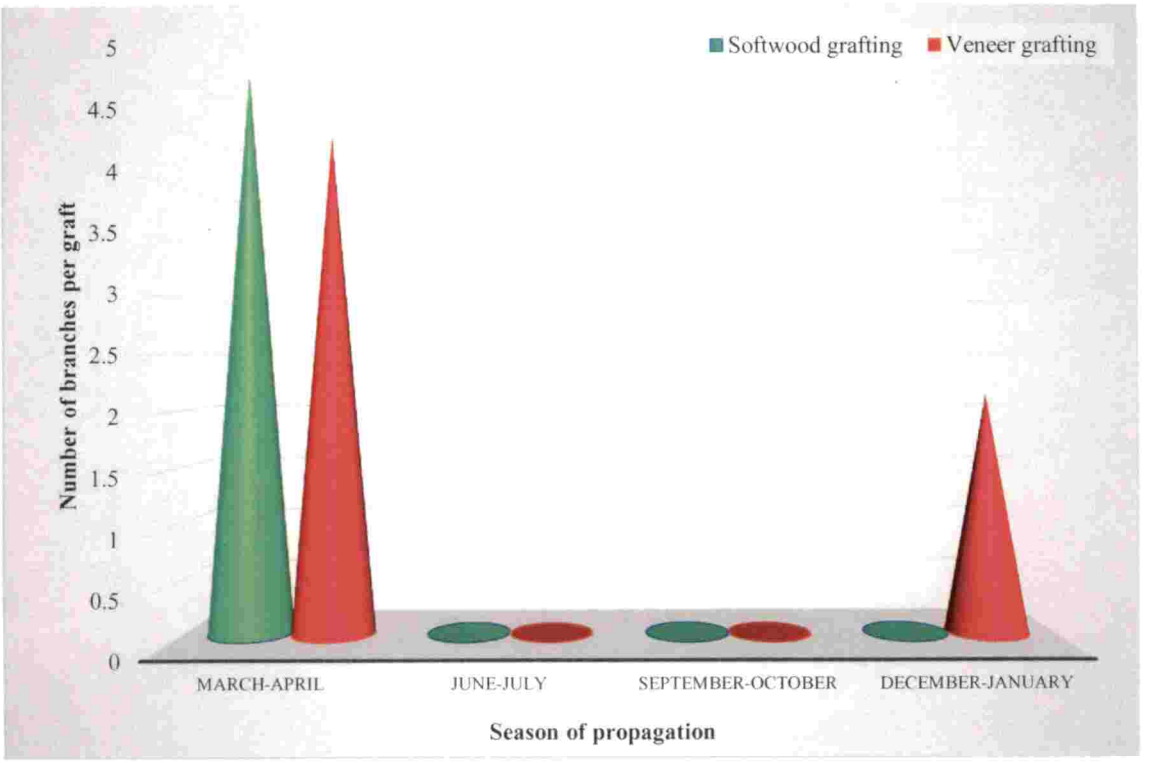


Fig 3: Number of branches at 90 days after grafting

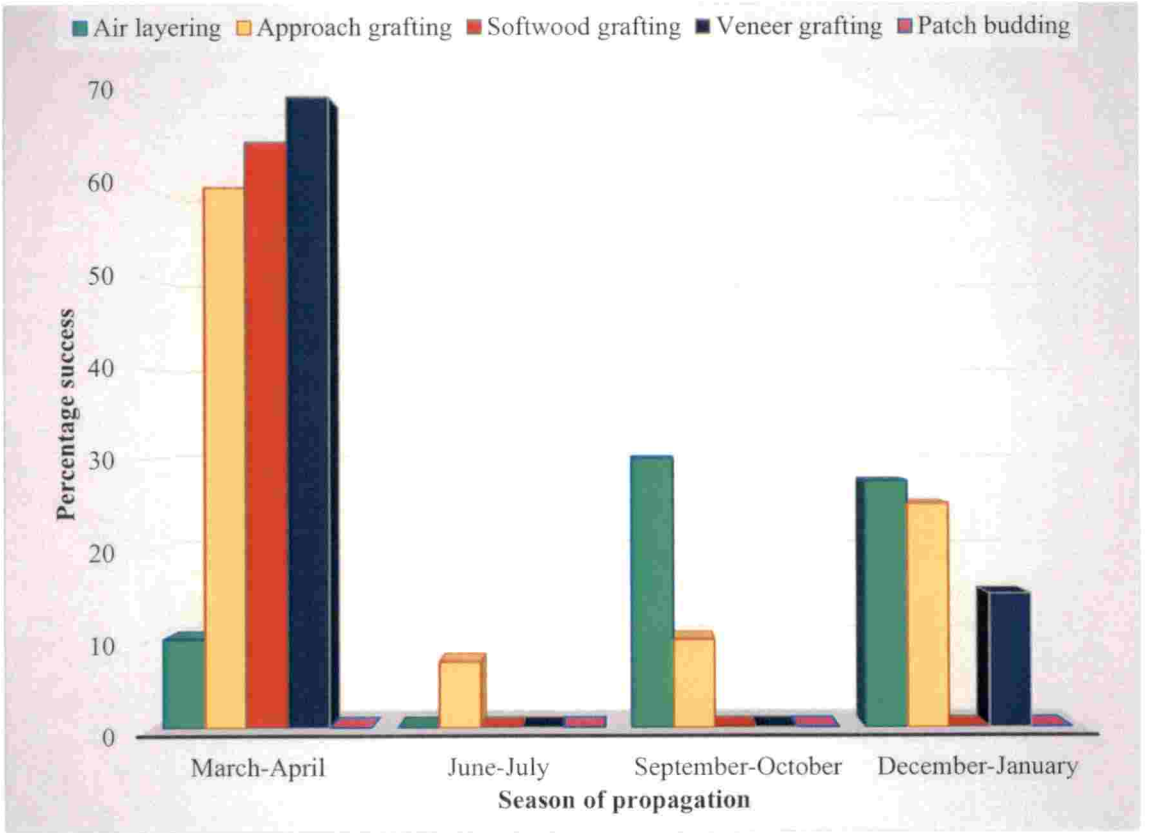


Fig 4: Success percentage at 90 days after grafting

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Season of grafting had a highly significant influence on the number of branches per graft. March-April season grafts recorded highest number of branches (4.72) followed by December-January grafts (1.06). Both are significantly different from each other.

Influence of interaction of season of grafting and propagation method was highly significant on number branches. Softwood grafts produced during March-April recorded maximum number of branches (4.99) which is significantly on par with the number of branches produced by veneer grafts prepared during the same season (4.45). Lowest number of branches were recorded by veneer grafts prepared during December-January (2.13). The number of branches recorded zero for softwood grafts produced during June-July, September-October and December-January due to zero survival of grafts during those periods. Similarly, veneer grafting recorded zero branches during June-July and September-October.

The marginal difference for number of sprouted shoots or branches between softwood graft and veneer graft was recorded by Purushotham and Narasimharao (1990) and in the present study also softwood grafting marginally exceed veneer grafting in terms of number of branches in the grafts prepared during the same season (March-April).

The present study is in conformity with Kumar *et al.* (2003) who obtained similar results under Dharwad condition for number of branches per softwood graft. At 90 days after grafting highest number of branches were recorded in grafts prepared during October (4.62), while December grafts recorded lowest number of branches (3.02).

The results of the present investigation were in conformity with Uchoi (2010) who obtained maximum number of leaves (12.08) and branches per graft (4.45) in the month of March for softwood grafting in jamun under Bengaluru condition.

4.2.5 Final success percentage

Out of the five vegetative propagation methods evaluated, patch budding completely failed in all seasons hence it was omitted from statistical analysis. Success percentage was recorded 90 days after for each propagation method (Table 17 and Fig. 4).

The present study revealed that season of grafting plays a significant role in success of the grafts. The differences in success per cent between the seasons were highly significant. Overall highest success was obtained in propagules produced during March-April months (51.25%). Propagules produced during December-January recorded success

Table 17: Final success percentage at 90 days after grafting

Season	Propagation method				Season mean
	Air layering	Approach grafting	Softwood grafting	Veneer grafting	
March-April	10.00	60.00	65.00	70.00	51.25
June-July	0.00	7.50	0.00	0.00	1.88
Sept-Oct	30.00	10.00	0.00	0.00	10.00
Dec-Jan	27.50	25.00	0.00	15.00	16.88
Methods mean	16.88	25.63	16.25	21.25	

Factors	C.D.	SE(m)	F-Calculated
Season (S)	5.495	1.926	127.09**
Propagation method (P)	5.495	1.926	5.12**
Factor(S X P)	10.989	3.853	23.95**

*: Significant at 5% **: Significant at 1%

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Plate 10: Inspection of propagation unit and propagules by major advisor and researcher

Softwood grafting

Approach grafting

Veneer grafting

Plate 11: Successful grafts

of 16.88 per cent, followed by September-October (10%) and lowest success was recorded in propagules produced during June-July period (1.88%).

The differences due to method of propagation on final success percentage was highly significant. Highest success per cent of 25.63 per cent was recorded by approach grafting. Veneer grafting recorded 21.25 per cent which was significantly on par with approach grafting. Air layering recorded over all 16.88 per cent success while softwood grafting recorded overall lowest success percentage of 16.25 per cent. Both air layer and softwood grafting are at par with veneer grafting.

Interaction effect of propagation method and season of grafting on success percentage of propagules was highly significant. Among the different treatment combinations, veneer grafting recorded highest success of 70 per cent during March-April, which was on par with softwood grafting (65%) and approach grafting (60%) done during the same period.

There was no success recorded in softwood grafts prepared during June-July, September-October and December-January even though the grafts sprouted successfully. Similarly, in case of veneer grafts produced during June-July and September-October there was zero success; air layers produced during June-July recorded zero success even though there was successful rooting observed.

In Air layering, layers produced during September-October recorded maximum survival (30%) followed by December-January (27.5%) and March-April (10%).

Among the approach grafts, grafts prepared during March-April recorded highest survival (60%) followed by December-January grafting (25%) and September-October grafting (10%). Approach grafting done during June-July recorded lowest success (7.5%) which is significantly on par with September-October approach grafting (7.5%).

Softwood grafting recorded success only in the grafts prepared during March-April which was 65 per cent. Veneer grafting recorded maximum success of 70 per cent in March-April grafts and a success of 15 per cent was recorded in December-January grafts.

Purushotham and Narasimharao (1990) obtained 68 per cent and 49 per cent success for softwood grafts and veneer grafts respectively during April at Pandirimamidi (Andhra Pradesh). Better success was observed for grafts prepared with 10 cm scion. Higher success percentage during March, April and May months might be due to the

favourable environment with optimum temperature and optimum relative humidity which enhanced the union of the scion and stock cambial layers coupled with precocious callus formation and development of good vascular network between stock and scion (Hartmann *et al.,* 2010; Agasimani *et al.,* 2019; Praveenakumar *et al.,* 2019). Which might be a probable reason for higher success of softwood and veneer grafts prepared during March-April in the present investigation.

Leakey (2014) reported that in temperate trees when dormant scions (especially chilling treated) were used for grafting on active rootstocks, the success percentage was higher. Similar result was obtained in this study during March-April when naturally defoliated scions were used for grafting, significantly higher success percentage was obtained.

Hartmann *et al.* (2010) reported probable causes for graft failure were non-optimal temperature during cell division and formation of union, loss of cell turgidity due to desiccation of scion, physical movement in the junction of scion and rootstock and microbial infection.

The present study revealed that patch budding was not at all successful for tamarind propagation in this region. Similar complete failure of patch budded tamarind plants was reported earlier by Singh and Singh (2007) from Godhra (Gujarat). A case of complete failure of patch budded plants was reported by Biswas and Hossain (1986) who reported complete failure of patch budded plants during June in jackfruit at Joydebpur (Bangladesh) whereas Nachegowda *et* al., (2018) reported 94 per cent success in patch budded jackfruit at Kolar (Karnataka). Hence it can be concluded that geographical location and environmental conditions play a paramount role in graft success by controlling cell activity and plant physiology (sap flow) which will ultimately lead to success or failure of grafting and budding.

Melnyk *et al.* (2015) studied grafting in *Arabidopsis thaliana* and reported very critical results that the phloem took three days to form a proper connection between scion and stock after initial grafting, whereas the xylem took up to seven days for establishing cambial connection between scion and stock.

In the present study grafts prepared during June-July, September-October and December-January was failed to survive even after cent percent sprouting within 15 days in all the seasons. It was observed that most of the veneer and softwood grafts were

sprouted within 3-5 days compared to other regions where it generally takes 20-35 days to sprout (Singh and Singh, 2007). This early sprouting of scion might be accelerated due to boosting effect of high temperature and high humidity inside the mist house which led to sprouting of scion at the expense of reserved food in its tissues without the actual and perfect cambial union and leading to exhaustion of scion which makes it difficult for further growth after the union. Which subsequently resulted in drying up of sprouts before reaching a minimum length of 2 cm.

4.2.6 Influence of season and weather on success of propagation

Thorough analysis of weather data along with the success percentage revealed interesting results. The maximum success in veneer grafting, softwood grafting and approach grafting were obtained within the monthly mean maximum temperature range of 33-36.7°C. This appears to be the specific temperature required for successful graft union in tamarind of this zone (Fig. 5). Success was nil in the months having maximum temperature below 32.9°C. The monthly mean minimum temperature was nearly constant throughout the year.

The success was noticed in softwood grafting and veneer grafting when the relative humidity was in the range of 60-65 per cent (Fig. 5). Rainfall was another very important parameter which played significant role in success of grafting. In veneer grafting and softwood grafting, the success and survival was noticed only in the months of zero precipitation (Fig. 5), whereas approach grafting recorded maximum success of 25-60 per cent during zero precipitation month and 7.5-10 percent success during 290-790 mm rainfall.

Higher rainfall of above 500 mm per month caused complete leaf fall of the air layers and approach grafted plants along with complete leaf fall of trees. Trees recovered after heavy rains by starting new flush, but the air layered and approach grafted shoots along with rootstocks failed to recover after the receding of heavy rains, which lead to higher mortality of grafts and layers prepared during rainy season.

Sunshine hours expressed more influence on veneer and softwood grafting compared to air layering and approach grafting (Fig. 5). Higher success in the veneer and softwood grafts are appears to be slightly associated with longer sunshine hours. Sunshine in the range of 7-10 hours appears to be ideal for softwood and veneer grafting.

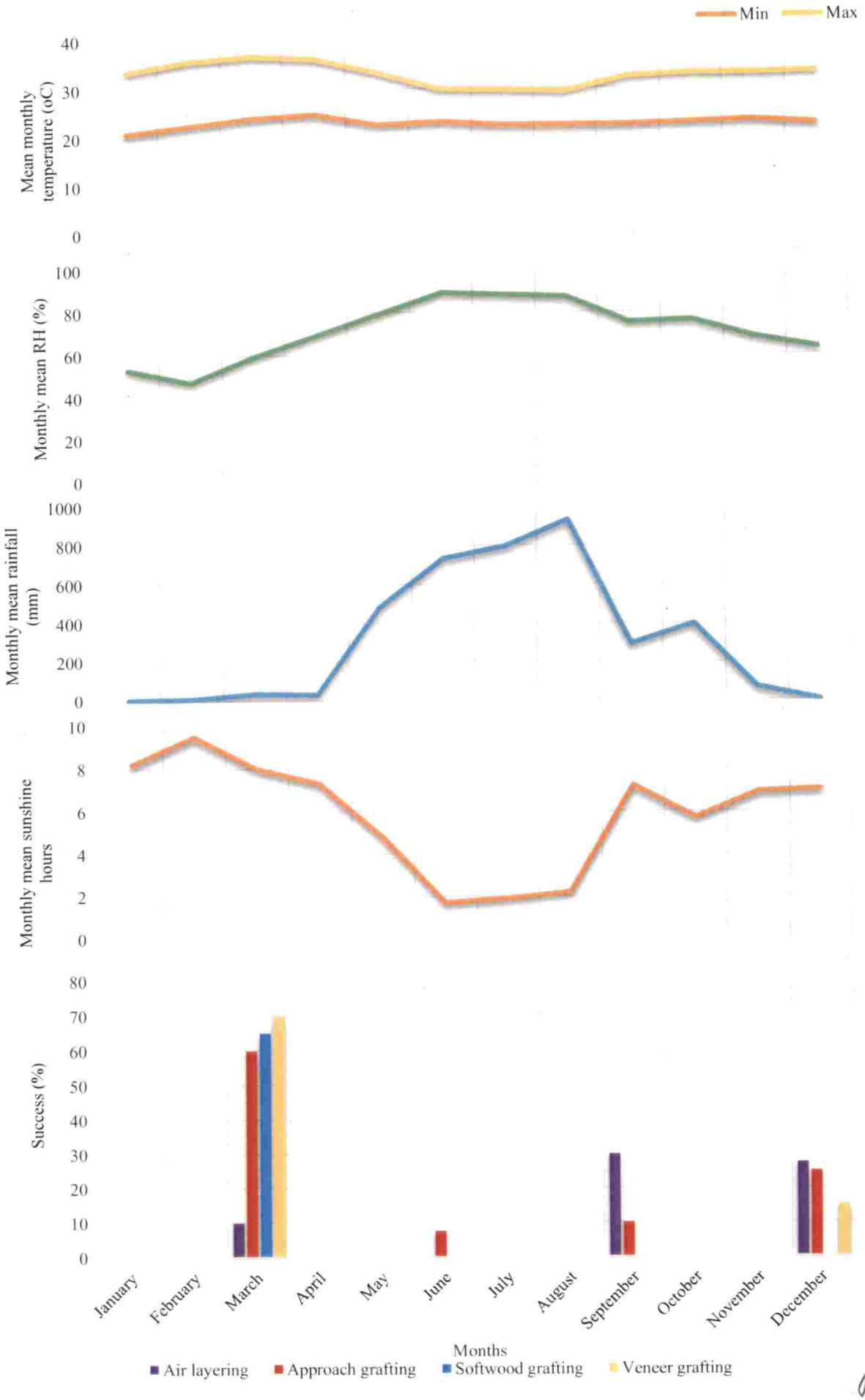

Fig 5: Propagation success per cent vs. monthly mean weather parameter

Under Dharwad condition for softwood grafting, Kumar *et al.* (2003) obtained lowest success of 12.03 per cent in December whereas highest success of 48.16 per cent was recorded during January followed by February (38.79%). Optimum atmospheric humidity of 60-65 per cent coupled with higher maximum temperature and the higher minimum temperature of 34°C and 16.7°C respectively after December month favoured higher grafting success in January and February. These factors might have accelerated cell activity and quick union of cambium across juxtaposed region. The lower rate of graft success in December-January grafts might be due dropped temperature which hindered successful union.

Lalaji (2001) also reported complete failure of patch budded plants in Rahuri, grafts prepared during 15th January, 15th February, 15th March and 15th December were failed to sprout and opined that low minimum temperature of 6.3 to 11.0°C and low RH of around 30 per cent were the probable reason for failure, which reduced cell division rate and callus formation across the union and they also obtained very less success during September which was reported to be due to unavailability of good bud woods as the tree was in pod development stage.

From this study, it can be concluded that ideal season for propagation of tamarind under Thrissur condition is between leaf fall and new flushing (March-April). Present study indicated veneer grafting as best method for this season followed by softwood grafting. Adoption of either veneer grafting or softwood grafting for mass multiplication and conservation of elite trees can be recommended based on the skill of the grafting person.

Summary

V. SUMMARY

The present study entitled "Morphometric evaluation and propagation studies in tamarind (*Tamarindusindica*L.)" was carried out at the Department of Plantation Crops and Spices, College of Horticulture, Kerala Agricultural University, Thrissur, during 2017-2019.

A preliminary survey of tamarind trees distributed in KAU main campus was carried out and 17 bearing trees were selected for study and were plotted in the google map and GPS coordinates were recorded. These accessions were observed for various qualitative and quantitative characters which include tree, leaf, flower and fruit characters to identify the extend of variability and major traits for breeding programme.

Wide variability was observed for tree characters among the accessions. Significant difference was observed for tree girth and accession KTI-9 recorded highest tree girth (3.16m). The minimum tree girth was observed in accession KTI-10 (1.00 m). Trees were grouped into regular and irregular bearers based on observations of two consecutive years. Ten out of 17 accessions were regular bearers. Three types of growth habit were observed in experimental population. Upright (47.06%) and semi-spreading types (41.17%) were predominantly found followed by spreading type (11.77%).

Tamarind leaf parameters expressed sizable variability and Accession KTI-10 recorded highest number of leaflets per leaf (32 leaflets) and the lowest in accession KTI-15 (24 leaflets) whereas leaf area recorded the highest value in accession KTI-5 (17.21 cm^2). The lowest leaf area was recorded in accession KTI-14 (6.47 cm^2). Among the accessions, predominant foliage type observed was dense (76.47%). New flush colour of the accessions varied from green, reddish green to reddish brown. Green was the predominant type (70.59%) among the selected accessions. KTI-15 was the only accession with reddish brown coloured new flush.

The flowering was observed from last week of March to the second week of May. Early flowering was noticed in KTI-13 (last week of March) and accession KTI -6 was the late flowering (second week of May). The average number of inflorescence per node was ranged from 1.00 to 1.13 whereas the average panicle length was ranged from 7.8 cm (KTI-6) to 32 cm (KTI-17). Based on the length, the panicles were grouped into low, medium and high. Majority of the accessions expressed high length panicle (58.82%), the

second largest group was low length (23.53%) and least number of accessions showed medium length panicle (17.65%).

Flowers were observed for five different qualitative characters *viz.,* bract colour, bracteole colour, corolla colour, sepal colour and filament colour. Characters like bract colour and bracteole colour were found to be highly variable among the accessions than the other characters. Among the selected accession 29.41 per cent of the accessions had pale pink bracts and 29.41 per cent of the trees had pale green bracts. The majority of accessions produced pink bracteoles (52.94%).

Variation in corolla colour, sepal colour and filament colour was very limited. The predominant corolla colour of accessions was pale yellow with red streaks (88.23%). Only two types of sepal colours were noticed among the selected accessions. Lemon chiffon coloured sepal (76.47%) was prominent followed by pale yellow (23.53%) coloured sepal. The predominant filament colour noticed among the accessions was green with dark streaks (88.24%) followed by green without dark streaks (11.76%).

Greater variability was noticed for quantitative parameters of flowers. The average corolla spread ranged from 2.17 cm (KTI-6) to 3.27 cm (KTI-7). KTI-17 recorded second highest corolla spread of 3.06 cm. Length of the ovary was recorded highest in KTI-3 (1.31cm) and the shortest ovary was recorded in KTI-7 (0.69 cm). Longest pistil was noticed in KTI-16(1.94 cm) while the shortest was observed in KTI-7 (1.05 cm). The average number of stamens was 3 in all the accessions except KTI-9 which had recorded 2.5 stamens. Total number of staminodes ranged from 2 (KTI-2) to 4.5 (KTI-9). Accession KTI-17 (1.787 g) recorded highest flower weight while the least floral weight was recorded in accession KTI-12 (1.093 g).

The reddish brown coloured pod was more common (70.59%) followed by grey colour pods (29.41%). Majority of the accessions expressed pods of semi curved shape (52.94) followed by curved pods (35.29%) and straight pods (11.77%). Three categories of pod weight were made *viz.,* low, medium and high. The majority of the accessions came under group medium (76.47%) followed by low (17.65%) and high (5.88%).

Three categories of pod length were made *viz.,* short, medium and long. The majority of the selected accessions grouped under medium (82.35%) followed by long (11.77%) and short fruits (5.88%). Two types of pulp colour were observed among the accessions *viz.,* brown colour pulp (58.82%) and reddish brown colour pulp (41.18%).

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Variability in pod characters expressed wider range of values. The average pod length was highest in accession KTI-16 (19.22 cm) and shortest pods were recorded in accession KTI- 4 (9.79 cm). The Accession KTI-16 showed a fruit length in the range of 7-23 cm. The highest pod girth was recorded in accession KTI-17 (8.40 cm) and accession KTI-12 recorded least pod girth of 6.24 cm. The average fruit weight was significantly high in accession KTI-10 (26.60 g). Accession KTI-12 recorded the lowest fruit weight of 11.28 g. The accession KTI-10 expressed a fruit weight in the range of 8-54 g. Shell weight of the selected accessions ranged from 2.94 g per pod in KTI-12 to 6.89 g per pod in KTI-10. The weight of the fibres ranged from 0.19-1.55 g per pod. Accession KTI-10 recorded highest pulp weight of 10.66 g and the lowest pulp weight was 4.14 g (KTI-12). KTI-16 recorded highest seed weight of 8.75 g per pod and KTI-7 recorded lowest seed weight of 3.41 g per pod with individual seed weight of approx. 0.59 g. Total number of seeds per fruit ranged from 4.43 (KTI-13) to 8.93 (KTI-16).

The number of fruits per unit area of the canopy ranged from 2.83 (KTI-16) to 9.83 (KTI-6). The number of fruits per unit area from KTI-6 (9.83), KTI-13 (9.67 fruits) and KTI-17 (9.33 fruits) were also on par with KTI-16. Highest pulp shell ratio was observed in KTI-13 (2.49: 1) and least was observed in KTI-12 (1.41: 1). Highest pulp seed ratio was recorded in accession KTI-7 (1.9) and lowest pulp seed ratio was recorded by KTI-15 (0.87).

The average pulp content of the fruits ranged from 34.79% (KTI-6) to 49.09% (KTI-7). The average shell content ranged from 19.07% (KTI-6) to 26.02% (KTI-12). KTI-12 recorded lowest fibre content of 1.69 % and the highest fibre content was recorded in KTI-10 (5.81%). Seed content of the fruit was ranged from 25.90 g in accession KTI-7 to 41.54 g in accession KTI-15.

The titratable acidity of the pulp expressed as the equivalent weight of tartaric acid ranged from 7.79% (KTI-9) to 21.94% (KTI-12). The TSS of pulp was ranged from 55 ^{O}Brix (KTI-12) to 70 ^{O}Brix (KTI-3). The ascorbic acid content was ranged from 11.17 mg (KTI-4) to 18.91 mg (KTI-17). The pulp TSS range was divided into three categories *viz.*, low, medium and high based on DUS (2017) standards. None of the accessions had high TSS and the majority of the accessions fell under the medium TSS category (64.71%). Based on the titratable acidity majority of the accessions came under class group high (70.59%).

Principal Component Analysis (PCA) of yield attributing characters derived nine clusters. The charachters considered were pod length, pod girth, fruit weight, pulp weight, seed weight, number of seeds per fruit, number of fruits per unit area and pulp content. First two principal components contributing 72.9 per cent of the total variation and the accessions were grouped into nine clusters. Accession KTI-12 is the only member of Cluster I, KTI-7 is the only member of Cluster II, KTI-2 is the only member of Cluster III. Cluster IV had 4 members *viz.,* KTI-11, KTI-14, KTI-5 and KTI-1. KTI-6 and KTI-15 were members of Cluster V. Cluster VI contain 3 members *viz.,* KTI-3, KTI-4 and KTI-9. KTI-17 and KTI-13 belongs to Cluster VII. KTI-8 and KTI-10 were members of Cluster VIII and KTI-16 belongs to Cluster IX.

Quantitative data of the clusters were generated based on the data of respective members. Pulp yield per unit area of tree canopy was estimated using data of number of fruits per unit area and average weight of fruits. Cluster VII recorded highest fruit yield per unit area (182.31 g). Members of these two clusters can be marked as plus trees and these tree can be included in crop improvement programmes in future.

Correlation study revealed extent of association among pod and flower characters. Fruit weight recorded highly positive and most significant correlation with pulp weight and seed weight. A strongly positive and significant correlation was observed between pulp content and corolla spread. Petal length was highly positively and significantly correlated with sepal length, filament length and corolla spread. Pod length expressed positive and significant correlation with pulp weight and seed weight. Pod girth recorded positively significant correlation with pulp content. Similarly flower weight also expressed significantly positive correlation with pulp content.

The various vegetative propagation methods like approach grafting, softwood grafting, veneer grafting, patch budding and air layering were evaluated. Overall highest success (55.25%) was obtained in propagules produced during March-April months. Propagules produced during December-January recorded success of 16.88 per cent, followed by September-October (10%) and lowest success was recorded in propagules produced during June-July period (1.88%).

Irrespective of the season of grafting, approach grafting recorded highest success percentage (25.63%) followed by veneer grafting (21.25%) which was on par with approach grafting. Air layering recorded 16.88 per cent success while softwood grafting

recorded lowest success percentage (16.25%). Both air layering and softwood grafting were on par with veneer grafting.

Interaction effect of propagation method and season of grafting on success percentage of propagules was highly significant. Among the different treatment combinations, veneer grafting recorded highest success of 70 per cent during March-April, which was on par with softwood grafting (65%) and approach grafting (60%) done during the same period.

There was no success recorded in softwood grafts prepared during June-July, September-October and December-January even though the grafts sprouted successfully. Similarly, in case of veneer grafts produced during June-July and September-October had zero success. Air layers produced during June-July recorded zero success even though there was successful rooting. Patch budding was a complete failure in all seasons.

Softwood grafting recorded success only during March-April which was 65 per cent. Veneer grafting recorded maximum success of 70 per cent in March-April and a success of 15 per cent was recorded in December-January.

An analysis of weather data with the success percentage revealed interesting results. The maximum success in veneer grafting, softwood grafting and approach grafting were obtained within the monthly mean maximum temperature range of 33-36.7^{O}C. This appears to be the specific temperature required for successful graft union under Thrissur condition. The monthly mean minimum temperature was nearly constant throughout the year.

Success was noticed in softwood grafting and veneer grafting when the relative humidity was in the range of 60-65 per cent. Rainfall was another very important parameter which played significant role in success of grafting. In veneer grafting and softwood grafting, the success and survival was noticed only in the months of zero precipitation, whereas approach grafting recorded maximum success of 25-60 per cent during zero precipitation month and 7.5-10 percent success during 290-790 mm rainfall. Sunshine hours expressed more influence on veneer and softwood grafting compared to air layering and approach grafting. Sunshine in the range of 7-10 hours is ideal for softwood and veneer grafting.

The unique flood of 2018 in Kerala with a monthly rainfall of above 500 mm caused complete leaf fall of the air layers and approach grafted plants along with complete

leaf fall of trees. Trees recovered after heavy rains by producing new flush, but the air layered and approach grafted shoots along with rootstocks failed to recover after the receding of heavy rains, which lead to higher mortality of grafts and layers prepared during rainy season.

It can be concluded that veneer grafting or softwood grafting can be adopted during March-April for higher success and survival of grafts in tamarind in the central part of Kerala.

Future line of work

Presence of high quantum of variability observed during this study within a small population of 17 genotypes produced 10 unique clusters based on yield related components. So following work can be taken up in the future.

- Survey of whole state of Kerala to record undocumented elite genotypes for climate smart agriculture.
- Molecular characterization of genotypes.
- Biochemical characterization of genotypes to identify nutritionally rich genotypes.

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APPENDIX I

Month	Temperature						RH (%)			Rainfall (mm)			Sunshine hours		
	Min (°C)			Max (°C)											
	2017	2018	2019	2017	2018	2019	2017	2018	2019	2017	2018	2019	2017	2018	2019
January	22.9	20.9	20.4	34.1	33.5	32.9	53	55	55	0.0	0.0	0.0	7.6	8.2	8.4
February	23.3	23.2	23.4	36.0	35.7	35.3	51	58	59	0.0	0.0	0.0	8.7	9.5	8.7
March	24.7	24.0	24.8	36.1	36.7	36.7	67	66	65	13.2	5.2	0.0	7.4	8.4	8.6
April	26.0	24.8	25.5	35.7	36.1	36.2	70	69	70	19.1	28.9	76.4	6.5	7.3	8.3
May	24.9	22.6		34.6	33.2		72	79		167.5	483.6		5.5	4.8	
June	23.5	23.2		30.4	29.8		87	89		630.2	730.0		2.0	1.7	
July	22.8	22.5		30.8	29.6		85	88		385.5	793.2		2.9	1.9	
August	23.3	22.5		30.1	29.2		87	87		470.0	928.0		3.1	2.2	
September	22.9	22.5		31.5	32.2		84	75		413.9	290.0		4.2	7.2	
October	22.3	22.9		31.7	32.8		81	76		183.4	393.0		4.9	5.7	
November	21.8	23.3		33.0	32.7		73	68		58.3	66.6		6.4	6.9	
December	21.1	22.5		32.4	33.0		63	63		11.5	0.0		7.3	7.3	

MORPHOMETRIC EVALUATION AND PROPAGATION STUDIES IN TAMARIND (*Tamarindus indica* L.)

By

SHANKARPRASAD K. S.

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ABSTRACT OF THE THESIS

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COLLEGE OF HORTICULTURE

VELLANIKKARA, THRISSUR- 680656

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ABSTRACT

The present study was carried out at the Department of Plantation Crops and Spices, College of Horticulture, Kerala Agricultural University, Thrissur, during 2017-2019. Seventeen bearing tamarind trees from the KAU main campus were selected for the study after preliminary survey and GPS coordinates were recorded for generating passport data. These accessions were observed for various qualitative and quantitative characters *viz.,* tree growth habit, leaf, flower and fruit characters and biochemical parameters. Ten out of 17 selected accessions were regular yielders. Upright (47.06%), semi-spreading (41.17%) and spreading (11.77%) types of growth habits were observed.

The flower initiation was observed from last week of March to the second week of May. Early flowering was noticed in accession KTI-13 and late flowering in accession KTI 6 and Acc. KTI 8. The average panicle length ranged from 7.8 cm (KTI-6) to 32 cm (KTI-17). Flowers were observed for qualitative and quantitative characters. Characters like bract colour and bracteole colour expressed higher variability among the accessions than the other characters. The bract colour varied from deep pink to pale green. Average corolla spread ranged from 2.17 cm to 3.27 cm among the selected accessions.

Wide range of variability was expressed in pod characters and biochemical composition. The average pod length was highest in Acc. KTI-16 (19.22 cm). Acc. KTI-10 recorded highest average fruit weight (26.60 g) followed by Acc. KTI-16 (23.64 g). The number of fruits per unit area of the canopy ranged from 2.83 to 9.83 among the selected accessions. Highest pulp: seed ratio was recorded in Acc. KTI-7 (1.9) while the lowest was recorded by Acc. KTI-15 (0.87). High variability was also noticed in biochemical composition of pulp like titratable acidity (7.79 to 21.94 %), TSS (55 to 70 ^{o}Brix) and Vitamin-C (11.17 mg to 18.91 mg per 100g). Accession KTI-12 recorded highest tartaric acid, Acc. KTI-3 recorded highest TSS and Acc. KTI-17 recorded highest Vitamin-C.

Correlation study revealed extent of association among pod and flower characters. Highly positive and significant correlation was observed between pulp content and corolla spread. Pod length exhibited highly significant positive correlation with fruit weight. Principal component analysis of yield attributing characters like number of fruits per unit area, pod length, pod girth, pod weight, pulp weight, pulp content, seed weight and number of seed per pod grouped accessions into nine clusters. Accession KTI-13 and

accession KTI-17 which were members of Cluster VII were marked as outstanding in terms of higher fruit yield per unit area of canopy and these accessions can be utilized for further breeding programmes.

Five propagation methods were evaluated during four seasons under the agro climatic situation of Thrissur district. The success per cent at 90 days after grafting was highest (51.25%) for the grafting done during March-April months irrespective of propagation methods. During this period a minimum temperature of 24°C and maximum 36°C with mean monthly relative humidity 66 per cent, monthly mean rainfall of 5.2 mm and sun shine of 8.4 hours were observed. Patch budding was total failure in all the seasons studied. Among the different propagation techniques approach grafting recorded overall success of 25.63 per cent irrespective of season and success per cent in veneer grafting was on par (21.25%). Considering the interaction effect, veneer grafting recorded highest success of 70 per cent during March-April and percent success in softwood grafting (65%) and approach grafting (60%) carried out during the same period were on par with veneer grafting. Veneer grafting and softwood grafting were found superior than all other methods of propagation when grafted in the month of March-April.