MORPHO-PHYSIOLOGICAL DIVERSITY ASSESSMENT OF *GARCINIA GUMMI-GUTTA* (L.) ROBS. GERMPLASM COLLECTION

By

KAVYA SHREEPAD RAYSAD

(2014-17-114)

THESIS

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DECLARATION

I hereby declare that this thesis entitled **"Morpho-physiological diversity assessment of *Garcinia gummi-gutta* (L.) Robs. germplasm collection"** is a bonafide record of research done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society.

Vellanikkara

Date: 07-11-2016

Kavya Shreepad Raysad

(2014-17-114)

Dr. A. V. Santhoshkumar
Professor and Head
Department of Tree Physiology and Breeding
College of Forestry
Kerala Agricultural University
Vellanikkara, Thrissur, Kerala

Date: 07-11-2016

CERTIFICATE

Certified that this thesis, entitled **"Morpho-physiological diversity assessment of *Garcinia gummi-gutta* (L.) Robs. germplasm collection"** is a record of research work done independently by **Kavya Shreepad Raysad (2014-17-114)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

Dr. A. V. Santhoshkumar
Chairman
Advisory Committee

Vellanikkara
7/11/16

CERTIFICATE

We, the undersigned members of the Advisory Committee of **Ms. Kavya Shreepad Raysad (2014-17-114),** a candidate for the degree of **Master of Science in Forestry,** agree that this thesis entitled **"Morpho-physiological diversity assessment of *Garcinia gummi-gutta* (L.) Robs. germplasm collection"** may be submitted by her in partial fulfillment of the requirement for the degree.

Dr. A. V. Santhoshkumar
Professor and Head,
Department of Tree Physiology and Breeding
College of Forestry,
Kerala Agricultural University,
Vellanikkara, Thrissur.
(Major advisor)

Dr. Latha, M.
Senior Scientist,
National Bureau of Plant Genetic Resources,
Vellanikkara, Thrissur.
(Member)

Dr. S. Gopakumar
Professor,
Department of Forest Management and Utilisation,
College of Forestry,
Kerala Agricultural University,
Vellanikkara, Thrissur.
(Member)

Dr. Jiji Joseph
Professor
Department of Plant genetics and Breeding,
College of Horticulture,
Kerala Agricultural University,
Vellanikkara, Thrissur.
(Member)

Mr. Jijeesh C. M.
Assistant Professor
Department of Silviculture and Agroforestry
College of Forestry,
Kerala Agricultural University,
Vellanikkara, Thrissur.
(Member)

07/11/16
EXTERNAL EXAMINER
Dr Kannan C.S. Warrier
Scientist E
IFGTB
Forest Campus
Coimbatore 641 002

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Dedicated to my parents

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Introduction

1. INTRODUCTION

Garcinia gummi-gutta (L.) Robs. commonly known as Malabar tamarind and *'kodampuli'* in Kerala is small indigenous, tropical, under-exploited fruit crop, belonging to family Clusiaceae (Guttiferae). The tree is native to South India and South Asia bears a small, sweet exotic fruit. This is one of the economic fruit trees, yielding fruits having much commercial potential as condiment and at same time having high medicinal value.

The tree is found commonly in the evergreen forests of Western Ghats of India from Konkan to Kerala and in the shola forests of Nilgiri hills up to an altitude of 2000 (George, 1998). Malabar tamarind trees are grown widely in the home gardens of Kerala with one or a few bearing trees in the homesteads (Abraham *et al.,* 2006). However, its potential remains unexploited as the tree is not generally cultivated at an orchard level and is often seen neglected as a miscellaneous tree crop in the backyards of homesteads. The Malabar tamarind is androdiocecious in nature with separate male and hermaphrodite trees (George *et al.,* 1992). The tree flowers during the beginning of summer (January-February) and matures in another 5 months (Muthulakshmi and Sara, 1999).

The fruit is round in shape with ridges. Rind is the economic part of the fruit. In Kerala, *G. gummi-gutta* has been traditionally used in fish curries for imparting its delicate flavour and also used in polishing gold, silver and coagulating rubber latex (Singh, 1993). Dried rind fetches a high price of about Rs. 200 kg^{-1} (Ajayghosh, 2007). The medicinal property of rind further increases its economic importance. Since acidic in nature, the fruit possess marked antiseptic properties also. The decoction is useful in rheumatism, bowel complaints. The fruit is also employed in veterinary medicine as a rinse for mouth disease in cattle (Raju and Reni, 2011).

The seeds of *G. gummi-gutta* yield edible fat rich in oleic acid and resemble kokum butter (Verghees, 1991). The yellow gum resin occurring in the bark makes good varnish. The timber, which is not good for construction work, is used for manufacturing matches and splints. The dried fruit is used as substitute for acetic acid in polishing gold, silver and brass.

In Kerala, scientific cultivation of the crop is not practiced anywhere. There are many intrinsic factors associated with *G. gummi-gutta* that makes the plant unsuited for commercial cultivation. The major reason is difficulty in recognizing the sex of the plant. The seedlings segregate into productive female and unproductive male trees. Seedling takes about seven to eight years to reveal its identity (Nazeema, 1992). *G. gummi-gutta* available in Kerala are all seedling origin with cross pollination and hence lot of variability is seen with respect to size of the tree, bearing age, flowering and ripening season, fruit size, shape and colour, rind recovery, yield and (-)-HCA content (Soni *et al.*, 2004).

Normally, the germination period of Malabar tamarind seeds are more than one year if they are sown immediately after harvest. This is because of the long term dormancy exhibited by the seeds (KAU, 2001). So in commercial nursery there is great problem in getting the seeds of Malabar tamarind germinated both for seedling production and root stock multiplication.

Knowledge about the variability of a crop is an important aspect that decides the success of plant breeding programme. Hence, exploration of crop variability is a prerequisite for making improvement in the crop through plant breeding and for commercial exploitation of the crop. The current study was aimed to assess the morphological and biochemical variability existing in different accessions of hermaphrodite Malabar tamarind in the orchard of National Bureau of Plant Genetic Resources, Regional Station, Vellanikkara.

Review of Literature

2. REVIEW OF LITERATURE

The relevant literature on the study entitled "Morpho-physiological diversity assessment of *Garcinia gummi-gutta* (L.) Robs. germplasm collection" is briefly reviewed here. Wherever sufficient literature is not available on the fruit or the product tried in this experiment, results of experiments conducted on related fruits or the products are also cited.

2.1. *Garcinia* genus

Garcinia is a large genus of family *Clusiaceae (Syn: Guttiferae)* which consists of over 35 genera and 800 species. The genus name was proposed in honour of a French botanist Dr. Laurent Garcin, who served in the Dutch Indies company in India (Glen, 2004). Trees belonging to this genus are commonly known as sap trees, mangosteens, garcinias or popularly as monkey fruit (Yapwattanaphum *et al.,* 2002). *Garcinia* consists of over 200 species distributed in the tropics of the world, chiefly in Asia, Africa, and Polynesia. They are evergreen polygamous trees, shrubs and herbs. About 35 species are reported to exist in India, 17 of which are endemic and economically important, with immense medicinal properties (Praneetha and Balamohan, 2014) Among this, seven are endemic to the Western Ghats, six in the Andaman and Nicobar Islands and four in the North Eastern region of India (Peter and Abraham, 2007).

Parthasarathy and Nandakishore (2014) reported that some species like *G. cambogia, G. indica*, and *G. cowa* are cultivated in certain parts of India. *G. pedunculata, G. kydia, G. cowa,* and *G. lanceaefolia* are the most important species in North Eastern parts of India. Many species of *Garcinia* have fruit with edible arils and are eaten locally. The best known species is the *G. mangostana*, which is now cultivated throughout Southeast Asia and other tropical countries.

Table 1. List of *Garcinia* species found in India

Sl. No.	Species	Distribution	References
1	*G. anomala*	Khasi hills	Haldankar *et al.*, 2015
2	*G. assamica*	A newly identified species from North East India.	Sarma, *et al.*, 2016
3	*G. atrovidis*	Assam	Haldankar *et al.*, 2015
4	*G. cowa*	Indigenous to east India (Assam, Mizoram, Bengal, Bihar and Orissa). Also found in Andaman Nicobar.	Lim, 2012
5	*G. echinocarpa*	Thirunelveli forests	Anandaraj *et al.*, 2015
6	*G. hanburyii*	South India	Anandaraj *et al.*, 2015
7	*G. hombroniana*	Nicobar Islands. It is cultivating in Kerala and Tamil Nadu	Lim, 2012
8	*G. imbertti*	S. India	Anandaraj *et al.*, 2015
9	*G. indica*	Western Ghats, Coorg, Wynad, coastal Maharashtra, Goa	Haldankar *et al.*, 2015
10	*G. mangostana*	Native to Thailand. Introduced in India and Sri lanka	Lim, 2012
11	*G. malabarica*	S. India	Anandaraj *et al.*, 2015
12	*G. morella*	Assam, Khasi Hills, Western Ghats	Anandaraj *et al.*, 2015
13	*G. nervosa*	Indigenous to peninsular Malaysia, Sumatra, Borneo and Phillipines. It is also found in Nicobar islands	Lim, 2012
14	*G. nigrolineata*	Eastern India	Sarma, *et al.*, 2016

15	*G. pushpangadaniana*	A newly identified species from Southern Western Ghats, found in Kerala and Tamil Nadu	Sabu, *et al.* 2013
16	*G. spitcata* Hook	Tree is indigenous to India and Sri Lanka	Lim, 2012
17	*G. succifolia* Kurz	S. India	Anandaraj *et al.*, 2015
18	*G. travancorica*	Western Ghats	Anandaraj *et al.*, 2015
19	*G. wightii*	S. Indian Forests, vulnerable	Anandaraj *et al.*, 2015
20	*G. xanthochymus*	Eastern Himalayas, Western Ghats, Andaman islands, Assam and Meghalaya	Anandaraj *et al.*, 2015

2.2. *Garcinia gummi-gutta:* An overview

G. gummi-gutta is a tropical under-exploited, semi-domesticated crop commonly called as brindle berry, Malabar tamarind, or pot tamarind (Kumar *et al.*, 2015). It is small to medium-sized tree and horizontal or drooping branches which are orthotropic and plagiotropic. Trees are 5 m to 20 m tall, about 70 cm DBH, with dark, smooth, lactiferous bark (Lim, 2012). It yields fruit that resembles small pumpkin and is green to pale yellow in colour (Kumar *et al.*, 2015).

2.2.1. Distribution

Malabar tamarind found commonly in the evergreen forest of Western Ghats of India from Konkan southwards to Travancore and shola forests of Nilgiris up to an altitude of 2000 m. The tree is reported to be a native of India (George *et al.*, 2002). It is also seen in Malaysia, Assam and Sri Lanka (Seidemann, 2005). In its natural habitat, the species occur as an understory tree in the lowland tropical rainforests in the wet and intermediate zones up to 1,800 m. It thrives on deep, well-drained slightly

acidic soil such as clayey loams and abhors calcareous soils (Lim, 2012). It prefers a warm humid tropical climate commonly seen in the coastal areas, evergreen forests and up to 1800 MSL in Nilgiris. Alluvial soils are the best for its cultivation (Sara *et al.,* 2002) and dry areas are not suitable (Mathew *et al.*, 2008).

According to Lim, (2012) and Abraham *et al.,* (2006) population size of male and female/hermaphrodite trees of Malabar tamarind exist mostly as natural populations in the forests of south Maharashtra, Goa, Karnataka, Kerala and Tamil Nadu. Sometimes, it is grown in farmer's field as single trees in homestead gardens of Kerala. Natural populations comprised only 5–10 percent of male trees. Some of the female trees are more than 100 years old and still fruiting profusely (Abraham *et al.,* 2006).

2.2.2. Propagation

Maheshswari (1964) states that thirty one species of *Garcinia* occur in India but most of these are under exploited. Most of these tropical fruit species show dormancy, *G. mangostana* being an exception (Normah *et al.,* 1997). In many *Garcinia* spp. prolonged dormancy is a limiting factor for large scale generation of planting material. Even though *Garcinia* spp. can be propagated by seeds, these are androdioecious (George *et al.,* 1992). Thus softwood grafting technique has been standardized to overcome the dioecious nature of *Garcinia* (KAU, 2002). For grafting, either its own seedlings or that of closely related species likes G. *cowa.* or *G. tinctoria* can be used as root stocks. Prolonged seed dormancy of *Garcinia* spp. causes delay in rootstock production and timely grafting. In case of *G. gummi-gutta,* seeds have a dormancy period of 8 to 9 months and on removal of seed coat, germination occurs within 2 months of sowing (KAU, 2001). But it is laborious and time consuming when done on a commercial scale (Joseph *et al.,* 2007). In *G. gummi-gutta* planting is usually done at 6x6 m distance. The seedlings start flowering 7 to 8 years of planting whereas in grafted plants starts flowering after 3-4 years (Tripathi *et al.,* 2015).

2.2.3. Utilization

G. gummi-gutta is a multipurpose tree grown in the home gardens of Kerala which is used as a condiment and garnish. Resin of Malabar tamarind is used as a pigment in miniature paintings and water colours (Singh, 1993). In North Eastern India, the sundried slices of the fruits are used for culinary purposes and as folk medicine (Parthasarathy *et al.,* 2013; Lim, 2012). In Kerala, rind is used in fish curries for imparting the unique delicate flavor (Muthulakshmi and Sarah, 1999). Fruit rind is hydragogue, anthelmintic and emetic, particularly in dropsies. It is employed in veterinary medicine as a rinse for diseases of mouth in cattle. It is also used for polishing gold and silver ornaments and as a substitute for acetic acid for coagulation of rubber latex. The seed oil is used in preparation of medicine and the gum makes a good varnish (Singh, 1993; Raju and Reni, 2001).

The seeds of *G. indica* fruits yield valuable edible fat known as kokum butter used in the preparation of confectionery, medicines and cosmetics in India. It has been used historically as a remedy for diarrhoea and dysentery in Ayurvedic medicine, and it is even used in cooking and baking to add a tart flavouring. It has non-greasy moisturizing properties that are being used in many cosmetics, creams, conditioners and soaps (Parthasarathy *et al.,* 2012).

In 1965, a pharmaceutically active ingredient (-)-hydroxy citric acid (-HCA) has been identified from the dried rind of *Garcinia* species. This has been shown to reduce obesity by accelerating fat burning and inhibit fatty acid synthesis. It is considered as one of the major non-wood forest produces in the Western Ghats (Hegde *et al.,* 2010; Soni *et al.,* 2004).

2.2.4. Pest and diseases

Muthulakshmi, *et al.*, (2000) reported that there is no severe pest or disease incidences in *G. gummi-gutta* aside from minor incidence of leaf spot, leaf blight and

fruit rot. Occurrence of gamboge a physiological disorder observed in fruits harvested during the rainy season, whereas early flowering trees are almost free of gamboge incidence.

2.3. Variability in the general tree characters

G. gummi-gutta is an evergreen, small to medium-sized tree with horizontal or drooping branches which are orthotropic and plagiotropic (Muthulakshmi, 1998; Lim, 2012). Trees are 5-20 m tall, about 70 cm DBH, with dark smooth, lactiferous bark. Tree canopy shapes are hemispherical, round, conical or pyramidal in *G. gummi-gutta*. But majority of the trees are conical shape (Muthulakshmi, 1998). Muthulakshmi *et al.*, (2000) also reported that dome-shaped trees are high yielding due to the huge canopy resulting from the receipt of more sunlight leading to the production of more fruiting branches.

2.4. Variability in leaf characters

In Malabar tamarind leaves are dark green, shining, simple and opposite (Thomas, 1965; Tripathi *et al.*, 2015; Lim, 2012).The leaf shape varies as oblong, obovate, oblanceolate and lanceolate (Muthulaksmi, 1998). The leaf lamina length varies from 5 to13 cm, breadth from 2.5 to 7.5 cm and petiole length 2.5 to 16 cm respectively (Tripathi *et al.*, 2015).

Sherly (1994) opined that in *G. cambogia,* the colour of emerging leaves show marked differences among male and hermaphrodite trees. In male trees, the emerging leaves showed light green in colour, while they showed pinkish red colour in hermaphrodites.

Mathew *et al.* (1996) reported that there is significant variation in length and breadth of the leaves of male and female *G. cambogia* trees. Difference in leaf breadth

is more conspicuous than leaf length and hence leaf breadth can be taken as one of the identifying characters for distinguishing female trees from males one. There is an also wide variation in case of length, width, length/width ratio and leaf area of male and female trees (Muthulaksmi, 1998).

2.5. Time of flowering

Muthulakshmi (1998) reported that in *G. gummi-gutta* male trees flower from December to March while peak flowering season in bisexual trees are from February to March. The duration of flowering reported shorter in bisexual trees i.e., about 2 to 3 months. According to sherly (1994), in *G. gummi-gutta* flowering seasons ranges from January to April, where as in *G. indica* tree flowers in November (Uthaia *et al.*, 2014). The *G. lanceaefolia* tree flowers from March to May (Baruah and Borthakur, 2012). According to Tripathi *et al.*, (2015) the flowering in mangosteen and *G. gummi-gutta* starts in March-April, where as in *G. xanthochymous* flowering takes place in May to June (Baruah and Borthakur, 2012).

2.6. Variability in flower characters

Lim (2012), Tripathi *et al.*, (2015), George (1988), and Sherly (1994) reported that Malabar tamarind tree is androdioecious exhibiting male and bisexual. Flower are borne in the axils of leaves or on tip of branches either solitary or in groups.

In Malabar tamarind, trees produce 10 to 40 male flowers as bunches that falls off quickly. The pedicel is longer and flower has 40 to 80 fertile stamens that are monoadelphous (Tripathi, *et al.*, 2015). In female/bisexual plants stamens are 6 to 20 and mostly sterile, arise around the ovary in a ring. Ovary is superior, globular, grooved with 6 to10 carpel with a single ovule in each. Stigma is sessile (Tripathi *et al.*, 2015; Lim, 2012; Songklanakarin, 2007).

Male flowers have long stalk, numerous stamens united at base forming ring and shows variation in length and colour. The stalk length varies from 22.9 to 10.9

mm. Female flower may be stalk less, small stalked measure 2.5 mm or long stalked measure 11.63 mm (Abraham *et al.,* 2010). The petals of the flowers on both male and bisexual varies in colour such as pink, cream, pinkish cream and yellow. Mean length of petal in the flower of bisexulal tree is 0.3 to 0.8 cm, where as in male from 0.3 to 0.5 cm (Muthulakshmi, 1998). However, the mean petal length in mangosteen is 2.43 cm and breadth 2.80 cm (Alex, 1996).

Songklanakarin (2007) reported that female flowers are solitary and occur singly or occasionally in clusters (2 to 3) in mangosteen, *G. speciosa,* and *G. atroviridis,* but clusters of 6 to10 flowers are usually found in *G. dulcis*. The flowers develop at the terminal buds of young branches in case of mangosteen; whereas in the other species, the flowers develop at both terminal and auxiliary buds.

2.7. Variability in fruit characters

The fruit is spherical, as large as a small orange, having 5–8 seeds compressed in an acid pulp (Raju and Reni, 2001). Muthulakshmi (1998) reported that after flowering, *G. gummi-gutta* tree takes three weeks for fruit set and the fruit takes 120 to 135 days to ripen which coincides with the rainy season (June-July), where as in *G. indica,* fruits ripen in April to May or June (Uthaia *et al.,* 2014) and in *G. lanceaefolia* fruiting starts from October to February (Baruah and Borthakur, 2012).

Tripathi *et al.,* (2015) noted that in *G. cambogia,* number of ridges per fruit varies from 6.6 to 10.2 and horizontal fruit diameter varies from 3.8 to8.4 cm. Variations in shape like ovoid or spherical were also observed. Fruits contain 7 to10 seeds surrounded by a succulent white or red aril which is edible, sweet or acrid. Abraham *et al.,* (2006) reported variation in Malabar tamarind fruit length from 43 to 82 mm and fruit girth from 122 to 217 mm. According to Tripathi (2015), the fruit length ranges from 54 to 78 mm and fruit breadth ranges from 48 to 71.5 mm.

2.7.1. Fruit weight

According to Hegde *et al.*, (2010) fresh fruit weight of Malabar tamarind varies from 30.1 to115.8 g, fresh weight of rind ranges from 24.1 to 89.9 g and number of seeds per fruit from 2.8 to 7.6. However, according to Kumar *et al.*, (2015) fruit weight in *G. gummi-gutta* ranges between 60.34 to 147.55 g, while fruit length ranges from 5.4 to 7.8 cm and fruit breadth varies from 4.8 to 7.15 cm. They also reported that, the thickness of rind ranges from 1.0 to 1.3 cm and rind weight from 72.1 to 92.8 g.

In case of kokum, fresh weight of fruit varies from 16.24 to 51.00 g, rind weight from 9.4 to 26.22 g and number of seeds per fruits from 2.6 to 7.0. According to Abraham *et al.*, (2010) fresh fruit weight in kokum varies from 13.3 to 200 g and fresh seed weight ranges from 0.9 to 2.4 g. However, Patil and Kattimani (2009) opined that in kokum highest rind weight is 17.87 g. Similar studies on *G. pedunculata* and *G. xanthochymus* done by Sharma *et al.*, (2015) and they concluded that fresh fruit weight and rind weight is 460.49 g and 57.26 g respectively.

2.7.2. Fruit yield

According to Sherly (1994), yield per tree in Malabar tamarind varies from 8.13 to 130.80 kg. However, Muthulakshmi (1998) concluded that dome shaped trees in *G. cambogia* yields more fruits than other category. Thomas (1965) opined that fully grown tree yields 127 to 154.02 kg. According to Muthulakshmi, *et al.*, (1998), in Malabar tamarind yield ranges from 50 to 600 kg.

Bhat *et al.*, (2010) opined that average yield of fruits among individual trees of *G. cambogia*, *G. indica* and *G. morella* are highly variable. When yield of them is compared with the yield of ten years later then, in case of *G. indica* the difference in yield between the years was not significant. While in case of *G. indica* and *G. morella* it was significant. When annual average yield was compared with the mean yield of

ten years, the annual fruit yield fluctuated around the mean fruit yield of ten years. However in all three species higher yield was observed every alternative year.

2.8. Seed characters

Abraham *et al.*, (2006) reported that in *G. gummi-gutta* seed number per fruit varies from 2 to 8, seed length and seed width ranges from 15.6 to 35.0 mm and 7.9 to 33.0 mm respectively. They also reported that seed weighed between 0.9 to 2.4 g and were having thickness between 4.3 to 9.0 mm.

2.8.1. Germination percentage

Malabar tamarind fruits ripe in monsoon season (Haldankar *et al.,* 2015). The seeds remain dormant for about 8 to 9 months and takes 10 months for germination, if sown with seed coat. Removal of seed coat without injury to cotyledon helps for germination in 20 to 25 days. Mathew and George (1995) opined that Malabar tamarind seeds take more than one year for germination, if they are sown soon after harvest and as the storage time increases, the time taken for germination decreases. Joseph *et al.,* (2007) reported that seed germination can be significantly improved by pre-treatment with H_2O_2, kinetin or cow milk instead of the laborious and time consuming process of seed coat removal. They also mentioned that germination of Malabar tamarind treated by GA 250 ppm recorded highest germination percentage.

According to Chacko and Pillai (1997), the seed coat removal before sowing, advances germination and enhances cumulative germination from 50 to 90 percent. The viable seeds with a moisture content of 41.65 percent fail to germinate on drying to 33.4 percent, which is an indicative of the recalcitrant nature of the seed.

Germination studies conducted by Joseph *et al.*, (2007) on *G. gummi-gutta* and *G. cowa* showed that soaking seeds in hydrogen peroxide (30%) for 30 min and overnight soaking in cow milk and kinetin (500 ppm) are effective in breaking the dormancy of seeds and results in 60.05 percent, 39.96 percent and 34.41 percent

germination respectively in *G. gummi-gutta* and 65.33 percent, 69.33 percent and 54.67 percent germination in *G. cowa* at 7 months after sowing.

Studies by Joshi *et al.* (2006) reported that the seeds of *G. gummi-gutta* follow *Garcinia* type of germination, in which the primary root and shoot emerge from the opposite ends of the seed. Embryo which fills up the seed is elongated hypocotyls with vasculature connecting two poles. Any seed fragment that contain vasculature produces a root and shoot irrespective of its size and position with precise polarity and a seed from which a seedling has germinated capable of producing another seedling.

2.9. Primary metabolites

Primary metabolites have an important role in survive of the species, playing an active function in the photosynthesis and respiration. It involved directly in growth and metabolism (Irchhaiya *et al.*, 2015).

2.9.1. Total carbohydrates

Carbohydrates are the major nutrients in fruits which are primary energy source of a cell and are simplest biomolecules synthesized naturally (Ting, 1956). According to Parthsarathy and Nandakishore (2014), total carbohydrates in *G. mangostana* (15.12 g/100 g) is high compared to *G. gummi-gutta* (6.46 g/100 g), *G. indica* (5.67 g/100 g) and *G. subelliptica* (4.38 g/100 g). Tripathi, *et al.*, (2015) stated that in mangosteen, edible portion contains 14.3 to 15.6 g/100 g carbohydrate, where in kokum rind it is 36.4 percent. Martinez *et al.*, (2002) reported that in cultivated fruits such as mango (11.9 g/100 g), passion fruit (6.5 g/100 g) and pineapple (14.4 g/100 g) are rich in carbohydrates. However even higher level of carbohydrates presented in *Rubus ellipticus* (86.4 g/100 g) and *Rubus niveus* (85.35 g/100 g) are reported by Ahmad *et al.*, (2015).

2.9.2. Reducing sugar

Reducing sugars are the simplest carbohydrate molecules like glucose and fructose having free aldehyde or ketone group and can reduce metal ions to lower oxidation state, usually provide sweetness to fruits (Ting, 1956). According to Parthsarathy and Nandakishore (2014) reducing sugars in *G. gummi-gutta* (0.51 g/100 g), *G. indica* (0.63 g/100 g) and *G. kydia* (0.60 g/100 g) are almost similar. However Sherly (1994) reported it to be 1.04 percent in rind of kodumpuli, while George (1988) reported it as 4.15 percent. Mahapatra *et al.,* (2012) investigated nutritional status of wild fruits and found higher reducing sugar in *Solanum torvum* (3%) compare to *Mimusops elengi* (0.8 %), *Phyllanthus acidus* (0.04%) and *Ziziphus rugosa* (0.58%).The Patil *et al.*, (2010) studied nutrient contents in carambola fruit at different ripening stage and they observed the increase in reducing sugars content from 0.33 percent in young to 1.32 percent in ripe fruits. Similar study was done by Othman and Mbogo (2009) in two varieties of mango and observed that fully ripened mangoes have highest content of reducing sugars compare to unripened and half ripened. Thakur (2013) found 11.94 percent reducing sugar in *Artocarpus hirsutus* fruits. In wild pomegranate fruits collected from different locations reducing sugar varied from 6.8 percent to 7.75 percent (Thakur, *et al.,* 2011).

2.9.3. Total protein content

Plant proteins are the source of several essential amino acids which human cells cannot biosynthesize (Jain, *et al.*, 2005). Tripathi, *et al.,* (2015) confirmed that the crude protein content in edible portion of mangosteen varied from 0.50 to 0.60 g/100 g, where as in kokum rind it was 1.92 percent. Parthsarathy and Nandakishore (2014) concluded that there is similarity in protein content between *G. indica* (4.78 g/100g) and *G. kydia* (4.33 g/100 g). Almost same range of protein was reported by Ahmad *et al.,* (2015) in *Rubus ellipticus* (4.37 g/100 g) and *Rubus niveus* (3.28 g/100 g). Patil *et al.*, (2010) studied nutrient contents in carambola fruit at different ripening

stage and they observed the increase in protein content from 0.65 percent in young to 0.85 percent in ripe fruits. Bhaskar and Shantaram (2013) reported very low amount of protein presented in *Averrhoa bilimbi* (0.9 g/100g) and *Averrhoa carambola* (1.53 g/100 g). However, Martinez *et al.,* (2002) were of the opinion that protein content in commonly cultivated fruits such as mango (8 g/100 g), passion fruit (6.2 g/100 g) and pineapple (4 g/100 g) are high.

2.9.4. Crude fat content

Fats are hydrocarbon molecules and second largest energy source for living cells. In plants, fats are the storage form of energy and found much abundant in seeds (Jain, *et al.,* 2005). Parthsarathy and Nandakishore (2014) reported very low amount of crude fats in fruit rind of *G. gummi-gutta, G. xanthochymus* and *G. kydia* (0.34 g/100 g, 0.41 g/100 g and 0.42 g/100 g respectively). According to Ramachandran (2014), in *G. indica* fat content was 1.4 g/100 g fresh weight. However Tripathi, *et al.,* (2015) opined that mangosteen edible portion contains 0.1 to 0.6 g/100 g, where as in kokum rind it was 10%. Furthermore, same percent of fat in kokum was reported by Swami *et al.,* (2014). Similar study of Martinez *et al.,* (2002) concluded that cultivated fruits like mango, passion fruits, pineapple and guava have very low amount of fat. The study conducted by Ahmad *et al.,* (2015) revealed the fat content in *Rubus ellipticus* and *Rubus niveus* were 2.73 g/100 g and 1.1 g/100 g respectively. In case of *G. pedunculata* and *G. xanthochymus* it was 0.44 percent and 7.57 percent respectively (Sharma *et al.,* 2015). However, very low amount of fat was reported in *Averrhoa bilimbi* (0.27 g/100g) and *Averrhoa carambola* (*0.32g*/100g) by Bhaskar and Shantaram (2013).

2.10. Minerals

Mineral ions are of prime importance in determining the nutritional value of fruit, major ones being potassium, calcium, and iron. The importance of minerals like potassium, calcium, sodium etc. to human health is well known. Required amounts of

these elements must be in human diet to pursue a good healthy life (Cristina *et al.*, 2014).

2.10.1. Phosphorus

Phosphorus is a component of nucleic acids and as phosphate esters plays an important part in the cellular metabolism (Gopalan *et al.*, 1994). The study by Thakur (2013) on *Artocarpus hirsutus* concluded that seeds (69.23 to 88.57 mg/100 g) have higher P content than fruits (45.13 to 47.49 mg/100 g). Parthsarathy and Nandakishore (2014) observed fruits of different species of *Garcinia* such as *G. gummi-gutta* (5.34 mg/kg), *G. indica* (4.51 mg/kg), *G. subelliptica* (5.43 mg/kg) and *G. kydia* (4.32 mg/kg) and confirmed almost similar level of phosphorus presence. But in mangosteen, edible portion it ranged from 0.02 to 12.0 mg/100 gm (Tripathi *et al.*, 2015). According to Morabandza *et al.*, (2013) mesocarp of *G. kola* contained 59.32 mg/100 g of P. Furthermore, wild fruits such as *Ziziphus rugosa* (0.45 mg/100 g), *Flacourtia indica* (0.13 mg/100 g) and *Glycosmis pentaphylla* (0.94 mg/100 g) had very low amount of P (Valvi and Rathod, 2011). In *Elaeocarpus serratus* fruits, it was 62.80 mg/100 g (Machamma, 2015). According to Ahmad *et al.*, (2015) P in *Rubus ellipticus* and *Rubus niveus* was 1.26 mg/100 g and 1.48 mg/100 g respectively.

2.10.2. Potassium

Potassium is a major mineral involved in metabolism and proper activity of different tissues and organs of human body (Ozcan, 2004). While studying mineral content, Parthsarathy and Nandakishore (2014) observed that the potassium in *G. mangostana* (78.3 mg/100 g) was higher compared to *G. gummi-gutta* (26.6 mg/100 g), *G. indica* (44.5 mg/100 g), *G. xanthochymus* (28.4 mg/100 g) and *G. kydia* (38.7 mg /100 g). However, Morabandza *et al.*, (2013) reported that mesocarp of *G. kola* contain 31.04 mg/100 g. Very high content of K was reported by Ahmad *et al.*, (2015) in *Rubus ellipticus* (680.16 mg/100 g) and *Rubus niveus* (720 mg/100 g). Mahapatra *et al.*, (2012) concluded that wild fruits such as *Ziziphus oenoplia* (720.38 mg/100 g),

Ziziphus mauritiana (327.34 mg/100 g), *Toddalia asiatica* (599.09 mg/100 g) and *Terminalia citrine* (1460.72 mg/100 g) contain high level of potassium than popular cultivated fruits. Machamma, (2015) reported, K content in *Elaeocarpus serratus* fruit to be 331.48 mg/100g. In *Artocarpus heterophyllus*, K content ranges from 292 to 407 mg/100g (Love and Poull, 2011). According to Thakur (2013), K in *Artocarpus hirsutus* fruits varied from 287.35 to 368.76 mg/100gm in two different altitudinal zones. In case of papaya and banana K content of fruits grown at different locations in Hawaii varied from 89.7to 221.4 mg/100 g and 288.5 to 485.0 mg/100 g respectively (Wall, 2006).

2.10.3. Sodium

Sodium is the principal element which regulates acid-base balance, involved in the maintenance of osmotic pressure of the body fluids (Soetan *et al.,* 2010). According to Okwu and Josiah (2006) Na in *G. cola* was 1.72 percent. Parthsarathy and Nandakishore (2014) found almost similar level of Na between different species of *Garcinia* i.e. *G. gummi-gutta* (2.88 mg/100g), *G. Mangostana* (2.58 mg/100g), *G. xanthochymus* (2.06 mg/100 g) and *G. kydia* (2.54 mg /100g). High level of sodium was reported in *Solanum torvum* (31.98 mg/100 g), *Mimusops elengi* (52.97 mg/100 g) and *Ziziphus oenoplia (26.15* mg/100 g) by Mahapatra *et al.,* (2012). The study carried out by Jeeva, (2009) confirmed that wild fruits such as *Baccaurea sapida* (0.780%), *Eleagnus latifolia* (1.250%), *Prunus cerasoides* (3.790%) and *Spondias axillaris* (0.353%) were rich source of sodium. Sodium content in papaya and banana fruits, grown at different locations in Hawaii varied from 5.6 to 24.3 mg/100 g and 3.4 to 29.9 mg/100 g of fresh weight respectively (Wall, 2006).

2.10.4. Calcium

Calcium plays an important role in building and maintaining strong bones and also large part of human blood and extra cellular fluids (Pravina *et al.,* 2013). But in many fruit tissues calcium is believed to be an important factor governing fruit storage

quality (Lechaudel *et al.*, 2005). Parthsarathy and Nandakishore (2014) stated that different species of *Garcinia* such as *G. gummi-gutta* (12.67 mg/100 g), *G. indica* (13.21 mg/100 g), *G. xanthochymus* (13.07 mg/100 g), *G. subelliptica* (12.33 mg /100 g) and *G. kydia* (12.54 mg /100 g) contain almost similar range of calcium. Morabandza, (2013) reported low value of Ca in mesocarp of *G. kola* (4.30 mg/100 g). According to Tripathi *et al.*, (2015) Ca in mangosteen varied from 0.01 to 8.0 mg/100 g. Mahapatra *et al.*, (2012) came to the conclusion that wild fruits such as *Phyllanthus acidus* (163.22 mg/100 g), *Glycosmis pentaphylla* (88.87 mg/100 g), *Solanum torvum* (146.57 mg/100 g) and *Ziziphus oenoplia* (94.76 mg/100 g) are good source of calcium. Furthermore, in fruits of *Ficus racemosa* (928.4 mg/100 g) high content of Ca was reported by Valvi and Rathod, (2011). Thakur (2013) observed that Ca content of *Artocarpus hirsutus* fruits varied from 13.08 mg/100 g to 25.10 mg/100 g in different altitudinal range.

2.10.5. Magnesium

Magnesium is an active component of several enzymes (Soetan *et al.*, 2010). According to Parthsarathy and Nandakishore (2014) Mg in *G. gummi-gutta* (14.35 mg/100 g) was lower compared to *G. indica* (33.45 mg/100 g), *G. mangostana* (60.43 mg/100 g), *G. xanthochymus* (30.62 mg/100 g) and *G. subelliptica* (34.45 mg/100 g). However, even lower value was reported by Morabandza (2013) in mesocarp of *G. kola* (2.40 mg/100 g). The study conducted by Valve and Rathod (2011) reported that wild edible fruits such as *Grewia tiliaefolia* (402.2 mg/100 g), *Cordia dichotoma* (123.6 mg/100 g) and *Ficus racemosa* (272.9 mg/100 g) possesses high Mg value. Adeyemi and Oladiji (2009) observed Mg content of the banana kept decreasing with ripening. They opined that decrease in the level of Mg could be attributed to the conversion of chlorophyll in unripe banana to carotenoids.

2.11. Secondary metabolites

Plants produce diverse assortment of organic compounds, but majority of which do not participate directly in growth and development. These substances are traditionally referred to as secondary metabolites (Croteau *et al.,* 2000). These are economically important as flavor, drugs and fragrances, pigments, pesticides, and food additives (Hussain *et al.,* 2012). In plants it plays important role in the ability to adapt changing environmental condition as well as biotic and abiotic stresses (Mazid *et al.,* 2011). However, in recent years due to the evolving commercial importance, secondary metabolites are getting good interest in research (Hussain *et al.,* 2012).

2.11.1. Total phenolics

Phenolics in plants are generally involved in defense against ultraviolet radiation, pathogens and predators. It contributes to the bitterness and astringency of the fruit (Dai and Russel, 2010). Phenolic compounds have multiple biological effects and one of the most reported effects are antioxidant activity (Kahkonen and Hopia, 1999). They are responsible for colour of red fruits, juice and wines, also involved in flavor properties (Cheynier, 2012). According to Muthulakshmi, (1998) the total phenol content in *G. cambogia* ranged from 265 to 380 mg/100 g. The study conducted by Morabandza *et al.,* (2013) concluded that mesocarp of *G. kola* contained phenolics of 68.33 mg/100 gm. Parthsarathy and Nandakishore (2014) observed almost equal level of phenolic content between *G. xanthochymus* (4.43 g/100 g) and *G. kydia* (4.32 g/100 g). But Sharma *et al.,* (2015) reported very low amount of phenolics in *G. pedunculata* (9.44 mg gallic acid equivalent/g) and *G. xanthochymus* (31.31 mg GAE/g). Karuppusamy, *et al.,* (2011) investigated the phenolics in wild fruits such as *Ziziphus rugosa*, *Rubus ellipticus* and *Grewia tiliaefolia*, and they found 41.8 mg GAE/100 g, 72.0 mg QE/100 g and 44.1 GAE/100 g, respectively. Similar study on *Prunus avium* (265 mg GAE/100 g) of fresh weight concluded the high level phenols presence (Karlidag *et al.,* 2009). Even higher level was reported in fresh weight (584 to 788

mg/100 g) of blackberry (Yilmaz *et al.*, 2009). Another study by Ikram *et al.*, (2009) reported the occurrence of phenolic content in *Psidium guajava* as 31.1 mg GAE/100 g and *G. atroviridia* as 29 mg GAE/100 g.

2.11.2. Total flavonoids

Flavonoids are polyphenols, widely distributed in plants (Rashidi *et al.*, 2010). They can act as potent antioxidants and metal chelators; also have long been recognized to possess antiinflammatory, antiallergic, antiviral, and anticarcinogenic activities (Tapas *et al.*, 2008; Okwu and Josiah, 2006). In plant systems flavonoids help in combating oxidative stress and act as growth regulators (Kumar and Pandey, 2013). According to Sharma *et al.*, (2015) *G. pedunculata* and *G. xanthochymus* possessed 50.607 and 313 mg quercetin equivalent/g of extract respectively. Karuppusamy, *et al.*, (2011) studied the flavonoids in wild fruits such as *Ziziphus rugosa* (41.8 mg QE/100 g), *Rubus ellipticus* (86.4 mg QE/100g) *Grewia tiliaefolia* (47.1QE/100 g) and *Mahonia leschenaultia* (95.5 mg QE/100 g) and concluded that wild fruits are also good source of antioxidants. Study by Huchin *et al.*, (2014) confirmed high level flavonoids presented in *Annona squamosa* (200.92 mg QE/ 100 g FW) and custard apple (418.24 QE/100 g FW). Another study done by Zhishen *et al.*, (1999) revealed that there is decrease in flavonoid content in *Morus alba* of fresh leaves on drying. They opined that it might be due to decomposition of flavonoids after a long period of storage or under high temperature. Furthermore, they observed the higher level of flavonoids in spring leaves of same species compared to autumn leaves and they concluded the spring leaves being mature whereas autumn leaves were senescent.

2.12. Vitamins

Vitamins are organic compounds that play a major role in regulation of enzymes, cell signals and metabolic pathways. They are non-energy producing organic compound, essential for normal human metabolism and must be supplied in small

quantities in the diet. The importance of vitamins is primarily in the prevention and treatment of deficiency diseases (Rajput *et al.*, 2011). Vitamins are traditionally divided into two groups: fat-soluble and water-soluble.

2.12.1. Vitamin B_1 (Thiamin hydrochloride)

Vitamin B_1 plays an important role in neuromuscular transmission. It is concerned in the proper utilization of carbohydrates in the body and in the absence of adequate amounts of thiamine full utilization of sugars and starches for meeting the energy needs is adversely affected (Rajput *et al.*, 2011). Parthsarathy and Nandakishore (2014) reported that the total vitamin B_1 in *G. gummi-gutta* (48 µg/100 g) was higher compared to *G. xanthochymus* (37 µg/100 g), where in *G. mangostana* and *G. subelliptica* same level of thiamine were recorded i.e. 50 µg /100g. Tripathi *et al.* (2015) concluded that edible portion of mangosteen contains 0.03 mg/100 gm of vitamin B_1. The investigation by Karlidag *et al.*, (2009) on underutilised fruits confirmed that *Manilkara hexandra* (0.13 mg/100g) has higher vitamin B_1 compare to *Aegle marmalos* (0.07 mg/100 g) and *Annona squamosa* (0.07 mg/100 g). Similar studies revealed that guava fruit contains 0.067 mg/100 g of vitamin B_1 (Kumari *et al.*, 2013).

2.12.2. Vitamin B_2 (Riboflavin)

Vitamin B_2 participates in the oxidation-reduction reactions in the metabolic pathways that are involved in energy production (Dai and Koh, 2015). Parthasarathy and Nandakishore (2014) reported that the vitamin B_2 content in *G. mangostana* (300 µg/100 g) was high when compared to *G. gummi-gutta* (275 µg/100 g), *G. xanthochymus* (250 µg /100g) *and G. kydia* (267 µg/100g). Vitamin B_2 content in some underutilized fruits such as *Morus alba* (0.13 mg/100 g pulp), *Feronia limonia* (0.17 mg/100 g pulp), *Annona squamosa* (0.17 mg/100 g) and *Aegle marmalos* (1.19 mg/100 g) were investigated by Gopalan *et al.*, (2004). Vitamin B_2 in watermelon (0.04 mg/100 g) was very low when compared to banana (0.13 mg/100g) as reported

by Ugbogu and Ogodo (2015). In guava fruit it was 0.04 mg/100 g (Kumari *et al.*, 2013).

2.12.3. Vitamin B_{12} (Cyanocobalamin)

Vitamin B_{12} plays an important role in the biochemical processes of methylation and transmethyation, deficiency produces pernicious anaemia (Rajput *et al.*, 2011). Parthasarathy and Nandakishore (2014) analyzed the six species of *Garcinia* and they confirmed the higher vitamin B_{12} in *G. indica* (12.06 µg/100 g) than *G. gummi-gutta* (8.75 µg/100 g), *G. mangostana* (9.52 µg/100 g), *G. xanthochymus* (10.76 µg/100 g), *G. subelliptica* (9.03 µg /100 g), and *G. kydia* (10.15 µg /100 g).

2.12.4. Vitamin C (Ascorbic acid)

Vitamin C is a highly water-soluble compound that has both acidic and strong reducing properties, an essential nutrient in humans as it functions as a cofactor in several vital enzymatic reactions (Rajput *et al.*, 2011). Parthsarathy and Nandakishore (2014) found that vitamin C in *G. mangostana* (60.43 mg/100 g) is high when compared to *G. gummi-gutta* (14.35 mg/100 g), *G. indica* (33.45 mg/100 g), *G. xanthochymus* (30.62 mg/100 g) and *G. subelliptica* 34.45 mg /100 g. However, Tripathi *et al.*, (2015) observed that edible portion of mangosteen contains 1.0 to 2mg/100 gm. Kumar *et al.*, (2013) reported that lemon (40.5 mg/100 g) has high vitamin C content compared to jack fruit (20.76 mg/100 g), sapota (34.49 mg/100 g) and pomegranate (34.14 mg/100 g). Thakur, (2013) reported vitamin C in *Artocarpus hirsutus* as 5.31 percent. Patil *et al.*, (2010) observed that in carambola, vitamin C content increased in ripe fruit (18.0 mg/g) as compared to young (9.5 mg/g) and half ripe fruits.

2.12.5. Vitamin A (Retinol)

Vitamin A is an essential nutrient needed in small amounts by humans for the normal functioning of the visual system; growth and development (Munjal, 2012).

According to Mazi *et al.,* (2013) *G. kola* fruit contained 1.36 mg/g of vitamin A. In case of baobab fruit vitamin A was 5.26 µg/100 g. Nkafamiya *et al.,* (2007) opined that underutilized fruits such as *Madhuca indica* (307 µg/100 g), *Manilkara hexandra* (495 µg/100 g) and *Ficus carica* (162 µg/100 g) are rich in retinol (Gopalan *et al.,* 2004). High level of vitamin A was reported in watermelon (8.65mg/100g) by Ugbogu and Ogodo (2015) than guava fruit (31 µg /100 g) by Kumari *et al.,* (2013).

2.12.6. Vitamin E (Tocopherol)

Vitamin E is recognised as a key essential lipophilic antioxidant in humans protecting lipoproteins, cellular and intracellular membranes from damage (Raederstorff *et al.,* 2015). Vitamin E in butter of different *Garcinia* species varied from 9 to 20.01 mg/g. (Parthasarathy *et al.,* 2014). In mango fruit it was reported to contain 0.90 mg/100 gm vitamin E in raw pulp (Guiamba, 2016). According to Morales *et al.,* (2013) *Prunus spinosa* and *Rubus ulmifolius* contained 5.41 mg/100 g and 13.48 mg/100 g respectively.

2.13. Physical properties of butter

The term butter or oil used to refer fats which are subset of lipids. Oil is usually used to refer the fats that are liquid at room temperature, while butter is usually used to refer to a fat that is solid at normal room temperature (Richard, *et al.,* 2010). The seeds of the *Garcinia* fruit have edible fat, commonly known as garcinia butter due to its solid state in room temperature. The seed oils of soybean, cotton, coconut and linseed oils are liquid at room temperature (Bachheti, 2012). According to Parthasarathy *et al.,* (2014) yield of butter is very high in *G. gummi-gutta* (47%) compared to *G. indica* (29.33%), *G. xanthochymus* (25.71%) and *G. mangostana* (24%). Swami *et al.,* (2014) reported that butter content in *G. cambogia* seed was 31 percent and also reported that fat from Malabar tamarind was edible, resembled kokum butter.

Parthasarathy *et al.*, (2014) observed the change in butter colour in different *Garcinia* species such as *G. gummi-gutta* (light brown), *G. indica* (pale white), *G. xanthochymus* (creamy-yellow) *and G. mangostana* (creamy-yellow). However, golden-orange colour butter was reported in mangostana (Ajayi *et al.*, 2007) and *G. xanthochymus* (Manohar *et al.*, 2014). Bachheti (2012) observed that soybean and cotton seed oils are yellow in colour, but coconut and linseed oils are colourless.

2.13.1. Melting point

The melting point of *G. indica* seed butter was high (about 40°C), hence it can be used along with the cocoa butter to increase the heat resistance property and hardness of the chocolate (Maheshwari and Reddy 2005). Ajayi *et al.*, (2007) reported that mangostana oil is liquid at room temperature (25±1°C). According to Swami *et al.*, (2014) the melting point of kokum butter is in the range of 39.5 to 40^0C. Similar study done by Parthasarathy *et al.*, (2014) reported that there is no much difference in melting point of different Garcinia species such as *G. mangostana* (37.9°C), *G. gummi-gutta* (39.4°C), *G. indica* (40.3°C) and *G. xanthochymus* (38.2 °C).

2.14. Chemical properties of butter

The chemical properties of oils are an important factor that determines its quality and stability (Neagu *et al.*, 2013). Saponification value, iodine value, acid values are some of the important characteristics of a vegetable oil.

2.14.1. Acid value

Acid value is the measure of susceptibility to decomposition and it represents the freshness as well as storage quality of an oil or fat. According to Parthasarathy *et al.*, (2014), the acid value of *Garcinia* varied from 3.7 to 4.5 mg NaOH/g in four species such as *G. gummigutta* (3.7 mg NaOH/g), *G. indica* (4.9 mg NaOH/g), *G. xanthochymus* (4.8 mg NaOH/g) and *G. mangostana* (4.5 mg NaOH/g), hence these

butters are good for the consumption. However, Ajayi *et al.*, (2007) reported that *G. mangostana* contained 4.58 mg NaOH/g. Similar study by Choppa *et al.* (2015) proved that Malabar tamarind seed oil (5.04 mg KOH/g) had high acid value when compared to sunflower oil (3.09 mg KOH/g), but lower than olive oil (6.6 mg KOH/g). Low level of acid value found in baobab seeds i. e. 0.033 mg KOH/g (Nkafamiyal *et al.*, 2007)

2.14.2. Saponification value

Saponification value indicates the character of the fatty acid present in the fat. Thus fats with high saponification value are very useful in production of liquid soap and shampoo (Akbar *et al.*, 2009). Parthasarathy *et al.*, (2014) reported that the saponification value is very high in coconut oil (251 to 263 mg KOH/g of oil),) and ghee (220 mg KOH/g of oil), where as in other oil such as olive (187-196 mg KOH/g of oil), sunflower (188-194), ground nut (188-195), mustard (169-176) and sesame (188-195 mg KOH/g of oil) it is low. Ajayi, *et al.*, (2007) reported that the saponification value of the *G. mangostana* oil was low (134 mg KOH/g), hence not likely to be suitable for soap making. In *G. indica* saponification value varied from 187 to193 mg KOH/g of oil (Ramachandran, 2014). Lower saponification value of Malabar tamarind seed oil (145.36 mg KOH/g) indicates the presence of long chain fatty acids with high molecular weight (Choppa *et al.*, 2015). Similar study on baobab seed revealed that saponification value of the oil was196 mg KOH/g (Nkafamiyal *et al.*, 2007).

2.14.3. Iodine value (IV)

Iodine value is a measure of the unsaturated nature of a fat (Akbar *et al.*, 2009). This value allows predicting the tendency of fat to become rancid. In *G. indica* it is very low (39.4) when compared to *G. gummi-gutta* (50.2) and *G. mangostana* (51.8) (Parhasarathy *et al.*, 2014). The study done by Ajayi, *et al.*, (2007) proved that IV in

G. mangostana oil was 53.6, whereas in *G. indica* it was 34 to 40 (Ramachandran, 2014). Swami *et al.,* (2014) reported that IV of *G. indica* butter to be 37.4. Choppa *et al.,* (2015) observed IV in *G. gummi-gutta* butter (131.0 g/100 g oil) and sunflower oils (131.6 g/100 g oil) to be similar. Thus higher IV for Malabar tamarind and sunflower seed oils indicates the presence of more double bonds in their fatty acid esters. NkafamiyaI *et al.,* (2007) observed that in baobab seed showed marked reduction in iodine value on exposure to light, darkness and refrigeration over a period of four weeks. Iodine value in cashew nut oil was 41.3 mg/100g, where as in apricot it was 102 (Bachheti, 2012).

Materials and Methods

3. MATERIALS AND METHODS

The present study was conducted on the hermaphrodite trees that are maintained as a germplasm collection in the orchard of National Bureau of Plant Genetic Resources, Regional Station (NBPGR), and Vellanikkara. The orchard is located on a leveled land of lateritic soil with a pH range of 5.0 to 5.5. Beside this, two standing trees in the homesteads of Thrissur were also included in the study.

The accessions taken for current study indicating place of collections, date of planting etc. are given in Table 2.

3.1. Variability in the general tree characters

Measure of variability in the tree included shape of the tree canopy, GBH and branching habit, height of the tree, height of first branch from the base and time of flowering.

3.1.1. Shape of the tree canopy

Canopy shapes of the tree of different accession were recorded through visual observation. Variation in canopy shapes was scored as round, dome, conical and pyramidal.

3.1.2. Height of the tree

The height of the tree from ground level to the tip of the tree was measured with the help of ravi multimeter and expressed in m. The height of the plant from the ground level to the first branching point was measured in m with the help of a measuring tape.

3.1.3. GBH and branching habit

Girth of trees were measured in cm at 1.37 m from the ground level and branching habit of the tree of different accessions were recorded through visual observation.

3.1.4. Time of flowering

Month of flowering of different trees were recorded.

Table 2. List of accessions taken for study

S. No.	IC No.	Date of planting	Village	District	State
1	IC244101-3	07.10.1990	Vayalathala, Cherukole	Pathanamthitta	Kerala
2	IC244090-3	04.10.1990	Anjalipra, Kannamangalam	Alappuzha	Kerala
3	IC244101-2	07.10.1990	Vayalathala, Cherukole	Pathanamthitta	Kerala
4	IC244100-3	07.10.1990	Manjapuzha, Mannarkulanji-Mezkkozhur	Pathanamthitta	Kerala
5	IC244100-1	07.10.1990	Manjapuzha, Mannarkulanji-Mezkkozhur	Pathanamthitta	Kerala
6	IC244097-3	07.10.1990	Kizhavaalloor, Konni	Pathanamthitta	Kerala
7	IC244078-3	03.10.1990	Perinjanam	Thrissur	Kerala
8	IC244085-2	04.10.1990	Komalapuram	Alappuzha	Kerala
9	IC244081-1-3	04.10.1990	Ezhupunna	Alappuzha	Kerala
10	IC244077-1-3	03.10.1990	Perinjanam	Thrissur	Kerala
11	IC244083-1-2	04.10.1990	Ezhupunna	Alappuzha	Kerala
12	IC409055	04.10.1990	Karuvatta South, Kumaarapuram	Alappuzha	Kerala
13	IC244077-1-2	03.10.1990	Perinjanam	Thrissur	Kerala
14	IC244110	10.10.1990	Purayar, Chengamanad, Parakadavu, Aluwa	Ernakulam	Kerala
15	IC244111-1	10.10.1990	Chengal, Vadakkumbagam, Angamaly, Aluwa	Ernakulam	Kerala
16	IC244113-1	10.10.1990	Peechanicaud, Karugutty, Angamaly	Ernakulam	Kerala
17	IC244113-2	10.10.1990	Peechanicaud, Karugutty, Angamaly	Ernakulam	Kerala
18	IC354021-2	21.07.2002	Cherpu	Thrissur	Kerala
19	IC244094	06.10.1990	Karikam, Vettikavala	Kollam	Kerala
20	IC354021-2	21.07.2002	Cherpu	Thrissur	Kerala
21	IC244106-1	10.10.1990	Erumala, Thrikariyur, Kothamangalam	Ernakulam	Kerala
22	IC244083-1-1	04.10.1990	Ezhupunna	Alappuzha	Kerala
23	IC244084-1	04.10.1990	Chertala Thekku	Alappuzha	Kerala
24	IC244084-2	04.10.1990	Chertala Thekku	Alappuzha	Kerala
25	IC244110-1-1	10.10.1990	Purayar, Chengamanad, Parakadavu, Aluwa	Ernakulam	Kerala
26	IC354070-3	28.07.2002	Mensi, Sirsi Tk.	Uttara Kannad	Karnataka
27	IC354018-3	20.07.2002	Chirekkekode	Thrissur	Kerala
28	IC244114-3	10.10.1990	Kattungachera, Porattusseri	Thrissur	Kerala
29	IC354022-3	21.07.2002	Cherpu	Thrissur	Kerala
30	IC342325-2	29.04.2002	Multipurpose Horticulture Farm	Shimoga	Karnataka

3.2. Variability in leaf characters

From each accession, 10 leaves were selected and various leaf characters were recorded which included leaf emergence, leaf length, leaf breadth, length to breadth ratio, leaf area, petiole length.

3.2.1. Leaf emergence

Ten vegetative buds were tagged at random on the shoots of individual trees to observe the growth pattern of leaves of from emergence to maturity. Linear growth measurements were recorded from the protuberance stage to maturity stage at four days interval without detaching the leaves.

3.2.2. Leaf length and breadth

The length of the leaf was measured from base to apex and recorded in cm. The breadth of the leaf at maximum point was measured and recorded in cm.

3.2.3. Length to breadth ratio

The length to breadth ratio was worked out for each leaf.

3.2.4. Leaf area

Leaf area of each leaf is measured by leaf area meter.

3.2.5. Petiole length

The pedicel length of ten leaves from each tree was observed and mean was worked out.

3.3. Variability in flower characters

The flowers were randomly selected from different aspects of the canopy of each tree for study and following observations were made.

3.3.1. Colour of petals

Colour of petals was noted with the help of munsel colour chart.

3.3.2. Petal length and breadth

Length and breadth of petals of ten flowers was noted from each tree and mean was calculated.

3.3.3. Pedicel length

Length of pedicel of ten flowers was noted from each tree and mean was calculated.

3.3.4. Flower weight

The weight of ten flowers from each tree was taken using an electronic balance and mean was worked out.

3.3.5. Number of flower per cluster

The flower number on each bunches were observed and recorded.

3.4. Variability in fruit characters

From each accession ten fruits were collected and various fruit characters were recorded which included fruit weight, fruits yield, rind weight.

3.4.1. Fruit weight

The weights of ten fruits were determined using electronic balance and mean weight was recorded.

3.4.2. Fruits yield

The total number of fruits on each tree was noted.

3.4.3. Rind weight

The weight of fresh rind from ten fruits was determined using electronic balance and mean was calculated.

3.5. Seed characters

Seed characters such as size, weight and germination percentage were recorded as follows,

3.5.1. Weight

Weight of ten seeds from each accession was taken and mean was calculated.

3.5.2. Seed size

The seed size of each accession was calculated by taking length and breadth measurement.

3.5.3. Germination percentage

The seeds collected from 32 accessions were treated by 500 ppm of GA (Gibberellic acid) for 18 hour and germination percentage was calculated after 11 month.

3.6. Biochemical and nutritional variability analysis

Biochemical and nutritional qualities of the fruits were assessed using standard procedure. Analysis was carried out for the following constituents.

3.6.1. Estimation of primary metabolites

The primary metabolites (carbohydrates, reducing sugar, protein and fat) were estimated using the following procedures

3.6.1.1. Total carbohydrates

Total carbohydrates were estimated by phenol sulphuric acid method. The diluted aqueous solution of fruit extract was mixed with 1ml phenol solution and 5 ml of 96 percent sulphuric acid. This mixture was allowed to stand at room temperature for 10 minutes and then it was placed on water bath for 20 minutes. After this, absorbance was measured at 490 nm against reagent blank in spectro photometer. A standard calibration curve was plotted against standard glucose (Sadasivam and Manikam, 1996).

3.6.1.2. Reducing sugar

Reducing sugar was estimated by the method given by Lane and Eyon (Ranganna, 1986). To 10 g of sample, 100 ml of distilled water was added and then clarified with neutral lead acetate. Excess lead was removed by adding potassium oxalate. The volume was then made

up to 250 ml. An aliquot of this solution was titrated against a mixture of Fehling's solution A and B using methylene blue as indicator. The reducing sugar was expressed as percentage.

3.6.1.3. Total protein content

Total protein content was estimated by Lowery's method (Sadasivam and Manikam, 1996). The buffer extracted sample was mixed with 5ml alkaline copper solution and allowed to stand for 10 minutes. This mixture was treated with Folin-Ciocalteau reagent and incubated at room temperature in the dark for 30 minutes and blue coloured developed was read at 660 nm in spectrophotometer. A standard calibration curve was plotted against standard bovine serum albumin.

3.6.1.4. Total fat content

Crude fat were determined by extracting known quantity of moisture free fruit material with petroleum ether in a soxhlet apparatus by heating the flask for 6 hour. After the completion of the process, the seed oil was separated from evaporating petroleum ether at 60 °C and cooled at room temperature. Fat percentage calculated by following formula,

$$\text{Percent crude fat} = \frac{\text{Weight of fat (g)} \times 100}{\text{Weight of sample (g)}}$$

3.6.2. Analysis of vitamins

Fat soluble vitamins were extracted from fruits using methanol-chloroform (1:1) and water soluble vitamins were extracted by using phosphate buffer of pH 7.5. The amount of vitamins present in the extracts was determined in a UV Vis (Ultraviolet-visible spectra) spectrophotometer using their respective molar extinction coefficient values. The molar extinction coefficients of vitamins were Vitamin B_1 (11305 cm-1/M at 246 nm), B_2 (12200 cm-1/M at 445 nm), B_{12} (27500 cm-1/M at 361 nm), C (14200 cm-1/M at 266 nm), A (53500 cm-1/M at 325nm) and E (21000 cm-1/M at 292 nm). Two milliliters of sample was taken in a quartz cuvette. Against the solvent as blank, the absorption of the sample at the wavelength respective to the vitamin was determined (Parthsarathy and Nandakishore, 2014).

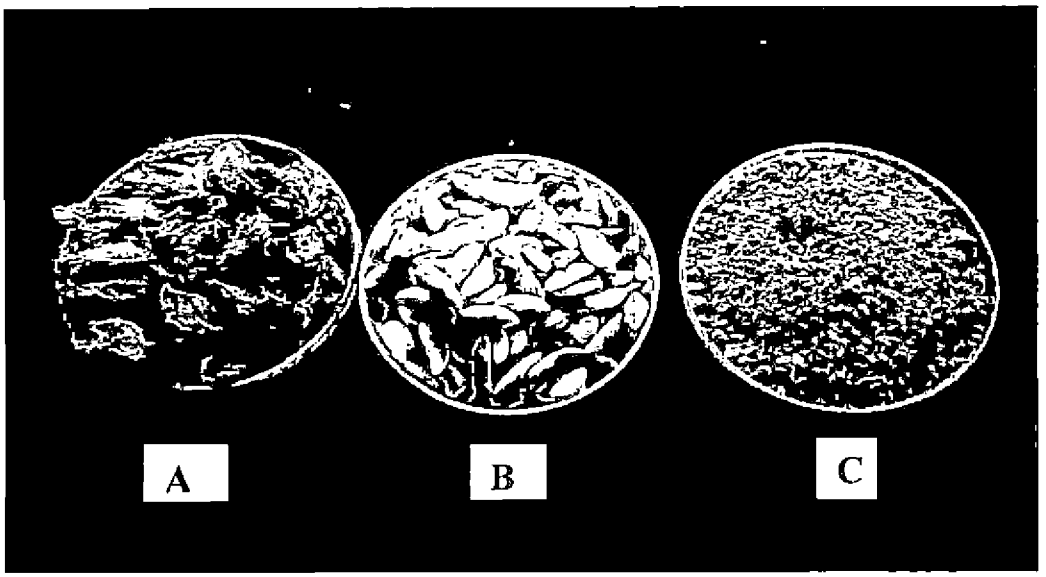

Plate 1. Steps in seed butter preparation (A) Seed with seed coat, (B) seed kernel and (C) kernel powder

Plate 2. Seed butter extracted from *G. gummi-gutta*

Amount of vitamin (mg/g of tissue) = (A × Molar mass / ε) × 1000

A = Wave length of maximum absorption of the vitamin

ε = Molar extinction coefficient of vitamin

3.6.3. Analysis of minerals

Minerals content (phosphorous, potassium, sodium, calcium and magnesium) were estimated using the following procedures

3.6.3.1. Phosphorus

The phosphorous content was analyzed colorimetrically as suggested by Jackson (1973). To 5 ml of predigested aliquot, 10 ml of nitric acid vanadomolybdate reagent was added and made up to 50 ml with distilled water. After 10 minutes this gave yellow colour with nitric acid vanadomolybdate reagent, which was read on the spectrophotometer at 420 nm wavelength. A standard graph was prepared using serial dilution of phosphorous solution and finally expressed in mg per 100 g of sample.

3.6.3.2. Potassium and Sodium

Potassium and sodium content was estimated by flame photometric method (Jackson, 1973). One gram of sample was digested with 9:4 mixture nitric acid and perchloric acid and made up to 50 ml. This solution was directly read in Flame Photometer by taking potassium chloride (KCl) as standard for K and sodium chloride (NaCl) for Na. The results expressed in mg per 100 g of sample.

3.6.3.3. Calcium and Magnesium

The calcium and Magnesium content was estimated by atomic absorption spectrophotometric method using diacid extract prepared from the sample (Yash, 1998). One gram of the sample was pre digested with 15 ml of 9:4 mixture nitric acid and perchloric acid and made up to 50 ml and used directly in atomic absorption spectrophotometer for the estimation of calcium and expressed in mg per 100 g of sample.

3.6.4. Analysis of secondary metabolites

The secondary metabolites like total phenols; total flavonoids were estimated using the following procedures

3.6.4.1. Total phenols

The total phenolics of each fruit extract were determined by the Folin-Ciocalteu method. The diluted aqueous solution of each extract was mixed with Folin-Ciocalteu reagent. This mixture was allowed to stand at room temperature for three minutes and then sodium carbonate solution was added. It was placed it on boiling water for one minute. Absorbance was measured at 650nm against reagent blank. A standard calibration curve was plotted against catechol. The result was expressed as mg of catechol equivalents (CE)/100 g of fruit weight (Sadasivam and Manikam, 1996).

3.6.4.2. Total flavonoids

The total flavonoid content was estimated using aluminum chloride method (Zhishen et *al.*, 1999). The 0.5 ml of test samples solution in methanol (5 mg/100 ml) was mixed with 2ml of distilled water and 0.3 ml of 5 percent sodium nitrate. After 6 minutes, 0.3 ml of 10% aluminum chloride and 2ml of 1 M sodium hydroxide were added and left at room temperature for 15 minutes. Absorbance of the mixtures were measured at 510 nm in spectrophotometer and total flavonoid concentration in a samples were calculated from the plot of linear graph plotted against quercetin. The results were expressed as mg equivalents of quercetin per 100 g of sample.

3.7. Analysis of seed kernel butter

Seeds from the fresh fruits were separated and dried thoroughly. About 100 g of kernels were separated from the seeds and washed in hot water to remove all impurities. Kernels were then slightly roasted in a gentle heat in a pan and then finely ground and fat extracted using soxhlet apparatus with petroleum ether as a solvent. The soxhlet apparatus was set to a temperature of 65–70°C and the overall process carried out for 12 hour. After the completion of the process, the seed oil was separated from evaporating petroleum ether at 60 °C (Choppa *et al.*, 2015).

3.7.1. Physical properties of fat

The physical properties of fat such as colour, pour point, melting point were estimated using the following procedures

3.7.1.1. Pour point

Pour point for the butters were estimated in the standard way by treating the samples to the specific temperature for a minute duration and observed the physical change in sample (Parthasarathy *et al.,* 2014).

3.7.1.2. Melting point

Melting point was determined by method given by Ranganna (1997). Fat sample was heated above melting point and dipped the fine glass capillary tubes into it to allow the sample to rise up the capillary tube. The fat was solidified by chilling in ice was to remain at 15 to 20 ^{0}C for 24 hour. Later the capillary tubes were attached to the bulb of a thermometer with a rubber band and immersed in a beaker containing cold water. The temperature of water rised slowly and the temperature at which the fat started rising was noted.

3.7.1.3. Colour

Colour was measured in a spectrophotometer using carbon tetrachloride as blank at the wave length of maximum absorption (510 nm) as mentioned by Ranganna (1997).

3.7.2. Chemical properties of fats

The Chemical properties of oil such as acid value, saponification value and iodine value were estimated using the following procedures.

3.7.2.1. Acid value

Acid value was determined by method given by Sadasivam and Manikam (1996). A known quantity of melted fat was dissolved in 50 ml neutral solvent and titrated against 0.1N potassium hydroxide with phenolphthalein as indicator.

$$\text{Acid value (mg KOH/g)} = \frac{\text{Titrate value} \times \text{Normality of KOH} \times 56.1}{\text{Weight of the sample (g)}}$$

3.8.2.2. Saponification value

Saponification value was determined by method given by Sadasivam and Manikam (1996). A known quantity of melted fat was mixed with 50 ml of alcoholic KOH and refluxed for 60 minutes. After cooling, about 1ml of phenolphthalein indicator was added and titrated against 0.5 N HCl until pink colour just appeared. Blank was prepared by taking only 50ml of alcoholic KOH.

$$\text{Saponification value} = \frac{28.05 \times (\text{titrate value of blank} - \text{titrate value of sample})}{\text{Weight of the sample (g)}}$$

3.8.2.3. Iodine value

Iodine value was determined by method given by Ranganna (1997). A known quantity of melted fat was mixed with 10ml carbon tetrachloride and 25 ml wijis solution. It was stored in a dark for 30 minutes and added with 15 ml of 10 percent potassium iodide solution. It was titrated with 0.1 $Na_2S_2O_3$ solution using starch as an indicator.

$$\text{I.V} = \frac{(\text{Blank titre} - \text{Sample titre}) \times \text{N of } Na_2S_2O_3 \times 12.69}{\text{Weight of Sample (g)}}$$

3.9. Statistical analysis

3.9.1. Cluster analysis

The data on the morphology and biochemical characters of different accessions were subjected to hierarchical clustering analysis. The analysis was carried out using between group linkage as the clustering method and Euclidean distance as the interval using the SPSS software.

3.9.2. Principle component analysis

The data on the morphology and biochemical characters of different accessions were subjected to principle component analysis using SPSS software.

3.9.3. Path coefficient analysis

Path coefficient analysis was performed for morphology and biochemical characters of different accessions using SPSS software.

Results

4. RESULTS

The results pertaining to the study entitled 'Morpho-physiological diversity assessment of *Garcinia gummi-gutta* (L.) Robs. germplasm collection' are presented in this chapter.

4.1. General tree characters

Information with regard to general tree characters of 30 accessions of *G. gummi-gutta* maintained at NBPGR, Thrissur and two trees from home garden are presented in Table 3.

The height of trees found to range from 3 m (IC354070-3) to 19 m (IC244113-2). The average height was 10.64 m. Height of first branch from base of the tree varied from 0.65 m (IC244097-3) to 3.5 m (IC244113-2) and average height of branch was 2.05 m. Measurement on GBH also showed wide variation. The GBH was found to range from 31 cm (IC354070-3) to 107 cm (IC354021-3) and mean GBH was 70.7 cm.

Tree showed marked difference in shape of canopy viz. conical, dome and pyramidal. Among these, fifteen trees were having conical, eleven were dome and six were pyramidal in shape.

Branching pattern also showed considerable variation i.e. horizontal, erect and drooping. Out of thirty two trees studied, sixteen were having drooping branches, eleven were having horizontal branches and the other five were having erect branches.

4.2. Leaf characters

Information regarding the variation in the leaf characters of different collections was presented in Table 4.

Area of the leaf varied from 22.78 cm^2 (IC354022-3) to 56.39 cm^2 (IC354070-3). The average leaf area was 37.69 cm^2. Leaf length ranged from 9.47 cm (IC244106-2) to 14.97 cm (IC409055) and average was 11.09 cm. Leaf breadth varied from 3.6 cm (IC244084-1) to 7.11 cm (IC244097-3). The average breadth was 5 cm. With respect to petiole length the range was from 1.83 cm (IC244100-3) to 0.79 cm (IC244083-1) and average was 1.37 cm.

Table 3: General tree characters of different accessions of *G. gummi-gutta*

Sl. No	Accessions	Crown shape	Branching habit	GBH (cm)	Tree height (m)	Height of First branch (m)
1	IC244101-3	Conical	Drooping	89	15.00	1.00
2	IC244090-3	Conical	Horizontal	90	12.00	2.15
3	IC244101-2	Conical	Drooping	88	12.75	2.45
4	IC244100-3	Pyramidal	Drooping	90	14.50	2.40
5	IC244100-1	Conical	Drooping	51	11.00	1.70
6	IC244097-3	Dome	Erect	54	08.00	0.65
7	IC244078-3	Conical	Drooping	39	04.50	0.72
8	IC244085-3	Dome	Drooping	87	13.50	2.45
9	IC244081-2	Dome	Horizontal	70	13.00	2.20
10	IC244077-1-3	Conical	Drooping	69	15.50	3.00
11	IC244083-1-2	Pyramidal	Horizontal	74	12.00	1.80
12	IC409055	Dome	Erect	63	13.00	2.51
13	IC244077-1-2	Dome	Drooping	70	10.00	2.20
14	IC244110	Conical	Horizontal	103	11.50	1.52
15	IC244111-1	Conical	Drooping	61	12.50	1.45
16	IC244113-1	Dome	Erect	87	10.00	2.25
17	IC244113-2	Conical	Drooping	82	19.00	3.50
18	IC354021-2	Conical	Horizontal	98	13.00	2.65
19	IC244094-1	Pyramidal	Horizontal	97	10.00	2.13
20	IC354021-3	Dome	Drooping	107	08.00	2.26
21	IC244106-2	Dome	Horizontal	79	06.50	1.78
22	IC244083-1	Conical	Drooping	75	11.00	3.00
23	IC244084-1	Dome	Horizontal	72	12.00	2.44
24	IC244084-2	Dome	Horizontal	74	10.00	1.85
25	IC244110-1-1	Conical	Erect	76	04.51	1.41
26	IC354070-3	Pyramidal	Drooping	31	03.00	3.00
27	IC354018-3	Pyramidal	Drooping	35	03.50	0.72
28	IC2447743	Conical	Erect	51	10.00	3.00
29	IC354022-3	Pyramidal	Drooping	46	07.00	0.95
30	IC342325-2	Conical	Horizontal	58	09.00	1.76
31	Home garden1	Conical	Horizontal	74	13.00	2.78
32	Home garden2	Dome	Drooping	68	12.50	1.98

Plate 3. *G. gummi-gutta* fruiting at NBPGR

Table 4: Leaf morphology of different accessions of *G. gummi-gutta*

Sl. No.	Accessions	Leaf area (cm^2)	Length (cm)	Width (cm)	Petiole (cm)
1	IC244101-3	44.94	11.38	5.67	1.28
2	IC244090-3	39.68	10.53	5.47	1.33
3	IC244101-2	39.42	11.52	4.74	1.63
4	IC244100-3	52.69	13.78	5.78	1.83
5	IC244100-1	38.30	11.54	4.77	1.52
6	IC244097-3	54.83	11.88	7.11	1.57
7	IC244078-3	35.64	11.18	4.61	1.54
8	IC244085-3	36.15	10.84	4.36	1.17
9	IC244081-2	22.94	10.21	3.84	1.13
10	IC244077-1-3	28.04	10.02	4.13	1.37
11	IC244083-1-2	47.82	10.28	5.49	1.55
12	IC409055	35.83	14.97	5.48	1.82
13	IC244077-1-2	27.71	10.02	3.80	1.31
14	IC244110	37.92	11.02	5.38	1.24
15	IC244111-1	36.36	11.01	4.90	1.12
16	IC244113-1	42.10	11.05	5.51	1.29
17	IC244113-2	36.36	11.01	4.90	1.12
18	IC354021-2	26.84	10.68	5.39	1.56
19	IC244094-1	30.91	11.08	4.61	1.29
20	IC354021-3	40.18	10.47	3.92	1.39
21	IC244106-2	30.24	09.47	5.12	1.10
22	IC244083-1	31.88	11.28	4.31	0.79
23	IC244084-1	43.28	9.53	3.60	0.96
24	IC244084-2	38.30	11.76	5.16	1.67
25	IC244110-1-1	37.30	11.13	5.09	1.68
26	IC354070-3	56.39	14.97	5.48	1.82
27	IC354018-3	31.74	10.06	4.95	1.28
28	IC2447743	33.61	10.37	4.96	1.23
29	IC354022-3	22.78	10.01	5.33	1.34
30	IC342325-2	43.42	10.44	5.58	1.25
31	Home garden1	39.38	10.06	5.14	1.37
32	Home garden2	43.12	11.36	5.33	1.48

4.3. Leaf emergence, growth and development

The data on leaf development of *G. gummi-gutta* are furnished in Table 5.

It took 30 to 32 days for the development of leaves from emergence to mature dark green stage. Both pinkish red and light green flushes were observed in hermaphrodite trees during the initial stages of development. After 16 days they turned into green.

There was not much variation in leaf length and breadth during initial stages of development among different accessions. Leaf length on 4th day varied from 0.25 cm (IC244110-1-1) to 0.49 cm (IC409055) and average length was 0.36 cm. The lowest breadth i.e. 0.17 cm was observed in IC354021-3, IC354018-3, IC244077-1-2, IC244077-1-3 and IC244078-3, highest breadth i.e. 0.29 cm observed in IC244090-3 and IC354070-3. The average breadth was 0.21 cm.

Leaf length on 8th day varied from 0.6 cm (IC244083-1) to 1.25 cm (IC244085-3). The mean length varied from 0.81 cm. The breadth ranged from 0.27cm (IC354018-3) to 0.49 cm (IC409055) and the average was 0.38 cm.

Leaf length on 12th day varied from 1.68 cm (IC244083-1) to 2.87 cm (IC244100-1). The mean length varied from 2.33 cm. The breadth ranged from 0.72 cm (IC244084-1) to 0.98 cm (IC244078-3). The mean breadth was 0.85 cm.

On 16th day there was no much variation observed. The leaf length ranged from 3 cm (IC244094-1) to 3.96 cm (IC244100-1). The mean length varied from 3.56 cm. The breadth ranged from 1cm (IC244083-1-2) to 1.86 cm (IC409055) and average breadth was 1.46 cm.

Leaf length on 20th day varied from 4.04 cm (IC244077-1-2) to 5.98 cm (IC409055). The average length was 5.28 cm. Leaf breadth ranged from 1.75 cm (IC244083-1-2) cm to 2.85 cm (IC244110) and mean length was 2.38 cm.

Leaf length on 24th day varied from 6.52 cm (IC244083-1) to 10 cm (IC409055). The average length was 7.84 cm. Leaf breadth varied from 2.34 cm (IC244084-1) to 4.24 cm (IC244084-2). The mean width was 3.35 cm.

Table 5: Increase in leaf length (cm) of *G. gummi-gutta* at different stages of leaf development

Sl. No.	Accessions	4th day	8th day	12th day	16th day	20th day	24th day	28th day	32nd day
1	IC244101-3	0.35	0.84	2.32	3.86	5.05	7.04	08.85	11.50
2	IC244090-3	0.34	0.79	2.10	3.50	4.64	7.12	10.05	10.42
3	IC244101-2	0.41	0.90	1.96	3.26	5.00	8.08	10.21	11.74
4	IC244100-3	0.45	0.75	2.63	3.32	5.62	9.97	12.08	13.25
5	IC244100-1	0.37	0.74	2.87	3.96	5.16	7.62	09.95	11.56
6	IC244097-3	0.40	0.93	2.08	3.65	5.94	7.81	10.90	11.02
7	IC244078-3	0.42	0.82	2.33	3.50	5.56	7.55	09.21	10.96
8	IC244085-3	0.43	1.25	2.50	3.06	5.18	8.30	09.35	10.85
9	IC244081-2	0.29	0.63	2.16	3.50	4.97	7.52	09.28	10.50
10	IC244077-1-3	0.38	0.80	2.75	3.78	5.46	7.60	08.95	10.47
11	IC244083-1-2	0.28	0.78	2.58	3.93	4.85	7.57	08.82	10.55
12	IC409055	0.49	0.92	2.86	3.85	5.98	10.00	12.64	14.84
13	IC244077-1-2	0.40	0.97	2.20	3.74	4.04	8.16	09.10	10.00
14	IC244110	0.27	0.79	2.76	3.56	5.85	8.74	09.95	11.30
15	IC244111-1	0.35	0.65	2.50	3.74	5.73	8.20	10.61	11.34
16	IC244113-1	0.38	0.76	2.04	3.06	5.87	7.85	10.38	11.61
17	IC244113-2	0.40	1.00	1.98	3.78	5.60	8.56	09.00	10.74
18	IC354021-2	0.42	0.94	2.50	3.49	5.97	7.44	10.98	11.05
19	IC244094-1	0.47	1.16	2.16	3.00	4.86	7.67	10.67	11.84
20	IC354021-3	0.36	0.78	2.65	3.52	5.50	7.95	10.00	11.15
21	IC244106-2	0.29	0.66	2.14	3.22	5.35	7.34	08.85	09.38
22	IC244083-1	0.30	0.60	2.12	3.76	5.00	6.52	10.60	12.06
23	IC244084-1	0.31	0.89	2.50	3.68	5.13	7.00	08.44	09.71
24	IC244084-2	0.37	0.72	1.68	3.80	5.68	6.87	11.46	13.00
25	IC244110-1-1	0.25	0.64	2.01	3.55	4.76	8.14	09.80	11.80
26	IC354070-3	0.42	0.95	2.86	3.83	5.36	8.96	12.59	14.74
27	IC354018-3	0.32	0.64	2.50	3.91	4.96	8.18	09.16	10.40
28	IC2447743	0.39	0.67	2.20	3.84	5.44	7.84	09.75	10.43
29	IC354022-3	0.40	0.86	1.92	3.37	4.95	7.10	10.00	10.35
30	IC342325-2	0.38	0.85	2.62	3.00	5.54	7.75	09.17	10.52
31	Home garden1	0.31	0.67	2.16	3.90	5.15	7.48	09.14	10.05
32	Home garden2	0.29	0.68	1.96	3.27	4.90	6.80	10.64	12.00

Plate 4. Different stages of leaf development in *G.gummi-gutta*

Table 6: Increase in leaf breadth (cm) of *G. gummi-gutta* at different stages of leaf development

Sl. No.	Accessions	4th day	8th day	12th day	16th day	20th day	24th day	28th day	32nd day
1	IC244101-3	0.26	0.41	0.92	1.80	2.78	3.30	4.59	5.05
2	IC244090-3	0.29	0.39	0.87	1.77	2.00	3.28	4.73	5.18
3	IC244101-2	0.25	0.48	0.83	1.39	2.47	3.77	4.09	5.44
4	IC244100-3	0.19	0.45	0.79	1.50	2.39	3.14	3.88	5.67
5	IC244100-1	0.18	0.37	0.84	1.47	2.66	3.38	4.27	4.74
6	IC244097-3	0.20	0.29	0.8	1.36	2.5	4.02	5.50	6.82
7	IC244078-3	0.17	0.35	0.98	1.60	2.01	3.15	3.84	4.62
8	IC244085-3	0.22	0.39	0.94	1.75	2.5	3.22	3.93	4.75
9	IC244081-2	0.20	0.36	0.75	1.19	2.27	2.81	3.05	3.62
10	IC244077-1-3	0.17	0.34	0.87	1.32	2.11	3.17	3.91	4.69
11	IC244083-1-2	0.21	0.47	0.76	1.00	1.75	3.00	4.39	5.55
12	IC409055	0.24	0.49	0.81	1.86	2.34	3.99	4.14	5.25
13	IC244077-1-2	0.17	0.33	0.93	1.67	2.16	2.74	3.02	3.73
14	IC244110	0.19	0.40	0.78	1.11	2.85	3.50	4.54	5.80
15	IC244111-1	0.20	0.38	0.89	1.55	2.63	3.72	4.37	5.05
16	IC244113-1	0.26	0.30	0.77	1.16	2.55	3.48	4.40	5.18
17	IC244113-2	0.24	0.36	0.81	1.55	2.21	3.67	4.72	5.15
18	IC354021-2	0.25	0.41	0.90	1.76	2.72	3.36	4.02	5.27
19	IC244094-1	0.20	0.34	0.86	1.39	2.63	3.09	3.73	4.80
20	IC354021-3	0.17	0.31	0.72	1.18	2.25	2.81	3.12	3.90
21	IC244106-2	0.21	0.44	0.88	1.41	2.39	3.31	4.15	5.31
22	IC244083-1	0.26	0.42	0.83	1.67	2.53	3.62	3.88	4.70
23	IC244084-1	0.19	0.31	0.72	1.02	1.97	2.34	2.69	3.46
24	IC244084-2	0.23	0.40	0.92	1.75	2.20	4.24	4.52	5.50
25	IC244110-1-1	0.21	0.40	0.91	1.53	2.58	3.65	4.45	5.24
26	IC354070-3	0.29	0.41	0.90	1.32	2.69	3.51	4.77	5.8
27	IC354018-3	0.17	0.27	0.86	1.56	2.16	3.11	3.86	4.70
28	IC2447743	0.23	0.45	0.96	1.17	1.99	3.20	4.39	4.50
29	IC354022-3	0.21	0.33	0.96	1.57	2.38	3.12	3.98	5.30
30	IC342325-2	0.24	0.45	0.91	1.48	2.73	3.66	4.35	5.87
31	Home garden1	0.26	0.44	0.95	1.60	2.57	3.03	4.43	5.38
32	Home garden2	0.21	0.35	0.80	1.56	2.40	3.72	4.50	5.76

On 28th day, minimum leaf length of trees ranged from 8.44 cm (IC244084-1) to 12.64 cm (IC409055). The average length was 10.01 cm. The leaf breadth varied from 2.69 cm to 5.5 cm. And average breadth was 4.13 cm.

On 32nd day, minimum length of leaf was 9.38 cm (IC244106-2), while maximum length was 14.84 cm (IC409055). The average length of leaf was 11.3 cm. The breadth varied from 3.46 cm (IC244084-1) to 6.82 cm. And average breadth was 5.05 cm.

4.4. Flower characters

Information regarding the flower characters observed is furnished in Table 7.

In Malabar tamarind, flowers were hypogenous, petals were regular, polypetalous and tetramerous in nature but pentamerous and/or hexamerous flowers also observed. Colour of petal was compared to 'Munsell colour chart' for identification. The majority of flowers were creamy yellow (5Y/8/6 and 5Y/8/4). However, pinkish red colour (10YR/8/6) also observed in IC244097-3.

The observation on number of flowers per cluster showed, there was no clusters of flowers as in male Malabar tamarind tree. Mostly single flower was observed in all accessions; in rare case double flowers were noticed.

Length of petal ranged from 0.7 cm (IC244113-2) to 1.14 cm (IC354021-3). The average petal length was 1.0 cm, regarding the breadth of petal, it varied from 0.45 cm (IC342325-2) to 0.88 cm (IC244110) and average breadth was 0.64 cm. Pedicel length of flower was in the range of 0.38 cm (IC409055) to 0.91 cm (IC244100-3). The average pedicel length was 0.50 cm. The weight of flowers varied from 0.38 g (IC409055) to 0.78 g (IC244100-3) and average was 0.60g.

Time of flowering was also noted during study. Eighteen accessions started flowering in February, while the rest came to flowers in March.

Table 7: Flower characters of different accessions of *G. gummi-gutta*

Sl. No.	Accessions	Petal length (cm)	Breadth (cm)	Pedicel length (cm)	Weight of flower (gm)	Flower colour	Time of flowering
1	IC244101-3	1.05	0.77	0.43	0.58	5Y/8/4	February
2	IC244090-3	0.95	0.63	0.28	0.76	5Y/8/4	March
3	IC244101-2	1.07	0.64	0.60	0.65	5Y/8/6	February
4	IC244100-3	1.11	0.83	0.91	0.46	5Y/8/4	February
5	IC244100-1	1.03	0.64	0.53	0.39	2.5Y/8/6	March
6	IC244097-3	0.95	0.80	0.55	0.78	10YR/8/6	February
7	IC244078-3	1.02	0.63	0.47	0.56	5Y/7/6	March
8	IC244085-3	1.10	0.74	0.54	0.74	5Y/8/6	March
9	IC244081-2	0.92	0.67	0.37	0.63	5Y/8/4	February
10	IC244077-1-3	0.90	0.55	0.44	0.69	5Y/8/6	March
11	IC244083-1-2	1.00	0.69	0.46	0.59	2.5Y/8/6	February
12	IC409055	0.99	0.56	0.38	0.38	2.5Y/8/6	February
13	IC244077-12	0.96	0.51	0.45	0.57	5Y/8/6	March
14	IC244110	1.10	0.88	0.48	0.61	2.5Y/8/6	March
15	IC244111-1	0.98	0.68	0.62	0.60	5Y/8/6	February
16	IC244113-1	1.02	0.63	0.84	0.61	5Y/7/6	February
17	IC244113-2	0.70	0.50	0.60	0.68	2.5Y/8/6	February
18	IC354021-2	1.05	0.66	0.46	0.64	5Y/8/6	February
19	IC244094-1	0.92	0.52	0.53	0.71	5Y/7/6	March
20	IC354021-3	1.14	0.68	0.56	0.70	5Y/8/6	February
21	IC244106-1	1.07	0.82	0.40	0.60	5Y/8/4	February
22	IC244083-1-1	1.00	0.73	0.39	0.58	5Y/8/4	March
23	IC244084-1	1.10	0.75	0.40	0.67	5Y/8/4	February
24	IC244084-2	0.95	0.56	0.45	0.48	5Y/8/6	February
25	IC244110-1-1	0.91	0.53	0.80	0.62	5Y/8/6	February
26	IC354070-3	0.94	0.60	0.31	0.54	2.5Y/8/6	March
27	IC354018-3	1.00	0.62	0.30	0.62	5Y/8/6	February
28	IC2447743	0.97	0.64	0.47	0.52	2.5Y/8/6	March
29	IC354022-3	1.13	0.52	0.40	0.60	5Y/8/6	February
30	IC342325-2	1.05	0.45	0.64	0.54	5Y/8/4	March
31	Home garden1	0.90	0.50	0.30	0.49	5Y/8/4	March
32	Home garden2	0.96	0.56	0.54	0.67	5Y/8/6	March

Plate 5. Variability in flower colour of *G. gummi-gutta*

4.5. Variability in fruit characters

The data on fruit characters observed are furnished in Table 8.

The wide variation was observed in weight of fruits and it ranged from 51.4 g (IC244078-3) to 148.5 g (IC244100-1). The average fruit weight was 85 g. Weight of rind varied from 29.6 g (IC349883) to 83.5 g (IC244101-3) and average weight was 48 g. Yield with respect to number of fruits produced per year ranged from 70 (IC342325-2) to 985 (IC244084-1).The average yield was 532. Mature fruits were yellow in colour with grooves in all the accessions.

4.6. Seed characters

Seed characters also showed considerable variation, the results are furnished in Table 9.

Weight of seeds dried in shade ranged from 0.65 g (IC244101-2) to 1.2 g (IC244078-3 and IC244113-1). The average seed weight was 0.85 g. The germination percentage was found highest in IC244077-12 (80 %) and lowest was in IC244110 (30 %). The average germination percentage was 54.69 % Seed length ranged from 1.9 cm (IC244084-1) to 3.5 cm (IC244113-2) and width ranged from 0.8 (IC244083-1-2) to 1.4 cm (IC2447743). The average seed length and breadth was 2.62 cm and 1.12 cm respectively.

4.7. Primary metabolites

Primary metabolites in fruits showed considerable variation among the various accessions (Table 10).

The minimum carbohydrate content was observed in IC244113-1(18.08 g/100 g), which was followed by IC354021-2 (18.82 g/100 g) and IC244090-3 (20.37 g/100 g). The highest carbohydrate content was observed in IC244083-1-2 (29.69 g/100 g), followed by IC244110 (29.32 g/100 g) and IC244100-1 (26.35 g/100 g). The mean carbohydrate content was 24.05 g/100g.

The protein content between different accessions showed variation ranged from 0.93 g/100 g (IC244083-1-2) to 1.29 g/100 g (IC244081-2). The average protein content reported was 1.08 g/100 g, which was more or less similar to protein content reported in IC244101-2, IC244097-3 and IC244077-1-2.

The crude fat content of fruits varied from 3.28 percent to 6.18 percent. The maximum crude fat observed in Home garden1 (6.18 %), followed by IC244097-3 (6.1 %), IC244090-3 (6.08 %) and IC244110-1-1 (6.02 %).The minimum crude fat was observed in IC244094-1 (3.28 %), followed by IC244110 (3.46 %), IC244113-1 (3.88 %) and IC244100-3 (3.7 %). The average crude fat was 4.89%.

The reducing sugar content of fruits found lowest (3.85%) in IC244110, IC244077-1-3 and IC354018-3 and highest (4.31%) in IC244106-1 and IC244094-1. The average reducing sugar was 4.07 %.

4.8. Secondary metabolites

The results on secondary metabolites in fruits are furnished in Table 11.

Phenolic content in fruit varied from 900 mg/100 g to 1020 mg/100 g. The highest phenolic content (900 mg/100 g) found in IC244085-3, IC244094-1 and home garden 2.The lowest phenolic content (1020 mg/100 g) was found in IC244081-2 and IC2447743. The average phenolics content was 1.05 g/100 g.

The average flavonoids content observed was 181.31 mg/100 g. The lowest flavonoids content was found in IC244077-1-3 (127 mg/100 g), which was followed by IC244097-3 (146 mg/100 g), IC244084-2 (147 mg/100 g) and IC244078-3 (148 mg/100 g). The highest flavonoid content was observed in IC342325-2 (240 mg/100 g), which was followed by IC244110 (237 mg/100 g) and IC244110-1-1 (236 mg/100 g).

4.9. Mineral composition of fruits

The studies on mineral composition of fruits are furnished in Table 12.

The Ca content of fruits varied from 105.44 mg/100 g to 212.25 mg/100 g. The highest Ca content found in IC244090-3 (212.25 mg/100 g), which was followed by IC409055 (210 mg/100 g), IC244101-2 (209.12 mg/100 g) and IC354021-2 (202.5 mg/100 g), while minimum Ca content found in IC244100-1 (105.44 mg/100 g), followed by IC244077-1-3 (112.52 mg/100 g) and IC354021-3 (202.5 mg/100 g). The mean Ca content was 172 mg/100 g.

Table 8: Fruit characters of different accessions of *G. gummi-gutta*

Sl. No.	Accessions	Fruit weight (g)	Rind weight (g)	Number of fruits per tree
1	IC244101-3	065.7	41.7	765
2	IC244090-3	058.1	29.7	640
3	IC244101-2	062.7	38.8	790
4	IC244100-3	082.4	44.8	536
5	IC244100-1	083.0	51.0	342
6	IC244097-3	076.7	42.2	780
7	IC244078-3	088.2	50.1	464
8	IC244085-3	098.0	49.0	750
9	IC244081-2	092.9	56.3	985
10	IC244077-1-3	115.0	75.3	968
11	IC244083-1-2	075.1	30.5	714
12	IC409055	121.1	74.9	685
13	IC244077-12	148.5	82.0	378
14	IC244110	130.0	64.3	214
15	IC244111-1	069.6	41.2	390
16	IC244113-1	057.5	29.6	566
17	IC244113-2	072.8	50.5	589
18	IC354021-2	071.0	30.7	442
19	IC244094-1	087.2	37.6	679
20	IC354021-3	096.9	48.9	520
21	IC244106-1	131.1	83.5	330
22	IC244083-1-1	074.1	53.2	364
23	IC244084-1	080.1	48.2	498
24	IC244084-2	051.4	31.4	860
25	IC244110-1-1	083.4	48.7	798
26	IC354070-3	060.7	32.9	114
27	IC354018-3	101.8	51.6	350
28	IC2447743	094.7	48.6	126
29	IC354022-3	074.4	39.8	252
30	IC342325-2	069.4	37.4	70
31	Home garden1	085.7	48.2	748
32	Home garden2	061.0	36.6	320

Plate 6. Variability in fruit size in *G. gummi-gutta*

Table 9: Seed characters of different accessions of *G. guimmi-gutta*

Sl. No.	Accessions	Seed size		Seed weight (g)	Seed germination %
		Seed length (cm)	Seed breadth (cm)		
1	IC244101-3	2.6	1.1	0.75	60.0
2	IC244090-3	3.0	1.3	0.70	46.6
3	IC244101-2	2.5	1.1	0.65	53.3
4	IC244100-3	2.0	1.0	0.75	36.7
5	IC244100-1	3.0	1.1	1.10	76.7
6	IC244097-3	3.2	1.3	0.85	53.3
7	IC244078-3	2.9	1.0	1.20	60.0
8	IC244085-3	2.0	0.9	0.70	66.7
9	IC244081-2	2.4	1.3	1.05	63.3
10	IC244077-1-3	2.5	1.1	0.95	73.3
11	IC244083-1-2	2.2	0.8	0.90	46.7
12	IC409055	2.8	1.2	1.05	56.7
13	IC244077-12	2.0	1.0	0.65	80.0
14	IC244110	3.0	1.4	1.00	30.0
15	IC244111-1	2.8	1.0	0.75	36.7
16	IC244113-1	2.3	0.9	1.20	53.3
17	IC244113-2	3.5	1.4	0.85	66.7
18	IC354021-2	2.8	1.1	0.85	53.3
19	IC244094-1	3.3	1.0	0.95	40.0
20	IC354021-3	2.0	1.0	0.90	46.7
21	IC244106-1	3.4	1.2	0.70	56.7
22	IC244083-1-1	2.8	1.1	1.05	63.3
23	IC244084-1	1.9	1.0	0.90	36.6
24	IC244084-2	2.7	1.3	0.85	76.7
25	IC244110-1-1	3.2	1.2	1.05	53.3
26	IC354070-3	2.5	1.0	0.80	50.0
27	IC354018-3	2.7	1.3	0.65	33.3
28	IC2447743	2.8	1.4	0.75	73.4
29	IC354022-3	2.0	1.1	0.75	53.3
30	IC342325-2	2.5	1.1	0.85	56.7
31	Home garden1	2.4	1.0	0.75	50.0
32	Home garden 2	2.2	1.2	0.70	46.7

Table 9: Seed characters of different accessions of *G. guimmi-gutta*

Sl. No.	Accessions	Seed size		Seed weight (g)	Seed germination %
		Seed length (cm)	Seed breadth (cm)		
1	IC244101-3	2.6	1.1	0.75	60.0
2	IC244090-3	3.0	1.3	0.70	46.6
3	IC244101-2	2.5	1.1	0.65	53.3
4	IC244100-3	2.0	1.0	0.75	36.7
5	IC244100-1	3.0	1.1	1.10	76.7
6	IC244097-3	3.2	1.3	0.85	53.3
7	IC244078-3	2.9	1.0	1.20	60.0
8	IC244085-3	2.0	0.9	0.70	66.7
9	IC244081-2	2.4	1.3	1.05	63.3
10	IC244077-1-3	2.5	1.1	0.95	73.3
11	IC244083-1-2	2.2	0.8	0.90	46.7
12	IC409055	2.8	1.2	1.05	56.7
13	IC244077-12	2.0	1.0	0.65	80.0
14	IC244110	3.0	1.4	1.00	30.0
15	IC244111-1	2.8	1.0	0.75	36.7
16	IC244113-1	2.3	0.9	1.20	53.3
17	IC244113-2	3.5	1.4	0.85	66.7
18	IC354021-2	2.8	1.1	0.85	53.3
19	IC244094-1	3.3	1.0	0.95	40.0
20	IC354021-3	2.0	1.0	0.90	46.7
21	IC244106-1	3.4	1.2	0.70	56.7
22	IC244083-1-1	2.8	1.1	1.05	63.3
23	IC244084-1	1.9	1.0	0.90	36.6
24	IC244084-2	2.7	1.3	0.85	76.7
25	IC244110-1-1	3.2	1.2	1.05	53.3
26	IC354070-3	2.5	1.0	0.80	50.0
27	IC354018-3	2.7	1.3	0.65	33.3
28	IC2447743	2.8	1.4	0.75	73.4
29	IC354022-3	2.0	1.1	0.75	53.3
30	IC342325-2	2.5	1.1	0.85	56.7
31	Home garden1	2.4	1.0	0.75	50.0
32	Home garden 2	2.2	1.2	0.70	46.7

Plate 7. Variation in seed size of *G. gummi-gutta*

Plate 8. Germinated seedlings of *G. gummi-gutta*

Table 10: Primary metabolites in different accessions of *G. gummi-gutta*

Sl. No.	Accessions	Carbohydrates (g/100 g)	Protein (g/100 g)	Crude fats %	Reducing sugar%
1	IC244101-3	26.35	1.19	5.52	4.11
2	IC244090-3	20.37	1.21	6.08	4.16
3	IC244101-2	25.24	1.07	4.34	4.22
4	IC244100-3	23.58	1.24	3.70	4.11
5	IC244100-1	26.91	0.99	4.78	3.90
6	IC244097-3	25.00	1.09	6.10	4.00
7	IC244078-3	26.04	1.22	5.94	4.16
8	IC244085-3	21.04	0.99	5.10	4.22
9	IC244081-2	24.69	1.29	3.52	3.95
10	IC244077-1-3	22.90	1.07	5.30	3.85
11	IC244083-1-2	29.69	0.93	4.10	4.00
12	IC409055	21.85	1.15	4.24	4.00
13	IC244077-1-2	25.43	1.09	5.94	4.16
14	IC244110	29.32	0.97	3.46	3.85
15	IC244111-1	23.51	1.05	4.50	4.03
16	IC244113-1	18.08	1.00	3.88	4.22
17	IC244113-2	24.38	1.06	5.66	4.11
18	IC354021-2	18.82	1.23	5.84	4.00
19	IC244094-1	25.67	1.09	3.28	4.31
20	IC354021-3	21.72	1.00	5.66	4
21	IC244106-1	22.22	0.95	5.54	4.31
22	IC244083-1-1	21.41	1.09	3.98	4.16
23	IC244084-1	25.86	1.01	4.70	4.11
24	IC244084-2	22.90	1.29	5.68	3.90
25	IC244110-1-1	20.74	1.06	6.02	4.11
26	IC354070-3	24.75	1.11	4.08	4.00
27	IC354018-3	25.92	1.04	3.92	3.85
28	IC2447743	21.72	1.15	5.26	4.03
29	IC354022-3	24.32	0.95	4.64	4.22
30	IC342325-2	26.91	0.95	4.36	4.03
31	Home garden1	28.08	1.06	6.18	4.22
32	Home garden2	24.30	1.01	5.30	4.00

Table 11: Secondary metabolites in different accessions of *G. gummi-gutta*

Sl. No.	Accessions	Phenolics (mg/100 g)	Flavonoids (mg/100 g)
1	IC244101-3	0950	154
2	IC244090-3	1080	201
3	IC244101-2	0950	214
4	IC244100-3	1155	158
5	IC244100-1	1082	173
6	IC244097-3	1150	146
7	IC244078-3	0960	148
8	IC244085-3	1200	235
9	IC244081-2	0900	158
10	IC244077-1-3	1020	240
11	IC244083-1-2	0950	164
12	IC409055	1100	152
13	IC244077-1-2	1050	205
14	IC244110	1082	237
15	IC244111-1	1152	180
16	IC244113-1	1035	154
17	IC244113-2	1155	216
18	IC354021-2	1080	150
19	IC244094-1	1020	154
20	IC354021-3	1075	206
21	IC244106-2	1020	155
22	IC244083-1	1075	211
23	IC244084-1	1090	154
24	IC244084-2	1050	147
25	IC244110-1-1	1080	236
26	IC354070-3	1050	214
27	IC354018-3	0980	160
28	IC2447743	0920	172
29	IC354022-3	1110	140
30	IC342325-2	1010	127
31	Home garden1	1160	230
32	Home garden2	1020	211

Table 12: Minerals content of fruits in different accessions of *G. gummi-gutta*

Sl. No.	Accessions	Ca (mg/100 g)	Na (mg/100 g)	K (mg/100 g)	P (mg/100 g)	Mg (mg/100 g)
1	IC244101-3	208.80	60	151.0	36.6	11.93
2	IC244090-3	212.25	98	227.1	41.2	11.61
3	IC244101-2	209.12	60	160.1	51.5	11.56
4	IC244100-3	191.34	52	121.2	52.4	11.19
5	IC244100-1	105.44	64	195.9	44.4	12.05
6	IC244097-3	132.30	74	135.4	40.5	11.69
7	IC244078-3	179.70	51	130.6	34.9	12.10
8	IC244085-3	161.30	82	159.3	35.8	11.69
9	IC244081-2	156.18	55	145.0	52.4	12.01
10	IC244077-1-3	112.52	86	157.5	42.2	11.68
11	IC244083-1-2	174.82	72	207.9	46.1	12.02
12	IC409055	210.00	93	141.6	31.6	12.07
13	IC244077-1-2	200.00	91	133.9	34.8	11.80
14	IC244110	189.40	98	167.1	38.1	11.82
15	IC244111-1	193.20	69	115.8	26.4	12.62
16	IC244113-1	176.60	45	190.4	28.3	11.75
17	IC244113-2	152.40	71	148.4	20.4	11.80
18	IC354021-2	202.50	75	201.2	25.2	11.76
19	IC244094-1	175.60	96	134.8	35.2	12.33
20	IC354021-3	131.50	68	144.5	23.5	11.88
21	IC244106-1	197.40	59	129.6	48.4	12.54
22	IC244083-1-1	174.40	92	165.4	39.5	11.57
23	IC244084-1	158.40	62	189.2	29.6	11.99
24	IC244084-2	177.80	68	158.3	50.2	11.80
25	IC244110-1-1	119.40	84	193.5	38.9	12.87
26	IC354070-3	163.50	56	141.6	33.8	11.66
27	IC354018-3	170.50	44	166.4	29.4	11.84
28	IC2447743	200.40	68	210.7	41.6	12.46
29	IC354022-3	203.10	41	138.9	30.5	10.00
30	IC342325-2	139.50	68	147.4	47.7	11.83
31	Home garden1	192.40	65	156.2	48.5	11.05
32	Home garden2	157.30	90	131.7	36.4	12.63

The variation in Na content was also observed among the various accessions. The lowest Na content was observed in IC354022-3(41 mg/100 g) and highest Na content found in IC244090-3 (98 mg/100 g). The average Na content recorded was 70.5 mg/100 g. The K content of fruits between different accessions varied from 115.8 mg/100 g to 227.1 mg/100 g. The maximum K content was found in IC244090-3 (227.1 mg/100 g) and minimum was in IC244111-1(115.8 mg/100 g). The average K content found was 159.3 mg/100 g.

The average P content of fruits recorded was 38 mg/100 g. The P content between different accessions ranged from 20.4 mg/100 g to 52.4 mg/100 g. The highest P content found in IC244100-3 (52.4 mg/100 g) and lowest was recorded in IC244113-2 (20.4 mg/100 g).

The Mg content found maximum in IC244110-1-1 (12.87 mg/100 g) and minimum in IC354022-3 (10 mg/100 g). The average Mg content was 11.86 mg/100 g.

4.10. Vitamins content in fruits

Vitamins content of fruits showed considerable variation, the results are furnished in Table 13.

The variation in vitamin B_1 content between fruits of different accessions was observed. The highest vitamin B_1 was recorded in IC244084-2 (54.55 µg/100 g) and lowest was in IC244100-3 (29.64 µg/100 g). The mean vitamin B_1 content was 43.26 µg/100g.

Vitamin B2 content of fruits ranged from 11.26 µg/100 g to 25.07 µg/100 g. The highest vitamin B_2 found in IC244084-2 (25.07 µg/100 g) and lowest was recorded in IC244106-1(11.26 µg/100 g). The mean vitamin B2 content was 18.76 µg/100 g.

The average vitamin B_{12} content found in fruit was 43.53 µg/100 g. The vitamin B_{12} content between accessions ranged from 30.39 µg/100 g (IC244106-1) to 56.4 µg/100 g (IC244097).

The wide variation in Vitamin C content was observed. Vitamin C content ranged from 16.69 mg/100 g to 27.76 mg/100 g. The lowest vitamin C content was reported in IC244100-3 and highest was in IC244097-3. The mean vitamin C content was 23.02 mg/100 g.

Vitamin A content of fruits found to range from 8.85 µg/100 g (IC244084-2) to 16 µg/100 g (IC244100-1). The average vitamin A content was 12.16 µg/100 g.

Table 13: Vitamins in fruits of different accessions of *G. gummi-gutta*

S. No.	Accessions	Vitamin B_1 (µg/100 g)	Vitamin B_2 (µg/100 g)	Vitamin B_{12} (µg/100 g)	Vitamin C (mg/100 g)	Vitamin A (µg/100 g)	Vitamin E (µg/100 g)
1	IC244101-3	34.47	14.23	34.16	19.27	14.29	35.28
2	IC244090-3	39.65	16.10	39.56	23.4	13.95	40.10
3	IC244101-2	44.56	19.85	47.94	24.86	11.02	25.73
4	IC244100-3	29.64	13.29	32.69	16.69	14.41	35.08
5	IC244100-1	43.22	18.99	43.09	22.18	16.00	45.42
6	IC244097-3	50.65	24.07	56.40	27.08	11.29	32.58
7	IC244078-3	40.78	17.56	41.74	21.45	11.20	47.53
8	IC244085-3	49.81	23.35	54.28	26.76	10.69	37.24
9	IC244081-2	46.48	20.26	46.97	25.93	10.56	30.87
10	IC244077-1-3	40.67	16.44	40.13	21.62	10.45	32.82
11	IC244083-1-2	38.20	15.03	35.88	20.09	10.70	27.50
12	IC409055	47.04	18.90	42.07	21.13	09.03	23.50
13	IC244077-1-2	52.55	22.06	48.48	23.63	11.68	37.06
14	IC244110	47.32	20.17	46.10	23.16	13.25	27.90
15	IC244111-1	48.18	21.00	49.20	26.58	11.24	26.57
16	IC244113-1	37.56	15.90	38.21	21.39	14.89	29.10
17	IC244113-2	43.20	20.40	44.57	22.77	15.49	38.10
18	IC354021-2	39.27	14.74	37.54	24.27	12.18	32.10
19	IC244094-1	41.31	15.52	38.47	20.76	14.47	37.01
20	IC354021-3	41.28	17.51	43.07	24.75	13.82	35.70
21	IC244106-2	33.41	11.26	30.39	19.11	11.07	39.50
22	IC244083-1	53.65	23.65	53.11	27.76	11.90	30.16
23	IC244084-1	45.93	21.91	48.22	20.64	12.89	33.93
24	IC244084-2	54.55	25.07	55.20	27.27	08.85	25.19
25	IC244110-1-1	43.18	21.88	46.60	25.70	15.40	38.46
26	IC354070-3	43.53	19.28	40.25	24.50	14.67	29.70
27	IC354018-3	46.65	21.34	47.45	23.79	09.78	27.11
28	IC2447743	35.08	16.10	37.65	19.02	10.01	35.65
29	IC354022-3	42.07	17.69	43.67	22.36	10.52	42.20
30	IC342325-2	49.28	22.72	48.27	24.84	10.56	21.34
31	Home garden1	38.10	15.36	38.24	21.05	10.60	28.40
32	Home garden 2	42.99	18.63	43.37	23.08	12.34	27.64

The highest vitamin E content was found in 47.53 µg/100 g (IC244078-3) and lowest was in 21.34 µg/100 g (IC342325-2). The mean vitamin E content was 33.01 µg/100 g.

4.11. Physico-chemical properties of butter

The physico-chemical properties of butter among various accessions of Malabar tamarind is given in table 14.

Malabar tamarind seed yielded butter which was solid at room temperature. The butters isolated from various accessions showed melting range from 36^0C to 42^0C. The 46.8 percent of accession studied showed melting range of 36-40^0C and 53.1 percent of accessions showed melting range of 38-42^0C.

Colour of Malabar tamarind seed oil was measured in a spectrophotometer using carbon tetrachloride as blank at the wave length of 510 nm. The colour varied from light brown to dark brown.

The saponification value of seed butter varied from 171.81 mg KOH/g (IC244094-1) to 189.34 mg KOH/g (IC244084-2, IC244101-2) and average was 181.62 mg KOH/g.

The acid value range was 3.09 mg KOH/g (IC244077-12) to 4.49 mg KOH/g (IC244084-2, IC244094-1, and IC244077-1-3). The average acid value observed was 3.80 mg KOH/g.

The iodine value ranged from 48.22 (IC244094-1) to76.14 (IC2447743) and average was 60.

4.12. 1. Correlation between morphological characters of *G. gummi-gutta*

A correlation matrix between morphological characters of *G. gummi-gutta* trees (Table 15) showed a significant and positive relation between petal length and petal breadth, weight of fruits and rind weight, Number of fruits per tree and tree height, tree height and height of first branch from base. From this result it was clear that as the petal length increases there was a significant increase in petal breadth, like wise as tree height increases height of first branch from base also increases. There was also significant and negative correlation was observed between petal length and weight of flower, pedicel length and rind weight.

Table 14: Physico-chemical properties of butter in different accessions of *G. gummi-gutta*

S. No.	Accessions	Melting range (^{0}C)	Colour (510 nm)	Saponification value (mg KOH/g)	Acid value (mg KOH/g)	Iodine value
1	IC244101-3	36 - 40	1.044	182.32	4.49	63.45
2	IC244090-3	38 - 42	1.103	182.32	3.92	65.99
3	IC244101-2	38 - 42	0.742	189.33	4.49	63.45
4	IC244100-3	36 - 40	1.301	185.13	3.37	55.84
5	IC244100-1	36 - 40	1.143	181.62	3.37	52.03
6	IC244097-3	38 - 42	1.119	173.91	3.37	58.37
7	IC244078-3	36 - 40	0.805	183.73	4.49	68.53
8	IC244085-3	38 - 42	1.241	185.13	3.93	53.29
9	IC244081-2	36 - 40	1.255	182.33	3.92	65.98
10	IC244077-1-3	38 - 42	1.450	185.83	4.49	50.76
11	IC244083-1-2	38 - 42	1.056	180.22	3.37	60.91
12	IC409055	36 - 40	1.117	178.82	3.93	55.84
13	IC244077-1-2	38 - 42	1.275	182.33	3.08	64.72
14	IC244110	36 - 40	1.053	176.72	3.37	60.91
15	IC244111-1	38 - 42	1.105	180.92	3.93	57.11
16	IC244113-1	38 - 42	0.858	185.83	3.65	67.26
17	IC244113-2	36 - 40	1.321	184.43	4.20	63.45
18	IC354021-2	38 - 42	1.240	182.32	3.37	57.10
19	IC244094-1	36 - 40	1.105	171.80	4.49	48.22
20	IC354021-3	36 - 40	1.328	175.31	3.37	50.76
21	IC244106-2	36 - 40	1.262	180.92	3.37	55.84
22	IC244083-1	36 - 40	1.045	187.23	3.92	58.37
23	IC244084-1	38 - 42	1.364	179.52	3.37	57.11
24	IC244084-2	38 - 42	1.246	189.34	4.49	59.64
25	IC244110-1-1	38 - 42	1.196	175.31	3.93	54.72
26	IC354070-3	36 - 40	1.423	187.94	3.65	67.26
27	IC354018-3	36 - 40	1.114	178.12	3.37	60.91
28	IC2447743	38 - 41	0.847	178.82	3.09	76.14
29	IC354022-3	38 - 42	1.255	175.31	3.65	72.33
30	IC342325-2	38 - 42	1.032	185.13	3.92	65.99
31	Home garden1	36 - 40	1.135	183.02	4.49	63.45
32	Home garden2	38- 42	1.243	180.92	3.65	65.99

Table 15: Correlation between morphological characters of *G. gummi-gutta*

Traits	Petal length	Petal breadth	Pedicel length	Weight of flower	Weight of fruits	Rind weight of fruits	Number of fruits per tree	Tree height	Height of first branch
Petal length	1								
Petal breadth	0.519**	1							
Pedicel length	0.098	0.066	1						
Weight of flower	-0.091	0.140	-0.012	1					
Weight of fruits	0.107	0.146	-0.193	-0.096	1				
Rind weight of fruits	-0.029	0.105	-0.202	-0.169	0.909**	1			
Number of fruits per tree	-0.299	-0.011	0.053	0.254	-0.078	0.006	1		
Tree height	-0.228	0.067	0.123	0.055	-0.066	0.041	0.397*	1	
Height of first branch	-0.336	-0.198	-0.028	-0.053	0.002	0.092	0.047	0.497**	1

Table 16: Correlation between biochemical characters of *G. gummi-gutta*

	Ca	Na	K	P	Mg	Phenol	Flavonoids	Crude fat	Protein	Carbohydrate
Ca	1									
Na	-0.390	1								
K	-0.030	0.140	1							
P	0.004	-0.031	0.024	1						
Mg	-0.226	0.319	0.073	-0.048	1					
Phenol	-0.100	0.211	-0.175	-0.300	-0.304	1				
Flavonoids	-0.206	0.469**	0.094	-0.040	0.050	0.270	1			
Crude fat	-0.069	0.123	0.108	-0.099	-0.057	0.208	0.178	1		
Protein	0.286	-0.002	-0.202	0.199	0.116	-0.190	-0.194	0.143	1	
Carbohydrate	-0.071	-0.081	-0.139	0.281	-0.311	-0.189	-0.034	-0.222	-0.208	1

4.12.2. Correlation between biochemical characters of *G. gummi-gutta*

A correlation matrix between biochemical characters of *G. gummi-gutta* trees are furnished in Table 16. Sodium had a significant and positive relation with flavonoids, Mg and phenol. P had significant and positive relation between carbohydrate and protein; phenol had a positive correlation with flavonoids and crude fat. There was also significant and negative correlation was observed between Ca and Na, Mg and phenol, crude fat and carbohydrates.

4.13. Path analysis for rind yield

Based on the estimates of correlation of various quantitative traits correlated to rind yield of *G. gummi-gutta* were used for path analysis. The estimates of direct and indirect effects of the quantitative traits on rind yield are shown in Table 17.

The contribution of residual effect on rind yield was 0.0546. As per Lenka and Mishra (1973), the direct and indirect effects were classified into:

>1.00	-	very high
0.30 - 0.99	-	high
0.20 - 0.29	-	moderate
0.10 - 0.19	-	low
0.09 - 0.00	-	negligible

4.13.1. Direct effect on rind yield

High, positive and direct effect was exerted by rind weight (0.5637). Low and negative, direct effect was exerted by fruit weight (-0.199) and petal breadth (-0.107). Negligible, direct effect was exerted by petal length (0.032), flower weight (0.022) and number of fruits per tree (0.008) on rind yield.

4.13.2. Indirect effects on rind yield

4.13.2.1 Petal length

Negligible, positive and indirect effect was exerted by petal breadth (0.017) and fruits weight (0.004) through petal length towards rind yield. Negligible, indirect and negative effect was exerted by flowers weight (-0.003), rind weight (-0.001) and number of fruits per tree (-0.010) through petal length towards rind yield.

4.13.2.2. Petal breadth

Negligible, positive and indirect effect was exerted by number of fruits per tree (0.001) through petal breadth towards rind yield. Negligible, indirect and negative effect was exerted by petal length (-0.056), fruit weight (-0.016), flower weight (-0.015) and rind weight (-0.011) through petal breadth on rind yield.

4.13.2.3. Flower weight

Negligible, positive and indirect effect was exerted by number of fruits per tree (0.006) and petal breadth (0.003) through flower weight toward rind yield. Negligible, indirect and negative effect was exerted by rind weight (-0.004), fruit weight (-0.002) and petal length (-0.002) through flower weight toward rind yield.

4.13.2.4. Fruit weight

Low, negative and indirect effect was exerted by rind weight (-0.109) through fruit weight towards rind yield. Negligible, negative and indirect effect was exerted by petal length (-0.013) and petal breadth (-0.018) towards rind yield. Also positive, negligible and indirect effect was exerted by number of fruits per tree (0.010) through fruit weight.

4.13.2.5. Rind weight

High, positive and indirect effect was exerted by fruit weight (0.579) and low, negative and indirect effect was exerted by flower weight (-0.108) through rind weight towards rind yield. Also negligible, negative and indirect effect exerted by petal length (-0.019) and negligible, positive and indirect effect was exerted by petal breadth (0.064) and number of fruits per tree (0.006) through rind weight towards rind yield.

Table 17: Path analysis with direct and indirect effects of fresh rind yield of *G. gummi-gutta*.

Traits	Petal length	Petal breadth	Flower weight	Fruit weight	Rind weight	Number of fruits per tree
Petal length	0.032	-0.056	-0.002	-0.013	-0.019	-0.242
Petal breadth	0.017	-0.107	0.003	-0.018	0.064	-0.008
Flower weight	-0.003	-0.015	0.022	0.012	-0.108	0.202
Fruit weight	0.004	-0.016	-0.002	-0.199	0.579	-0.065
Rind weight	-0.001	-0.011	-0.004	-0.109	0.579	0.008
Number of fruits per tree	-0.010	0.001	0.006	0.010	0.006	0.008

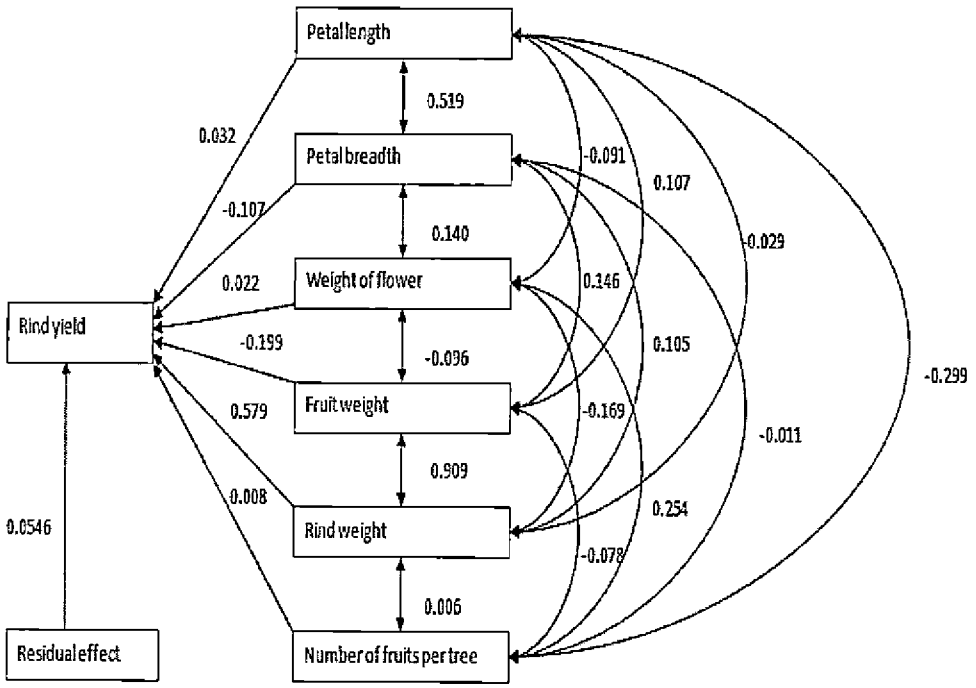

Fig. 1. Path diagram showing direct and indirect effects on rind yield of *G. gummi-gutta*

4.13.2.6. Number of fruits per tree

Moderate, positive and indirect effect was exerted by flower weight (0.202) and moderate, negative and indirect effect was exerted by petal length (-0.242) through number of fruits per tree towards rind yield. Negative, negligible and indirect effect was exerted by fruit yield (-0.065) and petal breadth (-0.008). Also negligible, positive and indirect effect was exerted by rind weight (0.008) through number of fruits per tree towards rind yield.

4.14. Path coefficient analysis for fruit yield

Based on the estimates of correlation of various quantitative traits to fruit yield, traits significantly correlated to fruit yield of *G. gummi-gutta* were used for path analysis. The estimates of direct and indirect effects of the quantitative traits on fruit yield are shown in Table 18. The contribution of residual effect on fruit yield was 0.0486.

4.14.1. Direct effect

High, positive and direct effect was exerted by number of fruits per tree (0.880) and fruit weight (0.404) on fruit yield. Negligible, positive and direct effect was exerted by rind weight (0.090), flower weight (0.032) and petal length (0.027) on fruit yield. Also negligible, negative and direct was exerted by petal breadth (-0.099) on fruit yield.

4.14.2. Indirect effects

4.14.2.1. Petal length

Negligible, positive and indirect effect was exerted by petal breadth (0.014) and fruit weight (0.003) through petal length towards fruit yield. Negligible, negative and indirect effect was exerted by number of fruits per tree (-0.008), flower weight (-0.002) and rind weight (-0.001) through petal length toward fruit yield.

4.14.2.2. Petal breadth

Negligible, positive and indirect effect was exerted by number of fruits per tree (0.001) through petal breadth towards fruit yield. Negligible, negative, indirect effect was exerted by

petal length (-0.052), fruit weight (-0.015), flower weight (-0.014) and rind weight (-0.010) through petal breadth toward fruit yield.

4.14.2.3. Flower weight

Negligible, positive, indirect effect was exerted by number of fruits per tree (0.008) and petal breadth (0.004) through flower weight towards fruit yield. Negligible, negative and indirect effect was exerted by rind weight (-0.005), petal length (-0.003) and fruit weight (-0.003) through petal breadth toward fruit yield.

4.14.2.4. Fruit weight

High, positive, indirect effect was exerted by rind weight (0.367) and negligible, positive and indirect effect was exerted by petal breadth (0.061) and petal length (0.044) through fruit weight towards fruit yield. Also negligible, negative and indirect effect was exerted by flower weight (-0.040) and number of fruits per tree (-0.003) through fruit weight towards fruit yield.

4.14.3.4. Rind weight

Negligible, positive, indirect effect was exerted by fruit weight (0.082), petal breadth (0.009) and number of fruits per tree (0.001) through rind weight towards fruit yield. Negligible, negative and indirect effect was exerted by weight of flower (-0.015) and petal length (-0.003) through rind weight towards fruit yield.

4.14.3.5. Number of fruits per tree

Moderate, positive, indirect effect was exerted by weight of flower (0.220) and moderate, negative and indirect effect was exerted by petal length (-0.264) through number of fruits per tree towards fruit yield. Negligible, positive, indirect effect was exerted by rind weight (0.009). Also negligible, negative and indirect effect was exerted by fruit weight (-0.070) and petal breadth (-0.009) through number of fruits per tree towards fruit yield.

Table 18: Path analysis with direct and indirect effects of fresh fruit yield of *G. gummi-gutta.*

Traits	Petal length	Petal breadth	Flower weight	Fruit weight	Rind weight	Number of fruits per tree
Petal length	0.027	-0.052	-0.003	0.044	-0.003	-0.264
Petal breadth	0.014	-0.099	0.004	0.061	0.009	-0.009
Flower weight	-0.002	-0.014	0.032	-0.040	-0.015	0.220
Fruit weight	0.003	-0.015	-0.003	0.404	0.082	-0.070
Rind weight	-0.001	-0.010	-0.005	0.367	0.090	0.009
Number of fruits per tree	-0.008	0.001	0.008	-0.032	0.001	0.880

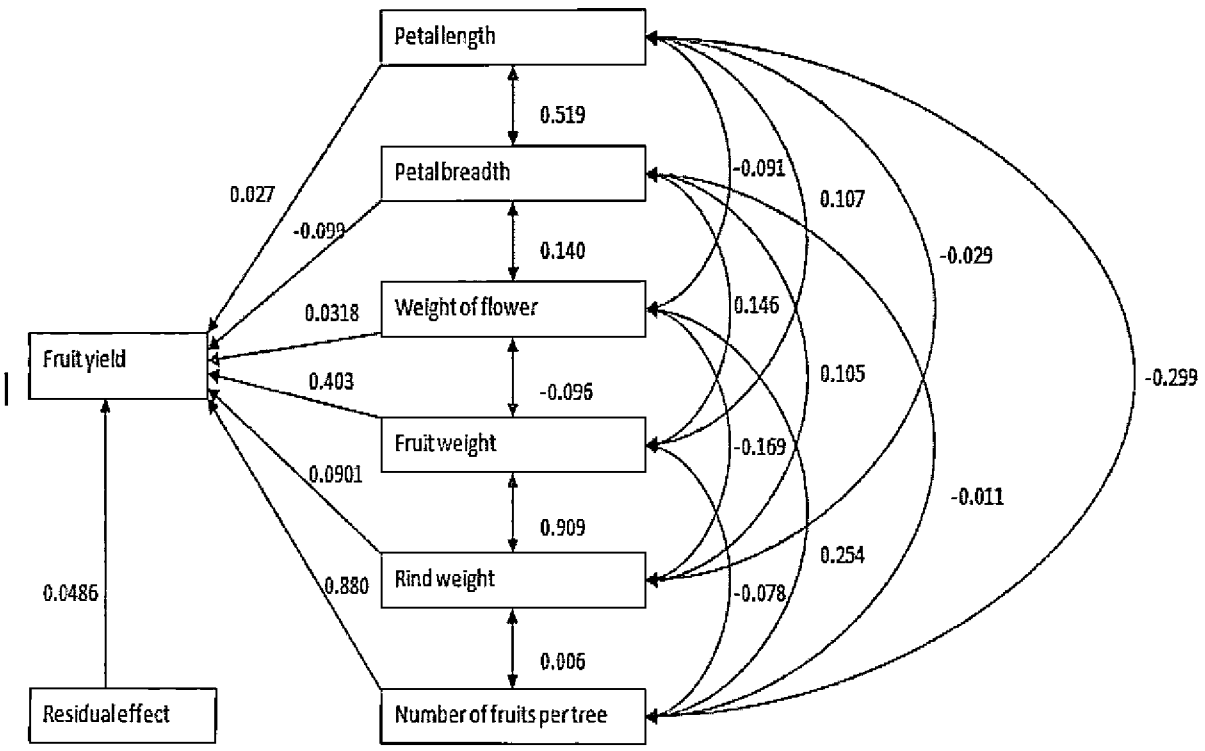

Fig. 2. Path diagram showing direct and indirect effects on fruit yield of *G. gummi-gutta*

4.15. Cluster analysis for morphology and biochemical characters of *G. gummi-gutta*

Hierarchical cluster analysis using wards method was employed to classify the entries in the study (Fig. 3). Forty-seven characters viz. saponification value, acid value, iodine value, petal length, petal breadth, pedicel length, flower weight, fruit weight, rind weight, number of fruits per tree, leaf characters, Ca, Na, K, P, Mg, tree height, height of first branch, phenol, flavonoid, crude fat protein, carbohydrate, reducing sugar, vitamin B_1, vitamin B_2, vitamin B_{12}, vitamin C, vitamin A, vitamin E, seed weight and seed germination were considered and dendrogram was formulated.

Thirty two fruit bearing accessions were used in formulating dendrogram. The detail of each cluster is presented in Table 19. Out of 32 accessions including two trees from home garden, five clusters were formed. IC244101-3, IC244101-2, IC244083-1-2, IC244084-2, IC244110-1-1, IC244081-2 and IC244077-1-3 formed one cluster. IC244090-3, IC409055, IC244094-1, IC244100-3, IC244113-2, IC44097-3, IC244085-3 and Home garden1 formed second cluster. IC244078-3, IC244113-1, IC354021-3, IC354021-2 and IC244084-1 formed third cluster. IC244100-1, IC244077-12, IC244083-1-1, Homegarden2, IC244106-1, IC354018-3, IC244111-1, IC244110 and IC354022-3 formed fourth cluster. IC354070-3, IC342325-2 and IC2447743 formed fifth cluster. Among 5 clusters, forth was biggest and fifth was smaller. The cluster wise distribution of morphology and biochemical characters using dendrogram was furnished in Table 19.

Clusterwise distribution of morphology and biochemical characters Showed (Table 20) that cluster1 composed of highest acid value, number of fruits per tree, P, flavonoids, protein, vitamin C and seed germination. Cluster II composed of highest value of Ca, Na, tree height, phenol content and reducing sugar. Similarly cluster III composed of highest fruit weight, rind weight, carbohydrates, vitamin B_1, vitamin B_2 and vitamin B_{12}. Cluster IV composed of highest petal length, petal breadth, pedicel length, flower weight, K, crude fat, vitamin A and vitamin E. Cluster V had highest saponification value, iodine value, leaf length, leaf breadth, Mg and height of first branch.

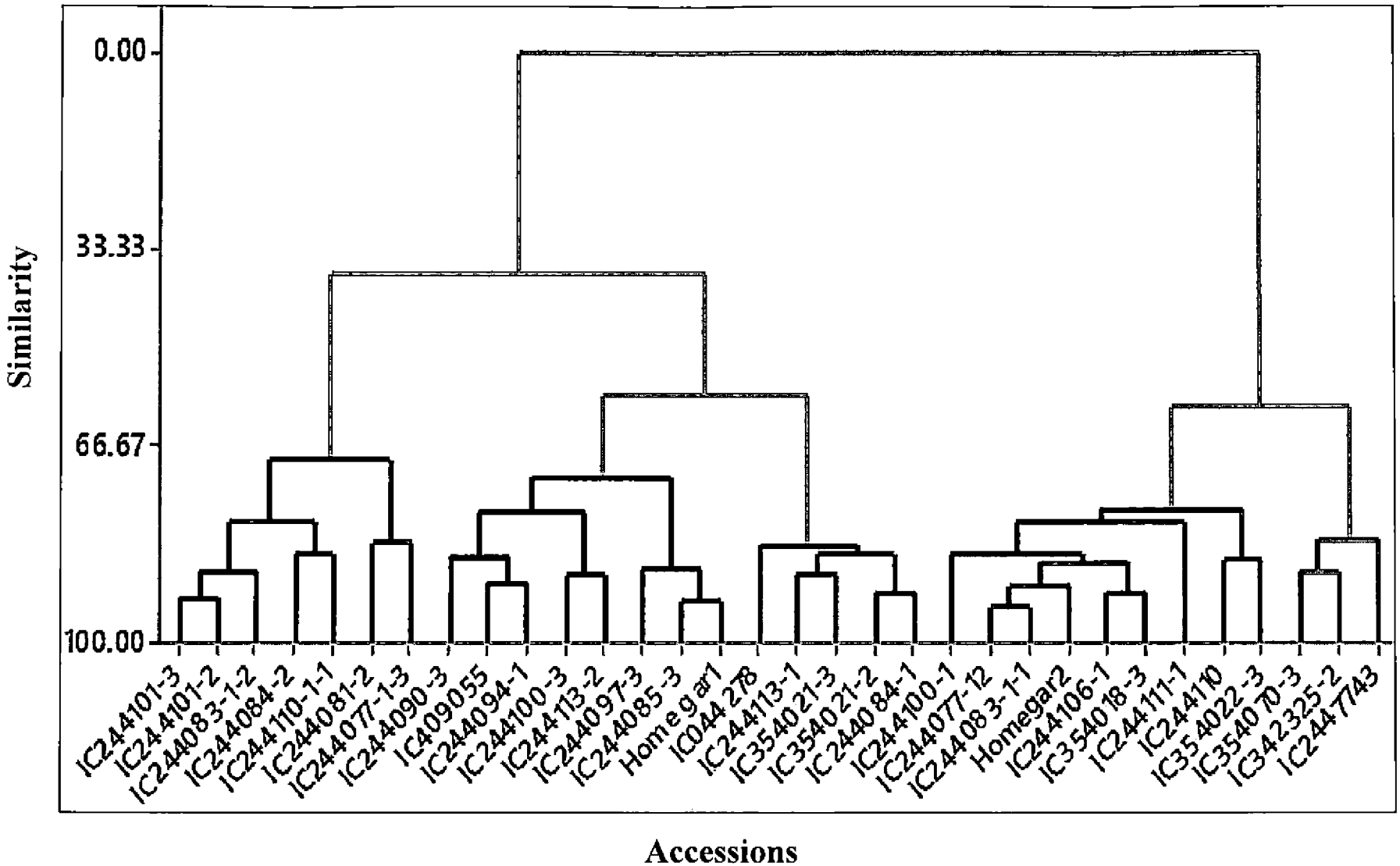

Fig.3: Dendrogram on morphology and biochemical attributes in 30 accessions and 2 home garden collections of *G. gummi-gutta*

Table 19: Clusters formed by accessions based on morphology and biochemical characters using dendrogram

Clusters	I	II	III	IV	V
Accessions	IC244101-3 IC244101-2 IC244083-1-2 IC244084-2 IC244110-1-1 IC244081-2 IC244077-1-3	IC244090-3 IC409055 IC244094-1 IC244100-3 IC244113-2 IC44097-3 IC244085-3 Home garden1	IC244078-3 IC244113-1 IC354021-3 IC354021-2 IC244084-1	IC244100-1 IC244077-1-2 IC244083-1-1 Home garden2 IC244106-1 IC354018-3 IC244111-1 IC244110 IC354022-3	IC354070-3 IC342325-2 IC2447743

Table 20: Clusterwise distribution of morphology and biochemical characters using dendrogram

Variable	Cluster I	Cluster II	Cluster III	Cluster IV	Cluster V
Saponification value (mg KOH/ 100 g)	183.52	180.57	180.46	181.34	183.96
Acid value (mg KOH/100 g))	004.17	003.96	003.52	003.65	003.56
Iodine value	059.85	058.06	060.91	060.15	069.79
Petal length (cm)	000.97	000.95	001.03	001.07	000.99
Petal breadth (cm)	000.63	000.64	000.66	000.67	000.56
Pedicel length (cm)	000.50	000.51	000.46	000.55	000.47
Flower weight (g)	000.61	000.63	000.58	000.64	000.53
Weight of ten fruits (g)	000.78	000.85	000.97	000.79	000.75
Rind weight of ten fruits (g)	000.46	000.47	000.56	000.42	000.39
Number of fruits per tree	840.00	675.88	326.67	498.00	103.33
Leaf length (cm)	011.37	011.63	010.93	010.99	011.89
Leaf breadth (cm)	005.01	005.38	005.01	004.49	005.39
Ca (mg/100 g)	165.52	178.45	176.75	169.74	167.80
Na (mg/100 g)	069.29	078.88	072.00	060.20	064.00
K (mg/100 g)	167.61	153.00	149.41	171.18	166.57
P (mg/100 g)	045.41	038.20	036.43	028.30	041.03
Mg (mg/100 g)	011.98	011.68	011.87	011.90	011.98
Tree height (m)	011.82	012.88	009.50	009.50	007.33
Height of first branch (m)	001.96	002.32	001.70	002.06	002.58
Phenol (mg/100 g)	985.71	1127.5	1063.4	1048.0	993.30
Flavonoids (mg/100 g)	187.57	186.50	185.78	162.40	171.00
Crude fats %	004.93	005.04	004.67	005.20	004.57
Protein (g/100 g)	001.13	001.11	001.01	001.09	001.08
Carbohydrate (g/100 g)	024.64	023.75	024.82	022.10	024.46
Reducing sugar %	004.02	004.14	004.05	004.10	004.02
Vitamin B_1 (µg/100g)	043.16	042.43	045.56	040.96	042.63
Vitamin B_2 (µg/100g)	018.97	018.37	019.42	017.52	019.37
Vitamin B_{12} (µg/100g)	043.84	043.28	044.98	041.76	042.06
Vitamin C (µg/100g)	023.53	022.46	023.52	022.50	022.79
Vitamin A (µg/100g)	011.61	012.49	011.98	013.00	011.75
Vitamin E (µg/100g)	030.84	034.00	033.73	035.67	028.89
Seed weight (g)	000.02	000.02	000.02	000.02	000.02
Seed germination %	060.94	052.08	052.97	049.98	060.03

4.16. Principal component analysis (PCA)

A principal component analysis was carried out using the biochemical and morphological characters of all the entries in the study.

4.16.1. Biochemical features

The scree plot of PCA (Fig 4) showed that the first two components had eigen values >2.The first two main principal components explain 34.9 percent of variation of the biochemical properties of the entries (Table 20). PC1 accounted for 21.6 percent of the total variation contributed chiefly by vitamin B_1, vitamin B_2, vitamin B_{12} and vitamin C with PC loading of 0.453, 0.450, 0.453 and 0.422 respectively. Whereas PC2 accounted for 13.2 percent of the total variation,contributed majorly by iodine value, vitamin A, phenol and vitamin E with PC loading of 0.332, -0.396, -0.309 and -0.305 respectively. The traits, which contributed more positively to PC1 were vitamin B_1, vitamin B_2, vitamin B12 and vitamin C. PC 2 contributed more positively by iodine value and vitamin A, whereas phenol and vitamin E were negetively contributed. PC3 accounted for 9.8 percent of total variation and variables such as carbohydrates, reducing sugar and crude fat were the main contributing factors with loading of 0.369, -0.377 and 0.363 respectively. PC4 accounted for 8.4 percent of total variation and had Mg, phenol and Na as main contributers with loading of -0.454, 0.335 and -0.337 respectively. PC5 had high loading for K, acid value and iodine value i.e. -0.412, 0.419 and -0.345 respectively and contributed 7.4 percent of total variation. In PC6 three attributes such as Ca, Na, vitamine E were main contributing factors with loading of -0.480, -0.431 and 0.315 respctively. It explained 6.2 percent of total variation. PC7 had K, flavonoids and protein as a main contributing factors with loading of -0.431, -0.459 and 0.340 respectively. Similarly in PC8 crude fat, carbohydrates and saponification value were main contributing factors with loading of 0.477, 0.429 and -0.329 respectively. However, crude fat and carbohydrates positively contributed, but saponification value contributed negatively. Further, PC9 accounted for 4.5% of total variation and the reducing sugar, phenol and vitamin C were main contributing factors here.

From the PC loading plot (Fig.5) it could be inferred that the characters like vitamin B_1, vitamin B_2, vitamin B_{12} and vitamin C are linked together. It is evident that the angle between the above characters are extremely acute in nature which infers that they are positively

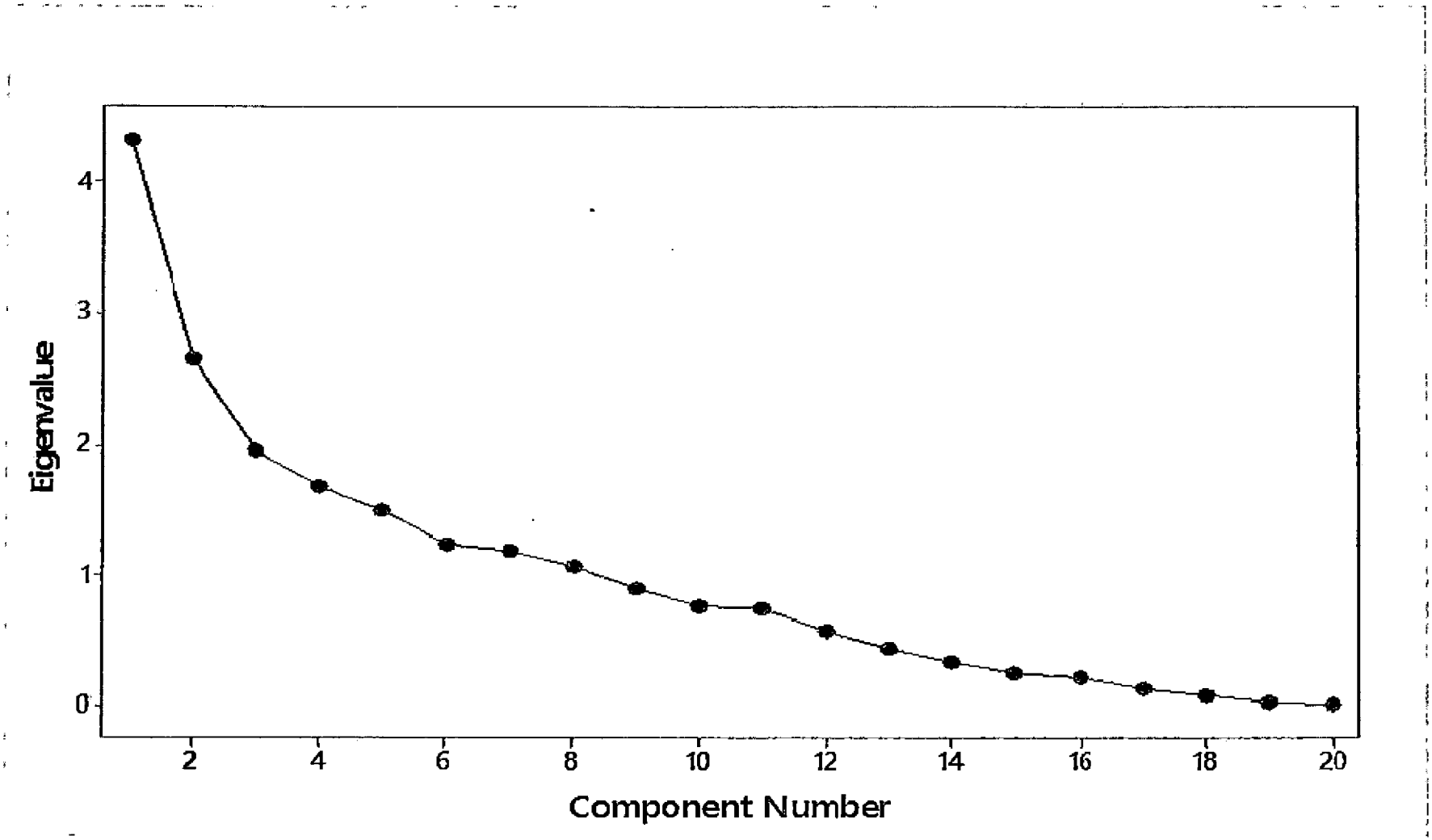

Fig. 4: Scree plot of biochemical characters of *G. gummi-gutta*

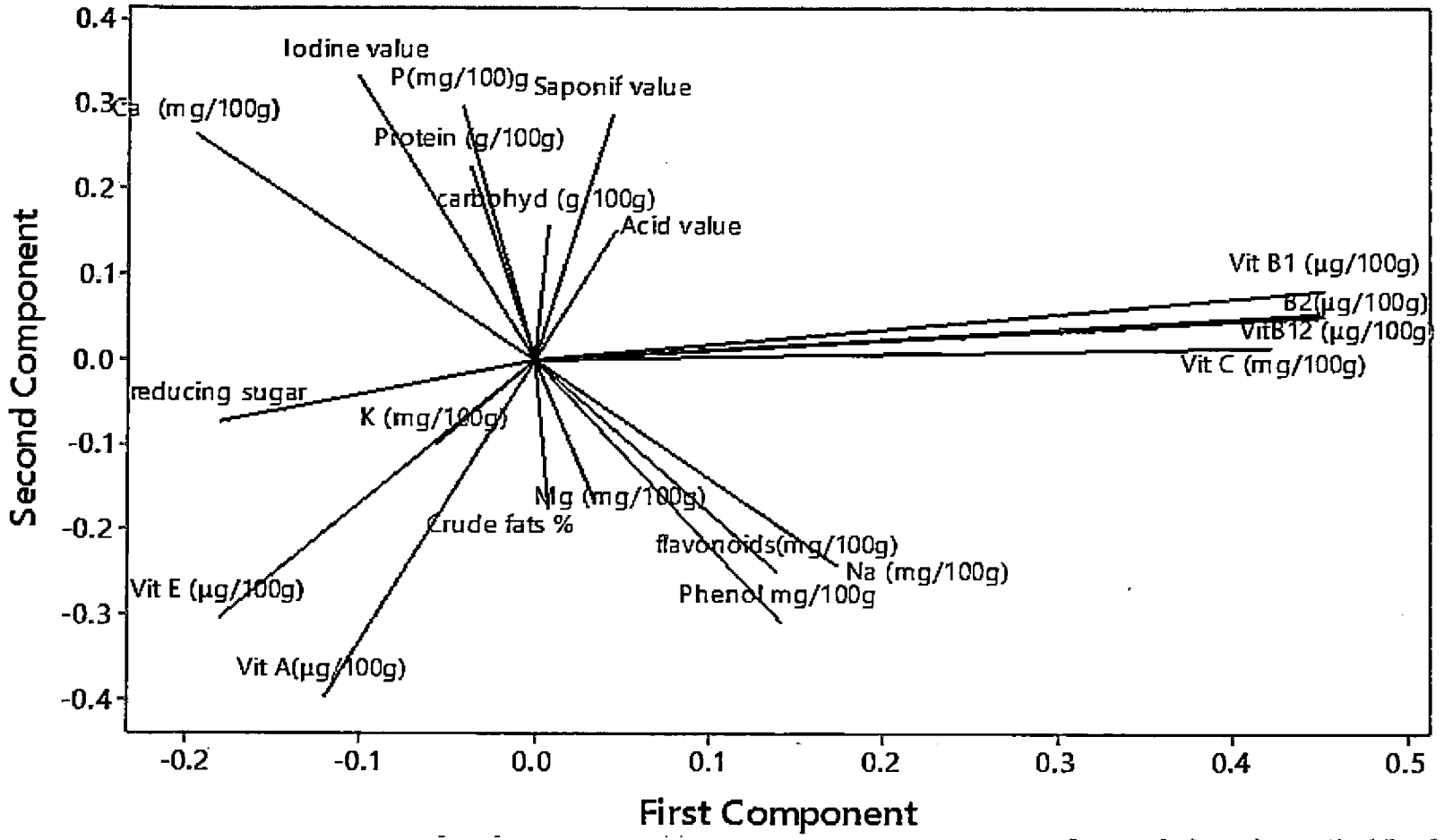

Fig5: Loading plot of biochemical characters of *G. gummi-gutta*

Table 21: Principle component analysis of biochemical characters of *G. gummi-gutta*

Variables	Components								
	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9
Saponification value (mg KOH/g)	0.044	0.287	-0.321	-0.199	0.125	0.298	-0.223	-0.329	0.077
Acid value	0.045	0.150	-0.351	-0.203	0.419	0.024	0.225	0.026	0.235
Iodine value mg KOH/g)	-0.103	0.332	-0.086	0.136	-0.345	0.200	-0.227	0.282	0.305
Ca (mg/100 g)	-0.194	0.262	-0.243	0.130	-0.107	-0.480	-0.243	0.116	0.048
Na (mg/100 g)	0.173	-0.242	-0.050	-0.337	0.106	-0.431	-0.215	0.254	-0.074
K (mg/100 g)	-0.057	-0.101	0.054	-0.304	-0.412	0.205	-0.431	0.042	-0.043
P (mg/100 g)	-0.042	0.297	0.038	-0.294	0.299	0.190	-0.027	0.196	-0.276
Mg (mg/100 g)	0.033	-0.164	0.219	-0.454	-0.111	-0.249	0.280	0.061	0.370
Phenol (mg/100 g)	0.141	-0.309	-0.248	0.335	0.157	-0.075	-0.137	-0.156	-0.396
Flavonoids (mg/100 g)	0.139	-0.250	-0.169	-0.232	0.255	0.123	-0.459	0.138	0.079
Crude fats %	0.008	-0.176	-0.363	-0.106	-0.220	0.159	0.175	0.477	-0.280
Protein (g/100 g)	-0.037	0.227	-0.311	-0.308	-0.171	-0.062	0.340	-0.177	-0.234
Carbohydrates (g/100 g)	0.007	0.156	0.369	0.111	0.392	0.189	-0.008	0.429	0.001
Reducing sugar %	-0.181	-0.073	-0.377	0.240	0.162	-0.166	-0.013	0.178	0.421
Vitamin B_1	0.453	0.082	0.001	0.085	-0.045	-0.074	0.025	0.078	0.090
Vitamin B_2	0.450	0.054	0.003	0.086	-0.091	0.109	0.046	0.042	0.120
Vitamin B_{12}	0.453	0.051	-0.046	0.124	-0.078	0.066	0.067	0.079	0.057
Vitamin C	0.422	0.014	-0.136	-0.007	-0.126	0.046	0.031	-0.057	0.122
Vitamin A	-0.121	-0.396	-0.013	-0.045	0.078	0.278	-0.024	-0.283	0.328
Vitamin E	-0.180	-0.305	-0.187	0.099	-0.096	0.315	0.306	0.272	0.027
Eigenvalue	4.32	2.64	1.96	1.68	1.49	1.24	1.19	1.061	0.89
Proportion	0.216	0.132	0.098	0.084	0.074	0.062	0.060	0.053	0.045
Cumulative	0.216	0.349	0.446	0.531	0.605	0.667	0.727	0.780	0.824

associated. Like wise acid value, saponification value, phosphorous and carbohydrate have positive association. Phenol, flavonoids, sodium also positively associated. However vitamin A and E are negatively associated with vitamin B_{12} and vitamin C. The characters which were absolutely perpendicular to each other like Ca and acid value have no association.

4.16.1.1. Grouping of biochemical characters

Based on the first two components of the PC analysis grouping pattern was made (Table 22). Out of 30 accessions and 2 trees from home garden, 4 groups were formed. This was furnished in Fig 6, which graphically represented relative positions of various accessions. Group III was formed maximum number of accessions and group II formed minimum accessions. The mean performance of groups (Table 23) depicted that group I had high value for saponification value, acid value, phosphorous, vitamin B_1, vitamin B_2 and vitamin B_{12} content, moderate iodine value, Ca, phenol content and low reducing and crude fat content. Group II showed very high value of iodine, calcium and carbohydrates. For other characters group II showed moderate value. However, vitamin A, vitamin E and K displayed maximum mean value in group III. In group IV phenol, flavonoids, crude fat and Mg expressed maximum value and for other characters such as Ca, P, saponification value, acid value it expressed low value.

4.16. 2. Morphological features

The scree plot of PCA (Fig.7) showed that the first 2 components had eigen values >2. The first two main principal components explain 37.4 percent of variation of the morphological properties of the entries (Table 24).

PC1 accounted for 21.6 percent of the total variation. The fruit weight, rind weight, pedicel length and leaf breadth were important contributing factors with loading of 0.573, 0.558, -0.262 and -0.399 respectively. However, fruit weight and rind weight were positively and pedicel length and leaf breadth were negatively contributed here. PC2 had high loading for petal length, tree height and height of first branch with total variation of 17.3 percent. PC3 contributed 13.9 percent of total variation and weight of flower, rind weight and seed weight were main contributing factors here with loading of -0.647, -0.647 and 0.366 respectively. Similarly PC4 had accounted for 11.6 percent of total variation with petal length and pedicel breadth as main

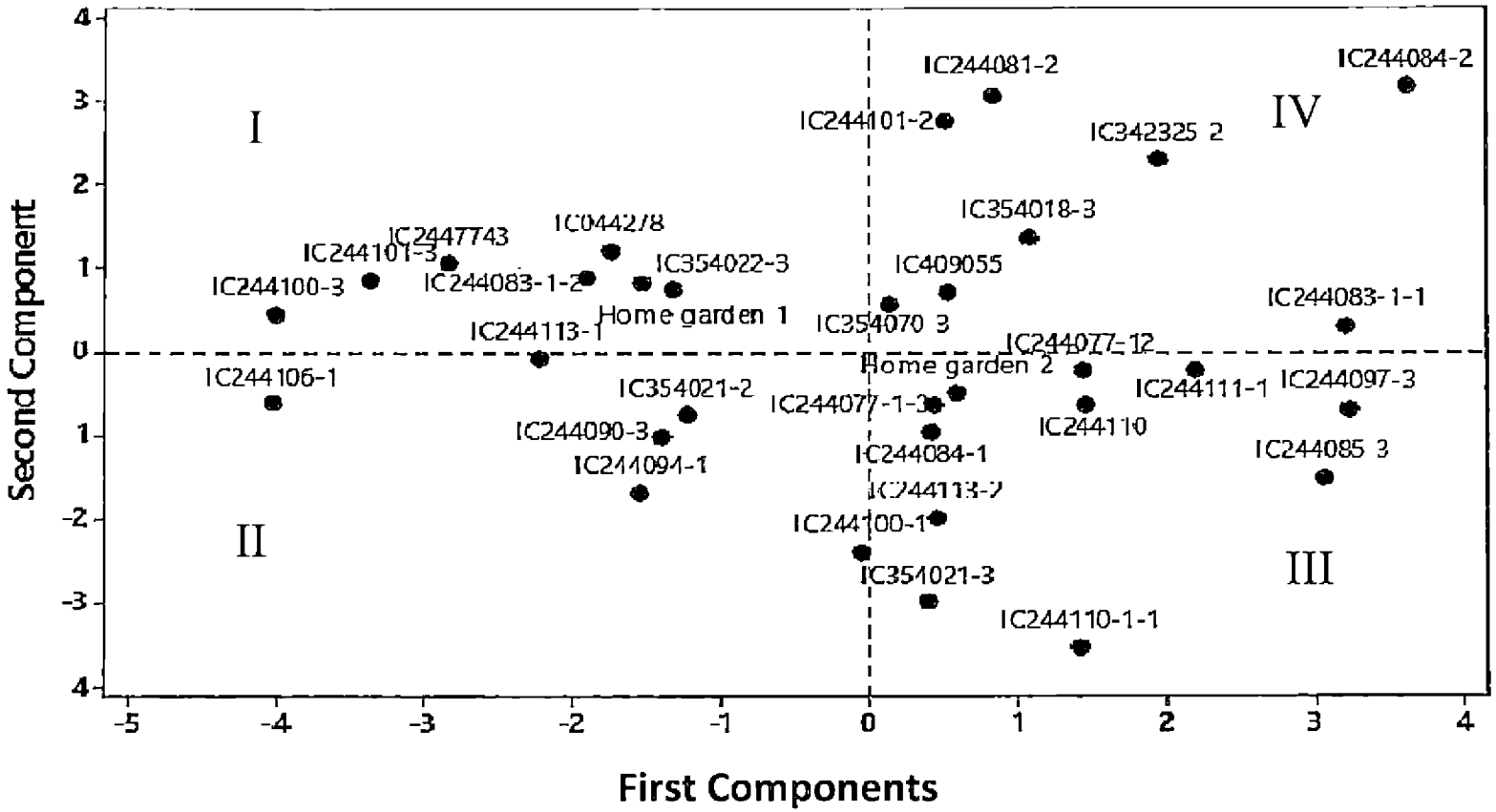

Fig. 6: Grouping of 32 accessions of *G. gummi-gutta* based biochemical characters from first 2 components

contributing factors. PC5 had high loading for tree height, number of fruits per tree and height of first branch from base and percentage variation of 9.6 percent. PC6 accounted for 7.6 percent of

Table 22: Group wise distribution of *G. gummi-gutta* based on biochemical characters in PCA.

Groups	Cluster size	Accessions
I	9	IC244078-3, IC354022-3, Home garden1, IC244083-1-2, IC2447743, IC244100-3, IC244101-3
II	6	IC244106-1, IC354021-2, IC244090-3, IC244094-1,IC244100-1, IC244113-1
III	11	IC244097-3, IC244085-3, IC244077-1-3, IC244110, IC244111-1, IC244113-2, IC354021-3, IC244084-1, IC244110-1-1-1, IC244077-1-2, Homegarden2
IV	8	IC244081-2, IC244084-2, IC342325-2, IC354018-3, IC409055, IC354070-3, IC244083-1-1, IC244101-2.

Table 23: Mean performance of the groups in PCA.

Groups	I	II	III	IV
Saponification value (mg KOH/g)	184.78	181.22	180.81	180.03
Acid value (mg KOH/g)	003.96	003.85	003.69	003.70
Iodine value	062.18	065.81	057.74	057.93
Ca (mg/100 g)	175.13	192.94	178.30	155.25
Na (mg/100 g)	067.00	058.43	072.83	079.55
K(mg/100 g)	153.23	159.50	179.83	152.39
P (mg/100 g)	042.01	041.51	037.12	033.33
Mg (mg/100 g)	011.79	011.54	012.01	012.04
Phenol (mg/100 g)	1014.00	1029.00	1052.00	1097.00
Flavonoids (mg/100 g)	172.88	166.57	164.50	206.00
Crude fats %	004.27	005.05	004.90	005.25
Protein (g/100 g)	001.13	001.11	001.08	001.04
Carbohydrates (g/100 g)	024.21	025.68	022.01	024.02
Reducing sugar %	004.01	004.12	004.15	004.04
Vitamin B_1 (µg/100g)	048.22	036.91	039.07	045.98
Vitamin B_2 (µg/100g)	021.38	015.61	015.42	020.67
Vitamin B_{12} (µg/100g)	047.66	037.72	037.88	047.31
Vitamin C (µg/100g)	025.01	019.99	021.85	024.16
Vitamin A (µg/100g)	010.80	011.68	013.76	012.59
Vitamin E (µg/100g)	026.70	035.95	037.21	033.45

Table 24: Principle component analysis of morphological characters of *G. gummi gutta*

Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12
Petal length	0.086	0.514	-0.051	0.288	0.204	0.338	-0.121	-0.236	-0.250	0.576	-0.095	-0.118
Petal breadth	0.106	0.313	-0.183	0.559	0.228	-0.065	-0.298	0.313	0.219	-0.484	-0.129	0.054
Pedicel length	-0.262	0.039	0.076	0.458	-0.094	0.070	0.773	-0.081	-0.227	-0.205	-0.049	-0.007
Weight of flowers	0.012	-0.085	-0.647	0.030	-0.161	-0.023	0.104	0.557	-0.252	0.245	0.308	-0.088
Fruit weight	0.573	0.041	0.167	0.084	0.011	-0.275	0.179	0.083	-0.129	0.174	0.060	0.686
Rind weight	0.558	-0.062	0.225	0.103	0.011	-0.313	0.132	0.049	-0.036	0.011	0.033	-0.709
No. of fruits per tree	-0.042	-0.379	-0.200	0.347	-0.346	-0.306	-0.342	-0.325	-0.347	0.045	-0.367	0.032
Leaf length	-0.329	0.000	0.494	0.126	0.149	-0.175	-0.304	0.213	-0.491	-0.037	0.446	-0.002
Leaf breadth	-0.399	0.172	0.010	-0.011	0.193	-0.657	0.132	0.145	0.286	0.394	-0.257	-0.020
Tree height	-0.013	-0.463	-0.117	0.381	0.366	0.019	0.010	-0.297	0.373	0.201	0.472	0.033
Height of first branch	0.023	-0.484	0.171	0.026	0.428	0.310	0.036	0.413	-0.124	0.140	-0.499	0.008
Seed weight	-0.048	-0.043	0.366	0.306	-0.613	0.224	-0.100	0.299	0.399	0.289	0.018	0.005
Eigenvalue	2.4111	2.0781	1.667	1.388	1.153	0.909	0.796	0.5865	0.482	0.258	0.202	0.071
Proportion	0.201	0.173	0.139	0.116	0.096	0.076	0.066	0.049	0.040	0.021	0.017	0.006
Cumulative	0.201	0.374	0.513	0.629	0.725	0.800	0.867	0.916	0.956	0.977	0.994	1.000

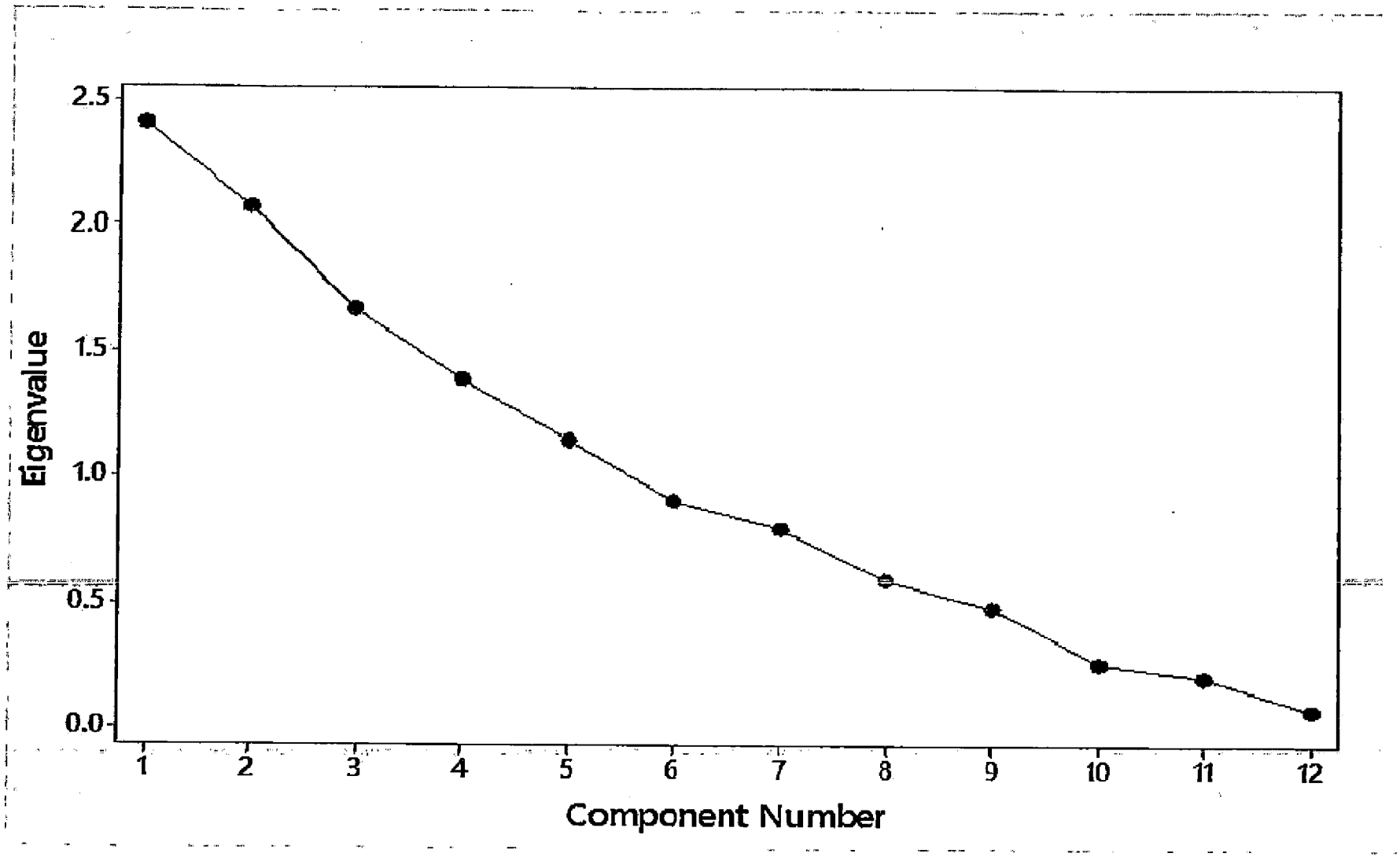

Fig. 7: Scree plots of morphological characters of *G. gummi-gutta*

total variation with petal length and leaf breath as main contributing factors. However, PC7, PC8, PC9, PC10, PC11 and PC12 had eigen values less than 1.00 and thus regarded as making no significant contribution to the total variation.

From the PC loading plot (Fig 8) it could be inferred that the characters fruit weight and rind weight were linked together. It was evident that the angle between the above characters were extremely acute in nature which infers that they were positively associated. Like wise number of fruits per tree, tree height and height of first branch had positive association. Pedicel length, leaf length and leaf breadth are also positively associated. However, fruit weight and leaf length were negatively associated with vitamin B_{12} and vitamin C. Since, they form obtuse angle between these characters.

4.16. 2.2. Grouping based on morphological characters

Based on the first two components of the PC analysis grouping was made (Table 25). Out of 30 accessions and two trees from home garden, 4 groups were formed. This was furnished in Fig 9, which graphically represented relative positions of various accessions. Group I was formed by maximum number of accessions and group IV formed minimum number of accessions. The mean performance of groups depicted (Table 26) that group I had high value for flower weight, moderate value for petal length, pedicel length and tree height and low value for petal breadth, rind weight and fruit weight. Group II showed very high value for fruit weight, rind weight, tree height and height of first branch from base. For petal length, petal breadth, number of fruits per tree and leaf length group II showed moderate value. However, pedicel length, weight of flower and leaf breadth displayed low value. Group III expressed high value for petal length, petal breadth and weight of seeds and moderate value for pedicel length, weight of flower, number of fruits per tree and length leaf. The low value expressed by tree height and height of first branch expressed in group III. In group IV pedicel length, leaf length and leaf breadth expressed maximum value and for petal length, petal breadth, weight of flower and weight of fruit expressed moderate value.

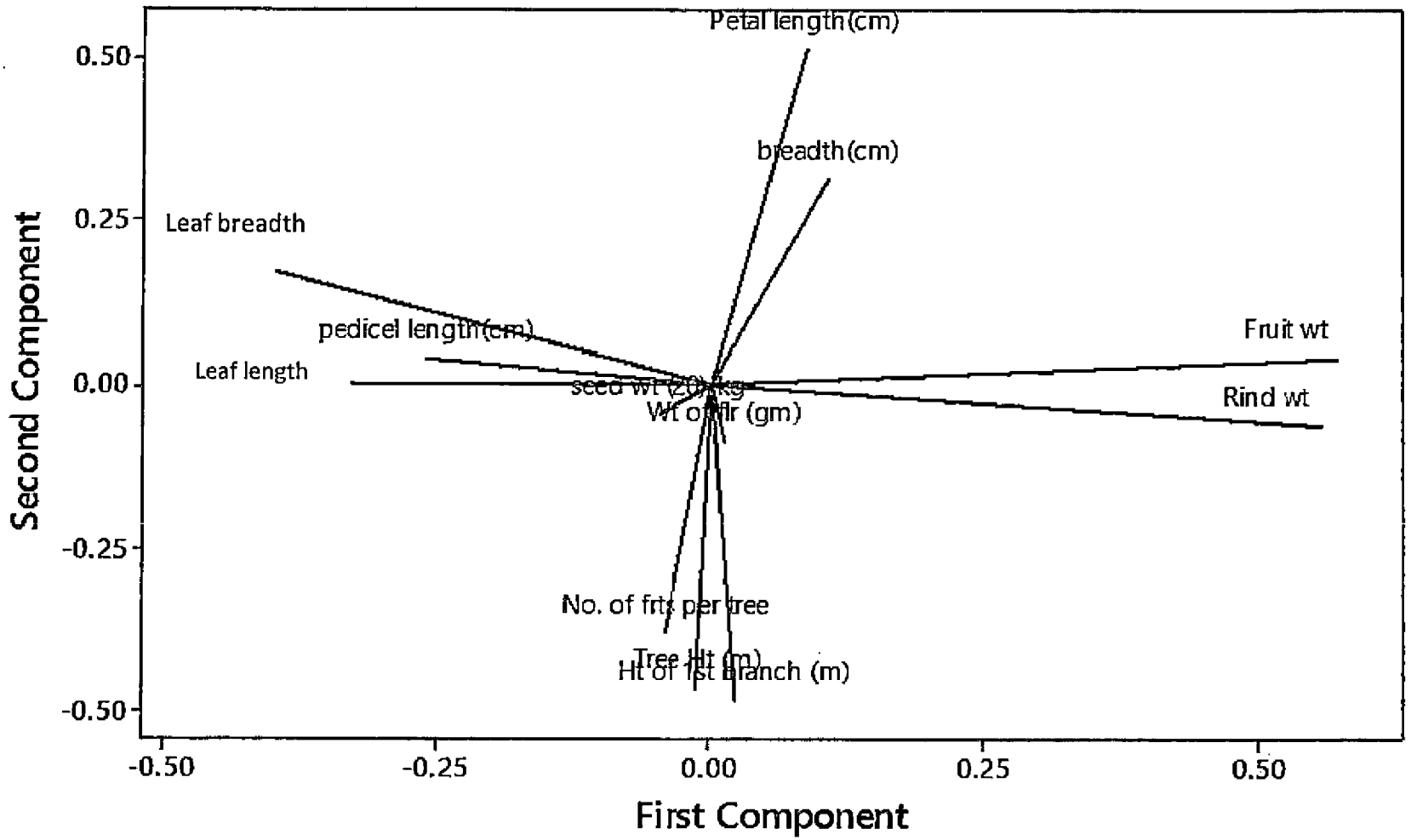

Fig. 8: Loading plot of morphological characters of *G. gummi-gutta*

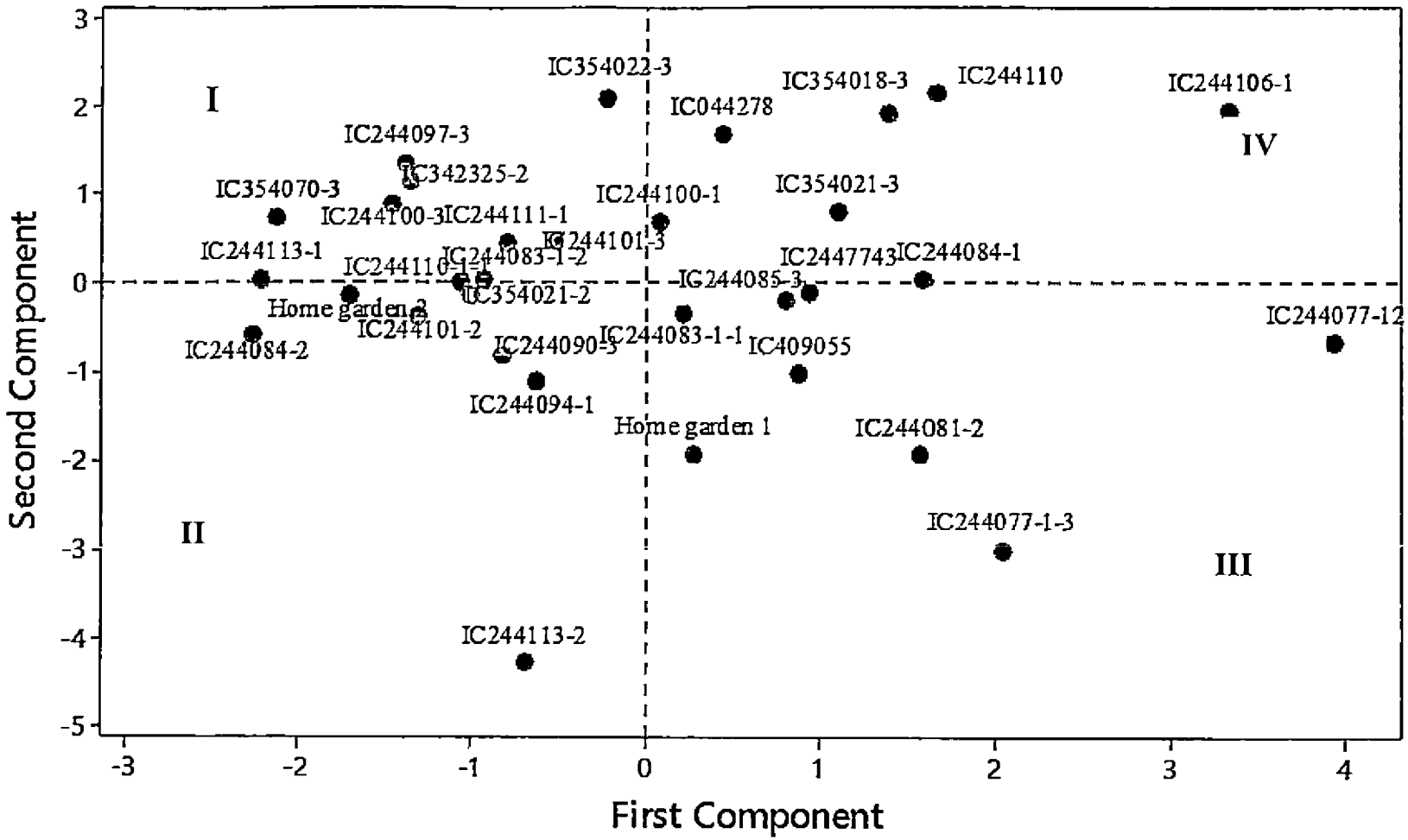

Fig. 9: Grouping of accessions of *G. gummi-gutta* based morphological characters from first 2 components

Table 25: Grouping of morphological characters

Groups	Group size	Accessions
I	9	IC354022-3, IC342325-2, IC354070-3, IC244113-1, IC244100-3, IC244111-1, IC244097-3, IC244101-3, IC244083-1-2
II	8	IC244113-2, IC244094-1, IC244090-3, IC354021-2, IC244101-2, Homegarden2, IC244084-2, IC244110-1-1
III	8	IC244085-3, IC244081-2, IC244077-1-3, IC409055, IC244077-1-2, IC244083-1-1, IC2447743, Home garden1
IV	6	IC244106-1, IC244110, IC354018-3, IC244078-3, IC354021-3, IC244084-1

Table 26: Mean performance of groups

Groups	I	II	III	IV
Petal length (cm)	0.939	0.968	1.066	1.026
Petal breadth (cm)	0.575	0.613	0.717	0.663
Pedicel length (cm)	0.533	0.418	0.449	0.573
Flower weight (g)	0.651	0.575	0.593	0.589
Fruit weight (g)	0.685	1.038	1.016	0.702
Rind weight (g)	0.380	0.609	0.568	0.378
Number of fruits per tree	639.75	625.50	388.28	465.22
Leaf length (cm)	11.630	11.150	10.637	11.653
Leaf breadth (cm)	5.293	4.578	4.647	5.588
Tree height (m)	11.720	12.375	8.143	10.111
Height of first branch (m)	2.265	2.643	1.591	1.696
Seed weight (g)	0.017	0.017	0.018	0.017

Discussion

5. DISCUSSION

The results from the investigation on variation in tree, flower, fruit, seed and nutritional value, among thirty hermaphrodite trees of *Garcinia gummi-gutta* located in the orchard of National Bureau of Plant Genetic Resources, Regional station, Vellanikkara and two trees selected from local home garden are discussed in this chapter.

5.1. Variability study

For any tree improvement program, first necessary step is to scan for all available genetic variation within a species and identification of the most effective genotype matching to the locality. Screening and evaluation of different genotypes of tree species for morphological and biochemical characteristics is important for tree breeding programs (Sharma and Bakshi, 2014). Thus present study was an attempt to characterize the collection of *G. gummi-gutta* at NBPGR, Vellanikkara.

5.1.1. General tree characters

The observations on the canopy shapes among the trees in the study indicated presence of conical, dome and pyramidal shapes with majority having conical shape (Table 3). Among the entries, 46.8 percent were having conical shape followed by dome (34.3%) and pyramidal (18.75%). Muthulakshmi, (1998) and Ajayghosh (2007) also reported that in *G. gummi-gutta,* trees, conical canopy was more common. During study, it was observed that dome shaped trees such as IC244081-2, IC244084-2 and IC244097-3 yielded higher number of fruits (Table 8). This has been earlier reported in *G. gummi-gutta* by Muthulakshmi, (1998) and Parvati, (2007). The reason for this might be that such trees have more canopy area and receive more amount of sunlight, leading to production of more fruiting branches.

Branching pattern (Table 3) study showed that 50 percent of trees were having drooping branches, followed by horizontal (34.3%) and erect branches (15.6%). The difference in branching pattern might be due to their different genetic makeup or response to soil and climatic conditions. It was also noted that trees with horizontal and drooping branches were having more

fruit yield than those with erect branches (Table 8). This observation was corroborated with finding of Ajaygosh (2007) and Parvathy (2007).

The tree height varied from 3 m to 19 m among various entries with a coefficient of variation (CV) of 34.13 percent (Table 3). The accessions namely IC244113-2, IC244077-1-3 and IC244101-3 had tree height of 15 m and above. The low tree height was found in IC354070-3, IC354018-3 and IC244084-1 (3 m to 5 m).

The height of first branch from base of the tree (Table 3) varied from 0.65 to 3.5 m (IC244113-2) and average height of branch was 2.05 m. The accessions namely IC244097-3, IC244078-3 and IC354018-3 showed low height of first branch from base (0.65 to 0.72 m), while IC244113-2, IC354070-3 and IC2447743 showed first branch from base at high position (3 to 3.5 m). During study observed that taller trees had a first branch from base at high position. The correlation coefficient also showed that there was high significant correlation between tree height and height of first branch (Table 16).

Girth at Breast Height (GBH) among various accessions had a CV of 28.32 percent (Table 3). The GBH was found to range from 31 cm to 107 cm with a mean GBH of 70.7 cm. The accessions such as IC354021-3, IC354021-3 and IC244101-3 recorded high GBH (90 to 110 cm). The Accessions IC354070-3, IC354018-3 and IC244078-3 had lower GBH (30 to 40 cm). Variations in GBH among entries may be due to reduction in available sunlight, which retarded the apical dominance and lateral growth, dominated leading to increase in GBH. The GBH range observed during study was corroborated with finding of Ajaygosh (2007) in *G. gummi-gutta.*

5.1.2 Leaf characters

The analysis of variation in leaf length among the genotype (Table 4) showed narrow variation with CV of 11.78 percent. Highest leaf length was noticed in IC354070-3(14.97 cm) which was on par with IC409055. The lowest leaf length was observed in IC244106-2 (9.47 cm) and IC244084-1 (9.53 cm). Other accessions showed leaf length closer to mean value (11.09 cm). The Leaf breadth varied from 3.6 cm (IC244084-1) to 7.11 cm (IC244097-3). The mean

and CV of leaf breadth was 5.0 cm and 14.20 percent respectively. The leaf length and breadth ratio can vary among different genotypes and this variation can be used for some level of genotype differentiation (Serdar and Kurt, 2011).

Knowledge of leaf area is an important parameter in understanding photosynthesis, light interception, water and nutrient use, crop growth, and yield potential (Williams and Martinson, 2003). In present study the accessions such as IC24401-3, IC244097-3, IC354070-3 and IC244083-1-2 had leaf area (Table 4) more than average leaf area (37.69 cm^2), while IC244081-2, IC354021-2, IC354022-3 and IC244094 had leaf area lower than average leaf area. The CV for leaf area was higher (21.84%) compared to other leaf characters. The maximum leaf area was noticed in IC354070-3(56.39 cm^2) and minimum leaf area in IC244081-2 (22.94 cm^2). The petiole length (Table 4) in *G. gummi-gutta* ranged from 0.79 cm (IC244083-1) to 1.83 cm (IC244100-3) and average was 1.37 cm. The CV of leaf petiole was 18.09 percent. According to the study by Ajaygosh (2007) petiole length in *G. gummi-gutta* varied from 1.50 cm to 1.70 cm in hermaphrodite trees of *G. gummi-gutta*. Petiole length strongly influences foliage clumping since increase in petiole length reduce the shading of basal lamina portions by the stem and adjacent leaves, leading to significantly increased light harvesting efficiency (Niinemets *et al.*, 2004).

Observation on leaf growth and development (Table 5) during present study showed that period of 30 to 32 days elapsed between emergence and formation of fully developed leaves of mature green colour. An important aspect noted was wide differences in leaf length and breadth development during growth period among different accessions.

5.1.3 Flower characters

In Malabar tamarind, flowers were hypogynous, petals were regular, polypetalous and tetramerous in nature but pentamerous and hexamerous flowers were also observed. The colour of petal in 25 percent accessions were light creamy yellow, while in 37 percent of accessions it was creamy yellow and 21.8 percent had yellow petal (Table 7). However, pinkish red colour was also observed in one accession (IC244097-3). The variation in petal colour observed is probably due to genetical reasons, since climatic factors have no major control over flower

colour. The petal colour observed in this study was corroborated with finding of Ajaygosh (2007) and Muthulakshmi (1998) on *G. gummi-gutta* where they observed colour of flowers to range from creamy yellow to light pink.

The number of flowers per cluster ranged from one to two in each accession. Mostly single was observed, in rare cases double flowers noticed. During the present study no significant variation among various entries for number of flowers per clusters was observed.

Petal length (Table 7) ranged from 0.7 cm (IC244113-2) to1.14 cm (IC354021-3). The average petal length was 1.0 cm. The breadth of petal, varied from 0.45 cm (IC342325-2) to 0.88 cm (IC244110) and average breadth was 0.64 cm. The CV value indicated higher variability in petal breadth (CV of 17.02 %) than petal length (CV of 8.89 %) among different accessions.

Pedicel length of flower had high variation than flower weight among various accessions, with CV of 30.14 percent (Table 7). Pedicel length ranged from 0.28 to 0.91 cm. The accessions viz. IC244101-2, IC244113-1 and IC244110-1-1 had pedicel length of 0.8 to 0.9 cm. While accessions namely IC244090-3, IC354018-3 and Home garden1 had petal length near to 3 cm. and average pedicel length was 0.50 cm. However, pedicel length reported by Parvathy (2007) in male trees was higher (0.87 to 1.1 cm) than observed in hermaphrodite trees during the present study. The correlation analysis (Table 15) indicated that there was a significantly high positive correlation between petal length and breadth.

The variation in weight of flowers in *G. gummi-gutta* was observed during the study (Table 7). Flower weight varied from 0.38 to 0.78 g with an average of 0.60 g and CV of 15.94 percent. The entries like IC244097-3, IC244090-3 and IC244085 had higher flower weight (0.70 to 0.78 g), while IC409055 and IC244100-1 had low flower weight (0.3 to 0.4g). The weight of male Malabar tamarind flower reported by Parvathy (2007) (0.24 to 0.46 g) in male tree was comparatively lower than in hermaphrodite trees observed in this study.

All trees started flowering during February to March (Table 8). The observation from current study was accordance with finding of Muthulakshmi (1998) and Ajayghosh (2007). In present study 56 percent of trees started flowering during February and remaining trees (44%) flowered in March. This variation may be due to plant adaption to specific climate. The flowering period in hermaphrodite trees were shorter when compared to male trees. The possible

reason for the shorter duration of flowering in hermaphrodite trees may be that a good amount of stored food is channelized for production of fruits in them.

5.1.4. Fruit characters

Fruit characters have been found to be important in structuring morphological variation in many tropical trees. It is clear therefore that fruit and nut traits provide an opportunity for identification and selection of plus trees for domestication (Fandohan *et al.,* 2011). During present study, moderate variation was observed in weight of Malabar tamarind fruits with CV of 27.59 percent (Table 8). The fruit weight among the entries ranged from 51.4 g to 148.5 g. The highest fruit weight was observed in IC244077-1-2, which was followed by IC244106-1 (131.1 g) and IC244110 (130 g). However, Abraham *et al.,* (2006) reported that weight of Malabar tamarind had variation from 8.2 to 161.0 g indicating a larger variation than found in the present study.

The rind weight of fruits of the various entries varied from 29.6 to 83.5g with average of 48 g. The CV of rind weight was 30.75 percent. The accessions IC244106-1, IC244077-1-2 and IC244077-1-3 had higher rind weight (83 to 75 g), while IC244090-3, IC244083-1-2 and IC244113-1 had lower rind weight (29 to 35 g). Abraham *et al.,* (2006) observed a larger variation in rind weight (7.2 to 125 g) in same species.

The accessions showed wide variability in fruit yield with CV value of 46.74 percent (Table 8). The number of fruits per tree per year ranged from 70 (IC342325-2) to 985 (IC244084-1).The average yield was 532 fruits per tree. The accessions IC244081-2, IC244085-3 and IC244084-2 yielded higher number of fruits(800 to 980), while accessions IC354070-3, IC2447743 and IC342325-2 had low number of fruits (70 to 130). The fruit yield of Home garden1 was comparatively higher than Home garden2.This variation may be because of different genotype, along with management practices, age etc. According to Ajayghosh (2007) number of fruits produced in *G. gummi-gutta* per year ranged from 82 to 1837. Bhat *et al.,* (2010) reported that in Malabar tamarind trees, fruit yield was higher every alternative year. This fact could not be ascertained since the present study was carried out over just one year.

All mature fruits observed were yellow in colour with grooves. Pinkish-red colour fruits reported by Abraham *et al.,* (2006) in *kodumpuli* were not found during study.

5.1.5 Seed characters

Seed weight between different accessions showed lesser variations with CV value of 18.44 percent (Table 9). Weight of seeds which were shade dried ranged from 0.65 to 1.2g. The low seed weight (0.65- 0.70 g) was observed in accessions IC244101-2, IC244090-3, IC244085-3 and IC244077-1-2. The seed weight was higher in IC244100-1, IC244081-2 and IC244097-3. The seed weight observed in present study was corroborated with report of Abraham *et al.*, (2006) in same species.

Germination percentage showed marked difference between the accessions (Table 9). The germination percentage was found highest in IC244077-12 (80%) and lowest in IC244110 (30%). This wide variation might be due to immature seeds or loss of viability. During present study many empty/immature seeds were observed in Malabar tamarind. Muthulaksmy (1998) also reported about presence of immature seeds in *G. gummi-gutta.* Mathew *et al.*, (1995) reported that seeds take more than one year for germination if they are sown soon after harvest. In present study it was confirmed and also observed that GA treatment to seeds with seed coat had no effect on seed germination.

The seed length and breadth had narrow variation with CV value of 17.11 percent and 13.90 percent respectively (Table 9). Seed length among various entries ranged from 1.9 to 3.5 cm and seed breadth varied from 0.8 to 1.4 cm. The entries such as IC244084-1, IC354022-3 and IC354021-3 showed lower seed length (1.9 to 2 cm), while accessions IC244097-3, IC244100-1 and IC244094-1 showed higher seed length (3 to 3.5 cm). Similarly lower seed breadth was seen in IC244083-1-2, IC244085-3 and IC244113-1 (0.8 to 1 cm), while IC244110, IC244113-2 and IC2447743 had higher seed breadth (1.4 cm).

The analysis for morphological characters indicated that the entries differed widely in some of the characters like tree height, height of first branch from base, pedicel length, rind weight and number of fruits per tree, while the variation was little for some of the characters (GBH, leaf length, leaf breadth, leaf area, leaf petiole, petal length, petal breadth, flower weight, fruit weight, seed length, seed breadth and seed weight).

5.2. Primary metabolites

A primary metabolite is a kind of metabolite that is directly involved in normal growth, development, and reproduction. It usually performs a physiological function in the organism (Irchhaiya *et al.*, 2015).

Carbohydrates are the major nutrients in fruits which are primary energy source of a cell and are simplest biomolecules synthesized naturally (Ting, 1956). In present study carbohydrate content in different entries had low variation with CV of 11.61 percent (Table 10).The carbohydrate contents among the accessions varied from18.08 g/100 g (to 29.69 g/100 g. The higher carbohydrate content was observed in IC244083-1-2 (29.69 g/100 g), IC244110 (29.32 g/100 g) and Home garden1 (28.08 g/100 g). The low carbohydrate content was found in IC244113-1 (18.08 g/100 g) and IC244113-1 (18.82 g/100 g). The mean carbohydrate content among the entries was estimated to be 24.05 g/100 g. It was very high when compared to carbohydrate content reported by Parthsarathy and Nandakishore (2014) in *G. gummi-gutta* (6.46 g/100 g). The lower limit in the present study was more or less comparable with carbohydrate reported in *G. mangostana* (14.3 to 15.6 g/100 g) by Ajayi*et al.*, (2007).

Plant proteins are the source of several essential amino acids which human cells cannot biosynthesize (Jain, *et al.*, 2005). The protein content between different accessions showed low variation with CV of 9.4 percent (Table 10). The protein content varied from 0.93 g/100 g (IC244083-1-2) to 1.29 g/100 g (IC244081-2). The average protein content was 1.08g/100 g. It was very low when compared to protein content reported by Parthsarathy and Nandakishore (2014) in *G. gummi-gutta* (3.25 g/100 g), *G. indica* (4.78 g/100 g) and *G. kydia* (4.33 g/100 g). The protein content observed during present study was higher when compared to mangosteen (0.50 to 0.60 g/100 g) reported by Tripathi, *et al.*, (2015).

Fats are hydrocarbon molecules and second largest energy source for living cells. In plants, fats are the storage form of energy (Jain, *et al.*, 2005).The crude fat content in *G. gummi-gutta* varied from 3.28 percent to 6.18 percent in present study (Table 10). The entries namely IC244094-1, IC244110 and IC244081-2 had low fat content (3.28 to 3.50%), whereas, Home garden1, IC244090-2 and IC244110-1-1 showed higher crude fat content (6 to 6.18 %). The CV value for crude fat was 18.4 percent, while average was 4.89 percent. *G. gummi-gutta* seems to

have lower crude fat content compared to kokum (10%) by Tripathi, *et al.*, (2015) and *G. xanthochymus* (7.57 %) by Sharma *et al.*, (2015).

Reducing sugars like glucose and fructose are the simplest carbohydrate molecules having free aldehyde or ketone group and can reduce metal ions to lower oxidation state and they usually provide sweetness to fruits (Ting, 1956). The reducing sugar content in fruits of *G. gummi-gutta* had a CV of 3.19 percent. The reducing sugar found lowest (3.85%) in IC244110, IC244077-1-3 and IC354018-3 and highest (4.31%) in IC244106-1 and IC244094-1. The average reducing sugar found was 4.07 percent. The observation on reducing sugar content corroborated with George (1988) report as 4.15 percent, but higher the value reported (1.04%) by Sherly (1994) on same species.

5.3. Secondary metabolites

There is a growing interest in secondary metabolites, mainly because of their antioxidant potential and the association between their consumption and the prevention of some diseases (Haminiuk *et al.*, 2012).

Phenolic compound have multiple biological effects and one of the most reported effect is antioxidant activity (Kahkonen and Hopi, 1999).They are responsible for red colour of fruits, juice, wines and flavor (Cheynier, 2012).In present study phenolics content in *G. gummi-gutta* showed very low variation with CV of 7.19 percent (Table 11). The phenolic content varied from 900 mg/100 g (IC244081-2) to 1200 mg/100 g (IC244085-3). Values nearer to average phenol content were observed in IC244077-1-2, IC244084-2 and IC354070-3 (1050 mg/100 g). However, it was high when compared to phenolics reported by Muthulakshmi, (1998) on the same species (265 to 380 mg/100 g). Even higher level of phenolics (3.26 g/100 g) in *G. gummi-gutta* was reported by Parthsarathy and Nandakishore (2014). The variation in phenolics might be due to influence of solvent used to extract phenolics. The study by Sala *et al.*, (2010) proved that the amount of phenolics extracted can be influenced by the solvent used to extract the compound. However variation observed during present study between different accessions is due to genetic or environmental, since same solvent (methanol) used throughout the study.

Flavonoids are polyphenols, widely distributed in plants. In fruits it contributes to fruit colour (Rashidi *et al.*, 2010). In present study flavonoids in *G. gummi-gutta* ranged from 127 to

240 QE mg/100g (Table 11) with CV of 19.01 percent. The entries namely IC244077-1-3, IC244110-1-1 and Home garden1 had high level of flavonoids, while accessions such as IC342325-2, IC54022-3 and IC244097-3 had lower flavonoids content. The average flavonoid content found was 181.31 QE mg/100 g. These values were lower when compared to flavonoids reported in *G. xanthochymus* (313 QE mg/g) and higher when compared to *G. pedunculata* (50.607 QE mg/g) by Sharma *et al.*, (2015). Males *et al.*, (2006) opined that flavonoid content varies due to various factors such as type of soil, microclimatic conditions, geographic position, site, age and vegetation stage of plants and leaves. However in present study, factors like site condition, ages of the trees were almost similar. Hence variation found here may be mostly due to genetic reasons.

5.4. Mineral composition of fruits

Mineral ions are of prime importance in determining the nutritional value of fruit (San *et al.*, 2009). Major ones are Na, K, P and Ca. The variability observed in content of minerals among various accessions during study was might be due to genetical or environmental.

Calcium plays important role in building and maintaining strong bones (Pravina *et al.*, 2013). In many fruit tissues, Ca is believed to be an important factor governing fruit storage quality (Lechaudel *et al.*, 2005). In present study, Ca content showed low variability among different accessions with CV of 17.33 percent (Table 12). The Ca content in fruits ranged from 105.44 mg/100 g to 212.25 mg/100 g. The accessions IC244090-3, IC409055, IC244101-3 and IC354021-2 had higher Ca content (200 to 210 mg/100 g), while accessions IC244100-1, IC244077-1-3 and IC244110-1-1 showed low Ca value (105 to 120 mg/100 g). However, Ca value found in this study was high when compared to report by Parthsarathy and Nandakishore (2014) on *G. gummi-gutta* (12.67 mg/100 g).

Sodium is the principal element which regulates acid-base balance, involved in the maintenance of osmotic pressure of the body fluids (Soetan *et al.*, 2010). The statistical analysis between different entries revealed the presence of variation in Na content among the entries (Table 12). The average Na content recorded was 70.5 mg/100 g with CV of 23.39 percent. Some of the accessions like IC35244094-1, IC244110-1-1, IC2444077-1-3 and IC244085-1 had higher Na content (96 to 80 mg/100 g). Low Na content was found in IC354022-3, IC354018-3

and IC244113-2 (40 to 45 mg/100 g). However, the Na value observed among entries was high when compared to low Na value (2.88 mg/100 g) reported in *G. gummi-gutta* by Parthsarathy and Nandakishore (2014).

Potassium is a major mineral involved in metabolism and proper activity of different tissues, organs of human body (Ozcan, 2004). In present study K content showed coefficient of variation (17.93%) nearly same as Ca among various accessions. The K content (Table 12) ranged from 115.8 mg/100g to 227.1 mg/100 g. The average K content found was 159 mg/100 g. High levels of potassium in the fruits improve the physical quality, disease resistance, and shelf life of fruits and fruit products (Ahmad *et al.,* 2015). Thus accessions of high potassium content such as IC244090-3, IC244083-1-2, IC2447743 and IC354021-2 (200 to 210 mg/100 g) can be selected. The low level of K content was observed in IC244111-1, IC244100-3 and IC244106-1 (115 to 130 mg/100 g). However, The K content observed during study was lower when compared to reported in *G. gummi-gutta* (26.6 mg/100 g) by Parthsarathy and Nandakishore (2014).

Phosphorus is a component of nucleic acids and as phosphate esters plays an important part in the cellular metabolism (Gopalan *et al.,* 1994). The average P content recorded in present study was 38 mg/100 g. The P content between different accessions ranged from 20.4 mg/100 g to 52.4 mg/100 g (Table 12). The CV for P content (23.37%) in fruits of *G. gummi-gutta* was similar to that of Na. Among the accessions, high level of P (50 to 53 mg/100 g) was found in IC244085-3, IC244101-2 and IC244110-1-1. The accessions IC244113-2, IC354021-2 and IC354021-3 had lower P content (20 to 30 mg/100 g). However, the present finding on P content is high when compared to report by Parthsarathy and Nandakishore, (2014) in *G. gummi-gutta* (5.34 mg/kg) and *G. indica* (4.51 mg/kg).

Magnesium is an active component of several enzymes (Soetan *et al.,* 2010). In present study Mg content of various accessions showed low variation with a CV of 4.39 percent (Table 12). The Mg content was found lowest in IC354022-3(10 mg/100 g), followed by Home garden1 (11.05 mg/ 100 g) and IC244100-3 (11.19 mg/100 g). High Mg content was observed in IC244110-1-1 (12.87 mg/100 g) which also contained high level Ca. The average Mg content

was 11.86 mg/100 g. This observed value was lower when compared to Mg reported in G. *gummi-gutta* (14.35 mg/100 g) by Parthsarathy and Nandakishore (2014).

5.5. Vitamins content in fruits

Vitamins are organic compounds that play a major role in regulation of enzymes, cell signals and metabolic pathways. The vitamin analysis carried out in present study for various entries showed moderate variations with CV value of less than 20 percent (Table 13).Vitamin B_1 (thiamine) plays important role in neuromuscular transmission. In the present study, vitamin B_1 content varied from 29.64 µg/100 g to 54.55 µg/100 g among the various entries with CV of 13.79 percent. The mean vitamin B_1 content was 43.26 µg/100 g. The accessions IC244097-3, IC244077-1-2, IC244083-1 and IC244084-2 had high vitamin B_1 value (50 to 54.55 µg/100 g), while accessions IC244100 -3, IC244101-3 and IC2447743 had low vitamin B_1 (29 to 35 µg/100 g). The Home garden1 and Home garden2 had vitamin B_1 value, which were close to mean value (43.2µg/100 g). Parthsarathy and Nandakishore (2014) reported that vitamin B_1 in *G. gummi-gutta* was 48 µg/100 g. This value was close to vitamin B_1 content in IC244111-1(48.18 µg/100 g) and IC244110 (47.32 µg/100 g) during the study.

Vitamin B_2 participates in the oxidation-reduction reactions in the metabolic pathways that are involved in energy production (Dai and Koh, 2015). In present study, vitamin B_2 content ranged from 11.26 to 25.07 µg/100 g with CV of 18.41 percent. The highest vitamin B_2 content was found in IC244084-2 (25.07 µg/100 g), followed by IC244097-3 (24.07µg/100 g) and IC342325-2 (22.72 µg/100 g) and lowest was found in IC244106-1(11.26 µg/100 g), followed by IC244100-3 (13.28µg/100 g) and IC244101-3 (14.32µg/100 g). The mean vitamin B_2 content was 18.76 µg/100 g. This value was low compared to vitamin B_2 reported by Parthasarathy and Nandakishore (2014) in *G. gummi-gutta* (275 µg/100 g).

Vitamin B_{12} plays an important role in the biochemical processes of methylation and transmethyation, deficiency of which produces pernicious anaemia (Rajput *et al.*, 2011). The average vitamin B_{12} content in fruits of *G. gummi-gutta* was found to be 43.53µg/100 g. Among various accessions vitamin B_{12} content ranged from 30.39 to 56.4 µg/100 g with a CV of 14.91 percent. The accessions IC244097-3, IC244085-3 and IC244084-2 had higher level of vitamin

B_{12} (54 to 56 µg/100 g), while entries like IC244106-2, IC244100-3 and IC244101-3 showed low levels of vitamin B_{12} (30 to 35 µg/100 g).

However, vitamin B_{12} value found in the study was high when compared to value reported by Parthasarathy and Nandakishore (2014) in *G. indica* (12.06 µg/100 g) and *G. gummi-gutta* (8.75 µg/100 g). Even higher vitamin B_{12} of 120 µg/100 g was reported by Fowomola, (2010) in mango.

Vitamin C is a highly water-soluble compound that has both acidic and strong reducing properties. It an essential nutrient in humans as it functions as a cofactor in several vital enzymatic reactions (Rajput *et al.*, 2011). Moderate variation in Vitamin C content was observed during study (CV of 27 %). Vitamin C content ranged from 16.69 to 27.76 mg/100 g. The higher vitamin C content (26 to 28 mg/100 g) was observed in IC244097-3, IC244085-3 and IC244083-1, while low vitamin C content (16 to 19 mg/100 g) was found in IC244100-3, IC244101-3 and IC2447743. The mean vitamin C content was 23.02 mg/100 g. This average vitamin C content was more than value reported by Parthsarathy and Nandakishore (2014) in *G. gummi-gutta* (14.35 mg/100 g), but more or less comparable with lowest reported value (16.69 mg/100 g) during study.

Parthsarathy and Nandakishore (2014) reported that *Garcinia* fruit extracts do not contain vitamin A and E in detectable range. However, in present study Vitamin A content in *G. gummi-gutta* found to range from 8.85 µg/100 g (IC244084-2) to 16 µg/100 g (IC244100-1) with CV value of 16.61 percent. The accessions IC409055, IC244084-2 and IC354010-3 showed low vitamin A content (8.85 to 10 µg/100 g), while entries like IC244100-1, IC244113-2 and 1C244110-1-1 showed high vitamin A content (15.4 to 16µg/100 g). The average vitamin A content was 12.16 µg/100 g. This average vitamin A value found was low when compared to vitamin A reported in *G. kola* (1.36 mg/g) by Mazi *et al.*, (2013). The vitamin E content found in present study varied widely among different accessions (CV of 19.12%). Vitamin E content of fruits ranged from 21.34 µg/100 g (IC342325-2) to 47.53 µg/100g (IC244078-3). The entries such as IC244097-3, IC244077-1-3 and IC244084-1 had vitamin E content close to average value (33.01 µg/100 g). However, these values were low when compared to vitamin E reported

in seeds of *G. gummi-gutta* (14.31 mg/100 g) by Parthsarathy *et al.*, (2014) and *G. kola* (2.54mg/100 g) by Mazi *et al.*, 2013.

5.6. Physical properties of butter

Malabar tamarind seed oil is solid at room temperature, thus considered as butter. During study melting range of butter of different accession varied from 36 to 42 ^{0}C, which was comparable with report of Parthasarathy *et al.*, (2014). The 56 percent of accessions studied had melting range of 38^{0}C to 42^{0}C and 46 percent of accessions showed melting range of 36 to 40^{0}C. Due to high melting point, Parthasarathy *et al.*, (2014) opined that it can be used along cocoa butter to increase heat resistant and hardness of chocolate.

Colour of Malabar tamarind seed butter when melted varied from light brown to dark brown. This result corroborated with Parthasarathy *et al.*, (2014) who reported butter colour in *G. gummi-gutta* as light brown.

5.7. Chemical properties of butter

The chemical properties of oils are an important factor that determines its quality and stability of butter (Neagu *et al.*, 2013).

5.7.1. Saponification value

Saponification value indicates the character of the fatty acid present in the fat. High value indicates the presence of lower fatty acids with low molecular weight. The fats with high saponification value are very useful in production of liquid soap and shampoo (Akbar *et al.*, 2009). In present study, between different accessions of Malabar tamarind, saponification value showed very low variation with CV of 2.45 percent. Saponification value varied from171.81 mg KOH/g (IC244094-1) to 189.34 mg KOH/g (IC244084-2, IC244101-2).The average value was 181.62 mg KOH/g. This value was more or less similar to value reported by Parthasarathy *et al.*, (2014) in same species (187.9 mg KOH/g). Choppa *et al.*, (2015) reported saponification value of *G. gummi-guttta* as 145.36 mg KOH/g. The saponification value observed during present study was comparable with high saponification value of sunflower (188-194).

5.7.2. Acid value

Acid value is the measure of susceptibility to decomposition and it represents the freshness as well as storage quality of fat (Akbar *et al.,* 2009). There was not much variation of acid value was observed between different accessions during study. The acid value had a CV of 12.16 percent. The acid value ranged from 3.09 to 4.49 mg KOH/g. The highest acid value observed in IC244084-2, IC244094-1, and IC244077-1-3. The low acid value was noticed in IC244077-12, followed by IC244077-1-2.The average acid value observed was 3.80 mg KOH/g.

Thus, this butter is good for the consumption. According to Parthasarathy *et al.,* (2014), the acid value of *G. gummi-gutta* was 3.7 mg NaOH/g. This value was comparable with acid value of IC244113-1, IC354070-3, IC354022-3 and Homegarden2 (3.646 mg KOH/g). Choppa *et al.* (2015) observed that Malabar tamarind seed oil (5.04 mg KOH/g) had high acid value when compared to sunflower oil (3.09 mg KOH/g), but lower than olive oil (6.6 mg KOH/g).

5.7.3. Iodine value

Iodine value is used to measure of the unsaturation of a fat. This value allows predicting the tendency of fat to become rancid (Akbar *et al.,* 2009).In Iodine value among the various accessions had a CV of 10.75 percent (Table 14).The iodine value among different entries varied from 48.22 to 76.14. The high iodine value was noticed in IC2447743 (76.14) followed by IC354022-3 (72.33). The accessions IC244094-1 (48.22) and IC354021-3 (50.76) had low iodine value. While Home garden1 and Home garden2 had iodine values which were near to average iodine value (60.68). The iodine value observed in study indicated the presence of more double bonds in their fatty acid esters. Parthasarathy *et al.,* (2014) reported that iodine value in *G. gummi-gutta* to be 50.2, which was similar to iodine value observed in IC244077-1-3 (50.76) and IC354021-3 (50.76). However, Choppa *et al.,* (2015) reported that iodine value in *G. gummi-gutta* to be much higher (131.0 g/100 g oil) and in the same range as in sunflower oils (131.6 g/100 g).

5.8. Correlation between the various characters of *G. gummi-gutta*

A correlation matrix between morphological characters of *G. gummi-gutta* trees showed-

a significant and positive relation between petal length and petal breadth, fruit weight and rind weight, number of fruits per tree and tree height, tree height and height of first branch from base (Table 15). From this result it was clear that as the petal length increases there is a significant increase in petal breadth. Likewise, as tree height increases height of first branch from base also increases. There was also significant and negative correlation was observed between petal length and weight of flower, pedicel length and rind weight.

The correlation between biochemical characters of *G. gummi-gutta* showed (Table 16) the presence of significant, high and positive correlation between Na and flavonoids, the positive correlation between Na and Mg, Na and phenol. The other biochemical characters were not correlated to Na. The Ca had a significantly positive correlation with protein and had negative correlation with Na, Mg and phenol. K had positive correlation with crude fat and negative correlation with Phenol, protein and carbohydrates. P had the negative correlation with all the characters other than carbohydrates and protein, which had the significantly positive correlation. Mg had significant and negative correlation with phenol and carbohydrates and other characters were negligible. Phenol had the positive correlation with flavonoids and crude fat.

These correlations are useful in indirect selection in *G. gummi-gutta*.

5.9. Cluster analysis for morphology and biochemical characters of *G. gummi-gutta*.

The cluster analysis grouped the thirty accessions and two entries from home gardens into five clusters. It helps to identify the most distant accessions and most closely placed ones for hybridisation. IC244101-3, IC244101-2, IC244083-1-2, IC244084-2, IC244110-1-1, IC244081-2 and IC244077-1-3 formed cluster I. IC244090-3, IC409055, IC244094-1, IC244100-3, IC244113-2, IC44097-3, IC244085-3 and Home garden1 formed second cluster II. IC244078-3, IC244113-1, IC354021-3, IC354021-2 and IC244084-1 formed cluster III. IC244100-1, IC244077-12, IC244083-1-1, Homegarden2, IC244106-1, IC354018-3, IC244111-1, IC244110 and IC354022-3 formed clusterIV. IC354070-3, IC342325-2 and IC2447743 formed cluster V. Among 5clusters, fourth was biggest and fifth was smallest. Similar study on *G. gummi-gutta* done by Sherly (1994) and Muthulakshmi (1998) revealed existence of genetic diversity in Malabar tamarind enabling clustering.

Cluster wise distribution of morphology and biochemical characters Showed that cluster1 composed of highest acid value, number of fruits per tree, P content, flavonoids , protein, vitamin C and seed germination percentage. Cluster II composed of highest value of Ca, Na, tree height, phenol content and reducing sugar. Cluster III had highest fruit weight, rind weight, carbohydrates, vitamin B_1, Vitamin B_2 and vitamin B_{12}. Cluster IV was composed of entries with highest value in all flower characters, K, crude fat, vitamin A and vitamin E. Cluster V had highest saponification value, iodine value, leaf length, leaf breadth, Mg and height of first branch.

5.10. Path analysis on rind and fruit yield

Based on the estimates of correlation of various quantitative traits with rind yield of *G. gummi-gutta*a path analysis was done. The contribution of residual effect on rind yield was 0.0546, which indicated the effect of unknown source on yield. The rind weight exerted the high, positive and direct effect on rind yield. The fruit weight and petal breadth exerted low and negative effect on rind yield. Negligible, direct effect was exerted by petal length, weight of flower and number of fruits per tree on rind yield.

Path analysis on fruit yield showed the direct, high and positive effect exerted by number of fruits per tree and weight of ten fruits on fruit yield. Negligible, positive and direct effect was exerted by rind weight of ten fruits weight of flower and petal length on fruit yield. Negligible, negative and direct was exerted by petal breadth on fruit yield.

5.11. Principal Component Analysis

The most significant trends in the datasets were revealed by applying PCA, which is a procedure that lies within the frame-work of multivariate statistical analysis.

5.11.1. Biochemical features

The scree plot of PCA showed that the first two PC's had cumulative variance 34.9 percent. The PCA of biochemical attributes showed that PC1 accounted 21.6% of the total variation and was contributed highly by vitamin B_1, vitamin B_2, vitamin B_{12} and vitamin C. PC2 accounted for 13.2 percent of the total variation and was contributed significantly by iodine value,

vitamin A, phenol and vitamin E. PC3 accounted for 9.8 percent of total variation. PC3 accounted for 9.8 percent of total variation and variables such as carbohydrates, reducing sugar and crude fat were the main contributing factors. PC4 accounted for 8.4 percent of total variation and had Mg, phenol and Na as main contributers. PC5 had high loading for K, acid value and iodine value and contributed 7.4 percent of total variation. In PC6 three attributes such as Ca, Na, vitamine E were main contributing factors and explained 6.2 percent of total variation. PC7 had K, flavonoids and protein as a main contributing factors. Similarly PC8 accounted 5.3 percent of total variation with crude fat, carbohydrates and saponification value as main contributing factors. PC9 accounted for 4.5 percent of total variation and the reducing sugar, phenol and vitamin C were main contributing factors.

From the PC loading plot (Fig. 5) it could be inferred that the characters like vitamin B_1, vitamin B_2, vitamin B_{12} and vitamin C are linked together. Like wise acid value, saponification value, phosphorous and carbohydrate have positive association. Phenol, flavonoids, sodium also positively associated. However vitamin A and E are negatively associated with vitamin B_{12} and vitamin C. The selection based on these characters can influence the other characters as per these relationships.

Based on the first two components of the PC analysis grouping was made (Table 22). Out of 30 accessions and 2 entries from home garden, 4 groups were formed. Group III had maximum number of accessions and Group II had minimum accessions. The mean performance of clusters depicted in Table 23. Group I had high value for saponification value, acid value, phosphorous, vitamin B_1, B_2 and B_{12} content, moderate iodine value, Ca, phenol content and low reducing and crude fat content. Group II had very high value of iodine, calcium and carbohydrates. For other characters group II showed moderate value. Vitamin A, vitamin E and vitamin K had maximum mean value in group III. In group IV, phenol, flavonoids, crude fat and Mg had maximum value and for other characters such as Ca, P, saponification value, acid value, it had low value.

5.11.2. Morphological features

Using Kaiser's criterion (Eigenvalue >1) (Kaiser, 1958), two significant components were obtained that explained 37.4 percent of total variation (Table 22). The first component, which accounted for 21.6% of the total variation, was strongly correlated with fruit weight, rind

weight, and pedicel length and leaf breadth. The second component, which accounted for 17.3 percent of the total variation, was mainly correlated with the petal length, tree height and height of first branch. The third component, that explained 13.9 percent of the total variation, was associated with weight of flower, rind weight and seed weight. The fourth component, accounted for 11.6 percent of the total variation, was determined by the characters of petal length and pedicel breadth as main contributing factors.The fifth component explained 9.6 percent of the total variation, and was associated with tree height, number of fruits per tree and height of first branch from base. PC6 accounted for 7.6 percent of total variation with petal length and leaf breath as main contributing factors. However, PC7, PC8, PC9, PC10, PC11 and PC12 had eigen values less than 1.00 and thus regarded as making no significant contribution to the total variation.

The PC loading plot (Fig. 8) indicated that characters like fruit weight and rind weight were positively associated. Like wise number of fruits per tree, tree height and height of first branch had positive association. Pedicel length, leaf length and leaf breadth were also positively associated.

Based on the first two components of the PC analysis grouping was made (Table 25). Out of 30 accessions and two entries from home garden, this graphically represented relative positions of various accessions. Group I was formed by maximum number of accessions and group IV had minimum number of accessions. Based mean performance group I had high value for flower weight, moderate value for petal length, pedicel length and tree height and low value for petal breadth, rind weight and fruit weight. Group II had very high value for fruit weight, rind weight, tree height and height of first branch from base. For petal length, petal breadth, number of fruits per tree and leaf length group II had moderate value. However, pedicel length, weight of flower and leaf breadth displayed low value in this group. Group III had high value for petal length, petal breadth and weight of seeds and moderate value for pedicel length, weight of flower, number of fruits per tree and length leaf. The low value of tree height and height of first branch was seen in group III. In group IV, pedicel length, leaf length and leaf breadth had maximum value and for petal length, petal breadth, weight of flower and weight of fruit had moderate value.

The present investigation on the assessment of variability amongst the accessions maintained at NBPGR and local entries from Vellanikkara showed that there is considerable variation amongst the accessions in terms of the morphological, biochemical characteristics. The variation was high in tree height, height of first branch from base GBH and pedicel length, moderate in leaf area, seed germination, Na content, P content and flavonoids and low in leaf length, leaf breadth, petal length, petal breadth, pedicel length, Ca, Mg, Vitamin A, Vitamin B1, Vitamin B12, all primary metabolites studied and all biochemical characters of seeds studied. The study also found significant associations between these characters. The clustering done using hierarchical cluster analysis and PCA indicates possibility of taking up hybridisation work in this species for improving the yield and nutritional value of this important tree crop of home gardens in Kerala.

Summary

SUMMARY

The present investigation was to examine the variation among 30 different accessions of hermaphrodite trees of *Garcinia gummi-gutta* of about 26 year age that are maintained as a germplasm collection in the orchard of National Bureau of Plant Genetic Resources, Regional Station (NBPGR), Vellanikkara. Beside this, two hermaphrodite trees from homesteads of Thrissur were also included in this study. The study tried to evaluate variability with respect to general tree characters, leaf, flower, fruits and seed characters, biochemical characters of fruits, physical and biochemical characters of seed butter. The salient findings of the studies are summarized below.

1. Plant height in *G. gummi-gutta* varied from 3 m to 19 m among different accessions and height of first branch from base of the tree ranged from 0.65 m to 3.5 m. Measurement on GBH also showed wide variation. The GBH found to range from 31 cm to 107cm.
2. Variation was noticed in the canopy shape, viz., conical, dome, pyramidal and in branching habits like erect, drooping and horizontal.
3. The leaf length ranged from 9.47 cm to 14.97 cm and Leaf breadth varied from 3.6 cm to 7.11 cm. Leaf area varied from 22.78 cm^2 to 56.39 cm^2.
4. The young leaf bud took 30 to 32 days for the development of leaves from emergence to mature dark green stage. Both pinkish red and light green flushes were observed in hermaphrodite trees during the initial stages of development. After 16 days they turned into green.
5. The flowering started within the period of February to March in all the accessions. Flowers were hypogynous, petals were regular, polypetalous and tetramerous in nature but pentamerous and/or hexamerous flowers also observed.
6. For majority of flowers, petal colour was creamy yellow and yellow. However, pinkish red colour flower observed in IC244097-3. The number of flowers per cluster ranged from one to two in each accession. Mostly single was observed, in rare case double flowers were noticed.
7. Length of petal ranged from 0.7 cm to1.14 cm and petal breadth varied from 0.45 cm to 0.88 cm. Pedicel length of flower was in the range of 0.38 cm to 0.91 cm. The weight of flowers varied from 0.38 g to 0.78 g.

8. Wide variation was observed in weight of fruits and it ranged from 51.4 g to 148.5 g. Weight of rind varied from 29.6 g to 83.5 g. Yield with respect to number of fruits produced per tree ranged from 70 to 985. Mature fruits were yellow in colour with grooves.
9. Weight of seeds which were shade dried for a week ranged from 0.65 g to 1.2 g. The germination percentage varied from 80% to 30%. The average germination percentage was 54.69 %.
10. The study on primary metabolites showed that carbohydrate content estimated was varied from 18.08 g/100 g to 29.69 g/100 g, the protein content ranged from 0.93 g/100 g to 1.29 g/100 g. The crude fat content was varied from 3.28% to 6.18% and reducing sugar content ranged from 3.85% to 4.31% among different accessions.
11. Secondary metabolites of fruits showed considerable variation. The phenolics content varied from 900 mg/100 g to 1020 mg/100 g. The flavonoids content ranged from 127 mg/100 g to 148 mg/100 g.
12. Mineral composition of fruits revealed that there was variation among accessions. The Ca content varied from 105.44 mg/100 g to 212.25 mg/100 g. The wide variation in Na content observed was ranged from 41 mg/100 g to 98 mg/100g. The K content varied from 115.8 mg/100 g to 227.1 mg/100 g. P content recorded was ranged from 20.4mg/100 g to 52.4 mg/100 g and Mg content varied from 10 mg/100 g to12.87 mg/100 g.
13. Vitamins content of fruits also showed considerable variation. The vitamin B_1 content between different accessions varied from 29.64 µg/100 g to 54.55 µg/100 g. Vitamin B_2 content ranged from 11.26 µg/100 g to 25.07 µg/100 g. Vitamin B_{12} content ranged from 30.39 µg/100 g to 56.4 µg/100 g. Vitamin C content ranged from 16.69 mg/100 g to 27.76 mg/100 g, vitamin A content varied from 8.85 µg/100 g to 16 µg/100 g.
14. A correlation matrix between morphological characters of *G. gummi-gutta* trees showed a significant and positive relation between petal length and petal breadth, weight of fruits and rind weight, number of fruits per tree and tree height, tree height and height of first branch from base.

15. The correlation between biochemical characters of *G. gummi-gutta* showed the presence of significant, high and positive correlation between Na and flavonoids, the positive correlation between Na and Mg, Na and phenol, Ca and protein, K and crude fat.
16. Path analysis for rind yield showed that rind weight had high, positive and direct effect on rind yield, while fruit weight and petal breadth had low, negligible and direct effect on rind yield. The characters such as petal length, petal breadth and weight of flower, weight of fruits, rind weight and number of fruits per tree had indirect effects on rind yield.
17. Path analysis for fruit yield revealed that number of fruits per tree and fruit weight had high, positive and direct effects on fruit yield. Similarly negligible, positive and direct effect was exerted by rind weight, weight of flower and petal length on fruit yield. Also negligible, negative and direct was exerted by petal breadth on fruit yield.
18. The cluster analysis grouped 32 accessions into five clusters. Among 5 clusters, forth cluster was largest and fifth was smallest.Cluster1 composed of trees with highest acid value, number of fruits per tree, P, flavonoids, protein, vitamin C and seed germination. Cluster II composed of trees with highest value of Ca, Na, tree height, phenol content and reducing sugar. Similarly cluster III composed of trees with highest fruit weight, rind weight, carbohydrates, vitamin B_1, vitamin B_2 and vitamin B_{12}. Cluster IV composed of trees with highest petal length and breadth, pedicel length, flower weight, K, crude fat, vitamin A and vitamin E. Cluster V had trees with highest saponification value, iodine value, leaf length, leaf breadth, Mg and height of first branch.
19. Principal Component Analysis on biochemical feature showed that PC1 accounted 21.6 percent of the total variation and were contributed highly by vitamin B_1, vitamin B_2, vitamin B_{12} and vitamin C. PC2 accounted for 13.2 Percent of the total variation, contributed majorly by iodine value, vitamin A, phenol and vitamin E. PC3 accounted for 9.8 percent of total variation. PC4 accounted for 8.4 percent of total variation and had Mg, phenol and Na as main contributeurs. PC5 had high loading for K, acid value and iodine value and contributed 7.4 percent of total variation. In PC6 three attributes such as Ca, Na, vitamine E were main contributing factors. It explained 6.2 percent of total variation. PC7 had K, flavonoids and protein as a main contributing factors.
20. From PC loading plot for biochemical feature inferred that the characters like vitamin B1, vitamin B_2, vitamin B_{12} and vitamin C are linked together. Similarly acid value,

saponification value, phosphorous and carbohydrate have positive association. Phenol, flavonoids, sodium were also positively associated. The selection based on these characters can influence the other characters as per these relationships.

21. The PCA of morphological attributes were showed PC1 accounted for 21.6 percent of the total variation and fruit weight, rind weight, pedicel length and leaf breadth were important contributing factors. PC2 had high loading for petal length, tree height and height of first branch with total variation of 17.3 percent, PC3 contributed 13.9 percent of total variation. PC4 accounted for 11.6 percent of total variation with petal length and pedicel breadth as main contributing factors.
22. From the PC loading plot it could be inferred that the characters fruit weight and rind weight were linked together. Like wise number of fruits per tree, tree height and height of first branch have positive association. Pedicel length, leaf length and leaf breadth were also positively associated. However fruit weight and leaf length were negatively associated with vitamin B_{12} and vitamin C.

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MORPHO-PHYSIOLOGICAL DIVERSITY ASSESSMENT OF *GARCINIA GUMMI-GUTTA* (L.) ROBS. GERMPLASM COLLECTION

by

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ABSTRACT OF THE THESIS

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VELLANIKKARA, THRISSUR – 680 656
KERALA, INDIA

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ABSTRACT

Morpho-physiological diversity assessment of *Garcinia gummi-gutta* (L.) Robs. germplasm of hermaphrodite trees of National Bureau of Plant Genetic Resources, Regional Station (NBPGR), Vellanikkara and two local accession was carried out at College of Forestry, Vellanikkara. The objective of this study was to explore the variability in terms of vegetative, flower, fruit, seed characters, biochemical characters of fruits and seed butter in the 32 entries of *G. gummi-gutta*.

Study indicated presence of conical, dome and pyramidal canopy shape with most trees having conical shape crowns in *G. gummi-gutta*. Horizontal, erect and drooping branching pattern was observed among the entries, with drooping branches predominating. Wide variation in tree height and height of first branch from base and GBH was observed. High correlation was observed between tree height and height of first branch.

Leaf characters such as leaf length, breadth and leaf area had considerable variation among the accessions. Flower characters study revealed the presence of cream, yellow and pinkish red colour petals. Petal length, petal breadth, pedicel length and weight of flowers too varied among the entries. Petal length and breadth were correlated.

The fruit characters such as fruit weight, rind weight, fruit yield had wide variation (CV of 27.59%, 46.7% and 30.75% respectively). The yield varied from 70 to 980 fruits per trees. Seed characters like seed length, breadth, seed weight and germination differed among the accessions. Significant correlation was noticed between fruit weight and rind weight, number of fruits per tree and tree height.

The study on primary metabolites content in fruits showed considerable variation in terms of carbohydrate, protein, crude fat and reducing sugar. Among them reducing sugar showed low variation with CV of 3.19 percent. Secondary metabolites in fruits like phenolics and flavonoids content too varied among the accessions. Phenol content varied from 900 mg/100 g to 1200 mg/100 g. The fruits of various accessions differed in terms of mineral content like Ca, Na, K, P, K and Mg. The vitamins such as vitamin B_1, B_2, B_{12}, C, A and E showed low variation among the accessions in the present study. The vitamin C varied from 16.69 to 27 mg/100 g. The correlation between biochemical characters of *G. gummi-gutta* indicated the presence of significant, positive correlation between Na and flavonoids, Na and Mg, Na and phenol, K and crude fat, phenol and flavonoids. Path analysis for fruit yield indicated that number of fruits per tree and fruit weight had high, positive and direct effects on fruit yield. Path analysis indicated that rind weight had high, positive and direct effect on rind yield.

Melting point and colour of seed butter varied among the accessions. Biochemical characters of butter such as saponification value, acid value and iodine value had lower extent of variation.

The PCA analysis on morphological feature indicated that the first two PC's could explain 37.4 percent of the variation. The first component was composed of fruit weight, rind weight, and pedicel length and leaf breadth. The second component was influenced by petal length, tree height and height of first branch. The PCA analysis on biochemical feature indicated first two PCs with Eigen values >1 could explain the 34.9 percent of the variation. The first component was mainly composed of vitamin B_1, vitamin B_2, vitamin B_{12} and vitamin C. The second components were strongly associated with iodine value, vitamin A, phenol and vitamin E.

The present investigation related to variation in morphological and biochemical parameters in *G. gummi-gutta* indicated considerable variation among the accessions. Trees could be grouped into five clusters based on these characters using cluster analysis. Thus, there is a possibility of taking up hybridisation work using the present germplasm for improving the yield and nutritional value of this important tree crop of Kerala.