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Passion-Fruit Products

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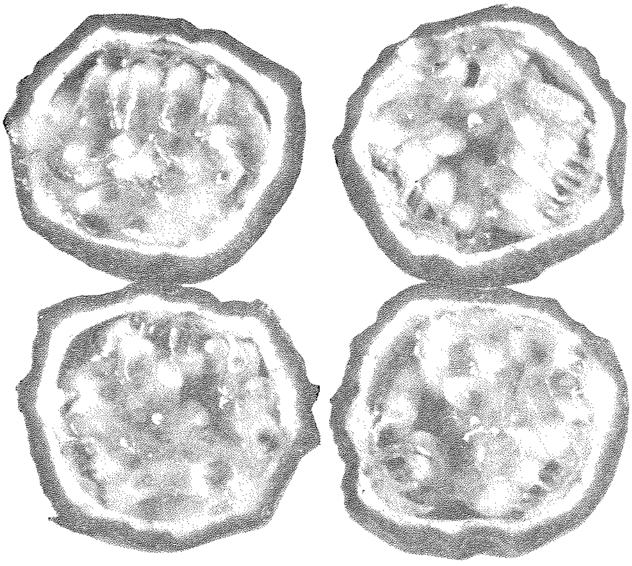

Fig. 1.—Showing the pulp within the tough exterior skin of passion-fruit. The pulp encloses small seeds and is contained in embryo sacs.

Last year Dr. Vickery, Chief of the Division of Food Preservation, attended the First Pacific Rim Food Conference, organized by the Institute of Food Technologists, where he presented a number of papers relating to technical and economic problems affecting trade in food products among the Pacific Rim countries. Amongst these was the present paper which, with minor revisions, is reproduced here with the kind permission of Dr. George Stewart, Executive Editor of I.F.T. publications.

INTRODUCTION

The passion-flower vines (*Passiflora* species) are native to tropical America. Among the 400 or so species in the genus are several which produce edible fruits, but only one, *Passiflora edulis*, has become a cultivated plant of commercial importance. Commercial cultivation of passion-fruit appears to have commenced in Australia about 1892 using the purple variety of *P. edulis*. Subsequently this purple variety was introduced from Australia into Hawaii and California (Poore 1935; Akamine *et al.* 1956). Later a yellow-skinned variety of *P. edulis*, designated *flavicarpa*, was introduced into Hawaii, also from Australia, and became the favoured commercial variety in the Hawaiian Islands, where the local name is "lilikoi". The purple passion-fruit remains the important variety in Australia and in India, and also in Africa where the ancient name of "granadilla" or "grenadilla" has been retained. The yellow variety appears to grow more vigorously and yield more prolifically than the purple variety.

The passion-fruit is an oval or sometimes round fruit weighing approximately one ounce and having, in the case of the purple variety, a dark purple, leathery skin or, in the case of the yellow variety, a bright yellow, waxy skin. Within the fruit are numerous embryo sacs containing black or dark brown seeds enclosed in orange-yellow gelatinous pulp (see Fig. 1). The pulp has an acid but highly attractive and distinctive flavour. There is a real but subtle difference in flavour between the purple and yellow varieties, and the pulp of the yellow variety tends to be more acid.

EXTRACTION OF PULP AND JUICE

A simple procedure of cutting the fruit in halves and scooping with spoons is still used in Africa for extraction of passion-fruit pulp. The pulp may also be extracted in a manner similar to citrus juice extraction by reaming the halved fruit on a small burr or wire loop. In Australia and Hawaii, however, commercial processors have found that mechanical methods of extraction are essential.

In Hawaii a centrifugal extractor (see Fig. 2) has been developed and applied successfully in commercial practice (Kinch and

Shaw 1954; Boyle, Shaw, and Sherman 1955; Kinch 1960). The fruit is sliced by means of a gang of rotating knives, and the slices ($\frac{5}{8}$ in.) drop directly into a perforated centrifuge bowl. The bowl has sloping sides and four baffles at right angles to the sides. When it is rotated at a speed representing a centrifugal force of 175 *g*, the pulp and seeds from the slices are thrown out through the holes in the basket while the residual skins climb the walls of the basket and are thrown out over the edge. The pulp and skins are then collected from separate chutes. The extractor has a capacity of 4000 lb of passion-fruit per hour, and an efficiency of extraction of 94% is claimed.

The mechanical extractor commonly used in Australia is based on a different principle. It consists of two rotating disks independently driven, and mounted so that there is a wide clearance at the top but so that the disks almost touch at the bottom. Whole passion-fruit are fed in at the top, and drop down so that they are squashed between the disks. In practice, the skin bursts suddenly and the pulp and seeds are expelled cleanly. The burst skins are carried on by the disks and rejected, while the pulp drops between the disks through a coarse screen which removes fragments of skin. The extractor has a capacity of 5000 lb of fruit per hour, and the yield is stated to be similar to that obtained by extraction with spoons.

In Australia, passion-fruit pulp and beverages made from it are commonly consumed with the seeds still present. In fact the public tends to regard the presence of the seeds as evidence of passion-fruit content. In Hawaii, however, the seeds are always removed. In the subsequent discussion the term "passion-fruit pulp" will be used to describe the fruit contents, including the seeds, and the term "passion-fruit juice" will refer to the screened pulp without the seeds.

The operation of seed removal is commonly performed in a brush finisher, or a paddle finisher with the paddles faced with "Neoprene", having a screen with 0·033-in. holes. Boyle, Shaw, and Sherman (1955) recommend a second finisher with a 60–80 mesh screen to remove seed fragments which appear as black specks in the juice.

In Australian experience (Australia, Tariff Board 1960), 1 bushel (36 lb) of passion-fruit yields about 13·3 lb of pulp, which in turn yields about 1 gallon (10·7 lb) of screened juice and 2·6 lb of seeds. Similar yields are obtained from the yellow passion-fruit in Hawaii, the average yield of juice being 30–33%, and yields up to 40% are obtained from selected strains (Akamine *et al.* 1956).

CHEMICAL COMPOSITION

The most comprehensive information on the composition of passion-fruits has been compiled by Pruthi and Lal (1959*a*) who examined purple passion-fruits grown in India. Their observations are summarized in Table 1 together with those of some other workers relating to both purple and yellow varieties. The composition of commercial juices of Australian origin lies within the ranges found by Pruthi and Lal (1959*a*).

Among the soluble carbohydrates of passion-fruit juice, sucrose makes up 25%

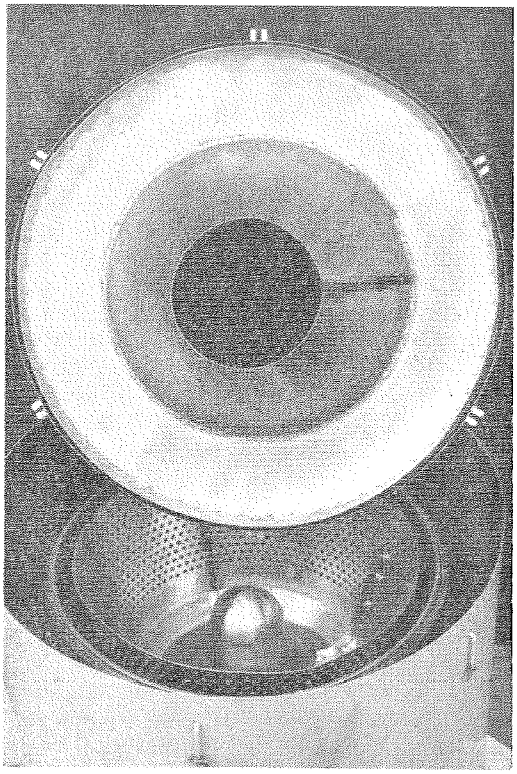

Fig. 2.—A centrifugal extractor used for separating the pulp and seeds from the skin. The illustration shows the perforated bowl within the juice container, the outer rind container, and the lid.

Table 1—Composition of Passion-Fruits

Variety:	Purple			Purple	Purple	Yellow			Not known
Source:	India			Australia	Qld., Aust.	Hawaii			Belgian Congo
Reference:	Pruthi and Lal (1959*a*)			Osmond and Wilson (1954)	Gurney (1937)	Boyle, Shaw, and Sherman (1955)			Wilbaux (Pers. commun.)
Fruit Characteristics	Max.	Min.	Mean			Max.	Min.	Mean	
Weight (g)	47·2	9·0	28·4	—	29·2	—	—	—	—
Length (cm)	5·7	4·0	5·1	—	—	—	—	—	—
Diameter (cm)	5·1	3·0	4·5	—	—	—	—	—	—
L/D ratio	1·3	1·0	1·1	—	—	—	—	—	—
Specific gravity	0·997	0·943	0·973	—	—	—	—	—	—
Fruit Components									
Peel (g/100g)	65·4	32·0	49·6	51	45·2	—	—	—	—
Residue (g/100g)	21·8	7·0	13·6	—	10·5	—	—	—	—
Juice (g/100g)	52·9	21·8	36·8	—	44·3	—	—	—	—
No. of seeds per fruit	191	60	142	—	—	—	—	—	—
Composition of Juice				Pulp Incl. Seeds	Pulp Incl. Seeds				
Moisture (g/100g)	82·5	76·9	80·4	76·0	71·1	84·2	79·6	82	86·4
Ether ext. (g/100g)	0·08	0·01	0·05	2·2	—	1·2	0	0·6	—
Soluble solids (g/100g)	21·9	14·4	17·3	—	16·3	18·0	13·0	15·0	—
Specific gravity	1·091	1·063	1·072	—	—	—	—	—	—
Acidity (g/100g)	4·8	2·4	3·4	—	2·1	5·0	3·0	4·0	3·75
Brix/Acid ratio	7·7	3·4	5·3	—	—	—	—	—	—
pH	3·2	2·6	2·8	—	3·3	3·3	2·8	3·0	3·5
Ca pectate (g/100g)	0·06	0·04	0·05	—	—	—	—	—	—
Reducing sugars (g/100g)	8·3	3·6	6·2	—	5·1	7·8	6·2	7·0	4·7
Non-reducing sugars (g/100g)	7·9	2·3	4·6	—	4·2	—	—	—	—
Total sugars (as invert) (g/100g)	13·3	7·4	10·0	184*	—	11·6	9·3	10·0	8·2
Crude fibre (g/100g)	—	—	—	—	14·2	—	—	0·2	—
Starch (g/100g)	3·7	1·0	2·4	—	—	—	—	—	—
Protein (g/100g)	1·2	0·6	0·8	2·4	2·4	1·2	0·6	0·8	0·77
Mineral matter (g/100g)	0·52	0·36	0·46	—	0·70	—	—	—	0·4
Ca (mg/100g)	18·4	9·7	12·1	11	—	—	—	5	—
P (mg/100g)	60·4	21·4	30·1	—	—	—	—	18	—
Fe (mg/100g)	4·0	2·3	3·1	1·2	—	—	—	0·3	—
Ascorbic acid (mg/100g)	69·9	21·9	34·6	17	—	20	7	12	—
Thiamine (mg/100g)	0·04	0·02	0·03	—	—	—	—	—	—
Riboflavin (mg/100g)	0·19	0·12	0·17	0·10	—	—	—	—	—
Nicotinic acid (mg/100g)	1·9	1·5	1·7	1·4	—	—	—	—	—
Carotene (i.u. vitamin A/100g)	1547	1073	1345	10	—	—	—	570	—

* Carbohydrate

of the total sugars, and glucose and fructose are also present (Pruthi and Lal 1955*b*). The principal acid in passion-fruit juice is citric acid, which contributes 93–96% of the total acidity, while malic acid contributes 4–7% (Pruthi 1958). Mucic acid is also present (Anet and Reynolds 1954). Passion-fruit juice contains little pectin but significant amounts of starch, which may settle out as a white or grey precipitate during storage of the juice or beverages made from it (Knock 1951). Cillie and Joubert (1950) found the starch to be almost pure amylopectin with a molecular weight about 7,000,000 and an average chain length of 17 glucose residues.

Passion-fruit juice is a useful source of ascorbic acid, and the purple variety appears to show higher ascorbic acid contents than the yellow variety (see Table 1). Ross and Chang (1958) found that the stability of ascorbic acid in passion-fruit juice was comparable to its stability in citrus juices.

The orange-yellow colour of passion-fruit juice is due to a complex mixture of carotenoid pigments in which β-carotene predominates. The distribution of the principal carotenoid pigments, according to Pruthi and Lal (1958*a*), is shown in Table 2.

The volatile flavouring substances responsible for the unique aroma and flavour of passion-fruit have been studied by Hiu (1959) who has found 18 separate components and has identified four of these as *n*-hexyl caproate, *n*-hexyl butyrate, ethyl caproate, and ethyl butyrate.

PRESERVATION

The earliest studies on the preservation of passion-fruit juice appear to have been made by Poore (1935). Poore held frozen juice for 2 years at 0 to 10°F without noteworthy changes in colour, flavour, or aroma, but pasteurized bottled juices deteriorated rapidly in flavour during storage. Later workers have found that the distinctive aroma and flavour of passion-fruit are elusive and very sensitive to change during heat treatment. It is preferable therefore to avoid heat treatment, by preserving the juice by freezing. The preparation of frozen passion-fruit juice in consumer-size cans has been described by Boyle, Shaw, and Sherman (1955), and Scott (1959) has analysed the costs of operating a processing plant.

There is a considerable trade in frozen passion-fruit juice between New Guinea and Australia. After mechanical extraction and removal of the seeds, the juice is de-aerated to remove air incorporated in the finisher, and filled into lacquered 4-gallon square cans. The filled cans are transported by air from the processing plant in the New Guinea highlands to a refrigerated store at a coastal port, where the juice is frozen and held until shipped as frozen cargo to Australia. The frozen juice retains satisfactory quality for at least 1 year at 0°F.

Another alternative to heat treatment for the preservation of passion-fruit pulp or juice is the use of chemical preservatives. In the past, Australian beverage manufacturers have prepared or have imported from Africa large quantities of passion-fruit juice preservatized with 1000–1500 p.p.m. of sulphur dioxide or benzoic acid, or preferably with a mixture of the two preservatives. The preservatized products, however, show marked deterioration of aroma and flavour.

Table 2—Carotenoid Pigments of Passion-Fruits
From Pruthi and Lal 1958*a*

Pigment	Total Carotenoids (%)
Free xanthophylls	10·3–21·5
Xanthophyll esters	11·1–34·6
Epiphasic non-saponfiable pigments, including phytofluene, α-carotene, β-carotene and ζ-carotene, and 3 minor pigments	45·7–76·3

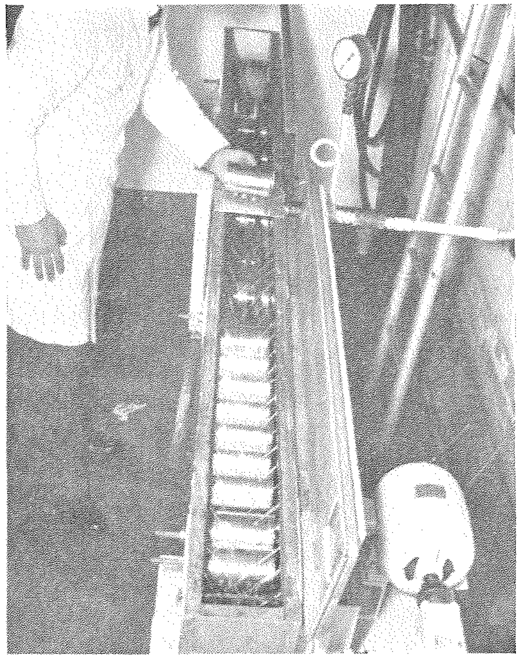

Fig. 3.—The "spin cooker" for pasteurization of canned passion-fruit juice, showing the cans being cooled by water jets after heat treatment.

When pasteurization of passion-fruit juice by heat is necessary, best results are achieved by agitated pasteurization in the can (Pruthi 1959*a*; Seale and Sherman 1960). The screened juice is filled cold into lacquered cans, sealed under mechanical vacuum or steam flow, and processed in atmospheric steam, the cans being rotated axially at 100–150 r.p.m. on an inclined belt. Process times of 1·5 min for No. 1 Tall (301 × 411) cans and 4 min for No. 10 (603 × 700) cans give centre temperatures of 170–180°F, which are adequate for preservation. A commercial pack of sweetened pulp in 4-oz. cans (211 × 111) is processed 1·25 min to a centre temperature of 175°F. After pasteurization the cans are cooled immediately under water sprays at the same rate of rotation (see Fig. 3). Immediately after processing the "spin-cooked" juice is very close to fresh juice in flavour. During storage of the canned product some flavour deterioration occurs, at a rate dependent upon the storage temperature. Addition of sugar increases flavour stability, and pasteurized juice sweetened to 50°Brix shows satisfactory flavour retention for at least 1 year at room temperature. Pruthi (1959*b*, 1959*c*) has reported on retention of colour, flavour, and ascorbic acid, in passion-fruit juices preserved by various methods.

A few workers have investigated the concentration of passion-fruit juice. Morris (1935) prepared a four-fold concentrate by freezing and centrifuging, and Pruthi and Lal (1959*b*) used a batch-type vacuum evaporator. To restore volatile flavouring substances to their product Pruthi and Lal concentrated and added back the first 10–15% of the distillate. The concentrate was then hot-filled into cans and frozen. Some concentrate prepared in this way was mixed with sugar and dehydrated in a vacuum shelf dryer to prepare a passion-fruit powder which was packaged with an in-package desiccant. Both concentrate and powder were claimed to be acceptable products, although the flavour was inferior to fresh juice. Seagrave-Smith (1952) prepared a 1:1 blend of passion-fruit and pineapple juices, with sugar added to bring the solids content to 38·4%. This blend was evaporated under vacuum and cut back with fresh blend, or with fresh blend together with the first 10% of distillate, and then the final concentrate was frozen. It was claimed to have satisfactory aroma and flavour, although not as good as the initial blend.

The starch in passion-fruit juice introduces difficulties in pasteurization and concentration, since gelling of the starch during heating increases the viscosity substantially. Knock (1951) reports that enzymic degradation of the amylopectin permits the preparation of relatively free-flowing four-fold concentrates, but suggests that centrifugal separation of the starch may be more suitable for commercial operations.

UTILIZATION

Because of its unique and intense flavour and high acidity, passion-fruit juice has been described as a natural concentrate. When sweetened and diluted it provides a highly palatable beverage, and the flavour blends well with other fruits and fruit juices in the preparation of fruit salads and punches. Consumer preferences in Hawaii and California for frozen sweetened passion-fruit juice intended for dilution before consumption were investigated by Scott (1956). He concluded that for most general acceptance the sugar:juice ratio should not be more than 55:100 nor less than 45:100, and the dilution should be 1+3. In Australian experience, passion-fruit juice sweetened to 50°Brix (sugar:juice ratio approximately 70:100) gives a very pleasing beverage when diluted 1+4.

Passion-fruit juice is also highly suitable for flavouring ice-cream, cake fillings, frostings, gelatin desserts, sherberts, and chiffon pies (Boyle, Shaw, and Sherman 1955; Shaw *et al.* 1955; Seale and Sherman 1960).

Blends

Menzies and Kefford (1949) found that blends of 5 or 10% of passion-fruit juice with apple juice were very attractive in flavour and were most favoured among six blends of apple juice tested. In South Africa, blends of passion-fruit juice with pear, apple, peach, and orange juices have been prepared (Anon. 1949). A blended punch which is canned in Hawaii contains orange, pineapple, guava, papaya, and passion-fruit juices (Anon. 1955).

Cordials and Syrups

Passion-fruit cordials or squashes are popular beverage bases in Australia and South Africa. They consist of passion-fruit juice with sugar syrup and acid added so that they normally contain 50–55% soluble solids and 1–2% acid. Cordials are diluted 1+4 or 1+5 with water for consumption. They are usually artificially coloured and preservatized with benzoic acid (600–770 p.p.m.) or sulphur dioxide (220–350 p.p.m.), since they are expected to be stable against spoilage after the bottle is opened. Standards of composition in South Africa require not less than 30% passion-fruit juice by volume (South African Bureau of Standards 1959). In Australia the minimum juice content varies from 12·5 to 25% by weight in different States.

Coetzee, Hugo, and Pratt (1951) describe the preparation of blended syrups incorpor-

Table 3—Composition of Passion-Fruit Skins

Variety:	Yellow		Purple	Purple
Source:	Hawaii		Qld., Aust.	India
Reference:	Otagaki and Matsumoto (1958)		Gurney (1937)	Pruthi and Lal (1955*b*)
	Original Skins	Dried Skins	Original Skins	Dried Skins
Moisture (g/100g)	83	16·8	81·7	—
Crude protein (g/100g)	—	4·6	1·9	8–10
Ether ext. (g/100g)	—	0·33	0·2	—
Ash (g/100g)	—	6·8	1·9	—
Crude fibre (g/100g)	—	25·7	7·3	—
N-free ext. (g/100g)	—	45·9*	7·0	—
Pentosans (g/100g)	—	15·7	—	—
Lignin (g/100g)	—	6·5	—	—
Pectin (g/100g)	—	20·0	—	10–12
CaO (g/100g)	—	—	0·06	—
P_2O_5 (g/100g)	—	—	0·032	—

* Carbohydrate.

ating passion-fruit juice. Blends of passion-fruit juice with grapefruit, grape, and plum juices were preferred to similar syrups made from passion-fruit alone. Pruthi and Lal (1955*a*) present a flow sheet and an analysis of costs for the preparation of passion-fruit squash. The same workers (Pruthi and Lal 1958*b*) investigated the fortification of passion-fruit squash with ascorbic acid and found that there was 2·5% loss during pasteurization and about 50% loss during 1 year's storage at room temperature.

Carbonated Beverages

Carbonated beverages based on passion-fruit juice have a very distinctive and attractive flavour. They are made from bottler's syrups similar in composition to the cordials described above. Regulations in New South Wales prescribe a minimum fruit juice content of 3%, and maximum preservative limits of 114 p.p.m. sulphur dioxide or 385 p.p.m. of benzoic acid, or equivalent mixtures of the two preservatives.

BY-PRODUCTS

Skins

Since passion-fruit skins make up 50% of the weight of the raw material considerable interest has been shown in possibilities for profitable utilization of the skins. Martin and Reuter (1949) isolated from the skins of purple passion-fruit a pectic substance which by enzymic hydrolysis yielded D-galacturonic acid, arabinose, and L-sorbose, but no galactose. Sherman, Cook, and Nichols (1953) found the pectin content of yellow passion-fruit skins to be 3% on a wet basis or 20% on a dry basis. The pectin showed good jellying properties, comparable to citrus pectins. It contained 76–78% galacturonic acid and 8·9–9·2% methoxyl groups, and both arabinose and galactose were found to be present. Pectin-esterase was present in the passion-fruit skin and required to be inactivated by steam blanching for maximum yields of pectin to be obtained.

Otagaki and Matsumoto (1958) have examined the suitability of passion-fruit by-products for utilization as stock feed. The skin of yellow passion-fruit is high in carbohydrates, low in ether-extractable material, and contains a moderate amount of crude protein. It is readily dehydrated without lime pretreatment and the dried material is palatable to dairy cattle at 22% of the ration. A typical analysis is shown in Table 3. Laboratory-scale studies by the same workers indicated that it should be possible to produce good-quality silage from passion-fruit skins.

Table 4—Composition of Passion-Fruit Seeds and Seed Oils

Variety: / Source: / Reference:	Not known / Belgian Congo / Wilbaux (Personal communication)	Purple / Qld., Aust. / Gurney (1937)	Purple / India / Pruthi and Lal (1955*b*)	Yellow / Hawaii / Otagaki and Matsumoto (1958)	Not known / Not known / Jamieson and McKinney (1934)
Composition of Seeds					
Moisture (g/100g)	10·3	—	—	—	—
Ash (g/100g)	1·4	—	—	—	—
Fat (g/100g)	20·2	—	20–25	—	18
Protein (g/100g)	10·7	8·5	10–14	—	—
Fibre (g/100g)	37·2	—	50–55	—	—
Cyanogenetic glycosides	Nil	—	—	—	—
Composition of Seed Oils					
Specific gravity	—	—	—	0·9208	0·9207
Refractive index	1·472–1·482	—	—	1·5729	1·4737
Sap. No.	200–220	—	—	191·3	190·4
Iodine No.	82·7	—	—	137·5	140·4
Reichert-Meissel No.	—	—	—	0·17	0·11
Polenske No.	—	—	—	0·25	0·21
Thiocyanogen No.	—	—	—	84·2	81·2
Acetyl No.	—	—	—	14·9	81
Unsap. matter (%)	—	—	—	0·77	0·62
Fatty Acid Distribution					
Arachidonic (%)	—	—	—	0·9	0·4
Linolenic (%)	—	—	—	2·6	5·6
Linoleic (%)	—	—	—	67·5	62·3
Oleic (%)	—	—	—	13·0	19·9
Satd. acids (%)	—	—	—	16·0	8·9

Table 3 also includes some analyses of the skins of purple passion-fruits.

Seeds

The seeds of passion-fruit contain about 10% protein and about 20% of an edible oil which compares favourably with cottonseed oil in feeding value and digestibility (Otagaki and Matsumoto 1958). The presscake from the seeds is not suitable for feed purposes since it contains about 60% crude fibre and 30–35% lignin. Some analyses of seeds and seed oils of passion-fruits are shown in Table 4.

In Australia there is a rather extraordinary trade in passion-fruit seeds to pastrycooks who add the seeds to artificially flavoured "passion-fruit" icings for cakes.

PASSION-FRUIT INDUSTRY IN THE PACIFIC AREA

Production in Australia

Passion-fruit growing in Australia is concentrated mainly in New South Wales, although there are small areas in Queensland, Victoria, and Western Australia. Actually, most of the coastal strip of arable land extending from the Hawkesbury River into Queensland is suitable for passion-fruit growing (Levitt and McGillivray 1959). At the present time, however, the industry is a small one as is shown by the acreage and production data set out in Table 5. Generally speaking, passion-fruit is planted as a catch-crop in new citrus orchards, with trellises for the vines set out between the young trees.

Table 5—Passion-Fruit Production in Australia
From Carver (1958) and Australia, Tariff Board (1960)

	1950–51	1954–55	1955–56	1956–57	1957–58	1958–59
Total Area (acre)	1348	1654	1645	1328	1126	1266
Bearing Area (acre)	922	1068	1167	908	—	—
Total Production (bus.)	51,466	87,760	70,708	49,256	38,596	54,047
N.S.W. Production (bus.) . .	35,000	66,363	51,324	36,794	26,520	41,216
Yield per bearing acre (bus.) . .	56	82	61	54	—	—

By the time citrus trees come into bearing, the passion-fruit vines have finished their profitable life and are removed. In recent years a greater demand for passion-fruit by processors has encouraged a few growers to grow passion-fruit alone.

Two crops are obtained from the vines each year, the summer crop being heavier. Processors draw their requirements mainly from the summer crop; the lighter winter crop is usually sold at higher prices on the fresh fruit market. The average yield per acre is about 60 bushels (see Table 5), although a grove in good condition should yield 150 bushels (about 2½ tons) per acre. The principal horticultural hazards affecting production are a virus disease causing the condition known as "bullet" or "woodiness" (Simmonds 1959), the fungal disease "brown spot", and *Fusarium* root rot. In Queensland most recent plantings are based on grafted vines with a *flavicarpa* rootstock which has some resistance to *Fusarium*.

Production in New Guinea

As a result of the enterprise of one Australian manufacturer of passion-fruit products, a passion-fruit industry has been established in the highlands of New Guinea, at Goroka and Mt. Hagen. The venture has received active encouragement from the Commonwealth Department of Territories, since no other crop yet tried has proved so suitable for cultivation by a native people making its first contact with Western civilization.

The natives are supplied with plants of the purple passion-fruit and grow them under semi-wild conditions in scattered stands, using trees and the fences round their subsistence gardens as supports for the vines. The vines are not pruned, and the free-growing method of cultivation is claimed to protect the vines substantially from disease and insects. The "bullet" virus and the "brown spot" fungus have not yet been encountered in New Guinea plantations.

The fruit is purchased from the native growers for 2*d.* per lb. Although this is approximately one-sixth of the price received by Australian growers, the New Guinea processor is also faced with the costs of air and sea transport of the frozen juice to Australia.

The most recent official statistics relating to imports of passion-fruit pulp and juice from New Guinea into Australia are shown in Table 6. Since Australia is the only present market for these products, Table 6 implies that the annual commercial production of passion-fruit in New Guinea has increased from about 20,000 bushels in 1955–56 to about 40,000 bushels in 1958–59.

Production in Hawaii

Commercial growing of passion-fruit in Hawaii is an industry of recent origin. According to Scott (1955) and Otagaki and

Table 6—Imports of Passion-Fruit Pulp and Juice into Australia
From Australia, Tariff Board (1960)

	Africa* (gal)	New Guinea (gal)
1951–2	79,321	15
1952–3	29,046	3333
1953–4	21,062	7658
1954–5	34,517	16,023
1955–6	18,827	24,807
1956–7	7580	11,097
1957–8	8739	33,376
1958–9	5401	42,583

* Union of South Africa, Kenya, and Tanganyika.

Matsumoto (1958) the acreage has grown from almost nothing in 1953 to 392 acres in 1955 and 1000 acres in 1957. Expansion in the industry is predicted, since passion-fruit grows well on rough land not well suited to the major crops of sugar-cane and pineapple, and passion-fruit culture is regarded as a desirable contribution towards diversification in the agricultural economy of the Hawaiian Islands.

The yellow passion-fruit grows vigorously and yields prolifically under Hawaiian conditions. Yields as high as 23 tons per acre are reported and the normal average yield is apparently about 10 tons per acre. This is very much greater than yields obtained from purple passion-fruit in Australia. Evidently current total production of passion-fruit in Hawaii is of the order of 10,000 tons per year.

The Australian Market

The passion-fruit flavour in beverages and other products is popular with the Australian public, and the demand for passion-fruit by processors, principally cordial and soft drink manufacturers, exceeds the local supply. Therefore supplies of passion-fruit from within Australia have been supplemented by imports from Papua-New Guinea, South Africa, Kenya, and Tanganyika (see Table 6).

In recent years the effective annual demand for passion-fruit in Australia has been about 115,000 bushels, of which approximately 65,000 bushels are used for processing (Australia, Tariff Board 1960). This demand is much greater than the highest reported annual production (see Table 5), but passion-fruit growers have claimed that the area under crop and the annual production could readily be increased several times and the whole of the Australian demand satisfied.

However, the position is almost entirely governed by economic factors. Growers demand a price of approximately 40*s*. per bushel for passion-fruit. On this basis, Australian juice sells at 65*s*. per gallon, as compared with 32*s*. per gallon for African juice landed in Australia. Passion-fruit beverages are currently retailed at higher prices than other competing fruit juice drinks, and sales have declined. Processors are paying 30*s*. per bushel for Australian passion-fruit and claim that they cannot afford to pay more, whereas growers maintain that they cannot continue to produce passion-fruit at this price. There is little doubt that passion-fruit growing is a depressed industry and that returns to growers are poor. This situation may be attributed largely to the low average yields obtained from the purple passion-fruit grown under Australian conditions.

As a result of grower representations, duties have been imposed upon passion-fruit products imported from Africa, but Papua-New Guinea production up to 25,000 gallons per year is admitted free of duty and the Australian Tariff Board (1960) has recommended that this amount be increased to 45,000 gallons.

It appears likely that production in Papua-New Guinea could be expanded to meet all of Australia's requirements for imported passion-fruit products, but the Department of Territories is reluctant to encourage expansion while the future market in Australia is uncertain.

The American Market

Scott (1955, 1958) has endeavoured to assess the potential market in mainland U.S.A. for frozen passion-fruit juice from Hawaii. He estimates that a market could be developed for juice equivalent to 50,000 tons of passion-fruit, representing the production from 5000 acres yielding 10 tons per acre.

Australian processors are also interested in the American market, and a trial shipment has been made of passion-fruit juice sweetened to 50°Brix and pasteurized in 6-oz cans by spin-cooking.

Future Outlook

There is no doubt that passion-fruit could be more widely grown in many tropical and warm-temperature environments in the countries of the Pacific Rim. On Hawaiian experience the yellow variety, in particular, is hardy and grows well in a variety of soils at elevations from sea level to 2500 ft, provided there is a uniform and moderate rainfall. The purple variety is tolerant of light frosts and of short periods of moisture stress, but not of waterlogged soil conditions.

It is not at all certain, however, that there are markets available for any additional production of passion-fruit products. In countries such as mainland U.S.A., where the public is unfamiliar with the fruit, passion-fruit beverages and other products must be vigorously promoted in competition with many other fruit juice products. This promotion must be based almost solely upon the unique flavour characteristics of passion-fruit, since it has no special nutritional properties. In countries such as Australia, where the passion-fruit is well known, expansion of the market for passion-fruit products depends upon the establishment of more acceptable prices to the consumer.

In summary, it may fairly be reasoned that passion-fruit is likely to remain a significant but minor crop in the commerce of the Pacific area.

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Chemical Aspects of Fruit Quality

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Based on a paper prepared for the Conference of Technical Officers, Fruit and Vegetable Storage Research, Sherbrooke, Victoria, November 7-10, 1960

CHEMICAL aspects of fruit quality can be grouped under colour, texture, and flavour.

COLOUR

The colour of fruit is due to the lipid-soluble (but water-insoluble) chlorophyll and carotenoids and to the water-soluble anthocyanins. The destruction of the green pigment chlorophyll is a feature of ripening in practically all fruits. In many it is accompanied by an increase in the orange to red carotenoids. In apples and peaches the ground colour is due to chlorophyll and carotenoids, while the red blush developed under the influence of light is due to anthocyanins. In many varieties of plums the red to blue anthocyanin pigments are present in the flesh as well, and develop during ripening.

Studies of changes in the pigments during ripening have been extremely limited. Von Loesecke (1929) showed that the colour change in ripening bananas is due primarily to destruction of chlorophyll, the carotenoids remaining practically unchanged. Miller, Winston, and Schomer (1940) showed that colouring of oranges on the tree was due to increase in carotenoids as well as to destruction of chlorophyll. However, ethylene colouring of harvested oranges involved no change in the carotenoids. The development of the red carotenoid lycopene in ripening tomatoes was shown by Went, LeRosen, and Zeichmeister (1942) to be temperature-dependent, as it occurred at 66°F, but not at 91°F. Chaudhary (1950) found an increase in the carotenoids of mangoes during ripening.

Although ground colour has been used as an index of maturity in many fruits, there has been little attempt to correlate it with pigment concentrations. The concentration of chlorophyll is the most likely to give a good correlation.

TEXTURE

Firmness (or softness) and juiciness appear to be related primarily to the composition and structure of the cell wall. Both softening and development of juiciness are aspects of ripening, but need to be considered separately, as the former can occur without the latter in over-stored peaches and plums. These fruits soften on removal from cool storage, but become mealy or gelatinous instead of juicy. It is plausible to assume a preferential softening of the middle lamella, allowing separation of cells without release of contents, but this does not seem to have been investigated.

Degradation of pectin is the major chemical change of the cell wall constituents during ripening. The characteristic changes of normal ripening appear to be a decrease of insoluble and a corresponding increase of soluble pectin, a decrease of the molecular size, and a decrease in esterification. This conclusion fits the results of most investigators in the field (see bibliography below) except those of Date and Hansen (1953), who found a synthesis of pectin during storage. Changes in calcium binding may also be important. Abnormal ripening has not been appreciably investigated.

The penetrometer is a suitable instrument for testing firmness or softness. There are no standard tests for juiciness, but they would seem to be very desirable. Correlations of these physical measurements with chemical determinations of pectin can be sought, but would not necessarily be very good. The structural organization of the pectic constituents in the cell wall may be as important as their mean concentration in the whole tissue.

FLAVOUR

The taste of sweetness or sourness is due primarily to the balance between sugar and water-soluble acid content. Sugar forms a high proportion of the soluble solids. During maturation on the tree the sugar tends to increase and the acid to fall. After picking, sugar only increases at the expense of starch already present, and acid is generally lost more slowly. The correlation between taste and either titratable acidity or the soluble solids/acid ratio is not very close, but may be adequate (e.g. with oranges) for control purposes.

Reliable work on the volatile flavours has only been in progress for the last 15 years, and has been made possible by the development of chromatography. The most recent and promising gas chromatography has only been applied to this field during the last 5 years. Esters of the lower fatty acids and alcohols, free acids and alcohols, and lower aldehydes and ketones form a high proportion of the volatile flavouring constituents of apples, grapes, strawberries, and pineapples. Pineapple flavour contains a high proportion of esters, predominantly ethyl acetate. Aldehydes predominate in tomato flavour, and terpene hydrocarbons in oranges and grapefruit. Changes in the volatile constituents during ripening have not been investigated.

The possibility of correlating flavour, as determined by tasting, with a simple chemical determination is very limited. Most volatile flavours are due to complex mixtures of substances and could be seriously affected by absence of minor constituents. Pineapple flavour is relatively simple, as not only do esters predominate, but a single ester, ethyl acetate, is the major constituent. Ester determinations in pineapple juice have been found useful for control purposes. However, the chemical pattern in most fruit flavours is too complex, and the only measurement likely to give an adequate correlation with tasting tests is a gas chromatogram. This consists of a number of comparatively sharp peaks spaced at intervals above a comparatively flat base-line. Each peak represents a volatile constituent, whose relative concentration can be determined from the peak height or area. In samples of different flavours, as determined by tasting, there may be a correlation with the height of certain peaks. The identification of the flavouring constituent associated with each peak would first have to be undertaken.

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Census of Cool Stores in Australia at December 1958

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With the cooperation of State Departments of Agriculture, the South Australian Fruitgrowers' and Market Gardeners' Association, and other bodies, who supplied the information, a census of fruit cool stores in Australia was compiled in 1959. The census listed all stores handling fresh fruit as at December 1958, the main kinds of fruit stored, capacity of the store in bushel cases, principal constructional material, method of refrigeration, and age of the buildings. This information had not previously been collected for the Commonwealth and it was believed that the census would be both interesting and useful, being the first attempt to present an essentially true record of fruit cool storage facilities in Australia. The results of the census are summarized in this article. Copies of the full report are obtainable from the Division.

THERE were, at December 1958, 505 cool stores for fruit in Australia, ranging in capacity from a few hundred bushels for a small grower's store or a retailer's cool store to over a quarter of a million bushels for the largest cooperative and proprietary cool stores. The largest fruit cool store in Australia is that of the Shepparton Preserving Co., Shepparton, Victoria, which has a capacity of 320,000 bushels.

The principal fruits stored are apples and pears and, to a lesser extent, canning peaches. Cool storage of other fruits and vegetables, while significant in some cool stores, is unimportant in the total. Australia has sufficient fruit cool storage space to cool store half of the apples and pears produced. Victoria has a little over half of the total fruit cool storage space in the Commonwealth, enough to store approximately 79% of that State's production of apples and pears, or 67% of the production of apples, pears, and peaches. By contrast, Tasmania, the main apple-exporting State, with a production of apples almost twice that of Victoria and a production of apples and pears only a little less than Victoria's, has storage capacity for only about 16% of the production of those fruits. Western Australia, the third most important apple-producing State and second to Tasmania as an exporter, has, with 36%, the second lowest ratio of cool storage capacity to production of apples and pears.

For many years the private orchard cool store has played a very significant part in the cool storage of fruit in Victoria. At the end of 1958 there were 220 grower stores in that State, providing one-third of the total fruit cool storage capacity. Their average size was almost 7000 bushels capacity.

A significant recent development has been the erection of orchard cool stores in New South Wales, Tasmania, and South Australia. In New South Wales they number 50, have an average capacity of approximately 4500 bushels, and account for about one-fifth of the State's fruit cool storage capacity. Tasmania has 30 orchard cool stores of an average size of about 7000 bushels, and they account for almost one-quarter of that State's

Table 1—Fruit Cool Stores in Australia at December 1958

State	No. of Growers' Stores	Total Capacity (bus.)	No. of Coop. Stores	Total Capacity (bus.)	No. of Pty. Stores	Total Capacity (bus.)	State Total	
							No.	Capacity (bus.)
Qld.	10	53,500	3	190,000	11	307,100	24	550,600
N.S.W.	50	243,700	9	585,600	33	320,550	92	1,149,850
Vic.	220	1,524,794	30	2,004,913	31	1,000,600	281	4,530,307
Tas.	30	215,400	3	175,000	12	445,000	45	835,400
S.A.	21	119,000	10	574,050	6	125,800	37	818,850
W.A.	5	19,400	2	61,000	19	537,360	26	617,760
Total	336	2,175,794	57	3,590,563	112	2,736,410	505	8,502,767

fruit cool storage capacity. About one-quarter of the fruit cool stored in Australia is held in the 336 growers' own stores.

Cool stores owned by growers' cooperatives have 42% of the total fruit cool storage capacity. They are particularly important in South Australia (70%), New South Wales (51%), and Victoria (44%). Proprietary cool stores, with about one-third of the total Australian capacity, are predominant in Western Australia and more important than either growers' own or cooperative stores in Tasmania and Queensland.

The cooperative cool stores, each serving many growers, are comparatively large, the average capacity of the 57 cooperatives in Australia being 63,000 bushels. In contrast, the average capacity of the 112 proprietary stores is 24,500 bushels. If the 28 proprietary stores with a capacity of less than 5000 bushels are excluded, the remaining 94 have a total capacity of 2,699,360 bushels and an average size of 28,700 bushels.

While space does not permit full reproduction of the census report, Tables 1–3 summarize the main results.

It is realized that the original data are neither complete nor entirely up to date, although they are as accurate as could be obtained at the time. The census does present, for the first time, an essentially true record of fruit cool storage facilities in this country.

Table 2—Production of Principal Fruits Cool Stored (1000 bus.)
Average of 1955–56 and 1956–57 seasons

State	Apples	Pears	Peaches	Total: Apples and Pears	Total: Apples, Pears, and Peaches
Qld.	728	50	83	778	861
N.S.W.	1496	403	793	1899	2692
Vic.	2635	3087	1020	5722	6742
Tas.	4663	414	6	5077	5083
S.A.	996	324	406	1420	1726
W.A.	1602	125	71	1727	1798
Australia	12,128	4406	2382	16,534	18,916

Some special-purpose stores, such as large cannery cool stores (mainly in Victoria), are little used for long storage for the fresh fruit market or for precooling for export, and are not readily available for these purposes. However, there are a number of multi-purpose stores, generally large, which at times store fruit in considerable quantities. Some of these were included in the census and the proportion of their capacity available for fruit was estimated. Others, although not designed as fruit stores, have considerable space which could be used in an emergency, but these were not included because they do not normally store fruit. The amount of space in these stores suitable for fruit is also variable and unknown.

Table 3—Cool Storage Space for Fruit

State	Total (1000 bus.)	As Percentage of Production of:	
		Apples and Pears	Apples, Pears, and Peaches
Qld.	551	71	64
N.S.W.	1150	61	43
Vic.	4530	79	67
Tas.	835	16	16
S.A.	819	58	47
W.A.	618	36	34
Australia	8503	51	45

The Queensland Food Preservation Research Laboratory

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Dr. Trout is a graduate of the Universities of Queensland and Cambridge, and a Fellow of the Royal Australian Chemical Institute. In 1928 he was awarded a C.S.I.R. Student Endowment to the Low Temperature Research Station, Cambridge, where he spent three years on post-harvest physiology problems. He returned to Australia in 1931 and spent seven years in Melbourne in cooperative research with the Victorian Department of Agriculture. In 1938 he was transferred to Homebush and continued his research on fruit and vegetable storage in conjunction with Professor E. Ashby and Dr. R. N. Robertson of the Botany School of the University of Sydney, and with officers of the New South Wales Department of Agriculture. In 1945 he joined the Queensland Department of Agriculture and Stock as Assistant Director of Horticulture, and was appointed Director of Horticulture in 1947. He also became Director of the Food Preservation Branch when this was created in August 1960.

THE Food Preservation Research Laboratory of the Queensland Department of Agriculture and Stock, completed in May 1960, is situated at Hamilton, a suburb of Brisbane.

The history of the Laboratory dates back to 1945 when the Queensland Department of Agriculture and Stock was reorganized and, as part of the Horticulture Branch programme, research was commenced on the storage, transport, and processing of fruits and vegetables grown in Queensland. The facilities available for this research were extremely limited and most of the experimental work had to be conducted in commercial storage rooms or in conjunction with canneries. It was soon realized that research under such conditions would not provide many of the answers which industry required. For example, the storage behaviour of fruits and vegetables depends to a large extent on temperature, humidity, and composition of the storage atmosphere, and it is necessary to have facilities where all these factors can be controlled very accurately.

As a first step towards the provision of these facilities a site was selected in Harbour Road, Hamilton, adjacent to the offices and storage block of the Queensland Cold Storage Co-operative Federation Ltd., and only a short distance by road to the C.O.D. Cannery at Northgate. Considerable time had to be

Portion of the cold storage block at Hamilton.

spent in designing the cool room block and in drawing up plans and specifications for the four main laboratories and the special equipment required. The building was started by the Queensland Department of Public Works in 1958, and officers of the Queensland Department of Agriculture and Stock took up duty in the Laboratory on May 16, 1960.

Built at a cost of £150,000, with another £30,000 for equipment, the Laboratory covers an area of about 10,000 sq.ft. Immediately behind it is an area of about three-quarters of an acre which has been reserved for Departmental purposes to provide for future expansion.

On August 4, 1960, a Food Preservation Research Branch was created, with Dr. S. A. Trout as the Director. The present staff at Hamilton consists of physiologists, chemists, food technologists, a microbiologist, laboratory technicians, a processing assistant, an experimentalist, and laboratory attendants. There are now about 20 research workers, and this personnel will be augmented from time to time to cope with the many urgent problems requiring investigation. Initially, research will be on fruits and vegetables, but work on other foods will be undertaken at a later date.

The Laboratory consists of a library, offices, four main laboratories (viz. physiology, microbiology, chemical, and processing) in the eastern portion of the building, and a series of cold rooms in the western portion of the building.

The cold storage block consists of two low-temperature storage rooms, an air-blast freezer, and two lots of four rooms above freezing point, separated by a refrigerated anteroom.

A portion of the cold storage block is shown above. The eight cool rooms and the anteroom are refrigerated by calcium chloride-brine, forced-draught coolers. The anteroom is kept at about 38°F to prevent condensation, while the other rooms are maintained at 30, 32, 34, and 36°F for deciduous fruits, 45 and 50°F for citrus and tropical fruits, and 65 and 85°F for ripening purposes. The rooms are of brick, with a full vapour seal of rock asphalt. Application of the vapour seal, the corkboard insulation, and the supply and fixing of the stainless steel trimmed doors and door frames, were covered by the refrigeration contract. The erection of the brickwork and other structural work in connection with the refrigeration block was carried out by officers of the Queensland Department of Public Works.

All switches are iron clad and are enclosed in a moisture-proof cupboard on the outside wall fitted with a stainless steel door. There are nine brine pumps for each of the eight cool rooms and the ante-room. The brine can be returned to one of two brine tanks or recirculated through the system. Thus coil surface temperature can be regulated to give accurate control of temperature and a range of humidities. It has been established that humidity is an important factor in ripening fruit and it could also be of significance in the cool storage behaviour of fruits and vegetables.

The two low-temperature rooms for storing frozen foods are refrigerated by shelf coils. Each room has 12 circuits fed through a distribution attached to a low-temperature thermostatic expansion valve. The design of these circuits was one of the difficult features of the installation, as the supply of refrigerant and the load had to be equal for each circuit. These rooms can reach a temperature of —50°F.

Each of the two brine tanks is refrigerated by a separate unit. The evaporators are multiple-circuit bare-pipe coils formed into brine races. Propeller-type agitators circulate the brine throughout these races at 100 ft/min.

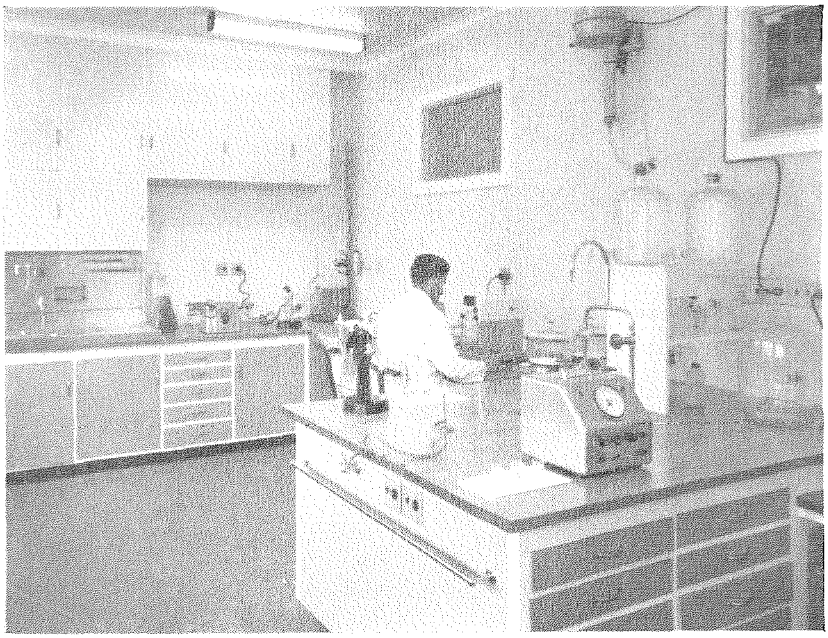
At the end of the ante-room is the blast freezer. This blast freezer, which circulates air at variable speeds up to 900 ft/min, is designed to reach a temperature of —70°F. It is insulated with 6 in. of expanded rubber with an air-sealed metal outer skin, and refrigerated by a 2-stage 6-cylinder Worthington compressor.

The other compressors are Worthington 2-cylinder single-stage machines. "Refrigerant 22" is used throughout. Capacities are as follows:

Brine Sets ..	.. 2 Units each of 48,000 B.t.u.
Low-Temp. Sets	.. 2 Units each of 12,000 B.t.u.
Blast Unit ..	.. .. 1 Unit of 16,500 B.t.u.

The refrigeration system is completely automatic.

In addition to the cold storage block and various laboratories there is a modern processing unit for experimental work on freezing, canning, and dehydration. A pilot plant for conducting this work is installed in the processing room, and the equipment includes fruit and vegetable washers, juice extractors, a hammer mill, dicer, peelers, blanching



The canning laboratory at Hamilton.

tanks and chambers, and steam-jacketed pans. A small canning line, complete with vacuum syruper, vacuum closer, cooker, and retorts, is installed to enable many types of products to be canned. The canning laboratory is shown on page 19.

A turbulent-film evaporator, complete with a volatile flavour recovery system, is being installed for the production of frozen or pasteurized concentrated fruit juice. This unit will be capable of handling 5 gallons of fresh juice per hour, this quantity yielding about 1 gallon of fully flavoured concentrate. The unit will operate on a very high vacuum, enabling the juice to be evaporated at about 75–80°F. To condense the vapours and recover the volatile flavours a 5-ton refrigeration system will be used to cool the surface condensers.

Two low-temperature storage cabinets with a total capacity of about 10 cu.ft. are also installed in the processing room for specialized storage experiments. These cabinets can be maintained at temperatures as low as −60°F, and are cooled by a single-stage compressor using "Freon" refrigerant. Accurate temperature control is maintained by the use of thermostats controlling solenoid valves on liquid and vapour lines, as well as energizing contactors which control the motor. The chambers are lined with stainless steel and surrounded by eutectic tanks.

A small polyphase freezer is being constructed for freezing tropical fruits and strawberries. Its extremely rapid freezing rate helps to maintain firmer textures for the soft-fleshed fruits. It is proposed to add a small plate freezer to the processing equipment in due course.

The laboratory is divided into four main sections—Storage and Transport, Chemical, Microbiological, and Processing. The Storage and Transport Section will be concerned with developing improved methods of storing, transporting, and ripening Queensland horticultural crops, in order to eliminate much of the wastage which takes place between the producer and the consumer. It is also hoped to determine whether it is possible to export to distant markets a greater variety of Queensland-grown fruits and vegetables. The Chemical Section will be concerned with changes in stored and processed foods, particularly fruit quality, which is so important in the marketing of a foodstuff. The Microbiological Section will be concerned with the identification and control of spoilage organisms in fresh and processed foods, and with developing methods for the utilization of fruit residues. The Processing Section will concentrate on improving methods of canning, freezing, and dehydrating fruits and vegetables, developing a wider range of tropical fruit products, and on producing on a semi-commercial scale a number of pure fruit juice concentrates.

In the new Laboratory many of the results obtained by research over the last 15 years can now be investigated on a semi-commercial basis under accurately controlled conditions. This is essential, because commercial application of a laboratory process before it is exhaustively tested could lead to disastrous results. The Hamilton refrigeration equipment has been designed so that fruit temperatures in every position in the room do not fluctuate more than one-tenth of a degree Fahrenheit.

In addition to having modern experimental facilities, the Laboratory is well equipped with recording instruments and chemical apparatus for determining changes during the storage, transport, and processing of foodstuffs.

The completion of this most modern and well-equipped laboratory reflects great credit on the Queensland Departments of Agriculture and Stock and Public Works and the various industries which have made substantial contributions towards the purchase of laboratory equipment. The precise degree of control of temperature and humidity which can be achieved in the cold storage rooms shows what is possible today with modern automatic refrigeration equipment. The facilities and equipment now available will enable much fundamental work to be done on the perishable crops being grown in Queensland.

In a tropical State like Queensland wastage through spoilage can occur rapidly, and the results which are likely to be obtained at the new Laboratory should therefore be of great benefit to both the producer and the consumer.