VARIABILITY AND PROPAGATION STUDIES IN PUMMELO (*Citrus grandis* (L.) Osbeck.)

By

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THESIS

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DECLARATION

I hereby declare that the thesis entitled **"Variability and propagation studies in Pummelo (*Citrus grandis* (L.) Osbeck.)"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

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ANUPAMA. T.V.

To

My daughter, Devika

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fig.	figure
cm	centimetre
g	gram
kg	kilogram
ml	millilitre
mg^{-1}	milligram per litre
IBA	Indole butyric acid
IAA	Indole acetic acid
NAA	Naphthalene acetic acid
GR	Growth regulator
viz.	namely

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INTRODUCTION

INTRODUCTION

Citrus is the world's leading tree-fruit crop. It is grown in tropical and subtropical climates and has wide distribution in the world. Citrus fruits are well known for their refreshing taste and nutritional value. As food habits of people are being shifted towards natural products, citrus fruits are highly preferred for consumption. Major citrus producing countries are USA, Brazil Israel, Spain and Morocco. Although, domestic consumption is the principal market for citrus fruit, these countries are exporting a sizeable amount of fresh fruits to the world market. Global annual citrus production was estimated over 105 million tonnes in 2003-2004 (FAO, 2005).

Citrus is the third most important fruit crop in India occupying about 13.03 per cent of the total land under various fruits (Bal, 2002). The most important commercial citrus in India is the mandarin orange followed by the sweet orange and acid lime. The estimated area under citrus fruits is 0.56 million hectares with a production of 4.58 million tonnes (Shikamany and Sidha, 2004).

Citrus fruit species represent a wealth of as yet untapped potential for valuable research effort and development. Pummelo (*Citrus grandis* (L.).Osbeck.), the largest fruit in the citrus family, is one among them. It is a bushy tree grown in many tropical countries, particularly South East Asia. Pummelo is a native of Thailand and Malaysia and spread to China, India and Persia.

Pummelo fruits are rich in vitamin C (more than mandarin!) and also contain significant amounts of protein, carbohydrates, calcium, phosphorous and vitamins A, B_1, B_2 and B_{12}. The fruit is mainly used for fresh consumption and also for extraction of the juice as a drink. The outer fruit skin is a source of pectin and the white or pinkish inner pith is processed into candies. Fruits have a long shelf life due to the thick fruit peel; it is excellent for transport to far markets. Pummelo fruits are used as "temple fruits" and are given as gifts at various religious and cultural festivals in some Asian countries.

Pummelo peel contains volatile oils comprised of citral, geraniol, linalool and methyl anthranilate. It also contains protein, fat, vitamin B_1, B_2, C and reported to promote platelet- aggregation and anti-inflammatory effect. Aromatic flowers are used for extraction of essential oils in Vietnam. The leaves, flowers, fruits, seeds, gum from declining trees, decoction from the plant parts and juice from the fruit are used as herbal remedies for fever and gastric disorders in Philippines. Chemicals (nordentatin and xanthalectin) found in the bark are strong anti bacterial agents. Wood from declining and dead trees is used as fuel and also for the fabrication of certain farm implements. Pummelo trees, with their large, yellow fruits and evergreen canopies are excellent landscape materials and are used as live trellises and nurse crops.

There is no world production statistics exclusively for pummelo, however, according to FAO, the total production of grapefruit and pummelo was 5.05 million tonnes in 1994, which was 6.2 per cent of the total Citrus production of the year. The principle countries for commercial production of pummelo are Thailand, Malaysia, Indonesia, Vietnam, China and Japan. Pummelo ranks third (11%) of Thailand's export of fruits (Paudyal and Haq, 1999).

In India, cultivation of pummelo is confined to certain localised regions and no commercial variety is known except Nagpur Chakotra. Pummelo is grown in the homesteads of Kerala especially in the southern districts and is mainly perpetuated through seedlings. It is largely self-incompatible and does not produce nucellar seedlings.

Cross-pollination occur between pummelo and other species of genus *Citrus* resulting in great range of genetic variability in pummelo. Despite the high diversity, little research has been carried out on varietal improvement using local land races. As a result, the quality and quantity of pummelo are very low in farmers' field as they are cultivating inferior trees grown from the seeds. Hence it is desirable to undertake a systematic study to assess the diversity of pummelo in our state. More over citrus fruit especially grape fruit, the mutant of pummelo, is now a days being recommended for the diabetic patients and calory conscious people as it contains zero per cent fat and cholesterol and only six per cent sugars. So effort has to be taken to select and utilize superior pummelo trees, which are the cheap source of vitamin C.

As viable seeds are less in this crop and monoembryonic seedlings exhibit variation in their habits, standardization of a viable vegetative propagation method and identification of the best season is much important in this crop, which is at present lacking. Vegetative propagation of pummelo shortens the juvenile period and it could be used for the multiplication of the superior and seedless accessions.

The present study was undertaken with the following objectives.

1. To study the variability in pummelo in relation to phenotypic characters
2. To study the physico-chemical properties of fruits
3. To standardize vegetative propagation techniques.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Pummelo or Shaddock (*Citrus grandis* (L.). Osbeck.) is regarded as an ancestral species of the genus *Citrus* that belongs to the family Rutaceae, sub-family Aurantioidae, tribe Citreae and sub tribe Citrinae (Purseglove, 1968).

The synonyms for *Citrus grandis* are *Citrus maxima* Merril. and *Citrus decumana* L. (Purseglove, 1968; Singh, 1995).

Purseglove (1968) suggested that pummelo is a native of Thailand and Malaysia and spread to China, India and Persia. It was taken to Barbados in the 17th Century by Shaddock and is called shaddock in the West Indies and United States However, Jorgensen (1984) reported that although it occurs wild in Indonesia and Malaysia, it originally occurred in China where it was recorded in 2200 BC.

Arora (1998) opined that Nepal has the highest diversity of pummelo among south Asian countries. According to Min (1997) China is the primary centre of origin for pummelo while Japan, India, Thailand, Philippines and Malaya are the secondary centres.

Three variants of this species are *C. grandis var. megaloxycarpa* or *C. megaloxycarpa* (sour pummelo), *C. grandis var. keem* syn. *C. megaloxycarpa var. keem* and *C. grandis var. rugosa* (Mahalung or Lemon thumb of India) (CSIR, 1992).

Pummelo is a monoembryonic species. The tree grows upto 3-10 m height. Leaves are large with broadly winged petiole. Lower surface of the leaf is pubescent. Flowers are fragrant, crowded in short axillary racemes. Fruits are large, sub globose to pyriform in shape with thick and spongy rind. Pulp is mildly sweet and moderately juicy. Rind is thick, smooth with large oil glands on them (Ghosh, 2001).

Mainly two types, viz., white fleshed and red or pink fleshed are available in pummelo. The fruits are used as table fruit. The fruit is also squeezed for its juice. It is a good source of vitamins A, B, and C. The peel, which consists of epidermis, oil glands and albedo, is used for extraction of oil (Singh, 1995).

The leaves are used for seasoning meat and and fish preparations in the Philippines. Fruits are commonly used as offerings in temples in Asian countries. A liqueur is also prepared from the fruit (Rajput and Haribabu, 1985; Randhawa and Srivastava, 1986). The flowers are highly aromatic and gathered in North Vietnam for making perfume. The wood is heavy, hard, tough, fine-grained and suitable for making tool handles (Morton, 1987).

Pummelos may flower 2 to 4 times a year. The main crop matures in November (Morton, 1987).

2.1 VARIABILITY STUDY

2.1.1 Variability in pummelo

The aim of exploration or collection is to capture maximum variability of a crop and it's wild relatives to meet the needs for conservation. Maintenance of biological diversity helps in sustaining the agricultural productivity (Drew, 1997).

Citrus grandis seedlings exhibit high levels of variability and many varieties occur wild in Southeast Asia. Pummelo is monoembryonic and in most cases, self-incompatible (Soost, 1964).

Anupunt and Hailstones (1999) observed wide genetic diversity in pummelo in Thailand. He reported that the most abundant source of genetic resources for this species is in the viscinity of villages where disturbances to the natural ecosystem have been minimized.

In a study conducted on 15 pummelo cultivars grown under different locations in West Bengal to assess the genetic variability, the fruit characteristics viz., fruit weight, peel thickness, peel weight, number of segments per fruit, 100 seed weight, TSS/ total sugar, acidity and TSS/ acidity differed significantly (Maiti *et al.*, 2001).

2.1.1.1 Tree characters

Ghosh (2001) described pummelo as a spreading, round topped almost thorn less tree.

Tree characters such as height, tree habit, shape and mode of branching are described by NBPGR (2002) for assessing citrus plants.

The pummelo trees are 16 to 50 feet (5-15 m) tall, with a somewhat crooked trunk 4 to 12 inch (10-30 cm) thick, and low, irregular branches. Some forms are distinctly dwarfed. The young branchlets are angular and often densely hairy, and there are usually spines on the branchlets, old limbs and trunk (Morton, 1987).

Paudyal and Haq (1999) observed tree height, canopy volume, trunk diameter, growth habit and tree shape for describing pummelo plants.

2.1.1.2 Varieties

Kao pan of Thailand and Buntan of Formosa are two named varieties of pummelo (Singh, 1995).

Chakotra and Gagar are two cutivars of *C. grandis* grown in India (Singh and Chadha, 1993).

2.1.1.3 *Leaf characters*

Leaf characters form important criteria in identification of varieties. Descriptors are provided for leaf shape, petiole wing shape, leaf length, width and leaf margin (NBPGR, 2002).

Leaf margin (entire, serrate, crenate) and petiole (degree of wing development) are two important characters in identification and classification of a Citrus species (Ghosh, 2001).

Petiolar wing is most developed in the members of Papeda group, followed by the pummelo and least developed in citrons (Rajput and Haribabu, 1985). Leaves are large, ovate-oblong to elliptic, rounded or acuminate, petiole broadly winged pubescent and cordate (CSIR, 1992).

2.1.1.4 *Flower characters*

Flowers are borne singly or in clusters, 3-7 cm in diameter. Petals are cream coloured, stamens 20-25, ovary with 11-16 loculi (Purseglove, 1968).

NBPGR (2002) formulated descriptors for flower/inflorescence characters, which include arrangement of flowers, inflorescence position, number of buds per inflorescence, size of flower, petal colour, number of petals/ flower and number of stamens/flower.

In most of Papedas, pummelo, sour lime and *Citrus pennivesiculata*, the petals are four in number. The stamens are markedly smaller than the pistil in pummelo. In grapefruit, pummelo and tight skinned acidic fruits, the petals are strongly reflexed (Ghosh, 2001).

Zirkle (1937) described a method of staining the pollen grains to assess their fertility using acetocarmine. He found that plumpy, well shaped and fertile pollen grains took the stain in contrast to sterile or non-viable ones. Acetocarmine staining technique has been used in several crops such as guava (Balasubramaniam, 1959), pomegranate (Nath and Randhawa, 1959), sapota (Nalawadi. *et al.*, 1977), banana (Karmacharya, 1984), and lovi-lovi (Prasad, 1998).

The average size of the pollen grains ranged between 53.15 - 53.82 micro metres and 47.82 – 48.26 micro metres, in green type and red type custard apple (*Annona squamosa*) respectively (Sahoo *et al.*, 2000).

2.1.1.5 Fruit characters

Fruits are very large, globose, or pear shaped, 10-30 cm in diameter, often yellowish when ripe and with thick peel. Pulp vesicles are large, pale yellow to pink with sweetish juice (Purseglove, 1968). The oil glands on the surface of fruits of *Fortunella* and pummelo are markedly raised. The rind is thick and spongy in pummelo. With respect to colour of pulp, pink colour is seen in some pummelos and grapefruits and straw coloured in lemons (Ghosh, 2001).

Fruits are described by their shape, base shape, apex shape, skin colour, weight, length, width, skin surface, oil glands on skin, mesocarp colour, number of segments, colour of carpels, juice content, juice colour, juice taste and flavour (NBPGR, 2002). Fruits are large, turbinate, light yellow to orange, rind very thick, white spongy, smooth, gland dotted, segments large, 11-14 in number, covered with thick leathery septa, juice vesicle long, tapering, pulp light pink, rose, white or light yellow. Fruits are composed of 23-24 per cent peel, 175 ml juice and 3-4 per cent seed (CSIR, 1992).

The average number of segments per fruit could be as high as 17 in some pummelos or as low as four in some kumquats (*Fortunella japonica*).

Correspondingly pummelos were the largest citrus fruits in terms of fresh weight and diameter while kumquats were the smallest (Tissaret *et al.*, 1990).

Karaya (1988) reported that Pummelo pyriformis and the grapefruit Yubileinyi were completely self incompatible and set seed only after cross pollination. Their fruit set was also higher with crossing than selfing. According to Susanto *et al.* (1993), the weight of the seedless pummelo fruits was similar to that of the seeded ones at various harvest times. The shape of the seedless fruits was more pyriform and necked, the peel thicker and the degreening of rind slower compared with seeded fruits. TSS and acids in juice of the seedless fruits were lower than those of the seeded ones.

The normal season of cropping is from January-March in North India and September-November in South India (Singh, 1995).

Wattanavicheanand and Aroonyadet (2003) reported that oil gland size on fruit surface showed a positive correlation with sugar acid ratio. The density of oil glands in the matured Kao Nampheung pummelo was equal to more or less than 26.47 oil glands/square cm.

2.1.1.6 Bio chemical characters

Pummelo fruits contain TSS of 11.2-13.2^0 brix, citric acid 2.31-2.70 per cent, total sugars 8.0-9.5 per cent, sucrose 5.0 percent, vitamin C 20 milli gram per 100 gram fruit (CSIR, 1992).

Atul *et al.* (1998) observed that pear shaped pummelo fruits had maximum weight (1550 g), rind thickness (26.3 cm), juice content (52.32 per cent) and TSS (8.2° brix) while oval shaped fruits recorded maximum weight of 1175 g and rind thickness of 19.50 cm. In another study, Murthy *et al.* (1989) reported that the oblate fruits had the highest fruit weight (1.49 kg), fruit circumference (56.9 cm), number of segments (18.85), segment weight (48.8 g) and titrable acidity (298.6 mg/100 ml juice); the oblong had the most juice content per 100 g of pulp (58.6 ml); the ovoid recorded the highest TSS content (10.64° brix) and the spherical scored most in the organoleptic test.

The bitter component, naringin was found only in fruit skins of pummelo and rough lime. Sensory analysis further confirmed that the juice extracted from pummelo and rough lime were bitter (Yusof *et al.*, 1993).

Chen *et al.* (1993) reported the cultivars Dongguoqiyan shatianyou and Gulaoqian shatianyou have the highest ascorbic acid content (88.6-100 mg/100 ml juice. According to Shen *et al.* (1999), when 102 pummelo cultivars and selections were compared in China, cultivar Shatianyou 2 recorded the thinnest rind (1.14 cm), the highest sugar content (8.52%) and the highest vitamin C content (158 mg/100 ml juice).

Paudyal and Haq (1999) catalogued the pummelo germplasm in Nepal and reported out that in pummelo fruits, acidity varied from 0.65- 4.03 per cent, TSS from 7.0-12.8° brix and TSS/acidity ratio from 2.8-14.2.

2.1.1.7 Seed characters

Thakur and Bajwa (1971) studied polyembryony in different citrus species and reported that pummelo has 1.02 embryo per seed and percentage of polyembryonic seed is two.

Pummelo is a monoembryonic species, having very large, coarsely veined (striated), irregularly shaped seeds, which are white within (Ghosh, 2001). Paudyal and Haq (1999) observed that pummelo seeds exhibit a high level of variability due to cross-pollination and germination of seeds occurs within two-three weeks.

Descriptors were formulated by NBPGR (2002) for seed characters viz., number of seeds per fruit, seed length, width, shape, colour of cotyledons and number of embryos. Chen *et al.* (2002) found that embryo abortion caused seedless ness in pummelo and average seed number per fruit ranged from two to 32.

2.1.2 Variability in other fruit crops

Thimmaraju *et al.* (1977) reported a large genetic diversity in seedling population of tamarind (*Tamarindus indica*), being a highly cross-pollinated crop and owing to its wide geographical distribution and adaptability to different agro climatic regions.

In phalsa (*Grewia asiatica*), a lot of variability exists in Central India, Rajasthan, Bihar, and other parts of South India and suggested that surveys have to be made to collect promising types (Pareek and Panwar, 1981).

Attri *et al.* (1999) studied fourteen collections of mango for their genetic variability and correlation among various fruit characters in South Andaman. A remarkable variability was observed for fruit length, breadth, stone, TSS, sugars, ascorbic acid, carotenoids and overall quality.

Jyothi (2000) observed wide variability in leaf, inflorescence, and fruit characters in pickling type mango in Kerala; and significant variation was noticed in quality parameters in terms of acidity, TSS, ascorbic acid, polyphenols, crude fibre content and juice content.

In ripe fruits of selected genotypes of bael (*Aegle marmelos*), in Tarai region of Uttar Pradesh, significant variations were recorded for fruit characters viz., shape, size, weight, volume, rind thickness, fibre, mucilage, peel, pulp, seed, TSS and acidity while TSS/acid ratio and ascorbic acid did not differ significantly (Singh *et al.*, 2000).

In kodampuli (*Garcinia cambogia*), Muthulakshmi *et al.* (2001) reported considerable variability in terms of vegetative, floral, fruiting and biochemical characters in survey conducted in the homesteads of Kerala.

According to Srivastava and Rajput (2003), extensive explorations of carambola (*Averrhoa carambola* L.), in Uttar Pradesh indicated high variability in fruit characters viz., shape, apex, skin colour, weight, diameter, seeds per fruit, fibre content, TSS (4.7-8.1° brix), acidity (2.01-3.98%), juice content (55-85%) and shelf life (11-16 days).

In a study to explore variability in jackfruit in Kerala, Muthulakshmi (2003) found a lot of variability in terms of vegetative, floral, fruiting, and biochemical characters. Significant variation was reported in total sugars (8.16-19.30%), reducing sugars (1.63-5.23%), non-reducing sugars (5.96-14.98%), TSS (14.63-33° brix) and acidity (0.69-4.95%).

Galgal (*Citrus pseudolimon* Tanaka.) germplasm in Himachal Pradesh was randomly surveyed for the extent of variability with respect to fruit characters and yield, and considerable variation was noticed for juice content, fruit length, rind thickness, fruit and core diameter (Badiyala and Sharma, 2004).

Ahmed *et al.* (2004) reported that in Quince (*Cydonia oblonga* Mill.), wide variability existed in fruit shape (round, oblong-ridged, round, flat and apple shaped), fruit cavity (wide and deep), fruit skin colour (light yellow, deep yellow, deep golden, light green), flesh colour (creamish and white), moisture content (60-80%), fruit weight (25-310 gram), TSS (5-13° brix), acidity (0.2-0.8%) and total sugar (2.5-8.9%).

2.2 PROPAGATION STUDIES

2.2.1 Cutting

Rooting through cuttings is the most simplest and easiest method of plant propagation. This is rapid, less expensive, and does not require special techniques as in other propagation methods.

Citrus propagation through cuttings is possible as most *Citrus species* exhibit a tendency of adventitious rooting (Sandhu, 1991). Citron and sweet lime root rapidly while grapefruit and sweet orange are difficult to root (Nanda and Kochar, 1991).

2.2.1.1 Effect of type of cutting on rooting

Singh (1963) reported that hard wood cuttings of sweet lime gave better rooting than that of Kagzi lime. In contrast, Gangwar and Singh (1965) found that semi hard wood cuttings rooted better than hard wood cuttings in sweet lime.

Ferguson *et al.* (1985) found juvenile three leaf cuttings of Citrumelo produced more roots compared to mature ones. Sixty seven per cent rooting was obtained from younger wood cuttings of Meyer lemon while older wood gave 44 per cent rooting (Gorgoshidze and Kartvelishvili, 1985). According to Kim *et al.* (1992), in *Citrus junos*, apical and basal cuttings proved to be more efficient in rooting.

In baduvapuli (*Citrus pennivesiculata*), soft wood cuttings gave higher per cent of rooting at higher concentrations, and hard wood cuttings at intermediate concentrations and combinations of growth regulators tried. Hard wood cuttings gave significantly higher number of roots, higher value for length of longest roots and higher number of leaves to other types (Sareena, 1996).

2.2.1.2 Effect of growth regulator and it's concentration on rooting

Growth regulators in proper concentrations are proven to accelerate the process of rooting in cuttings of a wide range of plant species. The effect of auxin in the process of root formation in cuttings was found by Thimann and Koeffli (1935). It was also demonstrated by Copper, 1935; Hitchcock and Zimmermann, 1936; Pearse, 1938. Though different growth regulators were used by them, today the most commonly used growth regulators in inducing rooting are IBA, IAA and NAA.

Dikshit (1956) observed that Kagzi lime cuttings with 250-300 mg l^{-1} IAA gave 65 per cent rooting. IAA and IBA in general showed a root promoting effect in lemon and lime cuttings, IBA having better performance (Sen and Bose, 1962). According to Gabricidze (1971), lemon cuttings treated with IAA 200 mg l^{-1} or IBA 75 mg l^{-1} rooted in 15-20 days. In Citrumelo cuttings, best rooting responses were reported with IBA and NAA treatment, both at 3000mg l^{-1} (Ferguson *et al.*, 1985). Arora and Yamadagni (1985) reported that NAA at 4000, 3000 and 2000 mg l^{-1} respectively proved to be the best for cuttings for Baramasi, Kagzi kalan and Eureka lemon. IBA 100 mg l^{-1} gave 36-67 per cent rooting in sweet lime (Sandhu and Singh, 1986).

Sareena (1996) reported that in baduvapuli (*Citrus penniveśiculata*), IBA at 1500 mg l^{-1} gave the highest rooting percentage in cuttings (43.3), which was on par with IBA 2000 mg l^{-1}. IBA at 1900 mg l^{-1} produced significantly higher roots.

With regard to the method of treatment, Singh (1963) observed that quick- dip application of 2000 mg l^{-1} IBA showed an increase in rooting and sprouting percentage of sweet lime cuttings. According to Shafrir (1973), dipping Washington Navel orange cuttings in IBA 1000 or 2000 mg l^{-1} for 10 seconds proved to be the best for rooting.

When comparing the qualitative aspects of rooting, Shafrir (1973) found significant increase in the number of roots per cutting, proportion of cuttings suitable for transplanting and the survival rate in Washington Navel orange treated with IBA 1000 or 2000 mg l^{-1}. In sweet lime IBA 100 mg l^{-1} gave highest root number and largest root per cutting (Bajwa and Khajurla, 1977). With regard to the percentage bud break, rooting and survival, primary root number, length, diameter and fresh weight, IAA 400 mg l^{-1} gave the highest results in Assam lemon (Pandey and Gupta, 1990). In *Citrus junos* IBA 1000-4000 mg l^{-1} gave the highest rooting percentage and root length (Kim *et al.*, 1992).

In West Indian cherry (*Malpighia glabra*), IBA at 500, 1000 and 1500 mg l^{-1} was tried in hard and semi hard wood cuttings and the maximum number of primary roots (9.37), number of secondary roots (16.37), length of primary roots (22.04) and maximum survival (90 %) were observed in hard wood cuttings treated with IBA at 1500 mg l^{-1} (Singh and Attri, 2000).

In olive cuttings when semi hard wood cuttings were treated with 1000, 3000, 4000 and 5000 mg l^{-1} IBA, maximum rooting was observed in 3000 mg l^{-1} (Mukhtar *et al.*, 2001).

Ercisli *et al.* (2002) treated hard wood cuttings of kiwifruit (*Actinidia deliciosa*) with 2000, 4000 and 6000 mg l^{-1} IBA. Among them, 6000 mg l^{-1} IBA gave the best results.

Le *et al.* (2002) studied the propagation of Pummelo by cuttings in Vietnam and reported that rice husk substrate was better than sand and that NAA at 1000 mg l^{-1} gave the maximum percentage of rooting (84.4).

2.2.1.3 Seasonal influence on rooting of cuttings

Singh (1959) reported that the overall success of sweet lime cuttings was better in late planting during September than late winter planting in January or

February. According to Bhambota (1959), hormone treated cuttings of sweet lime and sour lime planted in August gave rooting within three weeks after planting while cuttings planted in February showed rooting after eight weeks only. Summer planting proved to be superior to winter planting in sweet lime cuttings (Singh and Singh, 1961). In another report by Choudhary *et al.* (1963), showed that sweet lime cuttings planted during February proved superior to that in September planting. In sweet lime again, Gangwar and Singh (1965) observed that July was better than September for rooting of cuttings.

Kim *et al.* (1992), suggested that Mid-March in case of spring propagation and early September in case of autumn propagation have been identified as optimum time with growth regulator treatment whereas July gave the best percentage of rooting in *Citrus junos.* Arslanov (1994) reported that the best time for striking of roots in Meyer lemon cuttings was found to be early August. In baduvapuli (*Citrus pennivesiculata*), February to October was the best period in respect of percentage of rooting of cuttings. Earliest rooting was observed during June (Sareena, 1996).

2.2.2 Layering

Air layering is advantageous to many species, which will not root easily by cuttings, by enabling the plant to be established on it's own roots. It was successfully employed in carambola (Campbell, 1989), litchi (Badiyala *et al.*, 1991; Dutta *et al.*, 1995), sapota (Chatterjee *et al.*, 1990), tamarind (Navaneetha *et al.*, 1991) Loquat (Polat and Kaska, 1992), Guava (Singh *et al.*, 1992), breadfruit (Kembelo, 1992; Jyothi and Nair, 1993) and karonda (Misra and Singh, 1990). In Citrus this method is employed mainly for lime, lemon, citron, pummelo and sweet lime (Hulamani and Reddy, 1974; Mishra and Agarwal, 1975).

2.2.2.1 *Effect of rooting media on the rooting of layers*

According to Hartman *et al.* (1993), the texture, porosity and water logging capacity greatly influence the extent of rooting.

In *Citrus pennivesiculata* Tan., Sareena (1996) found that the best media for layering were coconut fibre and saw dust when experimented with sphagnum moss and coir dust as the other two media.

Rao and Hassan (1957) reported that among the eight different media tried in cashew air layering, wood shavings, coconut coir husk, coir husk dust and sand proved to be the best. When different media, viz., saw dust, red sand and cattle manure alone and in combination were tried for air layering in cashew, percentage rooting was highest in saw dust alone and lowest in cattle manure alone (Almeida *et al.*, 1992). In guava, when sphagnum moss was tried for layering, root emergance took 43 days and number of primary roots ranged from 37.8-75.8 (Mishra and Singh, 1995).

2.2.2.2 *Effect of season on rooting of layers*

In *Citrus pennivesiculata*, good rooting of layers was obtained from March to October while rooting was poor from November to February. Maximum success in layering was recorded in April (Sareena, 1996).

According to Pushpalatha (1986), air layering conducted during June, July and August revealed no success in rooting, even with growth regulator treatment in aonla (*Phyllanthus emblica*). When air layering with moist coir dust was done in rambutan (*Nephelium lappaceum* L.), on monthly intervals, layering in November gave more number of rooted twigs compared with other months and shortest period for roots to appear was recorded in July (Heenkenda, 1988). In litchi (*Litchi chinensis*), air-layering trials with sphagnum moss shown that percentage of rooting and survival was highest in the month of July (Sharma and Grewal, 1989). Hulamani *et al.* (1989) reported that in cocoa, highest rooting percentage (48.6), numbers of roots per layer (8.48) and survival percentage (60.3) were obtained with air layering in April.

In karonda (*Carissa carandas*), air layering was found successful when done in July (Mishra and Singh, 1990). In air layers of tamarind, rooting and subsequent survival was best in the month of May, in shoots treated with IBA (Navaneeta *et al.*, 1991). According to Nath (1994), air layering in April gave the highest percentage rooting (72.4), number of primary roots (11.0), root length (7.5 cm) and survival percentage of rooted layers (75.6) in carambola. The greatest rooting success was observed during May and July 85.1 and 98.3 percentage respectively in air layers of pomegranate (Hore and Sen, 1994).

Layering in January gave the highest rate of success (100 %) and layering in May and August gave the lowest (45 %), in allspice (Haldankar *et al.*, 1995).

Castro and Silveira (2003) reported that in peach, air layering during June, when plants were dormant, resulted in highest number of secondary roots.

2:2.3 Budding

Budding is by far, the most common and widely used method of vegetative propagation in Citrus.

2.2.3.1 Method of budding

2.2.3.1.1 Patch budding

Budding methods like T-budding, patch budding and chip budding were a failure in baduvapuli (*Citrus pennivesiculata*) in spite of different pre treatments to the buds and performance during different months (Sareena, 1996).

Singh and Singh (1954) recommended patch budding for commercial propagation of mango during June. Patch method of budding was found to be superior to any other method in mango under Uttar Pradesh conditions (Teaotia and Maurya, 1970). Pandey *et al.* (1979) obtained 90.00 per cent success for patch budding in guava when one year old seedlings were used as rootstock.

According to Pushpalatha (1986) in aonla (*Phyllanthus emblica),* patch budding was the best in terms of sprouting (66.67 %) and survival (30.00 %), compared to T-budding (36.67 and 8.33 % respectively). Among shield, T, inverted T, patch, forkert, chip, I and ring methods of budding, tried in jackfruit seedlings, bud take and subsequent shoot growth occurred only with patch, forkert and I–budding (Kelasker *et al.*, 1993). The patch method of budding was more successful than the modified forkert budding in guava (Singh *et al.*, 1998).

In custard apple (*Annona squamosa*), when shield budding, patch budding and soft wood grafting were tried, sprouting was more in plants propagated by shield method followed by patch budding (Joshi *et al.*, 2000). Nayak and Sen (2000) reported that among four methods of budding tried viz., chip, patch, forkert and T budding, in ber (*Zizyphus mauritiana*), patch budding had the highest percentage success (80.00%) followed by forkert method (70.00%) under West Bengal conditions.

2.2.3.1.2 Modified forkert method

Gandhi (1955) reported that forkert method of budding produced better results in mango. In guava, Srivastava (1962) stressed the superiority of forkert method of budding over shield method due to the vigorous growth.

In another report by Shant and Bindra (1989), showed that forkert budding was inferior to inarching and veneer grafting in mango. Propagation trials in walnut (*Juglans regia*) showed that patch and chip budding were successful whereas forkert and T-budding were unsuccessful (Gautam, 1990).

According to Joolka and Rindhe (2000) in Pecan (*Carya illinoinensis*), the proportion of successful plants was highest (98.50 %) in chip budding followed by forkert budding (98.32 %).

2.2.3.2 Effect of season on budding

Budding can be done any time during the growing period of Citrus. There is wide variation in the results obtained by various workers depending on the location, season and species used for budding.

Singh (1957) found that June was a better season for citrus budding as compared to that in March, April, September and October under Saharanpur conditions. But in mosambi orange, Bruno (1962) observed that rainy season budding (May-September) led to poor bud break with high mortality due to *Fusarium* and *Phytophthora* infections. According to Singh (1979), highest percentage of success (83.0 %) was obtained in Kagzi lime on *Citrus karna* when the budding was done in April, compared to that in any other month. Bud take, bud sprouting and bud survival were best in February and September in budded plants of *Citrus karna* (Sen and Kapadia, 1984).

When scion of *Citrus grandis* was budded on *C. jambhiri* stock, budding in February resulted in the highest bud take (88.25 %) and longest shoot (18.52 cm), compared to that in August, September and March (Singh *et al.*, 1989). T budding and veneer grafting were most successful when carried out in June, in pummelo (Chattopadhyay and Swarnakar, 1993).

According to Kelaskar *et al.* (1993), January and February were the best months for budding in jackfruit. In guava, Singh *et al.* (1998) found that the best time for budding was July followed by August. When chip, patch and T budding were conducted in aonla at monthly intervals, budding during May and June gave the lowest rate (Sharma *et al.*, 2000). The percentage of bud take in annona was highest in the month of August (74.40 %) and lowest in May (36.60 %) in the budding trials conducted by Joshi *et al*. (2000).

In jamun (*Syzigium cumini)*, bud sprouting was early in June and July, while budding in May resulted in maximum shoot length, shoot diameter and number of functional leaves (Chovatia and Singh, 2000). Joolka and Rindhe (2000) reported that highest bud sprouting was in June followed by that in July, in pecan nut (*Carya illinoinensis*).

In pecan again, this was confirmed by Chandel and Ananda (2002) who found that patch budding in June resulted in high bud take (73.80 %), followed by that in July (70.60%). Srivastava *et al*. (2002) reported that in aonla, budding success percentage and growth of buds were maximum when performed during June.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The investigations were undertaken in the Department of Pomology and Floriculture, College of Horticulture during the year 2003-2005. The project was carried out in two parts, to study the variability in relation to vegetative, flowering and fruiting characters for selecting promising types and to standardize the propagation techniques in pummelo.

PART-I

3.1. VARIABILITY STUDY

Survey was conducted in the homesteads in the central districts of Kerala, viz., Thrissur, Ernakulam and Kottayam, during the period 2003-2005 (Fig.1). Observations on general tree characters, leaves, flowers and fruits were recorded on 40 accessions. Tree characters were recorded using the NBPGR descriptor for *Citrus* species annexed as Appendix-1.

3.1.1 General tree characters

Following observations on general tree characters were made on 40 accessions.

3.1.1.1 Type of planting material

Planting material from which the tree was grown was recorded.

3.1.1.2 Tree height

Height of the trees of different accessions was recorded.

3.1.1.3 Tree habit

Tree habit of different trees was visually observed and classified as (i) upright, (ii) spreading (iii) compact (iv) drooping.

Fig. 1. Map showing locale of the study

3.1.1.4 *Tree shape*

Canopy shape of the trees of different accessions was recorded visually and classified as (i) ellipsoid (ii) spheroid (iii) ellipsoid-oblate (Fig.2).

3.1.1.5 *Mode of branching / branch density*

Mode of branching / branch density of different accessions was observed.

3.1.1.6 *Number of bearing branches*

Number of bearing branches of different accessions was recorded.

3.1.1.7 *Bearing season*

Bearing season of each accession was noted.

3.1.2 Leaf characters

From each accession, ten fully mature leaves were collected and the following observations were recorded.

3.2.2.1 *Leaf shape*

Leaf shape was observed and classified as (i) elliptic, (ii) ovate, (iii) obovate, (iv) lanceolate (v) orbicular (Fig.3).

3.1.2.2 *Leaf size*

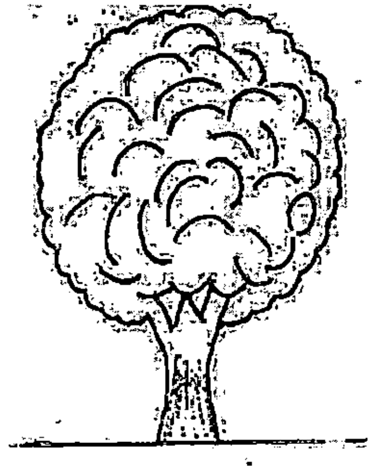
(i) Leaf length

The length of the leaf, including petiole was measured from the base to apex and recorded in centimetres.

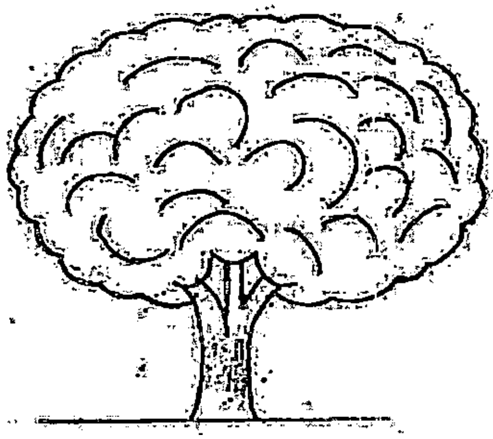
(ii) Leaf width

The width of the leaf at maximum point was measured and recorded in centimetres.

(i) Ellipsoid



(ii) Spheroid



(iii) Ellipsoid-oblate

Fig. 2. Classification of the tree shape

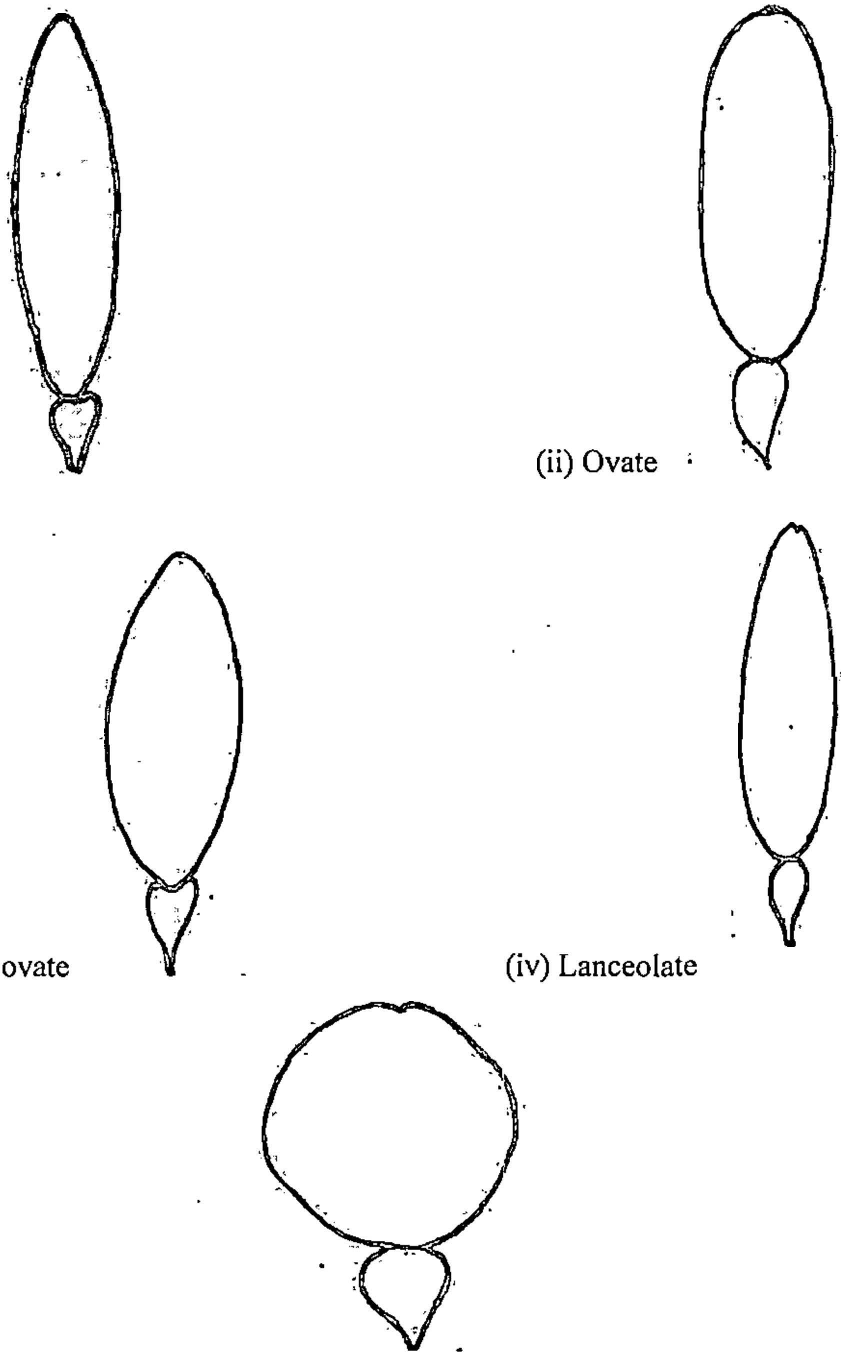


Fig. 3. Classification of leaf shape

(iii) Length / width ratio

The length / width ratio was worked out for each leaf.

3.1.2.3 Petiole wing shape

Petiole wing was observed and classified as (i) cordiform, (ii) deltoid, (iii) obovate (Fig.4).

3.1.2.4 Leaf margin

Leaf margin was observed and categorized as (i) crenate (ii) dentate (iii) entire (v) wavy (Fig.5).

3.1.2.5 Aroma of crushed leaves

Aroma of crushed leaves was recorded as either (i) deep or (ii) mild.

3.1.3 Floral characters

3.1.3.1 Season of flowering

Season of flowering in different trees was recorded.

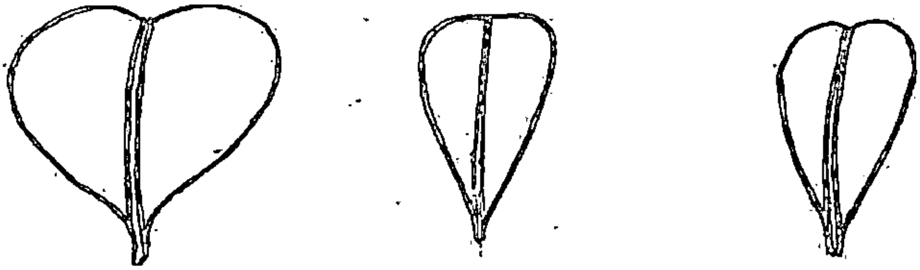
3.1.3.2 Arrangement of flowers

Arrangement of flowers was noted and classified as (i) solitary (ii) crowded.

3.1.3.3 Inflorescence position

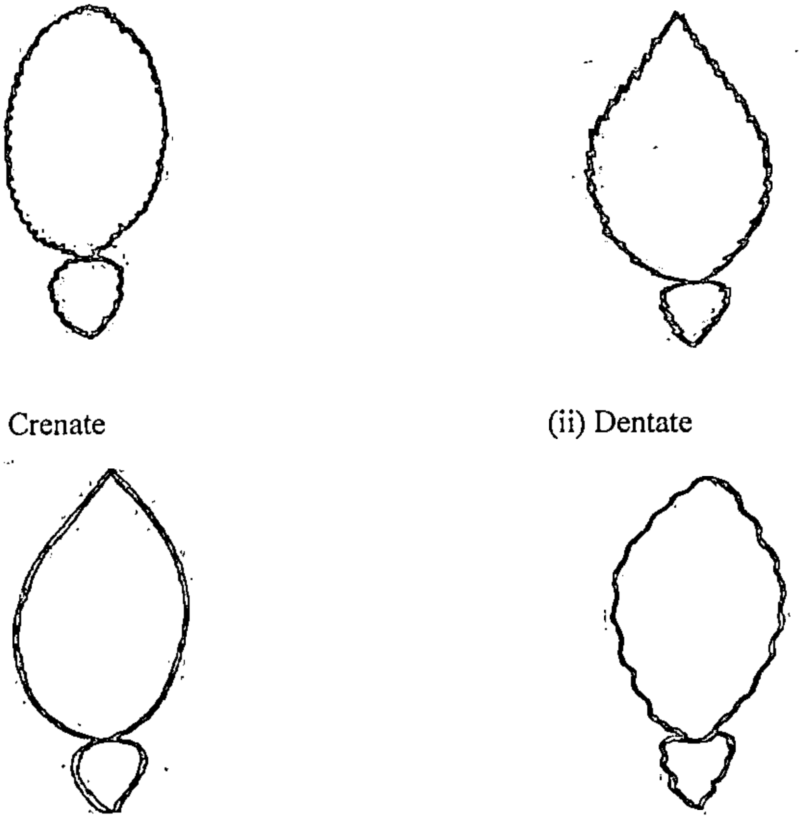
Inflorescence position was noted and classified as (i) axillary (ii) terminal (iii) both.

The following flowering characters were recorded on ten pummelo trees maintained in the Central Nursery orchard, Kerala Agricultural University, Vellanikkara.



(i) Cordiform (ii) Deltoid (iii) Obovate

Fig. 4. Classification of petiole wing shape



(iii) Entire (iv) Wavy

Fig. 5. Classification of leaf margin

3.1.3.4 Number of flower buds / inflorescence

Number of flower buds / inflorescence was recorded in 20 flowering branches, in each tree.

3.1.3.5 Size of flower

(i) Flower length

Length of 20 flowers was measured from base to tip of flower and the mean was expressed in centimetres.

(ii) Flower breadth

Breadth of 20 flowers was measured at the broadest part and expressed in centimetres.

3.1.3.6 Petal colour

Petal colour was noted and classified as (i) white, (ii) yellow, (iii) purple.

3.1.3.7 Number of petals/ flower

Number of petals/ flower was counted in 20 flowers and the mean was recorded.

3.1.3.8 Number of stamens/ flower

Number of stamens/ flower was counted in 20 flowers and the mean was recorded.

3.1.3.9 Pollen fertility

Ten well-matured unopened buds were selected from pummelo trees. Pollen from each bud was collected in acetocarmine (one percent)- glycerin mixture and kept on a slide and covered with clean cover slip. The slides were kept undisturbed for thirty minutes to allow the pollen grains to take the red stain properly before examining it under the microscope. Fertility was calculated as the percentage of normal, well stained pollen grains to the total number of pollen grains in each microscopic field. Ten such fields were observed in each slide. The average was worked out and expressed as percentage. The diameter of pollen grain was measured using ocular micrometer, from each slide and was expressed in micrometer.

3.1.4 Fruit characters

Fruits collected from different accessions were evaluated for the following characters

3.1.4.1 External characters

3.1.4.1.1 Fruit shape

Different fruit shapes are observed and classified as (i) spheroid, (ii) ellipsoid, (iii) pyriform, (iv) oblique, (v) oblate, (vi) ovoid-oblique and (vii) ovoid (Fig.6).

3.1.4.1.2 Fruit skin colour

Fruit skin colour was observed in all accessions and categorized as (i) yellow, (ii) greenish yellow and (iii) green.

3.1.4.1.3 Fruit base shape

Fruits are classified according to different base shape viz., (i) necked, (ii) convex, (iii) truncate, (iv) concave, (v) concave collared and (vi) collared with neck. (Fig.7)

3.1.4.1.4 Fruit apex shape

Fruit apex shapes were observed and classified as (i) mammiform, (ii) angular, (iii) convex, (iv) truncate and (v) depressed. (Fig.8).

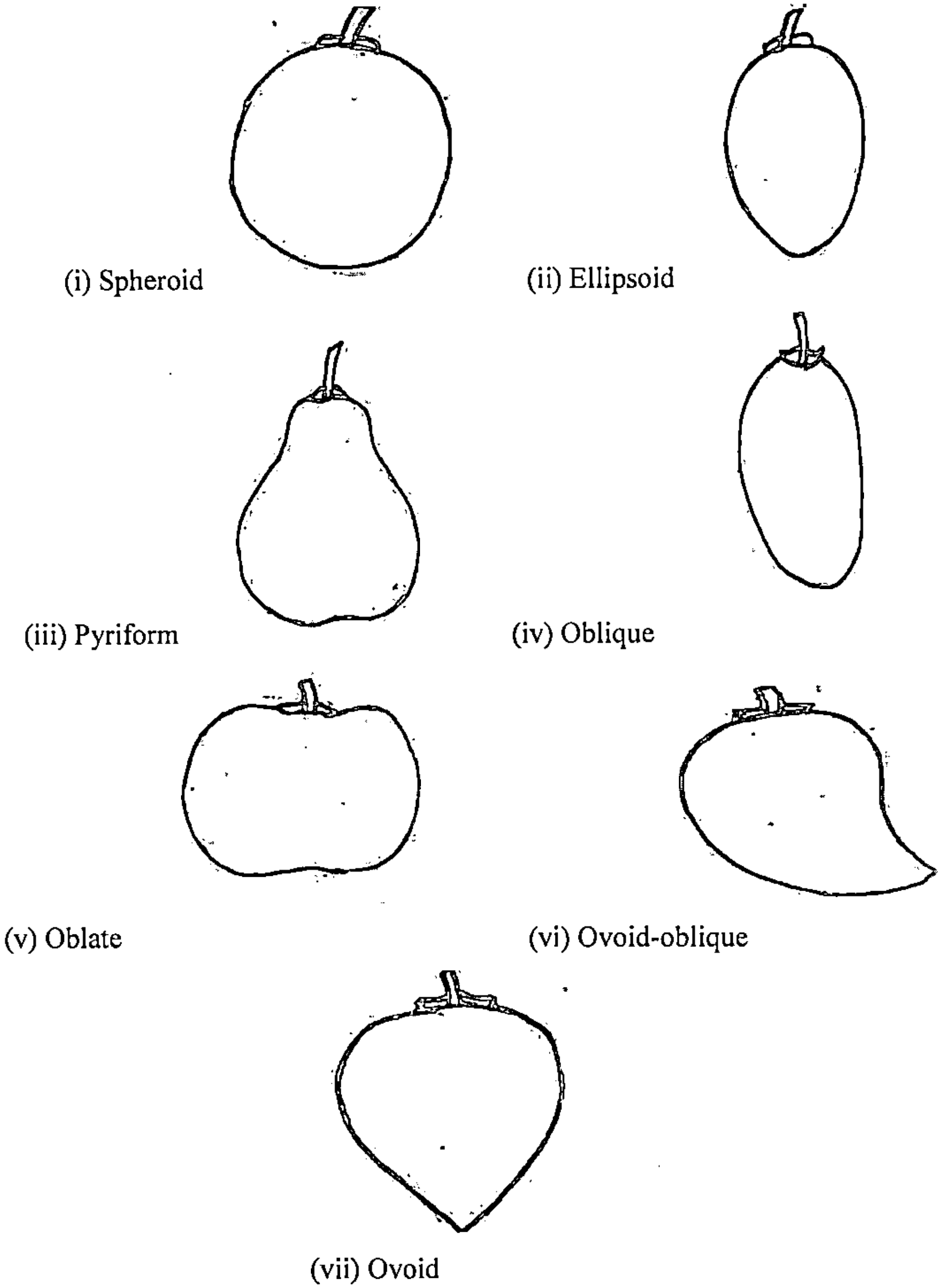


Fig. 6. Classification of fruit shape

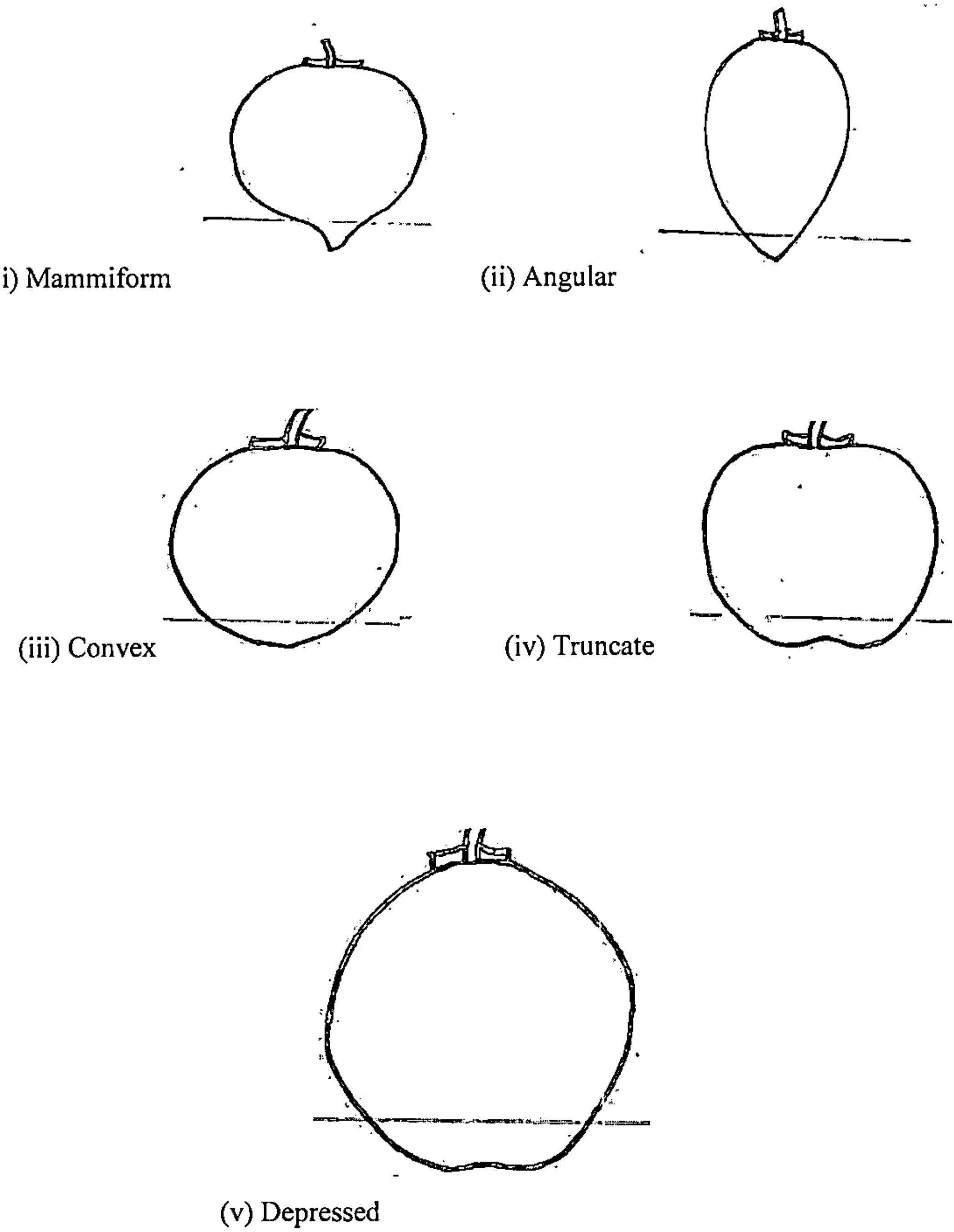


Fig. 7. Classification of fruit apex shape

3.1.4.1.5 Fruit skin surface

Fruit skin surface was observed and classified as (i) smooth, (ii) pitted

3.1.4.1.6 Presence of oil glands

Presence of oil glands on fruit surface was categorized as (i) inconspicuous, (ii) conspicuous and (iii) very conspicuous.

3.1.4.2 Physical parameters

3.1.4.2.1 Number of fruits per tree

Number of fruits per tree in each accession was visually observed and recorded.

3.1.4.2.2 Size of fruit

(i) Fruit length

Length of fruits was measured for five fruits from base to apex using a flexible twine and mean was calculated and recorded in centimetres.

(ii) Fruit width

Width of fruits was measured for the same five fruits at the maximum point and recorded in centimetres.

3.1.4.2.3 Fruit weight

Weight of five fruits from each accession was taken and mean was calculated and expressed in gram.

3.1.4.2.4 Rind weight

The rind from the fruit was peeled and mean weight was recorded for five fruits of each accession and expressed in gram.

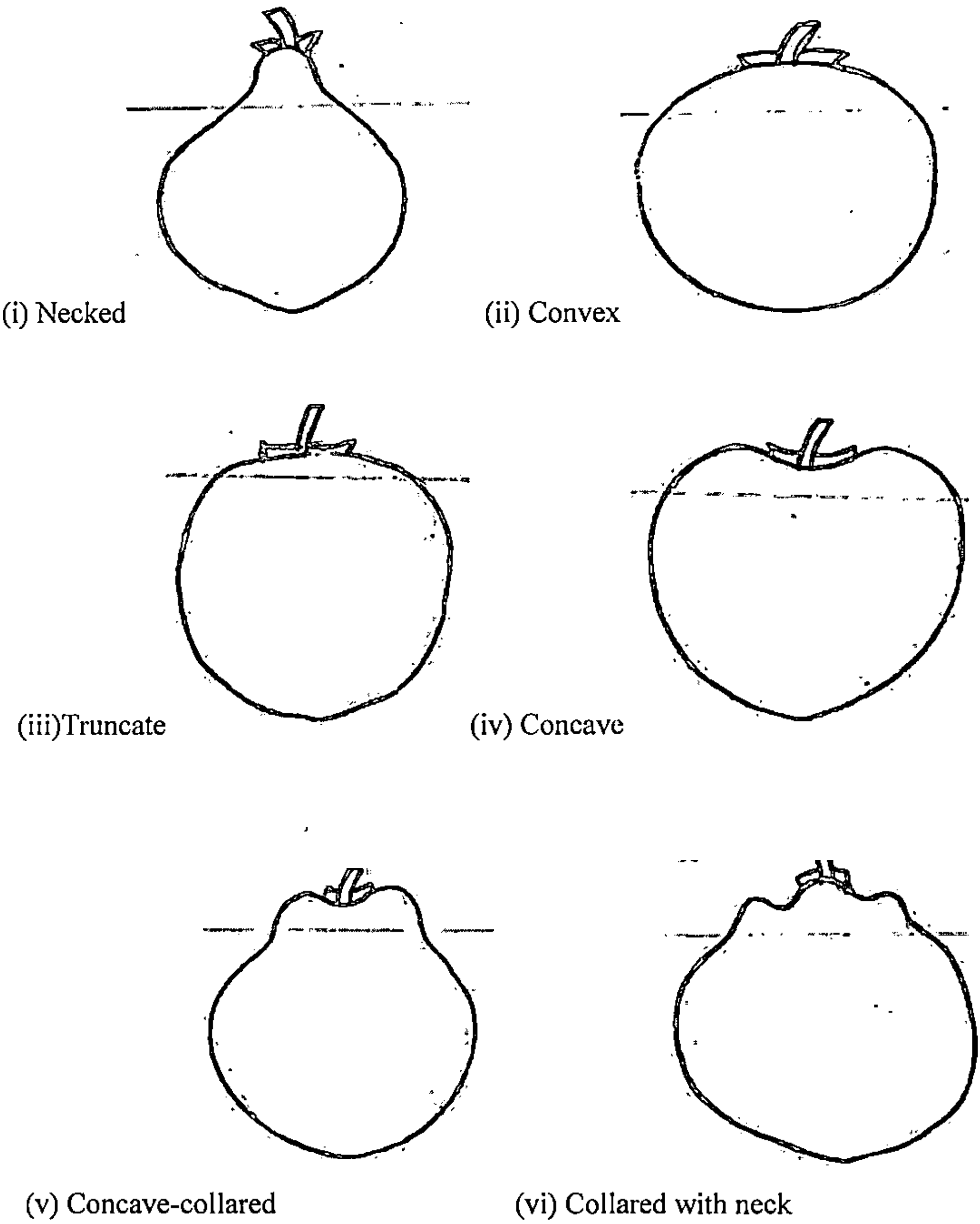


Fig. 8. Classification of fruit base shape

3.1.4.2.5 Density of oil glands

Number of oil glands was counted in one square centimetre area on the fruit surface. Five such areas were marked and mean was found out.

3.1.4.2.6 Number of segments

Number of segments of five fruits from each accession was counted after removing the rind and the mean was worked out.

3.1.4.2.7 Length of segment

The length of segment was measured for five fruits from each accession and mean was calculated and expressed in centimetres.

3.1.4.2.8 Width of segment

The width of segment at the maximum point was measured for five fruits from each accession and mean was calculated in centimetres.

3.1.4.2.9 Weight of segment

Weight of segment was measured for five fruits and mean was expressed in gram.

3.1.4.2.10 Juice content

Hundred gram juice vesicles was taken from ripe fruit and extracted using a mixer. Juice was extracted through a muslin cloth and the volume was measured by a measuring cylinder. Volume was expressed in millilitres/100 g (%).

3.1.4.2.11 Yield

Yield per tree was calculated by multiplying the number of fruits with the mean fruit weight and expressed in kilograms.

3.1.4.2.12 Segment weight -rind weight ratio

Segment weight – rind weight ratio was measured for five fruits and the mean was recorded.

3.1.4.3 Internal characters

3.1.4.3.1 Mesocarp colour

Mesocarp colour was noted and categorized as (i) white, (ii) yellow, (iii) light pink.

3.1.4.3.2 Colour of carpels/juice vesicles

Colour of carpels/juice vesicles was observed and classified as (i) yellow, (ii) green, (iii) red, (iv) pink and (v) cream.

3.1.4.3.3 Juice colour

Juice colour was noted visually and categorized as (i) white, (ii) cream, (iii) yellow, (iv) pale pink, (v) pink, and (vi) reddish.

3.1.4.3.4 Juice taste

Juice taste was noted and classified as (i) very poor, (ii) poor, (iii) fair, (iv) good and (v) excellent.

3.1.4.3.5 Juice aroma/ flavour

Juice aroma/ flavour was noted and classified as (i) mild, (ii) moderate, and (iii) strong.

3.1.5 Bio chemical characters

3.1.5.1 Total soluble solids

Total soluble solids (TSS) was recorded for the juice extracted from juice vesicles using a hand refractometer and expressed in degree brix (A.O.A.C, 1980).

3.1.5.2 Acidity

Acidity was determined by titration with standard sodium hydroxide (0.1N) and expressed as percent of citric acid as per Ranganna (1997).

3.1.5.3 TSS/acidity ratio

TSS/acidity ratio was calculated by dividing the value of the TSS of the fruit with acidity.

3.1.5.4 Ascorbic acid

Five gram of juice vesicles was taken and extracted with four percent oxalic acid. Ascorbic acid was estimated using standard indicator dye 2,6-dichlorophenol indophenol and expressed as mg/100 g fruit as per (Sadasivam and Manickam (1992).

3.1.5.5 Reducing sugars

Estimation of reducing sugar was done and expressed as gram of glucose per 100 gram of juice (Ranganna, 1997).

3.1.5.6 Total sugars

Estimation of total sugars was done and expressed as gram of glucose per 100 gram of juice (Ranganna, 1997).

3.1.6 Sensory evaluation of fruits

Sensory evaluation of fruits was carried out with the help of a panel consisting of 10 members. They were asked to evaluate the samples for it's appearance, colour, taste, flavour, sweetness, juiciness and overall acceptability on a ten point hedonic scale (Appendix II). The ratings were as follows.

0.0-2.0 - Very poor

2.1-4.0 - Poor

4.1-6.0 - Satisfactory

6.1-8.0 - Good

8.1-10.0 - Excellent

3.1.7 Seed characters

3.1.7.1 Number of seeds/ fruit

Number of seeds/ fruit was counted in five fruits for each accession and mean was taken.

3.1.7.2 Size of seed

(i) Seed length

Seed length was measured for twenty seeds for each accession and mean was taken and expressed in millimetres.

(ii) Seed width

Seed width was measured at the maximum point for twenty seeds for each accession and mean was calculated in millimetres.

3.1.7.3 Seed shape

Seed shapes were noted visually and classified as (i) fusiform, (ii) clavate, (iii) cuneiform, (iv) ovoid, (v) deltoid, (vi) globose and (vii) semi- spheroid (Fig. 9).

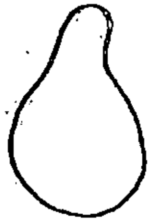
3.1.7.4 Colour of cotyledons

Colour of cotyledons was observed by splitting the seed and classified as (i) cream, (ii) yellow, (iii) green, and (iv) brown

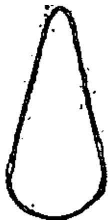
3.1.7.5 Number of embryos

Number of embryos in seeds of each accession was found out by germinating them in polybags filled with potting mixture.

(i) Fusiform



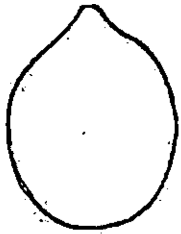
(ii) Clavate



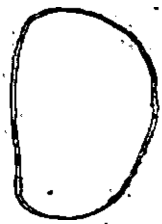
(iii) Cuneiform

(iv) Ovoid

(v) Deltoid



(vi) Globose



(vii) Semi-spheroid

Fig. 9. Classification of seed shape

3.1.7.6 Nature of embryony

Seeds from fruits of each accession were put to germinate in polybags to observe the type of embryony.

PART II

3.2. PROPAGATION STUDIES

Vegetative propagation techniques such as cutting, layering and budding were standardized. These methods were performed at monthly interval from May to September.

3.2.1 Cutting

Soft wood, semi hard wood and hard wood cuttings were prepared from the trees and they were treated with different concentrations of growth regulators viz. NAA, IAA, IBA and two commercial formulations viz., Rootex and Keradix. The treatments were as follows

T_1 - IBA 1000mgl^{-1}

T_2 - IBA 2000mgl^{-1}

T_3 - IBA 3000mgl^{-1}

T_4 - IAA 1000mgl^{-1}

T_5 - IAA 2000mgl^{-1}

T_6 - IAA 3000mgl^{-1}

T_7 - NAA 1000mgl^{-1}

T_8 - NAA 2000mgl^{-1}

T_9 - NAA 3000mgl^{-1}

T_{10} - Keradix powder

T_{11} - Rootex powder

T_{12} - Control

Replications - 2

Number of cuttings/ treatment - 20

3.2.1.1 Preparation of growth regulators

Stock solutions of 3000mgl^{-1} of IBA, IAA and NAA were prepared separately after dissolving the growth regulators in minimal quantity of alcohol and were diluted with distilled water to appropriate concentrations.

3.2.1.2 Growth regulator treatment

Basal ends (5 cm) of the cuttings were dipped in the prepared growth regulator solution for three seconds. Rootex and Keradix are in the powder form and they were applied through quick dip method after wetting the basal ends of cuttings.

3.2.1.3 Planting

The treated softwood, semi hardwood and hardwood cuttings were planted separately in polybags filled with potting mixture in the ratio of 2:1:1: sand, soil and cow dung and kept in a mist chamber.

3.2.1.4 Observations

The cuttings were observed for sprouting. Observations on rooting parameters viz., percentage of rooting, days to root and number of roots/ cutting (2 and 4 months after planting) were recorded.

3.2.2 Layering

Air layering was the method adopted. Trees with low-lying branches suitable for air layering were selected for the study. Three to four month old shoots were layered using different media, viz., coconut fibre, saw dust and sphagnum moss. Ten shoots were tried under each medium starting from the month of May to September 2004 during the first week of every month.

3.2.2.1 Layering operation

A strip of bark about 2.5 cm wide was removed from around the stem at a position of about 25 cm from the tip of the shoot. Moistened medium was placed around the stem to enclose the cut surface and a piece of polythene film was wrapped around so as to cover the medium and the two ends were tied firmly with gunny threads.

3.2.2.2 Observations

Observations on rooting viz., percentage of rooting, days to root and number of roots/layering were recorded for each medium after 2 months of operation.

3.2.3 Budding

Two methods of budding viz., patch budding and modified forkert budding were performed in four month old rootstocks of pummelo and Rangpur lime. Twenty-five buddlings were made under each treatment and rootstock at monthly interval from May to September.

3.2.3.1 Seedlings for rootstocks

Pummelo seeds and Rangpur lime seeds were collected and put to germinate in pots filled with sand. At 4-5 leaf stage they were transplanted into polybags and kept under partial shade. When the seedlings attained pencil thickness, healthy and vigorous seedlings were selected for budding.

3.2.3.2 Preparation of scion shoot

Four to six month old scions were selected as the bud woods from trees grown in orchard of Central nursery, Kerala Agricultural University, Vellanikkara.

3.2.3.3 Budding operation

Two methods of budding, viz., patch and modified forkert were done.

(i) Patch budding

A patch of bark was removed from the stock and in the same manner a patch containing the bud was removed from the bud wood. It was inserted on the stock and the union was wrapped tightly with polythene.

(ii) Modified forkert budding

A transverse incision was made in the bark of the rootstock and then the bark was peeled off carefully to a length of 5.0 cm. Bud shield taken from the scion was pushed under the flap till the exposed edges of the stock and scion meet. Flap was then cut to half and was brought to cover the bud shield partially and was then wrapped with polythene.

3.2.3.4 Observations

The budded plants were examined for the sprouting of the buds. Observations viz., percentage of bud take, time taken for sprouting of buds, number of sprouts and percentage survival after 90 days of sprouting were recorded for the two methods were taken at monthly intervals for 3 months.

3.3 STATISTICAL ANALYSIS

Statistical analysis was conducted as per Panse and Sukhatme (1976). Simple correlations among and between biometric and biochemical characters of fruits were worked out. Cluster analysis using Mahalanobis D^2 statistics was carried out to study the extent of divergence. Factor analysis to work out a selection index was done using principal component method.

The data on propagation methods, viz., cutting, layering and budding were analyzed using ANOVA technique adopted for completely randomized design for more than one factor.

RESULTS

4. RESULTS

The research project entitled "Variability and propagation studies in pummelo (*Citrus grandis* (L.). Osbeck.)" was conducted in two parts viz.,

Part I- Variability analysis

Part II- Propagation study

The study was undertaken in the Department of Pomology and Floriculture, College of Horticulture, Vellanikkara during 2003-2005. The results of the studies are presented below.

PART -I

4.1 VARIABILITY STUDY

4.1.1 General tree characters

The information with regard to general tree characters on 40 accessions of pummelo is presented in the table 1. Trees surveyed belong to 15 to 25 years old age group. Places of accessions were presented in Appendix III.

4.1.1.1 Planting material

Out of the 40 accessions studied, 39 were originated as seedlings and the remaining one was raised from a layer which was observed at Thrissur district.

4.1.1.2 Tree shape

Trees showed variation in canopy shape and the different shapes recorded were spheroid, ellipsoid and ellipsoid-oblate. But majority of the trees surveyed (60.00%) were ellipsoid-oblate in shape.

4.1.1.3 Tree habit

Spreading, drooping and upright branching habits were observed with 57.50 per cent accessions showing spreading branches.

Table 1. General tree characters of different accessions of pummelo

AC No.	Planting material	Tree height	Tree habit	Tree shape	Branching density	No. of bearing branches	Bearing season
1	2	3	4	5	6	7	8
1	Seedling	4	Spreading	Spheroid	Medium	23	Nov-Dec
2	Seedling	4	Upright	Ellipsoid	Sparse	15	Dec-Jan
3	Seedling	5	Spreading	Spheroid	Sparse	19	Nov-Dec
4	Seedling	5	Drooping	Ellipsoid-oblate	Medium	20	Dec-Jan
5	Seedling	4	Drooping	Ellipsoid-oblate	Medium	20	Nov-Dec
6	Seedling	5	Drooping	Ellipsoid-oblate	Dense	28	Nov-Dec
7	Seedling	6	Upright	Spheroid	Dense	30	Nov-Jan
8	Seedling	5	Spreading	Spheroid	Dense	35	Oct-Dec
9	Seedling	4	Spreading	Ellipsoid-oblate	Dense	25	Nov-Jan
10	Seedling	3	Spreading	Ellipsoid-oblate	Medium	20	Dec-Feb
11	Seedling	4	Drooping	Ellipsoid-oblate	Dense	25	Dec-Feb
12	Seedling	5	Spreading	Ellipsoid-oblate	Medium	20	Dec-Feb
13	Seedling	5	Spreading	Ellipsoid-oblate	Dense	30	Nov-Jan
14	Seedling	4	Drooping	Ellipsoid-oblate	Dense	30	Oct-Dec
15	Seedling	4	Spreading	Ellipsoid-oblate	Dense	23	Sept-Jan
16	Seedling	4	Spreading	Ellipsoid-oblate	Medium	25	Irregular
17	Seedling	3	Spreading	Spheroid	Dense	45	Oct-Jan
18	Seedling	4	Drooping	Ellipsoid-oblate	Medium	20	Nov-Jan
19	Seedling	4	Spreading	Ellipsoid-oblate	Dense	25	Dec-Feb
20	Seedling	3	Drooping	Ellipsoid-oblate	Medium	20	Oct-Jan
21	Seedling	5	Drooping	Spheroid	Dense	31	Nov-Jan
22	Seedling	5	Drooping	Ellipsoid-oblate	Dense	35	Oct-Jan
23	Seedling	3	Drooping	Ellipsoid-oblate	Dense	40	Nov-Jan

Contd.

Table 1. Contd.

1	2	3	4	5	6	7	8
24	Seedling	4	Drooping	Ellipsoid-oblate	Dense	32	Oct-Jan
25	Seedling	5	Upright	Ellipsoid	Medium	25	Dec-Feb
26	Seedling	4	Spreading	Ellipsoid-oblate	Dense	30	Dec-Feb
27	Seedling	3	Spreading	Ellipsoid-oblate	Dense	21	Nov-Jan
28	Seedling	2	Spreading	Spheroid	Medium	25	July-Nov
29	Layer	3	Upright	Spheroid	Medium	16	Irregular
30	Seedling	4	Spreading	Ellipsoid-oblate	Medium	20	Oct-Jan
31	Seedling	4	Drooping	Ellipsoid-oblate	Dense	31	Irregular
32	Seedling	3	Spreading	Ellipsoid-oblate	Medium	22	Sept-Jan
33	Seedling	2	Spreading	Spheroid	Medium	20	Sept-Jan
34	Seedling	5	Upright	Spheroid	Dense	38	Nov-Feb
35	Seedling	4	Spreading	Ellipsoid-oblate	Medium	20	Sept-Jan
36	Seedling	5	Spreading	Spheroid	Sparse	16	Oct-Jan
37	Seedling	4	Spreading	Spheroid	Medium	25	Oct-Jan
38	Seedling	5	Spreading	Spheroid	Dense	34	Oct-Jan
39	Seedling	5	Spreading	Ellipsoid-oblate	Dense	22	Sept-Jan
40	Seedling	5	Upright	Spheroid	Medium	20	Sept-Jan

4.1.1.4 Tree height

Tree height of the different accessions ranged from 3m-6m. AC-7, from Pala of Kottayam district showed maximum height of 6m.

4.1.1.5 Branching density

Branching density showed variations viz., sparse, medium and dense. Fifty per cent of the accessions showed dense branches.

4.1.1.6 Number of bearing branches

Number of bearing branches visually observed ranged from 16 to 45 among the accessions. AC.17 from Muppathadam of Ernakulam district showed the highest number of branches (45).

4.1.1.7 Bearing season

The bearing season started from September and extended up to February with peak season in November-December (Plate 1.).

4.1.2 Leaf characters

Information regarding the variation in leaf characters of different accessions is furnished in the Table 2.

4.1.2.1 Leaf length

Wide variation was noticed in leaf length and it ranged from 5.94 cm (AC. 28) to 15.56 cm (AC.34). Average leaf length was 11.49 cm with a coefficient of variation of 21.09.

4.1.2.2 Leaf width

Regarding the width of leaves, the range was from 2.71 cm (AC.28) to 8.72 cm (AC.34) with a mean value of 5.50 cm. Coefficient of variation was 22.72.

Plate 1. Pummelo trees in bearing

Table 2. Leaf characters of different accessions of pummelo

AC. No.	Leaf shape	Petiole wing shape	Leaf length (cm)	Leaf width (cm)	Leaf length/width ratio	Leaf margin	Aroma of crushed leaves
1	2	3	4	5	6	7	8
1	Orbicular	Deltoid	14.02	6.39	2.19	Crenate	Mild
2	Ovate	Deltoid	12.65	5.25	2.41	Crenate	Deep
3	Ovate	Deltoid	10.24	5.56	1.84	Entire	Deep
4	Ovate	Cordiform	13.74	5.69	2.41	Entire	Mild
5	Ovate	Deltoid	12.09	6.80	1.77	Crenate	Deep
6	Ovate	Deltoid	9.61	4.65	2.07	Crenate	Deep
7	Ovate	Deltoid	10.40	6.73	2.29	Wavy	Deep
8	Ovate	Deltoid	13.85	5.73	2.42	Crenate	Deep
9	Ovate	Cordiform	10.75	6.21	2.41	Crenate	Deep
10	Ovate	Deltoid	9.50	3.40	2.79	Entire	Mild
11	Obovate	Cordiform	9.92	5.02	1.98	Entire	Deep
12	Obovate	Cordiform	12.29	6.75	1.82	Entire	Deep
13	Ovate	Cordiform	10.29	5.49	1.87	Crenate	Deep
14	Ovate	Deltoid	14.64	6.12	2.43	Crenate	Deep
15	Ovate	Deltoid	11.66	5.56	2.10	Crenate	Deep
16	Ovate	Cordiform	11.76	5.33	2.22	Crenate	Mild
17	Ovate	Deltoid	10.27	5.21	1.97	Entire	Deep
18	Ovate	Cordiform	12.07	6.79	1.78	Crenate	Deep
19	Ovate	Cordiform	12.32	5.21	2.36	Crenate	Deep
20	Obovate	Deltoid	9.95	3.68	2.70	Entire	Mild
21	Ovate	Deltoid	11.86	4.32	2.74	Crenate	Deep
22	Ovate	Deltoid	10.35	5.23	1.98	Crenate	Deep
23	Obovate	Deltoid	9.61	4.69	2.05	Entire	Deep
24	Ovate	Cordiform	11.71	6.17	2.42	Crenate	Deep
25	Ovate	Deltoid	12.47	6.70	1.86	Crenate	Deep

Contd.

Table2 Contd.

1	2	3	4	5	6	7	8
26	Ovate	Cordiform	9.58	4.58	2.09	Crenate	Deep
27	Ovate	Cordiform	13.72	5.67	2.42	Crenate	Mild
28	Ovate	Cordiform	5.94	2.71	2.18	Crenate	Deep
29	Ovate	Deltoid	12.34	6.86	1.80	Crenate	Mild
30	Ovate	Deltoid	9.67	3.39	2.86	Wavy	Deep
31	Ovate	Deltoid	14.59	6.11	2.39	Crenate	Mild
32	Ovate	Deltoid	9.74	5.85	1.67	Crenate	Mild
33	Ovate	Cordiform	7.07	4.29	1.65	Crenate	Deep
34	Ovate	Cordiform	15.56	8.72	2.01	Entire	Deep
35	Ovate	Deltoid	13.09	6.40	2.05	Crenate	Deep
36	Ovate	Deltoid	15.47	6.03	2.62	Entire	Mild
37	Ovate	Cordiform	14.40	5.77	2.52	Entire	Deep
38	Ovate	Cordiform	13.06	5.01	2.61	Entire	Deep
39	Obovate	Cordiform	7.48	4.46	1.67	Crenate	Deep
40	Ovate	Deltoid	6.23	3.15	1.98	Crenate	Mild
Mean	-	-	11.49	5.50	2.17	-	-
CV	-	-	21.09	22.72	15.28	-	-

4.1.2.3 Leaf length/width ratio

The ratio of leaf length to width ranged from 1.65 (AC.33) to 2.86 (AC.30), recording a coefficient of variatrion of 15.28 and an average of 2.17.

4.1.2.4 Leaf shape

Orbicular, ovate and obovate leaf shapes were noticed, with 85.00 percentage of the accessions showing ovate leaves (Plate 2.).

4.1.2.5 Petiole wing shape

Deltoid as well as cordiform shapes were noted for petiole wing, with 57.50 percentage of the trees showing deltoid shape for petiole wing (Plate 3.).

4.1.2.6 Leaf margin

Variation was also noticed in leaf margin viz., crenate, entire and wavy. Crenate leaf margin dominated among the accessions (65.00%).

4.1.2.7 Aroma of crushed leaves

Mild and deep aromas were sensed for crushed leaves, with 72.00 percentage of accessions recording deep smell.

4.1.3 Floral characters

Observations on the floral characters of pummelo are furnished in Table 3.

4.1.3.1 Season of flowering

Most of the trees started flowering in April-May and it extended up to November-December. Accessions16, 29 and 31 also showed perpetual flowering habit

Plate 2. Variation in leaf size and shape

Plate 3. Cordiform and deltoid types of petiole

4.1.3.2 Arrangement of flowers

Both solitary and crowded type arrangement were noted for pummelo flowers (Plate 6.).

4.1.3.3 Inflorescence position

The inflorescence was axillary in most of the trees, while terminal inflorescence was also noted.

4.1.3.4 Petal colour

Petal colour was creamy white (Plate 4.).

4.1.3.5 Number of flowers per inflorescence

Number of flowers per inflorescence ranged between four and twelve. Average number of flowers per inflorescence was 7.4 (Table 3.).

4.1.3.6 Flower length

Flower length showed an average value of 2.25 cm and it ranged from 1.40 to 3.37 cm. (Plate 5.).

4.1.3.7 Flower breadth

Flower breadth ranged from 1.10 to 1.98 cm. Average flower breadth recorded was 1.46 cm.

4.1.3.8 Number of petals per flower

There was no variation with respect to the number of petals, it was four petals per flower in all the cases.

4.1.3.9 Number of stamens

Number of stamens in a single flower ranged from 29.6 to 38.6. Average number of stamen was 33.94.

4.1.3.10 Pollen fertility

Fertility of pollen was studied using the acetocarmine staining technique and average pollen fertility was found to be 83.94 per cent. Fertility ranged between 78.00 per cent and 90.00 per cent (Plate 7.).

4.1.3.11 Pollen diameter

Diameter of pollen grains ranged from 32.20 to 37.10 microns. Average diameter was 35.09 microns.

Table 3. Variation in floral characters of pummelo

Sl. No.	No. of flowers/ inflorescence	Flower length (cm)	Flower breadth (cm)	No. of petals	No. of stamens	Pollen fertility (%)	Pollen diameter (micron)
Mean	7.40	2.25	1.46	4.00	33.94	83.94	35.09
Range	4-12	1.40-3.37	1.10-1.98	-	29.6-38.6	78.0-90.0	32.22-37.10

4.1.4 Fruit characters

Information regarding the variations in the external characters, physical parameters and internal characters of the fruits from the different accessions are furnished in Table 4., Table 5. and Table 6, respectively.

4.1.4.1 External characters

4.1.4.1.1 Fruit shape

Fruits showed variations such as pyriform, spheroid, oblate and oblique. Majority of the fruits had spheroid shape (21 accessions), followed by pyriform shape (Plate 8.).

4.1.4.1.2 Fruit colour

Fruits of different accessions noted at full maturity stage had either yellow or greenish yellow in colour (Plate 9.). Most of the fruits were yellow in colour (28 accessions) (Table 4.).

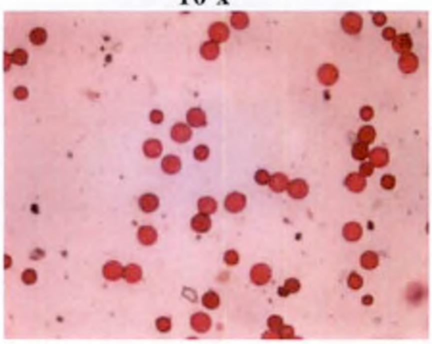
Plate 4. Pummelo bud and flower

Plate 5. Variation in flower size.

Plate 6. Pummelo flowers borne singly and in clusters

Plate 7. Pollen of *Citrus grandis*

10 x



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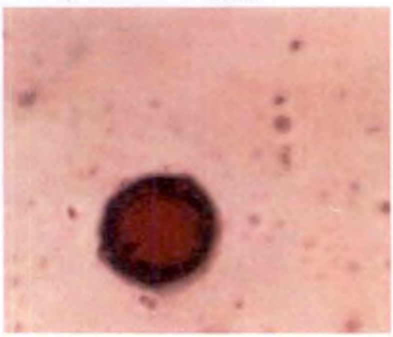


Table 4. Variation in external characters of fruits of different accessions

AC No.	Fruit shape	Fruit colour	Fruit base shape	Fruit apex shape	Fruit skin surface	Presence of oil glands
1	2	3	4	5	6	7
1	Pyriform	Yellow	Concave collared	Depressed	Smooth	Conspicuous
2	Pyriform	Yellow	Concave collared	Depressed	Smooth	Conspicuous
3	Spheroid	Greenish yellow	Concave collared	Truncate	Pitted	Very conspicuous
4	Oblate	Yellow	Concave	Depressed	Smooth	Very conspicuous
5	Spheroid	Yellow	Truncate	Truncate	Smooth	Very conspicuous
6	Spheroid	Yellow	Truncate	Truncate	Smooth	Conspicuous
7	Pyriform	Yellow	Concave collared	Truncate	Smooth	Conspicuous
8	Pyriform	Greenish yellow	Truncate	Depressed	Smooth	Very conspicuous
9	Pyriform	Yellow	Concave collared	Depressed	Smooth	Conspicuous
10	Spheroid	Yellow	Truncate	Depressed	Smooth	Conspicuous
11	Spheroid	Yellow	Truncate	Depressed	Smooth	Very conspicuous
12	Oblate	Yellow	Concave collared	Depressed	Smooth	Conspicuous
13	Oblate	Greenish yellow	Truncate	Truncate	Smooth	Very conspicuous
14	Spheroid	Yellow	Truncate	Truncate	Smooth	Very conspicuous
15	Spheroid	Yellow	Concave collared	Truncate	Smooth	Very conspicuous
16	Pyriform	Greenish yellow	Concave collared	Truncate	Smooth	Very conspicuous
17	Spheroid	Yellow	Truncate	Truncate	Smooth	Very conspicuous
18	Oblate	Greenish yellow	Truncate	Truncate	Smooth	Conspicuous
19	Spheroid	Yellow	Truncate	Depressed	Smooth	Very conspicuous
20	Spheroid	Greenish yellow	Truncate	Truncate	Smooth	Conspicuous
21	Pyriform	Greenish yellow	Concave collared	Truncate	Smooth	Very conspicuous

Contd.

Table 4. Contd.

1	2	3	4	5	6	7
22	Spheroid	Yellow	Concave collared	Truncate	Smooth	Very conspicuous
23	Pyriform	Yellow	Concave collared	Depressed	Pitted	Conspicuous
24	Spheroid	Yellow	Truncate	Truncate	Smooth	Very conspicuous
25	Spheroid	Yellow	Truncate	Truncate	Smooth	Very conspicuous
26	Oblate	Greenish yellow	Concave	Depressed	Smooth	Very conspicuous
27	Spheroid	Greenish yellow	Truncate	Truncate	Smooth	Very conspicuous
28	Pyriform	Greenish yellow	Concave collared	Truncate	Smooth	Conspicuous
29	Pyriform	Yellow	Concave collared	Truncate	Smooth	Very conspicuous
30	Spheroid	Yellow	Truncate	Truncate	Smooth	Conspicuous
31	Oblate	Greenish yellow	Truncate	Truncate	Smooth	Very conspicuous
32	Spheroid	Yellow	Concave	Truncate	Smooth	Very conspicuous
33	Spheroid	Yellow	Truncate	Truncate	Smooth	Conspicuous
34	Spheroid	Yellow	Convex	Convex	Smooth	Very conspicuous
35	Pyriform	Yellow	Convex	Convex	Smooth	Conspicuous
36	Spheroid	Yellow	Convex	Convex	Smooth	Very conspicuous
37	Oblique	Yellow	Convex	Depressed	Smooth	Very conspicuous
38	Spheroid	Yellow	Truncate	Truncate	Smooth	Very conspicuous
39	Oblate	Yellow	Concave	Depressed	Smooth	Very conspicuous
40	Spheroid	Greenish yellow	Truncate	Truncate	Smooth	Conspicuous

Plate 8. Spherical, pyriform and oblate fruits of pummelo

Plate 9. Variation in fruit size and colour

4.1.4.1.3 Fruit base shape

Trees recorded wide variability in fruit base shape viz., concave-collared, concave, truncate and convex. Truncate fruit base shape dominated (60.00 %) among the accessions (Table 4.). Concave shape was observed for two trees.

4.1.4.1.4 Fruit apex shape

Variations recorded in fruit apex shapes were depressed, truncate and convex; with most of the trees showing truncate shaped apices (57.50%).

4.1.4.1.5 Fruit skin surface

Majority of the collections showed smooth skin surface. Two accessions, viz., AC.3 from Chempu of Kottayam district and AC.23 from Aluva of Ernakulam district had pitted surface.

4.1.4.1.6 Presence of oil glands

Oil glands were very conspicuous in twenty-five accessions and less conspicuous in the rest (Table 4.).

4.1.4.2 Physical parameters

4.1.4.2.1 Number of fruits per tree

Number of fruits per tree ranged from 50 to 250. AC.17 and AC.30 recorded the highest number of fruits (Table 5.).

4.1.4.2.2 Fruit length

Data on the mean fruit length showed the presence of wider variability among the collections. AC.23 had the maximum length for fruit with 21.20 cm, followed by AC.12 with 20.80 cm, collected from Edathala and Kottayam, respectively. Other accessions that recorded a length of 20.00 cm and above were

Table 5. Variation in physical parameters of fruits

AC No.	No. of Fruits	Fruit Length	Fruit Width	Fruit Weight	Rind Weight	Density of oil glands	No. of. Segments	Segment Length	Segment Width	Segment Weight	Juice Content	Total segment wt./rind wt.	Yield
		cm	cm	gm	gm	no/sq.cm		cm	cm	gm	%		kg/tree
1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	135	17.84	12.02	498.00	120.00	20.40	10.00	6.58	3.36	37.00	65.40	3.08	87.15
2	120	18.82	13.16	1166.00	560.00	20.40	12.00	8.28	4.22	50.00	66.36	1.07	139.92
3	140	18.40	17.00	1486.00	700.00	30.80	14.00	8.30	4.44	55.00	57.16	1.10	208.04
4	110	18.40	23.00	1960.00	890.00	38.80	15.00	8.70	4.82	65.00	47.80	1.09	215.60
5	130	16.30	15.00	710.00	3400.00	33.00	10.00	10.98	4.76	35.00	42.60	1.02	159.75
6	120	18.90	19.70	980.00	300.00	27.40	12.00	9.72	3.68	55.00	43.94	2.20	220.50
7	130	20.00	16.90	1230.00	500.00	26.00	10.00	9.36	3.52	70.60	32.86	1.41	159.90
8	110	17.20	15.40	946.00	380.00	32.40	12.00	8.28	4.18	46.40	31.80	1.46	165.55
9	120	20.50	16.60	1700.00	590.00	20.20	14.00	14.12	4.88	78.00	60.20	1.85	255.00
10	110	14.00	15.90	590.00	130.00	18.00	11.00	11.70	3.68	40.00	72.60	3.38	118.00
11	120	18.60	21.00	1460.00	680.00	30.00	13.00	10.38	2.98	58.00	69.10	1.10	197.10
12	135	20.80	24.00	870.00	200.00	26.40	16.00	8.76	2.94	41.40	65.30	3.31	104.40
13	120	16.84	20.60	570.00	190.00	30.00	16.00	7.72	3.42	18.70	32.60	1.57	114.00
14	200	17.14	18.90	910.00	454.00	34.20	14.00	9.12	4.46	25.00	34.50	0.77	204.75
15	110	16.50	17.00	860.00	220.00	40.80	12.40	7.56	3.76	39.00	68.40	2.19	193.50
16	100	17.90	16.20	1030.00	520.00	53.00	14.40	7.98	3.88	35.00	57.60	0.96	195.70
17	190	13.00	15.60	546.00	180.00	31.00	12.00	6.58	3.36	30.00	46.90	2.00	136.50
18	120	16.20	21.00	656.00	210.00	26.20	11.00	8.40	3.52	40.00	32.60	2.09	147.60
19	110	14.80	17.60	756.00	242.00	35.80	11.00	7.30	3.72	45.00	50.30	2.04	113.40
20	150	13.30	13.90	578.00	160.00	26.00	11.00	6.30	3.16	35.00	45.40	2.40	106.93

Contd.

Table 5.Contd.

1	2	3	4	5	6	7	8	9	10	11	12	13	14
21	125	16.40	15.90	940.00	205.00	43.80	10.00	9.88	3.74	72.40	60.70	3.53	178.6
22	130	14.80	15.20	724.00	160.00	35.80	10.00	11.28	4.24	55.00	44.40	3.43	144.8
23	125	21.20	20.00	1304.00	495.00	28.00	11.00	9.26	4.20	72.40	62.20	1.60	228.2
24	130	17.10	17.30	946.00	371.00	31.20	12.20	9.32	3.68	45.00	56.10	1.47	203.39
25	120	15.60	16.00	706.00	286.00	36.80	11.00	7.22	3.34	38.00	42.00	1.46	158.85
26	120	17.20	20.60	1124.00	658.00	33.40	13.00	9.18	4.56	22.00	33.70	0.43	224.8
27	115	16.50	16.90	875.00	300.00	38.40	11.60	8.66	3.28	48.00	56.80	1.85	105
28	120	17.80	13.40	976.00	450.00	27.20	9.00	7.62	3.06	50.00	42.50	1.00	97.6
29	100	18.80	14.80	1015.00	495.00	34.20	13.00	7.74	4.14	42.00	53.20	1.10	111.65
30	110	10.20	9.80	193.00	50.00	23.80	11.00	5.02	2.88	12.00	18.10	2.64	48.25
31	100	12.04	15.00	520.00	194.00	38.60	12.00	8.62	3.02	18.20	23.00	1.12	143
32	100	18.60	19.60	1402.00	566.00	31.80	11.20	9.32	4.26	73.00	51.00	1.44	140.2
33	100	12.80	13.30	534.00	227.00	21.40	13.00	7.26	2.54	22.40	23.40	1.28	120.15
34	110	14.80	17.50	1246.00	530.00	34.20	9.00	9.88	5.12	77.60	43.40	1.31	155.75
35	75	14.60	12.00	569.00	256.00	29.80	10.00	9.18	4.04	30.60	34.90	1.19	99.575
36	75	15.50	18.80	1086.00	340.00	38.40	10.00	11.06	5.20	72.00	26.10	2.11	157.47
37	140	16.30	17.00	852.00	332.00	40.80	12.00	8.24	4.26	42.40	75.30	1.53	106.5
38	70	17.50	19.20	870.00	280.00	32.20	14.00	8.58	3.14	41.40	73.80	2.07	147.9
39	60	18.10	24.80	1765.00	997.00	33.60	14.00	8.72	4.44	50.00	53.30	0.70	88.25
40	50	13.20	16.90	722.00	380.00	23.00	13.00	5.08	3.24	20.80	28.10	0.71	126.35
Mean	116.37	16.61	17.11	946.77	378.45	31.43	12.02	8.68	3.82	45.10	48.15	1.70	150.73
CV	27.91	14.89	19.09	40.14	56.35	23.03	14.93	20.03	17.39	39.32	32.23	47.37	31.35

AC.7 (20.0 cm) and AC.9 (20.5 cm). Lowest fruit length of 10.20 cm was recorded for AC.30 from Arimbur of Thrissur district. The average fruit length of 40 entries was found to be 16.61 cm.

4.1.4.2.3 Fruit width

The mean values for the fruit width ranged from 9.80 cm to 24.80 cm. AC.39 from Vilanganoor of Thrissur district had the maximum width of 24.80 cm, followed by AC.12 with 24.00 cm. AC.30 showed the lowest width of 9.80cm. Average width of 40 collections was 17.11 cm.

4.1.4.2.4 Fruit weight

Data on the mean fruit weight showed wide variation among the collections (Table 5.). The maximum fruit weight of 1960.00 g was observed in AC.4, collected from Kudavechoor and the minimum weight of 193.00 g was recorded in AC.30 from Arimbur. The average fruit weight was 946.77g. A higher fruit weight was also shown by AC. 9 (1700.00 g) and by AC. 39 (1765.00 g).

4.1.4.2.5 Rind weight

The data on the mean rind weight of 40 entries revealed great diversity. The highest rind weight of 997.00g was observed in AC. 39, and lowest was found in AC. 30 with 50.00 g. Average rind weight recorded was 378.45g (Table 5.).

4.1.4.2.6 Density of oil glands

The mean values for the density of oil glands ranged from 18.00 to 53.00 numbers per square cm., the highest recording for AC.16 and lowest for AC. 10 (Table 5.). The density of 30 numbers per square cm. was regarded as 'very conspicuous' oil glands and below as 'conspicuous'. Density of oil glands recorded an average value of 31.43 numbers per square cm.

4.1.4.2.7 Number of segments

The mean values for the number of segments ranged from 9.00 to 16.00, indicating wide variability in number of segments. Highest segment number was recorded in two accessions, viz., AC.12 and AC.13, both collected from Kottayam. Lowest segment number of 9.00 was shown by AC. 28 and AC.34. Average segment number of 40 entries was 12.00 (Table 5.).

4.1.4.2.8 Segment length

The entries recorded mean segment length in the range of 5.02-14.12 cm (Table 5.). Maximum segment length of 14.12 cm was observed in AC.9, collected from Kuravilangadu of Kottayam district, followed by AC.22, having a value of 11.28 cm, from Thottumugham of Ernakulam district. The average value of the segment length was 8.68 cm. Minimum segment length was recorded by AC.30 (Plate 10.).

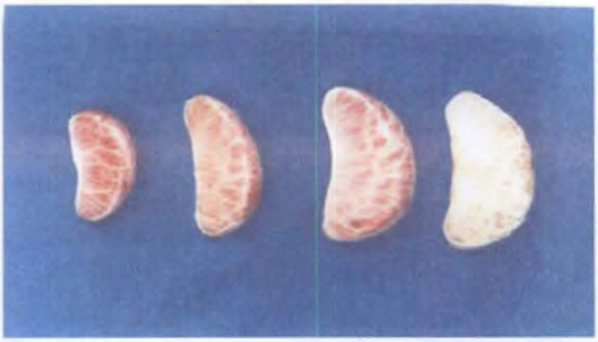
4.1.4.2.9 Segment width

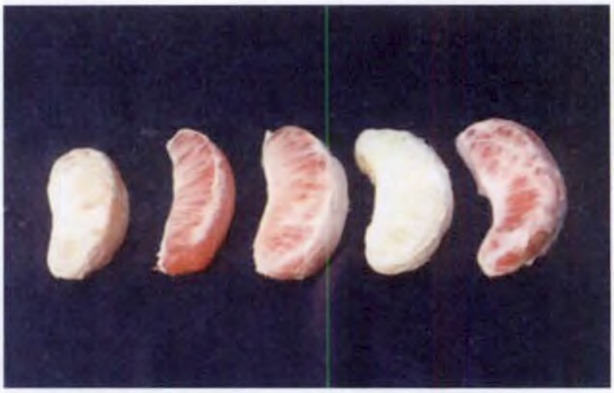
Segment width of the fruits of the accessions also showed variation ranging from 2.54 to 5.20 cm. AC.36, showed the maximum segment width of 5.20 cm, closely followed by AC.34, having a width of 5.12 cm, collected from Mannampetta and Chelakkottukara, respectively, both of Thrissur district. Minimum segment width of 2.54 cm was observed in AC.33. Mean segment width of 40 entries was found to be 3.82 cm (Table 5.).

4.1.4.2.10 Segment weight

Data on the mean segment weight showed wide variability, having a range of 12.00- 78.00g. Maximum segment weight of 78.00g was recorded by AC.9, collected from Kuravilangadu (Table 5.), closely followed by AC.34 having 77.60 g weight, from Chelakkottukara. AC.30 showed the minimum weight of 12.00g. The average segment weight of 40 entries was 45.10g.

Plate 10. Variation in segment size and colour





4.1.4.2.11 Juice content

Mean juice content of the collections showed variations ranging from 18.10-75.30 per cent. Maximum juice content of 75.30 per cent was noticed in AC.37 from Amballur of Thrissur district. AC.38 from Peechi and AC.10 from Kaduthuruthy also had high juice content of 73.80 per cent and 72.60 per cent respectively.

4.1.4.2.12 Segment weight-rind weight ratio

Mean segment weight – rind weight ratio ranged from 0.43 (AC.26) to 3.53, (AC.21). Average segment weight – rind weight ratio was 1.70.

4.1.4.2.13 Yield per tree

Yield of the fruits per tree for each accession was calculated by multiplying mean fruit weight by the number of fruits. The value shows a range of 48.25-255.00 kg; the highest recorded by AC.9. The average yield was found to be 150.73 kg per tree (Table 5.).

4.1.4.3 Internal characters

4.1.4.3.1 Mesocarp colour

Fruits of different accessions showed either white or light pink coloured mesocarp (Plate 11.). Most of the fruits had light pink coloured mesocarp (25 accessions) (Table 6.).

4.1.4.3.2 Carpel colour

Different collections recorded variations in carpel colour viz., pale yellow, light pink, pink and red. Majority of the accessions showed pink colour for the carpels (47.50%), followed by red colour (25.00%) and pale yellow (17.50%)colour (Plate 12, 13 and 14).

Plate 11. Fruits showing light pink and white mesocarp

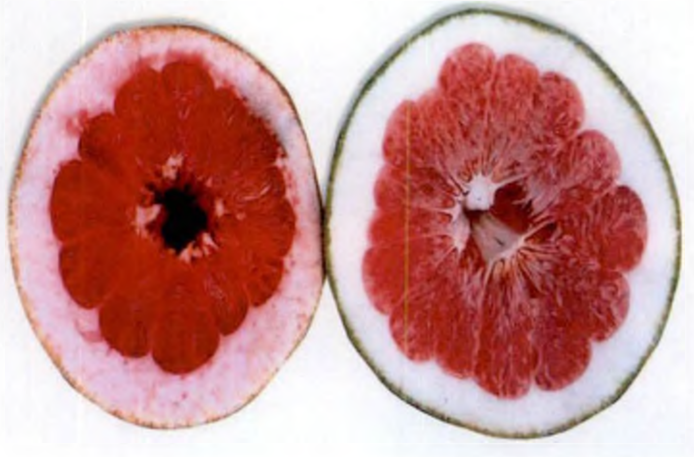


Plate 12. Cross section of fruits showing colour variation of carpels

Plate 13. Segments without peel

Table 6. Variation in internal characters of fruits

AC No.	Mesocarp colour	Carpel. Colour	Juice colour	Juice taste	Juice flavour
1	2	3	4	5	6
1	White	Pale yellow	Pale yellow	Very poor	Strong
2	Light pink	Pink	Pale pink	Poor	Moderate
3	White	Pale yellow	Cream	Poor	Strong
4	White	Pale yellow	Cream	Poor	Moderate
5	Light pink	Pink	Pink	Poor	Moderate
6	Light pink	Pink	Pale pink	Poor	Moderate
7	Light pink	Pink	Pink	Very poor	Strong
8	Light pink	Pink	Pink	Very poor	Strong
9	Light pink	Pink	Pink	Poor	Strong
10	White	Pale yellow	Cream	Poor	Moderate
11	Light pink	Red	Reddish	Poor	Moderate
12	Light pink	Red	Reddish	Poor	Moderate
13	White	Pink	Pink	Very poor	Moderate
14	White	Pale yellow	Cream	Poor	Strong
15	Light pink	Red	Reddish	Poor	Strong
16	Light pink	Pink	Pink	Very poor	Moderate
17	White	Red	Reddish	Poor	Strong
18	Light pink	Pink	Pink	Very poor	Moderate
19	Light pink	Pink	Pale pink	Very poor	Strong
20	White	Pale yellow	Cream	Poor	Moderate
21	Light pink	Pink	Pale pink	Poor	Moderate
22	White	Red	Reddish	Poor	Strong

Contd.

Table 6. Contd.

1	2	3	4	5	6
23	White	Pale yellow	Cream	Poor	Moderate
24	Light pink	Red	Reddish	Poor	Moderate
25	Light pink	Pink	Pale pink	Very poor	Moderate
26	Light pink	Pink	Pale pink	Very poor	Moderate
27	Light pink	Pink	Pale pink	Very poor	Strong
28	Light pink	Pink	Pale pink	Very poor	Moderate
29	Light pink	Pink	Pale pink	Poor	Strong
30	Light pink	Red	Reddish	Poor	Moderate
31	White	Light pink	Pale pink	Poor	Moderate
32	White	Pink	Pink	Poor	Moderate
33	White	Light pink	Pale pink	Very poor	Moderate
34	Light pink	Pink	Pink	Very poor	Moderate
35	Light pink	Red	Reddish	Poor	Moderate
36	White	Light pink	Pale pink	Poor	Moderate
37	Light pink	Red	Reddish	Very poor	Strong
38	Light pink	Red	Reddish	Poor	Strong
39	White	Light pink	Pink	Very poor	Strong
40	Light pink	Pink	Pink	Very poor	Moderate

4.1.4.3.3 Juice colour

Colour variations ranging from pale yellow, cream, pale pink, pink and reddish were noticed for juice from the fruits of different accessions (Table 6.). Pink juice colour dominated among the accessions (Plate 15.).

4.1.4.3.4 Juice taste

Taste of the juice from fruits of different accessions were either poor or very poor as being bitter. Sixty per cent accessions recorded poor juice taste.

4.1.4.3.5 Juice flavour

Juice flavours sensed were either moderate or strong with most of the fruits showing moderate flavour for juice.

4.1.5 Bio chemical characters

The data regarding the bio-chemical characters of the fruits from the surveyed accessions are presented in Table 7.

4.1.5.1 Total soluble solids (TSS)

The mean values of the TSS of the fruit juice revealed wide variations, with values ranging from 5-11^0 brix. Maximum and minimum values for TSS was found in accessions from Kottayam district, AC.5 and AC.9 from Kumarakom and Kuravilangadu respectively.Accessions which recorded a higher TSS of 9.0 and above were AC.4, 11, 12, 15, 17, 20, 22, 25, 26, 27 and 37. The average value of TSS was found to be 7.82.

4.1.5.2 Acidity

Wider variation was noticed in the mean values of acidity of fruit juice in the 40 collections and the range was from 0.41 to 1.74 per cent. The highest value of

Plate 14. Variation in carpel colour

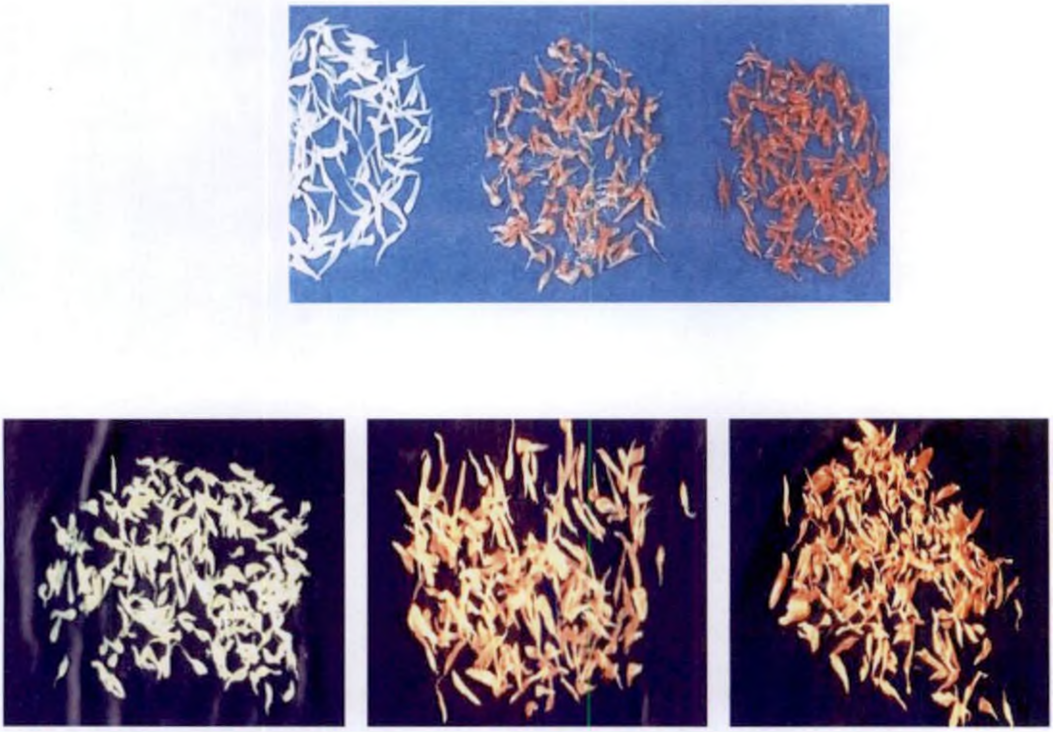


Plate 15. Variation in juice colour

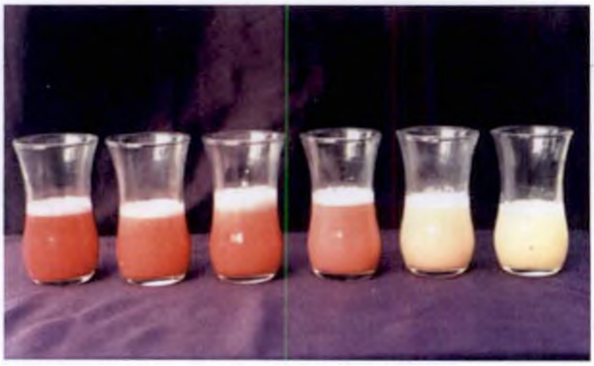


Table 7. Variation in biochemical parameters of fruits

AC.No.	TSS (^{0} brix)	Acidity (%)	TSS/Acidity	Total sugar (%)	Reducing sugars (%)	Non reducing sugars (%)	Ascorbic acid (mg/100g)
1	2	3		5	6	7	8.00
1	8.50	0.67	8.30	5.32	2.31	3.01	18.00
2	8.00	0.73	7.81	5.21	1.53	3.68	32.00
3	7.00	0.69	10.13	6.10	1.37	4.73	25.00
4	9.00	0.97	9.26	6.25	3.09	3.16	18.00
5	11.00	1.38	7.95	5.71	1.98	3.74	55.00
6	7.00	0.95	5.07	4.17	1.45	2.72	30.00
7	6.00	1.18	5.10	4.11	1.32	2.79	30.00
8	6.00	1.18	5.10	4.13	1.36	2.78	20.00
9	5.00	1.10	4.54	3.98	1.07	2.91	28.00
10	8.00	0.72	11.17	5.02	2.08	2.94	16.00
11	9.00	1.05	8.57	4.44	1.27	3.17	52.50
12	9.30	1.33	6.01	6.68	1.87	4.81	70.00
13	6.00	1.00	6.01	4.08	1.72	2.36	25.60
14	7.00	0.64	8.55	4.66	1.54	3.12	24.00
15	9.00	0.41	22.22	5.49	1.18	4.31	70.00
16	8.30	1.51	5.49	5.25	2.67	2.58	74.00
17	9.50	0.18	8.07	6.73	1.99	4.74	38.00
18	8.80	0.79	11.08	5.39	2.16	3.24	90.00
19	5.60	0.61	9.12	4.69	1.32	3.38	22.80
20	10.50	1.74	6.03	4.89	1.72	3.17	47.50
21	8.00	1.20	7.73	4.83	1.68	3.15	18.00
22	9.50	0.51	12.69	6.59	1.42	5.17	75.00

Contd.

Table 7. Contd.

1	2	3	4	5	6	7	8
23	8.50	0.97	8.74	4.00	1.36	2.64	31.40
24	6.80	0.82	8.30	4.57	1.51	3.06	65.00
25	9.00	0.49	18.51	5.00	2.50	2.50	65.50
26	10.00	0.64	15.62	6.45	2.08	4.37	88.40
27	9.00	0.79	11.33	4.35	1.43	2.92	31.90
28	8.00	0.96	8.32	4.13	1.87	2.26	26.90
29	7.00	0.61	11.40	4.30	2.53	1.77	59.80
30	6.20	0.74	8.36	5.08	1.87	3.20	87.50
31	6.50	1.05	6.19	4.11	1.50	2.61	19.95
32	8.20	0.56	14.56	6.33	1.89	4.44	66.00
33	7.00	1.13	6.17	4.74	1.48	3.26	20.60
34	5.80	1.50	3.86	3.39	1.59	1.80	55.00
35	8.80	0.54	16.39	5.13	0.81	4.32	72.50
36	8.80	0.46	19.08	4.00	1.71	2.29	95.00
37	9.00	0.69	13.02	4.63	2.53	2.10	22.80
38	8.90	0.79	11.21	6.50	2.79	3.70	40.00
39	6.50	1.23	5.29	4.44	1.27	3.17	47.50
40	6.00	1.49	4.03	3.35	1.56	1.79	36.50
Mean	7.82	0.90	9.41	4.95	1.76	3.19	45.29
CV	18.68	39.02	45.66	18.68	28.75	26.82	53.06

1.74 per cent was shown by AC. 20, collected from Thammanam, whereas the lowest was observed in AC. 15 from Aluva with 0.41 per cent, both from Ernakulam district. A few other collections viz. AC. 1, 3, 14, 19, 22, 25, 26, 29, 32, 35, 36 and 37 recorded an acidity of less than 0.70 per cent (Table 7.). The average acidity value of the 40 entries was turned to be 0.90 per cent.

4.1.5.3 TSS/acidity ratio

The mean values of TSS/acidity ratio ranged from 3.86 to 22.22, indicating high variability. TSS/acidity ratio was highest (22.22) in AC.15 from Aluva of Ernakulam district and lowest (3.86) was shown by AC.34. Average value of the ratio was found to be 9.41.

4.1.5.4 Total sugars

The data on the mean values of the total sugar content showed the presence of variability ranging from 3.35 to 6.73 per cent among the fruits. AC. 17 from Muppathadam of Ernakulam district showed the maximum value of 6.73 per cent and AC.40 recorded the minimum value. The collections, which revealed a total sugar content above 6.00 per cent, were AC. 3, 4, 12, 17, 22, 26, 32 and 38. The average total sugar content of the different fruits was 4.95 per cent.

4.1.5.5 Reducing sugars

Variations were noticed in the mean values of the reducing sugar content of the fruit juice of different accessions (Table 7.). AC.4 from Kudavechoor of Kottayam district showed the highest reducing sugar content of 3.09 per cent while AC.35 recorded the lowest content of 0.81. Reducing sugar content recorded an average of 1.76 per cent among the collections.

4.1.5.6 Non reducing sugars

Mean non-reducing sugar content of different accessions ranged from 1.77 to 5.17 per cent. Maximum value of 5.17 per cent was observed in AC. 22, collected from Thottumugham of Ernakulam district, closely followed by AC.12 (4.81) and AC.17 (4.74). Minimum value was observed in AC.40 (1.79). Average non-reducing sugar content of 40 entries was found to be 3.19 per cent.

4.1.5.7 Ascorbic acid (Vitamin C)

The data revealed a very high variation in the ascorbic acid content of the fruits of 40 accessions, and the range was from 16.00 to 95.00 mg per 100 g of the fruit. An accession collected from Mannampetta of Thrissur district, AC.36 had the highest content of 95.00 mg, closely followed by AC.18 with 90.00 mg and by AC. 26 having 88.40 mg. Lowest value was observed in AC.10. Other accessions that showed a higher content of vitamin C of 70.00 mg and above were AC.12, 15, 16, 22, 26, 30 and 35. Average ascorbic acid content calculated was 45.29 mg per 100 g fruit (Table 7.).

4.1.6 Sensory evaluation of the fruits

In the sensory evaluation of the fruit segments based on seven characters namely appearance, colour, taste, flavour, sweetness, juiciness and overall acceptability, the characters were scored with a 0-10 scale. Means of the scores of the judges were ranked for each of the seven characters and results are given in Table 8.

4.1.6.1 Appearance of the segments

Score for mean appearance of the segments ranged from 4.03 to 7.29. Score of 4.1-6.0 suggesting satisfactory was recorded from 72.50 per cent samples and score of 6.1-8 suggesting good was recorded in 27.50 per cent samples. AC.11 scored maximum, followed by AC.27. The average score was 5.48.

4.1.6.2 Colour of the segments

Colour of the segments showed a range of 3.32-7.40. Fifty per cent of the samples scored satisfactory; 32.50 per cent scored good and 17.50 per cent scored

Table 8. Variation in mean rank of sensory qualities of fruits

AC.No	Appearance	Colour	Taste	Flavour	Sweetness	Juiciness	Overall acceptability
1	2	3	4	5	6	7	8
1	4.03	3.99	3.97	3.96	3.48	4.49	3.99
2	6.25	6.62	5.09	4.45	4.39	5.22	5.34
3	5.90	5.35	5.63	5.01	5.16	5.74	5.47
4	5.10	4.26	4.14	4.17	3.69	5.22	4.43
5	5.50	6.36	4.71	5.26	4.37	5.37	5.26
6	6.52	7.26	5.49	5.41	4.75	6.39	5.97
7	5.43	4.55	3.77	4.97	2.30	6.11	4.52
8	5.35	5.05	2.87	4.05	2.38	6.06	4.29
9	4.16	3.96	3.45	3.67	3.34	4.11	3.78
10	4.91	4.39	5.53	4.84	5.75	5.95	5.23
11	7.29	7.40	7.30	6.55	6.98	7.40	7.15
12	6.54	6.76	6.90	6.60	6.90	7.41	6.85
13	4.39	4.57	4.52	5.12	4.05	5.92	4.76
14	4.24	3.85	4.61	4.54	4.30	5.32	4.48
15	6.09	6.50	5.19	4.37	4.40	6.42	5.49
16	6.65	5.64	4.90	4.80	4.19	5.68	5.31
17	6.13	6.34	4.23	4.28	4.58	4.60	5.03
18	5.73	5.69	5.18	4.10	4.15	5.17	5.00
19	5.77	6.76	5.10	4.82	4.11	5.09	5.28
20	6.03	6.26	4.99	4.94	4.46	5.30	5.33
21	6.43	6.38	5.20	5.12	5.23	5.72	5.68
22	5.39	5.99	4.98	5.18	4.62	5.32	5.25
23	6.74	5.45	5.44	5.16	5.35	5.86	5.67
24	5.95	5.79	3.32	3.19	2.73	4.20	4.20
25	5.27	4.47	4.43	3.65	4.60	5.27	4.62
26	4.93	4.71	4.28	4.84	5.20	4.89	4.81
27	6.82	6.49	4.54	4.50	4.22	5.58	5.36
28	4.22	5.15	3.65	2.63	2.88	3.95	3.74
29	5.28	5.68	4.84	5.49	3.15	5.90	5.06
30	5.99	6.50	4.97	4.69	4.68	5.93	5.46
31	4.98	3.34	5.19	2.89	2.67	5.58	4.11
32	4.39	4.32	4.58	3.98	3.81	6.26	4.56
33	4.35	3.99	4.03	4.31	3.31	4.70	4.08
34	5.49	4.74	2.61	3.04	2.12	1.90	3.32

Contd.

Table 8. Contd.

1	2	3	4	5	6	7	8
35	5.18	4.84	3.51	3.63	3.51	3.57	4.04
36	5.38	3.32	4.17	3.97	3.74	4.19	4.13
37	5.85	7.10	5.46	5.13	5.55	6.15	5.87
38	4.70	5.85	6.13	5.50	5.75	6.70	5.77
39	4.94	3.70	3.15	3.64	3.07	4.02	3.75
40	5.00	5.00	4.31	4.43	4.02	6.10	4.81
Mean	5.48	5.35	4.65	4.52	4.19	5.36	4.93
Range	4.03-7.29	3.32-7.4	2.61-7.3	2.63-6.6	2.12-6.98	1.9-7.41	3.32-7.15

poor for segment colour. The average score was 5.35 (Table 8.). AC.11, followed by AC.6, scored maximum rank

4.1.6.3 Taste of the segments

Seventy per cent of the samples scored satisfactory and 22.50 per cent scored poor. Only 7.50 per cent samples scored good. Maximum mean rank was given to AC. 11 (7.30), followed by AC.12 (6.90). The average score for taste was 4.65.

4.1.6.4 Flavour of the segments

Mean score for the flavour of the segments ranged from 2.63 to 6.60 among the samples. AC.12 scored most (6.60), followed by AC.11. Average score was 4.52. Five per cent samples scored good, 67.50 per cent samples were recorded satisfactory flavour and 27.50 per cent were poor.

4.1.6.5 Sweetness of the segments

Sweetness of the segments scored values from 2.12 to 6.98, with an average score of 4.19 (Table 8.). The samples with score 2-4 were 27.50 per cent. AC.11 scored maximum mean rank (6.98), followed by AC.12. Five per cent samples scored good and 57.50 per cent scored satisfactory.

4.1.6.6 Juiciness of the segments

Juiciness of the segments had the scores in the range of 1.9 to 7.41. Twenty per cent samples showed scored good, 72.50 per cent scored satisfactory and 2.50 per cent scored very poor for juiciness. AC.12 scored maximum mean rank (7.41), followed by AC.11. Average score for juiciness was 5.36.

4.1.6.7 Overall acceptability of the segments

Scores for overall acceptability of the segments were in the range of 3.32 to 7.15. Scores of 6-8 was observed in 5.00 per cent of the samples. Overall acceptability was satisfactory for 82.50 per cent samples and poor for 12.50 per cent samples (Table 8.). Mean overall acceptability was maximum for AC.11, followed by AC.12. Average score was 4.93.

4.1.7 Seed characters

Both seedless and seeded fruits were found among the accessions, with domination of seedless types (25 accessions) (Plate 16,17,18.). Seedless fruits are with underdeveloped seeds or no seed at all (Plate 19.). Seed characters were hence recorded for the remaining 15 accessions. The data with respect to the seed characters of the fruits of seeded collections are given in Table 9.

4.1.7.1 Number of seeds per fruit

The number of seeds per fruit ranged from 3.0-38.6, among the seeded types. Maximum number of seeds (38.6) was observed in AC.24, and minimum (3.0) in AC.20, both collected from Ernakulam district.

4.1.7.2 Seed length

The range of seed length varied from 0.65 cm to 2.19 cm, with an average of 1.31 cm (Table 9.). Maximum seed length was observed in AC. 24 and minimum in AC.5.

4.1.7.3 Seed width

Seed width had the average value of 1.03 cm. AC.24 showed the maximum seed width (1.77 cm) also, and AC.2 had the minimum (0.52 cm).

4.1.7.4 Seed weight

Plate 16. Seeded fruit

Plate 17. Seedless fruit with thin rind

Plate 18. Seedless and seeded segments of cream and pink types

Table 9. Seed characters of different accessions of pummelo

AC.No.	Seeds/fruit	Seed length (cm)	Seed width (cm)	Seed weight (g)	Seed Shape	Cotyledon colour	No.of embryos	Embryony	Germination %	Days for germination
1	2	3	4	5	6	7	8	9	10	11.00
1	Seedless									
2	5.80	0.72	0.52	0.33	Deltoid	White	1.00	Mono	100.00	21.00
3	Seedless									
4	21.40	2.00	1.69	1.87	Deltoid	White	1.00	Mono	91.60	15.00
5	25.60	0.65	0.54	0.32	Globose	White	1.00	Mono	81.00	24.00
6	Seedless									
7	Seedless									
8	19.20	1.93	1.53	0.55	Irregular	White	1.00	Mono	70.00	13.00
9	13.00	0.71	0.56	0.35	Irregular	White	1.00	Mono	70.00	20.00
10	Seedless									
11	Seedless									
12	Seedless									
13	4.80	0.79	0.64	0.41	Deltoid	White	1.00	Mono	45.00	16.00
14	Seedless									
15	33.80	1.74	1.09	0.49	Deltoid	White	1.00	Mono	50.00	23.00
16	21.00	1.89	1.50	0.55	Deltoid	White	1.00	Mono	36.60	28.00
17	Seedless									
18	Seedless									
19	10.00	1.67	1.09	0.38	Irregular	White	1.00	Mono	45.00	25.00
20	3.00	0.65	0.54	0.31	Deltoid	White	1.00	Mono	8.30	29.00
21	Seedless									
22	Seedless									

Contd.

Table9. Contd.

1	2	3	4	5	6	7	8	9	10	11
23	27.60	1.73	1.53	0.29	Deltoid	White	1.00	Mono	54.00	28.00
24	38.60	2.19	1.77	2.03	Deltoid	White	1.00	Mono	92.00	17.00
25	Seedless									
26	Seedless									
27	Seedless									
28	Seedless									
29	Seedless									
30	Seedless									
31	Seedless									
32	5.60	0.75	0.53	0.35	Deltoid	White	1.00	Mono	6.25	29.00
33	Seedless									
34	Seedless									
35	Seedless									
36	9.60	1.08	0.94	0.43	Deltoid	White	1.00	Mono	66.60	18.00
37	11.20	0.74	0.67	0.37	Globose	White	1.00	Mono	83.00	25.00
38	Seedless									
39	15.60	1.76	1.36	0.34	Deltoid	White	1.00	Mono	36.30	20.00
40	Seedless									
Mean	16.61	1.31	1.03	0.58			1.00		58.47	21.93
CV	0.64	0.44	0.45	0.92			0.00		0.48	0.23

Seeds extracted from fruits of AC.24 had the maximum weight of 2.03 g and that from AC.23 had the minimum weight of 0.29 g. Average seed weight was found to be 0.58 g (Table 9.).

4.1.7.5 Seed shape

Deltoid and globose seed shapes were observed among the seeded fruits along with some showing irregular shaped seeds. Major seed shape was the deltoid (Plate 20.).

4.1.7.6 Cotyledon colour

All the seeded types showed white coloured cotyledons.

4.1.7.7. Number of embryos

All the seeded accessions produced only one seedling per seed on germination, indicating monoembryony (Plate 21.).

4.1.7.8 Germination percentage

Germination percentage of seeds ranged from 8.30 to 100.00(Plate 22.). Maximum percentage of 100.00 was observed in AC.2, accessed from Chempu region of Kottayam district and minimum of 8.30 in AC.20. Average germination percentage calculated was 58.47 (Table 9.).

4.1.7.9 Days for germination

Minimum days for germination were found in AC.8, from Pala of Kottayam district having 13 days. Maximum time was taken by AC.20 and by AC.32, both having 29 days. The average value found was 21.93 days.

4.1.8 Correlation studies

4.1.8.1 Correlation between physical characters of fruits

Plate 19. Developed and underdeveloped seeds

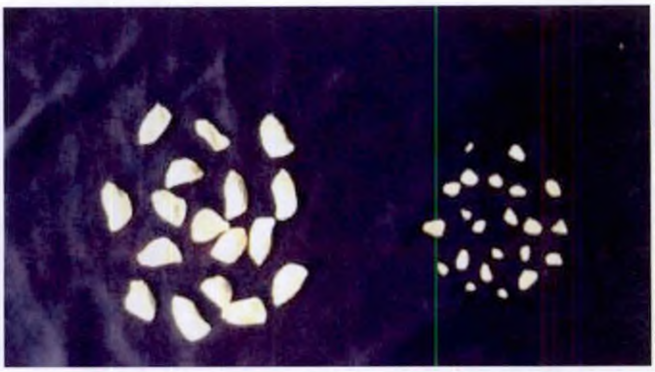


Plate 20. Variation in seed size and shape

Plate 21. Monoembryonic seedlings of pummelo

Plate 22. Survival of pummelo seedlings

The correlation matrix for the physical characters of the fruits is presented in Table 10. Fruit length was significantly and positively correlated with fruit width, weight, rind weight, segment length, width, and weight. But no significant correlation was found between fruit length and two other parameters viz., density of oil glands and segment number.

Fruit width had significant and positive correlation with fruit weight, rind weight, segment length, width, and weight. It was also significantly correlated with segment number and juice content. Fruit weight was showing highly significant positive correlation with rind weight and segment characteristics viz. length, width and weight. Correlation between fruit weight and juice content was also significant and positive.

Rind weight was correlated with only one segment character i.e. segment width. No significant correlation was observed between density of oil glands and any other fruit characters.

Segment length was correlated with segment width and segment weight in a highly positive and significant manner, while segment width was highly significantly correlated with segment weight. Segment number and weight are found to be negatively correlated. Juice content showed positively significant correlation only with fruit width and fruit weight.

4.1.8.2. Correlation between physical characters of fruit and yield

Yield per tree showed highly significant and positive correlation with number of fruits, fruit length, fruit width, fruit weight and rind weight. The segment characters viz., segment length, width and weight also revealed significant positive correlation with yield. The correlations of yield between characters like density of oil glands, segment number and juice content were not significant (Table 11).

4.1.8.3 Correlation between bio chemical characters of fruit

Table 10. Correlation matrix for the physical characters of the fruits

Sl. No	Fruit length	Fruit width	Fruit weight	Rind Weight	Density of oil glands	Segment number	Segment length	Segment width	Segment weight	Juice content
	1	2	3	4	5	6	7	8	9	10
1	1.0000									
2	0.9214**	1.0000								
3	0.8208**	0.8657**	1.0000							
4	0.4861**	0.6247**	0.6090**	1.0000						
5	0.1789	0.1993	0.1524	0.1497	1.0000					
6	0.2693	0.3160*	0.2724	0.1368	0.2538	1.0000				
7	0.4675**	0.4567**	0.4542**	0.1725	0.0231	0.1630	1.0000			
8	0.4244**	0.4797**	0.5812**	0.3618*	0.2722	0.0303	0.5491**	1.0000		
9	0.4518**	0.4136**	0.4520**	0.2080	0.0786	-0.1479	0.7492**	0.5217**	1.0000	
10	0.2807	0.3470*	0.3153*	0.1543	0.0715	0.2410	0.2488	0.0634	0.3092	1.0000

Table 11. Correlation coefficients between the physical characters of the fruit and yield

	No. of fruits	Fruit length	Fruit width	Fruit weight	Rind weight	Density of oil glands	Segment number	Segment length	Segment width	Segment weight	Juice content
Yield	0.658**	0.573**	0.564**	0.595**	0.102**	-0.042 NS	0.085 NS	0.373*	0.373*	0.351*	0.221 NS

* Significant at 5 per cent level
** Significant at 1 per cent level

Data on the correlation coefficients between bio chemical characters of the fruits are presented in the Table 12. TSS of the fruit was negatively correlated with acidity, but not in a significant manner, whereas acidity and total sugar content of the fruits are showing significant negative correlation.

TSS of the fruit was correlated with total sugar and reducing sugar content in positive and highly significant manner, but showing no significant correlation with ascorbic acid. Acidity was negatively correlated with other bio chemical characters insignificantly, but the negative correlation between acidity and total sugars was significant.

Highly significant and positive correlation was observed between total sugar content and reducing sugar content. Ascorbic acid showed no significant correlation with any of the characters.

Table 12. Correlation coefficients between bio chemical characters of fruits

	TSS	Acidity	Ascorbic acid	Total sugar	Reducing sugar
TSS	1.000				
Acidity	-0.1141	1.000			
Ascorbic acid	0.2889	-0.1801	1.000		
Total sugar	0.5220**	-0.3720*	0.2810	1.000	
Reducing sugar	0.4085**	-0.0600	0.0684	0.3832*	1.000

* Significant at 5 per cent level
** Significant at 1 per cent level

4.1.8.4 Correlation between biometric and quality parameters of fruit

Relations were worked out between biometric and biochemical characters of fruit. The results are presented in Table 13. No significant correlation was observed between the biometric characters of the fruit and important biochemical characters viz., TSS, acidity and ascorbic acid.

Table 13. Correlation coefficients between biometric and bio chemical parameters

	Acidity	TSS	Ascorbic acid
Fruit length	0.178	0.010	-0.191
Fruit width	0.169	-0.009	-0.144
Fruit weight	0.146	-0.105	-0.107
Rind weight	0.126	-0.100	-0.014
Density of oil glands	-0.050	0.178	0.195
No. of segments	-0.007	-0.070	-0.083
Segment length	0.004	-0.052	0.016
Segment width	-0.091	-0.046	0.129
Segment weight	0.016	0.00	0.063

4.1.9 Cluster analysis

In order to find the genetic divergence, non-hierarchial Euclidean cluster analysis was carried out using Mahalanobis D^2 statistic, subjecting 20 parameters. The analysis yielded three clusters.

The cluster wise compositions of accessions are presented in Table 14. The average inter and intra cluster distances are aligned in Table 15. Seven accessions were accommodated in cluster I, 10 in cluster II and 23 in cluster III. Maximum divergence was observed between clusters I and II, which was followed by that between cluster III and I. The intra cluster divergence ranged from 3.608 to 4.095. Cluster I was having least intra cluster divergence and cluster II had maximum intra cluster divergence. Genotypes from different geographical regions were grouped in the same cluster indicating relationship between genetic distribution and geographic distribution is weak.

The cluster means for the external parameters of the accessions are furnished in Table 16. Maximum values for tree height (4.70), number of branches (33.90), leaf width (5.75 cm) were recorded in cluster II, whereas that for leaf length (12.22 cm) and number of fruits per tree (120.43) were recorded in cluster III. The

Table 14. Composition of clusters based on D^2 statistic in pummelo

Cluster No	No. of entries in cluster	Accessions in the cluster
I	7	13, 20, 28, 30, 31, 33, 40
II	10	3, 4, 6, 7, 8, 9, 11, 23, 34, 39
III	23	1, 2, 5, 10, 12, 14, 15, 16, 17, 18, 19, 21, 22, 24, 25, 26, 27, 29, 32, 35, 36, 37, 38

Table 15. Average inter and intra cluster distances

(Figures along the main diagonal distances indicate intra cluster distances)

	I	II	III
I	3.608	0.000	0.000
II	5.836	4.095	0.000
III	4.261	3.558	3.705

Table 16. Cluster means for different external parameters of trees

Cluster no.	Tree height (m)	No. of branches	Leaf length (cm)	Leaf width (cm)	No. of fruits/tree
1	3.57	28.14	9.10	4.12	108.57
2	4.70	31.55	11.12	5.75	114.00
3	4.26	28.00	12.22	5.71	120.43

Table 17. Cluster means for different physical parameters of fruits

Cluster no.	Fruit length (cm)	Fruit width (cm)	Fruit weight (g)	Rind weight	Density of oil glands (no./sq.cm)	No.of segments	Segment length (cm)	Segment width (cm)	Segment weight (g)	Juice Content (%)
1	13.74	14,70	584.71	208.14	27.14	11.40	6.80	3.05	25.30	30.44
2	18.61	19.19	1407.70	606.20	606.20	12.22	9.67	4.23	62.80	50.18
3	16,62	16.94	856.57	322.82	322.82	12.20	8.82	3.89	45.26	52.66

Table 18. Cluster means for different biochemical parameters of fruits

Cluster No.	TSS of juice (^{0} brix)	Total acidity (%)	Ascorbic acid (mg/100g)	Total sugars (%)	Reducing sugars (%)
1	7.17	1.16	37.79	4.34	1.67
2	6.98	1.08	33.74	4.5	1.51
3	8.39	0.74	52.60	5.34	1.89

cluster means for the physical parameters of the fruits are given in the Table 17. Maximum values for fruit length (18.61cm), fruit width (19.19 cm), fruit weight (1407.70 g), rind weight (606.20 g), number of segments (12.22), segment length (9.67 cm), segment width (4.23 cm) and segment weight (62.80 g) were recorded in cluster II whereas density of oil glands (33.30 no./sq.cm) and juice content (52.66%) were maximum in cluster III.

The cluster means for the biochemical characters of the fruits are furnished in Table 18. The maximum value for acidity (1.16%) was recorded in cluster I. Cluster III recorded maximum values for TSS (8.39^0 brix), ascorbic acid (52.60 mg/100 g), total sugars (5.34%), reducing sugars (1.89%) and minimum value for acidity (0.74%).

Cluster I recorded minimum values for all characters except acidity. Considering the quantitative aspects of fruits, accessions in the cluster II are the best, and cluster III excelled in qualiitative aspects of fruits.

4.1.10 Factor analysis

In order to find out a selection index for overall quality of pummelo fruits, factor analysis was carried out using ten important parameters, viz., fruit length, fruit width, fruit weight, rind weight, number of segments, segment weight, segment length, segment width, juice content and total sugar content. Three components were extracted using principal component analysis, and cumulative variance explained was found to be 72.5 %. The first principal component explained 42.7 % of variance.

The component matrix is given in Table 19. Based on the component loadings of the first principal component, the selection index was calculated as,

$$S.I. = 0.804 * x_1+0.659* x_2+0.944* x_3+0.805* x_4+0.287* x_5+0.753* x_6+0.619* x_7+0.65*x_8+ 0.449*x_9 +0.002 *x_{10}$$

where x_1= fruit length, x_2 = fruit width, x_3 = fruit weight, x_4 = rind weight, x_5 = no. of segments, x_6 = segment weight, x_7 = segment length, x_8 = segment width, x_9 = juice content and x_{10} = total sugar content.

The mean value of all the ten parameters taken as the standard and the selection index based on the mean values was taken as the minimal criterion for selection. All the accessions having selection index value higher than this are regarded as good with respect to the above parameters. Selection index value based on the mean values turned to be 1290. Accessions numbered 2, 3, 4, 7, 9, 11, 14, 16, 23, 26, 28, 29, 32, 34, 36 and 39 were found to have a greater selection index value. Selection index values of the accessions were given in the Table 20.

Table 19. Component matrix

Component Matrix			
Parameter	Component		
	1	2	3
Fruit length	.804	.158	.174
Fruit width	.659	.448	-.174
Fruit weight	.944	-.0013	-.184
Rind weight	.805	.112	-.395
No. of segments	.287	.840	-.210
Segment weight	.753	-.483	.190
Juice content	.449	.197	.714
Total sugars	.002	.479	.551
Segment length	.619	-.404	.233
Segment width	.650	-.383	-.142
Extraction Method: Principal Component Analysis.			

Table 20. Selection index value for the surveyed accessions

AC.No	Fruit length	Fruit width	Fruit weight	Rind weight	No.of. segments	Segment weight	Segment length	Segment width	Juice content	Total sugar	Selection index value
	cm	cm	g	g		g	cm	cm	%	%	
	1	2	3	4	5	6	7	8	9	10	11
1	17.84	12.02	498.00	120.00	10.00	37.00	6.58	3.36	65.40	5.32	655.43
2	18.82	13.16	1166.00	560.00	12.00	50.00	8.28	4.22	66.36	5.21	1654.17
3	18.40	17.00	1486.00	700.00	14.00	55.00	8.30	4.44	57.16	6.09	2071.52
4	18.40	23.00	1960.00	890.00	15.00	65.00	8.70	4.82	47.80	6.25	2679.99
5	16.30	15.00	710.00	340.00	10.00	35.00	10.98	4.76	42.60	5.71	1025.28
6	18.90	19.70	980.00	300.00	12.00	55.00	9.72	3.68	43.94	4.17	1267.87
7	20.00	16.90	1230.00	500.00	10.00	70.60	9.36	3.52	32.86	4.11	1669.79
8	17.20	15.40	946.00	380.00	12.00	46.40	8.28	4.18	31.80	4.13	1283.49
9	20.50	16.60	1700.00	590.00	14.00	78.00	14.12	4.88	60.20	3.98	2208.94
10	14.00	15.90	590.00	130.00	11.00	40.00	11.70	3.68	72.60	5.02	758.95
11	18.60	21.00	1460.00	680.00	13.00	58.00	10.38	2.98	69.10	4.44	2041.31
12	20.80	24.00	870.00	200.00	16.00	41.40	8.76	2.94	65.30	6.68	1087.37
13	16.84	20.60	570.00	190.00	16.00	18.70	7.72	3.42	32.60	4.08	758.54
14	17.14	18.90	910.00	454.00	14.00	25.00	9.12	4.46	34.50	4.66	1297.71
15	16.50	17.00	860.00	220.00	12.40	39.00	7.56	3.76	68.40	5.49	1084.28
16	17.90	16.20	1030.00	520.00	14.40	35.00	7.98	3.88	57.60	5.25	1479.90
17	13.00	15.60	546.00	180.00	12.00	30.00	6.58	3.36	46.90	6.73	734.54
18	16.20	21.00	656.00	210.00	11.00	40.00	8.40	3.52	32.60	5.39	870.68
19	14.80	17.60	756.00	242.00	11.00	45.00	7.30	3.72	50.30	4.69	998.63
20	13.30	13.90	578.00	160.00	11.00	35.00	6.30	3.16	45.40	4.89	750.23
21	16.40	15.90	940.00	205.00	10.00	72.40	9.88	3.74	60.70	4.83	1169.33
22	14.80	15.20	724.00	160.00	10.00	55.00	11.28	4.24	44.40	6.59	908.26

Contd.

Table 20.

23	21.20	20.00	1304.00	495.00	11.00	72.40	9.26	3.74	62.20	4.00	1753.82
24	17.10	17.30	946.00	371.00	12.20	45.00	9.32	4.24	56.10	4.57	1287.65
25	15.60	16.00	706.00	286.00	11.00	38.00	7.22	4.20	42.00	5.00	977.15
26	17.20	20.60	1124.00	658.00	13.00	22.00	9.18	3.68	33.70	6.45	1662.35
27	16.50	16.90	875.00	300.00	11.60	48.00	8.66	3.34	56.80	4.35	1164.46
28	17.80	13.40	976.00	450.00	9.00	50.00	7.62	4.56	42.50	4.13	1372.84
29	18.80	14.80	1015.00	495.00	13.00	42.00	7.74	3.28	53.20	4.30	1448.31
30	10.20	9.80	193.00	50.00	11.00	12.00	5.02	3.06	18.10	5.08	262.49
31	12.04	15.00	520.00	194.00	12.00	18.30	8.62	4.14	23.00	4.11	701.47
32	18.60	19.60	1402.00	566.00	11.20	73.00	9.32	2.88	51.70	6.33	1897.05
33	12.80	13.30	534.00	227.00	13.00	22.40	7.26	3.02	23.40	4.74	943.23
34	14.80	17.50	1246.00	530.00	9.00	77.60	9.88	4.26	43.40	3.39	1716.32
35	14.60	12.00	569.00	256.00	10.00	30.60	9.18	2.54	34.90	5.13	812.85
36	15.50	18.80	1086.00	340.00	10.00	72.00	11.06	5.12	26.10	4.00	1402.84
37	16.30	17.00	852.00	332.00	12.00	42.40	8.24	4.04	75.30	4.63	1173.00
38	17.50	19.20	870.00	280.00	14.00	41.40	8.58	5.20	73.80	6.49	1149.21
39	18.10	24.80	1765.00	997.00	14.00	50.00	8.72	4.26	53.30	4.44	2573.61
40	13.20	16.90	722.00	380.00	13.00	20.80	5.08	3.14	28.10	3.35	1046.54
Mean	16.61	17.11	946.78	378.45	12.02	45.11	8.68	3.83	48.15	4.96	1290.00

PART-II

4.2 PROPAGATION STUDIES

Vegetative propagation techniques such as cutting, layering and budding were tried in pummelo to standardise the method. Results are as follows

4.2.1 Cutting

4.2.1.1 Standardisation of type of cutting, month and growth regulator concentration

Data on the effect of type of wood, growth regulator concentration and month on observations, viz., percentage of rooting, days for rooting and number of roots are presented in Tables 21, 22, 23, 24 and 25.

4.2.1.2 Percentage of rooting

The performance of cuttings with respect to the percentage of rooting as influenced by effect of hormone concentration and month are given in table 21. In May, NAA 1000 mg l^{-1} had significantly higher percentage of rooting (21.6%), followed by NAA 2000 mg l^{-1}, which is on par with IBA 1000 mg l^{-1}. IBA 3000, 2000, IAA 1000, 2000 and 3000 mg l^{-1} produced no significant difference among them with respect to rooting percentage, all recording 3.3 percent. Treatments viz., Rootex, Keradix and control were not responded.

In the month of June and July, rooting performance of the cuttings was very poor. In both months, NAA 1000 mg l^{-1} was the significantly superior treatment (13.3 and 18.3 %), followed by NAA 2000 mg l^{-1} (10.0 and 8.3%) and IBA 1000 mg l^{-1} (3.3 and 6.6 %). Other treatments failed to root, but in July IAA 1000 and 3000 mg l^{-1} recorded 3.3 percentage rooting that was on par with IBA 1000 mg l^{-1}.

All the treatments responded well with respect to rooting, in August, the most superior being NAA 1000 mg l^{-1} with 35.0 percentage, followed by NAA 2000 mg l^{-1} (25.0%) and by IBA 1000 mg l^{-1} (20.0%). Rooting percentage of IBA 3000

Table 21. Effect of GR concentration and month on percentage of rooting

	Rooting (%)				
TREATMENTS	MAY	JUNE	JULY	AUGUST	SEPTEMBER
IBA 1000	10.0 (2.8)	3.3 (1.5)	6.6 (1.9)	20.0 (4.4)	38.3 (6.1)
IBA 2000	3.3 (1.5)	0.0 (0.7)	0.0 (0.7)	6.6 (2.3)	33.3 (5.8)
IBA 3000	3.3 (1.5)	0.0 (0.7)	0.0 (0.7)	16.6 (4.0)	33.3 (5.8)
IAA 1000	3.3 (1.5)	0.0 (0.7)	3.3 (1.5)	10.0 (3.2)	29.1 (5.4)
IAA 2000	3.3 (1.5)	0.0 (0.7)	0.0 (0.7)	15.0 (3.3)	33.3 (5.8)
IAA 3000	3.3 (1.5)	0.0 (0.7)	3.3 (1.5)	20.0 (4.2)	31.6 (5.6)
NAA 1000	21.6 (4.6)	13.3 (3.6)	18.3 (4.2)	35.0 (5.8)	63.3 (7.9)
NAA 2000	10.0 (3.2)	10.0 (3.2)	8.3 (2.6)	25.0 (5.0)	40.0 (6.3)
NAA 3000	3.3 (1.5)	0.0 (0.7)	0.0 (0.7)	13.3 (3.6)	26.6 (5.2)
Keradix	0.0 (0.7)	0.0 (0.7)	0.0 (0.7)	3.3 (1.5)	13.3 (3.6)
Rootex	0.0 (0.7)	0.0 (0.7)	0.0 (0.7)	3.3 (1.5)	13.3 (3.6)
Control	0.0 (0.7)	0.0 (0.7)	0.0 (0.7)	3.3 (1.5)	6.6 (2.3)

CD (0.05) Growth regulator Vs month for % of rooting -0.305

Values in parenthesis are transformed values (Square root transformation)

mg l^{-1} (16.6%) and of IAA 3000 mg l^{-1} (20.0%) was on par with that of IBA at 1000 mg l^{-1}. There was no significant difference between the treatments viz., NAA 3000 mg l^{-1}, IAA1000 mg l^{-1} and IAA 2000 mg l^{-1}. IBA 2000 mg l^{-1} (6.6%) was better than the powder formulations and control.

In September, NAA 1000 mg l^{-1} recorded significantly higher percentage of rooting (63.3%). IBA 1000 mg l^{-1} (38.3%) and NAA 2000 mg l^{-1} (40.0%) were on par and they are the second best treatments. The rooting percentage did not vary significantly among the treatments viz., IBA at 2000 mg l^{-1}, 3000 mg l^{-1}, IAA at 1000, 2000 and 3000 mg l^{-1}. Performance of Rootex and Keradix were on par with 13.3 percentage, but were inferior to NAA at 3000 mg l^{-1}. Control also showed relatively better percentage of rooting than in other months (6.6%).

Table 21 also revealed the interactive effect of month and GR concentration. With regard to the percentage of rooting, treatments viz., NAA 1000 mg l^{-1}, NAA 2000 mg l^{-1} and IBA 1000 mg l^{-1} showed higher percentage of rooting in all the months. These treatments recorded significantly higher value in September, followed by August and May. For NAA 1000 mg $l^{-1}$and NAA 2000 mg l^{-1}, difference between observations was not significant in May and July (21.6 and 18.3) and May and June (10.0 and 10.0), respectively. Percentage variation was not significant between the month of June and July (3.3 and 6.6), for IBA 1000 mg l^{-1}.

Data on the interaction effect of GR concentration and type of wood is presented in Table 22. NAA 1000 mg l^{-1} showed significantly higher rooting in hard wood cuttings (33.0%), compared to soft wood and semi hard wood cuttings, which are on par with each other (29.0%). Semi hard wood cuttings performed better treated with NAA 2000 mg l^{-1} and IBA 1000 mg l^{-1} (21.0 and 18.0% respectively), than soft wood (19.0 and 14.0%) and hard wood (16.0 and 15.0%). Performance of semi hard wood cuttings was the best in treatments viz., IAA 1000 mg l^{-1} (12.0%), IAA 3000 mg l^{-1} (14.0%), NAA 3000 mg l^{-1} (9.0%), Rootex (4.0%) and Keradix(4.0%), but on par with hard wood cuttings treated with IAA at

Table 22. Effect of GR concentration and wood on percentage of rooting

	Rooting (%)		
TREATMENTS	Softwood	Semi hard wood	Hardwood
IBA 1000	14.0 (3.0)	18.0 (4.2)	15.0 (2.8)
IBA 2000	10.0 (2.3)	8.0 (2.4)	8.0 (1.8)
IBA 3000	9.0 (2.2)	10.0 (2.6)	13.0 (2.7)
IAA 1000	9.0 (2.2)	12.0 (3.1)	6.5 (2.0)
IAA 2000	5.0 (1.5)	10.0 (2.6)	16.0 (2.9)
IAA 3000	7.0 (2.0)	14.0 (3.3)	14.0 (2.8)
NAA 1000	29.0 (5.1)	29.0 (5.1)	33.0 (5.5)
NAA 2000	19.0 (4.1)	21.0 (4.5)	16.0 (3.3)
NAA 3000	8.0 (2.1)	9.0 (2.5)	9.0 (2.3)
Keradix	3.0 (1.3)	4.0 (1.7)	3.0 (1.3)
Rootex	3.0 (1.3)	4.0 (1.7)	3.0 (1.3)
Control	0.0 (0.7)	4.0 (1.7)	2.0 (1.2)

CD (0.05) Growth regulator Vs wood for % of rooting - 0.237

Values in parenthesis are transformed values (Square root transformation)

3000 mg l^{-1} and NAA at 3000 mg l^{-1}. IBA at 2000 mg l^{-1} had more rooting in soft wood (10.0%), while semi hard wood and hard wood cuttings recorded same result (8.0%). IBA 3000 mg l^{-1} showed higher percentage of rooting in hard wood cuttings. Hard wood cuttings also well done with IAA at 2000 mg l^{-1} (16.0%).

It is clearly revealed that NAA 1000 mg l^{-1} induced the highest rooting percentage (63.3%), followed by NAA at 2000 mg l^{-1} (40.0%) and IBA at 1000 mg l^{-1} (38.3%) in September. Semi hard wood cuttings gave higher percentage of rooting in most of the treatments, followed by hard wood cuttings. Highest percentage of rooting was observed in the month of September, followed by August and May.

4.2.1.3 *Days for rooting*

Data regarding to the mean number of days taken for the rooting are presented in the Table 23. Lowest days for rooting were taken by soft wood cuttings at 1000 mg l^{-1} of NAA (29 days), followed by that at 2000 mg l^{-1} of NAA (30 days) and that at 1000 mg l^{-1} of IBA (31 days). Soft wood cuttings, in general, showed lesser days for rooting followed by semi hard wood cuttings and by hard wood cuttings.

4.2.1.4 *Number of roots*

The interaction effect of growth regulator concentration and type of cuttings on number of roots was presented in Table 24. Semi hard wood cuttings gave significantly higher number of roots compared to other types. NAA at 1000 mg l^{-1} produced significantly higher number of roots in hard wood cuttings (10.2 at 2 months after planting and 19.7 at 4 months after planting) compared to soft wood and semi hard wood cuttings. NAA at 2000 mg l^{-1} produced roots (7.2 and 14.8 at 2 and 4 months after planting respectively), in semi hard wood cuttings which was significantly superior than soft wood and hard wood cuttings. Semi hard wood

Table 23. Effect of GR concentration, wood and month on days to root

TREATMENTS	DAYS TO ROOT														
	MAY			JUNE			JULY			AUGUST			SEPTEMBER		
	S	SH	H	S	SH	H	S	SH	H	S	SH	H	S	SH	H
IBA 1000	35	30	-	-	35	-	-	30	-	32	35	39	31	35	40
IBA 2000	-	39	-	-	-	-	-	-	-	37	39	-	35	37	39
IBA 3000	-	38	-	-	-	-	-	-	-	40	39	40	35	35	40
IAA 1000	-	35	-	-	-	-	-	39	-	40	35	40	39	35	35
IAA 2000	-	40	-	-	-	-	-	-	-	-	35	38	40	40	40
IAA 3000	-	40	-	-	-	-	-	35	-	40	35	37	40	32	37
NAA 1000	30	31	33	31	30	31	30	31	39	30	30	31	29	30	31
NAA 2000	31	35	-	33	37	35	35	35	-	31	31	30	30	31	35
NAA 3000	-	40	-	-	-	-	-	-	-	39	40	39	39	40	40
Keradix	-	-	-		-	-	-	-	-	-	43	-	40	40	40
Rootex	-	-	-		-	-	-	-	-	-	45	-	41	40	45
Control	-	-	-		-	-	-	-	-	-	49	-	-	50	50

S-Softwood, SH-semi hard wood, H- hard wood

Table 24. Effect of GR concentration and wood on number of roots

TREATMENTS	WOOD					
	SOFT WOOD		SEMI HARD WOOD		HARD WOOD	
	Roots 2MAP	Roots 4MAP	Roots 2MAP	Roots 4MAP	Roots 2MAP	Roots 4MAP
IBA 1000	2.6(1.6)	6.0(2.2)	7.3(2.7)	15.4(3.9)	1.3(1.2)	2.9(1.5)
IBA 2000	1.5(1.2)	2.9(1.5)	3.1(1.7)	6.5(2.3)	1.8(1.1)	3.6(1.4)
IBA 3000	1.8(1.3)	3.5(1.6)	3.0(1.6)	6.5(2.3)	2.9(1.5)	5.5(1.9)
IAA 1000	1.3(1.2)	2.9(1.5)	5.9(2.3)	11.8(3.2)	2.4(1.4)	4.4(1.7)
IAA 2000	0.6(0.9)	1.0(1.0)	3.2(1.7)	5.6(2.1)	1.3(1.1)	2.2(1.4)
IAA 3000	1.3(1.2)	2.2(1.4)	4.9(2.2)	9.3(2.9)	3.5(1.6)	6.6(2.0)
NAA 1000	5.3(2.4)	11.4(3.4)	8.9(3.0)	18.4(4.3)	10.2(3.2)	19.7(4.4)
NAA 2000	4.1(2.1)	10.1(3.2)	7.2(2.7)	14.8(3.9)	4.3(1.9)	8.9(2.5)
NAA 3000	1.7(1.2)	3.9(1.7)	2.1(1.4)	4.4(1.9)	1.6(1.2)	3.2(1.5)
Keradix	0.3(0.8)	0.7(0.9)	1.3(1.1)	2.2(1.4)	0.8(0.9)	1.7(1.1)
Rootex	0.3(0.8)	0.6(0.9)	1.3(1.1)	1.9(1.3)	0.6(0.9)	1.3(1.0)
Control	0.0(0.7)	0.0(0.7)	0.6(0.8)	1.2(1.1)	0.4(0.8)	0.9(1.0)

CD (0.05) Growth regulator Vs wood for Roots 2MAP 0.075, Roots 4MAP 0.069

Values in parenthesis are transformed values (Square root transformation)

Table 25. Effect of GR concentration and month on number of roots

TREATMENTS	MONTHS									
	MAY		JUNE		JULY		AUGUST		SEPTEMBER	
	Roots 2MAP	Roots 4MAP	Roots 2MAP	Roots 4MAP	Roots 2MAP	Roots 4MAP	Roots 2MAP	Roots 4MAP	Roots 2MAP	Roots 4MAP
IBA 1000	4.1 (1.9)	8.7 (2.6)	1.7 (1.2)	3.3 (1.5)	2.5 (1.4)	5.3 (1.8)	4.8 (2.2)	10.7 (3.3)	5.6 (2.4)	12.44 (3.5)
IBA 2000	1.6 (1.2)	3.5 (1.5)	0.0 (0.7)	0.0 (0.7)	0.0 (0.7)	0.0 (0.7)	2.8 (1.6)	5.8 (2.2)	6.2 (2.5)	12.4 (3.5)
IBA 3000	1.8 (1.2)	3.8 (1.6)	0.0 (0.7)	0.0 (0.7)	0.0 (0.7)	0.0 (0.7)	5.4 (2.4)	10.6 (3.3)	5.7 (2.4)	11.4 (3.4)
IAA 1000	2.5 (1.4)	4.8 (1.7)	0.0 (0.7)	0.0 (0.7)	2.2 (1.3)	4.7 (1.7)	5.1 (2.3)	10.8 (3.3)	6.3 (2.5)	11.6 (3.4)
IAA 2000	1.8 (1.2)	2.8 (1.4)	0.0 (0.7)	0.0 (0.7)	0.0 (0.7)	0.0 (0.7)	2.6 (1.6)	4.7 (2.0)	3.9 (2.0)	7.1 (2.7)
IAA 3000	1.8 (1.2)	3.3 (1.5)	0.0 (0.7)	0.0 (0.7)	2.2 (1.3)	3.5 (1.5)	6.0 (2.5)	11.0 (3.3)	6.2 (2.5)	12.4 (3.5)
NAA 1000	8.2 (2.9)	17.1 (4.1)	7.0 (2.7)	11.1 (3.3)	7.2 (2.7)	14.8 (3.8)	9.0 (3.0)	18.5 (4.3)	9.2 (3.0)	20.9 (4.5)
NAA 2000	4.0 (1.9)	8.9 (2.7)	3.8 (2.0)	8.1 (2.9)	3.5 (1.8)	8.3 (2.6)	7.0 (2.7)	14.1 (3.8)	7.6 (2.8)	16.9 (4.1)
NAA 3000	0.8 (1.0)	2.1 (1.3)	0.0 (0.7)	0.0 (0.7)	0.0 (0.7)	0.0 (0.7)	3.8 (2.0)	7.9 (2.9)	4.3 (2.1)	9.0 (3.0)
Keradix	0.0 (0.7)	0.0 (0.7)	0.0 (0.7)	0.0 (0.7)	0.0 (0.7)	0.0 (0.7)	1.1 (1.1)	1.8 (1.2)	2.9 (1.8)	5.8 (2.4)
Rootex	0.0 (0.7)	0.0 (0.7)	0.0 (0.7)	0.0 (0.7)	0.0 (0.7)	0.0 (0.7)	1.0 (0.7)	1.5 (1.2)	2.7 (1.7)	4.7 (2.2)
Control	0.0 (0.7)	0.0 (0.7)	0.0 (0.7)	0.0 (0.7)	0.0 (0.7)	0.0 (0.7)	0.6 (0.9)	1.0 (1.0)	1.0 (1.1)	2.5 (1.6)

CD (0,05) Growth regulator Vs month for	Roots 2MAP	Roots 4MAP
	0.097	0.089

MAP-Months after planting

Values in parenthesis are transformed values (Square root transformation)

cuttings produced significantly more number of roots in all concentrations of IBA and IAA and also at NAA at 3000 mg l^{-1}.

Data on the interaction between the growth regulator concentration and month on number of roots was also studied which are furnished in Table 25. September yielded more number of roots in all the treatments compared to other months in NAA 1000 mg l^{-1} (20.9), NAA 2000 mg l^{-1} (16.9) and IBA 1000 mg l^{-1} (12.4) at 4 MAP. The second best season was August, followed by May where the number of roots produced was 18.5 and 17.1 in NAA 1000 mg l^{-1}, 14.1 and 8.9 in NAA 2000 mg l^{-1} and 10.7 and 8.7 in IBA 1000 mg l^{-1} (4 MAP). In June and July, the number of roots produced was very less in all the treatments. Among the different hormonal treatments, NAA 1000 mg l^{-1} produced significantly higher number of roots, 9.2 and 20.9 (at 2 MAP and 4 MAP), followed by NAA 2000 mg l^{-1} (7.6 and 16.9) and by IBA 1000 mg l^{-1} (5.6 and 12.4) during the month of September (Plate 23).

The treatments, IBA 2000 mg l^{-1}, IBA 3000 mg l^{-1}, IAA 2000 mg l^{-1} and NAA 3000 mg l^{-1} produced roots only in the months of May, August and September. IBA 3000 mg l^{-1} produced results significantly on par in the month of August and September, so as NAA 2000 mg l^{-1}. Keradix, Rootex and control produced roots only in the month of August and September.

4.2.2 Layering

4.2.2.1 Standardisation of the media and season for layering

The media exhibited different response during the same as well as during different months (Plate 24).

4.2.2.2 Days to root

When sphagnum moss was used as the medium time taken for rooting was significantly lower during the months, May (44.33 days), June (51.00 days) and

Plate 23. Rooting of cuttings after four months of planting*^

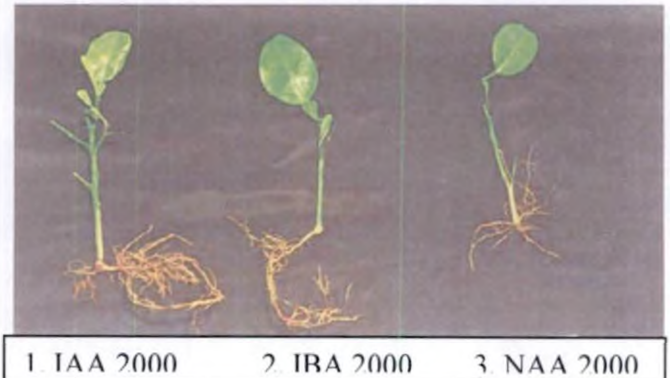
a) Soft wood cuttings

IBA 1000	IAA1000	NAA1000

IBA 2000	IAA 2000	NAA 2000

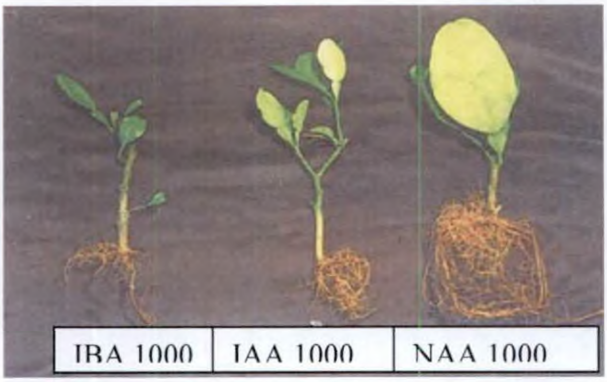
b) Semi hard wood cuttings

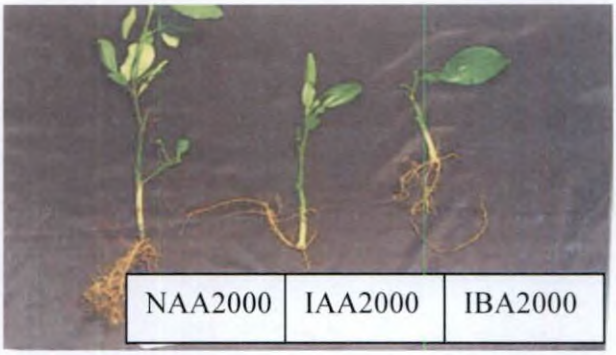
1. NAA 1000 2. IAA 1000 3. IBA 1000

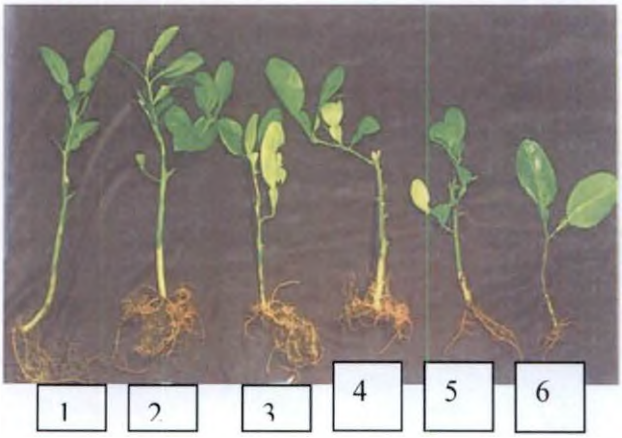


1. IAA 2000 2. IBA 2000 3. NAA 2000

c) Hard wood cuttings







1. **NAA 3000 2.IAA 3000 3.IBA 3000 4.Keradix 5.Rootex 6. Control**

*** Trial month- September**
^ Concentrations in mgl^{-1}

Table 26. Effect of media and months on days to root and number of roots per layer

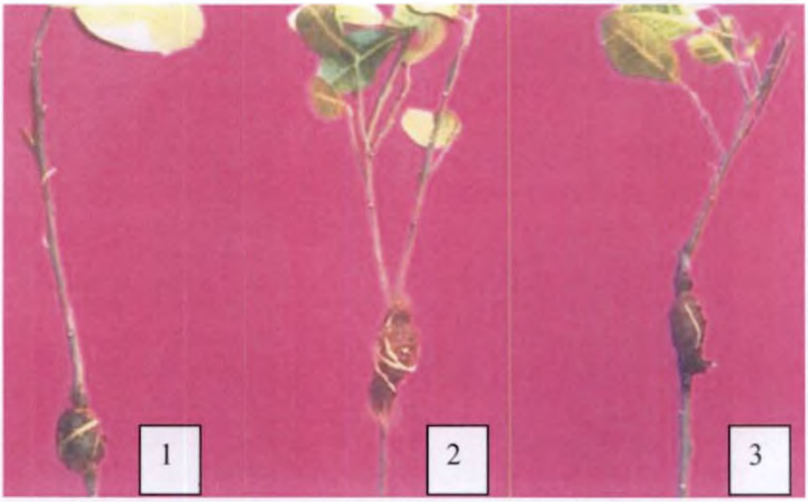
MEDIA	MONTHS									
	MAY		JUNE		JULY		AUGUST		SEPTEMBER	
	Days to root	No. of roots/layer	Days to root	No. of roots/layer	Days to root	No. of roots/layer	Days to root	No. of roots/layer	Days to root	No. of roots/layer
Sphagnum moss	44.33 (6.69)	23.77 (4.92)	51 (7.17)	20 (4.52)	40.7 (6.41)	21.9 (4.72)	23.22 (4.86)	28.33 (5.35)	65 (8.09)	17 (4.18)
Coconut fibre	54.55 (7.41)	21 (4.63)	60.75 (7.82)	14.63 (3.88)	32.11 (5.70)	24.33 (4.97)	30.63 (5.57)	27 (5.20)	53.83 (7.36)	21.33 (4.67)
Saw dust	60.87 (7.834)	16.37 (4.09)	74.14 (8.63)	10.14 (3.25)	46.55 (6.85)	22.11 (4.71)	36.43 (6.07)	19.57 (4.44)	81.2 (9.03)	11.8 (3.50)
CD (0.05)	0.1517	0.2049	0.1740	0.1740	0.2316	NS	0.2394	0.6028	0.2006	0.240

Values in parenthesis are transformed (Square root transformation)

Plate 24. Rooting in pummelo layers

Plate 25. Performance of layering media in different months*

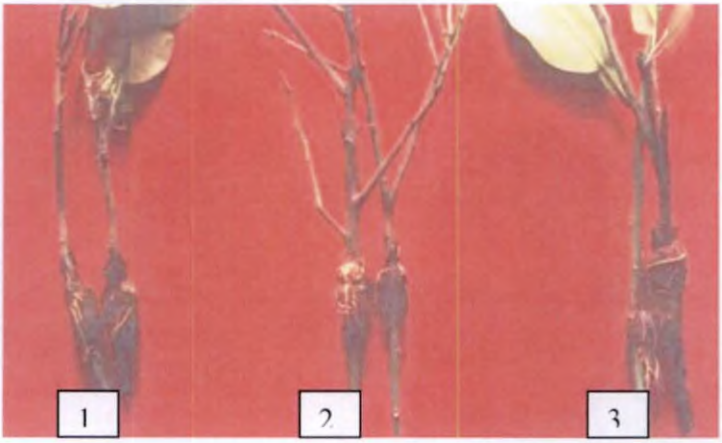
a) May



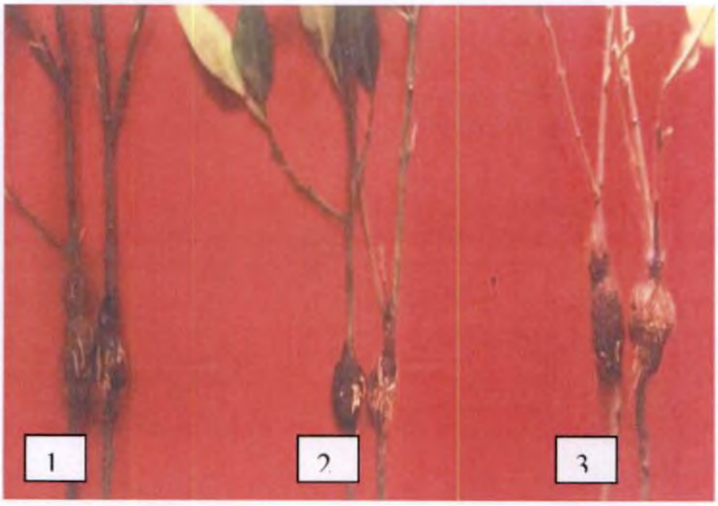
b) June

1.Sphagnum moss 2. Coconut fibre 3.Saw dust

c) July



d) August



1.Sphagnum moss 2. Coconut fibre 3.Saw dust

*** Three months after layering**

August (23.22 days). During July and September, coconut fibre recorded significantly lower days for rooting, 32.11 and 53.83 days respectively. Among the media sawdust took significantly longer days for rooting and lower number of roots for layer, irrespective of the month (Table 26).

4.2.2.3 Number of roots

Number of roots produced by each medium did not vary significantly in the month of July, but significant difference in the number of roots was noticed in other months, where sphagnum moss produced significantly higher number of roots in May (23.77), June (20.00) and August (28.33) (Plate 25). In July and September, it was coconut fibre, which produced significantly higher number of roots, 24.33 and 21.33 respectively (Table 26).

4.2.2.4 Percentage of rooting

Highest percentage of rooting (100.00 %) was obtained in the month of July when sphagnum moss was used as the medium. It was lowest in September (50.00%), recorded both by sphagnum moss and sawdust. Among the media, sawdust gave the lowest percentage for rooting when compared to sphagnum moss and coconut fibre in all the months.

August proved to be the superior month with regard to the days for rooting (23.22 days) and number of roots per layer (28.33), when sphagnum moss was used as the medium. On comparison with other months, coconut fibre and sawdust also showed lower days for rooting, 30.63 days and 36.43 days respectively, in August.

4.2.3 Budding

In spite of the different methods tried, viz., patch budding and modified forkert budding, and different rootstocks viz., pummelo and Rangpur lime, budding resulted in the absence of bud uptake. Budding was tried in different seasons, from May to September, but gave no positive results.

DISCUSSION

5. DISCUSSION

Pummelo, the largest citrus fruit is widespread throughout Southeast Asia and is found growing in home gardens and small plantations. It is frost hardy, grows well in warmer climates with plenty of rainfall. The centre of diversity is thought to be Japan, India, Thailand, Malaysia and the Philippines. Despite the high diversity in India reported by Maiti *et al.* (2001), little research has been carried out on varietal improvement using local land races. As a result the quality and quantity of production of pummelo are very low in farmers' field as they are cultivating inferior trees grown from seeds. Although variability studies were carried out in Nepal, by Paudyal and Haq (1999) and in West Bengal by Maiti *et al.* (2001), no such effort was undertaken in Kerala, where pummelo is the common citrus fruit, found in homesteads. Hence an attempt was made to conduct studies on the pummelo genotypes in Thrissur, Ernakulam and Kottayam districts, as these districts possess more number of local types.

A wide range of variation in morphological characters of tree, fruit, leaf and seed was identified during evaluation through survey and laboratory analysis. The results of present investigation on variability in vegetative, floral, fruiting characters and biochemical parameters of the fruit, and standardization of propagation methods in pummelo (*Citrus grandis*) are discussed in this chapter.

PART-I

5.1 VARIABILITY STUDY

5.1.1 General tree characters

All the genotypes located were seedling progenies except one layer, accessed from Thrissur district. Trees surveyed were having spheroid, ellipsoid and ellipsoid-oblate shapes. In ellipsoid-oblate types, branches are dense compared to other shapes and hence most of them show either spreading or drooping tree habit. Other tree habit observed is upright which is shown only by spheroid and ellipsoid trees. Tree height ranged from 3-6m among the accessions and fruit harvesting becomes difficult in trees above 5m height and there is high chance of breaking the fruit on falling the ground.

It was observed during the survey that trees grown at higher elevations were taller compared to those on low land. It was also noticed that tree raised from layer, eg. AC.29 had low-lying branches with fruits within reach.

The fruiting period started from September, and it lasted up to February with peak season in November- December, coinciding with winter period. In some accessions, sporadic bearing was seen viz., AC.16, 29 and 31.

5.1.2 Leaf characters

Wide variation was noticed in leaf length (5.94 to 15.56 cm), leaf width (2.71 to 8.72 cm), and leaf length/width ratio (1.65 to 2.86).

More than 60.00 per cent of the trees had common characters for leaf shape and leaf margin. Ovate and obovate were the common leaf shapes observed in 85.00 and 12.50 per cent trees, respectively. Crenate leaf margin dominated among 65.00 percent of the accessions. According to Ghosh (2001), leaf margin and petiole (degree of wing development) were two important characters in identification and classification of a citrus species. Most of the pummelo trees surveyed (57.50%) showed deltoid petiole.

Aroma of crushed leaves was suggested as a genetic marker in mango (Majumdar and Sharma, 2001). Jyothi (2000) reported that this character has a bearing on the smell of fruits in mango. In pummelo, both mild and deep aromas were present for crushed leaves and 72.00 percentage recorded deep smell.

5.1.3 Floral characters

In most of the pummelo trees flowering started by March- April. In some trees, flowering was seen in November-December also. AC.16, 29 and 31 exhibited perpetual flowering habit.

Characters included for describing the inflorescence as per NBPGR (2002) descriptor are arrangement of flowers, inflorescence position, number of flowers per inflorescence, size of flower, number and colour of petals, and number of stamens.

Arrangement of flowers was solitary and crowded, mainly axillary in position. The number of flowers per inflorescence ranged from four to 12. Pummelo, as described by Purseglove (1968) produced flowers with cream coloured petals, 20-25 stamens and ovary with 11-16 loculi. In the present study, a higher number of stamen per flower was observed and it ranged from 29.6 to 38.6, but all the flowers had cream coloured petals, four in number and fragrant, as explained by Ghosh (2001). Variation found in the flower size, viz., length and breadth were not so wide, with a range of 1.40 to 3.37 cm and 1.10 to 1.98 cm, respectively.

Pollen characteristics of pummelo such as pollen fertility and pollen diameter were studied during the investigation. Pollen fertility ranged between 78.00 to 90.00 per cent with an average of 83.94 per cent. Pollen diameter showed a range from 32.22 to 37.10 microns, the average being 35.09 microns.

5.1.4 Fruit characters

Fruits take 6-7 months for maturity. Harvesting season started from September and peak season was in November-December. In some trees that showed late flowering, fruits can be seen in April-May.

Pummelo fruits are described by their shape, base shape, apex shape, skin colour, weight, length, width, skin surface, oil glands on skin, mesocarp colour, number of segments, colour of carpels, juice content, juice colour, taste and flavour (NBPGR, 2002). These characters were studied for each accession.

Colour of the fruits did not show much variation. They were either yellow or greenish yellow. Spheroid, pyriform, oblate and oblique shapes were the shapes noticed in various pummelo accessions. Spherical fruits dominated among the accessions, alone recording 52.00 per cent. Fruit shape has a bearing on other physical and chemical characters of pummelo fruit (Atul *et al.*, 1998; and Murthy *et al.*, 1989).

Murthy *et al.* (1989) reported that the oblate fruits had the maximum weight and fruit circumference. In this study also, the accessions AC.4 and AC.39, which recorded the higher fruit weight of 1960.00 g and 1765.00 g, respectively, were having oblate fruits. These two accessions had the higher fruit length and width also.

Fruit apex and base shape were mainly truncate in the collections, recording 57.00 and 60.00 per cent, respectively. Fruit surface was smooth in all accessions except in AC.3 and 23, which showed pitted surface even though the pitted nature had no effect on fruit quality. As observed by Ghosh (2001), oil glands were conspicuous on fruit surface and very conspicuous in 62.50 per cent of the collections. Density of oil glands ranged from 18.00 to 53.00 numbers per square cm.

Statistically significant variation was noticed among the collections in terms of fruit length, width, weight and rind weight recording maximum coefficient of variation for rind weight. Fruit length ranged from 10.20 cm to 21.20 cm and width from 9.80 cm to 24.80 cm. Fruit weight variation was from 193.00 g to 1960.00 g and rind weight varied from 50.00 to 997.00 g. Highest fruit weight was recorded by AC.4 and rind weight by AC.39. When correlation was worked out, fruit length, width, weight and rind weight were found to be positively and significantly correlated with each other.

Fruit segment parameters, viz., number, length, width and weight were also studied. Tissaret *et al.* (1990) observed the average number of segments per fruit could be as high as 17 in pummelos. In the surveyed accessions, the segment number ranged from 9.0 to 16.0, the maximum shown by two accessions from Kottayam viz., AC.12 and AC.13. Significant correlation was noticed between segment number and fruit width, but no correlation was found between segment number and fruit length.

Mean values of segment length, width and weight revealed high variability. Segment length was highest in AC.9 (14.12 cm), whereas width was maximum in AC.36 (5.20). AC.9 recorded the maximum weight for segment (78.00g). Correlation between segment length, width and weight were found to be highly significant and positive. But it is seen that segment weight and number of segments are negatively correlated.

Among the accessions studied, AC.2, 3, 4, 7, 9, 11, 23, 26, 32 and 39 had bigger fruits. All these showed high segment weight also except AC.26.

Juice content of the fruit, a very important quality character, had a great diversity among the 40 accessions. AC.37 recorded the highest juice content of 75.30 per cent, closely followed by AC.38 (73.80%) and AC.10 (72.60%). As juice content is positively correlated with fruit width and weight, wider fruits can be selected for juice purpose. AC. 1, 2, 9, 10, 11, 12, 15, 21, 23, 37 and 38 can be given preference, as they recorded high juice content. Total segment weight/ rind weight ratio is an important criterion, which reveals the percentage of edible portion ranged from 0.43 to 3.53, the highest being in AC.21. Average value for total segment weight/ rind weight ratio was 1.70 with a coefficient of variation of 47.37.

Accessions showed either white or light pink coloured mesocarp with most of the fruits having light pink mesocarp. Majority of the accessions showed pink colour for the carpels followed by red colour and pale yellow colour. Colour variations ranging from pale yellow, cream, pale pink, pink and reddish were noticed for juice. Pink juice colour dominated among the accessions. In pummelo germplasm catalogue by Paudyal and Haq (1999), different juice colours observed were greenish, cream, pink and red.

Sixty per cent of the accessions recorded poor juice taste. Bitterness in juice of pummelo and rough lime was reported by Yusof *et al.* (1993) from the sensory analysis of the juice. Grapefruit and pummelo fruits contain bitter compounds limonin, nomilin and naringin which account for the bitterness of the juice (CSIR, 1992). Most of the fruits showed moderate flavour for juice.

Average yield of the trees was estimated by multiplying the number of fruits per tree with the average fruit weight. AC.9 recorded the highest yield of 255.00 kg. Average yield of the trees was found to be 150.73 kg. Yield per tree was highly significantly and positive correlated with number of fruits, fruit length, fruit width, fruit weight, rind weight, segment length, width and weight. Accessions like AC. 3, 4, 6, 14, 24 and 26 recorded yield above 200.00 kg per tree. According to yield, these accessions can be selected. Among these AC.26, which recorded good quality parameters, may be given preference.

5.1.5 Bio-chemical characters

Bio-chemical characters of fruits studied include TSS, acidity, total sugars, reducing and non-reducing sugars and ascorbic acid. All the characters showed high variation and maximum coefficient of variation was observed for ascorbic acid. Total soluble solids (TSS) of the fruits varied from 5 to 11° brix, acidity from 0.41 to 1.74 per cent, TSS /acidity ratio from 3.86 to 22.22 and total sugars from 3.35 to 6.73 per cent. Paudyal and Haq (1999), while cataloguing the pummelo germplasm in Nepal observed that the pummelo fruits had acidity in the range of 0.65-4.03, and TSS and TSS/acidity ratio varied from 7.0 to12.8 and 2.8 to14.2 respectively.

Reducing and non-reducing components of total sugars ranged from 0.81 to 3.09 per cent and 1.77 to 5.17 per cent, respectively. Ascorbic acid content, the important vitamin for which the citrus fruits are well known, was as low as 16.00 mg to as high as 95.00 mg per 100 g edible portion of pummelo fruit, whereas mandarin orange contains 20-50 mg ascorbic acid and sweet orange, 29-58 mg ascorbic acid per 100 g fruit (Bal, 2002). The high content of ascorbic acid in pummelo (88-158 mg) was reported by Chen *et al.* (1993) and by Shen *et al.* (1999).

TSS of the fruits revealed significant and positive correlation with total sugar and reducing sugar content, whereas total sugars are invariably in negative correlation with acidity. Ascorbic acid showed no significant correlation with any of the bio-chemical characters studied. Similarly no significant relation was observed when correlation between biometric and bio-chemical characters was considered. Among the accessions, AC.12, 22, 26 were good with respect to quality parameters as they shared greater vitamin C content and total sugars.

5.1.6 Sensory evaluation studies

Sensory evaluation of the fruit segments was conducted based on scoring with a ten point scale for the seven characters such as appearance, colour, taste, flavour, sweetness, juiciness and overall acceptability.

More than 70 per cent of the samples scored satisfactory for attributes viz., appearance, taste, flavour, juiciness and overall acceptability with scores ranging from 4.1 to 6.0. For characters such as colour, sweetness and flavour, 50-70 per cent samples recorded satisfactory. The score of 6.1-8.0, suggesting good was observed in less than 30 per cent of the samples, for all the seven characters. None of the samples scored excellent with score 8.1-10, for any of the characters. AC.11 scored the highest mean rank, followed by AC.12, for most of the sensory qualities. AC.11, 12 that topped in sensory evaluation were good in respect of TSS content also.

5.1.7 Seed characters

Seed characters have been included in the varietal description as per the descriptor provided by NBPGR (2002). Both seeded and seedless types were found among the collections. Characters such as number of seeds per fruit, seed length, width, weight, shape, cotyledon colour, embryony, germination percentage and days for rooting were recorded for seeded types.

In the study, there were accessions having very few seeds and this may be due to the presence of self and cross incompatibility as reported by Soost (1964) or due to embryo abortion as reported by Chen *et al.* (2002). According to him, embryo abortion caused seedlessness in pummelo and average seed number varied from 2 to 32. In the present study, the number of seeds per fruit ranged from 3.0-38.6. Seed length varied from 0.65 to 2.19 cm, width from 0.52 to 1.77 cm and weight from 0.29 to 2.03 g. Three seed shapes were noticed, viz., deltoid, globose and irregular.

Cotyledon colour was white in all the seeded accessions, and all the seeds exhibited monoembryony on germination, unlike other citrus species as reported by Ghosh (2001). But Thakur and Bajwa (1971) found that the percentage of polyembryonic seeds in pummelo is two, but such seeds were not noticed among the seeded types in this study.

Germination trials showed that, days for germination of the seeds ranged from 13 to 29 days; the minimum recorded in AC.8, and maximum in AC.20 and AC.32. Germination percentage was in the range of 8.30-100.00, with AC.2 having the maximum percentage of germination.

Seedless types dominated among the accessions, with 62.50 per cent. Seedless fruits maintained good size and weight, in spite of absence of seeds as in AC.3, 7, 11, 26, 29 and 34. The accessions, AC.11 and AC.12, which registered highest scores in sensory evaluation, were also seedless. These accessions can be selected and propagated through vegetative means.

5.1.8 Cluster analysis

Non-hierarchial Euclidean cluster analysis using Mahalanobis D^2statistics was carried out to study the extent of divergence. Mahalanobis D^2 multivariate analysis is a valuable tool for obtaining quantitative estimates of divergence between biological populations and in crop improvement programmes, understanding about the nature and degree of genetic divergence available in the germplasm, plays a pivotal role.

Based on the relative magnitude of D^2 values, 40 accessions were grouped into three clusters. Cluster III contained maximum accessions (23), and maximum divergence was observed between clusters II and I.

As evident from the cluster means of different parameters, cluster II was superior with respect to the quantitative characters. Cluster III was best in qualitative characters. Accessions from same locality fell in different clusters and that from different region fell in same cluster, revealing that geographic diversity might not have a direct relation with genetic diversity.

5.1.9 Factor analysis

Factor analysis was done to work out a selection index using ten parameters, viz., fruit length, width, fruit weight, rind weight, number of segments, segment weight, segment length, segment width, juice content and total sugar content. Based on the component loadings of first principal component derived from principal component analysis, a selection index was worked out taking the mean value of parameters as standard. The selection index value turned out to be 1290 and accessions numbered 2, 3, 4, 7, 9, 11, 14,16, 23, 26, 28, 29, 32, 34, 36 and 39 were found to have a greater selection index value. When selection is to be done as per the above parameters, these accessions can be given preference.

The great range of variability exhibited by pummelo is due to cross-pollination and seed propagation as described by Soost (1964). From the variability study, it was ensured that the wide variations noted in physical and bio chemical characters were due to the fact that all the accessions were seedling progenies except one.

Pummelo fruits are also reported to contain significant amounts of calcium, phosphorous and vitamins A, B_1, B_2 and B_{12} (Morton, 1987; Paudyal and Haq, 1999). Further studies can be pursued to know the content of them in pummelo fruits seen in Kerala. Studies can also be done to explore processing aspects of fruit pulp and peel. Pummelo peel was reported to be a rich source of pectin (50.00 %) and can be utilized for making jelly (Madhav, 2001).

Based on the selection index value, quantitative and qualitative parameters and sensory evaluation, six accessions viz., AC. 2, 9, 11, 12, 14 and 26 can be selected. These accessions can be maintained in the germplasm for further evaluation and multiplication.

PART-II

5.2 PROPAGATION STUDIES

Seed germination may not be preferred in pummelo as there's no self-pollination and polyembryony, and hence seedling may not inherit mother tree characters. More over, for seedless types, vegetative methods are the means for propagation. Hence in this study, attempts were made to standardize asexual propagation methods viz., cuttings, layering and budding. The results are discussed herewith.

5.2.1 Cuttings

Propagation through stem cuttings is commonly practiced in many horticultural crops since it is easy, inexpensive and most convenient. To increase the efficiency in rooting, the use of growth regulators is also now commonly employed, in many species. The present propagation trials with pummelo cuttings, using growth regulator treatments revealed the following:

Highest percentage of rooting was observed in the month of September, followed by August and May. September was the most congenial month for rooting of cuttings, as the summer was severe during May and there were very frequent and severe rains during June- July that lead to the rotting of the cuttings (Appendix.IV). NAA at 1000 mg l^{-1} showed the highest rooting percentage (63.3), followed by NAA at 2000 mg l^{-1} (40.0) and by IBA at 1000 mg l^{-1} (38.3) in September. Semi hard wood cuttings gave higher percentage of rooting in most of the treatments, followed by hard wood cuttings. The superiority of NAA treatment in pummelo was also reported by Le *et al.* (2002). They studied the propagation of pummelo by cuttings in Vietnam and reported that rice husk substrate was better than sand and that NAA at 1000 mg l^{-1} gave the maximum percentage of rooting (84.4).

Soft wood cuttings, in general, showed lesser days for rooting. Minimum time was taken by soft wood cuttings at 1000 mg l^{-1} of NAA (29 days), followed by

2000 mg l^{-1} of NAA (30 days) and 1000 mg l^{-1} of IBA (31 days). Though the developmental pattern of root was the same in juvenile and mature cuttings, the process is slower in mature than juvenile cuttings. Moreover juvenile tissues are less differentiated; so more cells are available for becoming meristematic for root initiation (Hartman *et al.*, 1993). This may be the reason for early rooting in immature cuttings.

Semi hard wood cuttings gave significantly higher number of roots compared to other types. NAA at 1000 mg l^{-1} produced significantly higher number of roots (9.2 at 2 months after planting and 20.9 at 4 months after planting), the next best treatment being NAA at 2000 mg l^{-1}.

Highest percentage of rooting was observed in the month of September, followed by August and May. September and August were proved to be the best months for rooting indicating that very high rainfall and humidity do not favour the establishment. The chances of rotting of cuttings were high when the rainfall was heavy as in the month of June and July, when the success rate was also the least. A similar result was reported by Sareena (1996) in another species of citrus, *Citrus pennivesiculata*, where the cuttings gave highest survival in the months of September and August.

Among the growth regulators, NAA and IBA showed good results. Advantage of NAA and IBA on rooting of citrus cuttings was reported by many workers. In Citrumelo cuttings, best rooting responses were reported with IBA and NAA treatment, both at 3000mg l^{-1} (Ferguson *et al.*, 1985). According to Arora and Yamadagni (1985), NAA at 4000, 3000 and 2000 mg l^{-1}, respectively, proved to be the best for cuttings for Baramasi, Kagzi kalan and Eureka lemon. The reduced root activity of IAA compared to NAA and IBA has been attributed to the fact that plant tissues possess several metabolisms that remove IAA from the growth regulating system (Leopold and Kriedemann, 1975). Even though IBA in general promoted root growth in many citrus species,eg. in lemon and lime cuttings (Sen and Bose, 1962), in Washington Navel orange (Shafrir, 1973), in sweet lime (Bajwa and Khajurla, 1977), in *Citrus junos* (Kim *et al.*, 1992) and in *Citrus pennivesiculata* (Sareena, 1996), it was only second to NAA in the present investigation. Proebsting (1984) reported that a particular species might react differently when treated with equivalent concentration of different auxins.

Attempts to propagate cuttings without growth regulator treatment was successful only in September, showing that propagation through cuttings without GR treatment had the lowest success rate. It can be concluded that NAA 1000 mg l^{-1} is the significantly best concentration of hormone, and September is the best month for raising the pummelo cuttings.

5.2.2 Layering

Among the different citrus species, air layering was found to be successfully employed mainly for lime, lemon, citron, pummelo and sweet lime (Hulamani and Reddy, 1974; Mishra and Agarwal, 1975). In another species of citrus, *Citrus pennivesiculata* good rooting of layers was obtained from March to October, in a trial conducted by Sareena (1996) under Kerala conditions.

Sphagnum moss is a popular medium used for air-layering, the superiority of which is claimed in fruit crops like guava, where, root emergence took 43 days and number of primary roots ranged from 37.80-75.80 (Mishra and Singh, 1995). In pummelo, sphagnum moss produced significantly higher number of roots (Fig.12) in May (23.77), June (20.00) and August (28.33) and had significantly lower days for rooting during the months, May (44.33 days), June (51.00 days) July (40.70 days) and August (23.22 days); (Fig.10). During July and August, coconut fibre recorded significantly lower days of 32.11 and 30.63 days respectively for rooting and significantly higher number of roots, (24.33 and 27.0 respectively).

August proved to be the best month with regard to the days for rooting (23.22 days) and number of roots per layer (28.33), when sphagnum moss was used as the medium whereas July recorded cent per cent rooting with sphagnum moss as the medium (Fig.11). A similar result was observed in litchi (*Litchi chinensis*), where air-

Fig. 10 Effect of layering media and month on days for rooting

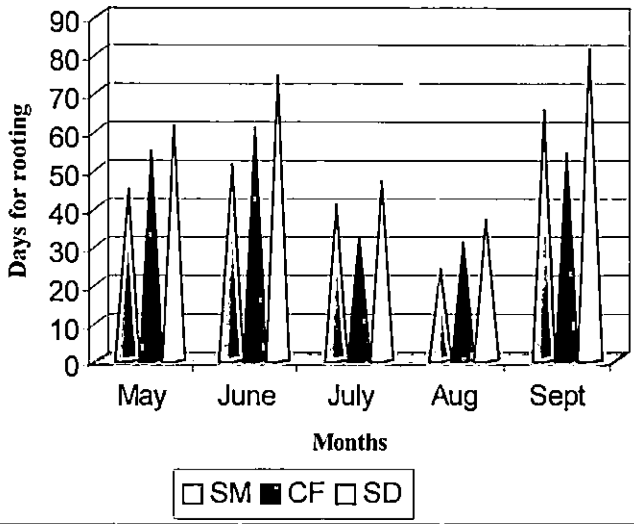
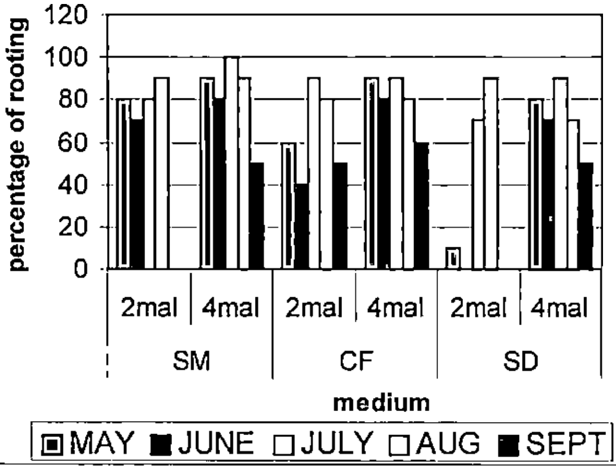
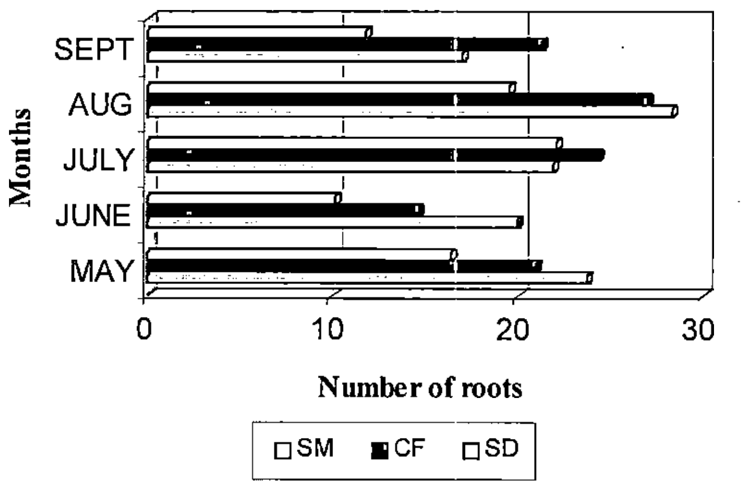


Fig.11 Performance of media and month on percentage of rooting



SM- Sphagnum moss
CF- Coconut fibre
SD- Saw dust
mal- months after layering

Fig. 12 Effect of media and month on number of roots per layer*



SM- Sphagnum moss
CF- Coconut fibre
SD- Saw dust

*** Four month after layering**

layering trials with sphagnum moss have shown that percentage of rooting and survival was highest in the month of July (Sharma and Grewal, 1989). In air layers of pomegranate, according to Hore and Sen (1994), the greatest rooting success was observed during July and May (98.30 % and 85.10 % respectively).

In the present study, the three media tried showed differential responses during the same month and during different months. The best medium for layering was sphagnum moss and the best season was August, followed by July. It was observed that Monsoon showers had a positive impact on rooting characters. Success of layering was least in the month of September, which recorded a very low rainfall and humidity. Coconut fibre can be preferred to sphagnum moss as it is locally available and less costly. Saw dust may be preferred next to sphagnum moss and coconut fibre, as it recorded the lowest percentage for rooting.

5.2.3 Budding

Patch budding and modified forkert budding, tried on pummelo and Rangpur lime rootstocks, were not successful. The different seasons also did not show any positive results.

Heavy monsoon showers during the budding period (May to September) and subsequent rotting, the fungal infections etc. may be the possible reasons for bud failure. Some workers reported similar results in other citrus species. Bruno (1962) observed that rainy season budding (May-September) led to poor bud break with high mortality due to *Fusarium* and *Phytophthora* infections, in mosambi orange (*Citrus sinensis*). In another study, Sareena (1996) reported bud failure in baduvapuli (*Citrus pennivesiculata*), in spite of different pre treatments to the buds and different seasons.

In the present studies on propagation, layering was found to be superior to other methods, with all the three media producing satisfactory rooting in all the five months tried. Propagation using cuttings can be preferred only in the month of August and September. Budding is not suggested for pummelo, due to poor budtake in spite of different seasons.

SUMMARY

6. SUMMARY

The experiment entitled "Variability and propagation studies in pummelo (*Citrus grandis* (L.). Osbeck.)" was taken up in the Department of Pomology and Floriculture, College of Horticulture, Vellanikkara during 2003-2005. The objectives of the studies were to estimate the variability in relation to phenotypic characters in pummelo, to study the physico-chemical properties of fruits and to standardize vegetative propagation techniques. Pummelo genotypes in Thrissur, Ernakulam and Kottayam districts of Kerala were surveyed for the study. The salient findings of this study are summarized below.

Forty accessions of pummelo were collected from three districts, 14 each from Kottayam and Ernakulam and 12 from Thrissur. All the accessions located were found to have originated as seedling progenies, except AC.29, which was a layer. Trees surveyed had spheroid, ellipsoid and ellipsoid-oblate shapes. Tree height varied from 3 to 6m among the accessions. Trees from layer had low lying branches. Upright tree habit was observed in spheroid and ellipsoid trees. Ellipsoid-oblate types showed both spreading or drooping tree habit and dense branches.

Fruiting period started from September, and extended up to February, with the peak season in November- December. Some accessions, AC.16, 29 and 31, showed sporadic bearing.

Ovate leaf shape, crenate leaf margin and cordiform petiole dominated among the accessions. Aroma of crushed leaves ranged from mild to deep. Wide variation was noticed in leaf size characters, viz., leaf length, leaf width and leaf length/width ratio, the mean values being 11.49 cm, 5.50 cm and 2.17 respectively. Highest variation was noted for leaf length.

In most of the accessions, flowering started by March- April. Some trees flowered in November-December also. AC.16, 29 and 31, exhibited perpetual flowering habit.

Both solitary and crowded arrangement of flowers was observed in pummelo, mainly borne axillary. Number of flowers per inflorescence ranged from four to 12. There was no variation in petal colour and number. Flower length and breadth ranged from 1.40 to 3.37 cm and 1.10 to 1.98 cm, respectively. Average number of stamen was 33.94. Pollen fertility ranged between 78.00 per cent and 90.00 per cent whereas pollen diameter ranged from 32.22 microns to 37.10 microns.

Wide variation was observed in the morphological and biometric characters of the fruits. Spheroid, pyriform, oblate and oblique shapes were prominant with 52.00 per cent of the accessions recording spherical shape. Fruits were either yellow or greenish yellow, in colour.

Fruit length and width showed wide variation from 10.20 to 21.20 cm and 9.80 to 24.80 cm, respectively. Fruit weight variation was from 193.00 g to 1960.00 g and highest fruit weight was recorded by AC.4. Maximum coefficient of variation was for rind weight, which ranged from 50.00 to 997.00 g highest being shown by AC.39. Significant and positive correlation was observed between fruit length, width, weight and rind weight. Number of fruits per tree ranged from 50 to 200 with AC.14 and AC.17 recording the highest number of fruits.

Number of segments ranged from 9.0 to 16.0, the highest being shown by AC.12 and 13. Segment number was positively and significantly correlated with fruit width, whereas no correlation was found with fruit length. Segment weight and number of segments were negatively correlated. Segment length was highest in AC.9 (14.12 cm), whereas width was maximum in AC.36 (5.20 cm) AC.9 showed maximum segment weight of 78.00 g. Correlation between segment length, width and weight are found to be highly significant and positive. AC. 2, 3, 4, 7, 9, 11, 23, 26, 32 and 39 had fruits with good size and weight.

AC.37 recorded the highest juice content of 75.30 per cent, closely followed by AC.38 (73.80%) and AC.10 (72.60%). Juice content was positively correlated with fruit width and weight. Total segment weight/ rind weight, showing the maximum percentage of edible portion, was highest in AC.21 and among the accessions it varied from 0.43 to 3.53.

Accessions showed either white or light pink coloured mesocarp with most of the fruits having light pink mesocarp. Carpel colour ranged from pale yellow to red. Wide variations were observed for fruit juice colour ranging from pale yellow, cream, pale pink, pink and reddish. Pink juice colour dominated among the accessions. Most of the fruits accessions recorded poor juice taste and moderate flavour for juice.

Yield per tree showed a range of 48.25 to 255.00 kg, with the average yield being 150.73 kg. AC. 3, 4, 6, 14, 24 and 26 recorded high yields. Yield per tree showed highly significant and positive correlation with number of fruits, fruit length, fruit width and fruit weight, segment length, width and weight.

Wide variations were noticed for TSS of the fruits (5-11^0 brix), acidity (0.41-1.74 %), total sugars (3.35- 6.73 %), reducing sugars (0.81- 3.09 %) and non-reducing sugars (1.77-5.17 %). TSS/acidity ratio ranged from 3.86 to 22.22. Maximum coefficient of variation was noted for ascorbic acid content, which varied from 16.00 to 95.00 mg per 100 g fruit.

No significant relation was observed between biometric and bio-chemical characters of fruits. There was significant and positive correlation of TSS of the fruits with total sugar and reducing sugar content. Ascorbic acid was found to have no relation with any of the bio-chemical characters studied.

Organoleptic evaluation of the fruits was done on the basis of appearance, colour, taste, flavour, sweetness, juiciness and overall acceptability. More than 50.00 per cent of the samples scored satisfactory for all the attributes. Less than 30.00 per cent of the samples only gained the score of 'good'. Sensory qualities of fruits of AC.11 and AC.12 were found to be the best.

Both seeded and seedless types were found among the collections. For seeded types, characters such as the number of seeds per fruit, seed length, width and weight showed variations from 3.0 to 38.6, 0.65 to 2.19 cm, 0.52 to 1.77 cm and 0.29 to 2.03 g, respectively. Shapes of the seeds were deltoid, globose and irregular. All the cotyledons were white and seeds exhibited no polyembryony. Days for germination of the seeds ranged from 13 to 29 and germination percentage from 8.30 to 100.00.

Forty accessions were grouped into three clusters, based on the basis of relative magnitude of D^2 values. Maximum divergence was observed between clusters II and I, while cluster III contained maximum accessions. Cluster II was superior with respect to the quantitative characters and cluster III in qualitative characters. The clustering pattern indicated weak association between geographical distribution of genotypes and genetic divergence.

Selection index was worked out based on the component loadings of first principal component derived from principal component analysis using ten fruit parameters viz., fruit length, width, fruit weight, rind weight, number of segments, segment weight, segment length, segment width, juice content and total sugar content, a selection index was worked out taking the mean value as standard. Sixteen accessions viz., AC.2, 3, 4, 7, 9, 11, 14, 16, 23, 26, 28, 29, 32, 34, 36 and 39 were found to have a greater selection index value than the standard (1290). AC. 2, 9, 11, 12, 14 and 26 excelled in quantitative and qualitative parameters, sensory evaluation and also had high selection index.

In propagation trials with cuttings, highest percent age of rooting was observed in the month of September in all types of cuttings. NAA at 1000 mg l^{-1} showed the highest rooting percentage (63.3) followed by NAA at 2000 mg l^{-1} (40.0) and by IBA at 1000 mg l^{-1} (38.3). Soft wood cuttings showed lesser days for rooting, least in 1000 mg l^{-1} of NAA (29 days), followed by that at 2000 mg l^{-1} of NAA (30 days) in September. Semi hard wood cuttings gave significantly higher number of roots with NAA at 1000 mg l^{-1} followed by NAA at 2000 mg l^{-1}. The treatments, IBA at 2000 mg l^{-1}, IBA at 3000 mg l^{-1}, IAA at 2000 mg l^{-1} and NAA at 3000 mg l^{-1} produced roots only in the months of May, August and September whereas Keradix, Rootex and control yielded roots only in the month of August and September.

The best medium for layering in pummelo was sphagnum moss as it yielded more number of roots per layer with lesser days for rooting, the second best being the coconut fibre. Saw dust was inferior to sphagnum moss and coconut fibre. Best season was turned out to be August, with lesser days for rooting and more number of roots per layer, followed by July, which showed the highest percentage of rooting.

Patch budding and modified forkert budding, done on pummelo and Rangpur lime rootstocks, were not successful in spite of the different seasons.

On comparison, layering was found to be superior to the other two methods of propagation. Cuttings can be recommended only in the month of August and September. Budding did not yield any positive results.

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* Originals not seen

APPENDICES

APPENDIX I

DESCRIPTIVE BLANK FOR PUMMELO (*Citrus grandis*)

Accession number

Acquisition date

Name of the farmer-

Address-

!.Plant descriptors

1) Type of planting material	: Seedling / Cutting / Layer / Graft/ Budding /Others
2) Tree age	:
3) Tree height (m)	:
4) Tree habit	: Upright/ Spreading /Compact / Drooping
5) Tree shape	: Ellipsoid / Spheroid / Ellipsoid-oblate/ Others
6) Branching density	:Sparse/ Medium / Dense
7) No. of branches	:

3.Leaf descriptors

1) Leaf/ leaflet shape	: Elliptic /Ovate / Obovate / Lanceolate /Orbicular/ Others
2) Petiole wing shape	:Cordiform/ Deltoid /Obovate /Others
3) Leaf length (cm)	:

4) Leaf width (cm) :

5) Leaf margin :Crenate/ Dentate/ Entire/ Wavy/ Others.

6) Aroma of crushed leaves : Deep/ Mild

4.Flowering descriptors

1) Flowering season :

2) Arrangement of flower : Solitary/ Crowded

3) Inflorescence position : Axillary/ Terminal/ Both

4) No. of flower buds/ inflorescence :

5) Size of flower :

6) Petal colour : White/ Yellow/ Purple/Others

7) No. of petals/ flower :

8)No. of stamens/flower :

9) Pollen fertility :

10) Date of start and end of flowering :

5.Fruit descriptors

1) Bearing season :

2) No. of fruits / tree :

3) Fruit shape : Spheroid /Ellipsoid/Pyriform/ Oblique /Oblate/ Ovoid-oblique/Ovoid /Others

4) Fruit base shape : Necked /Convex / Truncate / Concave /Concave collared / Collared with neck /Others

5) Fruit apex shape	: Mammiform /Angular/ Convex /Truncate Depressed/ Others
6) Fruit skin colour	:Yellow / Green / Orange / Others.
7) Fruit weight(g)	:
8) Fruit length(cm)	:
9) Fruit width(cm)	:
10) Fruit skin surface	:Smooth / Rugose / Papillate /Pitted / Bumpy /Longitudinally grooved and ridged / Hairy
11) Presence of oil glands	:Inconspicuous / Conspicuous / Very conspicuous
12) Density oil glands (No. of glands/square cm)	:
13) Mesocarp colour	: White / Yellow / others
14) No. of segments per fruit	:
15) Colour of carpels/juice vesicles	:Yellow / Green /Orange / Pink / Red /Others
16) Juice content (vol/ 100gm)	:
17) Juice colour	:White / Pale yellow / Yellow / Greenish/ Orange / Reddish /Others
18) Juice taste	: Very poor / Poor / Fair / Good / Excellent
19) Juice aroma/ flavour	: Mild / Moderate / Strong
20) Total soluble solids (%)	:
21) Fruit acidity (%)	:

22) Sugar content :

23) Vitamin C content :

6.Seed descriptors

1) No. of seeds /fruit :

2) Seed length (cm) :

3) Seed width (cm) :

4) Seed weight (g)

5) Seed shape : Fusiform /Clavate / Cuneiform / Ovoid /Deltoid / Globose / Semi-spheroid / Others

6) Color of cotyledons : Cream / Yellow / Green / Brown / Others

7) No. of embryos :

8) Nature of embryony :

APPENDIX II

SENSORY EVALUATION SCORE CARD

Sample: Date:

WELCOME!

You are before a pleasing task! Your task is simple; you need to evaluate the sensory quality attributes of the coded samples served before you. Kindly assign your preferred scores as given below for each quality attributes of the samples in the respective columns. Please rinse your mouth after each sample you taste.

	Quality attributes					
Code no.	Appearance	Colour	Taste	Flavour	Sweetness	Juiciness

Scores	Word description
0.0-2.0	Very poor
2.1-4.0	Poor
4.1-6.0	Satisfactory
6.1-8.0	Good
8.1-10.0	Excellent

Signature

Name

Designation

APPENDIX III

List of places of pummelo accessions

AC.	Place	District
1	Chempu	Kottayam
2	Chempu	Kottayam
3	Vaikom	Kottayam
4	Kudavechoor	Kottayam
5	Kumarakom	Kottayam
6	Kumarakom	Kottayam
7	Kadappattur	Kottayam
8	Pala	Kottayam
9	Kuravilangadu	Kottayam
10	Kadathuruthy	Kottayam
11	Kottayam	Kottayam
12	Kottayam	Kottayam
13	Appanchira	Kottayam
14	Erattupetta	Kottayam
15	Aluva	Ernakulam
16	Desom	Ernakulam
17	Muppathadam	Ernakulam
18	Manjummal	Ernakulam
19	Varappuzha	Ernakulam
20	Thammanam	Ernakulam
21	Choondi	Ernakulam
22	Thottumugham	Ernakulam
23	Edathala	Ernakulam
24	North Paravur	Ernakulam
25	Neryamangalam	Ernakulam
26	Kothamangalam	Ernakulam
27	Kadungallur	Ernakulam
28	Perumbavur	Ernakulam

29	Vellanikkara	Thrissur
30	Arimbur	Thrissur
31	Paravattani	Thrissur
32	Mannuthy	Thrissur
33	Oorakam	Thrissur
34	Chelakkottukara	Thrissur
35	Varakkara	Thrissur
36	Mannampetta	Thrissur
37	Amballur	Thrissur
38	Peechi	Thrissur
39	Vilangannur	Thrissur
40	Kodungallur	Thrissur

<u>**APPENDIX IV**</u>

Weather data during the period of study (May 2004- June 2005)

	Temperature (^{0}C)		Relative humidity (%)	Total rainfall (mm)	Total sunshine hours	Rainy days
	Maximum	Minimum				
May-04	34.4	22.0	84	578.3	104.3	21
Jun-04	31.3	21.6	85	786.0	98.9	24
Jul-04	31.8	21.6	85	369.6	66.4	24
Aug-04	31.3	21.5	83	386.9	137.1	14
Sep-04	32.8	22.6	80	208.8	154	10
Oct-04	33.8	20.8	73	493.2	185.3	11
Nov-04	32.8	21.4	65	71.7	211.9	3
Dec-04	33.6	18.6	55	0.0	279.9	0
Jan-05	35.0	19.8	56	7.6	264	1
Feb-05	37.6	17.4	53	00.0	280.7	0
Mar-05	38.2	22.0	42	00.0	193.2	0
Apr-05	36.7	22.8	74	171.4	208.2	10
May-05	35.5	21.5	72	89.2	217.5	5
Jun-05	33.2	21.8	86	711.4	94.3	23

VARIABILITY AND PROPAGATION STUDIES IN PUMMELO (*Citrus grandis* (L.) Osbeck.)

By

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ABSTRACT OF THE THESIS

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ABSTRACT

The present study entitled "Variability and propagation studies in pummelo (*Citrus grandis* (L.). Osbeck.)" was conducted at the Department of Pomology and Floriculture, College of Horticulture, Vellanikkara during 2003-2005. The objectives of the study were to explore the variability in vegetative, flowering, fruiting characters of pummelo through a comprehensive survey in Thrissur, Ernakulam and Kottayam districts of Kerala and to standardize vegetative propagation techniques in pummelo.

Variations were noticed in tree habit (upright, spreading and drooping), tree shape (ellipsoid, spheroid and ellipsoid-oblate), branch density (sparse, medium and high), among the 40 accessions surveyed. Leaf shape, length, width, length/width ratio, petiole wing shape, margin and aroma of crushed leaves showed variations.

Flowering season started by March-April. Late flowering types (November- December) were also observed. AC. 16, 29 and 31 exhibited perpetual flowering habit. Flowers were both solitary and crowded. Variations were observed in number of flowers per inflorescence (four-12), flower length (1.40-3.37 cm), breadth (1.10-1.98 cm), pollen fertility (78.00-90.00 %) and pollen diameter (32.22-37.10 microns).

The fruiting period was from September - February, with the peak in November- December. Variations were noticed in fruit shape (spheroid, pyriform, oblate and oblique), colour (yellow and greenish yellow), base shape (concave-collared, concave, truncate and convex), apex shape (depressed, truncate and convex) fruit skin surface (smooth and pitted), presence of oil glands (conspicuous and very conspicuous), mesocarp colour (white and light pink), carpel colour (pale yellow to red), juice colour (pale yellow to reddish), juice taste (poor and very poor) and juice flavour (moderate and strong).

Biometric characters viz., fruit length (10.20 - 21.20 cm), width (9.80 - 24.80 cm), fruit weight (193.00 -1960.00 g), rind weight (50.00 - 997.00 g), number of segments (9.0 - 16.0), segment length (5.02 - 14.12 cm), segment width (2.54 - 5.20 cm), segment weight (12.00 - 78.00 g), juice content (18.10 - 75.30%), total segment weight- rind ratio (0.43 - 3.53) and yield of fruits per tree (48.25 - 255.00 kg) were varied widely. Significant correlation was observed between yield, fruit length, width, weight, rind weight, segment length, width and weight.

Significant variations were noticed for bio chemical characters like TSS (5-11^0 brix), acidity (0.41-1.74 %), TSS/acidity ratio (3.86 to 22.22), total sugars (3.35- 6.73 %), reducing sugars (0.81- 3.09 %), non-reducing sugars (1.77 - 5.17 %) and ascorbic acid (16.00 - 95.00 mg per 100 g fruit). TSS was significantly correlated with total sugar and reducing sugar content.

Sensory attributes viz., appearance, colour, taste, flavour, sweetness, juiciness and overall acceptability of fruits, showed wide variations. AC.11 and AC.12 excelled in sensory qualities.

Seeded and seedless types were noticed among the collections. Seed characters varied with respect to the shape, number of seeds per fruit, length, width, weight, days for germination and germination percentage. Seeds had white cotyledons and exhibited monoembryony.

Cluster analysis yielded three clusters and showed the existence of genetic divergence in pummelo. Principal component analysis was done using ten fruit parameters and a selection index was worked out. Sixteen accessions had selection index value greater than the standard. AC.2, 9, 11, 12, 14 and 26 can be selected for further evaluation and multiplication.

Propagation methods viz., cutting, layering and budding were investigated in pummelo. Highest rooting percentage was obtained in cuttings treated with NAA at 1000 mg l^{-1} followed by NAA at 2000 mg l^{-1} and IBA at 1000 mg l^{-1} in the month of September. Soft wood cuttings showed lesser days for rooting and semi hard wood cuttings gave significantly higher number of roots, treated with NAA at 1000 mg l^{-1} treatment followed by NAA at 2000 mg l^{-1}.

The best medium for layering was sphagnum moss with more number of roots per layer and with lesser days for rooting. Second best medium was coconut fibre and saw dust was inferior to sphagnum moss and coconut fibre. August was the best month with lesser days for rooting and more number of roots per layer, followed by July, which showed the highest percentage of rooting.

Patch budding and modified forkert budding, tried on pummelo and Rangpur lime rootstocks, resulted in no bud take despite the different seasons.