PROCESS OPTIMISATION FOR PRODUCTION OF VALUE ADDED PRODUCTS FROM PUMMELO (*Citrus grandis* (L.) OSBECK)

By

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THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"Process optimisation for production of value added products from Pummelo (*Citrus grandis* (L.) Osbeck)"** is a bonafide record of research work done by me during the course of research and that it has not been previously formed the basis for the award to me of any degree, diploma, fellowship or other similar title, of any other University or Society.

Vellanikkara

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CERTIFICATE

Certified that this thesis entitled **"Process optimisation for production of value added products from Pummelo (*Citrus grandis* (L.) Osbeck)"** is a bonafide record of research work done independently by **Mrs. Suja G. Nair** under my guidance and supervision and that it has not formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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To My Dear Husband
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Introduction

1. INTRODUCTION

Pummelo (*Citrus grandis* (L.) Osbeck) is a tropical fruit tree, which possesses biggest fruits among the citrus species in the world. Its cultivation is widespread throughout South East Asia and can be found growing in home gardens and small plantations. The juicy fruits are eaten raw or used for juice extraction. A single tree can produce 70 to100 fruits per year (Plate 1.). The flesh of the fruit is segmented and constitutes 23 to 24 per cent of the fruit. The segments are filled with juicy sacs and the juice content varies between 30 and 75 ml / 100 g of the fruit. At the same time, the percentage of juice yield from other citrus fruits is hardly 35 to 40 per cent.

Besides high juice yield, pummelo has many nutritional and medicinal properties. The fruit contains vitamin C in high quantities (16 to 102 mg / 100 g of fruit). The other vitamins present are vitamin B_1, B_2 and B_{12}. The flowers, fruits and seeds are used for medicinal purposes (Paudyal and Haq, 1999). The outer fruit skin, which is soft and thick, is an excellent source of pectin and provides longer shelf life to the fruits. There exists a great variability among the trees with respect to fruit size, flesh colour, juice yield, aroma and taste. Hence pummelo can serve as a comparatively cheap source of raw material for production of citrus based products.

No work has been done so far to identify pummelo types having ideal processing attributes. The methods for juice extraction from the fruits and processes for production of value added products have not been standardised. Another major hurdle in citrus processing is development of bitter taste in the juices. This bitterness develops upon storage and heat processing of the products.

There exists a great potential for this under exploited fruit to be included in the list of citrus fruits that are being used by the processing industries, if proper technologies for its utilization could be evolved. This will provide a moral support for the producers through better demand for their produce. It will be very much advantageous for the processors if a cheaper and simple technology for processing and product preparation is available. The consumers will also be benefited in a big way of having a natural cheap source of nutrient rich products.

Plate 1. Pummelo tree bearing fruits

In this context, the present study was undertaken with the following objectives of

Standardising of harvesting index for pummelo,

Identifying the pummelo types having desirable processing attributes,

Evolving suitable methods for extraction of quality juice,

Standardising proper debittering technology for pummelo juice and

Production of juice based value added products

Review of Literature

2. REVIEW OF LITERATURE

Pummelo (*Citrus grandis* (L.) Osbeck) is a member of the family Rutaceae and is a spreading spiny tree (0.5 to 15 m high) which produces very large, round or pear shaped fruit (up to 30 cm in diameter and 1 to 2 kg in weight) with very sweet yellow or pink pulp. Pummelo or Shaddock is regarded as an ancestral species of the genus Citrus that belongs to the family Rutaceae, sub-family Aurantioidiae, 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). Chakotra and Gagar are two cultivars of *Citrus grandis* grown in India (Singh and Chadha, 1993). Pummelo fruits are large, sub globose to pyriform in shape with thick and spongy rind. Pulp is mildly sweet and moderately juicy. The rind is thick, smooth and has large oil glands on them (Ghosh, 2001).

Rabab Tenga (*Citrus grandis* Linn.) commonly known as pummelo is one of the important minor fruits in Assam. The fruit is mostly found in North Eastern States (Bharali and Saikia, 2004).

2.1 Uses of the fruit

The fruit is squeezed for its juice. The juice contains vitamin A, B, and C. The peel is used for oil extraction (Singh, 1995).

In Asia, the fruit is mainly grown in homestead gardens. The juicy arils of pummelo is either eaten raw or used for juice extraction. The fruit contains proteins, vitamin C, B_1, B_2, and B_{12}. The flowers, fruits and seeds are used for medicinal purposes. Flowers are also used for perfume extraction and the skin is used for extraction of pectins (Paudyal and Haq, 1999). Pummelo fruits are rich in vitamin C and also contain significant amounts of proteins, carbohydrates, calcium, phosphorus and vitamins like A, B_1, B_2 and B_{12}. The pulp is used for fresh fruit and juice extraction (ICUC, 2003).

2.2 Harvesting indices of citrus fruits

Cell division (the first stage), cell enlargement (the second stage) and the fruit maturation (the third stage) are the major fruit development stages of which, maturation is the last and the most important stage of fruit development, often involving high metabolic activity and cellular changes (Looney, 1970). The knowledge of these changes may be of immense use in standardising the maturity index, enhancing their shelf life and meeting state law for regulating fruit quality in the market (Ram *et al.*, 2004).

2.2.1 Changes in physical characters of citrus fruits associated with maturity

In pummelo, the physical parameters like fruit length, fruit width, fruit weight, rind weight, juice content, etc. increased as maturity advanced (Bollard, 1970; Bharali and Saikia, 2004).

Ting and Attaway (1971) reported that as maturity advance the juice content increases. The colour of rind changes from green to yellow during maturation of the fruit (Miller *et al.*, 1981). An experiment with local pummelo fruits showed that fruit weight, fruit volume, seed weight, volume of juice, increased from 60 to 200 DAFS and reported that DAFS can be used as a reliable index for determining the optimum time of harvest (Sharma, 2000).

The colour of juice vesicles and juice changed from greenish yellow to white as the fruit matures (Bharali and Saikia, 2004).

2.2.2 Changes in biochemical attributes of citrus fruits associated with maturity

In pummelo, as the fruit increases in size the acidity decreases (Chittraichelvan and Shanmugavelu, 1972; Joolka and Awasthi, 1980). Ascorbic acid content increased during maturity in kinnow fruits (Jawanda *et al.*, 1973; Josan *et al.*, 1988).

The levels of bitterness and acidity is the highest in early season fruit and decline as the season progresses in grape fruit (Attaway, 1977), Kinnow (Sandhu *et al.*, 1990) and Satsuma Mandarin (Ishikawa *et al.*, 1993).

The time of harvest is an important factor influencing the limonin content of the juice. The relative limonin content of juice in early season is higher than that of late season (Maier *et al.*, 1977).

Increase in total sugar content during fruit maturation has also been reported by Vij (1982) and Josan *et al.* (1988).

In pummelo, during maturity the pH increases which may be due to decrease in acidity and increase in total sugar content (Baruah and Mohan, 1985).

Increase in TSS to acid ratio was also reported in Mencola Mandarin by Cohen (1988) and by Singh *et al.* (1998) in Kinnow Mandarin.

The various biochemical changes taking place during fruit maturation has been studied in Nagpur Mandarin by Ladaniya and Singh (1998) and in kagzi lime by Selvaraj and Raja (2000).

Mature Satsuma Mandarin fruit contains relatively low concentration of bitter limonoid aglycene (Ozaki *et al.*, 2000).

Aggarwal and Sandhu (2003) reported that the total sugars, TSS, acidity, ascorbic acid, pectin, fat and limonin decreased as the harvesting time is delayed in kinnow mandarin.

The optimum time of harvest of pummelo is August to September (180 DAFS) when total soluble solids (TSS) and acidity reaches 9.0 and 0.77 percentage respectively. TSS, TSS / acidity ratio, and titrable acidity are used as reliable indices for determining the optimum time of harvest (Bharali and Saikia, 2004). They also reported that the TSS, total sugars, and ascorbic acid content increases as the maturity advances in pummelo.

A study conducted by Ram *et al.* (2004) revealed that TSS, brix acid ratio, sugars and ascorbic acid content of kinnow Mandarin fruit juice increased while acidity decreased with advancement of fruit maturation. They also reported that the naringin content did not show definite pattern of changes till fruits matured.

2.3 Variability in processing attributes of pummelo

Pummelo fruits are very large, globose or pear shaped having a diameter of 10 to 30 cm. Pulp vesicles are large pale yellow to pink in colour with sweetish juice (Purseglove, 1968).

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 fruits had the most juice content per 100 g of pulp (58.6 ml) and the ovoid recorded the highest TSS content (10.84° brix). The spherical scored highest in the organoleptic test. The average number of segments in a fruit may go up to 17 in some pummelos (Tissaret *et al.*, 1990).

Pummelo fruits are large, turbonate, light yellow to orange coloured. Rind is very thick, white, spongy, smooth having oil glands. Segments are large up to 11 to 14 in number covered with thick leathery septa. The juice vesicles are long, tapering, light pink, rose, white or light yellow in colour. Fruits are composed of 23 to 24 per cent peel, 175 ml juice and 3 to 4 per cent seed. Pummelo fruits contain TSS of 11.2 to 13.2° brix, citric acid 2.31 to 2.70 per cent, total sugars 8.0 to 9.5 per cent, sucrose 5.0 per cent, vitamin C 20 mg / 100 g fruit (CSIR, 1992).

Chen *et al.* (1993) reported that among the pummelo cultivars and selections available in China, Dongguoqiyan shatianyou and Gulaoqian shatianyou have the highest ascorbic acid content (88.6 to100 mg / 100 ml juice).

Susanto *et al.* (1993) reported that the weight of the seedless pummelo fruits was similar to that of the seeded ones. The shape of the seedless fruits was more pyriform and necked. TSS and acid content was lower in seedless fruits than the seeded ones.

The fruit contains about 10 percentage total sugar, 2.8 percentage citric acid, 20 mg / 100 g ascorbic acid, 38 mg / 100 g calcium, 52 mg / 100 g phosphorus and 0.6 g / 100 g fibre at optimum maturity (Mankad, 1994).

White fleshed and red or pink fleshed types are available in Pummelo (Singh, 1995; Ghosh, 2001).

Pear shaped pummelo fruits have maximum weight (1550 g), rind thickness (26.3 cm), juice content (52.32 %) and TSS (8.2° brix) while oval shaped fruits recorded maximum weight of 1175 g and rind thickness of 19.50 cm (Atul *et al.*, 1998).

According to Shen *et al.* (1999) when 102 pummelo cultivars and selections were compared in China, Shatianyou 2 cultivar recorded the thinnest rind (1.14 cm), 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 that in pummelo fruits, acidity varied from 0.65 to 4.03 per cent, TSS from 7.0 to 12.8° brix and TSS / acidity ratio from 2.8 to 14.2.

Fruits are described of 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).

Wattanavicheanand and Aroonyadet (2003) reported that oil gland size on fruit surface showed a positive correlation with sugar acid ratio.

Anupama (2006) collected 40 accessions of pummelo from three districts of Kerala (Kottayam, Ernakulam and Thrissur). She reported that the fruit weight showed wide variation among the collections. The fruit weight varied from 193 to 1960 g. Rind weight showed values from 50 to 997 g. The juice content varied from 23.00 per cent to

75.30 per cent, TSS from 5 to 11° brix, acidity from 0.41 to 1.74 per cent, total sugars from 3.35 to 6.73 per cent and vitamin C from 16.00 to 95.00 mg / 100 g fruit.

2.4 Peeling techniques

Lye peeling of segments reduced the bitterness in juice of kinnow which is due to the removal of white papery segment walls that contain high amount of bitter compounds and are incorporated to juice during juice extraction (Sandhu *et al.*, 1990; Sandhu and Singh, 2001).

Lye peeling was tried by Premi *et al.* (1995) to make peeling easy and to reduce bitterness in kinnow fruits. They reported an appreciable reduction in limonin content of kinnow juice when the juice was extracted after lye peeling using lye at varying strengths of 1.25 to 1.75 per cent at 82 to 83°C for a contact time of 40 seconds.

The segments of kinnow fruits when subjected to peeling using one per cent lye solution at 95 $\pm$ 2° C for a contact time of one minute was found to give a good peeling with no breakage of segments and loss of colour of flesh (Sogi and Singh, 2001).

2.5 Techniques of juice extraction

Even though a few methods have been used for the extraction of citrus juices, only screw type extractor is used to extract the juice from kinnow mandarin (Pruthi, *et al.*, 1984; Ramteke and Eipeson, 1990).

Extraction of citrus juice, especially orange juice needs a specific extractor, which can extract the pulp and at the same time separate the peel and the albedo (Braddock and Kesterson, 1979).

Method of juice extraction plays an important role in the content of bitter principles in citrus juice. (Mohsen *et al.*, 1986; Lotha and Khurdiya, 1994).

Lotha and Khurdiya (1994) tried five different methods of juice extraction from kinnow fruits *viz.*, hydraulic pressing, hand reaming, using screw type juice extractor, crushing without peel and crushing with peel. The crushing with peel method gave the highest juice yield and had the highest value for TSS, ascorbic acid but lowest acidity. The crushing with peel had high bitterness and hydraulic pressing and hand reaming were not bitter. They reported that the recovery of juice, pomace and peel was greatly influenced by the method of juice extraction.

Premi *et al.* (1994) reported that extraction of juice manually by squeezing reduced bitterness in kinnow fruit.

Screw type citrus juice extractor can be used to extract juice from kinnow fruits (Premi *et al.*, 1995; Aggarwal and Sandhu, 2004; Thakur *et al.*, 2004).

Sonkar and Ladaniya (1997) reported that when Nagpur Mandarin juice was extracted using screw press the juice was less bitter and more acceptable in comparison with hydraulic pressing.

Thakur and Kaushal (2000) reported that the physico-chemical qualities of kinnow juice are affected by the methods and level of juice extraction.

The methods of extraction of juice from citrus fruits are hydraulic pressing, expressing, reaming, squeezing, etc. The juice obtained by squeezing or peeling fruit and then extraction of juice in a way that seeds are not crushed, with a soft press was found to be better than other methods, but the only disadvantage is lesser juice recovery (Singh *et al.*, 2003).

Electrical juicer can be employed for juice extraction from (Mosambi) sweet orange (Jain, 2003) and pummelo (Bharali and Saikia, 2004).

2.6 Bitterness in citrus juices

A major problem in the citrus industry is the formation of bitterness in citrus juice and products within hours after extraction (Anon, 1986; Breksa *et al.*, 2005).

The single most hindrance in popularity of kinnow juice is the development of bitterness due to limonin and naringin (Premi *et al.*, 1994).

Citrus juices, though refreshing, and rich in minerals and vitamins, are too afflicted with this drawback of bitterness. Excessive bitterness lowers the quality and value of citrus juices (Berry, 2001). Sogi and Singh (2001) reported that the processing of kinnow fruit into various products is limited because of the development of bitterness during handling.

The major hurdle in citrus processing is developing of bitter taste in the juice. Without proper debittering technology the profitable citrus industry cannot flourish (Singh *et al.*, 2003).

2.6.1 Distribution pattern of bitterness principles in citrus fruits

Bitter principles are reported to be present in albedo, vascular tissues, membranes and seeds in citrus fruits (Siddappa *et al.*, 1953).

Bitter flavour in grape fruit and its juice is due to major contribution of flavonoid naringin (Kesterson and Hendrickson, 1957).

The intact fruits do not contain bitter limonin but rather a non-bitter precursor limonate A-ring lactone (Maier *et al.*, 1969). When juice is extracted, the non bitter precursor of limonin is gradually converted to limonin under acidic condition and conversion is accelerated by the action of limonate D-ring lactone hydrolase (Maier *et al.*, 1969). This is termed as delayed bitterness. The bitterness of the two - naringin and limonin is additive (Guadagni *et al.*, 1974).The five limonoids namely, limonin, nomilin, ischangin and nomilinic acid are bitter (Maier *et al.*, 1977). The nomilin is twice as bitter as limonin (Hasegawa *et al.*, 1974).

The major problem with the acceptability of the kinnow juice is the rapid development of bitterness in the juice. Limonin and naringin (naringin 7-neohesperidose) have been identified as the principles causing bitterness in kinnow (Barwal, 1984).

Gaonkar and Bamzi (1989) have found out that the contents of bitter principles in grapefruit, orange, lime and lemon are similar.

Bitterness in citrus juices is mainly attributed to limonin, naringin and nomilin (Roy, 1990).

The distribution pattern of bitterness principles in different parts of lime, pummelo and mandarin was studied by Yusof *et al.* (1990). They reported that the naringin content in skin of rough lime was more than that in the juice and seed. The limonin content in different parts of kinnow seeds, peel and juice were quite comparable with those in grape fruit seeds, whereas naringin content was considerably lower in kinnow, than in other citrus species. The bitter component, naringin was found in fruit skins of pummelo and rough lime. Sensory analysis confirmed that the juice extracted from pummelo and rough lime was bitter (Yusof *et al.*, 1993).

Premi *et al.* (1994) studied the distribution pattern of bittering principles in kinnow fruit. They found out that the seeds contained the highest limonin (9.50 mg / g), followed by peel (4.69 mg / g) and juice (0.218 mg / ml). The highest naringin content was in peel (0.420 mg / g), followed by juice (0.230 mg / ml) and seeds (0.134 mg / g).

They studied the sensory qualities of pummelo juice and confirmed its delayed bitter developing nature. They also reported that in the case of kinnow juice, peel and seeds have higher amount of limonin as compared to juice.

Bitterness in citrus juices is mostly attributed to limonin, naringin and nomilin (Berry, 2001).

Two classes of compounds namely, flavonoids and limonoids are responsible for bitterness. The fruit containing high flavonoids are bitter even when consumed fresh. The peel of the citrus fruit contains very high amount of flavonoids like naringin and neohesperdine which make them highly bitter. Among the flavonoids naringin is the widely occurring bitter principle. Limonin is the major cause of citrus juice bitterness and is widely distributed (Singh *et al.*, 2003).

The bitterness in kinnow juice gradually develops after extraction from the fruit and is referred to as delayed bitterness. Limonin is the principal bitter constituent of kinnow juice (Aggarwal and Sandhu, 2004).

2.6.2 Effect of storage and processing on development of bitterness in citrus juices

Development of bitterness in kinnow juice is influenced by the temperature of storage (Emerson 1948; Chandler and Kefford 1966; Premi *et al.*, 1994).

Heat processing of the kinnow juice was reported to result in the development of bitterness (Renote and Bains, 1982). Orange juice experiences delayed bitterness upon storage and heat processing (Berry, 2001).

2.6.3 Debittering of citrus juice

Different methods have been tried to reduce bitterness in citrus fruit juices like suppression of bitterness by addition of sweetening agents (Guadagni *et al.*, 1974), addition of β cyclodextrin monomer for forming inclusion complexes of limonin (Konno *et al.*, 1981), raising pH of the juice (Renote and Bains, 1982), conversion of bitter principles to non bitter components in the juice by the action of immobilised bacteria (Hasegawa *et al.*, 1983a) and use of adsorbent XAD-16 (Wilson *et al.*, 1989).

Post harvest treatments to overcome bitterness in citrus juices have largely concentrated on metabolic degradation of limonin, methods of juice extraction, masking of bitterness by different means, altering the entity of bitter principles using different techniques and selective removal of bitter principles and their precursors through various patented techniques (Berry, 2001).

The following post harvest approaches have been tried by different workers.

2.6.3.1 Harvesting time

The level of bitterness and acidity are highest in early season fruit and decline as the season progresses in kinnow (Sandhu *et al.*, 1990), Satsuma mandarin (Ishikawa *et al.*, 1993) and grape fruit (Attaway, 1977). Mature Satsuma mandarin fruit contains relatively low concentration of bitter limonoid aglycone (Ozaki *et al.*, 2000).

2.6.3.2 Method of extraction

Method of extraction (Mohsen *et al.*, 1986; Lotha and Khurdiya, 1994) plays an important role on contents of bitter principles in citrus juices. The type of extractor used for juice extraction and extraction pressure affects the limonin content of the juice (Fellers, 1989). Thus gentle extraction techniques, filtering the juice immediately after reaming and exclusion of air can result in juice low in or free from bitterness (Berry, 2001).

The juice obtained by squeezing or peeling fruit and then extraction of juice in a way that seeds are not crushed, with a soft press was found to be better than other methods, but the only disadvantage is less juice recovery (Singh *et al.*, 2003).

2.6.3.3 Use of bitterness suppressing agents

Neodiosmin is a very effective limonin bitterness suppressor (Guadagni *et al.*, 1976).

The use of 50 to150 ppm of Neodiosmin is recommended for reducing bitterness and improving acceptability of citrus juices (Guadagni *et al.*, 1977).

The β cyclodextrin monomer which is soluble in aqueous solution was shown to decrease the bitter taste of limonin and naringin in citrus juices (Konno *et al.*, 1981and 1982).

Addition of sugar, salt and chaat masala (a mixture of different condiments) was found to enhance acceptability of kinnow juice (Sandhu and Singh, 2001).

Addition of sucrose to juice also reduces bitterness as it masks the bitter taste of citrus fruits (Berry, 2001).

2.6.3.4 Increasing the pH of the juice

Increasing the pH of kinnow juice reduced its bitterness (Renote and Bains, 1982). The optimum pH for limonin bitterness suppression is 3.8 in orange juice (Guadagni *et al.*, 1993).

Thai-tangerine juice with raised pH had considerably low content of limonin (Chaiswadi *et al.*, 1998).This may be due to unfavourable conditions for conversion of limonate A-ring lactone to limonin (Maier *et al.*, 1969).

2.6.3.5 Acceleration of Limonoid metabolism in citrus fruits

This is done by exposing the fruits to ethylene (20 ppm) for 3 hours and then kept for several days in air. For instance, after 5 days at room temperature, the limonin content of juice prepared for ethylene triggered stored fruit decreased about 50 per cent from critical level of 24.3 ppm (Maier *et al.*, 1973).

Persimmons kept in a storage where concentration of ethanol vapour and carbon-dioxide was at optimal level removed bitter taste (Otau and Takashi, 1999).

2.6.3.6 Enzymatic removal of naringin and limonin

Naringin can be hydrolysed by α -rhamnosidase to rhamnose and prunin which is 1/3 as bitter as naringin (Horowitz, 1964) and then by β glucosidase to glucose and the aglycone naringenin which is non bitter.

Removal of naringin bitterness of grapefruit juice with naringinase immobilised in a hollow fiber has been reported by Oslon *et al.* (1979).

Use of enzyme for debittering process has been reported by Soares and Hotchkiss (1998).

The effect of naringinase on the bitterness of citrus juice was studied by Wang *et al.* (2004). The results showed that more than 85 per cent of the bitterness was removed by addition of 0.5 g / litre naringinase at 45 to 70° C at pH 3 to 5 for 60 minutes.

2.6.3.7 Biological removal of naringin and limonin

Bacteria such as *Arthrobacter globiformis* (Hasegawa *et al.*, 1972), *Pseudomonas* 321-8 (Hasegawa *et al.*, 1974), *Acinetobactor* sp. (Vaks and Lifshitz, 1981), *Corynebacterium fascians* (Hasegawa *et al.*, 1983a), *Bacterium* 342-152-1 (Hasegawa *et al.*, 1983b) and *Rhodococcus fascians* (Ibborra *et al.*, 1994) are capable of metabolising limonoids.

Immobilised *Corynebacterium fascians* (Hasegawa *et al.*, 1985) and *Rhodococcus fascians* (Ibborra *et al.*, 1994; Marwaha *et al.*, 1994; Bianchi *et al.*, 1995) were used to debitter the citrus juices.

2.6.3.8 Use of adsorbents

Activated carbon adsorbs limonin from bitter Navel orange juice but develops off flavour due to sulphite content (McColloch, 1950).

Nylon polymer was used in such a way that it would yield large surface area and could selectively adsorb significant quantities of limonin from the bitter Navel orange juice (Chandler *et al.*, 1968). They are also effective moderately in removing naringin (Johnson and Chandler, 1982).

Treatment of Washington Navel orange juice serum with cellulose acetate powder removed 44 to 70 per cent of limonin content in less than an hour (Chandler and Johnson, 1977).

Polyvinyl pyrollidone was used to remove naringin from Natsudaidai juice along with adsorbents nylon 66 and highly porous polymer (Maceda *et al.*, 1979).

β Cyclodextrin polymer was used to remove limonin and naringin from aqueous solution of filtered orange and grape fruit juices in batch / continuous treatments (Shaw and Wilson, 1983). α Cyclodextrin polymer also showed similar result (Shaw *et al.*, 1984).

There are two basic methods to treat juices with adsorbents *viz.*, fixed bed and stirred bed methods (Johnson and Chandler, 1988). These methods are being commercially employed in USA and Australia respectively to debitter orange and grapefruit juices.

When naringinase was entrapped in cellulose triacetate fibers, an enzyme column was made which could remove both limonin and naringin simultaneously (Tsen and Yu 1991). Activated packaging naringinase immobilised on cellulose acetate film (Soares and Hotchkiss, 1998).

Premi *et al.*, (1995) studied efficacy of five different debittering techniques for kinnow juice, namely (a) lye peeling, (b) raising of pH, (c) removal of bitter principles by treatment with XAD-16, (d) β cyclodextrin, (e) immobilised cells of *Arth. globiformis* II. The highest reduction in limonin content was recorded in the juice treated with adsorbent XAD -16.

2.7 Product development

Kinnow Mandarin juice can be used to make squash (Pruthi *et al.*, 1984; Aggarwal and Sandhu, 2004). Kinnow juice concentrates of 72° brix has been prepared and found to be acceptable (Sandhu *et al.*, 1990; Thakur *et al.*, 2000).

Lotha and Khurdiya (1994) reported that good quality nectar and squash can be prepared from kinnow Mandarin juice by blending the juice (extracted by crushing with peel and by hydraulic pressing method).

Citrus fruits can be used to produce many value added products *viz.*, ready to serve beverages, juice concentrates, squash, jam, jelly, candy, marmalade, pectin, oil, etc. (Berry, 2001). All these products are commonly derived from grape fruit, lime, lemon, mandarin and oranges.

Sogi and Singh (2001) developed juice, RTS beverage, squash, jam and candy using debittered kinnow juice and analysed the development of bitter principles in them.

The rind of the pummelo fruits is a good source of pectin and can be exploited for pectin extraction and preparation of jelly (Madhav, 2001).

Sharma *et al.* (2001) reported the preparation of Hill lemon juice concentrate of 45° brix.

Concentration of kinnow Mandarin juice by Reverse Osmosis was reported by Khamrui and Pal (2002) and Thakur *et al.* (2004).

'Nagpur' Mandarin juice (sweetened) 16° brix, pasteurised and heat processed can be stored in crown corked glass bottles under refrigerated condition up to six months in acceptable condition (Ladaniya and Singh, 1998).

Preparation of whey based kinnow Juice concentrate (WKJC) was reported by Khamrui and Pal (2004).

Bharali and Saikia (2004) reported that pummelo fruit juice can be effectively utilised for preparation of cordial.

Materials and Methods

3. MATERIALS AND METHODS

The investigation on "Process optimisation for production of value added products from Pummelo" (*Citrus grandis* (L.) Osbeck)" was carried out in the Department of Processing Technology, College of Horticulture, Kerala Agricultural University, Vellanikkara during the period 2004-06. The study comprised of the following experiments.

1. Standardisation of harvesting index for pummelo
2. Screening of pummelo types for processing attributes
3. Effect of different techniques on peeling of segments
4. Effect of methods of juice extraction on quality of pummelo juice
5. Effect of debittering techniques on quality of pummelo juice
6. Development of products based on pummelo juice

3.1 Standardisation of harvesting index for Pummelo

3.1.1 Collection of fruits

A survey was carried out at different parts of Thrissur, Kottayam and Ernakulam districts of Kerala for locating different types of pummelo. Fruits were collected from five accessions located in Trichur district, starting from fifth month after fruit set at monthly intervals till the fruits become completely yellow. The fruits fell down from the trees were also collected on the very next day from the ground (Plate 2.).

Three fruits were collected from each tree at various stages of maturity specified for analyzing the physicochemical characters.

3.1.2 Analysis of physico-chemical changes associated with growth and development

3.1.2.1 *Physical characters*

The physical characters of the fruits recorded were weight, length and width of fruits and physical composition such as rind weight, number of segments, segment weight and juice percentage (Plate 3.).

Plate 2. Fruits at different stages of maturity

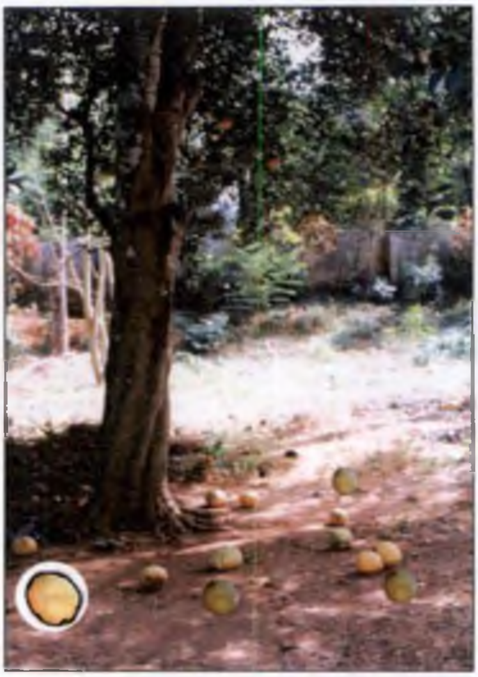
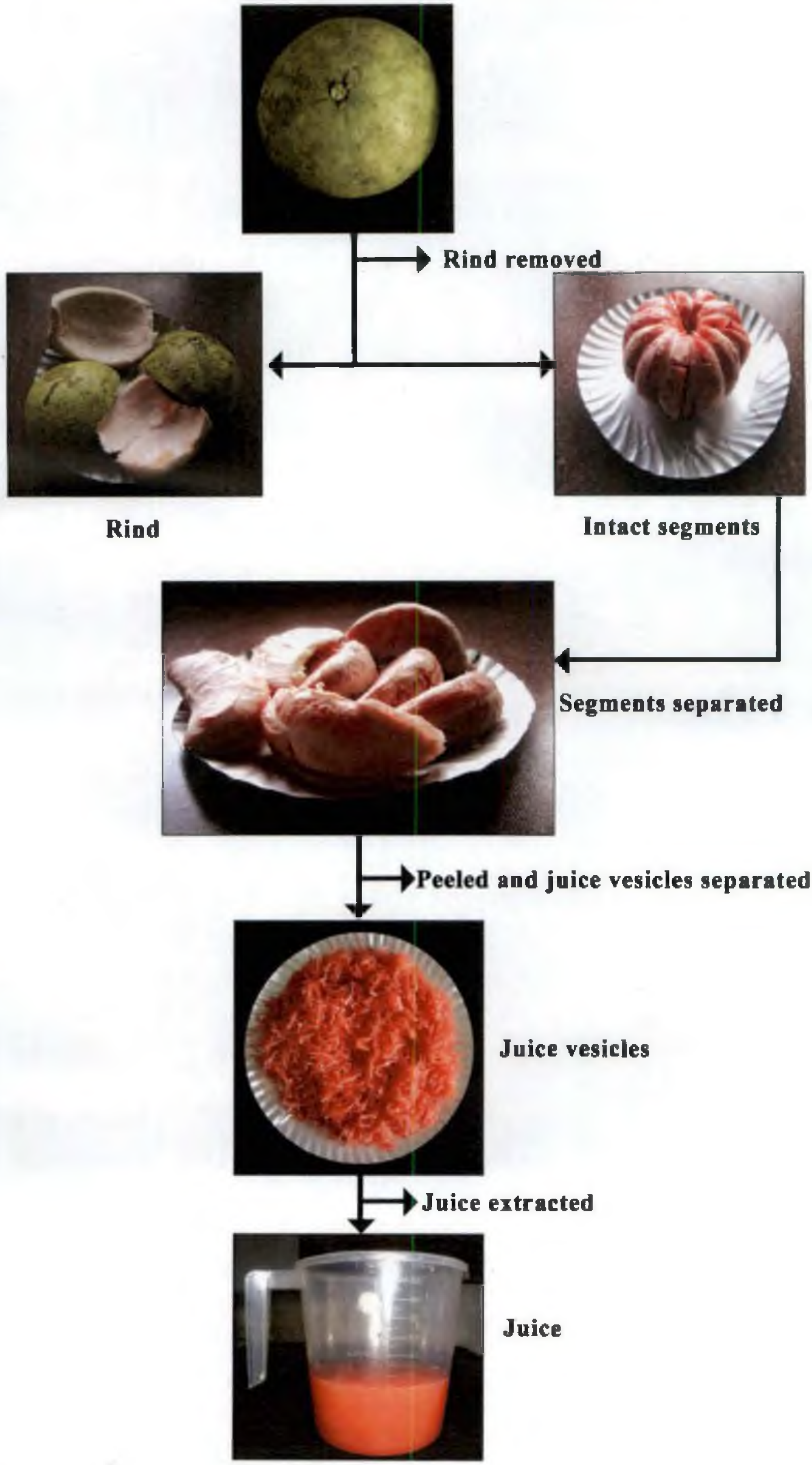


Plate 3 . Physical components of pummelo analysed



3.1.2.1.1 Fruit length

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

3.1.2.1.2 Fruit width

Width of the fruit was measured for the same three fruits at the maximum point and recorded in centimeters.

3.1.2.1.3 Fruit weight

Weight of three fruits from each accession was taken and mean was calculated and expressed in grams.

3.1.2.1.4 Rind weight

Rind of the fruit was peeled and mean weight was recorded for three fruits of each accession and expressed in grams.

3.1.2.1.5 Number of segments

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

3.1.2.1.6 Weight of segment

Weight of segment was measured for three fruits and mean was expressed in grams.

3.1.2.1.7 Juice content

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

3.1.2.2 *Biochemical characters*

3.1.2.2.1 Total soluble solids.

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

3.1.2.2.2 Acidity

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

3.1.2.2.3 Total sugars

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

3.1.2.2.4 Reducing sugars

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

3.1.2.2.5 Ascorbic acid

Five grams of juice vesicle was taken and extracted with four percent oxalic acid. Ascorbic acid was estimated by using standard indicator dye 2, 6-dichlorophenol indophenol and expressed as mg / 100 g of fruit

3.1.2.3 ***Internal characters***

3.1.2.3.1 Colour of flesh

Colour of the flesh was recorded by visual observation and recorded as greenish yellow (GY), white (W), light red (LR), light pink (LP), red (R) and pink (P).

3.1.2.3.2 Easiness to separate and peel the segments

The rind of the fruits was removed manually and the segments were separated and while separating the easiness / difficulty was marked as easy (E), slightly difficult (SD), difficult (D) and very difficult (VD) with the help of a score card. The easiness to peel the segments was recorded in the same manner.

3.1.2.3.3 Colour of juice

Colour of juice was recorded by visual observation and noted as greenish yellow (GY), cream (C), Light pink (LP), pink (P) Light red (LR) and red (R).

3.1.2.3.4 Bitterness

The bitterness was marked as not bitter (NB), slightly bitter (SB), bitter (B) and very bitter (VB).

3.1.2.3.5 Juice taste

The juice taste was recorded as very poor (VP), poor (P), fair (F) and good (G). Based on the analysis of physico-chemical characters and the internal characters, the ideal stage of maturity for consumption and processing of pummelo was identified.

3.2 Screening of Pummelo types for processing attributes

Twelve different types of pummelo collected from Thrissur, Kottayam and Ernakulam areas of Kerala (Plate 4.) and four types collected from IIHR Bangalore (Plate 5.) were evaluated for the following physico-chemical characters and sensory attributes.

3.2.1 *Physical characters*

Fruit length, fruit width, fruit weight, rind weight, number of segments, segment weight and juice content were recorded as given in Experiment I.

3.2.2 *Biochemical characters*

Total soluble solids (TSS), acidity, total sugars, reducing sugars, non reducing sugars and ascorbic acid content were recorded as explained in Experiment II.

3.2.3 *Sensory attributes*

The sensory attributes evaluated were colour of juice vesicles and juice content and taste and flavour of juice with the help of a semi trained panel. The colour of juice vesicles and juice was marked by visual observations. Juice taste and flavour was marked as very good, good, medium, poor and very poor.

Based on the study, the types possessing ideal processing characters were selected out based on DMRT analysis. Comparative evaluation of Bangalore and Kerala types for processing attributes were also done.

3.3 Evaluation of peeling techniques

The following treatments were tried to induce easy peeling of fruit segments to expose the juice vesicles. The type identified to possess ideal processing characters through Experiment I was selected for the study.

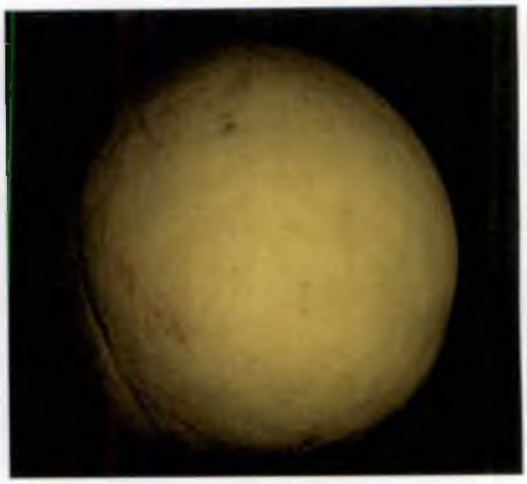
3.3.1 *Lye peeling*

The rind was removed manually and the segments were separated. They were dipped in hot lye solution of strengths 1.5, 2.0 and 2.5 percent for a contact time of 0, 60, 75, 90 and 120 seconds. Three segments were kept in each treatment. After the treatment, the segments were washed in one per cent citric acid to remove the excess alkali. Then they were washed in fresh tap water. Thus there were 16 treatments with three replications.

The following characters of the treated segments were evaluated in comparison with the control after the treatment.

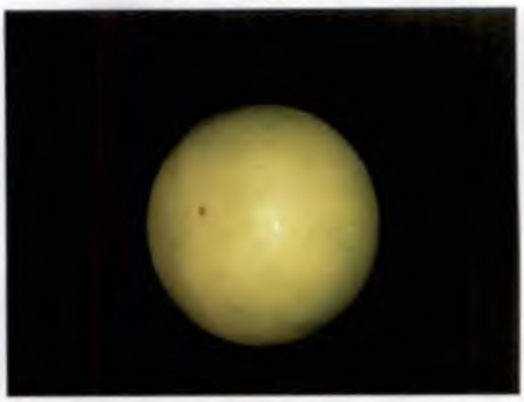
Plate 4. Pummelo accessions - Kerala

AC. 3



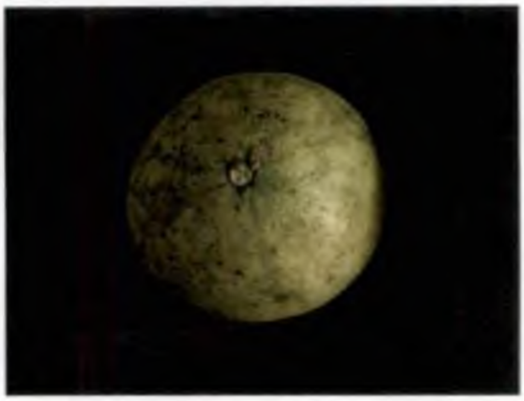
AC. 2

AC. 5



AC. 6

AC. 11



AC. 12

Plate 5. Pummelo selections - IIHR, Bangalore

IKP - 2

Kharapur

Midnapur

Devanahalli

3.3.1.1 Extend of peel removed

After dipping in lye solutions the extend of peel removed was recorded in the following manner.

Retention of peel	% removed
0	100
1/4	75
½	50
1/3	25

3.3.1.2 Colour change

The change in colour was recorded as light, medium and high by visual observation.

3.3.1.3 Extend of rupture of the juice vesicles

The extend of rupture of juice vesicles was recorded as slight, medium and heavy based on visual observation.

3.3.2 ***Effect of salt, sugar and steam on peeling of pummelo segments***

The segments separated from the fruits were smeared with salt and sugar at the rates given below.

Salt → 1, 2, 3, 4 and 5 percentage

Sugar → 1, 2, 3, 4 and 5 percentage

Control: Freshly separated segments

After smearing with salt and sugar, the segments were taken in a dish and steamed in water bath at 65 to 70° C for 15 minutes. There were 11 treatments replicated thrice. As a separate treatment, the segments were dipped in syrup and brine for 15 minutes at the concentrations given below and subjected to steaming for 15 minutes.

Brine strength: 0, 10, 15, 20, 25 and 30 per cent

Syrup strength: 0, 10, 15, 20, 25 and 30 per cent

Control: Freshly separated segments

There were 13 treatments replicated thrice.

The steamed segments were evaluated for extend of peel removed, colour change of juice vesicles and rupture of juice vesicles. The juice was extracted from the steamed segments and served to a trained panel for sensory evaluation using a score card give in Appendix II. Based on this, the best method of peeling was identified. The biochemical constituents of the juice extracted through the best method identified was analysed as given in experiment I and compared with that of hand extracted fresh juice.

3.4 Development of techniques for extraction of quality juice

This experiment was conducted to standardise a protocol for extraction of maximum quantity of quality juice from pummelo. The fruits collected from a single tree at Trichur area were used for the study. After removing the rind of the fruits, the segments were separated and peeled through the best method identified through Exp. III. The methods of juice extraction included in the study were

1. Osmoextraction
2. Screw pressing
3. Crushing in mixie and pressing
4. Hand pressing

3.4.1 *Osmoextraction*

The juice vesicles after separation from the segments were mixed with sugar at 10, 20, 30, 40 and 50 per cent level and kept for varying periods *viz.,* 1, 2, 3 and 4 hours for juice extraction. There were 20 treatments replicated twice. Based on the study, the ideal sugar percentage and incubation period for osmoextraction of juice from pummelo juice vesicles was identified.

3.4.2 *Screw pressing*

The juice vesicles after separation from the segments were put in a screw press and the juice was extracted.

3.4.3 *Crushing in mixie*

The juice vesicles after separation from the segments were crushed in mixie and then pressed in muslin cloth to extract the juice.

3.4.4 *Hand pressing*

The juice vesicles were taken in muslin cloth and pressed thoroughly to extract the juice.

There were 4 treatments replicated thrice.

The physico chemical and sensory attributes of the juice extracted through the best osmoextraction technique was compared with that of other methods. The efficiency of the method of extraction was evaluated based on juice yield, pomace content, TSS, acidity and ascorbic acid content of the juice and its sensory attributes.

Juice content (%)

The juice content (%) was recorded as given in Experiment I.

Pomace (%)

After extraction of juice from the vesicles, the left out mass was weighed and expressed in percentage.

The biochemical attributes were evaluated as given in Experiment I and sensory attributes as given in Experiment III.

3.5 Evaluation of debittering techniques

The juice extracted by the most effective method was subjected to debittering by using the following methods.

3.5.1 *Raising of pH*

The initial pH of the juice was recorded. Then the pH was raised to 4, 4.25 and 4.5 using sodium bicarbonate and then analysed for quality.

3.5.2 *Clarification*

The juice was added with pectin to analyse the possibility of removing the components that impart bitterness through sedimentation. Pectin was added to the juice at the rate 1, 2 and 3 per cent level and kept for one day. The clear juice was decanted and analysed for quality.

3.5.3 *Masking the bitterness*

The possibility of masking the bitter taste of the juice was studied by adding sucrose at 2, 4 and 6 per cent level. The juice was kept for one hour after addition of sucrose and then analysed for quality.

3.5.4 *Addition of pectinase*

The extracted juice was treated with pectinase enzyme @ 5 ml / kg of juice and kept for ten minutes for the enzyme to act. This juice was then analysed for quality.

The untreated juice was taken as the control.

There were 11 treatments replicated thrice. After all the treatments, the clear juice was filtered and analysed for the following qualities

pH / acidity

Ascorbic acid content in the treated juice

Sensory evaluation by a trained panel for evaluating the bitterness levels

The observations were recorded as given in the Experiment I.

3.6 Products based on pummelo juice

3.6.1 *Blended sweetened juice*

The most effectively debittered juice was blended with other juices like orange, grape and mango juice at varying levels of mixing to identify the best blend combination. The different levels of mixing tried were 10, 20 and 30 per cent. The pure pummelo juice served as the control. Thus there were ten treatments with three replications.

For preparing sweetened juice, the sugar content of the most acceptable combination was raised to 20, 25, 30 and 35 per cent level and served to a semi trained panel for sensory evaluation.

3.6.2 *Beverages*

Using the debittered juice and blended juice identified as most acceptable, beverages like RTS and squash were prepared using standard procedure and subjected to sensory evaluation.

3.7 Statistical analysis

All the experiments were conducted in Completely Randomised Design (CRD) using MSTATC package.

Results

4. RESULTS

The results of the present study entitled 'Process optimisation for production of value added products from pummelo (*Citrus grandis* (L.) Osbeck)' are presented in this chapter under the following sections.

1. Standardisation of harvesting index
2. Screening of pummelo types for processing attributes
3. Effect of peeling made easy techniques
4. Effect of method of juice extraction on quality of pummelo juice
5. Effect of debittering techniques on quality of pummelo juice
6. Products based on pummelo juice

4.1 Standardisation of harvesting index

Fruits of three different stages of maturity *viz.*, 5th, 6th and 7th month after fruit set (MAFS) were collected starting from 5th MAFS till the fruits became completely yellow. After turning to yellow (7th MAFS) within 7 to 10 days, the fruits start to fall down from the tree and these fruits were also collected on the next day after falling.

4.1.1 *Physico-chemical changes associated with maturity*

Information regarding the changes in physical and biochemical characters of the fruits of five accessions with respect to different maturity stages (Plate 6.) are given in Table 1. and Table 2.

4.1.1.1 *Physical Characters*

4.1.1.1.1 Fruit length

Irrespective of the accessions, the length of the fruits increased as the maturity advanced. There was no significant difference in average length of fruits between 5th MAFS and 6th MAFS, but the difference was significant between 5th and 7th MAFS. The average length of fruit was 14.14 cm at 5th MAFS which was increased to 15.69 cm at 7th MAFS.

4.1.1.1.2 Fruit width

Fruit width of all accessions studied increased progressively from 5th to 7th MAFS. In all the accessions, change in width between 5th to 7th MAFS was significant. The

Table 1. Changes in physical characters of pummelo fruits during growth and development

	MAFS	AC. 1	AC. 2	AC. 3	AC. 4	AC. 5	Mean	
Fruit length (cm)	5	16.40	15.53	10.03	13.87	14.87	14.14	
	6	16.83	15.73	10.43	14.33	16.13	14.46	
	7	18.23	16.33	11.07	14.97	17.83	15.69	
	F	18.23	16.33	11.07	14.97	18.33	15.89	
CD		NS						1.25
Fruit width (cm)	5	13.23	14.90	15.03	8.07	10.07	12.26	
	6	13.67	15.17	15.53	8.37	10.57	12.66	
	7	13.97	15.40	16.10	8.67	11.37	13.10	
	F	13.97	15.40	16.10	8.67	11.37	13.10	
CD		0.342						0.15
Fruit weight (g)	5	973.33	1241.67	603.67	445.00	525.00	757.73	
	6	1008.30	1291.67	657.67	491.67	565.00	802.87	
	7	1015.67	1330.33	766.33	573.33	611.67	859.47	
	F	1011.33	1331.67	756.33	541.67	611.33	850.47	
CD		NS						34.95
Rind weight (g)	5	463.33	339.33	112.00	136.67	94.10	229.09	
	6	486.67	383.00	153.30	182.00	144.77	269.95	
	7	506.00	396.33	210.00	210.33	167.20	297.97	
	F	493.33	396.00	210.00	209.19	168.37	295.37	
CD		NS						21.40
Number of segments	5	12.33	14.37	12.00	11.00	11.00	12.33	
	6	12.67	16.00	12.00	11.00	11.00	14.33	
	7	12.67	15.00	12.00	11.00	11.00	12.00	
	F	12.67	15.00	12.00	11.00	11.00	11.00	
CD		NS						NS
Segment weight (g)	5	508.00	902.33	500.33	298.33	402.65	522.29	
	6	507.33	918.67	521.67	331.67	420.13	539.89	
	7	510.67	934.00	550.00	358.33	444.87	559.57	
	F	511.00	934.00	547.67	357.67	444.33	558.93	
CD		NS						27.80
Juice content (%)	5	50.33	59.47	60.00	59.63	58.93	57.67	
	6	53.33	64.53	65.33	64.83	61.43	61.89	
	7	56.00	70.26	70.00	70.00	64.01	66.19	
	F	54.00	69.50	68.50	67.40	62.07	64.29	
CD		2.31						1.03

MAFS : Month after fruit set

F : Fallen

Plate 6. Variation in fruit size at different stages of maturity

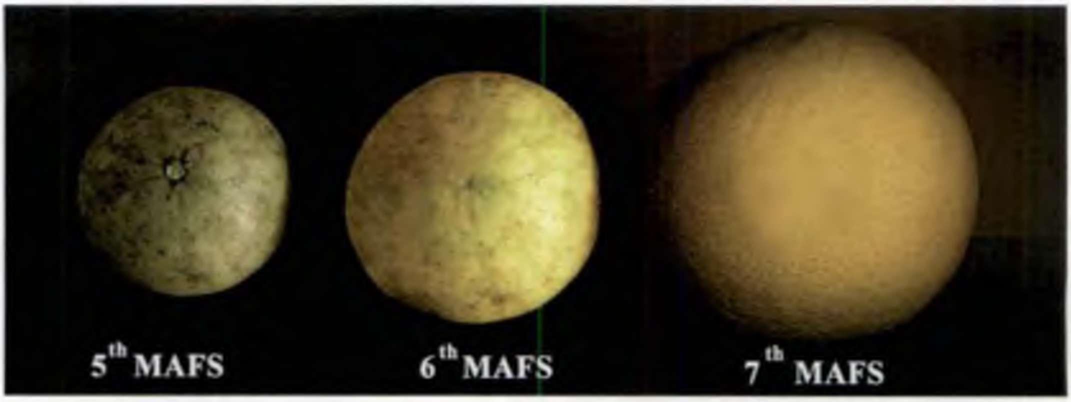


Plate 7. Variation in colour of segments and juice

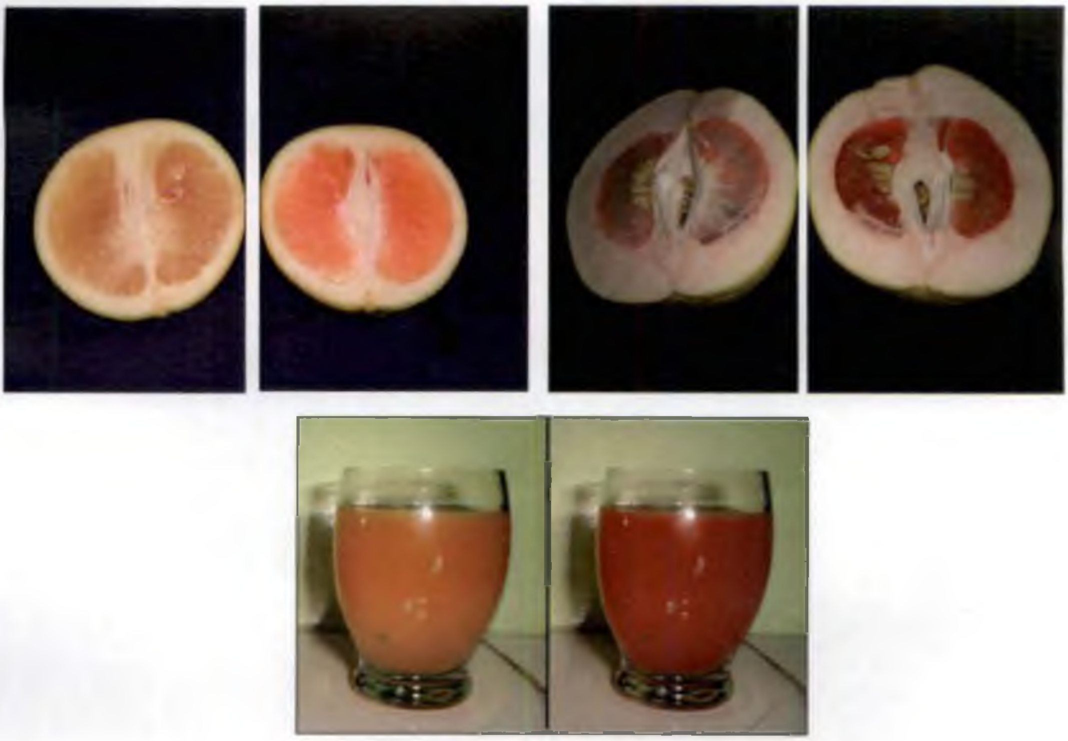


Plate 8. Variation in juice colour (IIHR, Bangalore selections)

average fruit width recorded at 5th MAFS was 12.26 cm which was increased to 13.10 cm at 7th MAFS.

4.1.1.1.3 Fruit weight

Fruit weight was one of the parameters which recorded high significant difference from 5th MAFS to 7th MAFS in all the accessions. On an average, the fruit weight increased from 757.73 g to 859.47 g from 5th MAFS to 7th MAFS. There was no significant difference in fruit weight of fallen fruits compared to that at 7th MAFS collected from the tree.

4.1.1.1.4 Rind weight

The average rind weight recorded at 5th MAFS was 229.09 g. This was increased to 269.95 g at 6th MAFS and then to 297.97 g at 7th MAFS. The rind weight of fallen fruits recorded a significant decrease compared to fruits collected from trees at 7th MAFS (295.37 g).

4.1.1.1.5 Number of segments

The number of segments remained constant from 5th MAFS till 7th MAFS in all the accessions.

4.1.1.1.6 Segment weight

In all the accessions, segment weight increased progressively as the maturity advanced. The average segment weight recorded at the 5th MAFS was 522.29 g which increased to 559.57 g at 7th MAFS .The segment weight of fruits at 7th MAFS collected from tree as well as the fallen fruits did not record a significant change.

4.1.1.1.7 Juice percentage

The percentage of juice in the fruits increased from 5th MAFS to 7th MAFS. The juice content recorded was 57.67 per cent, 61.89 per cent and 66.19 per cent at 5th, 6th and 7th MAFS respectively. The average juice content of the fallen fruits recorded significant decrease (64.29 per cent).

4.1.1.2 *Biochemical characters*

4.1.1.2.1 Total soluble solids (TSS)

The average value of TSS recorded at 5th, 6th and 7th MAFS showed a significant increase. The TSS was 6.95° brix at 5th MAFS which was increased to 7.39° brix at 6th MAFS and then to 8.16° brix at 7th MAFS. The TSS of fallen fruits showed a significant decrease (7.20° brix).

Table 2. Changes in biochemical constituents of pummelo fruits during growth and development

	MAFS	AC. 1	AC. 2	AC. 3	AC. 4	AC. 5	Mean	
TSS (° brix)	5	6.43	6.13	7.00	6.93	8.30	6.95	
	6	6.83	6.68	7.55	7.31	8.50	7.39	
	7	7.17	7.42	8.73	8.53	8.97	8.16	
	F	6.67	6.42	7.50	6.87	8.50	7.20	
CD		**0.35**						**0.16**
Acidity (%)	5	0.62	1.01	0.50	0.42	0.67	0.64	
	6	0.59	0.99	0.30	0.29	0.56	0.55	
	7	0.57	0.93	0.13	0.23	0.46	0.48	
	F	0.57	0.92	0.13	0.23	0.46	0.47	
CD		**0.09**						**0.04**
pH	5	3.99	6.10	0.81	1.44	2.88	4.04	
	6	4.00	6.22	1.88	1.53	3.50	4.10	
	7	4.05	6.25	3.13	2.63	4.19	4.20	
	F	4.05	6.25	3.13	2.63	4.19	4.20	
CD		**0.08**						**0.04**
Total sugars (%)	5	3.93	3.93	4.31	2.50	3.97	3.74	
	6	4.00	4.47	4.80	3.00	4.07	4.07	
	7	4.11	4.74	5.25	4.13	4.61	4.57	
	F	4.02	4.07	4.38	3.67	3.83	3.99	
CD		**0.30**						**0.14**
Reducing sugars (%)	5	1.93	1.07	1.31	0.10	0.60	1.00	
	6	2.53	1.36	1.53	0.67	0.94	1.41	
	7	2.66	1.59	1.70	1.26	1.52	1.75	
	F	2.60	1.30	1.13	0.50	1.17	1.34	
CD		**0.19**						**0.09**
Non reducing sugars (%)	5	2.00	2.93	3.06	2.40	3.37	2.75	
	6	1.45	3.12	3.27	2.33	3.13	2.66	
	7	1.45	3.15	3.54	2.87	3.09	2.82	
	F	1.42	2.77	3.24	3.17	2.70	2.66	
CD		**0.332.63**						**0.15**
Ascorbic acid (mg / 100 ml)	5	57.23	6.43	56.30	20.30	55.20	39.10	
	6	58.60	13.53	66.10	26.27	60.10	44.92	
	7	69.37	23.39	71.67	31.90	65.20	50.30	
	F	58.83	20.03	67.10	26.47	62.43	46.97	
CD		**1.24**						**0.55**

MAFS – Month after fruit set F – Fallen

4.1.1.2.2 Acidity

Mean acidity values of all accessions showed decrease from 5th MAFS to 7th MAFS. The value recorded was 0.64 per cent at 5th MAFS which was decreased to 0.48 per cent at 7th MAFS.

4.1.1.2.3 pH

The average pH values increased from 5th MAFS to 7th MAFS. The average pH recorded was 4.02 which increased to 4.20 at 7th MAFS.

4.1.1.2.4 Total sugars

The mean values of total sugars showed an increase from 3.74 per cent at 5th MAFS to 4.57 per cent at 7th MAFS. The fallen fruits recorded significantly lower sugar content at 7th MAFS plucked from the tree.

4.1.1.2.5 Reducing sugars

The data on the mean values of the reducing sugar content also recorded an increase from 5th MAFS (1.00 per cent) to 7th MAFS (1.75 per cent). The content was less (1.34 per cent) in fallen fruits compared to the fruits of same maturity collected from the tree.

4.1.1.2.6 Non reducing sugars

The mean values of non reducing sugar content increased from 2.75 per cent at 5th MAFS to 2.82 per cent at 7th MAFS and then decreased to 2.66 per cent in fallen fruits.

4.1.1.2.7 Ascorbic acid (Vitamin C)

The ascorbic acid content showed a very significant increase from 39.10 mg / 100 ml to 50.30 mg / 100 ml from 5th MAFS to 7th MAFS. The ascorbic acid content for the fallen fruits recorded was 46.97 per cent.

4.1.2 *Internal characters*

Information regarding the internal characters of fruits at different stages of growth and development is given in the Table 3.

4.1.2.1 Colour of flesh

The colour of flesh of red coloured varieties remained light pink/light red during 5th and 6th MAFS. Later it developed the characteristic pink/red colour by the 7th MAFS. For the white coloured varieties, the colour of the flesh was greenish yellow during 5th MAFS, which turned to white by the 7th MAFS.

Table 3. Variation in internal characters of fruits at different stages of growth and development

AC. No.	Stage (MAFS)	Colour of flesh	Easiness to separate segments	Easiness to peel	Juice colour	Bitterness	Juice taste
AC. 1	5	L.P	V.D	V.D	L.P	V.B	V.P
	6	L.P	D	D	L.P	B	V.P
	7	P	E	E	P	B	P
	F	P	E	E	P	B	P
AC. 2	5	G.Y	D	D	G.Y	V.B	V.P
	6	G.Y	E	E	G.Y	B	P
	7	W	E	E	C	S.B	F
	F	W	E	E	C	V.B	P
AC. 3	5	G.Y	D	V.D	G.Y	B	P
	6	G.Y	D	E	G.Y	S.B	F
	7	W	E	E	C	S.B	F
	F	W	E	E	C	B	P
AC. 4	5	L.P	D	D	L.P	B	P
	6	L.P	D	D	L.P	S.B	F
	7	P	E	E	P	S.B	F
	F	P	E	E	P	B	P
AC. 5	5	L.R	D	D	L.R	B	P
	6	L.R	E	D	L.R	S.B	F
	7	R	E	E	R	N.B	G
	F	R	E	E	E	B	P

MAFS : Month after fruit set

A.C. : Accession
V.P. : Very Poor
V.B. : Very Bitter
N.B. : Not Bitter
S.B. : Slightly Bitter
L.P. : Light Pink
L.R. : Light Red
W : White
G.Y. : Pale Yellow
V.D. : Very Difficult
P : Pink
R : Red
F : Fair
B : Bitter
F : Fallen
D : Difficult
E : Easy
G : Good
P : Poor
C : Cream

4.1.2.2 Easiness to peel and separate the segments

The easiness to peel and to separate the segments was recorded "very difficult" in all the accessions studied during 5th MAFS and "difficult" during 6th MAFS and as "easy" during 7th MAFS. Even the fallen fruits were easy to peel.

4.1.2.3 Colour of the juice

The colour of the juice was light pink/light red during 5th and 6th MAFS in red varieties which was later turned to pink/red by 7th MAFS. In the white coloured varieties, the colour of juice changed from greenish yellow to white as the fruits matured from 5th MAFS to 7th MAFS. There was not much change in the juice colour of the fallen fruits.

4.1.2.4 Bitterness

Juice from AC. 1 and AC. 2 were found to be "very bitter" at 5th MAFS. The taste of AC. 3, AC. 4 and AC. 5 were scored as "bitter" at this stage. The juice was "bitter" at 6th MAFS for AC. 1 and AC. 2. For AC. 3, AC. 4 and AC. 5 juice was "slightly bitter" at 6th MAFS. The juice was "bitter" even at 7th MAFS for AC. 1. For accessions AC. 2, AC. 3 and AC. 4 the juice was "slightly bitter" at 7th MAFS. It was "not bitter" for AC. 5 at 7th MAFS. In all the cases, juice turned to be "bitter" in fallen fruits.

4.1.2.5 Juice taste

The juice taste was recorded as "very poor" at 5th MAFS for AC. 1 and AC. 2 and "poor" for AC. 3, AC. 4 and AC. 5. At 6th MAFS, the juice taste was still "very poor" for AC. 1. For AC. 2, the juice was "poor" in taste at 6th MAFS and for AC. 3, AC. 4 and AC. 5 juice was "fair" in taste at 6th MAFS. At 7th MAFS, the juice taste was recorded as "poor" for AC. 1, "fair" for AC. 2, AC. 3 and AC. 4. The juice taste was "good" for AC. 5 at 7th MAFS. Fallen fruits in all the accessions recorded poor taste.

4.1 Screening of Pummelo types for processing Attributes

4.2.1 *Physico- chemical and sensory attributes of accessions collected from Kerala*

Information regarding the various physical, biochemical and sensory attributes of ripe fruits collected from three districts of Kerala *viz.*, Kottayam, Ernakulam and Thrissur are given in the Tables 4, 5 and 6.

4.2.1.1 *Physical characters*

4.2.1.1.1 Fruit length

Table 4. Variation in physical characters of fruits collected from three districts of Kerala

Area of collection	AC. No.	Fruit length (cm)	Fruit width (cm)	Fruit weight (g)	Rind weight (g)	No. of segments	Segment weight (g)	Juice content (%)
Kottayam	01	18.53	19.50	978.33	304.00	13.00	664.67	45.33
	02	18.67	21.83	1483.33	681.67	13.00	790.00	68.70
	03	20.40	23.53	873.33	207.00	14.67	656.33	73.70
	04	18.27	12.73	1136.67	501.97	12.00	633.03	64.27
	Mean	**18.97**	**19.40**	**1117.92**	**423.66**	**13.17**	**686.01**	**62.24**
	C.D	**0.32**	**0.63**	**34.34**	**36.41**	**0.49**	**35.47**	**0.66**
Ernakulam	05	17.33	24. 47	1380.00	401.67	12.33	971.67	65.07
	06	13.07	15.17	546.50	178.23	11.33	365.67	48.53
	07	14.90	15.30	727.00	161.50	10.33	365.37	45.33
	08	16.13	16.67	882.67	307.00	10.67	573.67	54.40
	Mean	**15.36**	**17.90**	**884.04**	**262.10**	**11.17**	**619.04**	**53.32**
	C.D	**1.32**	**0.86**	**29.02**	**6.62**	**1.53**	**24.53**	**0.92**
Thrissur	09	18.13	24.80	1756.67	993.87	12.67	761.53	53.80
	10	16.40	17.17	851.13	320.70	11.33	530.47	70.70
	11	17.50	19.70	854.00	281.73	13.33	571.13	74.83
	12	14..47	11.90	566.40	252.00	14.00	313.90	35.23
	Mean	**16.63**	**18.39**	**1007.05**	**462.08**	**12.83**	**544.26**	**58.64**
	C.D	**0.14**	**0.23**	**8.21**	**16.44**	**0.84**	**18.14**	**0.58**

Table 5. Variation in chemical constituents of fruits collected from three districts of Kerala

Area of collection	AC. No.	TSS (° β)	Acidity (%)	Total Sugars (%)	Reducing Sugars (%)	Non Reducing sugars (%)	Ascorbic Acid (mg/100ml)
Kottayam	01	6.93	0.68	5.25	2.14	3.11	30.67
	02	9.27	1.05	6.71	1:88	4.84	40.47
	03	8.17	1.26	4.78	1.68	3.10	70.37
	04	9.07	0.76	4.42	1.48	2.94	32.53
	Mean	**8.36**	**0.94**	**5.29**	**1.79**	**3.50**	**46.72**
	C.D	**0.28**	**0.03**	**0.14**	**0.09**	**0.12**	**2.15**
Ernakulam	05	6.47	0.84	4.41	1.26	3.16	48.20
	06	9.00	0.18	4.55	2.53	2.02	37.93
	07	8.70	1.18	6.51	1.78	3.86	73:33
	08	8.73	0.75	5.20	0.79	4.41	32.90
	Mean	**8.23**	**0.74**	**5.17**	**1.82**	**3.36**	**48.09**
	C.D	**0.14**	**0.12**	0.06	0.09	**0.12**	**1.09**
Thrissur	09	7.10	1.22	4.13	1.43	2.71	48.00
	10	8.97	0.68	4.45	1.31	3.14	23.53
	11	9.13	0.78	6.59	2.66	4.79	53.30
	12	8.07	0.55	5.29	1.47	3.79	72.53
	Mean	**8.32**	**0.81**	**5.12**	**1.49**	**3.61**	**46.13**
	C.D	**0.21**	**0.03**	**0.09**	**0.06**	**0.14**	**1.44**

The mean values for fruit length ranged from 13.07 cm to 20.40 cm for the 12 accessions studied. The highest mean fruit length was recorded for the accessions collected from Kottayam (18.97 cm), followed by Thrissur (16.63 cm) and Ernakulam (15.36 cm).

AC. 3 collected from Kottayam had the maximum fruit length of 20.40 cm and AC. 6 collected from Aluva had the minimum fruit length of 13.07 cm.

Within Kottayam district, AC. 2 recorded highest fruit length of 18.67 cm and AC. 4 collected from Chempu recorded the minimum fruit length of 18.27 cm. Among the four accessions collected from Ernakulam, AC. 5 collected from Kothamangalam had the maximum fruit length of 17.33 cm and the AC. 6 collected from Aluva had the minimum fruit length of 13.07 cm. Among the four accessions collected from Thrissur, AC. 9 from Vilangannoor had the maximum fruit length of 18.13 cm and AC. 12 collected from Peechi showed a minimum fruit length of 14.47 cm.

4.2.1.1.2 Fruit width

The data on the mean values of fruit width revealed that the maximum fruit width was for the accessions collected from Kottayam (19.40 cm), followed by Thrissur (18.39 cm) and then Ernakulam (17.9 cm).

Among the four accessions collected from Kottayam, the maximum average fruit width was recorded for AC. 3 (23.53 cm) and the minimum for AC. 4 collected from Chempu (12.73 cm). The mean values for fruit width of the four accessions collected from Ernakulam revealed that the maximum fruit width was for AC. 5 (24.47 cm) collected from Kothamangalam and the minimum fruit width was for AC. 6 (15.17 cm) collected from Aluva. Similarly, among the four accessions collected from Thrissur, the maximum mean fruit width was recorded for AC. 9 (24.80 cm) and the minimum for AC. 12 (11.90 cm).

The data on mean fruit width revealed that among all the 12 accessions the maximum fruit width was recorded for AC. 9 (24.80 cm) and the minimum for AC. 12 (11.90 cm) collected from Thrissur.

4.2.1.1.3 Fruit weight

The mean values of fruit weight have shown that the maximum fruit weight was for the accessions collected from Kottayam (1117.92 g) followed by Thrissur (1007.05 g) and minimum for that from Ernakulam (884.04 g).

Among all the 12 accessions collected, the maximum mean fruit weight was for AC. 9 (1756.67 g) collected from Thrissur and the minimum mean fruit weight was for AC. 6 (546.50 g) collected from Ernakulam.

Within Kottayam, the maximum fruit weight was recorded for AC. 2 (1483.33 g) and the minimum for AC. 3 (873.33 g). Among the four accessions collected from Ernakulam, the maximum fruit weight was recorded for AC. 5 collected from Kothamangalam (1380.00 g) and the minimum for AC. 6 (546.50 g) collected from Aluva. Within Thrissur, the maximum fruit weight was recorded for AC. 9 collected from Vilangannoor (1750.67 g) and minimum for AC. 12 (566.40 g) collected from Varakkara.

4.2.1.1.4 Rind weight

Out of the 12 accessions studied, the maximum mean rind weight was recorded for AC. 9 (993.87 g) collected from Thrissur and the minimum for AC. 7 collected from Ernakulam.

Among the three areas, the mean rind weight was the maximum for accessions collected from Thrissur (462.08 g), followed by accessions collected from Kottayam (423.66 g) and the minimum for accessions collected from Ernakulam (262.10 g).

Data on the mean rind weight collected from four accessions of Thrissur revealed that, the maximum rind weight was for AC. 9 (993.90 g) from Vilangannoor and the minimum for AC. 12 collected from Varakkara. Among the four accessions collected from Ernakulam, the maximum mean rind weight was recorded for AC. 5 (401.67 g) collected from Kothamangalam and minimum for AC. 7 (161.50 g) collected from Thottumugham. Among the four accessions collected from Kottayam, the maximum mean rind weight was recorded for AC. 2 (681.67 g) from Kottayam and minimum for AC. 3 (207.00 g) from the same district.

4.2.1.1.5 Number of segments

The maximum number of segments was recorded for AC. 3 (14.67) collected from Kottayam, followed by AC. 12 (14.00) collected from Thrissur. The minimum number of segments was recorded for AC. 7 (10.33) collected from Thottumugham, Ernakulam.

Among the three districts, the maximum mean number of segments was recorded for the accessions collected from Kottayam (13.17), followed by Thrissur (12.83) and minimum for accessions collected from Ernakulam (11.17).

Among the four accessions collected from Kottayam, the maximum number of segments was recorded for AC. 3 (14.67). The minimum number of segments was recorded for AC. 4 collected from Chempu (12.00). Among the four accessions collected from Thrissur, maximum number of segments was recorded for AC. 12 (14.00) and minimum for AC. 10 (11.33). Among the four accessions collected from Ernakulam, maximum number of segments was recorded for AC. 5 (12.33) collected from Kothamangalam and minimum for AC. 7 (10.33) collected from Thottumugham.

4.2.1.1.6 Segment Weight

The maximum mean segment weight was recorded for AC. 5 (971.67 g) collected from Kothamangalam and the minimum for AC. 12 (313.90 g) collected from Thrissur.

The mean values of segment weight collected from the three districts indicated that the accessions from Kottayam (686.01 g) had maximum segment weight, followed by accessions from Ernakulam (619.04 g) and minimum for the accessions from Thrissur (544.26 g).

Within Kottayam district, AC. 2 (790.00 g) had the maximum segment weight and AC. 4 (633.03 g) had the minimum segment weight. Similarly within Ernakulam, AC. 5 (971.67 g) had maximum segment weight and AC. 7 (365.37 g) had minimum segment weight. Among the four accessions collected from Thrissur, AC. 9 (761.53 g) recorded maximum segment weight and AC. 12 (313.90 g) collected from Varakkara had minimum segment weight.

4.2.1.1.7 Juice content

The maximum mean juice percentage was recorded for accessions collected from Kottayam (62.24 %) followed by accessions from Thrissur (58.64 %) and minimum for accessions from Ernakulam (53.32 %).

Among all the 12 accessions, the maximum juice content was recorded for AC. 11 (74.83 %) from Peechi followed by AC. 3 (73.70 %) from Kottayam and minimum for AC. 12 (35.23 %) from Varakkara.

Within Kottayam, the mean values indicated that the maximum juice content was recorded for AC. 3 (73.70 %) and minimum for AC. 1 (45.33 %). Within Ernakulam, the mean value for juice content was maximum for AC. 5 (65.07 %) from Kothamangalam and minimum for AC. 7 (45.33 %) from Thottumugham. Within, Thrissur, the maximum juice content was recorded for AC. 11 (74.83 %) and minimum for AC. 12 (35.23 %).

4.2.1.2 *Bio chemical attributes*

4.2.1.2.1 Total soluble solids (TSS)

The maximum TSS was for the fruits collected from Kottayam on an average (8.36° brix) followed by Thrissur (8.32° brix) and minimum from Ernakulam (8.23° brix). Among the 12 accessions studied, the maximum TSS was recorded for AC. 2 from Kottayam (9.27° brix) and minimum for AC. 5 (6.47° brix) from Ernakulam.

Among the four accessions studied in Thrissur, AC. 11 (9.13° brix) recorded maximum TSS and AC. 9 (7.10° brix) recorded minimum TSS. Among the four accessions studied in Kottayam, AC. 2 collected from Kottayam recorded a maximum TSS of 9.27° brix and AC. 1 recorded a minimum TSS of 6.93° brix. Among the four accessions studied in Ernakulam, AC. 6 (9.00° brix) recorded maximum TSS and AC. 5 (6.47° brix) collected from Kothamangalam recorded minimum TSS.

4.2.1.2.2 Acidity

The maximum acidity was observed for AC. 3 (1.26 %) from Kottayam and minimum for AC. 6 (0.18 %) from Aluva. Among the areas, accessions from Kottayam recorded maximum acidity (0.94 %), followed by Thrissur (0.81 %) and minimum from Ernakulam (0.74 %).

Within Kottayam, maximum acidity was recorded for AC. 3 (1.26 %) and minimum for AC. 1 (0.68 %). Within Ernakulam, maximum acidity was recorded for AC. 5 (0.84 %) from Kothamangalam and minimum for AC. 6 (0.18 %) from Aluva. Within Thrissur, maximum acidity was recorded for AC. 9 (1.22 %) from Vilangannoor and minimum for AC. 12 (0.55 %) from Varakkara.

4.2.1.2.3 Total sugars

The maximum mean total sugar content was recorded for AC. 2 from Kottayam (6.70 %) and minimum for AC. 9 (4.13 %) from Vilangannoor. Among the three districts, accessions from Kottayam recorded maximum mean total sugar content of (5.27 %) followed by Ernakulam (5.17 %) and then Thrissur (5.12 %).

Within Kottayam, the maximum total sugar content was recorded for AC. 2 (6.70 %) and minimum for AC. 4 (4.42 %).Within Ernakulam, the maximum total sugar content was observed for AC. 7 (6.51 %) and minimum for AC. 5 (4.41 %) from Kothamangalam. Within Thrissur, the maximum total sugar content was observed for AC. 11 (6.59 %) and minimum for AC. 9 (4.13 %).

4.2.1.2.4 Reducing sugars

The maximum mean reducing sugar content was recorded for AC. 11 from Thrissur (2.66 %) and minimum for AC. 8 (0.79 %) from Ernakulam. Among the three districts, accessions from Ernakulam recorded maximum mean reducing sugar content of (1.82 %) followed by Kottayam (1.79 %) and then Thrissur (1.49 %).

Within Kottayam, the maximum reducing sugar content was recorded for AC. 1 (2.14 %) and minimum for AC. 4 (1.48 %).Within Ernakulam, the maximum reducing sugar content was observed for AC. 6 (2.53 %) and minimum for AC. 8 (0.79 %). Within Thrissur, the maximum reducing sugar content was observed for AC. 11 (2.66 %) and minimum for AC. 10 (1.31 %).

4.2.1.2.5 Non reducing sugars

The maximum mean non reducing sugar content was recorded for AC. 2 from Kottayam (4.84 %) and minimum for AC. 6 (2.02 %) from Ernakulam. Among the three districts, accessions from Thrissur recorded maximum mean non reducing sugar content of (3.61 %) followed by Kottayam (3.50 %) and then Thrissur (3.36 %).

Within Kottayam, the maximum non reducing sugar content was recorded for AC. 2 (4.84 %) and minimum for AC. 4 (2.94 %).Within Ernakulam, the maximum non reducing sugar content was observed for AC. 8 (4.41 %) and minimum for AC. 6 (2.02 %). Within Thrissur, the maximum non reducing sugar content was observed for AC. 11 (4.79 %) and minimum for AC. 9 (2.71 %).

4.2.1.2.6 Ascorbic acid

The maximum ascorbic acid content was observed for fruits collected from Ernakulam (48.09 mg / 100 ml) followed by Kottayam (46.72 mg / 100 ml) and Thrissur (46.13 mg / 100 ml).

Among the 12 accessions, the maximum ascorbic acid content was observed in AC. 7 (73.33 mg / 100 ml) from Thottumugham and minimum for AC. 10 (23.53 mg / 100 ml) from Amballur.

Within Ernakulam, the maximum ascorbic acid content was for AC. 7 (73.33 mg / 100 ml) and minimum for AC. 8 (32.90 mg / 100 ml). Within Thrissur, the maximum ascorbic acid content was for AC. 12 (72.53 mg / 100 ml) from Varakkara and minimum for AC. 10 (23.53 mg / 100 ml). Within Kottayam, maximum ascorbic acid content was for AC. 3 (70.37 mg / 100 ml) from Kottayam and minimum for AC. 1 (30.67 mg / 100 ml) from Kumarakam.

4.2.1.3 *Sensory attributes*

4.2.1.3.1 Colour of vesicles

All the accessions collected from Kottayam had pink coloured flesh. Among the accessions collected from Ernakulam, AC. 5 and AC. 6 collected from Kothamangalam and Aluva respectively had red coloured flesh. AC. 7 and AC. 8 had pink coloured flesh

Among the accessions collected from Thrissur, AC. 9 had light pink flesh and accessions 10, 11 and12 had red coloured flesh (Plate 7).

4.2.1.3.2 Colour of juice

All the accessions from Kottayam showed pink coloured juice. Among the accessions from Ernakulam, AC. 5 and AC. 6 had reddish coloured juice and AC. 7 and AC. 8 had pink coloured juice. Among the accessions collected from Thrissur, AC. 9 had pink coloured juice and accessions 10, 11 and 12 had red coloured juice (Plate 7).

4.2.1.3.3 Juice taste

Most of the accessions collected from three districts showed poor or very poor taste as the juice was bitter. AC. 3 and AC. 11 was found to have a comparatively better taste.

4.2.1.3.4 Juice flavour

The juice flavour was recorded as medium to poor in almost all the cases.

4.1.2 Physico- chemical and sensory attributes of selections collected from Bangalore

4.1.2.1 Physico- chemical attributes

Information regarding the physical and chemical characters of fruits of four selections collected from IIHR, Bangalore is given in the Table 7.

4.2.2.1.1 Fruit weight

On an average, the maximum fruit weight was recorded for the Selection Midnapur (3333.00 g) and the minimum fruit weight for the Selection Kharapur (473.50 g). Other two selections *viz.*, IKP-2 recorded a fruit weight of 2300.33 g and Devanahalli a fruit weight of 1898.33 g respectively.

Table 6. Sensory attributes of the different accessions collected from Kerala (ripe stage)

Area of collection	AC. No.	Colour of vesicles	Colour of juice	Juice taste	Juice flavour
Kottayam	01	Pink	Pink	Poor	Medium
	02	Pink	Pink	Poor	Medium
	03	Pink	Pink	Fair	Poor
	04	Pink	Pink	Poor	Poor
Ernakulam	05	Red	Red	Poor	Medium
	06	Red	Red	Poor	Medium
	07	Pink	Pink	Poor	Medium
	08	Pink	Pink	Very Poor	Poor
Thrissur	09	Light pink	Pink	Very Poor	Poor
	10	Red	Red	Very Poor	Poor
	11	Red	Red	Fair	Medium
	12	Red	Red	Poor	Medium

Table 7. Variation in physical characters and chemical constituents of different selections collected from IIHR, Bangalore

Selections	Fruit weight (g)	Rind weight (g)	Segment weight (g)	Juice content (%)	TSS (° β)	Acidity (%)	Total Sugars (%)	Reducing Sugars (%)	Non Reducing sugars (%)	Ascorbic Acid (mg / 100 ml)
IKP-2	2300.33	866.67	1421.33	59.07	9.00	1.05	5.95	2.85	3.03	66.22
Kharapur	473.50	163.33	304.17	42.37	9.50	1.06	5.81	4.01	1.80	40.75
Midnapur	3333.00	1400.00	1931.33	60.73	8.50	0.89	4.93	2.90	2.03	62.67
Devanahalli	1898.33	720.33	1185.17	54.10	8.50	0.84	4.75	2.92	1.82	62.83
Mean	**2001.29**	**787.58**	**1210.50**	**54.07**	**8.88**	**0.96**	**5.61**	**3.17**	**2.42**	**58.12**
CD	**20.50**	**68.47**	**64.72**	**0.88**	**0.00**	**0.00**	**0.00**	**0.03**	**0.06**	**1.04**

4.2.2.1.2 Rind weight

The data on the mean values of rind weight recorded revealed that the maximum rind weight was for Midnapur (1400.00 g) followed by IKP-2 (866.67 g) and Devanahalli (720.33 g). The minimum rind weight was for Kharapur (163.33 g).

4.2.2.1.3 Segment weight

The maximum segment weight was recorded for Midnapur (1931.33 g) and the minimum for Kharapur (304.17 g).

4.2.2.1.4 Juice content

The highest juice percentage was recorded for Midnapur (60.73 per cent) and the least for Kharapur (42.37 per cent). IKP-2 closely followed Midnapur with a juice percentage of 59.07 per cent.

4.2.2.1.5 Total soluble solids (TSS)

The maximum TSS was recorded for the Selection Kharapur (9.50° brix), followed by IKP-2 (9.00° brix). Midnapur and Devanahalli recorded a TSS of 8.50° brix.

4.2.2.1.6 Acidity

The selection Kharapur recorded the maximum mean acidity of 1.06 per cent followed by IKP-2 (1.05 %). Midnapur and Kharapur had a mean acidity of 0.89 per cent and 0.84 per cent respectively.

4.2.2.1.7 Total sugars

The total sugar content recorded was maximum for the type IKP-2 (5.95 %), followed by Kharapur (5.81 %). The Selection Midnapur recorded an average total sugar content of 4.93 per cent and selection Devanahalli recorded a total sugar content of 4.95 per cent.

4.2.2.1.8 Reducing sugars

The maximum reducing sugar content was for Kharapur (4.01 %) and the minimum was recorded for Midnapur (2.90 %).

4.2.2.1.9 Non reducing sugars

The mean non reducing sugar content was maximum for IKP-2 (3.03 %) and minimum for kharapur (1.80 %).

4.2.2.1.10 Ascorbic Acid (Vitamin C)

The mean values recorded for ascorbic acid content revealed that the selection IKP-2 contain the maximum ascorbic acid content of 66.22 mg / 100 ml followed by

Devanahalli (62.83 mg / 100 ml) and Midnapur (62.67 mg / 100 ml). The minimum was recorded for Kharapur (40.75 mg / 100 ml).

4.1.2.2 *Sensory attributes*

Information regarding the sensory attributes of selections collected from IIHR, Bangalore is given in the Table 8.

4.2.2.2.1 Colour of the vesicles

The selections IKP-2, Devanahalli were red in colour. The selection Kharapur and Midnapur were pale yellow in colour.

4.2.2.2.2 Colour of the juice

The juice extracted from the selection IKP-2 and Devanahalli also showed red colour. The selections Kharapur and Midnapur gave a cream coloured juice (Plate 8).

4.2.2.2.3 Juice taste / Bitterness

All the selections had good taste with less bitterness. The minimum bitterness was recorded for IKP-2 followed by Kharapur.

4.2.2.2.4 Juice Flavour

All the selections had good flavour.

4.2.3 *Comparative evaluation of types collected from IIHR, Bangalore and Kerala*

The data on the comparison between IIHR types and Kerala types is given in the Table 9.

4.2.3.1 Fruit weight

The IIHR selections recorded more fruit weight (2001.29 g) than Kerala (1003.00g).

4.2.3.2 Segment weight

The segment weight (1210.50 g) of the Bangalore selections was also more than that of Kerala types (616.44 g).

4.2.3.3 Juice percentage

The juice per cent was higher in Kerala types (58.33 %) whereas the Bangalore types recorded 54.07 per cent on an average.

4.2.3.4 TSS (° brix)

The TSS was very high in IIHR selections (8.90° brix) compared to the Kerala accessions (8.33° brix).

Table 8. Sensory attributes of the different selections collected from IIHR, Bangalore

Selections	Colour of vesicles	Colour of juice	Juice taste	Juice flavour
IKP- 2	Red	Red	good	good
Kharapur	Pale yellow	cream	fair	good
Midnapur	pale yellow	cream	fair	good
Devanahalli	Red	red	good	good

Table 9. Comparative evaluation of types collected from IIHR, Bangalore and Kerala

Parameters	Bangalore	Kerala
Fruit weight (g)	2001.29	1003.00
Segment weight (g)	1210.50	616.44
Juice (%)	54.07	58.33
TSS (° brix)	8.90	8.33
Acidity (%)	0.96	0.83
Total Sugars (%)	5.61	5.19
Ascorbic Acid (mg / 100 ml)	58.12	46.98

4.2.3.5 Total sugar content

The total sugar content was more in IIHR selections (5.61 %) compared to Kerala accessions (5.19 %).

4.2.3.6 Acidity

The acidity recorded for Bangalore selections was 0.96 per cent and for Kerala accessions was 0.83 per cent.

4.2.3.7 Ascorbic acid (mg / 100 ml)

The ascorbic acid content recorded was also high in IIHR selections (58.12 mg / 100 ml) compared to Kerala accessions (46.98 mg / 100 ml).

4.3 Effect of peeling made easy techniques

4.3.1 *Lye peeling*

The information regarding the lye peeling is recorded in the Table 10 (Plate 9).

4.3.1.1 Extend of peel removed

The extend of peel removed was zero per cent for all the three concentrations (1.5, 2.0 and 2.5 %) of lye solution tried for a contact time of zero seconds. The result was same when the segments were treated with lye solution at a concentration of 1.5 per cent for a contact time of 60 and 75 seconds. The average percentage of peel removed when the segments were treated with lye solution at 1.5 per cent for 90 and 120 seconds were 25.66 per cent and 36.66 per cent respectively. The peel started to remove when the segments were treated in higher concentration of lye. The extend of peel removed was increased to an average value of 64.66 per cent when 2 per cent lye solution was used for a contact time of 60 seconds. The average percentage of peel removed for 2 per cent lye solution for a contact time of 75, 90 and 120 seconds were 66.66 per cent, 71.33 per cent and 75.00 per cent respectively. The extend of peel removed when the segments were treated in 2.5 per cent lye solution for contact time of 60, 75, 90 and 120 seconds was 75.00 per cent, 77.33 per cent, 83.66 per cent and 90.00 per cent respectively.

4.3.1.2 Colour of flesh

There was no change in colour of flesh, when the segments were treated in lye solution at all concentrations (1.5, 2.0 and 2.5 %) at zero contact time compared to the control. The lye solution at 1.5 per cent also did not change the colour of flesh for all contact times (60, 75, 90 and 120 seconds). Treatment of the segments with lye solutions

Table 10. Effect of lye on peeling of pummelo fruit segments

Concentration of lye (%)	Observation	Duration of treatment (seconds)				
		0	60	75	90	120
1.5	Extend of peel removed (%)	0.00	0.00	0.00	25.66	36.66
	Change in colour of flesh	Nil	Nil	Nil	Nil	Nil
	Rupture of juice vesicle	Nil	Nil	Nil	Nil	Nil
2.0	Extend of peel removed (%)	0.00	64.66	66.66	71.33	75.00
	Change in colour of flesh	Nil	Nil	Nil	Medium	Medium
	Rupture of juice vesicles	Nil	Slight	Slight	Slight	Medium
2.5	Extend of peel removed (%)	0.00	75.00	77.33	83.66	90.00
	Change in colour of flesh	Nil	Medium	Medium	High	High
	Rupture of juice vesicles	Nil	Medium	Medium	High	High
Control	Extend of peel removed (%)	0.00	0.00	0.00	0.00	0.00
	Change in colour of flesh	Nil	Nil	Nil	Nil	Nil
	Rupture of juice vesicles	Nil	Nil	Nil	Nil	Nil

at 2 per cent for 90 and 120 seconds started to deteriorate the colour of flesh and the colour change recorded was medium. Similarly, the treatment with lye solution at 2.5 per cent concentration recorded medium colour change for the contact times of 60 and 75 seconds and high change in colour of flesh for the contact times of 90 and 120 seconds.

4.3.1.3 Rupture of juice vesicles

The rupture of juice vesicles recorded was "nil" on an average when the segments were dipped in 1.5 per cent lye solution for all contact times. The juice vesicles ruptured was "nil" in 2.0 per cent lye solution at zero contact time, "slight" for 60, 75 and 90 seconds contact time and "medium" for 120 seconds contact time. In segments treated with 2.5 per cent lye solution, rupture of juice vesicles recorded was "nil" for zero contact time, "medium" for 60 and 75 seconds and "high" for 90 and 120 seconds.

4.3.2 ***Effect of steaming the pummelo fruit segments (smearing and dipping) on sensory attributes of juice***

The sensory score values pertaining to the effect of steaming the segments after smearing with salt and sugar is given in the Table 11 and 12.

4.3.2.1 Appearance

In the treatment where the segments were smeared with salt and subjected to steaming, the score for appearance was "fair" for all the concentrations. When the segments were smeared with sugar and steamed, the effect was same as that of control as both gained the score "fair".

When the segments were dipped in brine and syrup at different concentrations, the effect was same except for brine at 25 per cent and 30 per cent concentrations.

4.3.2.2 Colour

When the segments were smeared with salt and sugar, the score for colour ranged from "poor" to "fair".

When the segments were dipped in brine and syrup, the score for colour was "fair" for all treatments, except for brine at concentrations 10 and 15 per cent. The score for these treatments were "good".

4.3.2.3 Flavour

The flavour was ranked "poor" in most of the treatments and "fair" for smearing salt at 4 and 5 per cent levels.

Table 11. Effect of steaming of pummelo fruit segments (after smearing salt and sugar) on sensory attributes of juice

Treatments		Appearance	Colour	Flavour	Taste	Overall acceptability
Salt	1 per cent	3.00	2.00	2.00	2.33	2.33
	2 per cent	3.00	2.33	2.00	2.33	2.33
	3 per cent	3.00	2.00	2.33	2.00	2.00
	4 per cent	3.33	2.00	3.00	2.00	2.00
	5 per cent	3.33	2.00	3.66	3.00	3.00
Sugar	1 per cent	3.00	3.00	2.00	2.00	2.00
	2 per cent	3.00	3.00	2.00	2.00	2.00
	3 per cent	3.00	3.00	2.00	2.00	2.00
	4 per cent	3.00	3.00	2.00	2.00	2.00
	5 per cent	3.00	3.00	2.00	3.00	2.00
Control		3.00	2.00	2.00	2.00	2.00

Table 12. Effect of steaming the pummelo fruit segments (after dipping in brine and syrup) on sensory attributes of juice

Treatments		Appearance	Colour	Flavour	Taste	Overall acceptability
Brine	0 per cent	3.00	2.00	2.00	2.00	2.00
	10 per cent	3.00	3.66	2.00	3.00	3.00
	15 per cent	3.00	3.66	2.00	4.00	3.00
	20 per cent	3.00	3.00	2.33	3.00	3.00
	25 per cent	3.66	3.00	2.33	3.00	3.00
	30 per cent	3.66	3.00	2.33	3.00	3.00
Syrup	0 per cent	3.00	2.00	2.00	2.00	2.00
	10 per cent	3.00	3.00	3.00	2.33	3.00
	15 per cent	3.00	3.00	3.00	4.00	3.00
	20 per cent	3.00	3.00	3.00	4.00	3.00
	25 per cent	3.00	3.00	3.00	4.00	3.00
	30 per cent	3.00	3.00	3.00	4.00	3.00
Control		3.00	2.00	2.00	2.00	2.00

Plate 9. Effect of lye on peeling of fruit segments

Lye at low concentration

Lye at high concentration

Plate 10. Effect of steaming on peeling of pummelo segments

Steamed juice vesicles

4.3.2.4 Taste

The score for taste was "fair" for segments smeared with salt at concentration 5 per cent and for segments smeared with sugar at 5 per cent.

When the juice was extracted from the segments after dipping in brine and steaming, the taste of the juice was scored "good" at brine strength 15 per cent. The use of syrup at concentrations 15, 20, 25 and 30 per cent also gained "good" score.

4.3.2.5 Overall acceptability

The overall acceptability was highest for the juice extracted after dipping the segments in brine at concentration 15 per cent and then steaming. It gained a score "good". Other treatments ranked between fair to poor.

4.3.3 ***Biochemical attributes of pummelo juice (after dipping)***

The biochemical attributes of pummelo juice extracted from the segments after dipping in brine and syrup at different concentrations for 15 minutes and steaming for 15 minutes in water bath are presented in Table 13.

4.3.3.1 Total soluble sugars (TSS)

The TSS did not record much significant difference in the juice compared with the control in all the treatments with brine 10, 15, 20, 25 and 30 per cent. The values ranged between 8.7° brix to 8.9° brix.

When the segments were dipped in syrup and steamed, the TSS of the juice was slightly raised. It was 8.9° brix in control which was raised to 9.0° brix in 10 per cent syrup, 9.5° brix in 20 per cent syrup and 10.0° brix in 30 per cent syrup.

4.3.3.2 Acidity

The acidity of the juice was raised at higher brine concentrations. The value recorded was 1.2, 1.25 and 1.3 per cent at 20, 25 and 30 per cent brine solution whereas in control it was 0.79 per cent.

The juice extracted after dipping the segments in syrup and steaming did not show much change in acidity values compared to control.

4.3.3.3 Ascorbic acid

The ascorbic acid content did not record significant changes in all treatments. The value ranged from 57.00 mg / 100ml to 60.20 mg / 100ml.

Table 13. Effect of steaming the pummelo fruit segments (after dipping in brine and syrup) on biochemical attributes of juice

Treatment		Acidity (%)	TSS (° brix)	Ascorbic acid (mg/100ml)
Brine	0 per cent	0.79	8.90	59.60
	10 per cent	0.90	8.80	59.00
	15 per cent	0.90	8.80	59.20
	20 per cent	1.00	8.80	58.00
	25 per cent	1.20	8.70	58.00
	30 per cent	1.30	8.70	57.40
Syrup	0 per cent	0.79	8.90	57.00
	10 per cent	0.80	9.00	58.80
	15 per cent	0.79	9.20	59.06
	20 per cent	0.79	9.50	57.10
	25 per cent	0.79	10.00	56.09
	30 per cent	0.79	10.00	57.22
Control (Hand extracted juice)		0.79	8.90	60.20

4.2 Effect of method of juice extraction on physico chemical components and sensory attributes of pummelo juice

4.3.1 Effect of sugar and period of incubation on juice yield and quality

The physico chemical attributes of juice extracted from pummelo juice vesicles through osmoextraction are given in Table 14.

4.4.1 Juice yield

The influence of percentage of sugar and the period of incubation was found to influence the quantity and quality of juice. The yield of juice was increased as the level of the sugar was increased from 10 to 50 per cent. The juice yield ranged from 60 to 60.10 per cent when 10 per cent sugar was mixed with the juice vesicles and incubated for varying periods. The value was increased to about 68.88 per cent when the level of sugar was increased to 50 per cent and incubated for one to four hours.

4.4.2 Pomace yield

The pomace yield registered negative trend to that of juice yield. As the level of mixing of sugar was increased the pomace yield decreased.

4.4.3 Total soluble solids (TSS)

The TSS of the juice increased as the level of mixing of sugar was increased. The TSS of the juice ranged between 8.9° brix to 8.95° brix when juice vesicle was mixed with sugar at 10 per cent level. The TSS of juice recorded ranged between 16° brix to 16.03° brix when the level of mixing of sugar was increased to 50 per cent. The period of incubation had little effect on TSS of juice.

4.4.4 Acidity

The acidity of juice extracted from juice vesicles mixed with low level of sugar was high and the acidity decreased as the level of sugar was increased. The acidity of juice extracted from juice vesicles mixed with 10, 20, 30, 40 and 50 per cent ranged between 0.77 to 0.78, 0.68 to 0.77, 0.66 to 0.69, 0.67 to 0.68 and 0.66 to 0.68 per cent respectively.

4.4.5 Ascorbic acid

The ascorbic acid content of the juice extracted by mixing the juice vesicles with sugar at different levels and then incubated for varying periods did not record significant difference.

Table 14. Effect of sugar and period of incubation on juice yield and quality

Sugar percent	Incubation period (hours)	Juice content (%)	Pomace (%)	TSS (° β)	Acidity (%)	Ascorbic acid (mg / 100 ml)	Overall acceptability
10	1	60.00	40.00	8.90	0.78	56.00	very poor
	2	60.01	39.12	8.92	0.77	56.00	very poor
	3	61.01	39.00	8.93	0.77	56.01	very poor
	4	60.10	38.00	8.95	0.77	56.01	very poor
20	1	62.22	38.22	8.95	0.77	56.11	poor
	2	62.00	38.00	9.00	0.69	56.10	poor
	3	63.00	38.31	10.00	0.69	56.12	poor
	4	63.00	38.22	11.10	0.68	56.33	poor
30	1	65.52	38.11	12.10	0.66	56.14	fair
	2	65.50	35.00	13.00	0.69	56.22	fair
	3	67.12	35.60	14.00	0.69	56.32	good
	4	67.10	33.11	14.00	0.68	57.31	fair
40	1	68.00	32.42	14.50	0.67	56.32	poor
	2	67.20.	32.00	14.50	0.67	56.10	poor
	3	68.10	32.13	15.00	0.67	56.00	poor
	4	68.00	32.00	16.00	0.68	56.45	poor
50	1	68.85	32.33	16.00	0.66	57.50	very poor
	2	68.80	32.30	16.00	0.68	56.22	very poor
	3	68.88	32.33	16.02	0.68	57.12	very poor
	4	68.00	32.33	16.03	0.68	57.25	very poor
C. D		**6.08**	**6.10**	**0.52**	**0.00**	**0.60**	

4.4.6 Overall acceptability

The treatment with sugar at 30 per cent level scored "fair" to "good" at all concentrations. All other treatments scored "poor" to "very poor" for overall acceptability.

4.4.2 Effect of method of juice extraction on juice yield and physico chemical components of pummelo juice

The physico chemical attributes of juice extracted from pummelo fruit through various methods were analysed and the results are presented in Table 15.

4.4.2.1 Juice yield

Out of the four methods tried for extraction of juice from pummelo fruits, the highest content of juice (79.77 %) was obtained from fruits crushed in mixie and pressed with hand. Extraction through osmoextraction yielded 71.00 per cent juice. The lowest juice recovery was for fruits subjected to hand pressing (68.50 %).

4.4.2.2 Pomace percentage

Highest pomace per cent was recorded in screw pressing (38.33%), followed by extraction by hand pressing (34.90 %). The lowest pomace percentage was recorded when juice was extracted by crushing in mixie(24.60 %).

4.4.2.3. TSS

The TSS of the juice was highest when the fruits were subjected to osmotic extraction (14.3^0 brix). The TSS of juice extracted through hand pressing and crushing in mixie was 8.97^0 brix.

4.4.2.4. Acidity

The values for acidity of juice extracted through all the different methods were on par.

4.4.2.5. Ascorbic acid

The ascorbic acid content of juice extracted through osmotic method was recorded as 56.35 per cent, followed by hand pressing (56.16%) and crushing in mixie (56.14%). The value was lowest for screw pressing method (55.69%).

4.4.3 Effect of methods of juice extraction on sensory attributes of pummelo juice

The sensory attributes of pummelo juice extracted by the different methods are given in Table 16.

4.4.3.1. Appearance

Table 15. Effect of method of juice extraction on juice yield and its chemical attributes

Extraction method	Juice content (%)	Pomace (%)	TSS (° brix)	Acidity (%)	Ascorbic acid (mg / 100 ml)
T1	68.50	34.90	8.97	0.96	56.16
T2	71.93	38.33	8.73	0.92	55.69
T3	79.77	24.60	8.97	0.88	56.14
T4	71.00	33.67	14.33	0.97	56.35
Mean	**72.80**	**32.88**	**10.25**	**0.93**	**56.09**
C.D	**6.06**	**6.13**	**0.55**	**0.00**	**0.20**

Table 16. Effect of method of juice extraction on sensory attributes of juice.

Extraction method	Appearance	Colour	Flavour	Taste	Overall acceptability
T1	3	3	3	2	2
T2	2	2	1	1	1
T3	2	2	2	1	1
T4	3	4	3	3	3

T1 : Hand pressing.
T2 : Screw pressing.
T3 : Crushing in mixie.
T4 : Osmotic extraction.

The appearance of the juice extracted through hand pressing and osmotic extraction scored "fair" whereas the juice extracted through screw press and mixie scored "poor".

4.4.3.2. Colour

The colour of the juice was "poor" when extracted through screw press and mixie. The score for colour of the juice was "fair" for juice extracted through hand pressing and "good" for juice extraction by osmotic extraction.

4.4.3.3. Flavour

The flavour was "very poor" for juice extracted through screw pressing, "poor" for that extracted by crushing in mixie and "fair" for that extracted by hand pressing and osmotic extraction.

4.4.3.4 Taste

The juice extracted by screw pressing and by crushing in mixie scored "very Poor" for taste, "poor" for that extracted by hand pressing and "fair" for that extracted by osmotic extraction.

4.4.3.5. Overall Acceptability

The maximum score for overall acceptability was gained by juice extracted by osmotic extraction method (fair). The score gained by the juice extracted by hand pressing was "poor" and that obtained by screw pressing and crushing in mixie was "very poor".

4.5 Effect of debittering techniques on quality of pummelo juice.

4.5.1 *Sensory quality evaluation of pummelo juice in response to debittering techniques.*

Information regarding the sensory quality evaluation of pummelo juice in response to debittering techniques is given in the Table 17.

4.5.1.1 Appearance

The appearance of juice treated with sucrose (at all levels) to level to mask the bitterness scored "good" whereas the juice treated with pectinase enzyme (5 mg / 1000 ml) scored "fair". When scored for the appearance of the juice after raising the pH of the juice to 4.00, 4.25 and 4.50, the score gained was "fair". The juice treated with pectin scored "very poor" for all the three levels tried (1, 2 and 3 per cent level).

4.5.1.2 Colour

The colour of the juice kept as the control as well as that treatmented with sodium bicarbonate for raising pH and addition of sucrose was scored "good". The juice treated with pectinase enzyme scored "poor" for colour. The juice treated with pectin scored "very poor" for all levels.

4.5.1.3 Flavour

The control as well as the juice treated with sucrose (at all levels) scored "good" for flavour. The juice treated with pectinase enzyme scored "fair" where as raising of pH (at 4, 4.25 and 4.50) was not advantageous as the score gained was "poor". The flavour of juice added with pectin scored "very poor".

4.5.1.4 Taste

The juice treated with sucrose at 4 and 6 per cent levels scored "good' whereas the juice treated with sucrose at 2 per cent level scored "fair" for taste. The juice treated with pectinase as well as the juice kept as control and the treatment with sodium bicarbonate to raise the pH to 4 scored "fair". The taste of the juice was scored "poor" when pH was raised to 4.25 and 4.5. "Very poor" score was gained for the juice treated with pectin.

4.5.1.5 Overall acceptability

The maximum score for overall acceptability was for the juice treated with sucrose at 4 and 6 per cent levels. The juice treated with sucrose (2 per cent level), pectinase enzyme, sodium bicarbonate (pH 4) and the control ranked "fair" for overall acceptability. The juice treated with sodium bicarbonate (pH 4.25 and 4.5) scored "poor" for overall acceptability and the juice treated with pectin scored very poor.

4.5.2 *Effect of debittering techniques on biochemical attributes of pummelo juice*

The data pertaining to the effect of various debittering techniques on the biochemical attributes of pummelo juice is given in the Table 18.

4.5.2.1 pH

The pH of the juice treated with sodium bicarbonate to raise the pH to 4, 4.25 and 4.50 were recorded as 4.00, 4.20 and 4.50 respectively. The pH of the juice treated with pectin was recorded as 3.6 at all levels tried. The pH of the juice treated with sucrose (at all levels) and pectinase enzyme recorded a value of 3.5.

Table 17. Effect of debittering techniques on sensory attributes of pummelo juice.

Sl. No.	Parameters	Control	Raising of pH	Addition of pectin	Addition of Sucrose	Addition of pectinase enzyme
1	Appearance	3.00	3.66	1.00	4.00	3.00
2	Colour	4.00	4.00	1.00	4.33	3.66
3	Flavour	4.00	2.00	1.00	4.33	3.00
4	Taste	3.00	2.00	1.00	4.00	3.66
5	Overall acceptability	3.00	3.00	1.00	4.00	3.00

Table 18. Effect of debittering techniques on biochemical attributes of pummelo juice

Method		pH	Acidity (%)	Ascorbic acid (mg/ 100 ml)
Raising of pH	4.00 per cent	4.00	0.70	59.00
	4.25 per cent	4.20	0.40	58.50
	4.50 per cent	4.50	0.10	58.80
Addition of pectin	1.00 per cent	3.60	1.00	57.50
	2.00 per cent	3.60	1.00	58.80
	3.00 per cent	3.60	1.00	58.50
Addition of Sucrose	2.00 per cent	3.50	1.00	58.50
	4.00 per cent	3.50	1.00	58.50
	6.00 per cent	3.50	1.03	57.70
Addition of pectinase enzyme	5 mg / 1000 g	3.50	1.00	58.50
Control		3.60	0.90	59.00

4.5.2.2 Acidity

The acidity of the juice treated with sodium bicarbonate to raise the pH to 4, 4.25 and 4.5 was recorded as 0.7, 0.4 and 0.1 respectively. The acidity of the juice treated with pectin and sucrose was recorded as 1.0 per cent at all levels. The acidity of the juice treated with pectinase enzyme was recorded as 1.00 percent.

4.5.2.3 Ascorbic acid

The ascorbic acid content of the juice treated with sodium bicarbonate to raise the pH to 4, 4.25 and 4.5 was recorded as 59.0, 58.5 and 58.8 mg / 100 ml respectively. The ascorbic acid content of the juice treated with pectin at 1.0, 2.0 and 3.0 per cent was recorded as 57.5, 58.8 and 58.5 mg / 100 ml respectively. Ascorbic acid content of the juice treated with sucrose at 2 per cent and 4 per cent was recorded as 58.5 mg / 100 ml and at 6 per cent level was recorded as 57.7 mg / 100 ml. For the treatment of addition of pectinase enzyme, the ascorbic acid content was recorded as 58.5 mg / 100 ml.

4.6 Products based on Pummelo juice

The juice for product preparation was extracted by the best method identified through experiment 3 and 4 (dipping the segments in brine at 15 per cent strength for 15 minutes followed by steaming in water bath for 15 minutes, hand peeling and pressing). This was used alone as well as after blending with orange, grape and mango juice at various proportions for preparation of products *viz.*, sweetened juice, RTS and squash (Plate 10). The quality of the products was evaluated through scoring for sensory attributes.

4.6.1 ***Effect of blending***

Pummelo juice was blended with orange, grape and mango juice at various levels and scored for acceptability. The results are given in Table 19.

4.6.1.1 Appearance

When the orange juice was blended with pummelo juice at different levels, the blend at 30: 70 gained "fair" score. Other two levels were scored "poor" for appearance.

The juice blended with grape and mango juice (at all levels) scored poor to very poor.

Table 19. Sensory attributes of pummelo juice blended with other juice.

Juice	Level of blending		Appearance	Colour	Flavour	Taste	Overall acceptability
	Orange	Pummelo					
Orange	10	90	2	2	3	1	2
	20	80	2	2	3	2	2
	30	70	3	3	3	3	3
Grape	Grape	Pummelo					
	10	90	1	2	2	2	2
	20	80	1	2	2	2	2
	30	70	2	2	2	2	2
Mango	Mango	Pummelo					
	10	90	2	2	1	1	2
	20	80	2	2	1	2	2
	30	70	2	2	1	2	2
Control	Pummelo juice		2	2	3	2	2

Table 20. Sensory attributes of blended sweetened juice based on pummelo

Blend	Sugar content (%)	Appearance	Colour	Flavour	Taste	Overall acceptability
Orange juice 30 % + Pummelo juice 70%	20	3	3	2	2	2
	25	3	3	3	3	3
	30	3	4	3	4	4
	35	3	3	3	3	3
Pummelo juice	20	2	2	2	2	2
	25	2	2	2	2	2
	30	2	2	2	3	2
	35	2	2	2	3	2

Table 21. Sensory attributes of pummelo RTS and squash prepared with pummelo juice and selected blended juice

Products	Type	Appearance	Colour	Flavour	Taste	Overall acceptability
RTS	Pummelo juice	2	2	1	1	2
	Blended juice (Orange juice 30 % + Pummelo juice 70%)	3	3	3	3	3
Squash	Pummelo juice	2	2	1	1	2
	Blended juice (Orange juice 30 % + Pummelo juice 70%)	3	3	3	3	3

Plate 11. Products based on pummelo juice

Sweetened juice

RTS

Squash

4.6.1.2 Colour

The colour of the blend orange: pummelo at 30: 70 level scored "fair" and all other levels of blending with orange juice and mango juice as well as for grape juice scored "poor".

4.6.1.3 Flavour

The flavour of the pummelo juice blended with grape juice and mango juice at all levels scored "poor" and blended with orange juice scored "fair" at all levels.

4.6.1.4 Taste

The taste of the juice blended with orange juice at 30: 70 level scored "fair" while all other blends scored "poor".

4.6.1.5 Overall acceptability

The overall acceptability for juice blended with orange juice at 30: 70 level gained the score "fair". Other levels of blending with orange juice, grape juice and mango juice scored "poor".

4.6.2 ***Sensory attributes of sweetened juice***

The sensory attributes of the sweetened juice prepared with pummelo juice alone and that with blended juice (pummelo: orange at 70: 30 level) are given in Table 20.

4.6.2.1 Appearance

The appearance of the sweetened juice prepared with pummelo juice alone was scored "poor" at all levels of sugar added. The appearance of the blended sweetened juice was scored "fair" at all levels of sugar added.

4.6.2.2 Colour

The colour of the blended sweetened juice prepared by adding sugar at 30 per cent level was scored "good" whereas the juice added with sugar at all other levels were scored "fair".

4.6.2.3 Flavour

The flavour of the blended sweetened juice was ranked "fair" for sugar at 25, 30 and 35 per cent level and "poor" for sugar at 20 per cent level. The flavour of the sweetened pummelo juice was ranked "poor".

4.6.2.4 Taste

The taste of the sweetened juice was ranked "good" for blended sweetened juice at 30 per cent level and "fair" for 25 and 35 per cent level and "poor" for 20 per cent level. The score for pummelo sweetened juice was "poor" for added with sugar at all levels.

4.6.2.5 Overall acceptability

The overall acceptability was scored "good" for blended sweetened juice added with sugar at 30 per cent level and "fair" at 25 and 35 per cent sugar level.

4.6.3 Ready to serve beverage (RTS) and Squash.

The sensory attributes of RTS and squash prepared with pummelo juice alone and blended juices are given in Table 21.

4.6.3.1 Appearance

The appearance of RTS and squash prepared with blended juice ranked "fair" and that prepared with pummelo juice alone ranked "poor".

4.6.3.2 Colour

The colour of the RTS and squash prepared with blended juice ranked "fair" and that prepared with pummelo juice alone ranked "poor".

4.6.3.3 Flavour

The flavour of RTS and squash ranked "very poor" for that prepared from pummelo juice alone and "fair" for that prepared from blended juice.

4.6.3.4 Taste

The taste was "very poor" for RTS and squash prepared with pummelo juice alone and "fair" for that prepared with blended juice.

4.6.3.5 Overall Acceptability

The overall acceptability was "fair" for RTS and squash prepared with blended juice and "poor" for that prepared with pummelo juice alone.

Discussion

5. Discussion

Pummelo (*Citrus grandis* (L.) Osbeck) is wide spread throughout S.E Asia and can be found growing in home gardens and small plantations. It is a bushy, spreading evergreen with weeping habit induced by the weight of large fruits. It possesses the largest fruit among citrus in the world. A single tree bears 70 to 100 fruits per year. The fruits serve as the cheap source of vitamin C, minerals and possess many medicinal properties (Paudyal and Haq, 1999).

A survey conducted by Anupama (2006) in different parts of Kerala could collect 40 accessions of pummelo with wide genetic variability with respect to tree growth, plant and fruit characters. Even though there do not exist pummelo orchards in our state, it is grown as a prime entity in many homesteads especially in Kottayam, Thrissur and Ernakulam districts. When we analyse the post harvest scenario of this nutritionally rich fruit it can be seen that a major chunk of production is simply wasted. The consumption and utilization is mainly in the form of fresh fruits. Extraction of juice and its utilisation afresh is also there in limited scale. A discussion with the growers helped to identify the problem that stand in the way of utilisation of this citrus resource in its full potential.

The post harvest utilisation of this fruit is almost "zero" apart from its consumption in raw form. Many do not know when the fruits are to be harvested and as a result , the fruits are plucked without any criteria or the fallen fruits are collected . So the real taste or quality of these fruits is not being enjoyed by the consumers. Eventhough there exist types that produce highly acceptable fruits with respect to eating quality, a scientific accounting of such types is not done so far. Because of this, the farmers grow any type which is available to them.

There do not exist any method for enhancing the shelf life of fruits retaining their quality. The fruits usually develop bitterness during storage and it progressively increase with time. The fruit is quite big in size with about thirty eight per cent rind. The average segment weight range between 545 g to 686 g and the juice per cent of the fruit is between 45 and 61 per cent. The segments are covered with thick peel, which usually adhere with the juice vesicles. Removal of the peel is difficult and the processor will appreciate if suitable technique of peeling could be evolved through research efforts. Similarly extraction of juice is also difficult and the hand pressing generally yield low quantity of juice. The juice after extraction develops delayed bitterness as well. So an easy and ideal method for extraction of quality juice from pummelo is required for encouraging its processing. Because of these problems, the processing and product development gained little attention at present. Considering all this practical problems faced by the pummelo growers, the present study was taken up.

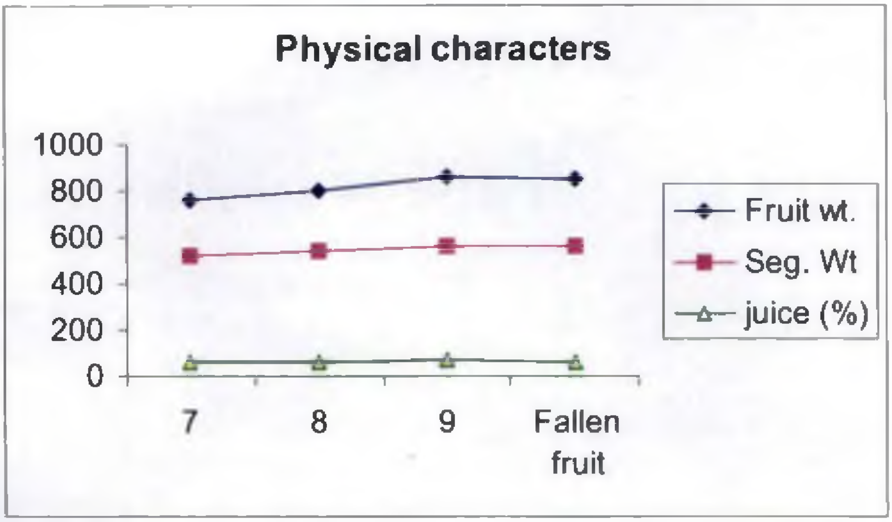
5.1 Standardization of optimum stage of harvest

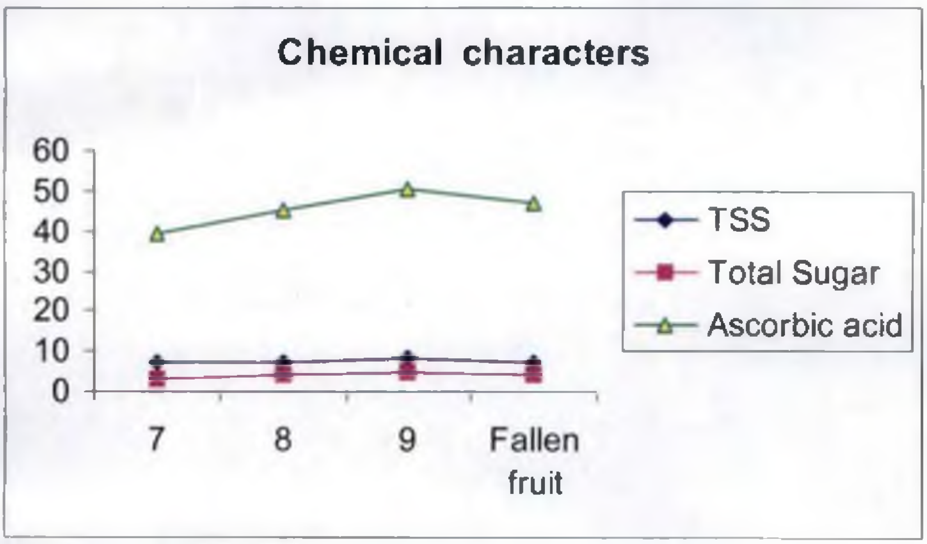
The optimum stage of harvest of pummelo fruits was identified through analyzing the physicochemical attributes (Fig 1.) and internal characters of the fruit. In pummelo, it is difficult to judge the optimum stage of harvest of fruits as there will be fruits of all growth stages on the tree at any point of time. Pummelo being a non climacteric fruit, it is to be harvested after ripening. Hence harvesting is to be done at correct stage. Primary observations on growth and development of the fruits have shown that up to five months maturity stage, the fruits are very small and dark green in colour. Normally people will not harvest them for consumption. As the maturity advances, the fruits grow in size and the colour start to fade. This change become prominent from 5th month after fruit set onwards. The fruits remain on the trees up to seven months maturity stage, then slowly detach from the pedicel and fall down within 7 to 10 days. Hence fruits of five to seven months maturity stage were selected for the study including those fell down from the tree. In pummelo, fruiting period starts from September and extended up to February, with the peak season in November to December (Anupama, 2006).

The dimensions *viz.*, length, width, weight of the fruits and segment weight increased from fifth to seventh month after maturity. The increase in these parameters may be attributed to an increase in the size of the cell, active cell division and accumulation of food substances in intercellular spaces of the fruit (Bollard, 1970 and Bharali and Saikia, 2004).

The colour of the rind changed from green to yellow during maturation of the fruit which is due to the lose of chlorophyll and increase in carotenoid pigment (Miller *et. al.*, 1981).

Fig. 1. Change in Physico - chemical characters of Pummelo fruits during growth and development





The number of segments of pummelo fruits is decided at the time of development of fruit itself and hence it recorded no change in response to growth and maturity.

The increase in segment weight and juice content possess a significant correlation. As the fruit develop, the juice vesicles also enlarge and become more juicy. The peel becomes thinner as the fruit matures and this is due to translocation of metabolites from peel to the juice vesicles for cell division and elongation for vesicle enlargement resulting in increase in segment weight. A part of the metabolites also get converted into juice (Ting and Attaway, 1971).

The TSS of the fruit increased from 6.9° brix at 5^{th} MAFS to 8.1° brix at 7^{th} MAFS. The increase may be due to the conversion of polysaccharides to soluble sugars. This is evident from the increase in total sugar content recorded in response to maturity of fruit (Jawanda *et al.*, 1973).

Change in titrable acidity was found to be significant and lowest acidity was recorded at 7^{th} MAFS. This decrease may be due to the dilution effect in response to the increase in size of fruit as explained by (Chittraichelvan and Shanmugavelu, 1972). As the maturity advances, the activities of acid hydrolyases increase in citrus fruits resulting in hydrolysis of acids.

The change in pH during fruit growth and development was found to be significant. The increase in pH during maturity may be due to decrease in acidity and increase in total sugar content (Baruah and Mohan, 1985).

The reducing, non-reducing and total sugar content of the fruit increased progressively from 5^{th} to 7^{th} MAFS. This may be attributed to the hydrolysis of starch into simple sugars and also by continuous mobilization of sucrose from leaves to the fruits (Bharali and Saikia, 2004).

The ascorbic acid content increased from 39.10 mg / 100ml at 5^{th} MAFS to 50.30 mg / 100ml at 7^{th} MAFS. It can be presumed that the maximum conversion of ascorbic acid precursors to ascorbic acid take place at 7^{th} MAFS. Ram *et al.*, 2004 explained that this increase may be due to the activation of ascorbic acid oxidase enzyme.

In red coloured types, the colour of the flesh / juice changed from light pink at 5^{th} MAFS to red in colour at 7^{th} MAFS. This shows the maximum accumulation of pigments at 7^{th} MAFS in the pummelo flesh. In white varieties, the colour of the flesh and juice turned from greenish yellow to white. Bharali and Saikia, (2004) reported that the chlorophyll content decrease and change to β carotene as the pummelo matures. This may be the reason for the change in colour of the flesh and juice. As the fruits matured from 5^{th} to 7^{th} MAFS, the easiness to peel and separate the segments increased. The development of clear integral part take place at correct time of maturity (Miller *et al.*, 1981) and hence the individual segments become more intact and peel develop in full. Hence it becomes easy to separate and peel the segments.

The overall taste and acceptability of the juice improved as the fruit matures and was high at 7^{th} MAFS. This is due to increase in TSS and sugar content of the juice and reduction in bitterness as evidenced in the present study. Vij (1982) and Josan *et al.* (1988) also reported the increase in total sugar content during fruit maturation.

Based on the evaluation of physicochemical and internal characters of fruits at different stages of maturity it can be concluded that 7^{th} MAFS is the ideal stage for harvesting pummelo. It is better to pluck the ripe fruits from the tree itself. The post harvest quality of the fallen fruits are less compared to the ripe fruits collected from the tree.

The results of the study clearly brought out the need of harvesting the pummelo fruits at ripened stage from the tree itself. Even though it is easy to collect the fruits from the ground, quality deterioration happens within a day after falling from the tree.

The length, width and weight of the fallen fruits did not record significant difference from that plucked from the tree at 7^{th} MAFS.

The rind weight and juice content of the fallen fruits decreased even when they were collected one day after falling. This may be due to leakage of metabolites from the fruits due to the fall and subsequent initiation of hydrolytic reactions, which also accelerate the leakage.

The TSS, sugar content and ascorbic acid content of the juice extracted from the fallen fruits recorded significant decrease. The reduction in sugar content may be due to the initiation of hydrolytic reactions especially that of glucose, fructose and sucrose invertase (Jawanda *et. al.,* 1973). Similarly detachment from the pedicel and falling on the ground might have activated ascorbic acid oxidase activity, which results in reduction in ascorbic acid content.

Thus the present study conclusively proved the fact that the ideal stage of harvest of pummelo fruits under Thrissur condition is 7th MAFS. The fallen fruits are comparatively inferior to those collected from the tree.

5.2 Variation in processing attributes of pummelo fruits

The important processing attributes of pummelo fruits are its physical characters such as size and weight of fruit, juice content, colour of juice and biochemical characters *viz.*, TSS, acidity, sugar and ascorbic acid content. In the present study, processing attributes of types collected from three different districts *viz.*, Kottayam, Ernakulam and Thrissur were studied separately. This helped to locate the areas where the ideal pummelo types with ideal processing characters is grown among the three districts (Fig 2 and 3). Apart from this, the processing attributes of 12 accessions were also compared irrespective of the location from where they were collected.

Statistically significant variation was noticed among the collections in terms of fruit length, width, weight and rind weight. Anupama (2006) also reported wide variability in these physical parameters among the 40 accessions collected from Thrissur, Kottayam and Ernakulam.

AC. 9 (1756.67 g) collected from Thrissur had the maximum fruit weight. This parameter is a total contribution of rind weight and segment weight. Segment weight is the total weight of peel weight and weight of juice vesicles. Hence total fruit weight cannot be taken as a criterion for selection of types. The prime component of interest is the juice content and quality of the juice. Hence juice percentage was taken as one of the parameter to screen out ideal types. The types ranked first, second and third in position with respect to different characters are given in Table 22.

AC. 11 recorded the highest juice percentage (74.83 per cent). This type collected from Thrissur was having red flesh colour. This accession was also ranked superior with respect to reducing sugar content (2.66 per cent). However, total sugar was high in AC. 2 collected from Kottayam area and hence this accession ranked superior in TSS (9.27° brix). The fruits of AC. 3 were highly acidic with an acid content of 1.26 per cent. The accessions with high ascorbic acid content were AC. 7 and AC. 12 (73.33 and 72.53 mg / 100 ml respectively). These accessions were collected from Ernakulam and Thrissur area

Table 22. Ranking of accessions collected from Kerala based on selected parameters

Sl. No.	Character	Rank		
		I	II	III
01	Fruit length (cm)	AC. 3	AC. 2	AC. 1
02	Fruit width (cm)	AC. 9, AC. 5	AC. 3	AC.2
03	Fruit weight (g)	AC. 9	AC. 2	AC. 5
04	Rind weight (g)	AC. 9	AC. 2	AC. 4
05	Number of segments	AC. 3	AC. 12	AC. 11
06	Segment weight (g)	AC. 5	AC. 2	AC. 9
07	Juice content (%)	AC. 11	AC. 3	AC. 10
08	TSS (° brix)	AC. 2	AC. 7, AC. 11	AC. 6
09	Acidity (%)	AC. 3	AC. 9	AC. 7
10	Total sugars (%)	AC. 2	AC. 4, AC. 11	AC. 1, AC. 12
11	Reducing sugars (%)	AC. 11	AC. 10	AC. 5
12	Non reducing sugars (%)	AC. 3, AC. 6	AC. 12	AC. 11
13	Ascorbic acid (mg / 100 ml)	AC. 7, AC. 12	AC. 3	AC. 11

Fig. 2 Variation in Physical Characters of fruits collected from three districts of Kerala

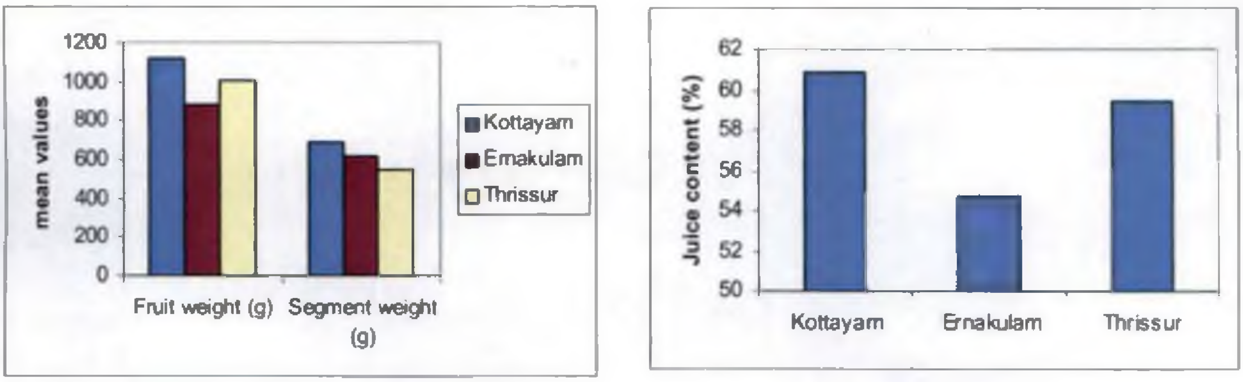
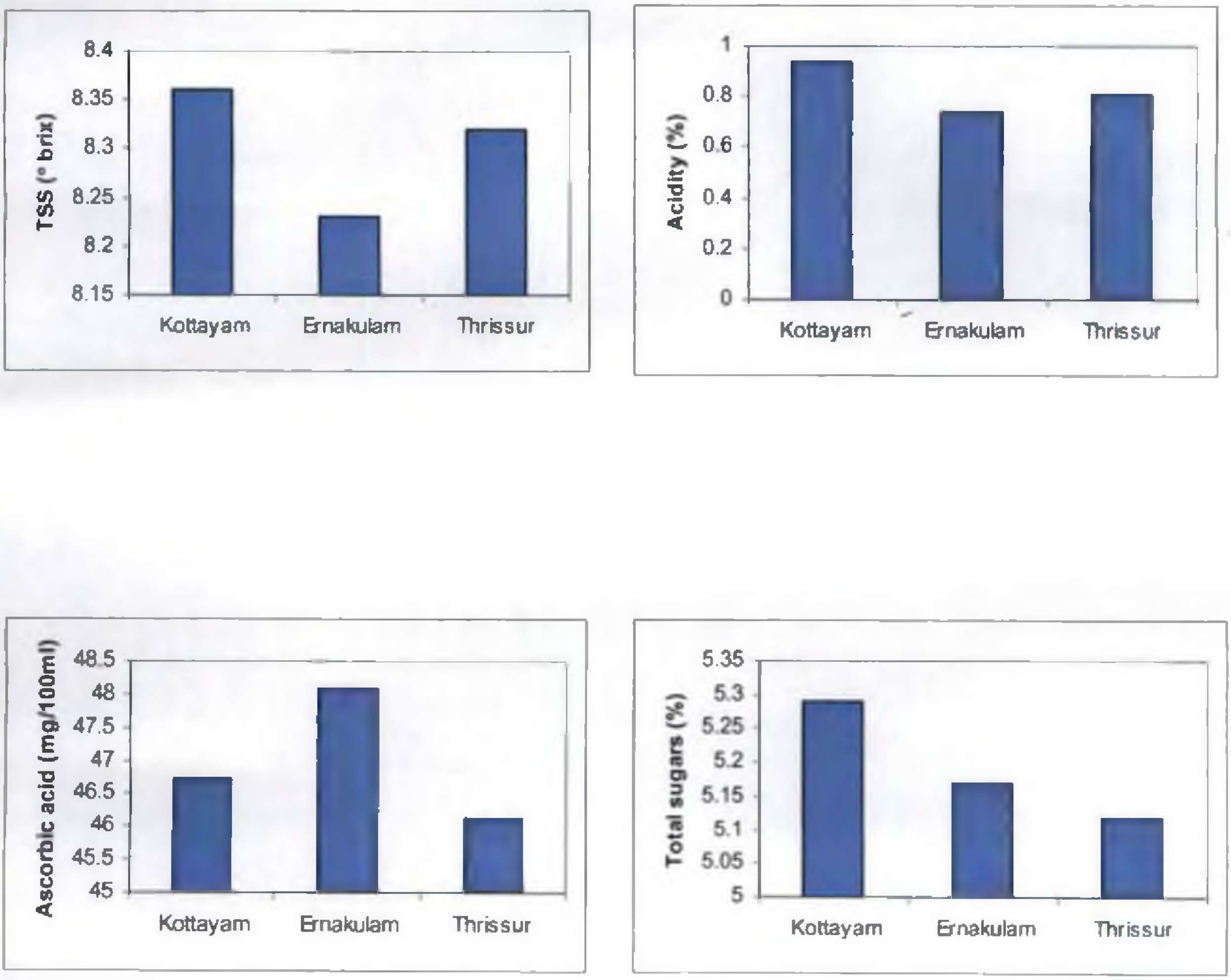


Fig. 3 Variation in Chemical characters of juice of fruits collected from three districts of Kerala.



respectively. The study clearly brought out the variation existing among different types of pummelo with respect to processing characters.

At present no attempt has been taken in the area of breeding for ideal pummelo types. The various positive characters are scattered within different types. Thus there exist great scope to undertake breeding in pummelo to evolve types possessing fruits with high fruit weight, segment weight and juice content. Emphasis is also to be given to locate types with bitterless or less bitter juice with high TSS and sugar content and ideal level of acidity. The types with ideal physico-chemical attributes can be selected from red, pink and creamy white group. Since vegetative propagation technique is well standardised in pummelo (Kefford and Chandler, 1961), once types with ideal processing attributes is located they can be perpetuated easily.

Murthy *et al.* (1989) also studied the physico chemical characters of pummelo fruits and observed that oblong fruits had the most juice content per 100 g of pulp (58.6 ml per 100g of pulp) and the ovoid types recorded the highest TSS content (10.84° brix). The spherical fruits gained more score in the organoleptic test. In pummelo, acidity varies from 0.65 to 4.03 percent, TSS from 7.0 to 12.8° brix and TSS / acidity ratio from 2.8 to 14.2 (Paudyal and Haq,1999).

Anupama (2006) also reported the variability with respect to internal characters of pummelo fruits. All these studies point to the need of proper selection and breeding of types to get pummelo types possessing high juice content with nutritionally rich bitterless juice.

As mentioned earlier, the different quality attributes were found scattered in different types. However for further studies two accessions were selected out based on their merits as important characters.

AC. 11 with high juice content and second in total sugars and third in ascorbic acid content was selected for further studies. It was available in Peechi area, Thrissur district. The juice percentage of the AC. 3 was 73.70 per cent and ranked second for the character after AC. 11. The acidity of the fruits of this accession was high 1.26 per cent and ranked second for sugar and ascorbic acid content. Hence AC. 3 and 11 was selected based on their merits expressed as overall processing characters. AC. 3 belong to Kottayam district. The colour of the flesh ad juice of AC. 3 was pink and that of AC. 11 was red. The accessions collected from Kottayam area was found comparatively better than the types collected from Thrissur and Ernakulam with respect to processing attributes. Anupama (2006) also pointed out the superiority of types collected from Kottayam compared to the types collected from other districts. The soil and climatic parameters of Kottayam may be more suitable compared to other two districts (Thrissur and Ernakulam) for growing pummelo.

5.2.1 Comparative evaluation of types collected from IIHR, Bangalore and Kerala.

The overall processing attributes of Kerala and Bangalore types were compared in the present study. The Bangalore types were found to be superior with respect to fruit weight, segment weight, TSS, acidity, total sugars and ascorbic acid content (Table 10 and Fig. 4). The fruits obtained were also comparatively less bitter and had good flavour. The fruits collected from IIHR, Bangalore for the study was from the selections of pummelo made by them with respect to yield and other fruit characters. Hence the types themselves were superior in quality. This again point out the need for undertaking improvement studies in pummelo in our state.

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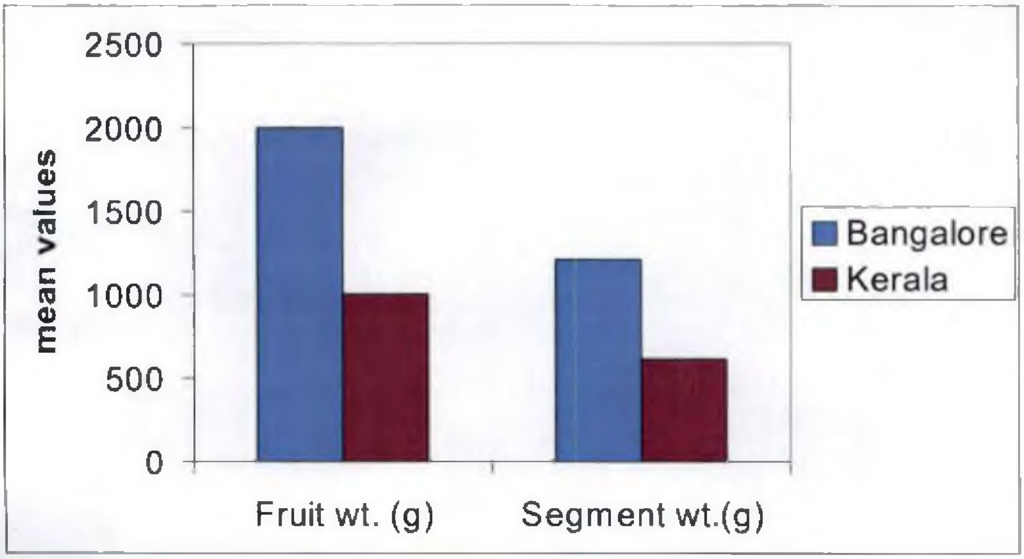
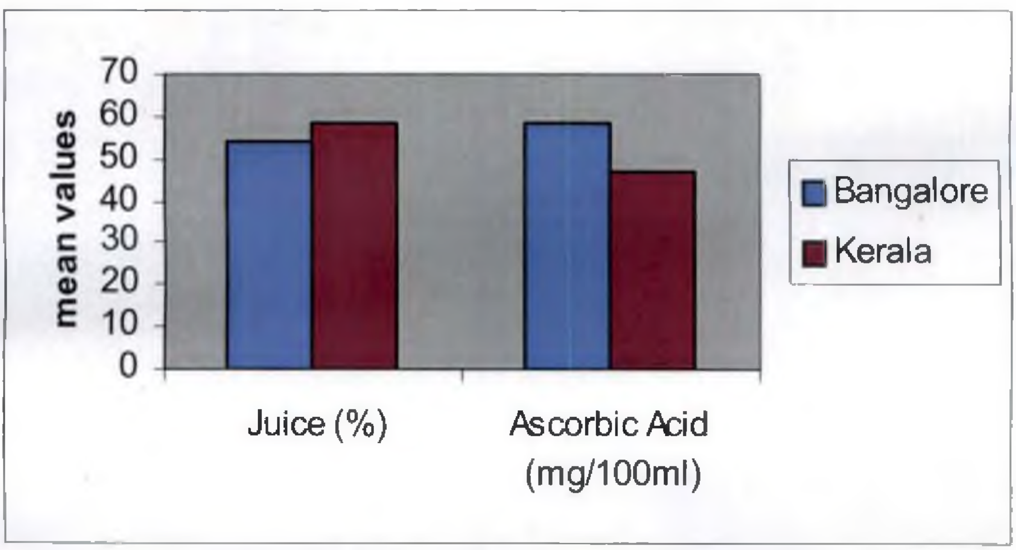
5.3 Effect of different methods on peeling of pummelo segments

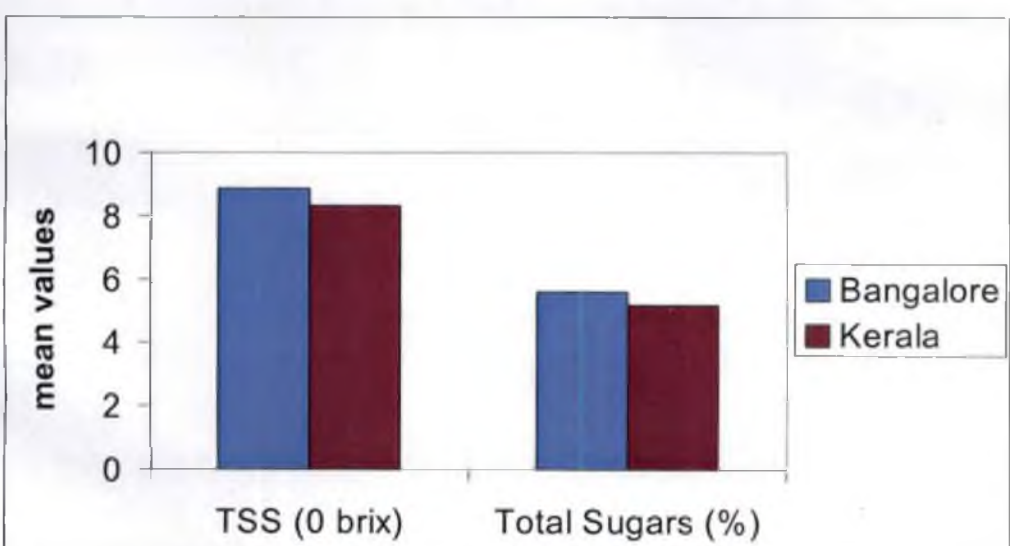
In the present study, effect of lye solution and treating the segments with salt, sugar and steam on peeling of segments was studied.

Treating the segments with lye solution at all concentration and contact time was not found to be an effective method for peeling. The lye at lower concentration at less contact time did not remove the peel on the segments. As the contact time was increased

Fig. 4 Comparison between Kerala and Bangalore types







peeling started (25.66-36.66%) at low scale and the juice expressed from the segments produced an alkali taste. When lye solution at high concentration (2-2.5%) was tried together with removal of peel, rupture of juice vesicles was a problem. Sogi and Singh (2001) reported the negative effect of peeling using lye at high concentration in kinnow mandarin. The rupture of peel and contact with lye might have released more bitter principles to the juice. Hence the peeling by treating the segments with lye was not selected.

Effect of smearing the segments with salt and sugar at varying levels and steaming on making the peeling easy was studied. Among the different treatments of smearing with salt and sugar tried, salt at lower levels were not effective. Smearing of salt at five per cent and then steaming for 15 minutes was found advantageous. The peel became soft and loose. So it became easy to peel the segments. Smearing the segments with sugar cannot be advised as it did not produce any advantage over and above control and treatment with salt. It is a comparatively a costly affair as well.

Instead of smearing with salt, dipping in brine at various concentrations was tried to make the process more easy. The results yielded valuable results. Dipping the segments in water alone and steaming was not effective in peeling (Table 12 and 13). Dipping the segments in 15 per cent brine for 15 minutes and then steaming in water bath for 15 minutes enhanced the easiness of manual peeling. The peel got detached from the juice vesicles due to salting and steaming. The colour of the flesh was found retained and there was no rupture of juice vesicles and they remained as an intact mass after removal of peel. Hence the juice was less bitter. The vesicles became very soft and hence after peeling it was easy to extract juice by putting the peeled mass in muslin cloth and pressing with hand. Comparative yield of juice was also high in this method. The organoleptic evaluation of the juice extracted from the segments steamed after dipping in brine and syrup revealed the superiority of these methods in peeling. The appearance, colour, flavour, taste and overall acceptability of the juice were scored "fair".

Treating the segments in syrup is comparatively expensive even though the results were encouraging. The syrup after dipping the segments expressed bitter taste and hence could not be used further.

The biochemical constituents *viz.*, acidity, TSS and ascorbic acid content of the juice extracted from segments subjected to the treatment did not vary significantly from that of control.

Madhav (2001) also reported the effect of salt treatment in reducing bitterness of pectin extracted from pummelo peel. Dipping the pummelo peels in six per cent salt and boiling for 30 minutes reduced bitterness in pectin extracted from the peel.

Therefore, dipping the fruit segments in brine 15 per cent for 15 minutes followed by steaming for 15 minutes can be selected as an efficient and economic method for peeling pummelo fruit segments.

5.4 Effect of methods of juice extraction on physical components of fruits and quality of juice

Pummelo is mainly consumed in fresh form after removal of rind and peel of the segments and rarely in the form of extracted juice. The main reason is that suitable method for extraction of quality juice from the fruit is not available. The peel is usually thick and adhered closely to the juice vesicles. Thus separation of peel from juice vesicles is difficult. Also the juice vesicles are somewhat hard in nature and pressing with hand normally yield less quantity of juice as evidenced in the study. Some people practice crushing in mixie and then pressing to get the juice. Naturally rupture of the cells will be more and this enhances the release of bitter principles more in quantity to the juice. Thus the juice extracted through this way is hopelessly bitter. The effect of extraction methods on physico chemical properties of kinnow mandarin juice was explained by Sandhu and Singh (2001). Singh *et al.* (2003) also reported that the method of juice extraction in citrus fruits affects the quality of juice.

In the present study, efforts were made to standardise an ideal juice extraction technique for pummelo, which is capable of giving maximum quantity of juice. The main quality parameter aimed at is less bitter juice with less change in nutritional value.

A novel method tried for extraction of juice from the vesicles was osmotic extraction. Mixing the juice vesicles with sugar and keeping for varying period was found to release the juice from the vesicles. The quantity and quality of the juice varied in relation to percentage of sugar and incubation period. The mass of juice vesicles when mixed with 30 per cent sugar and kept for three hours yielded 67.12 per cent juice, which gained comparatively 'good' score (Table 15). This may be due to the ideal blend of sugar acid ratio in the juice. Even though the juice yield and sugar content was increased when the juice vesicles was mixed with higher quantity of sugar, the organoleptic score gained by the juice was poor. As the rupture of cells was minimum in osmotic extraction the chances of bitter principles to get mixed with the juice is minimum. However increasing the level of sugar beyond 30 was not advantageous as it caused sudden rupture of cells, resulting bitterness in juice. Delayed bitterness was experienced for the juice extracted through osmotic method. As the enzyme responsible for converting precursors of bitterness to bitter principles is not inactivated its activity in the juice might be the reason for delayed bitterness (Maier *et al*., 1969).

Based on this result, in the present study three methods of juice extraction *viz*., hand pressing, screw pressing, crushing in mixie and pressing along with the best osmoextraction technique identified was tried. The juice vesicles were extracted from the segments through the best peeling method identified and subjected to extraction.

It is evident from the results that quantity of juice is greatly influenced by the method of juice extraction (Fig.5). The juice yield ranged from 66.00 to 79.00 percent in different methods of extraction. Effect of methods of juice extraction on juice recovery and its quality has been discussed by many workers (Jawanda *et al.,* 1973; Lotha and Khurdiya, 1994).

Juice recovery was increased when the segments were dipped in salt at 15 per cent for 15 minutes followed by steaming in water bath for 15 minutes and then subjecting to different methods of extraction. Steaming was found to enhance the easiness to peel and the juice vesicles missed their stiffness and became softer. Thus simply pressing with hand by transferring the peeled mass to a muslin cloth yielded 68.50 per cent juice. However the yield was comparatively low. This might be due to incomplete breaking of the juice vesicles as reported by Lotha and Khurdiya (1994). The same methods yielded low quantity of juice from kinnow Mandarin fruits. The selected osmoextraction technique yielded 71.00 per cent juice with high TSS and overall acceptability (Tables 16 and 17). The effect of salting in masking or removing the bitterness in citrus fruits has been reported by Madhav (2001). The possible effect of steaming in removing bitterness has been discussed elsewhere in the chapter.

Hence osmotic extraction can be effectively practiced after salting and steaming the segments and then removing the peel. The juice extracted by this method was used for the product development.

Crushing in mixie contributed to thorough breaking of juice vesicles resulting in more juice yield (79.77 %). But it is a fact that for any fruits especially for citrus juice yield cannot be taken as single criteria to select extraction method as quality of juice is another important criteria to be taken in account. Thus in the present study the two method *viz.,* crushing in mixie and screw pressing can be outrately rejected due to yield of poor quality juice. Hand pressing can be practiced for immediate juice extraction. However the other method *viz.,* salting followed by steaming and osmotic extraction can be suggested for getting maximum quantity of quality juice from pummelo. The ascorbic acid content of the juice did not record significant change with respect to method of juice extraction (Fig. 5).

5.5 Effect of debittering techniques

5.5.1 Bitterness

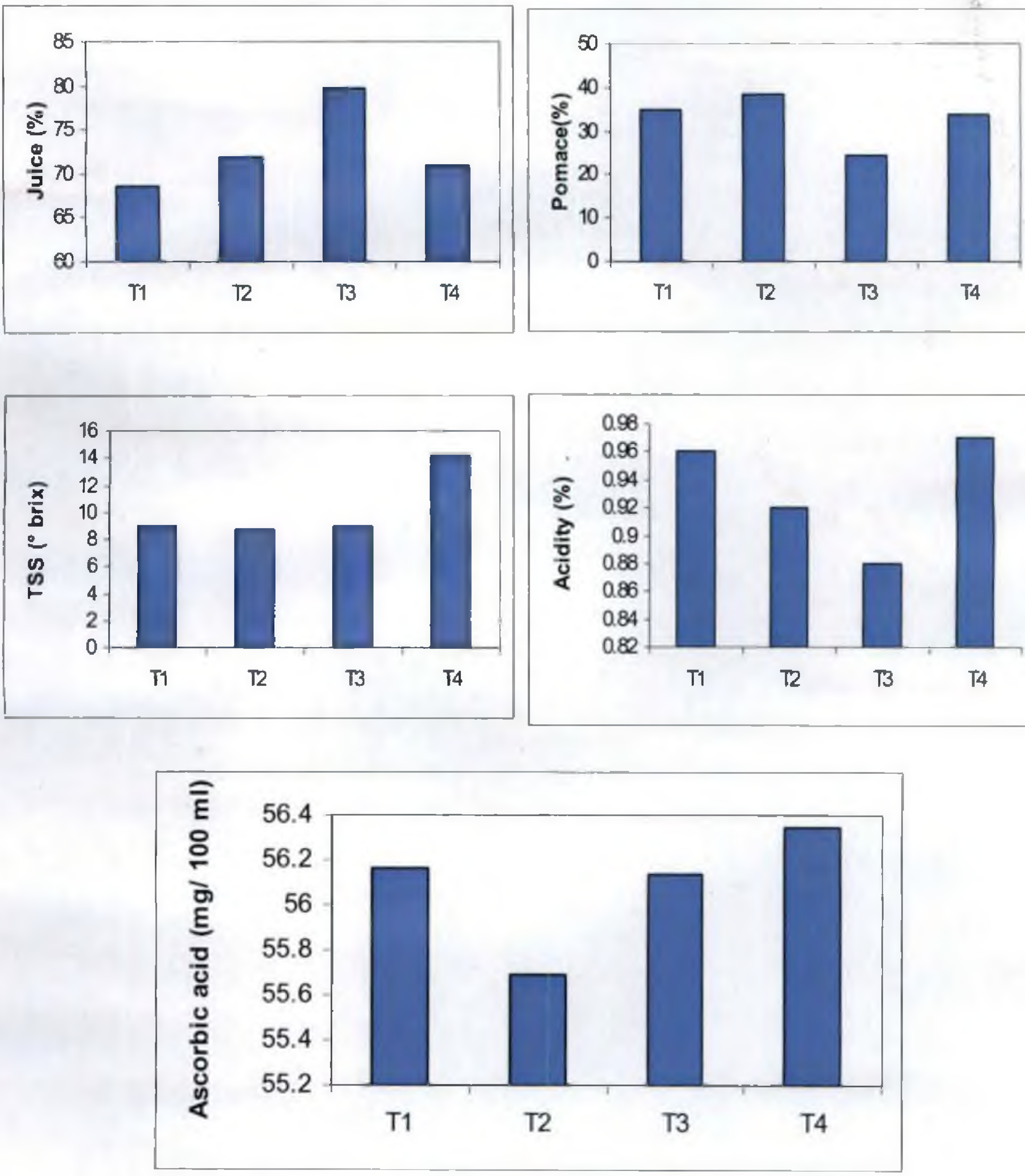
The level of bitter principles or their precursors is influenced by a number of factors including maturity, variety, cultivar, root stock, cultural practices and geographic location among others (Kefford and Chandler, 1961). The immature fruits usually yield bitter juice, but as ripening progress, bitterness decrease and may eventually disappear.

The difference in bitterness is attributed to the limonoid UDP-D glucose transferase activity that bring about conversion of limonoid aglycones into limonoid glucosides which are tasteless (Hasegawa and Miyake, 1996). The bitter oranges and pummelo have very low activity levels of this enzyme, hence juices from fruits harvested even at very late season possess severe limonoid bitterness problem. Hence selection of suitable cultivar and geographic location are very important with respect to acceptability of citrus fruits.

The major hurdle in processing of any citrus fruit is development of bitter taste in the juice. Singh *et al.* (2003) opinied that without proper debittering technology, a citrus industry cannot flourish profitably.

Two classes of components namely flavonoids and limonoids are responsible for bitterness. The fruit containing high flavonoids are bitter even consumed as fresh. The

Fig.5 Effect of method of juice extraction on juice yield and its chemical attributes



T1 - Hand pressing
T2 - Screw pressing
T3 - Crushing in mixie and pressing
T4 - Osmo extraction

evaluation of pummelo accessions grown in different parts of Kerala by Anupama (2006) have shown that fruits of some pummelo accessions are bitter to taste in fresh form.

Among flavonoids, naringin is the widely occurring bitter principle. As many as 37 limonoids have been identified in citrus and their hybrids. The four limonoids namely limonin, nomilin, ichangin and nomilinic acid are bitter (Maier *et al.*, 1977). Limonin is the major cause of citrus juice bitterness and is widely distributed. The analysis of bitter principles in pummelo have revealed the presence of limonin (Yusof *et al.*, 1990) and naringin in pummelo. So pummelo fruits are included in the group of citrus fruits possessing bitter taste.

An important hurdle that stands in the way of natural debittering process of pummelo fruits is the reduced limonoid UDP-0 glucose transferase activity in them. This enzyme is responsible for conversion of limonoid aglycones into limonoid glucosides which are tasteless (Hasegawa and Miyake, 1996). Since the activity of this enzyme is less in the pummelo fruits, forced debittering through artificial means is a pre-requisite for processing and product development based on pummelo fruits.

The intact fruits of pummelo are less bitter as they do not contain bitter limonin but rather a non-bitter precursor limonoate, a ring lactone (Maier *et al.*, 1968). When juice is extracted, the above non-bitter precursor is gradually converted to limonin under acidic condition and conversion is accelerated by the action of limonoate D-ring lactone hydrolase (Maier *et al.*, 1969). This bitterness is termed as delayed bitterness and this is an overwhelming problem in pummelo fruits (Sing *et al.*, 2003)

In the present study several individual and integrated approaches were made to overcome the problems of bitterness in pummelo fruits.

Kefford and Chandler (1961) suggested that the level of bitter principles and their precursors is influenced by a number of factors including maturity, variety, cultivar, rootstock, cultural practices and geographical location. The immature fruits usually yield bitter juice, but as ripening progress, bitterness decrease and may eventually disappear.

The present investigation gave importance in screening of pummelo types possessing 'less' or no bitterness. Out of 12 accessions evaluated AC. 3 and 11 were found to possess less bitter fruits. Anupama (2006) could identify two accessions with less bitter fruits.

The results were highly encouraging when evaluation of types collected from IIHR, Bangalore was done. Out of four selections evaluated two was not having any bitterness at all. Similarly fruits of the other two selections were less bitter in taste. As vegetative propagation is standardised in pummelo there exist scope for perpetuating less bitter types among cultivators. However, since geographic location has a say on the quality of fruits location specific evaluation of pummelo types is required to arrive at a final word on bitterness of types in relation of location. The bitterless types at Bangalore may sometimes develop bitterness when grown in Kerala.

Another effort made in the study was to standardise a harvesting time for pummelo fruits, when the fruits express maximum acceptable quality (Expt. I). The results of the study cleared indicated that time of harvest has a say on quality of juice. The level of bitterness was found to decrease steadily as the stage progress. Similar observations have been made in grape fruit (Attaway, 1977), kinnow (Sandhu *et al.*, 1990) and Satsuma mandarin (Ishikawa *et. al.*, 1993). Ozaki *et. al.*, (2000) reported that mature Satsuma mandarin fruit contains relatively low concentration of bitter limonoid aglycons.

Many workers have reported the influence of juice extraction method on imparting bitterness to citrus fruits (Mohsen *et. al.*, 1986 and Lotha and Khurdiya, 1994). When the juice is extracted, the bitter precursor limonoate – A ring lactone is gradually converted to limonin under acidic condition and the conversion is accelerated by the action of limonoate D-ring lactone hydrolase (Maier *et. al.*, 1969).

The study has shown that dipping the fruit segments in brine (15 %) for 15 minutes following steaming for 15 minutes was found to make peeling of segments easy and reduce the bitterness of juice. The process of dipping the segments in salt and steaming might have inactivated this enzyme prior to juice extraction from segments.

In the present study extraction of juice by osmotic technique by mixing the juice vesicles with 30% sugar level and keeping for three hours and then extracting the juice by taking the mass in muslin cloth and hand pressing without pressure was found to give comparatively less bitter juice. In this technique, the rupture of cells was minimised as most of the juice come out of the vesicles though osmosis. The rest of the juice could be extracted by applying less pressure from osmotically active cells. As discussed earlier, the intact fruits are less bitter and development of bitterness in juice extracted from them is due to increased activity of limonoate D-ring lactone hydrolase which convert limonate to limonin during extraction. This might be the reason for less bitterness of juice from salted and steamed pummelo segments. Similar results have been reported by Madhav (2001). For extraction of pectin from pummelo fruits, boiling of pummelo peels in six per cent salt and boiling for 30 minutes was tried which reduced bitterness in pectin extracted from the peel.

5.5.2 Use of bitterness suppressing agents

The method of suppressing bitterness adopted was increasing the pH, addition of pectin and pectinase and addition of sucrose at various levels as described in Expt.V.

Of the various methods tried addition of sugar, salt and pectin to juice and raising pH of the juice was reported to reduce bitterness and enhance the acceptability of kinnow juice (Sandhu *et. al.*, 1990 and Sandhu and Singh, 2001).

In the present study, addition of pectin and pectinase at various levels did not give encouraging results in this direction. However, addition of sucrose at various levels was found beneficial in reducing the bitterness of juice.

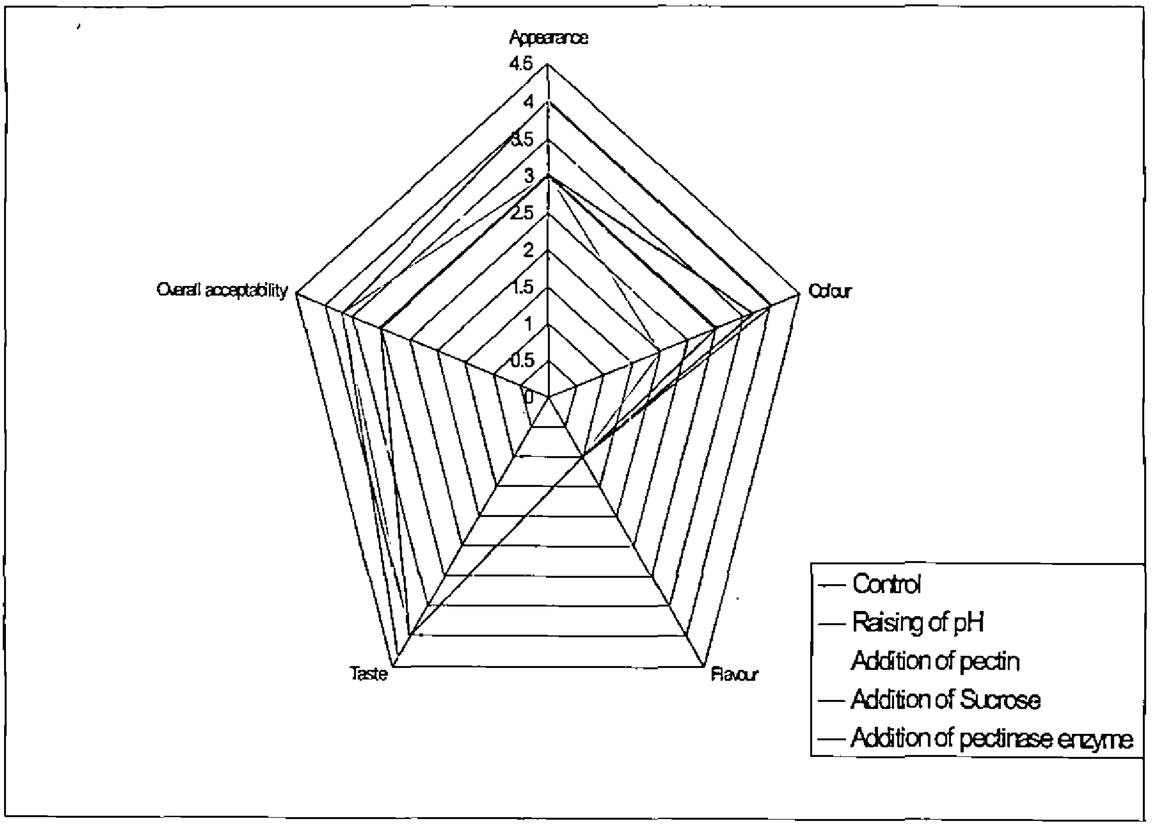
Juice added with sucrose at six per cent level was found most acceptable in organoleptic evaluation (Fig. 6). However, development of delayed bitterness at a lower scale was detected in this sweetened juice. Development of delayed bitterness in citrus fruits has been reported by many workers. (Maier *et al.*, 1969; Premi *et al.*, 1994; Berry, 2001 and Aggarwal and Sandhu, 2004). However, extraction of juice by salting and steaming and then raising the sugar level to six per cent by addition of sucrose was found effective. The juice gained high score value as it was sweet and less bitter.

5.6 Products based on pummelo

The suitability of pummelo juice for product preparation was studied by mixing the juice with orange, mango and grape juice. The orange juice and pummelo juice mixed at the ratio 30: 70 ratio respectively was found most acceptable. When mixed with mango and grape juice, the taste of pummelo juice was not there. At all levels the mango and grape juice masked the taste of pummelo juice. Being the member of the same family, the orange juice might be more compatible and scored "good" in organoleptic evaluation.

The pummelo and orange juice blended at the ratio 70: 30 ratio was used for preparation of sweetened juice. The blended juice added with 30 per cent sugar gained

Fig. 6 Effect of debittering techniques on sensory attributes of Pummelo juice



highest score compared to blended sweetened juice prepared with other levels of sugar (Fig. 7). Similarly sweetened pummelo juice at 35 per cent level gained comparatively more score in organoleptic evaluation. The brix value of blended sweetened juice and that of sweetened juice made with pummelo juice alone was 38° brix. From this it can be seen that for preparing sweetened juice based on pummelo it is better to raise the TSS at 38° brix. Ladaniya and Singh, (1998) have prepared sweetened juice based on Nagpur Mandarin and the products were found highly acceptable.

The RTS prepared with pummelo and blended juice did not score good (Fig. 8). As the ratio of juice and sugar was 15 per cent each and 70 per cent water was added in RTS preparation, the product was experienced to be very light and taste of pummelo was almost 'nil'. Thus the score gained was very less.

However, squash prepared with pummelo juice alone and blended juice was highly acceptable (Fig. 8). As the juice content was increased to 25 per cent as per standard of FPO in squash, taste of pummelo was predominant in the product.

Pruthi *et al.* (1984) and Aggarwal and Sandhu, (2004) prepared squash using Kinnow Mandarin juice. Kinnow juice concentrates prepared of 72° brix was found acceptable (Sandhu *et al.*, 1990; Thakur *et al.*, 2000).

Lotha and Khurdiya (1994) reported that good quality nectar and squash can be prepared from blended Kinnow mandarin juice.

Sogi and Singh (2001) have used debittered kinnow juice to make RTS beverage, squash, jam and candy.

Bharali and Saikia (2004) prepared cordial using pummelo fruit juice.

Present investigation pointed out that product development could be effectively done in pummelo as squash and sweetened juice prepared were come to the acceptable level. Possibilities of the preparation of other products like nectar, jam, marmalade and candy can be taken as a future line of work as the protocols are already been standardised in other citrus fruits.

Fig. 7 Sensory attributes of Pummelo juice blended with other juice

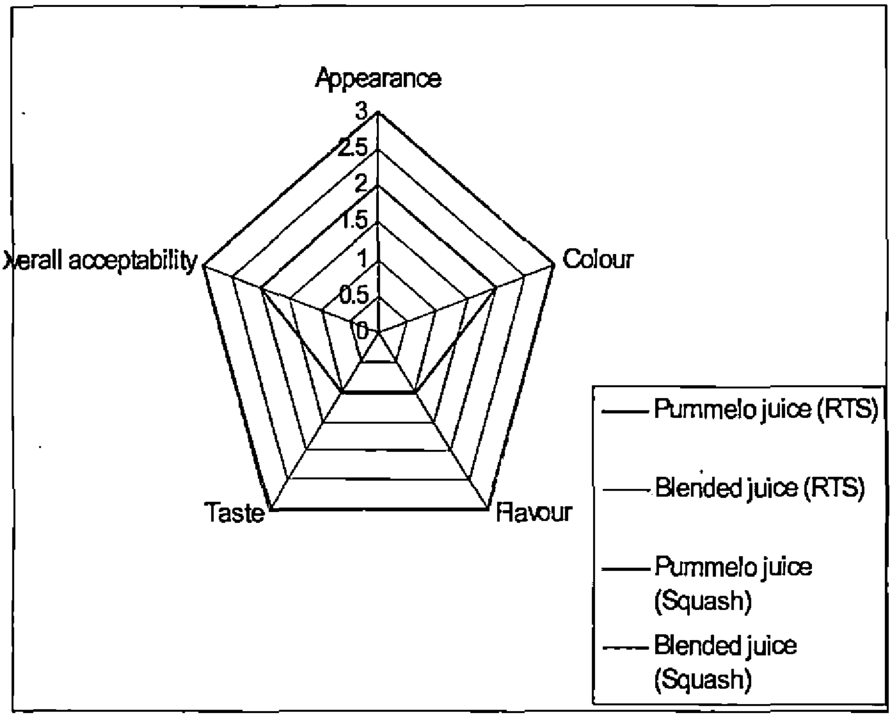
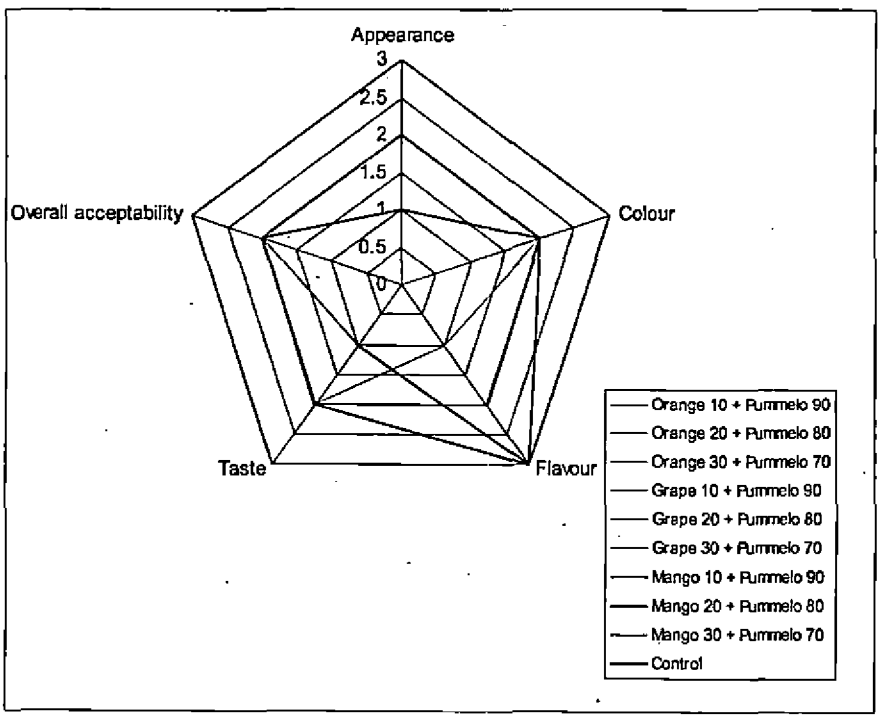


Fig. 8 Sensory attributes of Pummelo RTS and Squash prepared with pummelo juice and selected blended juice



Summary

Summary

The project entitled "Process optimisation for production of value added products from Pummelo (*Citrus grandis* (L.) Osbeck)" was carried out in the Department of Processing Technology, College of Horticulture, Vellanikara.

The optimum stage of harvesting of pummelo fruits was identified as 7th months after fruit set based on analysis of physico-chemical and internal characters of fruits at different stages of maturity. At this stage, the size and weight of the fruit as well as the fruit segments increased to the maximum. The juice content of the fruits was also high at this stage.

The analysis of biochemical constituents of juice at different stages of maturity of fruit emphatically proved that quality of juice is good at 7th month maturity stage. The TSS, sugar content and ascorbic acid content achieved maximum at this stage and the acidity decreased.

The most appealing colour develops to flesh and juice at 7th MAFS. Overall acceptability of juice was also high at this stage and was comparatively less bitter.

The quality of fruits plucked from the tree at 7th month maturity stage was more compared to that fallen from the tree at the same stage of maturity.

Evaluation of 12 accessions *viz.*, four each collected from Thrissur, Ernakulam and Kottayam have clearly brought out the variation in processing attributes existing in pummelo types. The study pointed out the need for identifying selection and breeding programme for getting pummelo types with ideal processing attributes.

Based on the merit of juice content, TSS, acidity and sugar content, AC. 11 and AC. 3 were selected out for further studies. The superiority of pummelo types collected from Kottayam district was evident with respect to fruit size, weight, juice content, TSS and ascorbic acid content.

The study could bring out an ideal process for easy peeling of pummelo segments. Dipping the fruit segments in brine at 15 per cent strength for 15 minutes followed by steaming helped the detachment of peel from juice vesicles and thus made the peeling easier. The juice vesicles became very soft due to steaming and hence juice could be extracted by hand processing. This technique yielded high quantity of quality juice. The quality of juice was good as there was no rupture of peel as well as juice vesicles.

The biochemical components of pummelo juice extracted from salted and steamed segments did not vary much from that extracted through hand pressing.

Bitterness of juice was identified as a major problem and several approaches were integrated and a protocol was developed through the study to extract quality juice from pummelo.

Among the different juice extraction techniques tried, osmoextraction by mixing the juice vesicles (separated from the salted and steamed segments) with 30 per cent sugar and incubating for three hrs was found to yield quality juice compared to other methods. Apart from the superiority with respect to biochemical attributes of this juice, the juice was less bitter to taste.

Addition of sucrose at six per cent level to the pummelo juice was effective in reducing the bitterness compared to other debittering techniques tried.

When pummelo juice alone was used for preparation of sweetened juice the appearance, colour, flavour, taste and acceptability of the product was not good.

Blending pummelo juice with orange juice was highly acceptable with respect to colour, taste, flavour and overall acceptability of juice. The ideal combination was 70 per cent pummelo juice and 30 per cent orange juice. The sweetened juice prepared with this ideally blended juice by adding with 30 per cent sugar was scored 'good'.

Pummelo juice alone or blending with orange juice ideal level was not suitable for preparations of RTS, probably due to low content of juice. However the squash prepared with pummelo juice alone and that with blended juice was found highly acceptable.

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Appendices

APPENDIX I

List of places of pummelo accessions- Kerala

AC. No.	Place	District
1	Kumarakam	Kottayam
2	Kottayam	Kottayam
3	Kottayam	Kottayam
4	Chempu	Kottayam
5	Kothamangalam	Ernakulam
6	Aluva	Ernakulam
7	Thottumugham	Ernakulam
8	Kadugallur	Ernakulam
9	Vilangannoor	Thrissur
10	Amballur	Thrissur
11	Peechi	Thrissur
12	Varakkara	Thrissur

APPENDIX II

Score card for the organoleptic evaluation of pummelo juice

Sl.No	Parameter	Score							
1	Appearance								
	Excellent	5							
	Good	4							
	Fair	3							
	Poor	2							
	Very poor	1							
2	Colour								
	Excellent	5							
	Good	4							
	Fair	3							
	Poor	2							
	Very poor	1							
3	Flavour								
	Excellent	5							
	Good	4							
	Fair	3							
	Poor	2							
	Very poor	1							
4	Taste								
	Excellent	5							
	Good	4							
	Fair	3							
	Poor	2							
	Very poor	1							
5	Overall acceptability								
	Excellent	5							
	Good	4							
	Fair	3							
	Poor	2							
	Very poor	1							

Date:

Name and signature

PROCESS OPTIMISATION FOR PRODUCTION OF VALUE ADDED PRODUCTS FROM PUMMELO (*Citrus grandis* (L.) OSBECK)

By

SUJA G. NAIR

ABSTRACT OF THE THESIS

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ABSTRACT

Pummelo (*Citrus grandis* (L.) Osbeck) is an important member of the citrus genus. The fruit is rich in vitamin C and has many medicinal properties. A major chunk of production of this fruit is being wasted due to the lack of scientific handling and processing technologies. In this context, the present investigation "Process optimisation for production of value added products from Pummelo (*Citrus grandis* (L.) Osbeck)" was taken up to standardise technologies for processing and value addition of pummelo.

The ideal stage for harvesting pummelo fruits in Kerala was found to be seventh month after fruit set. At this stage the fruits attain maximum size with high juice content, TSS and ascorbic acid content. The acidity of the fruits at this stage was low. The fallen fruits at the same stage were found to be inferior in quality.

Out of 12 accessions of pummelo analysed for their processing characters, AC. 3 collected from Kottayam and AC. 11 collected from Thrissur were selected out based on their merits with respect to size, juice content, TSS and ascorbic acid content. In general, the accessions collected from Kottayam were superior to those collected from Ernakulam and Thrissur. Similarly the selections from IIHR, Bangalore were superior to those collected from Kerala.

The study could bring out an ideal process for easy peeling of pummelo segments. Dipping the segments in 15 per cent brine for 15 minutes and then steaming for 15 minutes was found to be the most effective method. The quality of the juice extracted from the segments after this treatment did not vary much from that of fresh hand extracted juice.

Osmo extraction (by mixing the juice vesicles with 30 per cent sugar and incubating for 3 hrs.) was found to be a better method for juice extraction from the

peeled segments. The quality of the juice extracted through this method was comparatively better. Crushing in mixie and screw pressing yielded low quality juice.

Addition of sucrose at 30 per cent level was found to mask the bitterness in juice. Addition of pectin and pectinase and increasing the pH of the juice did not give valuable results.

Blending pummelo juice with orange juice at 70: 30 per cent level was good as this combination was scored to be highly acceptable with respect to colour, taste and overall acceptability. The sweetened juice prepared with this ideally blended juice, adding with 30 per cent sugar gained comparatively good score.

The squash prepared with sweetened pummelo juice blended with orange juice at 70: 30 proportion was found to be acceptable. The pummelo based RTS was not found as a good product. The studies done on value addition have shown that it is better to prepare the beverages with pummelo juice blended with orange juice than using pummelo juice alone.