Use of semi-permeable membranes to increase the shelf-life of passion fruits

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USE OF SEMI-PERMEABLE MEMBRANES
TO INCREASE THE SHELF-LIFE
OF PASSION FRUITS

by
GEORGE MESHACK NYAMBATI

A Master's Thesis
submitted in partial fulfilment of the requirements
for the award of Master of Philosophy of the
Loughborough University of Technology, 1984.

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Humberside College of Higher Education
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DEDICATED TO MY WIFE, VENNY C. NYAMBATI,
AND CHILDREN, LEVI J. MORIASI AND CLAIRE KEMUNTO.
ABSTRACT

The economic importance of the purple passion fruit (*Passiflora edulis* Sims) is increasing as it gains popularity in both developing and developed countries, not only as a source of juice, but also as a pleasant and nutritious whole fruit. It is a highly perishable fruit that shrivels and loses its fresh look within a few days post-harvest. There is therefore an increasing interest in improving its shelf-life.

Semi-permeable membranes such as Pro-long (a mixture of lipids, sucrose esters of fatty acids and glyceryl monostearate and a polysaccharide sodium carboxymethyl cellulose) have been reported to retard the rate of ripening, and thus extend the shelf-life of fruits such as mangoes, bananas, pears, avocados, limes and papaya. It has also been suggested that pectin can be used to preserve some fruits.

The aim of this study was to assess the value of Pro-long and pectin in increasing the shelf-life of purple passion fruit. In the initial experiments the effect of Pro-long was compared with similar concentration of pectin. Weight loss and degree of wrinkling were the main parameters that were taken into consideration during storage. Other factors assessed were organoleptic qualities, total soluble solids, sugars, acid changes, carotenoid content, anthocyanin levels, volatile flavour compounds, vitamin C, protein, calcium, pectin, respiration rate, organoleptic qualities and fungal infection.

No improvement was obtained on treating fruits with pectin and thus its use was abandoned in further experiments. Fruits treated with Pro-long at 2% and 2.5% were found to show a reduced weight loss when stored at 8°C, 16°C and 24°C. It also helped to retain a wrinkle free surface for longer periods. The respiration rate was reduced significantly, while sugars, and total soluble solids of the fruits increased more slowly compared to the controls. The gas-liquid chromatography results on volatile flavour compounds in purple passion fruit showed that Pro-long enhanced retention of these compounds.
Pro-long also decreased fungal rot, although at high temperatures some fungal spots were observable when the fruits were stored over 25 days.

The results show that Pro-long could be used in improving and extending the shelf-life of fresh purple passion fruit.
# CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>2. LITERATURE SURVEY</td>
<td>2</td>
</tr>
<tr>
<td>2.1 Passion fruit species and hybrids</td>
<td>2</td>
</tr>
<tr>
<td>2.2 Passion fruit growth and harvesting, production and utilization</td>
<td>5</td>
</tr>
<tr>
<td>2.2.1 Fruit setting, maturity and harvesting</td>
<td>5</td>
</tr>
<tr>
<td>2.2.2 Production and distribution</td>
<td>6</td>
</tr>
<tr>
<td>2.2.3 Utilization</td>
<td>9</td>
</tr>
<tr>
<td>2.3 Composition and nutritive value of passion fruit and its juice</td>
<td>10</td>
</tr>
<tr>
<td>2.3.1 General considerations</td>
<td>10</td>
</tr>
<tr>
<td>2.3.2 Sugars and starch</td>
<td>11</td>
</tr>
<tr>
<td>2.3.3 Pectic substances</td>
<td>14</td>
</tr>
<tr>
<td>2.3.4 Organic acids</td>
<td>15</td>
</tr>
<tr>
<td>2.3.5 Proteins</td>
<td>17</td>
</tr>
<tr>
<td>2.3.6 Enzymes</td>
<td>17</td>
</tr>
<tr>
<td>2.3.7 Non-protein nitrogenous substances</td>
<td>17</td>
</tr>
<tr>
<td>2.3.8 Vitamins and minerals</td>
<td>19</td>
</tr>
<tr>
<td>2.3.9 Polyphenols</td>
<td>23</td>
</tr>
<tr>
<td>2.3.10 Anthocyanins</td>
<td>23</td>
</tr>
<tr>
<td>2.3.11 Carotenoids</td>
<td>23</td>
</tr>
<tr>
<td>2.3.12 Volatile flavour constituents</td>
<td>25</td>
</tr>
<tr>
<td>2.4 Changes in passion fruit composition on ripening</td>
<td>28</td>
</tr>
<tr>
<td>2.5 Diseases and infestation of passion fruit (post-harvest)</td>
<td>30</td>
</tr>
<tr>
<td>2.5.1 Brown spot disease</td>
<td>30</td>
</tr>
<tr>
<td>2.5.2 Woodness virus disease</td>
<td>31</td>
</tr>
<tr>
<td>2.5.3 Insects and pests causing fruit damage</td>
<td>31</td>
</tr>
<tr>
<td>2.6 Storage of passion fruit</td>
<td>31</td>
</tr>
<tr>
<td>2.6.1 Use of polyethylene</td>
<td>32</td>
</tr>
<tr>
<td>2.6.2 Use of controlled atmosphere</td>
<td>32</td>
</tr>
<tr>
<td>2.6.3 Use of refrigeration</td>
<td>33</td>
</tr>
<tr>
<td>2.6.4 Use of irradiation</td>
<td>34</td>
</tr>
<tr>
<td>2.7 Use of Pro-long-in fruit storage</td>
<td>34</td>
</tr>
<tr>
<td>2.8 Use of pectin in fruit storage</td>
<td>35</td>
</tr>
<tr>
<td>2.9 Aims of the present work</td>
<td>36</td>
</tr>
<tr>
<td>3. MATERIALS AND METHODS</td>
<td>37</td>
</tr>
<tr>
<td>3.1 Materials</td>
<td>37</td>
</tr>
<tr>
<td>3.2 Pre-storage treatments and storage conditions</td>
<td>37</td>
</tr>
<tr>
<td>3.3 Experimental design</td>
<td>38</td>
</tr>
<tr>
<td>3.4 Taste panel assessment</td>
<td>41</td>
</tr>
<tr>
<td>3.5 Analytical methods</td>
<td>41</td>
</tr>
<tr>
<td>3.5.1 Sugar identification</td>
<td>41</td>
</tr>
<tr>
<td>3.5.2 Reducing sugars</td>
<td>42</td>
</tr>
</tbody>
</table>
Contents contd.

3.5.3 Total sugars ........................................... 43
3.5.4 Total acid .................................................. 44
3.5.5 Carotenoids ............................................... 44
3.5.6 Anthocyanins .............................................. 44
3.5.7 Volatile flavour compounds .................................. 46
3.5.8 Vitamin C ................................................... 47
3.5.9 Protein ..................................................... 48
3.5.10 Calcium determination ...................................... 48
3.5.11 Pectin ..................................................... 48
3.6 Respiration rate measurement ...................................... 48
3.7 Isolation and identification of fungal infection ................. 51

4. RESULTS AND DISCUSSIONS ........................................ 52
4.1 General considerations ......................................... 52
4.2 Weight loss .................................................... 54
4.3 Taste panel assessment ......................................... 59
4.4 Changes in constituents ....................................... 65
4.4.1 Total soluble solids in the pulp ....................... 65
4.4.2 Reducing and Total sugars in the pulp ............... 67
4.4.3 Total acid in the pulp .................................. 70
4.4.4 Total carotenoids in the pulp ....................... 73
4.4.5 Anthocyanins in the peel ................................ 73
4.4.6 Volatile flavour compounds in the pulp ............. 76
4.4.7 Vitamin C in the pulp ................................ 80
4.4.8 Protein in the juice ..................................... 82
4.4.9 Calcium in the pulp ..................................... 82
4.4.10 Pectin in the peel ...................................... 84
4.5 Respiration ................................................... 87
4.6 Fungal infection ............................................... 92

5. CONCLUSIONS ...................................................... 93

6. SUGGESTION FOR FUTURE WORK .................................. 94

7. APPENDIX .......................................................... 95
    Plate 1 ......................................................... 95
    Plate 2 ......................................................... 95
    Plate 3 ......................................................... 96
    Taste Panel Score Sheet .................................... 97

8. REFERENCES .......................................................... 98
INTRODUCTION

Passion fruit (*Passiflora* species) is a relatively unknown tropical fruit both in developing and developed countries. It is better known for its juice and is used in a variety of juice mixes. Under normal storage conditions, the fruit cannot be stored for more than 7 to 10 days, since wilting, fungal decay and fermentation of the pulp sets in (Pruthi, 1963). The appearance, flavour, weight and food value of the fruit are also seriously affected. These losses in quality prevent the fruit from competing well with other more durable fruits in the fresh market.

Various methods of extending its shelf-life have been tried. These include refrigeration, hypobaric storage, controlled atmosphere, use of polyethylene packaging, irradiation and waxing. In the past, refrigeration has been the commonest method of storing fresh fruits over extended periods, however some fruits may undergo adverse physiological and internal textural changes.

In general the various methods that have been employed in extending passion fruit shelf-life have proved either ineffective or uneconomical.

Recently various workers (Motlagh, 1982; Dhalla, 1982; and Tarimo, 1982) have investigated the application of an edible semi-permeable membrane in extending the shelf-life of fruits and vegetables. Successful reports on extending the shelf-life of avocados, pears, limes, mangoes and bananas by using the semi-permeable membranes have been reported. Such edible semi-permeable membranes include mixture of carboxymethylcellulose and sucrose esters (trade name "Pro-long") and pectin.

The present investigation aims to assess the usefulness of these semi-permeable membranes in extending the shelf-life of passion fruit.
2.

LITERATURE SURVEY

2.1 Passion fruit species and hybrids

Passion fruit has about 400 known species of which about 50-60 bear edible fruits (Martin and Nakasone, 1970). Many of these sixty edible species are well known for their exquisite exotic flavours (Torres and Martin, 1974).

The major edible species are *Passiflora edulis* Sims (the purple passion fruit), *Passiflora edulis* f. *flavicarpa* Deg. (the yellow passion fruit), *Passiflora ligularis* Juss., *Passiflora mollissima* (HBK.) Bailey, and *Passiflora quadrangularis* L. (the granadilla). The importance of these species, distribution and chief areas where cultivated have been summarised by Martin and Nakasone (1970) (see Table 1 and Fig. 1).

*P. edulis* Sims originated from Brazil and spread to the Caribbean, Pacific, India, Africa, South America and Australia. Within Brazil there are various species including rain-loving and drought tolerant forms. The fruit is purple skinned and has a similar shape and size to a large plum (Martin and Nakasone, 1970; Whittaker, 1972). Plate 1 shows the shape and size of this fruit species. It is ovoid and measures about 3.5 to 9 cm long and between 3.5 and 7 cm in diameter. The rind is about 3 to 6 mm thick and is brittle, while the pulp is always yellow and has some juice. The pulp embeds the black seeds which are about 3 mm long and when dry show small cavities all over the surface.

*P. edulis* f. *flavicarpa* Deg. originated from Australia as a hybrid of *P. edulis* Sims (Martin and Nakasone, 1970), while Seal and Sherman (1960) thought that the fruit originated from South America. There is not much difference between *P. edulis* Sims and *P. edulis* f. *flavicarpa*, however f. *flavicarpa* is yellow, ovoid 6-12 cm long and 4-7 cm wide. The rind is between 3-10 mm thick and its juice is highly aromatic (Martin and Nakasone, 1970).
Table 1: Principal *Passiflora* species, distribution and main cultivating areas

<table>
<thead>
<tr>
<th>Species</th>
<th>Subgenus</th>
<th>Distributions</th>
<th>Chief Areas Where Cultivated</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>P. edulis</em> Sims</td>
<td>Granadilla</td>
<td>Brazil to Argentina</td>
<td>India, Sri Lanka, Africa, Australia, Hawaii, Hawaii, Kenya, India, Australia, Caribbean.</td>
</tr>
<tr>
<td><em>P. edulis</em> f. flavicarpa Deg.</td>
<td>Granadilla</td>
<td>Unknown</td>
<td>Hawaii, Kenya, India, Australia, Caribbean.</td>
</tr>
<tr>
<td><em>P. ligularis</em> Juss.</td>
<td>Granadilla</td>
<td>Mexico to N. South America</td>
<td>South and Central America.</td>
</tr>
<tr>
<td><em>P. mollissima</em> (HBK.) Bailey</td>
<td>Taesonia</td>
<td>Andes, S.A.</td>
<td>South America, Australia, New Zealand.</td>
</tr>
<tr>
<td><em>P. quadrangularis</em> L.</td>
<td>Granadilla</td>
<td>Unknown</td>
<td>Mexico, Caribbean, Northern South America, Australia, Asian tropics.</td>
</tr>
</tbody>
</table>

Fig. 1 World map showing distribution and chief cultivating areas of principal Passiflora species.

Key:
- **P. edulis** Sims
- **P. edulis f. flavicarpa** Deg.
- **P. ligularis** Juss.
- **P. mollisima** (HBK.) Bailey
- **P. quadrangularis** L.
P. ligularis is common and well known in Central America, and now extends as far south as the northern parts of South America, however it is not a very widely utilised fruit as compared to the P. edulis varieties. The fruit is ovoid, 6-9 cm long and 4-5.5 cm diameter. It's colour ranges from green, yellow, orange to even purplish with frequent spots. The rind is tough and durable but thin as compared to the above two species.

P. mollissima (HBK) Bailey is distributed along the Andes of South America and occasionally found in Australia and New Zealand.

P. quadrangularis is cultivated in Mexico, Caribbean, North of South America, Australia and Asia.

2.2 Passion fruit growth and harvesting, production and utilization

2.2.1 Fruit setting, maturity and harvesting

Once the fruit has been planted from seeds under favourable conditions, the vines grow rapidly and produce fruits within a period of 9 months to one year. Ganapathy and Singh (1975) suggested that a maximum bearing of passion fruit is reached in about 16 to 18 months after planting. For countries that are developing their own agricultural resources and where a farmer operates a small land holding, it provides a handsome cash crop.

One of the factors that regulate yields in passion fruit is trellising. This is so because trellising supports a heavy weight under all conditions. Whittaker (1972) suggested that trellising helps to control passion fruit juice production while Gurnah and Gachanja (1980) reported that the fruits from trellised vines weighed more, had a higher total soluble solids and ascorbic acid content than those fruits that were not. The same authors reported that
pruning reduced disease incidence especially attack of \textit{Alternaria passiflorae} Simmonds.

Another factor that plays a significant role in yields is the application of nitrogen and phosphate fertilizers. Ganapathy and Singh (1975) reported that to produce 30 kg of fruits, 900 to 1000 grams of nitrogen is required. Once the fruits have become mature which is 72 days after flowering they turn yellow or purple depending on the variety, and then fall down from the vines. For the purple variety the partially turned purple fruits on the vine can be harvested. The immature fruits without yellow or purple tinge should not be harvested since their juice is of inferior quality. From one vine it is estimated to harvest up to 300 fruits which is between 8 and 12 kg of fruits per year. Harvesting should be daily since the fallen fruits become infected on the ground with brown spot.

The fruits once harvested are usually stored in lug boxes but not in bags and sacks as this accelerates sweating and deterioration. If the fruits are to be kept for a few days before collection by the processing factories, they should be spread out on an open wire rack for free air circulation while for fresh market the fruits harvested should still show some green around the stem.

2.2.2 Production and distribution

World production of passion fruit is thought to be relatively small although very little is known about the actual amounts produced. Despite its small production, the unique exotic flavour of the fruit has allowed the fruit to gain popularity in both developing and developed countries. In Australia for example passion fruit has provided the flavour for a successful fruit yoghurt combination (Casimir \textit{et al.}, 1981).
Casimir et al. (1981, and references therein) has mentioned Australia, India, Kenya, New Zealand, Brazil, South Africa, Fiji, Sri Lanka and Caribbean countries as the major world producing areas. Whittaker (1972) reported that passion fruit is not only grown in tropical and sub-tropical regions but in temperate to warmer climates of the world. Landgraf (1979) reported that Brazil was the major world producer and exported 2,700 tonnes of passion fruit juice in 1977-78 and 8,650 tonnes in 1978-79. Casimir et al. (1981) reported Australia to have had a fluctuating production of between 2,000 and 4,000 tonnes juice annually since 1970.

Table 2 shows production figures (Mott, 1969). Efforts to obtain more recent statistics on the world production of fresh passion fruit has not been successful.

The major importing countries of passion fruit juice include United Kingdom, continental European countries, Australia, New Zealand and North America (Mott, 1969). In 1965 the United Kingdom imported 190,000 litres of passion fruit juice from Kenya, while small amounts were known to be imported from South Africa and West Indies.

In continental Europe, Switzerland is the largest importer of passion fruit juice from Kenya (Kenya Farmer, 1969). Some reports suggest that passion fruit products from Switzerland are distributed to West Germany and this suggests that Switzerland provides a good channel for passion fruit products distribution throughout Europe.

The market prospects for passion fruit juice and its flavour components appear favourable in Australia, New Zealand and North America. Both Australia and New Zealand are reported to import passion fruit juice from New Guinea to supplement their domestic production.

Market prospects for passion fruit in the U.K. look less favourable because few families have seen or are familiar with the
Table 2: World production of passion fruit

<table>
<thead>
<tr>
<th>Country</th>
<th>Year</th>
<th>Total acreage</th>
<th>Bearing acreage</th>
<th>Total no. plants</th>
<th>No. plants in bearing</th>
<th>Production in tons of fruit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Australia</td>
<td>1964-5</td>
<td>1,380</td>
<td>886</td>
<td>-</td>
<td>-</td>
<td>1,300</td>
</tr>
<tr>
<td>2 Fiji</td>
<td>1966</td>
<td>200</td>
<td>120</td>
<td>-</td>
<td>-</td>
<td>1,610</td>
</tr>
<tr>
<td>3 Hawaii</td>
<td>1959</td>
<td>1,200</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>10,000</td>
</tr>
<tr>
<td>4 Kenya</td>
<td>1965</td>
<td>330</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1,130</td>
</tr>
<tr>
<td>5 New Guinea</td>
<td>1966/7</td>
<td>Scattered plots</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>455</td>
</tr>
<tr>
<td>6 New Zealand</td>
<td>1965</td>
<td>64</td>
<td>17,600</td>
<td>-</td>
<td>-</td>
<td>178</td>
</tr>
<tr>
<td>7 South Africa</td>
<td>1959-60</td>
<td>2,000</td>
<td>1,100</td>
<td>803,400</td>
<td>445,000</td>
<td>1,000</td>
</tr>
</tbody>
</table>

taste of fresh fruit. As suggested by Mann (1983) and Cutts (1983) a large proportion of the British population has never heard of passion fruit and as such it will be necessary to educate the general public concerning passion fruit in order to increase the market.

2.2.3 Utilization

Of the two major species mentioned earlier, the purple passion fruit (P. edulis Sims) is a greater contributor to the world market than the yellow passion fruit (P. edulis f. flavicarpa) which is a relative new-comer (Whittaker, 1972). Chan (1978) suggested that the two passion fruit species (P. edulis Sims and P. edulis f. flavicarpa) are not valued as much for their nutritional characteristics as for their exceptionally exotic aromas. The market for fresh passion fruit is rather limited but the juice can be used on its own without adding any artificial colour or flavour since both are naturally strong. Recent uses of the juice have been in a cordial drink, a carbonated drink and as a flavouring for sweets and ice cream (Owen, 1971; Chan et al., 1972). Adsule et al. (1980) reported that passion fruit juice can be applied in different food formulas since it provides an excellent flavour. Among the foods where it can be used are pies, cakes, puddings, sauces, salads, desserts and punch pies. It is also considered an excellent mix for alcoholic beverages such as vodka, gin and rum. Quite often it has been used as a flavourant in jams, butter, conserves, jellies, marmalades and hot spiced beverages. Apart from its edible properties, passion fruit can be an attractive ornamental plant in residential areas.

Pruthi and Lal (1959), Murray et al. (1973), Chan (1978), Hiu and Schewer (1961) and Parliment (1972) have all indicated that passion
fruit juice has increased in its use because of its exotic flavour. Pruthi et al. (1958) reported that purple passion fruit is being exploited in manufacturing beverages and tropical fruit salads in Australia, Kenya, South Africa, Hawaii, India and other tropical countries.

The passion fruit rind and seeds are produced in enormous quantities as by-products and as such present a serious disposal problem to the processing industry. According to Whittaker (1972) out of 1000 litres of juice produced per hour, 1 ton of skin shells and seeds are produced.

Utilization of passion fruit wastes into commercial products have been investigated. Martin and Reuter (1949) investigated the constituents of passion fruit rind and reported that a material behaving like pectin could be precipitated out using alcohol. Henderson et al. (1978) reported that during passion fruit processing operations, about 150 tonnes of seeds are discarded annually in Kenya alone. He proposed that seeds should be utilized for edible and non-edible oil products, while the meal from the oil solvent extraction could be used as an animal feed.

Other authors who have reported on utilization of passion fruit by-products are Sherman et al. (1953), Otagaki and Matsumoto (1958), Pruthi (1965) and Prasad (1980).

2.3 Composition and nutritive value of passion fruit and its juice

2.3.1 General considerations

The chemical composition and nutritive values of passion fruit vary widely. The variation is contributed by factors such as variety,
degree of ripeness, date of picking, locality and region where produced.

Singh et al. (1978) suggested that purple passion fruit should be harvested between 80th and 85th day when fruits are turning purple since this is when the sugars, acids and ascorbic acid content are optimal.

Casimir et al. (1981) gave detailed report on the chemical composition of passion fruit juices from Africa and South America as summarised in Table 3.

2.3.2 Sugars and starch

In whole passion fruit, out of the total soluble solid content of about 71%, sugars and starch constitute about 63%. The carbohydrates of the rind comprise starch, sucrose, glucose and fructose. The latter two contribute up to about 80% in almost equal concentration, (Susheela et al., 1960). Studies carried out by Pruthi and Lal (1960), using paper chromatography techniques and Chan and Kwok (1975) using thin layer chromatography and gas chromatography revealed that passion fruit juices consisted of three sugars glucose 3.6% and 3.24%; fructose 3.6% and 3.59%; and sucrose 3.8% and 2.85% respectively.

Ogata et al. (1972) reported the presence of a seven carbon sugar (mannoheptulose) in passion fruit pulp while Whittaker (1972) in his review reported passion fruit pulp to contain 6.5% to 8% reducing sugars and 1.5% to 3.0% non-reducing sugars. Table 4 summarises the sugar content of passion fruits from different cultivating areas (Benk, 1967).
<table>
<thead>
<tr>
<th>Country of origin</th>
<th>Angola</th>
<th>Brazil</th>
<th>Egypt</th>
<th>Kenya</th>
<th>Purple</th>
<th>Yellow</th>
<th>Curuba</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variety</td>
<td>Purple</td>
<td>Yellow</td>
<td>Yellow</td>
<td>Purple</td>
<td>Purple</td>
<td>Yellow</td>
<td>Banana</td>
</tr>
<tr>
<td>Total solids (%)</td>
<td>10-14</td>
<td>18.6</td>
<td>14.9</td>
<td>16.7</td>
<td>10-14</td>
<td>16.7</td>
<td>16.7</td>
</tr>
<tr>
<td>Soluble solids (%)</td>
<td>-</td>
<td>14.5-17</td>
<td>13.6</td>
<td>13.0</td>
<td>15.4-16.4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Insoluble solids ($)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.2-1.9</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Crude fibre (%)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.07-0.09</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total sugars (%)</td>
<td>-</td>
<td>7.8-11.3</td>
<td>11.4</td>
<td>12.1</td>
<td>8.5-9.9</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Invert sugars (%)</td>
<td>5.3-7.3</td>
<td>5.9-6.3</td>
<td>8.3</td>
<td>7.5</td>
<td>6.7-9.3</td>
<td>1.75</td>
<td>5.3-7.3</td>
</tr>
<tr>
<td>Sucrose ($)</td>
<td>1.6-2.2</td>
<td>-</td>
<td>3.2</td>
<td>4.6</td>
<td>0.7-1.8</td>
<td>6.60</td>
<td>1.6-2.2</td>
</tr>
<tr>
<td>Total acids (%)</td>
<td>3.2-3.7</td>
<td>0.7-0.8</td>
<td>3.9-5.5</td>
<td>0.6</td>
<td>0.6</td>
<td>3.2-3.7</td>
<td>3.90</td>
</tr>
<tr>
<td>Citric acid (%)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3.44</td>
<td>-</td>
</tr>
<tr>
<td>Malic acid (%)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.66</td>
<td>-</td>
</tr>
<tr>
<td>Tannic acid (%)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.66</td>
<td>-</td>
</tr>
<tr>
<td>pH</td>
<td>3.4</td>
<td>2.8-2.9</td>
<td>-</td>
<td>3.3</td>
<td>3.43</td>
<td>3.4</td>
<td>3.60</td>
</tr>
<tr>
<td>Protein ($)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.1-1.3</td>
<td>0.63</td>
<td>1.04-1.60</td>
</tr>
<tr>
<td>Pastein ($)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.21-0.24</td>
<td>-</td>
<td>0.04-0.06</td>
</tr>
<tr>
<td>Starch ($)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.1-1.2</td>
<td>1.24</td>
<td>-</td>
</tr>
<tr>
<td>L aid (%)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.05-0.08</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Tannin (%)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.07-0.08</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Minerals ($)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.57-0.98</td>
<td>0.23</td>
<td>0.75-0.77</td>
</tr>
<tr>
<td>K (mg)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>204-227</td>
<td>157</td>
<td>-</td>
</tr>
<tr>
<td>Na (mg)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.6-1.0</td>
<td>16.1</td>
<td>-</td>
</tr>
<tr>
<td>Ca (mg)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4.2-5.6</td>
<td>5.1</td>
<td>6.5-9.0</td>
</tr>
<tr>
<td>P (mg)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>15-22</td>
<td>87</td>
<td>7.0-9.7</td>
</tr>
<tr>
<td>Fe (mg)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.0-1.4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Feral value (10 gm)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.9-2.6</td>
<td>-</td>
<td>0.0-1.4</td>
</tr>
<tr>
<td>Chlorinated value (1 gm)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>15-20</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ascorbic acid (mg %)</td>
<td>20-40</td>
<td>29-32</td>
<td>30</td>
<td>32</td>
<td>29-45</td>
<td>42</td>
<td>17-20</td>
</tr>
<tr>
<td>Total carotenoids (mg %)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.3-1.7</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Carotene (mg %)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.6-0.9</td>
<td>0.25</td>
<td>0.30-0.35</td>
</tr>
<tr>
<td>Thiamine (mg %)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.08-0.11</td>
<td>-</td>
</tr>
<tr>
<td>Riboflavin (mg %)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.05-0.13</td>
<td>-</td>
</tr>
<tr>
<td>Nicotinic acid (mg %)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.6-1.8</td>
<td>-</td>
</tr>
</tbody>
</table>

Source: Costin et al. (1901).
Table 4: Total sugars (%) and reducing sugars (%) of passion fruit pulp from different cultivating areas

<table>
<thead>
<tr>
<th>Place</th>
<th>Total sugars (%)</th>
<th>Reducing sugars (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>India</td>
<td>7.4-13.3</td>
<td>3.6-8.3</td>
</tr>
<tr>
<td>Australia</td>
<td>-</td>
<td>5.1</td>
</tr>
<tr>
<td>Kenya</td>
<td>8.47-8.55</td>
<td>6.68-7.64</td>
</tr>
</tbody>
</table>

Source: Benk (1967).
During refrigerated storage at 6.5°C and 85-90% relative humidity, reducing sugars increased up to 6 weeks storage from 5.2% to 7.5% then started to decrease in the 8th week to 6.5% (Pruthi, 1963). Benk (1967) found that starch in Kenyan passion fruit juice constituted about 1.08% to 1.2% while those from India, Australia and South America were found to have a variation of between 1.24% and 3.7%.

Compilation from various sources showed the composition of starch in passion fruit juices to vary between 2.5% and 3.5% (Whittaker, 1972). Ganapathy and Singh (1976) observed that the total soluble solids for control fruit pulp increased from initial 18.92° Brix to 19.42° Brix after 6 days storage then decreased afterwards. Hou et al. (1978) found the average total soluble solids of an average mature passion fruit pulp to be 15.3° Brix. The passion fruit rind has been found to contain sucrose, glucose, fructose and starch (Susheela et al., 1960).

2.3.3 Pectic substances

Passion fruit juice is known to have minute amounts of pectic substances; however the rind contains an appreciable amount. Pectin structure consists of long chains of polygalacturonic acid in which their carboxylic groups are esterified. Ripe fruits usually contain the insoluble pectins that are formed by the reaction of carboxylic groups of pectin with calcium. This is known as proto-pectin. During ripening, partial enzymatic hydrolysis results and proto-pectin decreases with a corresponding decrease in soluble pectin.

Pruthi (1965) isolated, characterised and recovered pectin from purple passion fruit rind and found the yield to be between 10.8% and 14% on dry weight basis. Seelkopf and Febres (1966) reported
0.04% to 0.06% pectin on wet weight basis in the rind; while Bank (1967) reported 0.03% pectin on wet weight basis in Kenyan passion fruit. More recent reports on yellow passion fruit rind by Prasad (1980), gives an average yield of pectin on dry weight basis to be 15%.

2.3.4 *Organic acids*

Purple passion fruit juice is very acidic when the fruit is in a yellow-purple state and as the maturity of the fruit progresses the acidity of the juice decreases. As with carbohydrates, the acid content varies very much and this also depends on factors such as date of harvest, region, fruit size and variety (Pruthi, 1963).

The major acids that contribute to the acidity of passion fruit as reported by Chan et al. (1972) are citric acid, malic acid, lactic acid, malonic acid, succinic acid, ascorbic acid and galacturonic acid. Table 5 gives the amounts of the major acids found in passion fruit. Pruthi (1963) identified citric acid and malic acid as the major acids in passion fruit juice. Average maturity fruit has an average titrable acidity of 3.1% in its juice (Hou et al., 1978).

Ganapathy and Singh (1976) reported that acidity decreased from 2.42% at the fresh state to 1.96% in juice after 18 days of storage. Whittaker (1972) showed an average acidity of 2.5% to 3.5% in passion fruit pulp, while Bank (1967) reported acid values of 2.4% to 4.8%, 3.9%, 2.1% and 3.2% to 3.66% for passion fruit juices from India, South America, Australia, and Kenya respectively. Hashinaga et al. (1978) reported that as passion fruit matured the amounts of juice per fruit increased while free organic acids of the juice decreased.

Analysis of passion fruit rind by Susheela et al. (1960) revealed citric acid, malic acid, maleic acid and succinic acid to be present.
### Table 5: Major acids found in passion fruit

<table>
<thead>
<tr>
<th>Acid</th>
<th>Purple (mEq/100 g)</th>
<th>Yellow (mEq/100 g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Citric acid</td>
<td>13.10</td>
<td>55.00</td>
</tr>
<tr>
<td>Malic acid</td>
<td>3.86</td>
<td>10.55</td>
</tr>
<tr>
<td>Lactic acid</td>
<td>7.49</td>
<td>0.58</td>
</tr>
<tr>
<td>Malonic acid</td>
<td>4.95</td>
<td>0.13</td>
</tr>
<tr>
<td>Succinic acid</td>
<td>2.42</td>
<td>Trace</td>
</tr>
<tr>
<td>Ascorbic acid</td>
<td>0.05</td>
<td>0.06</td>
</tr>
<tr>
<td>Volatile acids</td>
<td>0.12</td>
<td>0.11</td>
</tr>
<tr>
<td><strong>Total acids</strong></td>
<td><strong>31.99</strong></td>
<td><strong>66.43</strong></td>
</tr>
<tr>
<td><strong>Titratable acidity</strong></td>
<td><strong>32.01</strong></td>
<td><strong>65.83</strong></td>
</tr>
</tbody>
</table>

Source: Chan *et al.* (1972).
2.3.5 **Proteins**

Pruthi (1963) reported the range of nitrogen content of purple passion fruit to vary from 0.096% to 0.192% i.e. crude protein \((N \times 6.25)\) varied from 0.6% to 1.2%. Benk (1967) analysed the protein content of Kenyan passion fruit and found it to range between 1.1% to 1.2%. Duckworth (1966) in his collective data from various sources reported the protein content to vary from 0.6% to 2.8%. Seelkopf et al. (1962 and 1966) reported 0.63%, 1.04% to 1.6% and 0.84% protein in Venezuelan purple, yellow and banana passion fruit respectively.

2.3.6 **Enzymes**

Little work has been done and reported on the enzymatic system of passion fruit. Ross and Chang (1958) reported the presence of catalase and phenolases in yellow passion fruit variety while Pruthi and Srivas (1963) reported the presence and inactivation of pectin methylesterase.

Czyhrinciw (1969) reported on the inactivation of pectinesterase in giant granadilla at 85°C for three minutes. Hashinaga et al. (1978) has shown that passion fruit juice \((P. edulis\) Sims) has two proteolytic enzymes that had maximum activity at 40°C and 50°C respectively and their specific activity and total activity increased as the fruit matured.

2.3.7 **Non-protein nitrogenous substances**

Free amino acids were detected in passion fruit by use of the micro-Kjeldahl method (Pruthi and Srives, 1964). The amino acids that were reported are leucine, threonine, valine, tyrosine, proline, glycine, aspartic acid, arginine and lysine (see Table 6). The same author reported that total nitrogen amino nitrogen and non-protein nitrogen were 0.138%, 0.067% and 0.07% respectively in passion fruit juice.
Table 6: Free amino acids in passion fruit juice

<table>
<thead>
<tr>
<th>Amino acids</th>
<th>Juice</th>
<th>Skin</th>
<th>Seeds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leucines</td>
<td>✓✓</td>
<td>✓✓</td>
<td>✓</td>
</tr>
<tr>
<td>Valine</td>
<td>✓</td>
<td>✓</td>
<td>T</td>
</tr>
<tr>
<td>Tyrosine</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Proline</td>
<td>✓</td>
<td>✓</td>
<td>T</td>
</tr>
<tr>
<td>Threonine</td>
<td>✓✓</td>
<td>✓</td>
<td>T</td>
</tr>
<tr>
<td>Glycine</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Aspartic acid</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Arginine</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Lysine</td>
<td>✓</td>
<td>T</td>
<td>T</td>
</tr>
</tbody>
</table>

Source: Pruthi and Srivas (1964).

T = Trace amounts
✓ = Detectable amounts
✓✓ = Abundant amounts
An alkaloid has been found in the leaves, stem and roots of *Passiflora* species. This type of alkaloid is related to harman. (the structure is shown in Fig. 2). The compound harman in *P. edulis* is known to be formed from the amino acid tryptophan (Slaytor and McFarlane, 1968). Lutomski et al. (1975), determined different alkaloids, flavonoids and carotenoids in purple and yellow passion fruits by thin layer chromatography. He found 0.012 mg % in purple passion fruit and 0.7 in yellow passion fruit. Of the seven alkaloids detected four were identified as harman, harmol, harmin and harmalin.

Cyanogenic glycosides are widespread in plant families such as Mimosaceae, Texaceae, Euphorbiaceae, Rosaceae and Passifloraceae (Conn, 1973), and hydrolysis can yield hydrocyanic acid. Gondwe (1976) working on Kenyan yellow and purple passion fruit reported that the fruits contain cyanogenic compounds. A higher concentration however was found in young immature fruits with 506 μ moles of cyanide per 100 g pulp and a progressive decrease in ripened but fallen to the ground fruits (10 μ moles to 0.39 μ moles of cyanide per 100 g pulp). From these results no toxicological importance was seen since the author calculated that for minimum lethal dose one needed to consume up to 1750 smooth ripe fruits that had fallen on the ground or 8800 of the wrinkled ripe fruits at one ingestion.

2.3.8 vitamins and minerals

Passion fruit is known to contain significant amounts of vitamin A, riboflavin, niacin and vitamin C.

The amount of vitamin A, as Φ-carotene, in passion fruit varies within species. For example the Φ-carotene of *P. ligularis* varies from 0 to 0.25 mg % while that of *P. quadrangularis* varies from 0.004 mg % to 0.04 mg % (Munsell et al., 1950). Pruthi (1958a) reported 0.717 mg % of Φ-carotene content in purple passion fruit.
Fig. 2 Harman structure

Source: Handler (1965).
while that of yellow passion fruit was found to be 1.01 mg %. Benk (1967) reported $\beta$-carotene content of passion fruit from various countries to vary widely (see Table 7). Duckworth (1966) reported $\beta$-carotene of passion fruit to be within the range of 0 to 0.93 mg %.

Thiamine was first reported to be present in passion fruit by French et al. (1951) and Pruthi (1959). Seelkopf and Febres (1966) working on Venezuelan yellow passion fruit found thiamine to be in the range of 0.08 to 0.11 mg % while Duckworth (1966) reported thiamine to vary from trace amounts to 0.04 mg %.

Riboflavin in passion fruit juice has been reported by Pruthi and Lal (1959). It varied from 0.12 mg % to 0.19 mg %. Duckworth (1966) reported a range of 0.1 to 0.18 mg %.

Pruthi and Lal (1959) have reported a maximum niacin content of 2 mg % in passion fruit. Duckworth (1966) reported niacin content to be in the range of 1.5 to 1.9 mg %.

Vitamin C has been extensively studied in fruits and vegetables because of its involvement in many biochemical processes, apart from its contribution nutritionally. Investigations of vitamin C in passion fruit goes as far back as 1940 when Joachim and Panditesskere reported its presence. Pruthi (1958b) and Seal and Sherman (1960) have reported that purple passion fruit contains more vitamin C than yellow passion fruit. Pruthi and Lal (1959) reported vitamin C content in passion fruit to fall within the range of 21.9 and 69.9 mg %.

The mineral content of passion fruit varies from 0.35% to 0.8%. Passion fruit juice has a high mineral content compared with other fruit juices; minerals present include calcium, iron and phosphorus (Casimir et al., 1981).
Table 7: Composition of vitamins (mg %) in passion fruit

<table>
<thead>
<tr>
<th>Country</th>
<th>Β-carotene</th>
<th>Thiamine</th>
<th>Riboflavin</th>
<th>Vitamin C</th>
</tr>
</thead>
<tbody>
<tr>
<td>India</td>
<td>0.3–0.8</td>
<td>–</td>
<td>–</td>
<td>21.9–69.6</td>
</tr>
<tr>
<td>Venezuela</td>
<td>0.3–0.35</td>
<td>0.08–0.11</td>
<td>0.09–0.13</td>
<td>17.3–20.2</td>
</tr>
<tr>
<td>Kenya</td>
<td>0.61–0.87</td>
<td>–</td>
<td>–</td>
<td>29.4–45.4</td>
</tr>
<tr>
<td>South America</td>
<td>0.25</td>
<td>–</td>
<td>–</td>
<td>41.5</td>
</tr>
<tr>
<td>Angola</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>20–40</td>
</tr>
</tbody>
</table>

Source: Benk (1967).
2.3.9 Polyphenols

Passion fruit juice has been found to contain a small percentage (42 mg %) of polyphenolic compounds (Pruthi, 1963). Passion fruit rind extracts have been shown to contain appreciable amounts of tannic acid as polyphenols, however resorcinol, gallic acid, catechol and pyrogallol have been found to be absent (Susheela et al., 1960).

2.3.10 Anthocyanins

Pruthi et al. (1961) has reported that the anthocyanin, pelargonidin-3-diglucoside is associated with the purple colour of the purple passion fruit. During storage the purple pigment in the rind shows some degradation which may be due to anthocyanin breakdown. Traces of anthocyanin compounds can be seen in the pulp of the over-ripened purple passion fruit.

2.3.11 Carotenoids

Passion fruit juice is usually yellow to orange in colour and this is in part due to trace amounts of flavones, although it is mainly due to a complex mixture of carotenoid pigments (Pruthi, 1963).

Leuenberger and Thommen (1972) reported the levels of carotenoids in fresh, pasteurized and frozen juice, skin and mucilage of purple passion fruit as shown in Table 8. The main constituents are $\beta$-carotene, phytofluene and $\gamma$-carotene. In addition to these three main carotenoid contributors, the same author identified $\beta$-apo-12-carotenal, $\beta$-apo-8'-carotenol kryptoxanthin, mutatoxanthin and aroxanthin in pasteurized passion fruit juice.
<table>
<thead>
<tr>
<th>Material</th>
<th>Total carotenoids (mg/100 gm)</th>
<th>β-Carotene (mg/100 gm)</th>
<th>Phytofluene (mg/100 gm)</th>
<th>ζ-Carotene (mg/100 gm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh juice</td>
<td>0.66</td>
<td>0.27</td>
<td>0.35</td>
<td>0.32</td>
</tr>
<tr>
<td>Skin</td>
<td>0.13</td>
<td>0.014</td>
<td>0.003</td>
<td>-</td>
</tr>
<tr>
<td>Mucilage&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.14</td>
<td>0.32</td>
<td>0.46</td>
<td>0.50</td>
</tr>
<tr>
<td>Pasteurized juice&lt;sup&gt;c&lt;/sup&gt;</td>
<td>2.0</td>
<td>0.9</td>
<td>0.53</td>
<td>0.6</td>
</tr>
<tr>
<td>Frozen juice&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1.8</td>
<td>0.72</td>
<td>0.43</td>
<td>0.73</td>
</tr>
</tbody>
</table>

<sup>a</sup> From Leuenberger and Thommen (1972); the passion fruit from Kenya were presumably purple.

<sup>b</sup> Thick pulp surrounding the seeds.

<sup>c</sup> Not from the same fruit as the fresh juice.
2.3.12 Volatile flavour constituents

The flavour of passion fruit is strong and as such the juice requires little or no flavour additives in its formulas (Owen, 1971). In addition to this advantage, the flavour is versatile in its application. The unique exotic flavours have largely been attributed to the presence of a large amount of ethyl and hexyl esters of butyric and hexanoic acids. Chan (1978) reported these acids to be in association with 20 to 160 other volatile flavour compounds all contributing to passion fruit aroma.

The history of the volatile flavour constituents of passion fruit was reviewed by Hiu and Schener (1961). Their studies were focused on yellow passion fruit and the results showed that hexyl hexanoate ester contributed about 70% of the petroleum ether extract while ethyl butyrate contributed 2%. In contrast the purple passion fruit flavours as reported by Parliament (1972) showed ethyl butyrate to be a major constituent (33%) and hexyl hexanoate was a relatively minor component (5%) (Table 9). The same percentage composition for ethyl butyrate was reported by Huet (1973).

Recent reviews and reports have shown that no single or small number of compounds are responsible for the characteristic exotic aromas of passion fruit but a varying number of compounds are involved. Murray et al. (1972 and 1973) studied comprehensively the flavour constituents of fresh purple passion fruit juice and identified 73 flavour constituents. Data for 22 other flavour constituents were also collected but not found adequate for their positive identification. Winter and Kloti (1972) have studied and reported the volatile constituents of purple passion fruit from Kenya.

Comparison of head space aromas of the two important commercial varieties of passion fruit (i.e. P. edulis Sims and P. edulis f. flavicarpa) was made by Murray & Whitfield (1974-75), and the results revealed
Table 9: Neutral compounds in purple passion fruit in order of increasing retention times on gas chromatographic analysis

<table>
<thead>
<tr>
<th>Peak</th>
<th>Component</th>
<th>Relative RT</th>
<th>% Comp</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Solvent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Ethyl acetate</td>
<td>0.06</td>
<td>4.3</td>
</tr>
<tr>
<td>3</td>
<td>Ethyl butyrate</td>
<td>0.16</td>
<td>33.3</td>
</tr>
<tr>
<td>4</td>
<td>Ethyl hexanoate</td>
<td>0.46</td>
<td>12.3</td>
</tr>
<tr>
<td>5</td>
<td>Hexyl acetate</td>
<td>0.60</td>
<td>1.7</td>
</tr>
<tr>
<td>6</td>
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<td>0.64</td>
<td>2.0</td>
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<tr>
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<td>1-Hexanol</td>
<td>0.72</td>
<td>3.1</td>
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<tr>
<td>8</td>
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<td>0.74</td>
<td>1.6</td>
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<td>9</td>
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<tr>
<td>11</td>
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<td>1.00</td>
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</tr>
<tr>
<td>17</td>
<td>a-Ionone</td>
<td>3.28</td>
<td>3.2</td>
</tr>
</tbody>
</table>

Source: Parliment (1972).
purple skinned passion fruit was richer in their aroma compounds, the majority of which were esters of ethyl, butyl and hexyl butanoates. Whitfield et al. (1973) isolated two novel compounds with intense rose-like aromas in the juice of purple passion fruit which had previously been studied and reported by Murray et al. (1972), and referred to as the "rose compounds". They were edulan I and II (Fig. 3).

Reports by Casimir (1977-78) have shown that immature purple passion fruit have linalool, hexanal, 2-methyl but-3-en-2-ol and α-terpineol as the major volatile components while in mature fruit the four components decrease in concentration and give way to aliphatic ester and carotenoid related components. These latter compounds reached a maximum concentration in the passion fruit that has just fallen from the vine. A review by Casimir et al. (1981) listed all the volatile flavour constituents previously reported in passion fruit.

2.4 Changes in passion fruit composition on ripening

Ripening is considered to begin during the later stages of maturation and ends at the beginning of senescence. Ripening can be defined as transforming a physiologically immature but inedible plant organ into a visually attractive olfactory and taste sensation (Wills et al., 1981). As reported by Pruthi (1963) passion fruits are grouped under climacteric fruits. Climacteric fruits are fruits that show a characteristic temporary rise in the rate of respiration.

During ripening of passion fruit the carbohydrate constituents
Fig. 3 Structure of 3,5,6,8a-tetrahydro-2,5,5a-tetramethyl-(2H)-1-benzopyrans. Edulan I and II

Edulan I

Edulan II
show some prominent biochemical changes, as discussed above. The sugars increase in amount due to hydrolysis of polysaccharides, although some of the sugars formed are used in respiration. The acidity of passion fruit increases at first then decreases during the early stages of development and later decreases slowly and progressively during and subsequent to ripening. This is expected since organic acids, like carbohydrates are respirable substrates and as such the acid changes are linked to the functioning of respiratory cycles. Passion fruit loses a lot of water by both respiration and transpiration during ripening and as such one expects wrinkling to take place. In due course the texture of the fruit softens which is associated with progressive solubilization and depolymerization of pectic substances.

Other constituents that change significantly during ripening of passion fruit are nitrogenous substances, pigments, volatiles and flavonoids as mentioned above. As expected with many fruits the nitrogenous compounds in the form of proteins do change and there is a rise in protein synthesis due to the presence of free amino acids. During senescence this process reverses and thus a progressive breakdown of tissue protein. Pigments commonly found in passion fruit are chlorophylls which break down giving way to anthocyanin synthesis of the peel. In the pulp carotenoids are formed and do increase.

In immature passion fruits the major volatile constituents usually dominate but as the fruit reaches maturation and sets on ripening aliphatic esters and carotenoid related compounds are produced (Casimir, 1977-78). Another abundant volatile that is formed during ripening in passion fruit is ethylene which contributes about 70-80% of the total carbon in the volatile fraction.
Flavonoids in purple passion fruit juices are about 1.06 mg % (Lutomski et al., 1975). During ripening the flavanoid content in passion fruit decreases since the mellowing of flavour features are usually contributed by them and associated to ripening process.

2.5 Diseases and infestation of passion fruit (post-harvest)

2.5.1 Brown spot disease

This disease has been reported by Ondieki (1975) on Kenyan passion fruit. It is known to be caused by the fungus Alternaria Passiflorae Simmonds. The disease is fond of attacking the aerial parts of the vines as well as the whole fruit. The symptoms of the disease is the development of reddish brown concentric spots with greenish margin. As the infection progresses the spots become large and develop into a series of concentric spots which might even result into yellowing and premature dropping of the leaves, while on the fruits the brown spots give a bad appearance and thus render the fruit less acceptable for sale in the fresh market. This disease is associated with high rainfall and humidity and has a common preference to older or neglected plantations. The same author reported of how a collapse of the Kenya passion fruit industry was caused by this disease.

Whittaker (1972) reported that the disease is sometimes associated with poor storage and handling of mature fruits. Gurnah and Gachanja (1980) helped to reduce the incidence of the disease while Ondieki (1975) suggested fungicides as a means of controlling the disease. Other minor fungal diseases are leaf spot which is caused by Septoria Passiflorae and basal rot caused by Fusarium species.
2.5.2 **Woodness virus disease**

The disease is caused by a virus that is transmitted by aphids (Bakker, 1974). The common symptoms of the disease are malformed fruit and typical foliage mottle (Ondieki, 1975). The malformation of the fruit is most serious as this can cause the hardening of the tissues of the pericarp and reduction of juice formation.

2.5.3 **Insects and pests causing fruit damage**

The well known insects that have been reported to cause damage on the passion fruit are the aphids. Bakker (1974) recorded occurrence of the aphids of different genera on *F. edulis* in Kenya. This record supports the fact that the passion fruit virus disease is associated with the aphids that infest the fruit.

Thrips are the other type of insects that infest the fruit, however they are commonly observed during dry weather spells only. The symptoms of the insect attack is the mottled punctures on the leaves and fruit, resulting into dropping of the immature fruit and subsequent leaf shrivel.

Sucking bugs such as *Leptoglossus membranaceus F.* have also been associated with passion fruit attack. The passion fruit red spider mites (*Bemisia tabaci Gennadius*) damage the fruit of *F. edulis* species as reported by Sloan (1946) and Nishida (1954).

2.6 **Storage of passion fruit**

Handling methods affect storage. After the fruit has been received in the fresh market or by a processor, storage becomes an essential factor. For processing the storage area should be a well ventilated and if in containers, the stacking should be in such a way
as to allow free air circulation. Storage of fresh passion fruit and other tropical and sub-tropical fruits has become an important project which is being reviewed time and again since rapid deterioration is a problem both to the farmer and the user (Pruthi, 1963). Special techniques to extend the shelf-life of fresh passion fruit have been developed as reviewed in outline below.

2.6.1 Use of polyethylene

The principle behind the use of polyethylene packaging is that oxygen present in the pack is consumed by the respiring product producing carbon dioxide and thus a modified gas atmosphere is created. The use of this method has been practised to extend the shelf-life of tropical and sub-tropical fruits. Banana for example has been experimented with using polyethylene packaging (Scott and Roberts, 1966; and Scott et al., 1971), also avocados (Oudit and Scott, 1973). Pruthi and Lal (1955) observed considerable reduction in moisture loss of passion fruit using polyethylene film packaging material. Ganapathy and Singh (1976) reported that passion fruits stored in unperforated polyethylene bags lost less percent weight than the control. While Cereda et al. (1976) reported that yellow passion fruits that were stored in polyethylene bags and paraffin waxed resisted withering compared to the control at a storage temperature of 5.6 to 7.2°C and a relative humidity of 85 to 90%. A report by Revista (1977) showed that yellow passion fruits stored in polyethylene bags lost about 0.96% weight after 14 days storage while the control lost about 35.10% at ambient temperatures.

2.6.2 Use of controlled atmosphere

This is a storage whereby the respiration rate of the product is
reduced by the presence of low oxygen content and a natural or artificial introduction of carbon dioxide. Biale (1960) reported the application of this technique on several fruits. Pruthi (1963) reported that less mature but rather acid fruits stored at a temperature of 7.2°C to 10°C under a controlled atmosphere of 5% CO₂ and 5% O₂ had their storage life extended from 3 weeks to 6 weeks. The best storage conditions of passion fruit as stated by Wills et al. (1981) is 5-9°C thus extending the storage from 21 to 35 days.

2.6.3 Use of refrigeration

Low temperature storage above 0°C is used to keep fruits in their natural condition for many days. The only snag with refrigeration storage is that when defrosting the fruits lose their natural texture and thus begin to deteriorate. Low temperatures slow down the chemical and biological processes in fruits particularly respiration.

Reports by Pruthi (1963) showed that passion fruit of both yellow and purple varieties could not be stored at ordinary temperatures for more than 7 to 10 days. For purple passion fruit Wardlaw (1937) reported that the fruit could be stored for 4-5 weeks at 2.2°C, 6°C and 10°C however in low temperatures a breakdown in the form of blood red discolouration on the skin was observed, while at high temperatures mould attack was eminent. William (1932) reported passion fruits packed in ground peat moss and stored at 2.2°C developed some mould and the flavour and skin deteriorated considerably as compared to the controls.

Pruthi (1963) reported that passion fruits stored at 6.5°C/85-90% relative humidity lost less weight after four weeks storage compared to those stored at 24-33°C and 55-70% relative humidity.
2.6.4 Use of irradiation

Irradiation is relatively a new field of preserving food products. Its use commenced at the end of the Second World War, but then it has been associated with many side problems. First it is an expensive method, secondly it produces deleterious side-effects, reducing the quality of the food, once a certain dose is passed. Colour and flavour are the most affected qualities of food by irradiation.

Irradiation produces Beta and gamma rays which are emitted by radioactive elements. For preservation purposes gamma radiation are the common ones that are used in food preservation. They are emitted as a result of liberating electromagnetic excess energy of an excited nucleus of a radio active element and one such element is $^{60}\text{Co}$. Many fruits and vegetables have been experimented upon to extend their storage life using radiation. Kahan et al. (1969) and Nyambati and Langerak (1981) have reported that double combination treatments of mild heat and irradiation interacted synergistically to inactivate Penicillium digitatum spores inoculated in freshly picked shawmuti oranges and Mexican limes respectively. Akamine and Goo (1971), reported that irradiation increased the rate of ripening in yellow passion fruit. In addition irradiation was useful in controlling the infestation against fruit flies.

2.7 Use of Pro-long in fruit storage

Pro-long is a trade name for the compound made up of a specific mixture of lipids, sucrose esters of fatty acids and glyceryl monostearate, and a polysaccharide, sodium carboxymethyl cellulose. It is manufactured by Geest and Tate and Lyle Ltd., and was developed for the use on exporting Windward Island bananas. Its use as a means
of extending the shelf-life of fruits and vegetables has been extended to apples, pears, plums, papaya and pineapples (Cutts, 1982) limes (Motlagh, 1982); mangoes (Dhalla, 1982) and avocados (Tarimo, 1982). However, its use has not proved effective in tomatoes, green pepper, aubergine, grapes and strawberries (Lowings and Cutts, 1982) the reason being that some of these fruits lack stomata on the surface. Besides being used to decrease respiration on a limited number of fruits and vegetables, Pro-long has been found to offer resistance to some fungal rots.

Pro-long is available as a dry powder and thus creates an advantage over other preservation methods in that it avoids the penalties of bulk, weight and microbial decomposition. It mixes and disperses well in water during application, is non-toxic and is an acceptable food additive. It is tasteless and odourless.

The effectiveness of Pro-long in extending the shelf-life of fruits and vegetables is that when the powder mixture is dissolved and dispersed in water and then applied to the product and allowed to dry, it creates a semi-permeable gas barrier. The barrier operates such that oxygen levels within the fresh fruit or vegetable are greatly lowered with a small equivalent rise in internal carbon dioxide levels. In effect the metabolic rate of the living cells is reduced.

2.8 Use of pectin in fruit storage

Pectins belong to the heteropolysaccharides. They fill the intercellular spaces and the middle lamella of the plant tissue. Pectins are usually found in large amounts especially in younger tissues. They are hydrophilics and thus play an important role in imbibing water in the early stages of plant tissue development.
Chemically pectin consists of long unbranched chains of polygalacturonic acid with carboxyl groups partially esterified with methyl alcohol. The link between galacturonic acid units is \(\beta 1-4\).

The most important use of pectin depends on its ability to form gels in jam manufacture. It is used as an emulsifier (Berk, 1983) and in medicine it is used as a cleaner for intestines, for treating wounds and in blood transfusions for raising the blood volume. Kertesz (1951) reported that pectin can be used in the steel industry while Doesburg (1965) established that pectin can be used in preparation of stable milk fruit juice mixtures.

Berk (1983) has reported an interesting development of possible means of using pectin gels as a protective film for coating foods. Fresh grape-fruits have been preserved by coating them with a gel containing low methoxyl pectin and calcium chloride. Nyambati (1982) reported that pectin could be used in extending the shelf-life of mangoes. It has not been tried with passion fruit.

2.9 **Aims of the present work**

The main aims of the present work were as follows:

a) To determine the most effective treatment with either Pro-long or pectin to extend the shelf-life of purple passion fruit at different storage temperatures.

b) To assess the changes in constituents during the storage periods which may affect the acceptability of the fruit, in particular to assess changes in the volatile flavour compounds.

c) To provide information on the mode of action of Pro-long by assessing respiration rate during storage.

d) To isolate and identify the fungus responsible for latent infection of passion fruit.
3. MATERIAL AND METHODS

3.1 Materials

Purple passion fruit (*Passiflora edulis* Sims) was used in all the experiments. The fruits were supplied by Geest Holdings Ltd., Spalding, who received them as air freight from Kenya. The estimated age of the fruits post-harvest was four to five days. The fruits were available when required throughout the year.

Pro-long was supplied by Geest Holdings Ltd., Spalding, in powder form in 250 g lots.

Pectin in the form of dry granules was supplied by Bulmers Ltd., of Hereford, England.

Thiabendazole fungicide (trade name: Storite) was supplied in powder form by Mark Sharp and Dohme Ltd., Hoddesdon. It contained 60% (w/w) active ingredient.

3.2 Pre-storage treatments and storage conditions

Treatment with fungicide (TBZ): The fruits were dipped into a 1000 ppm solution of thiabendazole for one minute. The fruits were removed and left to drain and dry.

Treatment with Pro-long: Three concentrations of Pro-long were used, 1%, 2% and 2.5%. These were prepared by mixing the correct weight of the powder with 500 cm$^3$ of distilled water in a homogeniser. The mixture was left to stand for one hour before dipping the fruits. The fruits were dipped in appropriate Pro-long solutions by hand and left for at least 30 seconds before they were removed and placed on wire trays to drain and dry.
Treatment with pectin: Three pectin concentrations (1%, 2% and 2.5%) were used. The solutions were prepared by mixing appropriate weights of pectin in 500 cm$^3$ distilled water. Further treatment of fruits was as described above for Pro-long.

Storage conditions: The fruits were stored at three different temperatures, 8°C ($\pm$2°C), 16°C ($\pm$2°C) and 24°C ($\pm$2°C) at 80-90% relative humidity using a controlled atmosphere cabinet (Fisons Scientific Apparatus Ltd., Loughborough).

3.3 Experimental design

Approximately 300 fruits were received for each experiment. On receipt the fruits were graded for size, presence of disease and wrinkles on the surface. For each consignment of the fruits received, 10-15% were usually found to be unsuitable. The selected fruits were washed in cold running tap water and treated with fungicide (TBZ) as described above. The fruits were then divided into two groups.

Group I: This consisted of 80 fruits which were divided randomly into four different batches of 20 fruits each. Batch 1 was used as a control and given no further treatments. Batch 2 was dipped into 1% Pro-long or pectin solution. Batch 3 was dipped into 2% Pro-long or pectin solutions. Batch 4 was dipped into 2.5% Pro-long or pectin solutions. These batches of fruits were used for measurements of weight loss only. The figure of twenty fruits for each batch had been arrived at by cumulative running means analysis (see Graph 1). All these batches were placed in cardboard boxes of 38 cm x 23 cm. Each box had 9 holes of approximately 5 mm diameter each at the
bottom for free circulation of air. They were placed at the appropriate temperatures; 8°C, 16°C or 24°C, at 80-90% relative humidity in a controlled atmosphere cabinet. Each fruit in this group bore a number for identification. The cardboard boxes containing the fruits were withdrawn from the controlled atmosphere cabinet one at a time and weighed at four days interval. The weighing of these fruits continued until it was decided to terminate the experiment as determined by taste panel analysis of the Pro-long treated fruits. Results are expressed as percentage weight loss.

Group II: This was made up of four batches of 40 graded fruits each. Each batch was treated as described above for Group I fruits; i.e. control, 1%, 2% and 2.5% Pro-long or pectin treatments. After treatments, these fruits were similarly placed into cardboard boxes and left at appropriate temperatures of 8°C, 16°C and 24°C at 80-90% relative humidity in a controlled atmosphere cabinet. Five fruits from each batch were selected at random and withdrawn weekly. They were then subjected to: examination of external appearance by the taste panelists and measurement of respiration rate (measurement twice a week). The fruits were then cut open and individually subjected to a taste panel analysis of the pulp. The pulp and the peel of all the fruits for each batch were then combined and subjected to analysis for pH, total soluble solids, sugars, acidity, carotenoids, volatile flavour compounds, vitamin C, protein and calcium. The combined peel was used for the measurement of anthocyanin levels and in one case for fruits stored at 15°C, extractable pectin was measured.
3.4 Taste panel assessment

Each treatment was assessed by a sensory panel of five people chosen from a group of research students and laboratory assistants. The assessment was carried out at weekly intervals for fruits stored at 8°C, 16°C and 24°C.

At every taste session an assessor was presented with four different treated samples on a plastic tetrapack container, then asked to assess the external characteristics of the fruit first and thereafter, the internal characteristics. Assessment of the samples was rated on the overall impression on a five-point non-hedonic scale similar to the one used by Mcbride and Richardson (1983) and Kramer (1956). A taste panel score sheet is in the appendix (see Section 7).

Mean scores and rank totals were calculated as described by Kramer (1956) and the significance of these values was established using Kramer's tables.

3.5 Analytical methods

3.5.1 Sugar identification

5 g of passion fruit pulp was macerated in a blender with 50 cm³ of hot 80% ethanol, then centrifuged in 100 cm³ centrifuge tubes at 2000 r.p.m. for 10 minutes. The contents were decanted into a rotary evaporation flask and the sugar ethanol solution was concentrated by evaporation until about 5 cm³ of the volume of sugar sample remained in the flask. Spotting of concentrated extract was performed using wire loops. For reference spots, 1% solution of pure sugar samples were used. The paper chromatography was carried out on Whatman filter No. 1 by descending method using ethyl acetate:acetic acid:water (14:3:3 ratio) solvent solution as described by Jukes (1978).
For identifying the sugars, the development solution used was silver nitrate (Trevelyan, Proctor and Harrison, 1950). The whole paper was dipped into a silver nitrate:acetone mixture followed by drying in hot air, then dipping the paper into 5% ethanolic sodium hydroxide before being washed in 10% sodium thiosulphate solution and water. The spots were identified by comparing the reference spots Rg values with the sample spots (Plate 2).

3.5.2 Reducing sugars

The method used for determining reducing sugars was a modified Lane and Eynon (1954) method.

10 g of passion fruit pulp was macerated with 20 cm$^3$ of hot 80% ethanol. The solution was heated in a water bath for 2 minutes to dissolve and extract all sugars into ethanol. The hot solution was then filtered through Whatman filter paper No. 54 on a Buchner funnel under suction. The residue was further washed, three times with an additional 30 cm$^3$ of 80% ethanol.

To the combined extract a few drops of 0.1% calcium carbonate were added and the extract evaporated in a rotatory film evaporator at 60°C to concentrate the dissolved sugars. The solution was transferred to a centrifuge tube and neutral lead acetate solution added dropwise until no more cloudiness occurred. Excess lead was removed by addition of a few drops of a saturated solution of potassium oxalate. The whole solution was centrifuged for 10 minutes at 2000 r.p.m., decanted into a 100 cm$^3$ volumetric flask and made up to the mark with distilled water.
For reducing sugar determination equal quantities of Fehling's solution 'A' and 'B' were pipetted into a conical flask and mixed. The test sample was placed in a burette. 15 cm$^3$ aliquots of the test sugar sample solution from the burette were added into the 25 cm$^3$ of mixed Fehling's solution in a conical flask. The flask was then heated on a bunsen flame to boiling. After boiling for 1 minute, 4 drops of methylene blue indicator were added while the solution was boiling. The titration was continued at the same boiling conditions until the end point was reached when a brick red precipitate colour was developed. Lane and Eynon (1954) tables were used to calculate the percentage sugar.

3.5.3 Total sugars

Using the test sample solution that remained in the titration of reducing sugars above, 50 cm$^3$ of the test sample solution was hydrolysed with 2 cm$^3$ of concentrated hydrochloric acid and the sample was placed in a water bath maintained at 80$^\circ$C for 15 minutes. To the hydrolysed test sample, sodium carbonate powder was added until effervescence stopped. The solution was made up to 100 cm$^3$ with distilled water and titrations and determination performed as in Section 3.5.2 were repeated.
3.5.4 Total acid

The titration indicator method as outlined by A.O.A.C. (1980) was used in determining the titratable acidity of passion fruit pulp.

10 g of passion fruit pulp from a homogeneous mixture of 5 fruits was weighed into a 200 cm$^3$ homogenising flask. 50 cm$^3$ of distilled water was added to the pulp content and homogenised for one minute using an Ultra-Turrax homogeniser. A further 50 cm$^3$ of distilled water was then added and the solution homogenised for a further one minute. The whole solution was filtered or centrifuged and then 10 cm$^3$ of the filtrate was titrated against 0.1 M sodium hydroxide with phenolphthalein as an indicator. Results were calculated and expressed in terms of percentage acidity as citric acid.

3.5.5 Carotenoids

5 g of passion fruit pulp was mixed with dry acid purified sand and extracted carotenoid with 15 cm$^3$ of petroleum ether (60-80°C): acetone mixture in 3:2 ratio. The mixture was filtered and the remaining pulp was extracted three times more with an additional 10 cm$^3$ aliquots of petroleum ether:acetone mixture. The combined extract was made up to 100 cm$^3$ and its absorbance measured at 450 nm using a Pye Unicam SP-800 spectrophotometer. Total carotenoid concentration was calculated using a standard curve, drawn using a pure standard solution of ß-carotene (Graph 2).

3.5.6 Anthocyanins

The method used for anthocyanin determination in passion fruit rind was similar to the one outlined by Rangana (1977).
Graph 2: Standard curve for estimation of carotenoid content of passion fruit pulp
5 g of the fruit rind was mixed with 50 cm³ of 1% hydrochloric acid in a Ystral food blender and blended at a maximum speed for one minute. The solution was then transferred to a 200 cm³ glass stoppered bottle using about 25 cm³ of 1% hydrochloric acid for washing the blender jar. The samples were stored overnight in a refrigerator at 4°C. The samples were filtered into a 200 cm³ volumetric flask and the extract washed down with 1% hydrochloric acid and made up to 200 cm³. The solution was filtered once again using a sintered glass funnel and its concentration measured spectrophotometrically at 533 nm using Pye Unicam SP-800 spectrophotometer.

Anthocyanin content was calculated using the following formula:

\[
\frac{A \times V \times 100}{W \times E}
\]

where:
- \(A\) = Absorbance at 533 nm
- \(V\) = Total volume of the solution
- \(W\) = Weight of the sample taken
- \(E\) = \(E\) value for 1% solution of pure anthocyanin at 533 nm as given by Rangana (1977).

3.5.7 Volatile flavour compounds

10 g of passion fruit pulp were placed in 100 cm³ conical flasks and 2 cm³ of benzyl acetate was added as an internal standard. The flask was sealed using a polyethylene gas impermeable membrane "cling film" together with an aluminium foil to prevent bursting. This also
ensured that no volatile flavours could escape from the head space of the conical flask. The sample was then placed into a temperature controlled water bath. The bath temperature was maintained at 40°C since this was considered low enough to prevent impairment of any fruit volatile flavours. The sealed sample was left in the water bath for exactly 30 minutes.

Using a 5 cm$^3$ air tight syringe, 3 cm$^3$ of the flavour sample from the head space was withdrawn and immediately injected into a gas chromatograph column for analysis. The separation of the flavour components was accomplished using a Perkin-Elmer Model F33 gas chromatograph with a flame ionization detector. Separation was carried out on a 2 metres by 0.125 inches stainless steel column packed with 10% diethylene glycol succinate polyester (DEGS) on Chromosorb W. HMDS 20-80, 80-100 mesh. The oven temperature was set at 140°C and the injection port temperature was 175°C. The flow rate of nitrogen carrier gas was 60 cm$^3$ per minute, while the pressure of hydrogen gas was 17 p.s.i. and that of air was 25 p.s.i. The gas chromatograph was connected to Shimadzu R.P.R-61 processor, which integrated the peak areas. Quantitative analysis of the volatile flavour constituents from the head space was calculated on relative terms of sample peak areas to that of the internal standard benzyl acetate.

3.5.8 Vitamin C

The method used to determine vitamin C was the titration method using 2,6-dichloroindophenol as described by the Association of Official Analytical Chemists (A.O.A.C., 1980).
3.5.9 **Protein**

Protein content in passion fruit juice was determined using the Kjeldahl method (A.O.A.C., 1980).

3.5.10 **Calcium determination**

The dry matter samples of the pulp were dry ashed and 1 g of the ash sample was taken and mixed with water, nitric acid and hydrochloric acid (3:1:1 ratio). The solution was then filtered into a 25 cm³ volumetric flask and the residue washed 3 to 4 times with distilled water and made up to 25 cm³. Using a Pye Unicam SP90 atomic absorption spectrophotometer the calcium content was measured and the display reading was conveyed to an already made calcium standard curve (Graph 3).

3.5.11 **Pectin**

The method used for determining pectin content in passion fruit rind was that described by Pearson (1976).

3.6 **Respiration rate measurement**

For each treatment, five fruits were weighed together and then placed into an empty desiccator (Fig. 4). The arrangement of the apparatus was similar to those described by Smock (1942) and Tarimo (1982). The apparatus containing fruits were then placed in a dark cupboard and carbon dioxide free air passed through the fruit samples for one hour. Blank runs were also performed.

Any carbon dioxide produced by the fruits was absorbed in 50 cm³ of 0.1 M sodium hydroxide, and precipitated out with 9 cm³ of 20% barium chloride. The solution was centrifuged at 2000 r.p.m. for 20
Graph 3: Standard curve for determination of calcium in passion fruit pulp.
Fig. 4  Apparatus used for measuring the respiration rate of passion fruit

Carbon dioxide free air

Potassium hydroxide pellets

Passion fruit samples

0.1 M sodium hydroxide in centrifuge tube
minutes and then decanted into 100 cm$^3$ volumetric flask and the total volume made up to 100 cm$^3$. The whole of this was transferred into a 250 cm$^3$ conical flask and titrated against 0.1 M hydrochloric acid solution using methyl orange as the indicator.

The formula for calculating the respiration rate as liberated carbon dioxide in passion fruit as

$$\frac{N \times V \times W}{200 \times M \times T} \text{ g CO}_2 \text{ kg}^{-1} \text{ h}^{-1}$$

Where:

- $N =$ molarity of sodium hydroxide solution used in absorbing the liberated carbon dioxide
- $V =$ volume of 0.1 hydrochloric acid used in the titration
- $W =$ molecular weight of carbon dioxide
- $M =$ weight of the sample fruit
- $T =$ time taken for respiration rate

### 3.7 Isolation and identification of fungal infection

The isolation method used was as described by Pruthi et al. (1958). Fungal affected fruits were separated and externally washed with sterile 95% ethanol using sterile cotton wool. They were finally washed with sterile distilled water. The affected area was cut using a sterile scalpel aseptically. The cut pieces were transferred to a potato dextrose agar plate. The plates were incubated at 25°C for 7 days before examination and fungal identification by microscopy after staining with lactophenol blue dye.
4. RESULTS AND DISCUSSIONS

4.1 General considerations

The purple passion fruit (*Passiflora edulis* Sims) was used throughout this investigation because of availability and its importance in the world markets.

Weight loss and degree of wrinkling were assessed during storage as the main parameters for determining shelf-life. Passion fruits lose moisture through their stomata and this results in thinning of the skin, wrinkling and disappearance of the fresh look and hence loss of acceptability to the consumer. In addition to assessment of degree of wrinkling, a taste panel was also used to assess other sensory quality parameters, namely: peel colour, pulp colour, taste, aroma and juiciness.

The three storage temperatures used, 8°C, 16°C and 24°C were chosen based on the following considerations. The temperature of 8°C was reported by Pruthi (1963) to be optimum for passion fruit storage. The temperature of 16°C was considered to be temperate and since market expansion of fresh passion fruit has extended to the temperate region, the storage assessment at this temperature was necessary. The temperature of 24°C was considered a typical tropical/sub-tropical temperature. The high humidity of 80-90% was used as this tends to decrease moisture loss and limit deterioration.

Cutts (1982) has shown that Pro-long used at concentrations between 1% and 3% is suitable for most tropical/sub-tropical fruits. 1%, 2% and 2.5% Pro-long levels were chosen in this investigation based on preliminary experiments. Pectin levels of 1%, 2% and 2.5% were used so that direct comparisons with Pro-long could be made.
Changes in several constituents of passion fruit which may affect acceptability were assessed during storage including: total soluble solids, reducing and total sugars, total acidity, carotenoids, anthocyanins in the peel, volatile flavour compounds, vitamin C, protein, calcium and pectin.

Total soluble solids and sugar analyses were carried out since they are of importance with respect to taste and hence to the eating quality of the fruit. Total acidity gives a measurement of sourness, which tends to decrease during ripening. Anthocyanins and carotenoids are coloured compounds in the peel and the pulp and hence are consumer acceptability parameters. The aroma of passion fruit is strong and distinctive and contributes to the overall acceptability, hence the volatile flavour compounds were assessed during storage.

Vitamin C, protein and calcium are normally considered as nutritional factors and in general do not affect immediate consumer acceptability, although for some fruits the vitamin C content is considered important with respect to marketing. Protein was assessed as it gives some indication of metabolism during ripening. The analysis of pectin in the peel was undertaken because of the importance with regard to texture.

The respiration rate during storage was assessed in order to provide information on the mode of action of Pro-long. A body of information on Pro-long and other semi-permeable membranes is being built up so that it may be possible to apply mathematical modelling techniques to their use. Information for passion fruit would be useful in this regard.

Isolation and identification of fungal infection was carried out in order to assess whether the fruit fungal infection was due to latent infection or environmental infection.
4.2 Weight loss

Results on weight loss in fruits that were treated with Pro-long and stored at 8°C (80-90% R.H.) are shown in Graph 4. When 2.5% Pro-long treated fruits were statistically compared with the controls and other treatments by analysis of t-test at 5% confidence level, it was found that there was a significant reduction in weight loss. For the other levels of Pro-long, no significant difference was found compared with the control.

For storage at 16°C and 24°C (Graphs 5 and 6) all three levels of treatment with Pro-long significantly reduced weight loss. When graphs 5 and 6 are compared it can be seen that at 24°C after 28 days storage, the weight loss is about the same as for the fruits similarly treated and stored at 16°C. However fruits that were used in these experiments were from different batches and therefore differed to some extent in their initial sizes and condition, so comparing one set of results with another is not entirely valid. The weight losses of fruits treated with pectin solution are shown in Graph 7. There was no significant difference between treated and control at the 5% confidence level.

Transpiration and respiration are responsible for weight loss in the fruit material. Transpiration is the loss of water from the plant cells through the stomata. It is affected by the surface area to volume ratio of the material. Respiration involves consumption of carbohydrate and oxygen with evolution of carbon dioxide from the living cells during development, maturation, ripening and senescence periods. During respiration weight is lost through loss of carbon in the form of carbon dioxide.
Graph 4: Effect of Pro-long treatment on weight loss at 8°C (80-90% R.H.)

Key:
- ○ Control
- □ 1% Pro-long
- ▲ 2% Pro-long
- ■ 2.5% Pro-long

Days stored

Percentage weight loss
Graph 5: Effect of Pro-long treatment on weight loss at 16°C (80-90% R.H.)

Key:
- ○ Control
- □ 1% Pro-long
- ▲ 2% Pro-long
- ■ 2.5% Pro-long
Graph 6: Effect of Pro-long concentration on weight loss at 24°C (60-90% R.H.)

Key:
- ○ Control
- □ 1% Pro-long
- ▲ 2% Pro-long
- ▼ 2.5% Pro-long

Days stored

Percentage weight loss
Graph 7: Effect of pectin concentration on weight loss at 8°C (80-90% R.H.)

- **Key:**
  - X: Control
  - □: 1% pectin
  - ○: 2% pectin
  - ■: 2.5% pectin

- **Axes:**
  - Y-axis: Percentage weight loss
  - X-axis: Days stored

- The graph shows the percentage weight loss over time for different concentrations of pectin.
The surface coating and its underlying tissues of the fruit play an important role in reducing and controlling water loss. Passion fruit has a waxy coating on the surface that is resistant to the passage of water vapour and carbon dioxide by processes of transpiration and respiration respectively. However in general, the natural waxy coating never completely stops the water vapour or carbon dioxide passage. Pro-long applied to the surface of the fruit acted as an extra barrier to water vapour or carbon dioxide movement, thus reducing weight loss compared with the controls. Pectin did not have the same effects as Pro-long. The reason might be that on passion fruit, pectin does not form a continuous membrane, unlike Pro-long. This aspect needs further investigation and possibly different formulations of pectin could be effective, however this present work concentrated on the use of Pro-long since it was clear that it proved very effective in reducing weight loss.

4.3 Taste panel assessment

A taste panel of six trained members was used to assess changes in the external parameters, peel colour and degree of wrinkling, and the internal parameters, pulp colour, taste, aroma and juiciness. In each case, as described in the Experimental Section, the fruits were scored on a 1 to 5 scale with the following stated in the taste panel assessment sheet:

- **Peel colour:**
  - 1 = green, 5 = deep purple
- **Degree of wrinkling:**
  - 1 = extensive, 5 = none
- **Pulp colour:**
  - 1 = pale yellow, 5 = orange
- **Taste:**
  - 1 = sour, 5 = sweet
- **Aroma:**
  - 1 = none, 5 = strong
- **Juiciness:**
  - 1 = minimum, 5 = maximum
The significance of the differences between the controls and the treated fruits was tested by Kramer's ranking tables (Kramer, 1956). The taste panel results for use of Pro-long at the three storage temperatures are given in the Graphs B, 9 and 10. For 8°C taste panel assessment was performed up to 42 days, 16°C was performed up to 35 days and for 24°C assessment was performed up to 28 days.

Peel colour of the purple passion fruit changes during storage, from deep purple to a green purple colour, presumably due to anthocyanin break down (see Section 4.4.5). The results on the change of peel colour at 8°C are rather difficult to understand because of the wide variation in assessment at day 0. This might be explained by the fact that the panelists had not adapted themselves to the range of colour since the 8°C storage assessment was the first taste panel assessment carried out after panel training. At the 16°C and 24°C storage temperatures the 2.5% and 2% Pro-long treated retained the purple colour more than the control (significant at 5% level). This is clearly seen for the 24°C storage (Graph 10a).

The degree of wrinkling is a very important parameter in consumer acceptability and it was used to gauge when the taste panel assessment was to be terminated, i.e. when the mean score reached about 2.2 then it appeared from comments of the taste panel members to be the point at which consumers might consider the fruit unacceptable. At all the storage temperatures Pro-long decreased the degree of wrinkling significantly at all three application concentrations (see Graphs 8b, 9b and 10b). This shows that Pro-long is very effective in keeping the fresh look of the fruits even when there is considerable weight loss; this is particularly apparent for the 8°C storage temperature.

The internal parameters assessed were pulp colour, taste, aroma and juiciness. Pulp colour of passion fruit changes from orange to pale yellow during storage presumably due to loss of carotenoids. On
Graph 8: Taste panel analysis of fruits stored at 8°C (80-90% R.H.)

- a) Colour of peel
- b) Degree of wrinkling
- c) Pulp colour
- d) Taste
- e) Aroma
- f) Juiciness

Mean scores

Days stored: 7, 14, 21, 28, 35, 42

Symbols:
- X: Control
- △: 1% Pro-long
- ○: 2% Pro-long
- ■: 2.5% Pro-long
Graph 9: Taste panel analysis of fruits stored at 16°C (80-90% R.H.)

- a) Colour of peel
- b) Degree of wrinkling
- c) Pulp colour
- d) Tastes
- e) Aroma
- f) Juiciness

Mean scores over days stored:

- X Control
- △ 1% Pro-long
- O 2% Pro-long
- ■ 2.5% Pro-long
Graph 10: Taste panel analysis of fruits stored at 24°C (80-90% R.H.)

a) Colour of peel

b) Degree of wrinkling

c) Pulp colour

d) Taste

e) Aroma

f) Juiciness

- 63 -
examining the results (Graphs 8c, 9c and 10c) it would appear that the original orange colour of passion fruit was retained better in Pro-long treated fruits than in the controls at all storage temperatures. These results on loss of carotenoids are discussed further in Section 4.4.4.

Taste makes an important contribution to the eating quality of purple passion fruit. The major taste components are the acids and sugars present in the fruit and during ripening the taste of purple passion fruit changes from sour to sweet. On examining the taste panel results (Graphs 8d, 9d and 10d) it would appear that no clear trends occurred in the taste of the controls or Pro-long treated fruits during storage and no significant differences were found between the controls and treated fruits. As discussed below (see Sections 4.4.2 and 4.4.3) acidity decreased during storage whereas sugar content increased, however the taste panel were unable to pick up these trends.

Aroma contributes to the overall acceptability of passion fruit because of its unique and exotic nature. Results in Graphs 8e, 9e and 10e show that the control scored much lower during the storage period at 16°C and 24°C (Significant at the 5% level). At 8°C storage temperature there was no significant difference between the control and Pro-long treated fruits. This is discussed further in Section 4.4.6.

The amount of juice in a fruit generally increases during ripening. On examining the juiciness results (Graphs 8f, 9f and 10f) there seems to be little difference between the controls and the treated fruits at 6°C storage temperature. However at the higher storage temperatures (16°C and 24°C), juiciness in Pro-long treated fruits was significantly higher than for the controls. One possible
explanation for the lower juiciness in the controls is their greater moisture loss during storage.

Although overall consumer acceptability was not assessed since the expert taste panel as used here is not suitable for such an assessment, it would appear from these results that the parameters generally considered as contributions to the consumer acceptability of the fruit are retained better in Pro-long treated fruits than controls, with the effect being more marked at the higher storage temperatures and higher Pro-long concentrations.

4.4 Changes in constituents

4.4.1 Total soluble solids in the pulp

The total soluble solids, which are a measure of soluble acids, sugars, etc., were measured using an Abbé refractometer. The results are shown in Table 10. There was an increase in total soluble solids in both the controls and Pro-long treated fruits at all three storage temperatures with no significant difference being observed between the controls and treated fruits. With pectin treated fruits at 8°C a small increase in total soluble solids was observed for the controls and treated fruits with again no significant differences being observed between the controls and treated fruits.

This increase in total soluble solids can be explained by the fact that during ripening and storage starch undergoes breakdown to sugars thus increasing the total soluble solids. The increase in total soluble solids observed on storage is in agreement with some previous reports on passion fruit e.g. Pruthi (1963) reported that
<table>
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<th>7°C</th>
<th>14°C</th>
<th>21°C</th>
<th>28°C</th>
<th>35°C</th>
<th>42°C</th>
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<th>7°C</th>
<th>14°C</th>
<th>21°C</th>
<th>28°C</th>
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<td>Control (Pro-long)</td>
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<td>14.5</td>
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<td>14.6</td>
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</tr>
<tr>
<td>Control (Pectin)</td>
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<td>15.0</td>
<td>15.0</td>
<td>15.0</td>
<td>15.0</td>
<td>15.0</td>
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<td>14.5</td>
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<td>15.0</td>
</tr>
<tr>
<td>1% Pro-long</td>
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<td>15.5</td>
<td>16.0</td>
<td>16.5</td>
<td>16.5</td>
<td>16.5</td>
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<td>14.7</td>
<td>15.6</td>
<td>15.5</td>
</tr>
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<td>14.5</td>
<td>15.0</td>
<td>15.0</td>
<td>15.0</td>
<td>15.0</td>
<td>15.0</td>
<td>14.0</td>
<td>14.0</td>
<td>14.5</td>
<td>15.0</td>
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<tr>
<td>2% Pro-long</td>
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<td>15.0</td>
<td>15.5</td>
<td>16.0</td>
<td>16.5</td>
<td>16.5</td>
<td>16.5</td>
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<td>14.6</td>
<td>14.6</td>
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<tr>
<td>2% Pectin</td>
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<td>14.0</td>
<td>14.5</td>
<td>15.0</td>
<td>15.0</td>
<td>15.0</td>
<td>15.0</td>
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<td>15.0</td>
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<tr>
<td>2.5% Pro-long</td>
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<td>15.5</td>
<td>15.5</td>
<td>16.0</td>
<td>16.0</td>
<td>16.0</td>
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<td>14.6</td>
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<tr>
<td>2.5% Pectin</td>
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<td>14.0</td>
<td>14.5</td>
<td>15.0</td>
<td>15.0</td>
<td>15.0</td>
<td>15.0</td>
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<td>14.0</td>
<td>14.5</td>
<td>15.0</td>
<td>15.0</td>
</tr>
</tbody>
</table>
the total soluble solids for fruits stored at 6.5°C increased from 16.3° Brix to 18.4° Brix after 8 weeks storage. However Ganapathy and Singh (1976) reported an increase in total soluble solids in passion fruit stored under different storage conditions up to 6 days then a drop at 12th and 16th day storage.

4.4.2 Reducing and total sugars in the pulp

The concentration of reducing and total sugars in control and Pro-long treated fruits stored at 0°C, 16°C and 24°C and pectin treated fruits stored at 0°C are given in Tables 11 and 12. For fruits stored at 0°C the total sugars in the controls and 1% Pro-long treated fruits reached a maximum at about 14 days of storage, whereas the fruits treated with 2% and 2.5% Pro-long, the maximum concentration was achieved after 28 and 35 days respectively. This can be explained in terms of Pro-long retarding the starch breakdown to give sugars. This effect was not detected by the taste panel (see Section 4.3).

The total sugars in the pectin treated fruits increased gradually during storage as also did the controls used in this experiment. This is presumably due to the fruit used for the pectin experiment being at an earlier stage of maturity. There was no significant difference between the pectin treated fruits and the controls, in agreement with the observation discussed above on weight loss and taste panel assessment. At 16°C and 24°C no significant differences were observed between the controls and Pro-long treated fruits.

The results for the reducing sugars cannot be directly compared with the results for the total sugars since different batches were used presumably at slightly different stages of maturity.

In general for all the fruits, controls and treated, the reducing sugars increased during storage. The increase in reducing
Table 11: Changes in % total sugars in fruits stored at 8°C, 16°C, 24°C (80-90% R.H.)

<table>
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<th>Temperature</th>
<th>Days</th>
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<th>16°C</th>
<th>24°C</th>
</tr>
</thead>
<tbody>
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</tr>
<tr>
<td>Control (Pro-long)</td>
<td>0</td>
<td>5.90</td>
<td>7.60</td>
<td>7.90</td>
</tr>
<tr>
<td>Control (Pectin)</td>
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<td>7.60</td>
<td>7.90</td>
</tr>
<tr>
<td>1% Pro-long</td>
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<td>11.30</td>
<td>10.60</td>
<td>11.50</td>
</tr>
<tr>
<td>1% Pectin</td>
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<td>5.50</td>
<td>5.50</td>
<td>6.00</td>
</tr>
<tr>
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<td>21</td>
<td>10.30</td>
<td>9.50</td>
<td>10.10</td>
</tr>
<tr>
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<td>5.50</td>
<td>5.50</td>
</tr>
<tr>
<td>2.5% Pro-long</td>
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<td>9.80</td>
<td>9.30</td>
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</tr>
<tr>
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<td>2.5% Pro-long</td>
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<td>8.50</td>
<td>9.50</td>
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<tr>
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</tr>
<tr>
<td>3% Pro-long</td>
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<td>9.20</td>
</tr>
<tr>
<td>3% Pectin</td>
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<td>6.00</td>
<td>6.00</td>
</tr>
<tr>
<td>Temperature</td>
<td>8°C</td>
<td>16°C</td>
<td>24°C</td>
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<tr>
<td>-------------</td>
<td>-----</td>
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<td></td>
</tr>
<tr>
<td>Days</td>
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<td>7</td>
<td>14</td>
<td>21</td>
</tr>
<tr>
<td>Control (Pro-long)</td>
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<td>4.70</td>
<td>4.90</td>
<td>4.95</td>
</tr>
</tbody>
</table>

Table 12: Changes in % reducing sugars in fruits stored at 8°C, 16°C and 24°C (80-90% R.H.) after treatment with Pro-long or pectin.
sugars may be due partly to the hydrolysis of sucrose and also due to the production of glucose as a result of slow starch hydrolysis (Pruthi, 1963).

4.4.3 Total acid in the pulp

Mature, unripe purple passion fruit is a fairly sour fruit, but during ripening the acids decrease. Tables 13 and 14 summarise the results of total acidity and pH values for purple passion fruit. At 8°C, after treatment with Pro-long and pectin and at 16°C after treatment with Pro-long the total acidity started off being fairly high but decreased during storage. Similar trends were observed in fruits stored at 24°C, however the starting acidity was low although within the range reported by Casimir et al. (1981). This presumably reflects the fact that this batch of fruit was at a later stage of maturity.

No significant differences were found between the controls and treated fruits at 8°C and 24°C but at 16°C the total acidity decreased less rapidly for the 2% and 2.5% Pro-long treated fruits compared with the controls. The pH values in general reflect the changes in total acidity, i.e. increase during storage, with no significant differences between the controls and treated fruits. The fall in total acids and increase in pH is explained by the fact that organic acids are substrates of respiration. The results are in agreement with other reports, e.g. Pruthi (1963) reported a decrease in acidity for passion fruits stored at 6.5°C, since the overall organic acid content in most fruits increases during the early stages of development and later decreases slowly and progressively during and subsequent to the process of ripening (Duckworth, 1966).
Table 13: Changes in total acidity (g/100 g pulp) of fruits stored at 8°C, 16°C and 24°C (80-90% R.H.) after treatment with Pro-long or pectin.

<table>
<thead>
<tr>
<th>Temperature</th>
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<th>16°C</th>
<th>24°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days</td>
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<td>7</td>
<td>14</td>
</tr>
<tr>
<td>Control (Pro-long)</td>
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<td>Control (Pectin)</td>
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<td>2.82</td>
<td>1.06</td>
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<td>1% Pro-long</td>
<td>4.32</td>
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<td>2.63</td>
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<td>1% Pectin</td>
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<td>2.69</td>
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<td>2% Pro-long</td>
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<td>2.5% Pro-long</td>
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<td>3.25</td>
<td>2.63</td>
</tr>
<tr>
<td>2.5% Pectin</td>
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<td>2.54</td>
<td>1.79</td>
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<td>Control (Pectin)</td>
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</table>
4.4.4 Total carotenoids in the pulp

On examination of results in Table 15 it is seen that on storage at 8°C and 16°C the carotenoid content increases and then declines whereas at 24°C the carotenoids decrease throughout storage. These differences are again presumably due to the different stages of maturity of the test fruit. In the taste panel analysis a corresponding decrease in pulp colour was observed. Panellists could distinguish between pulp colour of Pro-long treated fruits and controls. Whereas there were no significant differences in the carotenoid content between controls and treated fruits (Pro-long or pectin) at any storage temperature.

The taste panel score for the 16°C storage fruits at onset are lower than for 24°C in agreement with the carotenoid content results, although otherwise agreement between individual values of carotenoid content and taste panel scores is poor. The fact that the taste panel could distinguish better between the controls and treated fruits suggests that the method is of more value than carotenoid content with respect to pulp colour.

The decrease of the carotenoid content is possibly due to oxidation of carotenoids brought about by lipoxidase-type enzymes.

4.4.5 Anthocyanins in the peel

The results of the determination of anthocyanin content in passion fruit peel during storage is given in Table 16. There was a decrease of anthocyanin content in both controls and treated fruits during storage. Although the Pro-long treatment and pectin treatment appeared to retard anthocyanin loss, the difference between the treated fruits and the controls was not significant.

The anthocyanin degradation results in a decrease in the purple colour of the peel, as observed by the taste panel for Pro-long treated fruits and controls. The taste panel was able to discern a
Table 15: Changes in carotenoid content (mg/100 g pulp) of fruits stored at 8°C, 16°C and 24°C and 80-90% R.H. after treatment with Pro-long or pectin

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Day</th>
<th>8°C</th>
<th></th>
<th></th>
<th></th>
<th>16°C</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>24°C</th>
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<tbody>
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<td>21</td>
<td>28</td>
<td>35</td>
<td>0</td>
<td>7</td>
<td>14</td>
<td>21</td>
</tr>
<tr>
<td>Control (Pro-long)</td>
<td></td>
<td>1.94</td>
<td>3.21</td>
<td>1.40</td>
<td>0.83</td>
<td>0.51</td>
<td>0.43</td>
<td>0.40</td>
<td>0.55</td>
<td>0.93</td>
<td>2.01</td>
<td>0.79</td>
<td>0.56</td>
<td>0.36</td>
<td>1.04</td>
<td>1.08</td>
<td>0.73</td>
<td>0.55</td>
</tr>
<tr>
<td>Control (Pectin)</td>
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<td>2.26</td>
<td>2.32</td>
<td>2.72</td>
<td>3.70</td>
<td>1.74</td>
<td>1.34</td>
<td>1.35</td>
<td></td>
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<tr>
<td>1% Pro-long</td>
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<td>1.94</td>
<td>3.20</td>
<td>1.95</td>
<td>0.92</td>
<td>0.67</td>
<td>0.74</td>
<td>0.69</td>
<td>0.53</td>
<td>0.87</td>
<td>0.93</td>
<td>0.93</td>
<td>0.90</td>
<td>0.56</td>
<td>1.04</td>
<td>1.53</td>
<td>1.44</td>
<td>1.32</td>
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<td>3.99</td>
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<td>2.02</td>
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<td>0.76</td>
<td>0.72</td>
<td>0.55</td>
<td>0.94</td>
<td>1.04</td>
<td>0.96</td>
<td>0.97</td>
<td>0.65</td>
<td>1.04</td>
<td>1.46</td>
<td>1.40</td>
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<td>2.78</td>
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<td>3.73</td>
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<tr>
<td>Control (Pro-long)</td>
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</tr>
<tr>
<td>1% Pro-long</td>
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<tr>
<td>2.5% Pro-long</td>
<td>74.90</td>
<td>56.47</td>
<td>49.46</td>
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</tr>
</tbody>
</table>

Table 16: Changes in anthocyanin levels (mg/100 g) in the peel of passion fruit stored at 8°C, 16°C and 24°C (80-90% R.H.)
significant difference between the controls and Pro-long treated fruits at 24°C (see Section 4.3).

4.4.6 Volatile flavour compounds in the pulp

During fruit ripening volatile flavour compounds are synthesised and play an important role in determining optimal eating quality (Wills et al., 1981). Duckworth (1966) reported that ripening is normally associated with the formation of a wide range of volatile compounds which include esters, aldehydes, alcohols, ketones, terpenes and others. The production of these volatile flavour compounds in passion fruit normally begins during immaturity and continues through the climacteric stage and senescence.

In order to test the hypothesis that Pro-long treated fruits retain more flavour than the control fruits (Lowings and Cutts, 1982) gas chromatographic analysis of volatile compounds was carried out. Initial experiments were performed to select a suitable column and a diethylene glycol succinate column—DEGS was found to give the best results (see Experimental Section). Preliminary work on this column was concentrated on finding the optimum conditions for separating the peaks of the main volatiles present, which were found to be ethyl butyrate with small amounts of ethyl acetate and other compounds (as reported also by Parliament, 1972). Several column temperatures and conditions were tried but peaks were either too broad or not sufficiently distinguishable. Eventually it was decided to use conditions which did not separate the main volatiles but allowed the amounts to be determined relative to an internal standard, benzyl acetate. These conditions are given in the Experimental Section.

The results of the gas chromatographic analysis of volatile flavour compounds in the head-space above purple passion fruit pulp
held at $40^\circ C$ for 30 minutes are given in Table 17. Examples of the peaks obtained and computed relative to the internal standard (added at a fixed amount to the pulp) are given in Figure 5.

On examining the results it appears that the rate of flavour development in all fruits was slower at low storage temperature ($8^\circ C$) than at higher storage temperature ($16^\circ C$ and $24^\circ C$). In addition for Pro-long treated fruits, the maximum flavour peaking was delayed compared to controls.

At storage temperatures of $16^\circ$ and $24^\circ C$ after peaking there was a drop in total flavour compounds, while at $8^\circ C$ the flavour was still developing for the Pro-long treated fruits when the experiment was terminated at the end of 42 days. It is also interesting to note that in Pro-long treated fruits the total flavour retained at the end of the experiment was far greater than the amount of flavour compounds present at any stage in the control group. Furthermore in fruits stored at $16^\circ$ and $24^\circ C$ the amount of flavour compounds developed was several fold greater than at $8^\circ C$, although the taste panel was not able to clearly detect this. However the taste panel tested fruits stored at different temperatures at different times and hence their results are more meaningful with regard to treated fruits versus controls rather than between temperature conditions. The taste panel was able to distinguish aroma between controls and treated at $16^\circ C$ and $24^\circ C$ in agreement with these chromatographic results.

The results of this experiment therefore support the hypothesis of Lowings and Cutts (1982) that the flavour of some Pro-long treated fruits is enhanced, presumably due to the retention of volatile flavour compounds by the extra skin coating.
Table 17: Computed relative peak areas of volatile flavour compounds of treated fruits stored at different temperatures (80-90% R.H.)*

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>7</th>
<th>14</th>
<th>21</th>
<th>28</th>
<th>35</th>
<th>0</th>
<th>7</th>
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<th>21</th>
<th>28</th>
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<th>7</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0.078</td>
<td>0.09</td>
<td>0.10</td>
<td>0.09</td>
<td>0.056</td>
<td>0.046</td>
<td>0.098</td>
<td>0.16</td>
<td>0.15</td>
<td>0.15</td>
<td>0.12</td>
<td>0.11</td>
<td>0.15</td>
<td>0.62</td>
<td>0.71</td>
<td>0.75</td>
<td>0.28</td>
</tr>
<tr>
<td>1% Pro-long</td>
<td>0.078</td>
<td>0.104</td>
<td>0.12</td>
<td>0.17</td>
<td>0.15</td>
<td>0.30</td>
<td>0.098</td>
<td>0.21</td>
<td>1.24</td>
<td>0.44</td>
<td>0.40</td>
<td>0.87</td>
<td>1.59</td>
<td>1.63</td>
<td>0.59</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2% Pro-long</td>
<td>0.078</td>
<td>0.14</td>
<td>0.16</td>
<td>0.19</td>
<td>0.38</td>
<td>0.098</td>
<td>0.24</td>
<td>1.14</td>
<td>0.57</td>
<td>0.49</td>
<td>0.46</td>
<td>0.15</td>
<td>0.91</td>
<td>2.31</td>
<td>2.30</td>
<td>0.96</td>
<td></td>
</tr>
<tr>
<td>2.5% Pro-long</td>
<td>0.078</td>
<td>0.17</td>
<td>0.18</td>
<td>0.24</td>
<td>0.39</td>
<td>0.098</td>
<td>0.38</td>
<td>1.09</td>
<td>0.83</td>
<td>0.82</td>
<td>0.50</td>
<td>1.62</td>
<td>3.18</td>
<td>2.41</td>
<td>1.95</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Mean value of three determinations per treatment.
Fig. 5: Chromatograms from headspace analysis of purple passion fruit pulp showing increased retention of the major volatile flavour compounds in Pro-long treated fruits after 8 days storage at 24°C/80-90% R.H.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Relative peak areas</th>
</tr>
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<tbody>
<tr>
<td>Control</td>
<td>I.S. 0.3</td>
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<tr>
<td>1% Pro-long</td>
<td>I.S. 1.1</td>
</tr>
<tr>
<td>2% Pro-long</td>
<td>I.S. 2.08</td>
</tr>
<tr>
<td>2.5% Pro-long</td>
<td>I.S. 2.05</td>
</tr>
</tbody>
</table>

I.S. = Internal standard (Benzyl acetate)
V.F.C. = Volatile flavour compounds (the major component being Ethyl butyrate) detected during headspace analysis of purple passion fruit pulp.
4.4.7 Vitamin C in the pulp

Vitamin C, which is usually present in fresh fruits and vegetables, has an estimated daily requirement for man of 30 to 100 mg. In this experiment it was found that the concentration of vitamin C in freshly received fruits varied from about 30 mg to 70 mg per 100 g of fruit pulp.

The results of changes in vitamin C content of passion fruit are given in Table 18 in terms of the initial concentration scaled to 100. In general it appears that there was a drop in vitamin C content of the fruits with storage time in agreement with reports by Pruthi (1963). However the extent of degradation in control fruits was far greater than the corresponding fruits treated with Pro-long, at all storage temperatures (significant at the 5% level). At lower temperatures the reduction of vitamin C content was far less than the corresponding loss at higher temperatures (significant at 5% level). No significant difference was observed for the pectin treated fruits compared with the controls. It should be noted that the loss of vitamin C was far greater for the control in this experiment than the "Pro-long controls"; this is again presumably due to a different batch of fruit being used, as discussed above.

The reduction of vitamin C content can be explained by the fact that vitamin C, like other organic acids, is a respiratory substrate hence can be used during respiration. In addition the presence of oxygen readily oxidises the ascorbic acid and thus can contribute to the decrease. The Pro-long treated samples experienced a lower reduction of vitamin C compared to the controls probably because Pro-long slows down respiration (see Section 4.5) and also acts as an extra barrier against free movement of oxygen through the stomata.
<table>
<thead>
<tr>
<th>Temperature</th>
<th>Control (Pro-long)</th>
<th>Control (Pectin)</th>
<th>1% Pro-long</th>
<th>1% Pectin</th>
<th>2% Pro-long</th>
<th>2% Pectin</th>
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</thead>
<tbody>
<tr>
<td>Days</td>
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<td>7</td>
<td>14</td>
<td>21</td>
<td>28</td>
<td>35</td>
<td>42</td>
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<td>75.95</td>
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<td>24°C</td>
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<td>84.89</td>
<td>84.41</td>
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<td>84.72</td>
<td>61.38</td>
<td>50.00</td>
<td>43.44</td>
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</tr>
</tbody>
</table>

Table 18: Changes in vitamin C content relative to initial value equals 100 of treated purple passion fruits stored at 8°C, 16°C and 24°C (80-90% R.H.)
4.4.8 Protein in the juice

The protein content of most fruits is low - with levels reported for passion fruit of 0.5% to 2.9% (see Section 2.3.5). In this investigation the protein content at the start of the storage experiments varied between 0.85% and 1.12%. The results on variation in protein content on storage, which are calculated based on the initial level taken as 100, are given in Table 19. After 7 to 14 days storage it is seen that there is an increase in protein content of all the fruits at all storage temperatures followed by a decrease.

When the results of protein content were compared with respiratory measurements, it was seen that a rise in the protein content showed some correlation with a rise in the rate of respiration (see Section 4.5). Biale (1960) found high respiration rates associated with protein increase, and Wills et al. (1981) also reported an increase in protein synthesis during the climacteric phase of many fruits. Unlike in the respiration experiments, however no significant differences were observed between the control and treated fruits, except for the 8°C and 16°C controls having significantly lower protein after the peak stage.

For the pectin treated fruits, it was found that after a maximum at 14 to 21 days storage there was a sudden drop in protein concentration. The same was found to occur with the control during pectin experiment, suggesting that this sudden drop was due to the fruit in that particular batch rather than pectin treatments.

4.4.9 Calcium in the pulp

Calcium pectate forms in the peel as the passion fruit matures and therefore it was thought that a reduction in the calcium level
Table 19: Percentage change in protein content of purple passion fruits stored at 0°C, 16°C and 24°C (80-85% R.H.)

<table>
<thead>
<tr>
<th>Days</th>
<th>0°C</th>
<th>7°C</th>
<th>14°C</th>
<th>21°C</th>
<th>28°C</th>
<th>35°C</th>
<th>42°C</th>
<th>0°C</th>
<th>7°C</th>
<th>14°C</th>
<th>21°C</th>
<th>28°C</th>
<th>35°C</th>
<th>0°C</th>
<th>7°C</th>
<th>14°C</th>
<th>21°C</th>
<th>28°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (Pro-long)</td>
<td>100.0</td>
<td>130.6</td>
<td>166.3</td>
<td>158</td>
<td>147.9</td>
<td>123.4</td>
<td>112.2</td>
<td>100.0</td>
<td>114.1</td>
<td>192.9</td>
<td>62.3</td>
<td>49.4</td>
<td>47.1</td>
<td>100</td>
<td>125</td>
<td>85.7</td>
<td>69.6</td>
<td>50.0</td>
</tr>
<tr>
<td>Control (Pectin)</td>
<td>100</td>
<td>157.7</td>
<td>201.1</td>
<td>145.5</td>
<td>47.7</td>
<td>46.6</td>
<td>46.6</td>
<td>100</td>
<td>114.1</td>
<td>171.4</td>
<td>169.4</td>
<td>148.9</td>
<td>145.9</td>
<td>100</td>
<td>101.2</td>
<td>162.4</td>
<td>92.9</td>
<td>81.2</td>
</tr>
<tr>
<td>1% Pro-long</td>
<td>100.0</td>
<td>118.4</td>
<td>171.4</td>
<td>169.4</td>
<td>159.2</td>
<td>148.9</td>
<td>145.9</td>
<td>100</td>
<td>101.2</td>
<td>162.4</td>
<td>92.9</td>
<td>81.2</td>
<td>65.8</td>
<td>100</td>
<td>148.2</td>
<td>82.1</td>
<td>77.7</td>
<td>58.0</td>
</tr>
<tr>
<td>1% Pectin</td>
<td>100</td>
<td>151.1</td>
<td>174.4</td>
<td>180</td>
<td>62</td>
<td>61.1</td>
<td>57.7</td>
<td>100</td>
<td>105.1</td>
<td>162.2</td>
<td>171.6</td>
<td>161.2</td>
<td>151.0</td>
<td>146.9</td>
<td>100</td>
<td>103.52</td>
<td>145.8</td>
<td>89.41</td>
</tr>
<tr>
<td>2% Pro-long</td>
<td>100</td>
<td>105.1</td>
<td>162.2</td>
<td>171.6</td>
<td>161.2</td>
<td>151.0</td>
<td>146.9</td>
<td>100</td>
<td>103.52</td>
<td>145.8</td>
<td>89.41</td>
<td>84.7</td>
<td>76.5</td>
<td>100</td>
<td>146.42</td>
<td>83.0</td>
<td>75</td>
<td>69.6</td>
</tr>
<tr>
<td>2% Pectin</td>
<td>100</td>
<td>142.2</td>
<td>164.4</td>
<td>173.3</td>
<td>60</td>
<td>56.6</td>
<td>55.9</td>
<td>100</td>
<td>106.1</td>
<td>156.1</td>
<td>169.4</td>
<td>159.1</td>
<td>152.0</td>
<td>145.9</td>
<td>100</td>
<td>102.3</td>
<td>124.7</td>
<td>94.1</td>
</tr>
<tr>
<td>2.5% Pro-long</td>
<td>100</td>
<td>106.1</td>
<td>156.1</td>
<td>169.4</td>
<td>159.1</td>
<td>152.0</td>
<td>145.9</td>
<td>100</td>
<td>102.3</td>
<td>124.7</td>
<td>94.1</td>
<td>91.8</td>
<td>76.5</td>
<td>100</td>
<td>149.1</td>
<td>83.0</td>
<td>65.2</td>
<td>65.2</td>
</tr>
<tr>
<td>2.5% Pectin</td>
<td>100</td>
<td>126.6</td>
<td>172.2</td>
<td>171.1</td>
<td>58.8</td>
<td>57.7</td>
<td>55.5</td>
<td>100</td>
<td>126.6</td>
<td>172.2</td>
<td>171.1</td>
<td>58.8</td>
<td>57.7</td>
<td>55.5</td>
<td>100</td>
<td>126.6</td>
<td>172.2</td>
<td>171.1</td>
</tr>
</tbody>
</table>
in the pulp might occur during storage. The results of calcium content determination in passion fruit pulp are given in Table 20. It can be seen that the calcium content remained virtually unchanged throughout the storage period for all the samples, treated and controls. One explanation for these results is that the calcium reduction might have taken place before fruits were received for the experiment. Hence calcium content does not seem to be a useful indicator of shelf-life and the stage of ripening.

4.4.10 Pectin in the peel

Most fruits as they mature exhibit softening of the peel tissues. This is due to the depolymerisation of pectic substances by the enzyme system. The major enzymes involved in solubilizing and depolymerizing the pectins are pectinesterases and polygalacturonases. Their presence in passion fruit has been reported by Czyhrinciw (1969). Prasad (1980) reported an average percentage pectin yield from passion fruit rind on dry weight basis to be 15% while Pruthi (1965) reported pectin content to be in the range of between 10.8% and 14%.

If it is accepted that wrinkling and softening of passion fruit is associated with the breakdown of pectin in the peel one would expect less pectin to be extracted from passion fruit that show this deterioration. This hypothesis was tested by extracting total pectins from the fruits treated with Pro-long and stored at 16°C (80-90% R.H.).

The results are summarised in Graph 11. It can be seen that the amount of extractable pectin from the controls as well as Pro-long treated fruits almost halved over the storage period of the experiment with the final percentage of extractable pectin in all the samples approximately the same. The fruits appear to reach an equilibrium as
Table 2D: Changes in calcium content of the pulp of treated fruits stored at different temperatures (80-90% R.H.)

<table>
<thead>
<tr>
<th>Temperature</th>
<th>0°C</th>
<th>7°C</th>
<th>14°C</th>
<th>21°C</th>
<th>28°C</th>
<th>35°C</th>
<th>42°C</th>
<th>0°C</th>
<th>7°C</th>
<th>14°C</th>
<th>21°C</th>
<th>28°C</th>
<th>35°C</th>
<th>42°C</th>
<th>24°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days</td>
<td>0</td>
<td>7</td>
<td>14</td>
<td>21</td>
<td>28</td>
<td>35</td>
<td>42</td>
<td>0</td>
<td>7</td>
<td>14</td>
<td>21</td>
<td>28</td>
<td>35</td>
<td>42</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Pro-long)</td>
<td>170.25</td>
<td>160.08</td>
<td>161.30</td>
<td>164.5</td>
<td>166.30</td>
<td>163.6</td>
<td>165.3</td>
<td>115.9</td>
<td>121.5</td>
<td>124.5</td>
<td>122.6</td>
<td>121.7</td>
<td>122.0</td>
<td>126.0</td>
<td>125.0</td>
</tr>
<tr>
<td>Control</td>
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<td></td>
</tr>
<tr>
<td>(Pectin)</td>
<td>143.2</td>
<td>146.8</td>
<td>143.63</td>
<td>147.30</td>
<td>143.30</td>
<td>140.31</td>
<td>150.9</td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>1% Pro-long</td>
<td>170.25</td>
<td>158.90</td>
<td>160.32</td>
<td>157.22</td>
<td>168.40</td>
<td>171.3</td>
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<td>115.9</td>
<td>127.1</td>
<td>123.8</td>
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<td>123.0</td>
<td>126.4</td>
<td>124.3</td>
</tr>
<tr>
<td>1% Pectin</td>
<td>143.20</td>
<td>142.70</td>
<td>142.4</td>
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<td>146.3</td>
<td>144.5</td>
<td>140.7</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2% Pro-long</td>
<td>170.25</td>
<td>163.73</td>
<td>160.98</td>
<td>162.21</td>
<td>173.2</td>
<td>151.2</td>
<td>158.6</td>
<td>115.9</td>
<td>186.2</td>
<td>127.3</td>
<td>125.3</td>
<td>123.4</td>
<td>124.5</td>
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</tr>
<tr>
<td>2% Pectin</td>
<td>143.2</td>
<td>150.31</td>
<td>149.68</td>
<td>141.6</td>
<td>138.6</td>
<td>148.6</td>
<td>144.2</td>
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<td></td>
<td></td>
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<tr>
<td>2.5%</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pro-long</td>
<td>170.25</td>
<td>161.21</td>
<td>163.34</td>
<td>165.60</td>
<td>169.41</td>
<td>163.4</td>
<td>165.6</td>
<td>115.9</td>
<td>143.6</td>
<td>121.9</td>
<td>124.4</td>
<td>120.5</td>
<td>136.2</td>
<td>126.0</td>
<td>125.0</td>
</tr>
<tr>
<td>Pectin</td>
<td>143.2</td>
<td>141.23</td>
<td>148.6</td>
<td>147.3</td>
<td>153.6</td>
<td>151.8</td>
<td>146.63</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Graph 11: Percentage extractable pectin from fruits treated with Pro-long and stored at 16°C (80-90% R.H.)
regards the amount of extractable pectin at about 7-8%, although further storage would have been necessary to confirm this. It can be seen that the pectin in the controls decreased initially more rapidly than for the treated fruits, corresponding with the effect of Pro-long on respiration rates. Hence the more rapid wrinkling and softening of the peel in the controls during storage is probably in part due to the more rapid loss of pectin in addition to being caused by the more rapid water loss.

4.5 Respiration

Respiration can be described as oxidative breakdown of complex materials normally present in the cell, such as starch, sugars and organic acids, into simple molecules such as carbon dioxide and water, with a concurrent production of energy and other molecules (Wills et al., 1981).

In this investigation respiration in purple passion fruit was measured by the amount of carbon dioxide liberated. The results of the respiratory activity are summarised in Graphs 12, 13 and 14. In all cases there was an increase in the rate of carbon dioxide liberated up to a maximum followed by a drop, as is to be expected of a climacteric fruit.

On examining the results it is seen that Pro-long treated fruits reached the climacteric peak later than the controls. In addition the rates of respiration were generally less. The effect of temperature is also clearly seen both in respect of the higher respiration rates with temperature and also in the more rapid onset of the climacteric peaks. For controls the climacteric peaks were reached after 15, 12 and 3 days for 8°C, 16°C and 24°C respectively; for Pro-long treated
Graph 12: Respiratory activity of purple passion fruit stored at 8°C (80-90% R.H.)
Graph 13: Respiratory activity of purple passion fruit at 16°C
(80-90% R.H.)
Graph 14: Respiratory activity of purple passion fruit stored at 24°C (80-90% R.H.)
demonstrated that Pro-long does delay onset of the climacteric. The possibility exists, if similar data can be obtained for other fruits, of developing a mathematical modelling system based upon variation in parameters such as Pro-long concentration, temperature, humidity, type of fruit, surface to volume ratio, respiration rate, etc. This could be valuable in predicting the effect of Pro-long on the ripening and shelf-life of a whole range of both climacteric and non-climacteric fruits.

4.6 Fungal infection

At the storage temperature of 24°C and 80-90% relative humidity, the control and Pro-long treated fruits were often found to be affected by fungi despite being treated with thiabendazole prior to storage. It was thought that the fungi in question might well have been a latent infector.

The infection was isolated from the stored fruit and identified (see Experimental Section) as Alternaria passiflorae (Plate 3).

To test if the fungi identified in the control and treated fruits were latent, freshly received passion fruit with faint brown ring-like spots were picked from the batch soon after the fruits were received. A. passiflorae was again identified, indicating that the infection in the stored fruits was latent and not totally prevented by thiabendazole treatment. Hence it is important that measures are taken to control infection at the pre-harvest stage.
CONCLUSIONS

The following conclusions can be drawn in relation to the aims of the present work as set out in Section 2.9.

There was no observable extension in shelf life when pectin was used as a coating on purple passion fruit. In contrast, Pro-long was found to be highly effective in controlling weight loss and degree of wrinkling especially at 2% and 2.5% concentration under all storage conditions employed during this study. Using 2% or 2.5% Pro-long, an extension in shelf life of about 20, 13 and 10 days were achieved at 8°C, 16°C and 24°C respectively.

Pro-long treated fruits were adjudged by the taste panel to have no significant difference in taste compared with the controls however there was increased retention of flavour volatiles in the Pro-long treated fruits as ascertained by both the taste panel analysis and chemical analysis.

The climacteric peak in Pro-long treated fruits occurred later than in the controls and the peaks were significantly reduced indicating that Pro-long coating considerably decreased the respiratory rate and thus delayed the onset of ripening.

The fungus Alternaria passiflorae was isolated and identified as the causative agent of latent infection in purple passion fruit. Higher incidence of fungal infection occurred at higher storage temperatures and both controls and Pro-long treated fruits were affected. The fungicide thiabendazole (TBZ) proved ineffective, suggesting the use of anti-fungal measures at the pre-harvest stage.
SUGGESTION FOR FURTHER WORK

The following aspects should be further investigated:

- The effect of Pro-long on the shelf-life of passion fruit when applied immediately post harvest (in the field) and when fruits are stored under commercial conditions.

- The effect of Pro-long on the estimation of shelf-life of other edible species of passion fruit.

- The gas chromatographic method applied to individual volatile flavour compounds and relating the results to taste panel assessment.

- The application of mathematical modelling to the use of Pro-long on passion fruit and on other fruits when data is available and in particular in regard to the results on respiration rates and weight loss.
APPENDIX

Plate 1

Plate 2
Plate 3(a)

Plate 3(b)
TASTE PANEL SCORE SHEET

Tick the box above each rank number the impressions you think suits the sample.

1. EXTERNAL CHARACTERISTICS

a) Colour of the peel

<table>
<thead>
<tr>
<th>Sample</th>
<th>Any other comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

b) Degree of wrinkling

<table>
<thead>
<tr>
<th>Green</th>
<th>Purple</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extensive</td>
<td>None</td>
</tr>
</tbody>
</table>

2. INTERNAL CHARACTERISTICS (PULP)

a) Pulp Colour

<table>
<thead>
<tr>
<th>Pale</th>
<th>Yellow</th>
<th>Orange</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

b) Taste

<table>
<thead>
<tr>
<th>Sour</th>
<th>Sweet</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

c) Aroma

<table>
<thead>
<tr>
<th>None</th>
<th>Strong</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

d) Juiciness

<table>
<thead>
<tr>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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