POSTHARVEST TREATMENTS TO EXTEND THE STORAGE LIFE OF FEIJOA (*Acca sellowiana*)

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ABSTRACT

Feijoas (*Acca sellowiana*) have a short harvest season and a limited postharvest life. In feijoa, usually there is a large variation between individual fruit in terms of size, colour, chemical composition and physiological stage. This variation could be attributed to the time of fruit set which is relatively long, which leads to great variation in fruit maturity. In order for the New Zealand feijoa industry to export to distant markets a postharvest life of at least 6 weeks is required. Determining the maturity index of a crop is vital especially for trade regulations and marketing strategy. Feijoa do not change colour significantly during ripening, so the only unequivocal way of assessing fruit maturity is to cut the fruit open. An internal maturity rating scale has been developed by Plant and Food Research primarily based on locular development. The use of 'touch picking' depending on fruit retention force is considered the most practical and reliable method for the time being for determining minimum harvest maturity of feijoa. The aims of this work were to investigate options for a non-destructive method in determining maturity index of feijoa fruit compared to the internal maturity rating scale; extending storage life of feijoa fruit by cool storage and controlled atmosphere conditions to allow long distance sea freight to increase export opportunities; and to develop an understanding of feijoa ripening physiology in relation to ethylene and propylene treatments.

In this study, differences between the commercial pack houses in identifying the optimum fruit maturity of feijoa at harvest were large. Compression firmness was more reliable than acoustic firmness in determining maturity stages of different feijoa cultivars, but acoustic firmness was quite reliable for some cultivars. The Sinclair unit device was not suitable for measuring maturity index of feijoa fruit tested. Spin-spin relaxation time (T_2) and half height peak (ΔH_2) determined by NMR showed promise for identifying fruit maturity. In general, these non-destructive techniques used in this experiment showed some promise but further work is required to understand why the differences between cultivars and regions happen. Chemical changes such as total soluble solids, dry matter and titratable acidity were found unhelpful in determining maturity stages of feijoa fruits. There was no significant reduction in TSS or dry matter with maturity, but there was a clear reduction in titratable acidity. Even with this clear trend with titratable acidity, it is not helpful as it is still a destructive

measurement, nevertheless the internal chemical changes may be able to be estimated with a non-destructive technique such as Near Infrared Spectroscopy (NIRS). A combination of non-destructive methods such as firmness with NIR may be better than depending on a single index in identifying fruit maturity. In addition, the data clearly demonstrated that fruit at any particular internal maturity rating were clearly shown to have a wide range of firmness values, total soluble solids (TSS), titratable acidity (TA), skin colour, and aroma. This makes it likely that this maturity as measured by locular development is a poor descriptor for overall process of fruit ripening in feijoa.

As feijoa fruit mature, aroma volatile concentrations increase. The three characteristic compounds (ethyl butyrate, ethyl benzoate and methyl benzoate) of feijoa aroma were found more consistently in headspace analysis than solvent extracted flesh. Controlled atmosphere (CA) storage was found to suppress volatile production. Aroma could be used as a fruit quality measure. The e-nose has been shown to be sensitive to volatiles in other fruit, so it might have potential for measuring the changes in maturity of feijoa fruit. This technique is practical, non-destructive and cost effective. This technique should be tried in the future with feijoa cultivars.

To extend the postharvest life of feijoa fruit, cool storage in unlined trays at 4°C was tested. During cool storage, weight loss increased to about 6% after six weeks at 4°C and additional 5% during 7 days of storage at ambient temperature (20°C). Firmness (acoustic and compression) and other aspects of fruit quality decreased with time. Rate of ripening as measured by the change of internal maturity rating at 20°C increased with time. No significant changes were found in terms of total soluble solids during subsequent shelf life at 20°C for the entire period of storage. ‘Unique’, an early cultivar, generally had a shorter storage life than ‘Opal Star’.

The effects of five controlled atmospheres were also studied. Fruit were stored in a matrix of two levels of oxygen (2% and 5%) and two levels of carbon dioxide (0% and 3%), or air control, at 4°C for 10 weeks. Fruit were transferred to ambient temperature (20°C) after storage for 4, 6, 8 and 10 weeks for shelf life assessment for 7 days. For the entire period of storage, fruit weight loss was approximately 1.5-2% of the initial weight. The firmness of the fruit stored under CA conditions decreased

regardless of atmospheric conditions. In 'Opal Star', fruit underwent a significant colour change from dark to light green after the 10 weeks of storage. However, for 'Unique' there was no significant change in colour observed in the period tested. In both cultivars, there was a slight decrease in TSS over time. 'Opal Star' showed a good storage life with better fruit acceptability as compared to 'Unique'. In both cultivars, all the treatments caused some signs of injury after week 6. Generally, CA conditions were effective in reducing weight loss and external injury, and maintaining fruit firmness compared with air. 'Opal Star' had a good storage life with over 60% of fruit rated acceptable after 73 days of storage in CA treatments without CO_2. Hence 'Opal Star' may be suitable for export by sea.

The effect of three concentrations of ethylene (10, 100 and 1000 ppm) and one concentration of propylene (1300 ppm) applied for 24 hours on three different stages of maturity of 'Opal Star' and 'Unique' of feijoa suggests that 'Unique' and 'Opal Star' do not present typical climacteric activity. Feijoa fruit harvested at different stages of maturity were able to continue the ripening process without any acceleration by ethylene or propylene treatments. Different concentrations of exogenous ethylene or propylene had no effect on fruit firmness and colour changes. This could mean both cultivars are non-climacteric fruit according to the McMurchie et al., (1972) classification. However, this may also indicate that the fruit are already saturated with ethylene at early harvest stage. In 'Unique' highest ethylene production rates occur with early season fruit as they soften. Fruit at late harvest seems to be past the climacteric peak. In 'Opal Star' highest ethylene production occurred in late season, which may imply that climacteric peak happens at the ripe stage. There was no clear relationship between ethylene production and colour. This study supports the idea that the climacteric and non-climacteric classification is relatively general and unable to take into account the peculiarities of each species.

In conclusion, this thesis offers important insights into the regulation of postharvest loss of quality in feijoa. These insights should allow the future development of non-destructive at harvest maturity tests for feijoa. In addition, CA storage conditions are defined that could be used to support sea freight of feijoa to distant markets, although it remains to be seen whether aroma fully recovers after CA.

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CHAPTER 1
INTRODUCTION

Recently markets for tropical and subtropical fruits have been developed in many parts of the world. Growers and consumers in both producing and non-producing countries are increasingly interested in the benefit of tropical and subtropical fruits to the human diet. Export of high value fruit crops is one of the ways of earning valuable foreign exchange and diversifying the economy. However, the fruit must pass through many processes and maintain quality if it is to compete in the market. Tropical and subtropical fruit are generally more perishable than temperate fruit, thus facing greater problems in storage and transportation, the consequence of which often leads to arrival of the fruit in the importing country in an unsatisfactory condition.

In New Zealand, horticulture plays a very important role in the national economy. Horticultural exports in 2009 represented around 7.8% of New Zealand merchandise exports (HortResearch, 2009). Some temperate fruit crops such as kiwifruit and apple contribute significantly to world trade, whereas for others more effort is needed to develop international markets and meet customer demands (Hewett, 1993). Feijoa is a minor crop in New Zealand and valued at only $ 0.2 million (fob Export) and $ 1.7 million (domestic), produced from a total planted area of 251 ha (HortResearch, 2009). Feijoas are one of the fruit that has potential for export expansion. Feijoa trees can be grown almost everywhere in New Zealand, but late maturing cultivars may be affected by severe winter frosts in cooler regions.

Although feijoa fruit have a unique flavour and aroma that is alluring to the consumer, unfortunately they are relatively unknown in the world market. Feijoas have quite a short season with limited storage life. In order to maintain the quality of feijoas after harvest and extend their shelf life, the post-harvest handling system must guarantee that the fruit reaches markets in good condition. Without a clear understanding of the botanical characteristics of the fruit, not much improvement is possible. Since there are few studies on the extension of storage life of feijoas, the general objective of this

study is to build on existing knowledge about tree management and the stored fruit database to develop new techniques to expand the storage life of feijoa fruit, particularly by way of understanding the optimum stage of fruit harvest.

The feijoa (*Acca sellowiana* Berg.*)* or pineapple guava, also known as guavasteen, belongs to the family Myrtaceae; recently the genus name was renamed *Acca* instead of *Feijoa*, but the old name is still used in many references (Sharpe et al., 1993, Landrum, 1986). It is a small evergreen tree or shrub, 1-6 m high. It originates from the southern part of South America: southern Brazil, northern Argentina, western Paraguay and Uruguay. It was first collected from the region *Pelotas* in southern Brazil on the border of Uruguay by the German scientist, Fredrich Sellow, in 1815 (Sharpe et al., 1993). Feijoas were introduced to Europe in 1890 by the French botanist and horticulturist, Dr. Edouard Andre. It was introduced in New Zealand for the first time in 1908 through seeds, and became popular in the 1920s by importing improved cultivars from California (Thorp and Bieleski, 2002, Sharpe et al., 1993). In New Zealand feijoas received considerable attention as a fresh fruit and potential export crop compared with other commercial production regions (Sharpe et al., 1993). In 1983 the New Zealand Feijoa Growers Association was formed. The feijoa is a cool subtropical and tropical highland plant with considerable cold, drought and salt tolerance. It produces its best fruit with 1,500 mm rainfall per annum. Feijoas are not widely distributed but can be found planted commercially in Uruguay, New Zealand, United States of America (California), the Caucasian region of southern Russia (Georgia and Azerbaidzhan), Sicily and Portugal (Nagy, 1998).

1.1. BOTANICAL DESCRIPTION

In general, feijoas are attractive evergreen trees or shrubs with pale grey bark; the young bark is smooth and light reddish-brown, turning to pale grey and flaky with age. Leaves are smooth and glossy on the upper surface, finely veined and silver grey on the hairy underside. Flowers are reasonably large (approximately 2-3 cm diameter) and very attractive, emerging in November or December in New Zealand with a large tuft of red stamens. The flower petals are sweet and edible. Feijoa flowers have many stamens and a single style surrounded by four to six fleshy petals. Flowers are hermaphroditic, i.e. male and female parts are produced in the same

flower. Fruit is egg or pear shaped, green in colour, 4-6 cm long and 2.8-5 cm wide, 25-60 g with persistent calyx segments adhering to the apex (Thorp and Bieleski, 2002, Landrum, 1986). The skin is dull blue-green to blue or grayish green and is coated with fine whitish hairs until maturity. Skin texture may vary from smooth to coarse, depending upon the variety. The fruit is sweet with a strong aromatic flavour. Flesh is juicy and divided into a clear jelly-like seed pulp and a firmer, slightly gritty, opaque flesh nearer the skin. The normal way to eat the fruit is to cut it in half then scoop the contents out with a spoon. There are plentiful seeds, very small, more or less round and hardly noticeable when the fruit is ripe. The morphological structure of feijoa fruit consists mainly of two major regions, the pericarp which is known as flesh and the endocarp which is the edible portion of fruit known as pulp (Figure 1.1). The pulp portion consists mainly of locules that are filled with juice and seeds.

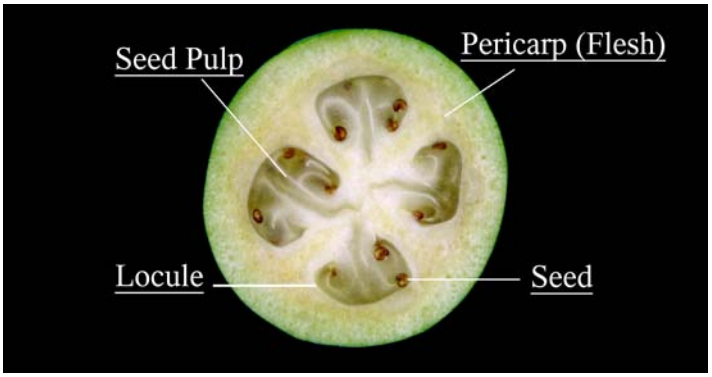


Figure 1.1 Feijoa cross section showing fruit anatomy.

1.2. SOIL AND CLIMATIC REQUIREMENT

1.2.1. Soil

Feijoas can be grown in a wide range of soil types, but for optimum production they should be planted in soil with good drainage and a pH in the range of 6.0-6.5. Feijoas grown in alkaline soil may show leaf yellowing and poor shoot growth (Thorp and Bieleski, 2002). Feijoas prefer rich organic soil with a fine particle size, but feijoas grown in sandy soil produce adequate shoot growth. Feijoas can tolerate drought and fairly high salt content, however adequate water should be provided to achieve good quality and high production. Low water application, especially during flowering and fruit formation, may cause fruit drop (Anonymous, 1996). Feijoa trees have a

superficial root system that can be protected by mulch and the avoidance of cultivation around the roots.

1.2.2. Temperature

Since no studies have been carried out to determine climatic requirements it is quite difficult to specify the optimum temperature for feijoa growth. However, looking back to the region where feijoas were first found we can perhaps identify the temperature needed. Feijoas are found in a region where the daily mean air temperature during summer can exceed 40°C and drop to -8.5°C in winter (Matto,1986, as cited in Thorp & Bieleski, 2002). Typical mean temperatures range between 16.5°C to 18.1°C with an average rainfall between 1,350 to 1,700 mm per annum. Feijoas are considered cold hardy but cannot withstand temperatures below -12°C as these might kill the flower buds (Thorp and Bieleski, 2002). Thus feijoas prefer cool winters and moderate summer temperatures with low humidity. In New Zealand, most commercial feijoas are grown in the North Island where conditions are moist with warm to subtropical climate. The feijoa needs winter chilling of 100-200 hours below 7°C to attain good flowering (Sharpe et al., 1993). Feijoas grown in warm places tend to produce a heavy wax bloom and fruit mature up to 8 weeks earlier than in colder places; in humid and high altitude areas, feijoas may fruit twice a year (Thorp and Bieleski, 2002).

1.3. CULTURAL PRACTICES

1.3.1. Pollination

Pollination plays a key role in most fruit production; without pollination no fruit will be produced. Most feijoa cultivars are self-sterile or partially self-sterile, i.e. they show self incompatibility and need to be pollinated with other cultivars. Even with self-fertile cultivars, higher fruit production will be produced when pollinated with other cultivars (Anonymous, 2006). To ensure good cross-pollination between cultivars, two or more different cultivars should be planted close to each other. Feijoa flowers are characterised by fairly large fleshy and edible petals with brightly coloured stamens that attract birds to feed and thus assist in transferring pollen from one plant to another. Bees can also be pollinators, but are not as good as birds

because feijoa flowers do not produce nectar to draw bees to visit. Natural pollinators such as birds and bees are not ideal for the production of superior fruit with high yield and cannot be depended upon to assure good fruit set. Different sources of pollen for cross-pollination each have a different effectiveness in terms of number of seed per fruit and fruit weight. Hand pollinated flowers tend to be 100% effective and produce superior quality fruit while open-pollinated flowers with mixed sources give ≈ 74% fruit set with inferior quality (Table 1.1).

Table 1.1. Effect of hand pollination and pollen source on fruit set and growth of 'Apollo' feijoas.

Fruit attribute	Pollinated methods			
	Open pollinated	Hand pollinated		
	Mixed pollen sources	'Gemini' pollen	'Triumph' pollen	'DSIR Mammoth' pollen
% fruit set	74	100	96	96
No. of seed/fruit	61	163	118	160
Fruit weight (g)	98	147	127	153

Source: Thorp & Bieleski, 2002

Generally, feijoas produce a high number of flowers with low fruit set; as low as 30% with open pollination (Thorp and Bieleski, 2002). Final fruit size is determined by the number of mature seeds in the fruit, which is in turn related to successful pollination (Patterson, 1989). In New Zealand, two important bird species visiting feijoa flowers for pollination are blackbirds (*Turdus merula)* and mynas (*Acridotheres tristis).* Usually birds visit feijoa flowers before and during bloom when petals increase their sugar content and became sweet and fleshy. Around the time of the bird visits, the stigma becomes receptive to pollen germination. In general, poor pollination might produce hollow fruit with no edible pulp and dry, small or misshapen fruit, thus reducing their chance to be marketable (Thorp and Bieleski, 2002, Thorp, 1984).

1.3.2. Propagation

Feijoas can be propagated by different methods, such as seeding, layering, cutting and grafting. The easiest way to propagate feijoa is by seed, but the fruit quality produced is not true to type. Consequently, this method can only be used for the production of a rootstock and selection programme. One major problem for the slow development of feijoas in New Zealand and overseas is the distribution of low quality fruit derived from seedlings (Thorp, 1984). To achieve uniform high quality fruit it is important to use different methods of propagation. Uniformity and superiority of fruit are essential for marketing. In-vitro propagation can also be used, but is quite difficult compared to other techniques (Thorp and Bieleski, 2002).

Layering is another method of propagation that is used to produce small numbers of plants. In New Zealand and France ground layering is practised, taking six months for roots to develop. Air-layering is another successful method whereby fruit will be produced after one year (Morton, 1987). Cutting propagation is considered more desirable: equal length 10-15 cm shoots, including three nodes, should be taken; the base of the cut is treated with rooting hormones and planted as soon as possible into the propagation bed. Beds should contain 75% pumice sand and 25% peat at 25ºC and be planted under saturated conditions (Thorp and Bieleski, 2002). Cuttings produce roots in 8-10 weeks. Rooted cuttings are then transferred into polyethylene bags until they reach a suitable height for transfer to the field.

High-yielding feijoas can be grafted onto seedling rootstocks, but feijoas are usually slow to produce callus, thus it is vital to have good contact between the cambium of the scion and rootstock to assure grafting success. Whip, tongue and veneer grafting can lead to success with skill and care, and grafted plants will bear fruit in two years. Grafted plants should be placed under a mist system or the grafted scion wrapped with plastic bags to increase humidity until signs of new growth are achieved (Thorp and Bieleski, 2002).

1.3.3. Fertilization

Feijoa grows relatively slow and needs a light application of a complete fertilizer. Application of 8-8-8 NPK every two months can advance fruit growth (Anonymous, 1996). Fertilizer application may differ depending upon the soil type and condition. Very few studies have been done to determine the exact nutrient requirement of feijoa. In general, fertilizer application should be increased as the trees gets older, high application of nitrogen should be avoided to reduce vegetative growth, and a light application of NPK should be applied around the tree (Nagy, 1998). According to Thorp and Bieleski (2002), feijoa trees have a low requirement for nitrogen in relation to potassium and phosphorus; high application of nitrogen, especially during the period of fruit growth, increases fruit size but might reduce storage life of the fruit.

1.3.4. Irrigation

Not much data is available on water requirements of feijoas. In New Zealand, feijoa trees largely get their water requirement from natural rainfall. However, in dry areas and in regions with low rainfall, irrigation should be employed to ensure good production. Feijoas can survive for many years in dry soils and have the ability to live in wet soils. For better quality and high production, irrigation should be practised in dry areas, especially during the period of flowering and fruit set. Since feijoas have a shallow root system, to a 50 cm depth of soil, they can be easily irrigated by drip or micro-sprinkler irrigation system (Thorp and Bieleski, 2002).

1.4. FRUIT GROWTH

After the flower is successfully fertilised the feijoa fruit will start to grow and ripen within 4-6 months after flowering. In New Zealand, visible signs of fruit growth occur in January and fruit ripen from early February to May, when all fruit tend to fall from the tree. Size development of fruit for the 'Apollo' cultivar exhibits two different stages: a slow initial growth, then a rapid increase after about 100 days from pollination, reaching its maximum rate over the last 40 days when fruit size increases quickly (Thorp and Bieleski, 2002). Generally, it takes about 120-140 days from fruit set to fruit fall. According to the work of Harman (1987) on the 'Mammoth' cultivar, size development of feijoa fruits from time of fruit set to maturity shows three stages;

a linear increase in size between 20 and 70 days after flowering followed by slower increase until 95 days and then a rapid increase toward maturity and fall from the tree. Fruit set in December reached full size earlier and had a higher sugar content than fruit set in January or February (Harman, 1987).

In early-set fruit, fruit size increases from about 70 days after pollination, whereas in late-set fruit the increase in size will start a few days after pollination. Well pollinated late-set fruit tend to catch up with the early-set fruit, so that all fruit begin rapid growth at about the same time and reach maturity together, regardless of the time of pollination. For example, late-set fruit 'Triumph' cultivar takes about 50 days from pollination until rapid growth, whereas 'Apollo' cultivars (early-set) takes only 35 days (Thorp and Bieleski, 2002).

Some cultivars have the potential to produce larger fruit than others, thus it is commercially important to grow new and improved cultivars with proven fruiting performance. Better orchard management can also improve fruit quality; fruit thinning by removing one-third of fruit including small and misshapen fruit can increase fruit size. Thinning can be done in January where the first sign of fruit increase in size can be observed.

1.5. FRUIT COMPOSITION

As feijoa fruit grow, the chemical composition and sugar content change. According to Harman (1987), the main sugars present in feijoa fruit are fructose, glucose and sucrose. Sugar content remained low until 90-100 days after flowering, and then started to increase rapidly. At fruit maturity or natural fruit drop, total sugar content was estimated at 16-24% of fruit dry weight or about 4% fresh weight. Sucrose content, in comparison with that of fructose and glucose, remained low during mid-development of fruit (90-100 days after flowering), but thereafter its concentration in the fruit increased rapidly. Thus, 120-140 days after pollination, the total sugar content of harvested mature fruit is mainly sucrose (38%). Starch content of feijoa fruit, unlike fruits such as apple and banana, remained below 1.5% dry weight throughout development (Harman, 1987). Accumulation of sugars follows

translocation via the phloem from leaves, or via the xylem from stored carbohydrates in the wood.

As fruit reaches maturity, there was a slight decline in acid content; the sugar to acid ratio remained low during early fruit development, but then increased rapidly from 80 days after pollination until maturity. Malic and citric acid are present at similar concentration and are the major non-volatile organic acids in feijoa fruit. Quinic acid is found in low concentrations throughout maturation. Mineral content of feijoa fruit continues to increase with fruit growth until the fruit falls from the tree (Harman, 1987). According to Shaw et al. (1983), the major mineral of feijoa fruit is potassium followed by P > Ca > Mg > Na > Fe > Cu > Zn > Mn, in descending order. Feijoa fruit can also be considered as a rich source of dietary fibre (3.8-4.3% of fruit fresh weight) (Romero-Rodriguez et al., 1994).

1.6. FRUIT MATURITY

High quality fruit at harvest is the most important determinant for export. It is very important to identify optimum maturity of the fruit at harvest. Harvesting fruit at the proper maturity ensures a long storage life and best eating quality. Fruit harvested too immature or too early in the season may have poor flavour, uneven ripening and be subject to shrivelling, whereas fruit harvested over-mature or late in the season may not be able to withstand long storage periods and is likely to become soft and rot very quickly. Different fruit have different optimum harvesting time depending upon their physiology, environmental conditions, ripening behaviour and the purpose of the final use (Kader, 1992). In New Zealand, only around 30-50% of feijoa fruit produced meets the export grade standards (Thorp and Bieleski, 2002), because of the mixture of seedling types in NZ plantations, leading to high individual variation between the fruit.

1.7. MATURATION AND RIPENING

There is a difference between the terms ‘maturation’ and ‘ripening’ in horticultural science, even though they overlap. Maturation can be defined as the stage of fruit development between growth and senescence where fruit still retain edible quality, while ripening is part of maturation, in which fruit reach maximum edible quality

(Reid, 2002). In postharvest physiology, mature fruit can be defined as the stage of development at which harvested fruit will attain minimum acceptable quality. The process of maturation and ripening involves softening, colour change and increases in sugar content (Toivonen, 2007). Harvesting the fruit at proper maturity plays a vital role in determining the storage life and final fruit quality (Kader, 1999).

The 'storage life' and 'shelf life' of a product are frequently-used terms in horticulture but need to be defined with care. In this thesis I have used 'storage life' to mean: "the maximum duration of storage (at low temperature, with or without additional treatments), at the end of which 90% of the fruit are (a) in marketable condition, and (b) retain a minimum of five days' shelf life". The corresponding term, 'shelf life', is defined as: "the maximum period of time after storage, during which the product is exposed to a specific temperature (normally 20°C or ambient, and, at the end of which, 80% of the fruit are still in acceptable condition for consumption". A storage life of 6 weeks is required to permit successful sea freight to global markets from New Zealand; a storage life of four weeks may be sufficient to allow sea freight to Australia our closest South-East Asian markets. Five days of shelf life are required to allow time for the product to move through the retail process and into people's homes. The term 'postharvest life' could be used to include the sum of storage and shelf life.

Almost all fruits except pears, avocado and bananas reach best eating quality when left to ripen on the plant. Fruit can be classified according to their ripening behaviour into two groups: 1) Fruit with the ability to continue ripening off the plant when harvested mature such as apple, avocado, banana, guava, kiwifruit, mango, papaya, peach, persimmon, sapote. 2) Fruit that do not ripen if they are removed from the plant at an immature stage e.g. citrus, grape, cherry, pineapple, pomegranate, lychee, berries and tamarillo. These kind of fruit need to be harvested fully-ripe to ensure optimum quality.

These two groups can also be classified based on respiratory and ethylene production into: 1) climacteric fruit where respiration rate and ethylene production increases before senescence. This group produces elevated amounts of ethylene and will respond to ethylene treatments leading to faster and more uniform ripening. In a ripening climacteric fruit, the rise in respiration coincides with the rise in ethylene

production which leads to colour changes, softening, tissue permeability increase, and aroma development. The climacteric pattern can be divided into four phases; pre-climacteric minimum, climacteric rise, climacteric peak and post-climacteric phase. 2) Non-climacteric fruit where a little amount of ethylene might be produced; ethylene doesn't play a role in ripening process. Non-climacteric fruit may also respond to ethylene with affects such as degreening in citrus fruit and pineapple. However, the distinction between climacteric and non-climacteric is not absolute, as some species such as melon and capsicum can have both climacteric and non-climacteric behaviour (Barry and Giovannoni, 2007). Both groups climacteric and non-climacteric are sensitive to ethylene (Toivonen, 2007). The response of fruit to ethylene treatment might differ depending on maturity stages of the fruit. For example, ethylene treatment of non-climacteric and immature stage of climacteric fruit may inhibit ethylene production by tissues. However, ethylene treatment of mature climacteric fruit may hasten the ripening process (Saltveit, 1999). Classification of fruits according to ethylene production is summarised in Table 1.2.

Table 1.2 Classification of fruits based on ethylene production.

Ethylene production rate	Fruits
Very low (0.01-0.1 µl/kg/h)	Cherry, citrus fruit, grape, strawberry, pomegranate
Low (0.1 – 1.0l µ/kg/h)	Blue berry, pineapple, raspberry
Moderate (1.0 – 10.0 µl/kg/h)	Banana, fig, guava, mango, plantain
High (10.0 – 100.0 µl/kg/h)	Apricot, apple, avocado (ripe), peach, pear, plum
Very High (>100 µl/kg/h)	Passion fruit

Ethylene production can also be classified into two systems (McMurchie et al., 1972). System 1 occurs during normal growth and development, characterised by low ethylene production; this system is auto-inhibitory i.e. when exogenous ethylene is applied it inhibits ethylene production. System 2 in the other hand, occurs during the climacteric or during fruit ripening and floral senescence; it is characterised by a high rate of ethylene production, and is autocatalytic i.e. stimulated by endogenous ethylene (Barry and Giovannoni, 2007).

1.8. RESPIRATION AND ETHYLENE PRODUCTION

The relationship between ethylene production and respiration was studied by Biale et al., (1954). The study covered fourteen species of fruit: tropical, subtropical and temperate. Feijoa was included in this study. Feijoa was classified as a climacteric fruit able to produce significant amounts of ethylene; the increase in ethylene production followed the rise of respiration.

Reid (1975) studied the relationship between respiration and ethylene production of mature feijoa fruit. He found that respiration rate decreases slowly to a minimum and then increases as fruit begin to ripen; this increase coincided with a rapid increase in ethylene production. In another work done by Harman (1987) respiration rate tended to decrease in feijoa fruit harvested early in the season and increase with fruit harvested late in the season. Fruit harvested after 100 days after flowering showed rapid increase in respiration, fruit size and sugar content.

Rate of ethylene production by feijoa fruit ranged between 0.1-0.4 $\mu l.kg^{-1}.hr^{-1}$ (climacteric minimum) to 40-50 $\mu l.kg^{-1}.hr^{-1}$ (climacteric maximum) at 20ºC (Kader, 2006). Ethylene production begins at a low rate after harvest and increases as the fruit ripen. Hence, feijoa should not be stored with other ethylene sensitive fresh produce (Thorp and Bieleski, 2002).

1.9. FRUIT RIPENING

To provide good characteristics of flavour and texture, feijoa fruit should be harvested ripe. Unripe fruit tends to be flavourless with hard flesh while overripe fruit develop brown seed pulp and have poor flavour. According to Nagy (1998), the volatile esters, methyl benzoate, ethyl benzoate, and ethyl butanoate, are mainly responsible for feijoa's aroma. In particular, Shaw et al., (1983) and Yong and Paterson (1990) found that feijoa fruit contain a high proportion of methyl benzoate compared to other volatile esters. Reid (1975) stated that the respiration rate of harvested fruit increased rapidly at about 100 days after flowering due to a rapid increase in fruit size and sugar content. Respiration rate decreased slowly in mature fruit and then suddenly increased with the onset of active ripening and increased production of ethylene. With the sudden increase in respiration rate different volatile esters develop to give

the aroma to the fruits. Harman (1987) demonstrated that respiration rate decreases in fruit harvested early in the season but increased in fruit harvested late in the season.

Different cultivars have different rates of ripening in relation to fruit maturation and natural fruit drop. Maturity standards and harvesting time are very important for maintaining postharvest quality (Fittall, 1997). Some cultivars such as 'Unique' (very early) and 'Apollo' (mid-season) cultivars reach full ripeness at the time of natural fruit drop. For other cultivars, e.g. 'Triumph' (late) and 'Gemini' (early season), it is claimed that fruit ripen off the tree (Thorp and Bieleski, 2002). In an experiment conducted to study quality attributes of four New Zealand varieties (‘Unique’, ‘Triumph’, ‘Apollo’ and ‘Mammoth’) during the 2002 season, it was found that there were significant differences within the fruit and between fruit batches in terms of average water vapour permeability, titratable acidity and brix to acidity ratio (Wiryawan et al., 2005).

As noted, different cultivars have different harvesting periods. The cultivars can be divided according to harvesting season into four categories; very early, early, mid-season and late varieties. Table 1.3 describes the major feijoa cultivars grown in New Zealand and some of their characteristics.

Table 1.3 **Characteristics of major feijoa cultivars grown in New Zealand.**

Cultivar	Harvest season	Fruit size	Pollination requirements	Comments	Reference
Unique	Very early	Small to medium	Self-fertile, normal set	Young trees over-crop; drooping tree form; short storage life	1
Robert	Very early	Medium	Self-sterile	Several leaf russet; strong compact tree; hollow fruit set	1
Sweethart	Very early	Large	Self-sterile	New variety, good taste	2
Anatoki	Early	Good size	Self-sterile	New variety, smooth fruit, sweet and mild flavour	2
Kaiteri	Early	Large	Self-sterile	New variety, smooth fruit, vigorous tree	2
Gemini	Early	Small to medium	Self-sterile	Smooth dark-green attractive fruit; small size; good storage life	1
Pounamu	Early	Medium	Self-sterile	Attractive dark-green fruit; good storage life	1
Mammoth	Early mid-season	Large	Self-fertile	Thick skin, excellent flavour and texture, upright tree	3
Apollo	Mid-season	Very large	Part self-fertile	Light crop of large fruit with excellent flavour; good storage life; vigorous shoot growth	1
Kakapo	Mid-season	Medium	Self-sterile	Good flavour; strong compact tree	1
Marion	Mid-season	Medium to large	Self-sterile	Smooth dark-green attractive fruit; hollow fruit set	1
Den's Choice	Mid-season	Medium to large		Very sweet, smooth and juicy fruit, mild aromatic	4
Wiki^{TM}Tu (anilvinkkoru)	Mid-late season	Very large	Partially self-fertile	Firm texture with good storage	2,4
Opal Star	Late	Medium to large	Self-sterile	Smooth dark-green attractive fruit; good storage life; high yields on compact tree	1
Triumph	Late	Medium	Self-sterile	Double fruit with good storage and handling properties	1

Sources:

Reference: 1- Thorp and Bieleski (2002) 2- WaimeaNURSERIES 3- (Anonymous, 1996) 4- Feijoa Grower Association

The skin of feijoa does not change colour markedly during maturation and ripening like many other tree fruits. Thus, it is very difficult to distinguish between ripe and unripe fruit. There are usually two ways of harvesting fruit: just prior to the time of natural drop by “touch-picking”, which involves gently tilting the fruit and pulling them down or by collecting mature fruit from the ground. Fruit collected before natural drop tend to be healthier and last longer. Harvesting fruit by "touch-picking" is based upon fruit retention force (Downs et al., 1988). Some cultivars should be harvested at a higher retention force than others, e.g. 'Apollo' and 'Unique', because their optimum harvest maturity is reached before natural drop. In contrast, other cultivars such as 'Triumph' attain optimum quality at close to the natural drop time (Thorp and Bieleski, 2002). To ensure good quality feijoas it is recommended to harvest fruit by "touch-picking" even though it is labour intensive (Thorp and Klein, 1987). Alternatively, catching nets under the tree can be used to simplify the harvesting of feijoa fruit and to reduce bruising damage. Fruit should be collected every day to ensure they are in good condition and free from sun-scald. This technique is time and money saving. There are different types of nets that can be used; they don’t have to be first-grade material. In California, growers developed a transportable catching net that seems practical in smaller trees growing on even or flat land. In New Zealand the harvesting period of feijoa fruit may last for three to four months, from March to June. In general, feijoa fruit become mature and ready for harvest over a four to six week period, but market-size fruit is typically picked over two to three weeks (Thorp and Bieleski, 2002).

1.10. FRUIT STORAGE

To minimize postharvest quality loss it is very important to maintain the correct storage and transport conditions from the packing shed to the consumer. After fruit is harvested, it is impossible to improve the quality. Proper storage conditions are vital to extend shelf life storage and maintain superior quality. Feijoa fruit usually picked fully mature, but not fully ripe and before falling to the ground, in order to assure good appearance and flavour. The optimum storage temperature and relative humidity for feijoa is 5 ± 1°C (41 ± 2°F), RH 90% to 95% and the fruit has the potential to be stored for four to five weeks depending on the cultivar and ripeness stage (Kader, 2006).

Fruits are graded according to colour, shape, size, and freedom from defects such as physical damage, scars, browning, chilling injury and decay (Kader, 2006). Different feijoa cultivars have different concentrations of soluble solids (10%-16%), titratable acidity (0.3%-1.4%) and pH (3.2-4.4). Different cultivars show different responses to cold storage. Some cultivars can be stored well whereas others show browning after seven days of storage; the response may also vary within the cultivar, depending on time of harvest, agricultural practices and fruit location on the tree. Thorp and Klein (1987) were able to store some commercial New Zealand feijoa cultivars at 4ºC for up to 4 weeks with subsequent shelf life of 5 days at 20°C, including 'Apollo', 'Gemini', 'Marion', and 'Triumph', whereas they claimed 'Unique' developed discolouration of flesh around the locules after only one week of storage at 4ºC and one day at 20ºC. Different cultivars have different polyphenol oxidase activity (PPO) which is responsible for internal browning. Zhu Jun-sheng (1987) pointed out that fruit with low concentration of PPO activity such as 'Gemini' and 'Marian' show little internal browning, whereas 'Apollo' fruit, with higher concentrations, shows more browning. At recommended cold storage temperature and during subsequent days at room temperature, flavour is the first quality attribute to decline due to decrease in soluble solids, titratable acidity levels and possibly esters; thus poor flavour and internal browning limit the storage life of feijoa fruit (Thorp and Bieleski, 2002).

Feijoa fruit stored at 0ºC exhibit chilling injury, the severity of damage depending on type of cultivar and storage time. Chilling injury symptoms can be perceived first on the stem end of the fruit by a change of colour from green to brown to black with sunken tissue followed by internal browning of the vascular elements; the flesh turns to a pink-brown colour (Thorp and Klein, 1987).

The effects of different temperatures (0ºC and 4ºC) on fruit colour, firmness, soluble solids, titratable acidity and percentage decay for two different feijoa cultivars ('Mammoth' and 'Triumph') were tested by Berger et al., (1991). It was found that fruit stored at 0ºC, with subsequent shelf life assessment at 18ºC, exhibited higher decay percentage in both cultivars than fruit stored at 4ºC and decay was higher in 'Mammoth' fruit compared to 'Triumph'.

1.11. TEMPERATURE MANIPULATIONS

The effect of temperature manipulations (heat treatments (HTs) and 'step-down' temperature storage) on three different cultivars of feijoa 'Opal Star', 'Unique' and 'Apollo' was studied by Woolf et al., (2006). It was found that in heat treatments where three different temperatures were used (30, 34 and 38°C) for 30-60 minute none of the warm water treatments were able to slow ripening after 3 weeks of storage at 4°C and 5 weeks of storage at 0°C.

In 'step-down' temperature storage, where temperature was reduced gradually by approximately 1°C over the storage period, four feijoa cultivars were examined 'Apollo', 'Gemini', 'Opal Star' and 'Unique' with three different temperature regimes 4°C, 0°C and 'step-down' temperature from 4°C to 0°C. At 0°C fruit tended to be less ripe compared with fruit stored at the higher temperature or step-down temperature with signs of chilling injury. Cultivars showed different response to cold temperature; out of four different feijoa cultivars the most tolerant was 'Apollo' and the least being 'Opal Star'.

'Triumph' was very sensitive and suffered significant damage when treated with hot (35-55°C) water (Woolf et al., 2006).

1.12. CONTROLLED ATMOSPHERE STORAGE

Very little work has been done on the response of feijoa to controlled atmosphere (CA) storage conditions. Controlled atmospheres can play a role in extending storage life in many fruits. In preliminary work with 'Triumph' feijoas, different concentrations of oxygen (2.1% and 4.8%) with 0% carbon dioxide were tested and it was found that controlled atmosphere can delay ripening during storage and subsequent shelf life at a room temperature of 20ºC. The best result was achieved at 2.1% oxygen and 0% carbon dioxide. Moreover, carbon dioxide damaged fruit at the low oxygen concentration, the symptoms appearing as brown localized regions with dry outer flesh (Thorp and Bieleski, 2002). East et al., (2009) found that the best treatment to reduce weight loss and delay colour change for 'Unique' feijoa was storing at 5°C in low oxygen and low carbon dioxide when compared to regular air. In recent work by Al-Harthy et al., (2009) CA appeared to offer some benefit for

increasing shelf life of some feijoa cultivars (details of this work will be discussed in chapter 5).

1.13. CALCIUM CHLORIDE AND ACETALDEHYDE

The effect of different concentrations of calcium chloride ($CaCl_2$) on slowing ripening of feijoa fruit cultivar 'Quimba' was studied by Ramirez et al., (2005). The fruits were stored at 6, 12 and 18ºC and 5, 10 and 15% $CaCl_2$ concentration. The results revealed that application of calcium can extend the storage life and decrease water loss percentage and increase the fruit firmness. According to Pesis et al., (1989), Pesis et al., (1991) and Pesis (1994), feijoa fruit aroma can be enhanced by exposing the fruit before storage to acetaldehyde or anaerobic conditions of 98% N_2, 99% CO_2 or 49% CO_2 / 50% N_2 for 24 hrs for touch-picked fruits. The augmentation of flavour was owing to the increase in volatiles (acetaldehyde, ethanol, ethyl acetate and ethyl butyrate); there were no significant differences between treated and non-treated fruit in total soluble solid (TSS) or acidity.

1.14. NON-DESTRUCTIVE METHODS FOR DETERMINING QUALITY

Quality is not simply a combination of physical measurements. Both intrinsic and extrinsic factors play a role. Quality generally depends on the specific user in the chain, so top quality for a grower is different to that seen by a retailer and that is different to what the end consumers sees and tastes.

The following section contains some basic information used to measure different stages of maturity of some fresh commodities; some of these techniques will be tested for feijoa fruit. There are many ways to evaluate quality of horticultural produce and for subsequent sorting of agricultural products. Quality can be characterized by certain basic attributes such as size, shape, colour, flavour, texture, taste, and freedom from defects and foreign materials. There is a relationship between many of the quality factors and the physical properties of the products. Therefore, it is often possible to develop non-destructive methods for evaluating quality depending on physical properties. This section reviews some of the major opportunities for non-destructive evaluation of quality.

1.14.1. Physical Properties

1.14.1.1. Density

Density or specific gravity is one of the most important physical properties of horticultural products. In many fruits and vegetables there is a linear relationship between density and maturity and postharvest quality maintenance. This change in maturity or density is a result of changes in physical or chemical composition of the produce such as increased soluble solids, decreased moisture content, or damage effects. Thus, density can be used as a non-destructive index for assessing maturity and quality. According to Chen and Sun (1991) certain damage can reduce density of produce, such as frost damage in citrus, insect damage in fruits and grains, puffiness in tomatoes, and hollow heart in potatoes. Zaltzman et al., (1987) reviewed previous studies related to quality attributes of agricultural products based on density. The techniques employed can be classified into three categories: flotation, fluidized-bed technology, and machine vision.

1.14.1.1.1. Flotation

Flotation of fruit and vegetables in water was established as a possible option for segregating variability within harvested produce to improve storage life, or to facilitate removal of poorer quality fruit based on their density which is affected by such internal characteristics as dry matter, soluble solids or defects (Clark et al., 2007). Density or specific gravity segregation was successful for tomato, kiwifruit, mango, pineapple and potato (Pathaveerat et al., 2008, Clark et al., 2007, Hu et al., 2002, Jordan et al., 2000).

Flotation can be used to separate agricultural products into different density classes by removing those products that float in water or solutions of known density. The lower the density of the produce the faster it will float to the surface. Kattan et al., (1968) used the concept of multiple-class sorting to classify tomato into five different maturity indices. Bryant (1942) used this technique to sort sweet potato, and Kunkel et al., (1952) to sort potato. This method was also used to segregate defective products from good ones, e.g. Perry and Perkins (1968) developed a system to separate freeze-damaged citrus fruit that float in a water and oil emulsion. Even though this technique is simple, it has some disadvantages such as safety, environmental hazards, and possible detrimental effect on product quality. In

addition, contamination of the solution during the sorting process might affect the specific gravity (Abbott et al., 1997). This technique was tried to segregate mixed maturity of 'Apollo' feijoa cultivar and found to be not useful due to low density related to a high volume of intercellular air spaces (Clark et al., 2005). In this study, different cultivars of feijoa will be tested.

1.14.1.1.2. Fluidized-Bed Technology

Very limited research has been done to utilize this technology for segregating horticultural commodities of different quality. In this process, air is forced through a bed of granular particles to produce a suspended state in which low density products will 'float' and the higher density ones will 'sink' to the bottom of the bed. Zaltzman et al., (1983), (1985), and (1987) developed a method that utilizes a fluidized-bed technology to separate potato tubers from clods and stones and suggested that this technology had potential for sorting horticultural products.

1.14.1.1.3. Machine Vision

In this technique a combination of machine vision with an automatic weighing system is used. Fruit volume can be estimated based on the dimensions measured from the camera's images. However, errors can be incurred with irregular shapes and a large range of sizes of produce. This technique is considered a simple method compared to other techniques such as mechanical measurements. In some fruits and vegetables, quality parameter changes are too small to be detected by using this technique to sort the product. Thus, density assessment techniques cannot be depended upon for indicating the maturity or quality of horticultural produce.

1.14.2. Mechanical Properties

Many agricultural products exhibit viscoelastic characteristics under mechanical loading. The extent to which this occurs depends on the amount of loading applied and rate of loading. According to Kramer and Szczesniak (1973), DeMan et al., (1976) and Sherman (1979), mechanical properties can be used to evaluate texture attributes of horticultural products, in particular firmness. There is an inverse relationship between firmness and maturity, i.e. as many fruit or vegetables become more mature firmness decreases gradually. Overripe or damaged fruits also tend to be softer. Therefore, firmness can be used as a tool for sorting and grading horticultural

produce. Several non-destructive methods of mechanical measurement have been developed for measuring firmness of horticultural products.

1.14.2.1. Force-Deformation

Many deformation-type instruments have been developed to measure firmness of commodities. In this process, deformation of the product is measured using constant load for a specific period of time. Hamson (1952) developed a non-destructive firmness testing unit for measuring tomato firmness, but significant differences in reading were recorded within a fruit due to difference in fruit structure. Kattan (1957) designed a tomato firmness tester based on a multipoint compression principle to reduce the effect of fruit heterogeneity. Perry (1977) designed a non-destructive tester for peach in which constant low pressure air was applied to small areas on opposite sides of the fruit. Bellon et al., (1993) reported a different method for measuring peach firmness in which deformation was measured by pressing a ball against the fruit at a constant force. Recently, a non conventional force deformation technique was introduced by Prussia et al., (1994) in which a laser is used to measure the amount of deflection caused by a short puff of pressurized air. This is quite similar to the device used by ophthalmologists to detect glaucoma. Under constant air pressure, firmer products tend to show less deflection than softer ones. The Laser-Air Puff test has been tested by many scientists for different horticultural products and the results indicate that this technique has the potential for sorting horticultural products with high precision.

1.14.2.2. Impact Force

There are many forms of impact technique that can be used to evaluate fruit and vegetable firmness. The simple drop-test has been most widely used. An object falls as a free body onto a rigid surface and the impact response is recorded and analyzed. The impact response has a direct relationship with fruit firmness. During impact, the object undergoes different phases of deformation, including initial elastic deformation, plastic deformation and final elastic recovery. The degree of impact force response generally varies with variety, firmness and drop height. Many studies have been carried out on the impact response of horticultural products. Lichtensteiger et al., (1988) and Nahir et al., (1986) reported that impact force response is highly correlated with fruit firmness and fruit mass. Delwiche et al., (1987) studied the impact forces of peaches on a rigid surface and showed that there was a high

correlation between impact force and the fruits' elastic modulus and Effegi penetrometer measurements. One major potential problem that might happen during the drop test is bruising of the fruit. Another way of measuring fruit firmness is an impact-probe, where the rigid impact mass strikes the fruit instead of the fruit impacting a stationary surface. By this means, handling problems and the influence of fruit mass and contact radius are reduced.

1.14.2.3. Low-Frequency Vibrations

Vibrational characteristics of agricultural products are generally directed by their mechanical properties such as elastic modulus (firmness), mass and geometry (Chen and Sun, 1991). A number of vibrational devices have been used to sort horticultural products during harvesting and post-harvest handling. Hamann and Carroll (1971) demonstrated that muscadine grapes can be sorted on the basis of firmness using low-frequency vibrational energy. Firmer fruit bounced out at a lower frequency whereas ripe fruit bounced out at a higher frequency. Hamann et al., (1973) tried the same technique on blueberries and found that bruised berries bounced at lower frequencies than un-bruised ones. Therefore, small fruit such as berries and grapes can be sorted by low frequency vibrations according to their firmness and shelf life. Different maturity indices of tomatoes have been also studied by many scientists using vibrational sorting including Bayer (1976), and Holmes (1979).

1.14.2.4. Sonic or Acoustic Vibration

Sonic or acoustic vibrations offer a non-destructive, rapid and efficient means of measuring horticultural product firmness. This technique measures mechanical properties of the whole fruit rather than local tissues. The resonant frequency is associated with mechanical properties of the object and is strongly influenced by object shape, size and density. Sonic or acoustic vibration is a traditional method for a qualitative assessment that has been used for a long time. For example, an easy and manual way of measuring watermelon ripeness is by thumping the melon and listening to the pitch of the response. Research for measuring mechanical properties of horticultural produce using this technique began in 1942 by Clark and Mikelson. They reported the relationship between textural characteristics of fruit and their vibrational properties and the natural frequency of vibration changes with ripening. Nybom (1962) proposed a method to measure resonant frequency of small sized fruits. Abbott and co-workers found that fruit firmness is highly correlated with a

stiffness coefficient, f^2m, where f is the second resonant frequency and m is mass (Finney, 1971, Abbott et al., 1968). A number of studies were done by many researchers using sonic vibration to measure firmness of horticultural products. Several instruments and laboratory prototype machines have been developed such as Aweta. Recently many scientists tested Aweta and their relationship with other non-destructive machines (Gaddam et al., 2005, Johnson and Dover, 2004, Chen and De Baerdemaeker, 1993, Chen et al., 1992). In this study, this method will be also tested.

1.14.2.5. Ultrasonic Sensing

Ultrasonic non-destructive techniques have been used to evaluate internal properties of live animals, metals, medicine and the internal properties of horticultural products (Chen and Sun, 1991). This process is based on subjecting the product to a random-noise generator and measuring the response of the product to sound waves. Once the material is subjected to ultrasound waves different phenomena are produced, depending upon the properties of the material. The phenomena produced are transmission, reflection, refraction, diffraction, interference, scattering and dispersion. The two most important phenomena used for non-destructive evaluation of horticultural commodities are transmission and reflection. Application of this technique for evaluating horticultural product quality has been slow due to the structure and composition of fruit and vegetables. Unlike liquid or viscoelastic material, fruit and vegetables are non-homogeneous solid materials often with significant air spaces. This creates problems for ultrasonic wave transmission through the whole product. The attenuation coefficient of fruits and vegetables is extremely high because of the porous nature of plant tissues. Several studies have been conducted using this technology to evaluate horticultural internal defects such as "hollow heart" in potatoes (Mizrach, 2008, Cheng and Haugh, 1994, Ha et al., 1991). Sarkar and Wolfe (1983) studied the potential of ultrasonics for quality evaluation of fresh and processed foods. They also evaluated the attenuation coefficient measurements of potato, cantaloupe and apple tissues within the frequency range of 0.5-1.0 MHz. Mizrach et al., (1989) were successful in using low frequency ultrasound (50 kHz) in determining some acoustic properties of tissue specimens of a number of fruits and vegetables including avocado, potato, cucumber, carrot, pumpkin, melon and apple.

1.14.3. Electromagnetic Properties

1.14.3.1. Optical Properties

Visual quality of fruits and vegetables is often a quick and simple method of measuring maturity and quality. However, such evaluation is imperfect due to inability of the human eye to detect radiation outside the visible range, such as ultraviolet (UV) and infrared (IR) and the work is tedious, tiring, imprecise and impractical for large scale operations. Optical properties of horticultural commodities can also be affected by internal and external defects such as mechanical damage which may occur during harvest and postharvest processing. Optical properties are among the most successful non-destructive techniques for assessing quality of fruits and vegetables. They are based on reflectance, transmittance, absorbance, or scatter of radiation in the ultraviolet (UV), visible and near-infrared (NIR) regions of the electromagnetic spectrum. When a light beam strikes a product, about 4% of the incident light is reflected off the surface and the remaining 96% is transmitted through the surface into the cellular structure and scatters in all directions (Chen and Sun, 1991). A large portion of radiation entering the product will be scattered at the point of incidence or absorbed by fruit constituents. The absorbed energy varies according to fruit constituents and the wavelength and path length of light. The absorbed energy will be transformed into different forms of energy. The optical properties of agricultural commodities determine the amount of radiation which leaves the surface of the produce. Therefore, determining optical properties of the product can help in understanding the quality of agricultural product (Chen and Sun, 1991). Near-infrared (NIR) has been used to determine dry matter content of potatoes (Dull et al., 1989), sugar contents of apples (Yan-de and Yi-bin, 2004), water content of mushroom (Roy et al., 1993) and firmness of some fruits (Xia-ping Fu et al., 2008, Fu et al., 2007). This technique works well mostly with fruits with thin skin, but with thick skinned fruit such as melons and pineapples light transmission through the skin is very difficult (Bellon et al., 1992). Recently NIR systems have been implemented in on-line grading lines (Nicolai et al., 2007). Optical properties of different horticultural products have been studied by many researchers and relationships between optical characteristics and quality of the product have been established. This technique has also been used to evaluate fruit maturity, colour, defects and contamination, and mechanical injuries.

1.14.3.2. Fluorescence and Delayed Light Emission

Fluorescence and Delayed Light Emission (DLE) are valuable techniques that can be used to evaluate maturity and quality changes of fruit and vegetables. Almost all fruit, vegetables and plant materials undergo photosynthesis, the rate of which is related to the chlorophyll concentration of the product. As fruit ripen or if it is injured, the chlorophyll content decreases. There are many factors affecting the intensity of DLE such as excitation duration, intensity, time, dark period, sample thickness and area of excitation, temperature and chlorophyll content of the plant material. Since DLE usually depends on chlorophyll content, varieties of the same product may have different DLE. Also due to strong dependence of fluorescence on environmental and physiochemical factors, such as temperature, pH, viscosity and ionic strength, it is very important to acquire specific measurement protocols. Several studies have been conducted to evaluate DLE technique to measure maturity of horticultural products. Jacob et al., (1965) found significant differences between four commercial colour grades of lemon due to various levels of chlorophyll concentration in the lemon skin. Chuma and Nakaji (1977) were successful in sorting tomato into three stages of maturity according to chlorophyll content and DLE intensity. Chuma et al., (1980) also indicated the possibility of using DLE measurement to determine the state of maturity of bananas; they found that intensity of emitted light decreased with ripening. Other investigations have been carried out to evaluate DLE when injuries happen to fruits and vegetables. Abbott et al., (1991) summarized some of the difficulties associated with DLE for detecting chilling injuries of pickling cucumber. DLE has been used by many scientists to sort the fruit by colour of chilling injury (Forbus and Dull, 1990, Gunasekaran, 1990).

1.14.3.3. X-Ray and Gamma Rays

X-rays and gamma rays are short wave radiations that provide a cross-sectional view of an object's interior. Short wave radiation has the ability to penetrate material bodies; the shorter the wavelength the larger the penetration. Both X-rays and gamma rays can penetrate most horticultural and food products, and consequently can be used in non-destructive evaluation of quality factors (Chen and Sun, 1991). Absorbance of both forms of radiation is associated with tissue density and water content. Density of many fruits and vegetables such as head lettuce increases with maturity (Baoping, 1999, Chen and Sun, 1991). X-ray technique has been used widely and commercially

for detecting bone fragments and other foreign objects in processed food. X-ray techniques can be used to determine some internal disorders and fruit quality based on density, pH, moisture content, soluble solids and titratable acidity (Barcelon et al., 1999). Garrett and Talley (1970) developed a technique using gamma rays for evaluating lettuce head maturity. Lenker and Adrian (1971) used X-ray techniques for determining maturity of lettuce heads. According to Diener et al., (1970) X-rays can also be used to detect bruises in apples. Bowers et al., (1988) found that X-ray techniques can be used to detect split pit in peaches. Brecht et al., (1990) used X-ray computed tomography to evaluate changes in tomato locules during maturity. Recently, X-ray inspection systems have been used in packaging facilities to detect internal defects on line, for example, detecting potatoes with hollow heart and separating freeze-damaged citrus fruits in the packing house. This method has the potential to be tested for feijoa cultivars.

1.14.3.4. Nuclear Magnetic Resonance (NMR)

NMR is a technique that detects the variation in concentration of hydrogen nuclei (protons) and state of water, sugars and oil or fat in the material (Baoping, 1999). It is a very useful technique that has the potential to evaluate maturity and quality parameters of agricultural products. NMR can be used to measure water content, water distribution, and oil content of the products (Baoping, 1999). Brusewitz and Stone (1987) measured moisture content of wheat using this technique. NMR was used to asses mealiness in apple (Faust et al., 1997) and to evaluate sugar content in apples and bananas (Cho and Krutz, 1989) and oil content in avocados (McCarthy et al., 1989). NMR has been used widely to investigate physiochemical properties of water in plant tissues and in foods. This technology has been used since the early 1950s to examine agricultural products from a biological and physiological point of view. Currently this technique is not practical to be used for routine testing. It is very expensive and difficult to operate. However, many attempts have been made to make it more feasible in the near future.

1.14.3.5. Magnetic Resonance and Magnetic Resonance Imaging (MRI)

Magnetic Resonance Imaging (MRI) is a useful application of NMR. MRI is a non-destructive and non-invasive technique that can be used to study the chemical and physical properties, anatomical structure, and dynamic processes of food materials and products. This technique has been used commercially in the medical field to

visualize internal structure of the human body and to detect tumors and other abnormalities (Neeman et al., 2001). MR techniques are based on the principle that certain nuclei, such as ^{1}H, ^{13}C, ^{31}P, and ^{23}Na, have a magnetic moment and are able to absorb resonance energy in the presence of an externally strong magnetic field when irradiated with a proper radio frequency. For food quality analysis, ^{1}H-MRI is of most interest compared to ^{13}C-MR or ^{31}P-MR because hydrogen is the prevailing component of fruits and vegetables (Butz et al., 2005). Hydrogen nuclei can be found in water, sugars, and oils and produce one of the strongest MR signals. Thus, MRI can be used to measure the moisture and fat contents of food products. Recently, MRI was used to evaluate internal quality factors of horticultural products such as bruises, dry regions, worm damage, state of maturity, and presence of seeds and pits (Butz et al., 2005, Baoping, 1999). Chen et al., (1989) illustrated that MRI is useful in providing high resolution images of internal structures of intact fruit and vegetables. Wang et al., (1988) used MRI to detect water core and its distribution in 'Red Delicious' apples. Rea et al., (2005) used MRI to investigate the internal structure of radishes and monitor variations induced by postharvest storage at low relative humidity. Galed et al., (2004) used MRI to monitor ripening and decay in citrus treated with chitosan solution. In summary, MRI has enabled scientists to examine several quality factors of fruits and vegetables in greater detail. This technique can also be used to examine internal and external objects that may be found mixed with food products.

1.14.4. Electrical Properties

Electrical properties of various agricultural products have been investigated by many scientists as a basis for quality evaluation. The electrical properties of agricultural materials are highly dependent upon many factors such as resonant frequency, density, temperature and moisture content of the product (Nelson, 1973). The electrical properties of hygroscopic materials are highly influenced by moisture content. Nelson (1987) made dielectric measurements on grains and seeds and examined the relationship to moisture content. The relationship between moisture content and electrical properties has been used to develop commercial instruments for measuring moisture content in grains and seeds (Chen and Sun, 1991). A wide range of instruments has been used to establish the electrical parameters of interest. The

two types commonly used to measure moisture content in grain and seed are conductive-type meters that measure conductivity of the product, and the capacitance-type meters that measure the dielectric constant. A conductivity-type moisture meter was relatively easy to operate, but the accuracy was affected easily by uneven moisture distribution within or among the kernels, whereas capacitance-type meters were not so sensitive to moisture distribution but were sensitive to variations in the packing of seeds within the test cell (Chen and Sun, 1991). Zachariah (1976) reported some of the work that has been done on electrical properties of fruit and vegetables for quality evaluation. Nelson (1973) critically reviewed electrical properties of agricultural products. Due to uneven distribution of moisture content inside fruit and vegetables, this technique is not practical for quality sorting.

1.15. CONCLUSION

There is a tremendous increase in demand for fresh fruit in the international market. Feijoa is no exception, as it has an attractive taste and aroma. However, the feijoa industry still faces challenges when introducing this fruit to the international market. One of the main problems is the high level of variation among individual fruit. This variation is usually a result of large genetic diversity among accessions. Quality standards need to be established in order for fruit to be accepted by consumers. Up until now there has been no acceptable objective, non-destructive maturity index for determining fruit maturity at harvest. The only technique available depends on destructive internal visual grading. The objective of this study was to identify a non-destructive maturity assessment method that can be used to assess optimum harvest maturity for feijoa fruit. It also aims to understand the quality changes that occurred during ripening. In addition, part of this study also was to try and extend the postharvest life of feijoa fruit with low temperature and controlled atmosphere storage conditions. The expected outcome of this research will help the feijoa industry to increase export opportunities. The specific objectives were to:

1) Evaluate the reliability of current harvesting methods in terms of the selection of mature fruit.
2) Establish a non-destructive method to determine fruit maturity at harvest.
3) Characterise chemical and physiological changes during fruit ripening.

4) Extend storage life of feijoa fruit by low temperature and controlled atmospheres.
5) Develop an understanding of feijoa ripening physiology in relation to ethylene and propylene treatments.

Chapter 2 outlines the material and methods used in subsequent chapters of this study, including laboratory techniques to study quality attributes, including destructive and non-destructive techniques.

Chapter 3 investigates the influence of different maturity stages, regions, and cultivars on quality indices such as TSS, titratable acidity, firmness, colour, flotation, dry matter, using destructive and non-destructive techniques and comparing the relationship with internal visual quality attributes.

A short harvest season and a limited storage shelf life are considered drawbacks to feijoa fruit being exported. Chapter 4 investigates the possibility of extending storage life of feijoa fruit with cool storage conditions using different feijoa cultivars or with the same cultivar sourced from different regions. Fruit quality after storage was also evaluated at ambient temperature.

Chapter 5 reports results of the experiments to extend the storage life of feijoa cultivars using controlled atmospheres.

Chapter 6 identified the effect of postharvest exogenous applications of ethylene and propylene on feijoa fruit at different stages of maturity. This experiment was also conducted to determine if feijoa is climacteric or non-climacteric.

Chapter 7 analyses the nature of, and changes in, feijoa fruit volatiles using GC and GC-MS with two different techniques, solvent and headspace analysis. In the concluding chapter 8, overall conclusions are presented and recommendations for further research are outlined.

CHAPTER 2
LABORATORY METHODS

2.1. INTRODUCTION

This study was conducted over 4 years, at Massey University Palmerston North (PN) and Albany (AL). Experiments conducted at Massey, PN included destructive and non-destructive techniques for measuring feijoa fruit quality, temperature and controlled atmosphere treatments in an attempt to extend the storage life of feijoa and ethylene and propylene treatments. At Albany, flavour compounds of feijoa were analysed using gas chromatography-mass spectrometry (GCMS). Some flavour analyses were also done at PN using gas chromatography (GC).

In the first two years, the work concentrated on identifying a maturity index for feijoa fruit using different destructive and non-destructive methods. In the following years attention shifted to methods that enabled extension of the storage life with temperature and/or controlled atmospheres. Additional objectives were to understand the effect of picking date on volatile production and to investigate the climacteric behaviour of the fruit.

Table 2.1 Main objectives of experimental programme.

Year	Key objective	Cultivars	Fruit sourced
2007	1. Identify maturity index by destructive and non-destructive measurements. 2. Extending storage life of feijoa by cold store.	Unique Opal Star Pounamu	Matamata Otaki Blenheim Rotorua
2008	1. Identify maturity index by destructive and non-destructive measurements. 2. Extending storage life of feijoa by controlled atmosphere. 3. Flavour analysis of feijoa fruit.	Unique Opal Star	Matamata
2009	1. Response of feijoa cultivars to ethylene & propylene. 2. Flavour analysis of feijoa fruit.	Unique Opal Star	Matamata

This chapter documents plant material and the general methods used in subsequent results chapters.

2.2. PLANT MATERIAL

In 2007, three cultivars; 'Unique', 'Pounamu' and 'Opal Star' were sourced from four growing regions representing different climatic conditions and growers (Matamata, Otaki, Blenheim, and Roturua) and from three maturity stages, i.e. 'graded' fruit (mature), 'immature' and 'over-mature' were used. Selection of these cultivars was based on three different characteristics of major feijoa cultivars such as harvesting time, pollination requirement (self fertile or self sterile) and fruit size (Table 1.3). In order to have graded fruit (mature), fruit were selected from a commercial pack-house after it was touch picked by expert pickers; their fruit selection depended on the retention force of the fruit at harvest. Each grower from each site picked and supplied their fruit, so different pickers were involved in the harvest at each site. Immature fruit were deliberately selected from fruit that required a greater force than mature fruit to be pulled from the tree. Over-mature fruit were collected after they had abscised and fallen to the ground.

In the following seasons (2008 and 2009) 'Unique' & 'Opal Star' from Matamata region were sourced as in 2007; it was found that Matamata provided the best fruit quality amongst those sources used in this study (Chapter 3).

Cultivars were harvested on different days; immediately after harvesting and grading fruit was transported by courier to the Postharvest Lab at Massey University, Palmerston North within 1-2 days. Harvest details are shown in Table 2.2.

Table 2.2 Harvest details of feijoa cultivars.

Year	Cultivar	Region	Harvest Date	Code
2007	Unique	Matamata	30-4-07	U-Mat
	Unique	Otaki	09-5-07	U-Otaki
	Unique	Rotorua	14-5-07	U-Rot
	Opal Star	Blenheim	14-5-07	OS-Ble
	Opal Star	Matamata	30-4-07	OS-Mat
	Pounamu	Blenheim	14-5-07	P-Ble
	Unique	Matamata	03-5-07	U-Mat
	Opal Star	Matamata	03-5-07	OS-Mat
	Unique	Otaki	09-5-07	U-Otaki
	Opal Star	Matamata	17-5-07	OS-Mat
	Pounamu	Blenheim	17-5-07	P-Ble
2008	Unique	Matamata	04-4-08	U-Mat
	Opal Star	Matamata	23-4-08	OS-Mat
2009	Unique	Matamata	07-4-09	U-Mat
	Unique	Matamata	14-4-09	U-Mat
	Unique	Matamata	29-4-09	U-Mat
	Opal Star	Matamata	23-4-09	OS-Mat
	Opal Star	Matamata	05-5-09	OS-Mat
	Opal Star	Matamata	15-5-09	OS-Mat

2.3. QUALITY MEASURES

2.3.1. Non-Destructive Firmness Measurement

Firmness was measured non-destructively using three devices, the acoustic firmness sensor (AFS Unit, AWETA BV, Nootdrop, Netherlands), compression firmness analyser (TA-XT-Plus, Stable Micro System, USA) and Sinclair CR4 compact analyser (Sinclair IQ Bench Top Host Version 2.02).

2.3.1.1. Acoustic Firmness

Fruit were placed horizontally along their longest axis on top of the sensor and impacted gently by a solid plastic rod (Tick length = 20 mm). The resulting mechanical vibration was then captured using a microphone (Microphone gain = 70). Measurements were made at three different locations on each fruit and the average was calculated and recorded.

2.3.1.2. Compression Firmness

Compression firmness measurements were made at the equator on opposite sides at two different locations of each fruit and the average of two readings were recorded. In this test a flat cylindrical (50.85 mm diameter) probe was pressed into the fruit equator at a speed of 1 $mm.s^{-1}$ to a 2 mm depth and the maximum force (N) was recorded.

2.3.1.3. Sinclair

Fruit were placed horizontally along their longest axis on an adjustable tray and impacted gently in three different locations. The firmness tester was calibrated with an elastic calibration ball of known firmness. The unit displays the Impact Quotient (IQ) value of the fruit and averages were calculated. Measurements were done on a set of 150 graded fruit (mature) from each cultivar. This device was only used in 2008 as it was unavailable in other seasons.

2.3.2. Magnetic Resonance Imaging (MRI)

Fruit of equal size were deliberately selected so as to fit into the MRI machine. Average weight was 55 g for 'Unique' and 58 g for 'Opal Star'. Two maturity stages were used for 'Opal Star', 'immature' and 'mature'; and 'mature' for 'Unique'. Measurements were done for one season only. MRI measurements were performed in a magnetic resonance imaging instrument consisting of an Oxford instruments 4.7 T superconducting magnet (200 MHz for ^{1}H resonance frequency) and a Bruker AMX200 console. For each fruit, an axial image at the fruit centre of the transverse relaxation (T_2) was acquired. This was calculated from 8 T_2 weighted images acquired using a multiple-echo spin-echo imaging sequence. Multiple spin-echo images were acquired from a single excitation at echo times (T_e) ranging from 10 to 80 ms at 10 ms intervals; 4 scans were taken with a repetition time (T_R) of 1500 ms.

Each individual image slice was 2 mm thick, with 64 x 64 voxels sampled over a field of view of 6 x 6 cm, giving in-plane resolution of 0.94 mm.

2.3.3. Weight Loss

Feijoa fruit were weighed on an individual basis. The mass of feijoa was recorded for all fruit using a Mettler Toledo balance, (PG 503-S, accuracy ± 0.001 g, Switzerland). Weight loss was calculated as a percentage of the initial weight measurement. Percentage weight loss was calculated as follows:

Equation 1 $$WeightLoss(\%) = \frac{InitialWeight(g) - FinalFruitWeight(g)}{InitialFruitWeight(g)} \times 100\%$$

2.3.4. Fruit Density Measurement

Volume and the density of fruit was determined based on Archimedes' principle "when an object is immersed in a fluid, it is buoyed up by a force equal to the weight of the fluid displaced by the object". Density of the fruit was calculated mathematically. The fruit was immersed in 1 L clean water with the help of a stable arm and a movable beam (Figure 2.1). It was positioned horizontally during submersion to minimize air bubbles forming on the fruit surface. Displacement volume was recorded using an electronic balance connected to a computer.

Figure 2.1 Measuring fruit volume.

2.3.5. Dry Matter

A small slice of the fruit less than 4 mm in thickness was taken and placed in the oven at 70^{o}C for two days. Weight of the slice was measured before and after drying. Dry matter percentage (DM %) was calculated using the equation:

Equation 2 $$\%Dry\ Matter = \frac{Final\ Dry\ Weight(g)}{Initial\ Wet\ Weight(g)} \times 100$$

2.3.6. Total Soluble Solids (TSS)

Fruit from each cultivar/grower were cut in half at the equator and squeezed by hand to get a few drops of juice onto a digital refractometer (RFM 330 Refractometer, Bellingham + Stanley Ltd, UK).

2.3.7. Titratable Acidity (TA)

Titratable acidity was measured using a Mettler DL21 Titrator, (Zurich, Switzerland). Pulp of the feijoa fruit was squashed using a hand sieve and tea spoon and 1 ml of extracted juice was diluted with 50 ml distilled water and titrated against 0.1 N NaOH solution. The normality of NaOH was verified by calibration with 0.1 N HCl. The pH end point was 8.2 (for malic acid). The same fruit were used to measure dry matter and TSS. Acid strength was calculated using the following equation:

Equation 3 $$N_1 \times V_1 = N_2 \times V_2$$

and food acid was calculated as a percent of total sample using the following equation

Equation 4

$$\%Acid(weight/volume, as\ malic\ acid) = \frac{N_1 \times V_1 \times Eqwt}{V_2 \times 1000} \times 100$$

Where
N_1 = Normality of titrant (NaOH)
N_2 = Normality of sample
V_1 = Volume of titrant (ml)
V_2 = Volume of sample (ml)
Eqwt = Equivalent weight of predominant acid (mg / mEq), i.e. malic acid = 67.05

2.3.8. Flotation

Whole fruit of different maturity stages were tested in water by placing the fruit in a bucket. Fruit were harvested from the Matamata orchard in early and mid April 2008. The choice of two cultivars 'Unique' and 'Opal Star' was to ensure the sample contained a wide range of TSS, dry matter and weight. Figure (2.2) illustrates the flotation of feijoa fruit in water.

Figure 2.2 Different maturity stages tested in water.

2.3.9. Internal Visual Grading

Fruit were cut in half and the seed pulp and flesh were compared visually to the maturity scale developed by Plant & Food Research, Mt Albert, NZ (Figure 2.3). A rating of 1 (or A in industry rating) represents immature fruit, 2-3 (B-C) mature fruit and above 4 (D) over-mature fruit.

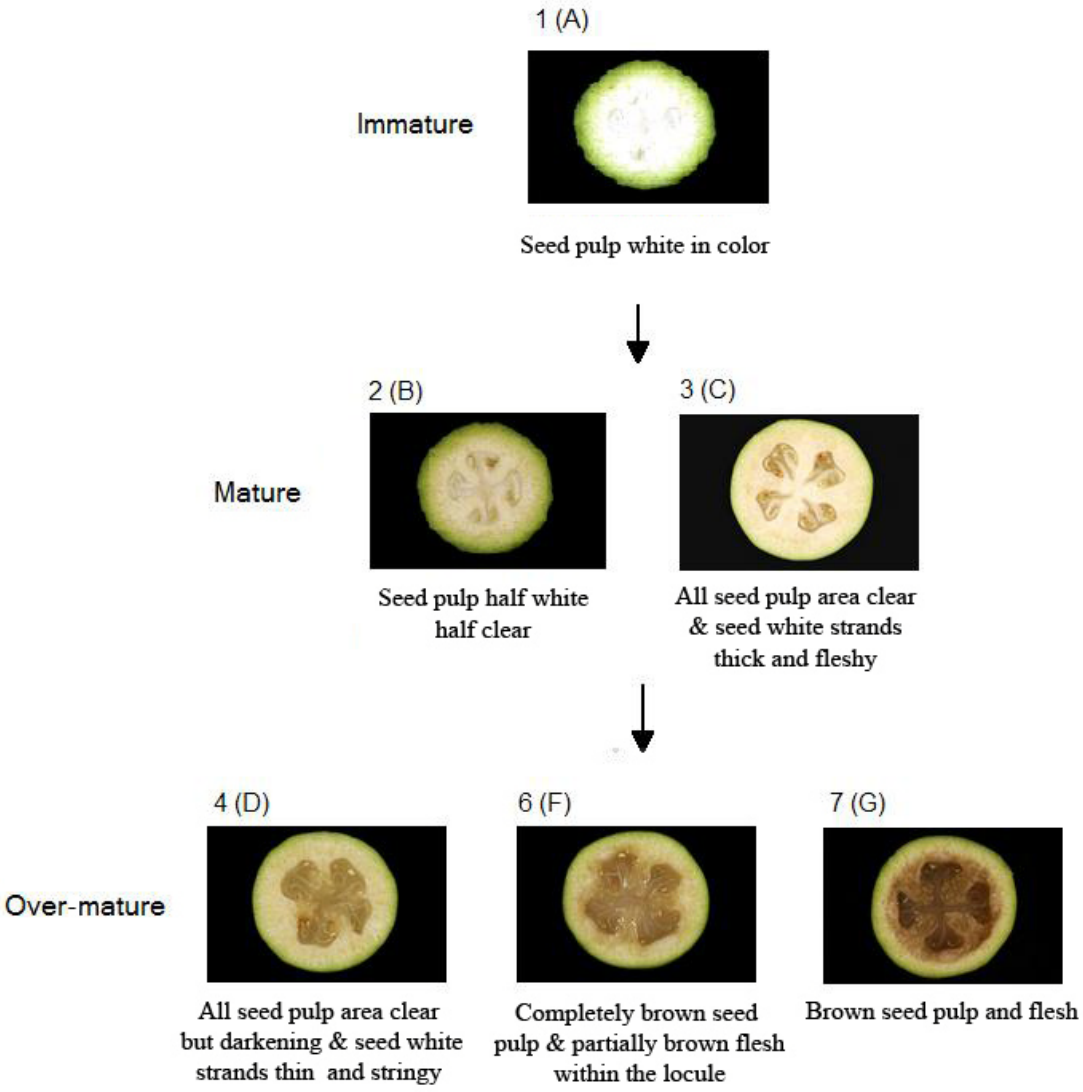


Figure 2.3 Feijoa maturity rating scale developed by Plant & Food Research, Mt Albert, NZ.

2.3.10. Fruit Colour Determination

Skin colour of fruit was determined using a spectrophotometer (CM-2600D, Konica Minolta, Albany, New Zealand) equipped with an 8 mm diameter measuring head. Measurements were made at three positions on the fruit equator. Average values of L*, a*, b*, C* and h° was calculated using Spectramagic NX software (CM-S100w 1.33, Konica Minolta, Albany, New Zealand). The device was set up using 100 % full UV, with the spectral component both included (SCI) and excluded (SCE). Measurement area value (MAV) was set at 8 mm with a reflectance measurement type. Calibration was conducted with a white colour tile. Hue angle (h) was used mainly to determine change of skin colour on the fruit. Skin colour measurements were taken only on intact areas of fruit skin, ignoring any areas of surface discolouration.

2.3.11. Fruit Disorder Measurements

Fruit skin discoloration was scored by estimating the percentage of surface area affected in each fruit, using six classes: 0, 0-10, 10-25, 25-50, 50-75, and 75-100 % as illustrated in figure 2.4. Fruit were also assessed on the 1st, 4th and 7th day after storage during shelf life at 20°C.

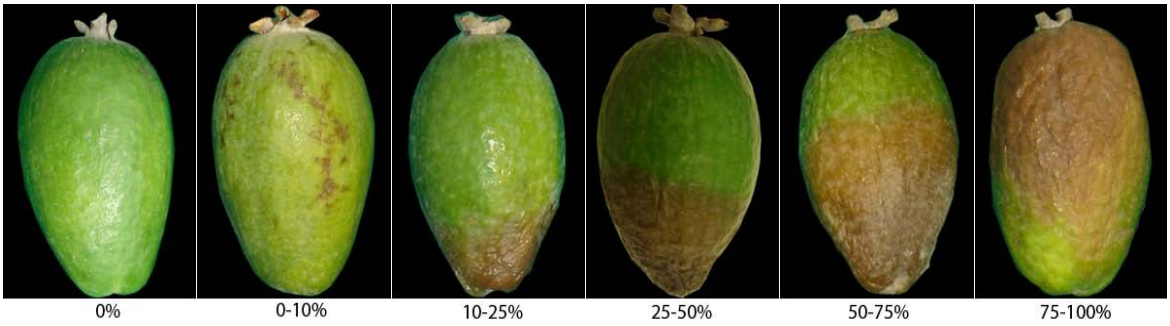


Figure 2.4 The six classes used to score the fruit injury of both cultivars 'Unique' and 'Opal Star'.

2.3.12. Respiration and Ethylene Production Rates

Fruit were placed individually into airtight glass jars (volume = 578 ml) equipped with a rubber septum on top to enable gas sampling, and left at 20°C (Figure 2.5). Samples of 1 ml for ethylene and CO_2 analysis were taken at 0, 15 and 30 minutes for

CO_2 and 0 and 30 minutes for ethylene using a watertight syringe. To determine the concentration of CO_2, 1 ml samples were injected into CO_2 analyser equipped with an O_2 electrode (Citicell C/S type, City Technology Ltd., London, UK) in series with a miniature infrared CO_2 transducer (Analytical Development Company, Hoddesdon, UK), N_2 as a carrier gas with a flow rate of 35 $ml.min^{-1}$.

For ethylene analysis, gas concentration was determined using a gas chromatograph (GC Varian model 3400 equipped with a 1/8 in alumina packed column). The column was set at 90°C with N_2 gas as the carrier and with flow rate of 35 $ml.min^{-1}$. Flame ionization detector temperature was set at 120°C with H_2 and air flow rates of 20 and 300 $ml.min^{-1}$ respectively. A standard sample gas (Beta standard 10.3 ± 0.2 ppm ethylene in air) was used for calibration. The GC was calibrated every 10-15 samples.

Figure 2.5 Determining the rate of ethylene and respiration production in airtight glass jars equipped with septum.

2.3.13. Aroma Volatile Analysis

Volatile profiles and concentrations were determined using either juice or pulp samples. Sample were prepared (see below) and stored at -80°C (juice) or -22°C (pulp) till the time of extraction. Extractions consisted of mixing the sample with a standard solution, storing at -22°C for 18 hours, decanting the unfrozen sample and concentrating the sample. After extractions samples were injected into either GC or GC-MS machine.

2.3.13.1. Sampling

In 2008 aroma volatiles from feijoa juice were extracted using a similar method to that described by Tough (1999), Dixon (1998) and Ampun (1997). To extract the juice five fruit of each treatment were cut in half and squeezed against a hand sieve with a tea spoon to remove larger particles, the collected juice was then stored at -80°C until extraction.

In 2009, seed pulp was used instead of fruit juice. Five to six feijoa fruit were cut in half; pulp was scooped with a teaspoon and stored inside a 125 ml clear wide mouth short jar, polypropylene caps with a Teflon (TFE) liner. Samples were then stored at -22°C until time of extraction.

2.3.13.2. Solvent Extraction

A standard solution (10 ml) containing a diethyl ether: n-pentane mixture (2:1 v/v Analar BDH) with 10 ppm of n-decane, and 10 ppm octyl acetate as internal standards, was mixed with 10 ml of feijoa juice (2008) or 10 g of feijoa pulp (2009) in 20 ml scintillation vials (Aheaton Scientific, NJ, USA). In 2009 only n-decane was used as the internal standard. Vials were shaken gently by hand for three to five seconds and stored at -22°C for a minimum of 18 hours. The unfrozen solvent was then decanted into clean 20 ml scintillation vials and stored at -22°C.

2.3.13.3. Headspace

This method is free of solvent and sample concentration is not needed. 10g of frozen pulp was transferred to 20 ml headspace vials sealed with magnetic screw caps with blue PTFE / white silicon septum 1.5 mm (Grace Davison Discovery Sciences). The sample was left at room temperature for 30 min before sample injection into GC-MS. The sample was incubated at 50°C for 10 minutes with agitation speed of 500 rpm

before extracting the volatiles. A 2.5 ml gas tight syringe was used. After each injection the syringe was cleaned at least 10 times by automatic nitrogen gas flush.

2.3.13.4. Sample Concentration

In 2008, the solvent extracts were dried under a stream of oxygen-free nitrogen (170 $ml.min^{-1}$) to 200 µl and placed in 250 µl flat bottom glass vials (Sun International Trading Cat. No. 200-232) using a clean Pasteur pipette. The flat bottom glass vial was stored in a 1.5 ml glass screw top auto sampler vial (Sun International Trading Cat. No. 200-250). 5 µl samples were injected into the GC. The syringe was washed at least 10 times between each injection with diethyl ether-n-pentane.

In 2009, the TECHNE Sample Concentrator (Figure 2.6) was used to accelerate the concentration process by evaporating the solvent from the sample before GCMS analysis. The concentrator consisted of a gas chamber in which needles carrying gas into the sample was attached. The flow of N_2 gas directed over the sample allowing evaporation of solvent from the liquid surface. In this year the unfrozen sample was dried completely and 10 ml of the standard solution was added using a clean Pasteur pipette 200 µl was then transferred into a 250 µl flat bottom glass vial fitted into a 1.5 ml glass screw top auto sampler vial. 5 µl samples were injected into GC-MS for analysis.

Figure 2.6 Sample concentrator used to evaporate the solvent from the sample.

2.3.13.5. Sample Analysis

In 2008 extracts were analysed with an HP 6890 Series plus Gas Chromatography (USA) equipped with split-splitless capillary injection port and flame ionization detector (FID). Separation was performed on a DB-Wax column (model no: J8W 123-7033). Operating conditions were as follows: column oven temperature 40°C, hold for 5 min, and then programmed increase in temperature at 10°C / min up to 190°C. Carrier gas was N_2 at a total flow rate of 14 ml / min, injections were made in split mode and the sample volume injected with Hamilton micro-litter syringe was 5 µl.

2.3.13.6. Gas Chromatography Mass Spectrometry Analysis

In GC-MS, the extracts were analysed by gas chromatography (GCMS-QP2010 plus, Shimadzu corporation) equipped with an auto injector (AOC 500 Shimadzu) and CombiPAL auto sampler (CTC Analytic AG). Separation was performed on capillary column of 5% diphenyl cross bond with 95% dimethyl polysiloxane. The capillary column was RTX5 (60 m x 0.25 mm i.d. x 0.25 µm film thickness; Restek). Oven temperature was programmed as in table 2.3 and 2.4 for subsequent head space and solvent extraction respectively. Carrier gas was helium at a constant flow rate of 2.05 ml / min.

Table 2.3 The column temperature for head space GC-MS.

Rate (°C / min)	Final Temperature (°C)	Hold Time (minute)
0	50	10.00
6.00	80	3.00
5.00	105	3.00
3.00	125	2.00
40.00	280	5.00

Table 2.4 The column temperature for solvent extraction GC-MS.

Rate (°C / min)	Final Temperature (°C)	Hold Time (minute)
0	40	5.00
10.00	190	5.00
10.00	200	2.00

2.3.14. Statistical Analysis

Analysis of variance (ANOVA) followed by Least Significant Differences (LSD) with a significance level of $P < 0.05$ were performed using SAS statistical program (version 9). The LSD values were calculated at each time point, or where possible on experiment wide. The experiments were carried out applying completely randomized design.

CHAPTER 3
DESTRUCTIVE AND NON-DESTRUCTIVE TECHNIQUES FOR MEASURING QUALITY OF FEIJOA FRUITS

3.1. INTRODUCTION

Quality involves many attributes that are interpreted differently according to a person's position in the chain from producer to consumer. To the producer, quality may mean high yield, good appearance and simplicity to deal with during harvesting and marketing whereas for the consumer it may initially be good appearance in terms of size, shape, colour, firmness and freedom from visible defects and decay, but in the end will be reflected in the time the product lasts in the home while retaining taste and nutritive value. Quality can be defined as the degree of excellence or superiority (Kader and Rolle, 2004) or fitness for purpose (Hewett, 2006). Consumers are aware of the importance of food quality, thus it has become necessary for producers and growers to be vigilant to provide good quality and healthy food.

There are many ways to evaluate food quality. Quality of fresh fruit and vegetables can be described by physical properties such as size, colour, firmness, flavour. Of these, firmness is often considered the most important. It is advantageous if these quality attributes can be assessed non-destructively. There have been many attempts to develop reliable non-destructive techniques so that each item can be assessed and graded appropriately. Any technique used should be simple, inexpensive and reliable.

Feijoa exhibit a wide range of maturity (from immature to over mature) during harvest for a given batch. To ensure better quality for marketing, and efficient use of labour and money, a maturity index has to be developed. A maturity index is widely used to identify when the commodity is ready for harvest or to predict storage potential. For feijoa fruit it is difficult to judge harvesting time based on external appearance as fruits having similar appearance are found to have varying maturity.

The most common method to harvest feijoa in New Zealand is through touch picking. As fruit mature an abscission zone develops on the stalk and the fruit becomes easy to harvest. The disadvantage of this technique is that it is picker dependent. In an early work trying to group fruit according to their retention force at harvest, no differences were found in total sugar and organic acid contents, and the sugar to acid ratio (Downs et al., 1988). To assess feijoa maturity, a sample of harvested feijoa fruit has to be cut open and compared to the internal features with the maturity index developed by Plant & Food Research Institute. The uniformity of maturity in harvested feijoa could be improved by using some kind of objective, quantitative non-destructive instrumental measurement such as acoustic firmness, compression firmness or the Sinclair firmness unit to grade fruit once harvested. All devices are widely and internationally used. Gaddam et al., (2004) used acoustic firmness to assess maturity of 'Unique' feijoa obtained from Taranaki, NZ. The present study aims to determine the relationship between acoustic firmness in a range of cultivars sourced from a number of regions or growers and determine the correlations between acoustic firmness and compression firmness, and visual (destructive) grading. The Sinclair unit was also useful in sorting avocado fruit according to ripeness (Howarth et al., 2003).

The internal appearance of feijoa is the best unequivocal measure of feijoa maturity, yet it is only visible when fruit are halved. Magnetic Resonance Imaging (MRI) can be used to evaluate the internal quality of intact fruit and vegetables. For example Wang et al., (1988) used MRI to detect water core in apple non-destructively. In this study a preliminary study with MRI has been conducted with the aim of assessing MRI as a technique to measure internal appearance of feijoas.

Density sorting by flotation in water is a simple, cheap and non destructive technique that can be used to separate some fruit and vegetables of different maturity. It is worth testing this method with different feijoa cultivars of different maturity stages.

In summary the objectives of this work are to (1) assess reliability of present touch-picking system used by growers in harvesting feijoa, (2) test non-destructive firmness

measures for varieties / regions and test other non-destructive methods such as MRI or flotation.

3.2. MATERIALS AND METHODS

In 2007, three cultivars: 'Unique', 'Pounamu' and 'Opal Star', of three maturity stages, i.e. graded fruit (mature), immature and over-mature, were sourced from four different regions representing differing climatic conditions and growers (Matamata, Otaki, Blenheim, and Roturua). A uniform line of mature fruit was selected from a commercial pack-house after it was touch picked from the tree by expert pickers relying on retention force of the fruit. Each site picked and supplied their fruit, so different pickers were involved in the harvesting process. Immature fruit were selected by picking fruit that required a greater force to be pulled from the tree than mature fruit. Over-mature fruit were collected from the ground after they had fallen. In 2008, only two cultivars were studied: 'Unique' and 'Opal Star' sourced from the Matamata region. Fruit were harvested on different days then transported by courier to the Postharvest Laboratory at Massey University, Palmerston North.

The assessment consisted of non-destructive measurements including weight, acoustic firmness, compression firmness, Sinclair firmness and Magnetic Resonance Imaging (MRI) and destructive measurements such as total soluble solids (TSS), titratable acidity, dry matter and visual grading (refer to chapter 2). All measurements were taken on the day fruit arrived in the postharvest laboratory and within 48 hours of harvest.

3.3. RESULTS AND DISCUSSION

3.3.1. Reliability of Touch Picking

Touch picking is the normal harvesting technique used by commercial orchards. This technique is subjective and there was a large variation in fruit internal maturity within the batches. The maturity rating used to assess reliability of touch picking refers to the visual scale shown in Figure 2.3. From the export-graded fruit provided from the Matamata orchard in 2007, 11% of the 'Opal Star' cultivar was immature and 89% mature, in good agreement with expectations, whereas with 'Unique' from the same orchard (an early cultivar), only 74% were mature with 14% immature and 12% over-mature (Table 3.1). Export-grade (mature) fruit should have all been at score 2-3 but

exhibited a range in maturities from 1-4 (A-D in the industry rating) with more immature in early season fruit and more over-mature fruit in mid and late-season. The touch picking technique appeared reliable for the single sample of 'Pounamu' but appears less reliable with other varieties such as 'Unique', where mature fruits represented between 68.4%-73.5% of the graded fruits. 80% of the harvested fruit should be in the maturity category range of 2 (B) in the industry rating (Kirk and Currie, 2006). Four out of seven batches failed to meet this standard. Pickers are not as good as the industry would like.

Table 3.1 Internal maturity of feijoa fruit harvested by touch picking at 'mature' grade.

Region	Cultivar	Internal Maturity Rating		
		< 2	**2-3**	**>3**
Matamata	Opal Star	11%	89%	0%
	Unique	14.3%	73.5%	12.2%
Blenheim	Opal Star	7%	92%	0%
	Pounamu	0%	100%	0%
Otaki	Unique	0%	68.4%	31.6%
Rotorua	Unique	0%	73.5%	26.5%
Matamata	Unique (2008)	7.2%	69.4%	23.4%

When asked to supply immature fruit, pickers found it difficult to distinguish between immature and mature fruit. Pickers from Blenheim and Otaki orchards delivered 93-100% mature fruit instead of immature fruit, compared with the more accurate harvesting by pickers from Rotorua and Matamata (Table 3.2). Collecting fruit from the ground did not necessarily mean that it was always over-mature (Table 3.3), with most of the fruit being mature with score of 2-3 rather than over-mature (score > 3). Together tables 3.1-3.3 demonstrate that there are serious problems with the use of conventional touch picking as a maturity guide. Because touch picking is not reliable in segregating between maturity stages, a wide range of maturities will be found in a consignment causing unnecessary wastage.

For export markets, where sea-shipment of more than 3 weeks is needed, fruit should be harvested at an early stage of maturity. Fruit harvested at a later stage of maturity are susceptible to over ripening and damage. Fruit should reach the final destination fresh, free from any defects, discolouration or non-uniform ripening. It is also very important for NZ growers to consider using a catching net below feijoa fruit. It was

very clear that most of the collected fruit from the ground were mature in the score of 2-3 (Table 3.3). Introducing this method for some cultivars may add value to the fruit, as it will reduce wastage and may reduce the labour cost and improve quality.

Table 3.2 Internal maturity of feijoa fruit deliberately harvested 'immature' by touch-picking.

Region	Cultivar	Internal Maturity Rating		
		<2	2-3	>3
Matamata	Opal Star	94.1%	5.9%	0%
	Unique	73.3%	26.7%	0%
Blenheim	Opal Star	6.5%	93.5%	0%
	Pounamu	-	-	-
Otaki	Unique	0%	100%	0%
Rotorua	Unique	66.7%	33.3%	0%

Table 3.3 Internal maturity of feijoa fruit collected from the ground (supposedly over mature).

Region	Cultivar	Internal Maturity Rating		
		<2	2-3	>3
Matamata	Opal Star	3.3%	96.7%	0%
	Unique	0%	96.7%	3.3%
Blenheim	Opal Star	0%	21%	79%
	Pounamu	-	-	-
Otaki	Unique	0%	45%	55%
Rotorua	Unique	0%	80%	20%

3.3.2. Acoustic Firmness

There is a general trend for feijoa fruit to soften during ripening. This experiment was designed with equal numbers of fruit in the 'immature', 'mature' and 'over-mature' grades, but because of the problems described in section 3.3.1, many were mis-graded, the data were therefore analysed using the true internal maturity score.

For both cultivars 'Unique' and 'Opal Star' there was a statistically significant interaction between region and maturity, and a significant effect of maturity on acoustic firmness (Table 3.4). However, the maturity effect, while statistically significant, showed no particular trend. There was no clear reduction in acoustic firmness in fruit from Matamata. Data from Matamata were influenced by the fact that this batch of fruit was used for method development. The standard cup-shaped cushion used to hold fruit during measurements was not well suited to feijoa and several readings failed to register, particularly for elongated fruit. This may have

contributed to inconsistency of these readings. When a flat cushion was used repeatability improved. When Matamata data were eliminated, there was a clear trend of reduced firmness as fruit matured. Acoustic firmness could be suitable as an indicator of harvest maturity. Average acoustic firmness of fruit from each region varied (Table. 3.4). For instance, graded mature fruit of cultivars 'Unique' and 'Opal Star' that were ready for export and from Matamata were much firmer than the same cultivars from other growers and regions (Figure 3.1). This difference is unlikely to relate to a climatic or soil effect and more likely to relate to different pickers' experience or harvest method used. The normal pattern of softening with maturity occurred in fruit from Blenheim and Rotorua, but in the firmer fruit from Matamata, there was an inconsistent pattern of softening.

Table 3.4 Acoustic firmness of 'Unique' and 'Opal Star' fruit from different regions and at different stages of maturity.

Cultivar	Unique								
Maturity	Regions (R)								Maturity
(M)	Matamata	n	Otaki	n	Rotorua	n	Blenheim	n	means
Immature	8.40	15	-	-	10.95	26	-	-	10.02**
Mature	8.92	93	6.89	49	7.14	73	-	-	7.85
Overmature	5.70	1	3.10	11	3.99	11	-	-	3.64
Region means	8.82NS		6.20		7.72		-	-	
M x R	**								
s^2	10.87								
	Opal Star								
Immature	6.83	24	-	-	-	-	9.08	4	7.15***
Mature	10.43	69	-	-	-	-	6.94	64	8.75
Overmature	-	-	-	-	-	-	1.88	23	1.88
Region means	9.50NS		-		-		5.76		
M x R	**								
s^2	9.80								

*, **, ***, NS Significant at the 5%, 1%, or 0.1% levels or not significant, respectively.
n: number of observation.
S^2: Error Mean Square.

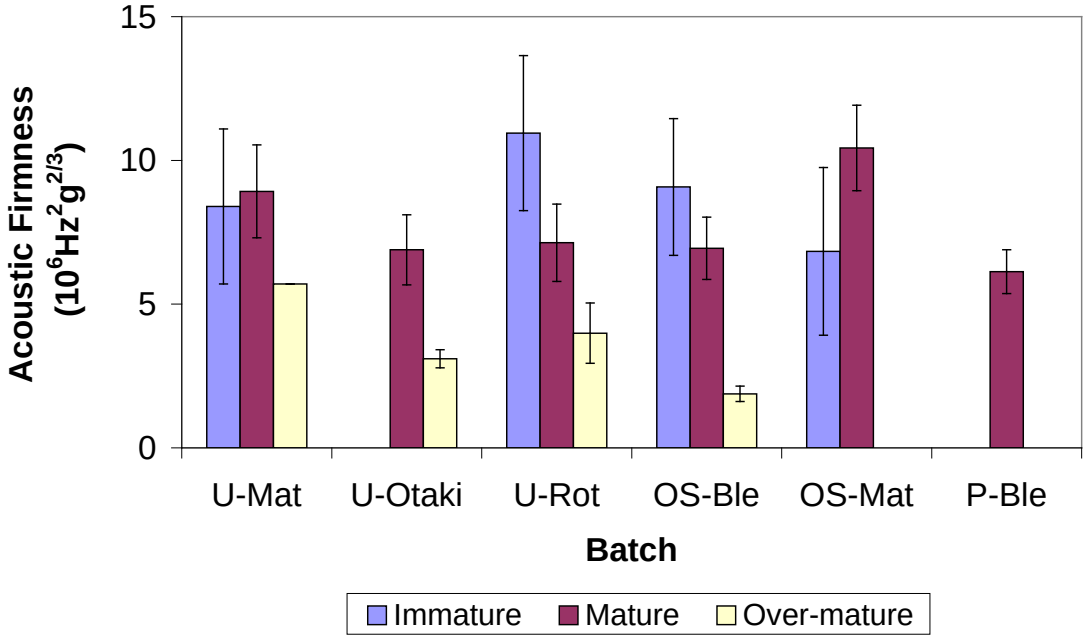


Figure 3.1 Acoustic firmness comparison between batches. Where U= 'Unique', OS= 'Opal Star', and P= 'Pounamu' cultivars. Mat= Matamata, Otaki= Otaki and Ble= Blenheim regions. Bars represent SDEV values.

3.3.3. Compression Firmness

Firmness of both cultivars ('Unique' and 'Opal Star') softened as maturity stages increased (Table 3.5) indicating that compression firmness was more reliable in determining maturity changes than acoustic firmness. Mature graded fruit produced in Matamata were firmer than fruit from other regions (Figure 3.2). For 'Unique' fruit there were no significant interactions between region and maturity, and no significant difference between regions (Table 3.5). However, for 'Opal Star' there was a significant interaction between region and maturity, the reduction in firmness with maturity was much more dramatic in fruit from Matamata than in fruit from Blenheim. Significant interactions between region and maturity were influenced mainly by region with maturity being a minor effect of the interaction. Average firmness of mature fruit ranged between 15-20 N, with the 'Pounamu' cultivar sourced from Blenheim at 16 N (Figure 3.2).

As the fruit supplied were of different weights (size), further analysis was conducted to establish whether there was any effect of fruit size on apparent compression

firmness but there was no effect (Figure 3.3) even in 'Opal Star', the fruit weight was not significantly different from 0 and R^2 was low ($R^2 = 0.13$). Similar results existed between fruit weight and acoustic firmness (data not shown). The large variation in fruit firmness of different varieties from each region was not unexpected. The main source of variation could be different pollination source, temperature and uneven maturity stages. In kiwifruit for instance, the firmness variation was because of uneven physiological maturity, differences in mineral concentrations and fruit colour (Feng et al., 2002). Fruit to fruit variation within a treatment is often larger then differences between treatments. For example, Wiryawan et al., (2002) found around 60% of the variation is referred to individual differences between fruits rather than between cultivars.

Table 3.5 Compression firmness of 'Unique' and 'Opal Star' feijoa fruit from different regions at different stages of maturity.

Cultivar	Unique								
Maturity	Regions (R)								Maturity
(M)	Matamata	n	Otaki	n	Rotorua	n	Blenheim	n	means
Immature	31.06	15	-	-	33.88	26	-	-	32.85***
Mature	19.31	93	18.11	49	18.16	73	-	-	18.65
Overmature	11.84	1	10.19	11	12.19	11	-	-	11.21
Region means	20.86^{NS}		16.66		21.28		-	-	
M x R	^{NS}								
s^2	32.65								
	Opal Star								
Immature	32.24	24	-	-	-	-	18.77	4	30.31***
Mature	20.40	69	-	-	-	-	15.79	64	18.18
Overmature	-	-	-	-	-	-	6.58	23	6.58
Region means	23.45***		-		-		13.59		
M x R	***								
s^2	21.95								

$^{*, **, ***, NS}$ Significant at the 5%, 1%, or 0.1% levels or not significant, respectively.
n: number of observation.
S^2: Error Mean Square.

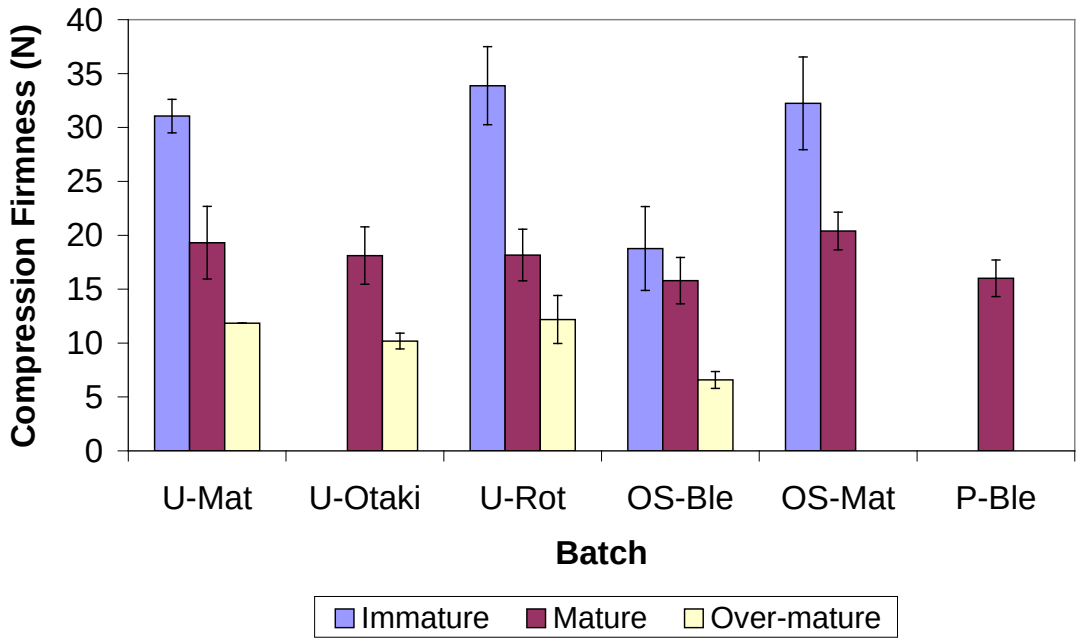


Figure 3.2 Firmness of different batches of feijoa cultivars from different regions. Where U= 'Unique', OS= 'Opal Star', and P= 'Pounamu' cultivars. Mat= Matamata, Otaki= Otaki and Ble= Blenheim regions. Bars represent SDEV values.

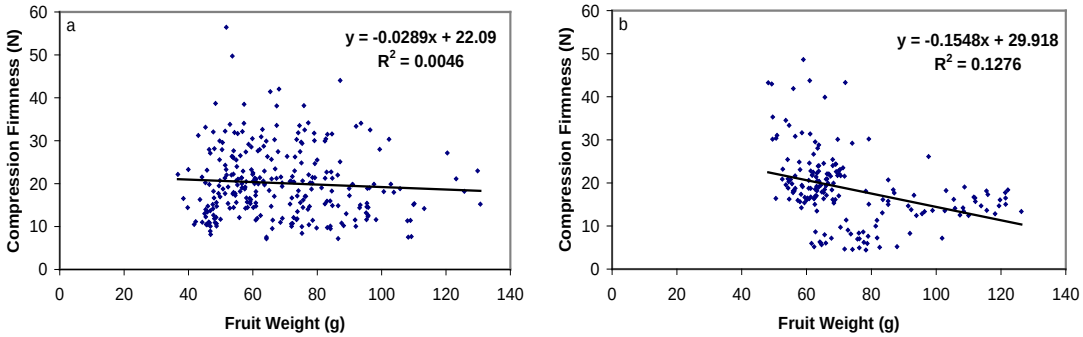


Figure 3.3 Relationship between compression firmness with fruit weight of two cultivars 'Unique' and 'Opal Star' sourced from different regions; (a). Unique from Matamata, Otaki and Rotorua, (b). 'Opal Star' from Blenheim and Matamata.

3.3.4. Determining Fruit Maturity by MR Image Analysis

There are three degrees of brightness of feijoa fruit (Figure 3.4) as seen in MR images; the darker regions represent the weaker signals as a result of less moisture content and water binding or the presence of rigid structures such as seeds. In other

words, the outer layer of fruit (flesh) is firmer and has lower moisture content than seed pulp. This suggests MRI that could possibly be used to examine internal fruit quality. Spin-spin relaxation time (T_2) values of seed pulp were different among cultivars and maturity levels ($P < 0.001$, Table 3.6). However, there were no differences in flesh T_2 values among cultivars. Hence, the results suggest that the formation of the locular gel is associated with an increase in the freedom of the water molecules to rotate, whereas the water molecules are more constrained in the flesh of both cultivars, this correlates with the observation that visual changes in feijoa usually starts to be seen from inside out.

Spin-spin relaxation time (T_2) values of seed pulp and fruit flesh increased as fruit ripened (Figure 3.5). This disagreed with Shanying et al., (2007) who observed T_2 (soft) < T_2 (firm) for tomatoes. In general this indicates that spin-spin relaxation time could potentially be a good indicator of maturity stage. Half height peak width values (ΔH_2) were significantly different ($P < 0.001$) as a function of cultivar and maturity (Table 3.6). A reasonable linear correlation was found between ΔH_2 and visual grading ($R^2 = 0.59$ for both cultivars, Figure 3.5). Correlations between compression firmness and spin-spin relaxation time of the flesh and pulp and the half height peak width were very weak for the 'Unique' cultivar as only one maturity stage was available for testing (Figure 3.6a). There was a reasonable correlation between compression firmness and spin-spin relaxation time of the flesh and pulp and the half height peak width for 'Opal Star ($R^2 \approx 0.5$, Figure 3.6b).

Although MRI scans can be used for evaluating the inner condition of fruits non-destructively, measuring internal quality of fruit or vegetables by MRI has the disadvantages of being expensive and time consuming. MRI equipment is very expensive to purchase, and very expensive to operate. Testing an individual fruit takes a long time as fruit has to be in a stable condition, with any movements causing a distorted image. It can take more than 30 minutes to get a very clear image. To date MRI has not been used commercially for horticultural commodities. However, it is not necessary to acquire a complete image if NMR were to be used for maturity grading; it may be possible to acquire a numerical estimate of T_2 or ΔH_2 at a focussed point within the locular gel in a much shorter time interval. Efforts are needed to

develop portable, easy to operate and affordable MRI that can be used as a non-destructive and rapid technique.

Table 3.6 Differences among fruit characteristics of 'Unique' and 'Opal Star' feijoa fruit used for MRI analysis.

Group	n	Weight (g)	CF (N)	°Brix	T_2-Pulp (ms)	T_2-Flesh (ms)	ΔH_2
OS-IM	3	55	32	12.3	111	42	189
OS-MA	13	58	19	11.7	195	55	120
U-MA	20	55	19	12.3	308	50	76
OS-MA vs. OS-IM		NS	***	NS	***	***	***
OS-MA vs. U-MA		NS	NS	NS	***	NS	***
S^2		39	22.5	1.7	4114	86.7	1070

OS-IM = Opal Star Immature.
OS-MA= Opal Star Mature.
U-MA = Unique Mature.
n = number of observation.
NS = not significant and *** significant at 0.1%.
S^2: Error Mean Square.

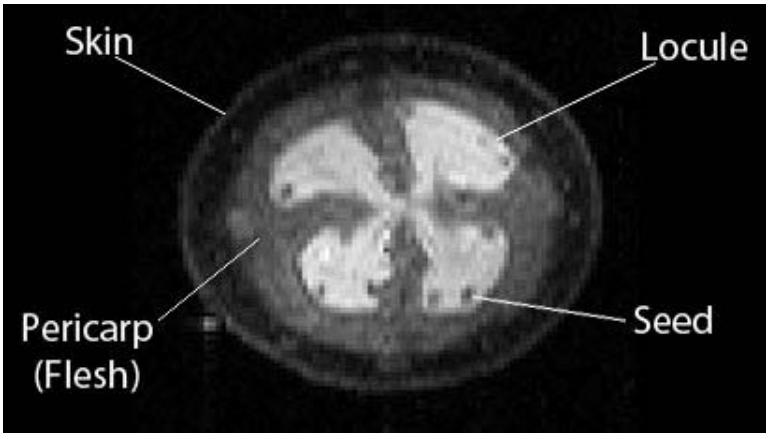


Figure 3.4 Two-dimensional MR image of feijoa fruit, the brighter the image the stronger the signal.

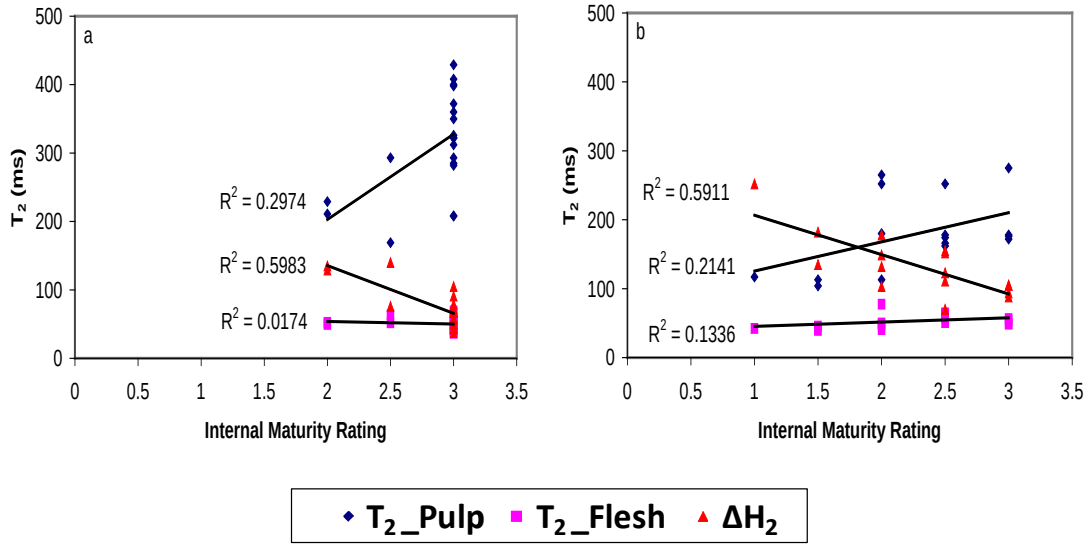


Figure 3.5 Relationship of spin-spin relaxation times of flesh (T_2 Flesh), spin-spin relaxation times of seed pulp (T_2 Pulp) and half height peak width (ΔH_2). (a). Unique-Matamata and (b). Opal Star-Matamata feijoas and internal maturity rating. Each data point represents an individual fruit.

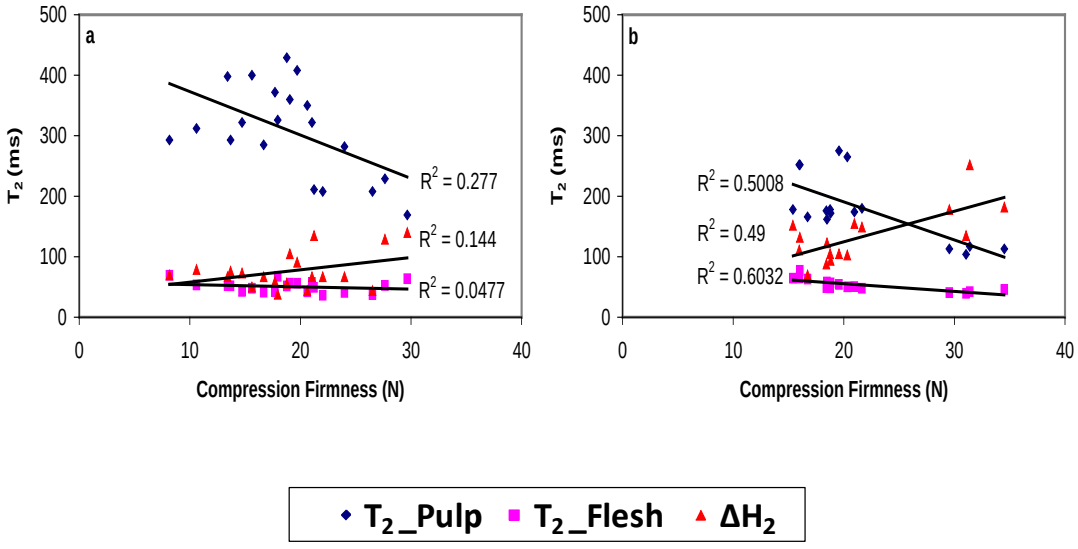


Figure 3.6 Spin-spin relaxation times of flesh (T_2 Flesh), spin-spin relaxation times of seed pulp (T_2 Pulp) and half height peak width (ΔH_2) and compression firmness. (a). Unique-Matamata and (b). Opal Star-Matamata feijoas. Each data point represents an individual fruit.

3.3.5. Fruit Weight

There was a large variability in fruit weight within and between cultivars provided from different regions. This variation may have resulted from cultural practices, cultivars and climatic conditions; however, some growers chose to supply fruit of different count sizes i.e. in trays with differing numbers of pockets. Therefore differences between regions do not necessarily reflect growing regions in this analysis. In trying to understand the relationship between fruit weight and visual grading, data from all cultivars from different regions were plotted against different maturity stages (Figure 3.7) but the relationship obtained was very weak (R^2 = 0.0028). Thus it is quite difficult to estimate maturity stages of feijoa fruit based on fruit size or weight. Fruit weight varied greatly within the same stage of maturity. There was no trend for fruit to increase in size with internal maturity score between 1 and 4.

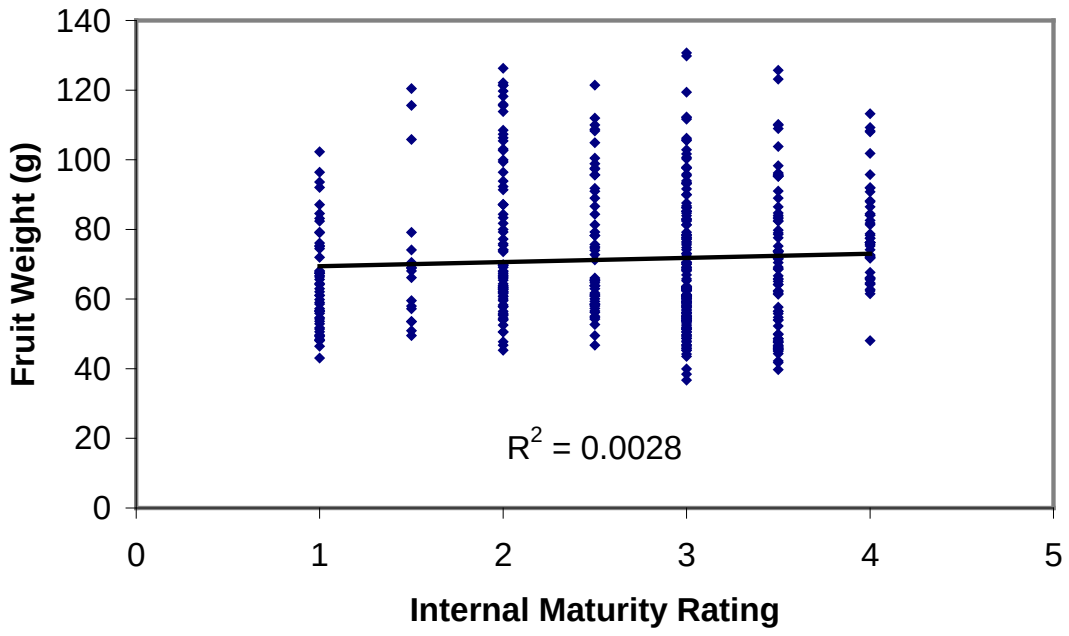


Figure 3.7 The relationship between internal maturity rating and fruit weight of all feijoa fruit tested. Each data point represents an individual fruit.

Cultivars also differed in shape between regions; 'Unique' fruit from Otaki was round in shape, whereas 'Unique' from Matamata was oval in shape (Figure 3.8). This difference could be due to different degrees of pollination, seed weight or be caused by different cultural practices. There is a relationship between seed number and fruit shape but it is complex (Lawes et al., 1990, Patterson, 1989).

Figure 3.8 Differences in shape between 'Unique' fruit provided from Otaki (above) and Matamata (below) orchards.

3.3.6. Dry Matter (DM) Content

Average dry matter of cultivars tested ranged from 13-17% with an inconsistent pattern between maturity and region (Table 3.7). 'Unique' fruit sourced from different regions and at different stages of maturities had similar dry matter contents. Hence dry matter would not be suitable as an indicator of harvest maturity. Immature fruit from Matamata region were higher in dry matter than other stages of maturity and regions. Figure 3.9 illustrates dry matter content of different feijoa cultivars at different maturity. For 'Opal Star' differences in fruit dry matter occurred between regions (Table 3.7) with fruit from Matamata having the higher dry matter. Average dry matter of the 'Pounamu' from Blenheim was in the same range as the other cultivars. There was a statistically significant trend of reduction in dry matter with maturity. It is possible that dry matter could be suitable as an indicator of harvest maturity for 'Opal Star'. However, regional effects were found larger than maturity effects, suggesting that across the industry the use of dry matter as a gauge for maturity would be risky. Similar results were also reported by Wiryawan et al., (2002) where different batches had different dry matter contents.

Table 3.7 Dry matter of 'Unique' and 'Opal Star' feijoa fruit from different regions at different stages of maturity.

Cultivar	Unique								
Maturity	Regions (R)								Maturity
(M)	Matamata	n	Otaki	n	Rotorua	N	Blenheim	n	means
Immature	15.24	15	-	-	14.61	15	-	-	14.92^{NS}
Mature	14.78	73	14.74	49	14.75	40	-	-	14.76
Overmature	13.99	1	14.77	11	14.79	5	-	-	14.73
Region means	14.85^{NS}		14.74		14.72		-	-	
M x R	^{NS}								
s^2	1.59								
	Opal Star								
Immature	16.14	20	-	-	-	-	14.90	2	16.03^{*}
Mature	15.91	53	-	-	-	-	14.60	44	15.32
Overmature	-	-	-	-	-	-	13.57	14	13.57
Region means	15.97^{**}		-		-		14.37		
M x R	^{NS}								
s^2	1.46								

$^{*, **, ***, NS}$ Significant at the 5%, 1%, or 0.1% levels or not significant, respectively.
n: number of observation.
S^2: Error Mean Square.

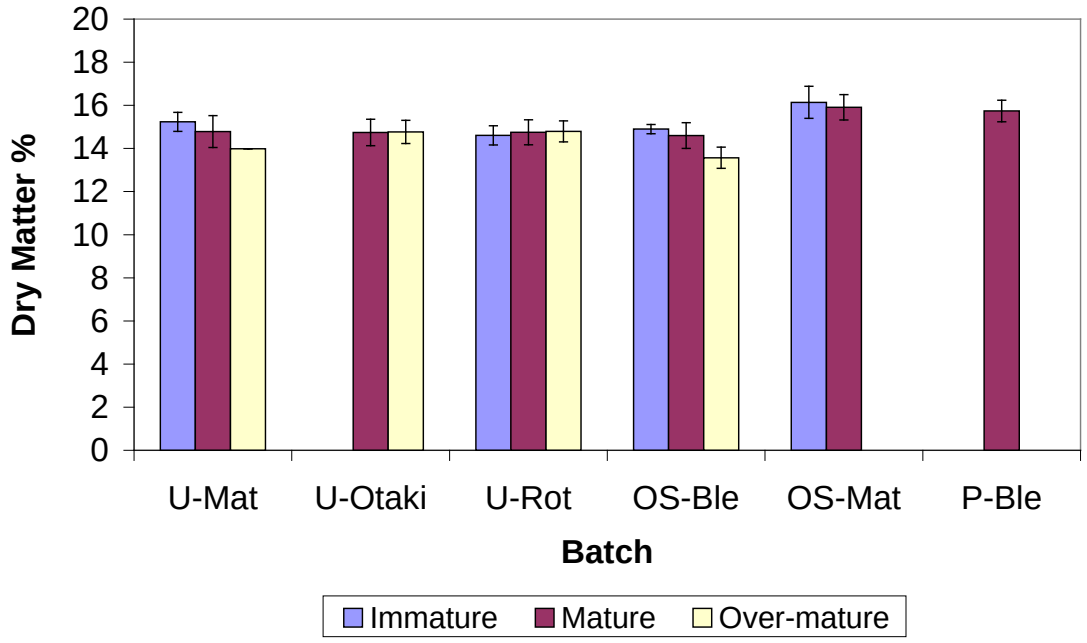


Figure 3.9 Dry matter content of different feijoa cultivars grown in different regions. Where U= 'Unique', OS= 'Opal Star', and P= 'Pounamu' cultivars. Mat= Matamata, Otaki= Otaki and Ble= Blenheim regions. Bars represent SDEV values.

3.3.7. Total Soluble Solids

In feijoa, the main compounds contributing to soluble solids (TSS) content and thus fruit sweetness are fructose, glucose and sucrose (Harman, 1987). Average TSS of different batches and maturities of feijoa fruit ranged between 10-13 °Brix (Table 3.8). In both cultivars, region of production had no influence on TSS. For 'Unique' there were no significant differences between maturity stages. However, for 'Opal Star' fruit TSS of mature fruit was higher than over-mature fruit. The TSS of 'Pounamu' sourced from Blenheim was within the range of the other cultivars. In general, there was a large variation of TSS among individual fruit in all cultivars (Figure 3.10). Wiryawan et al., (2002) comparing different cultivars namely; 'Unique', 'Apollo', 'Triumph' and 'Mammoth' sourced from different growers, and found that around 75% of the differences were a result of individual fruit differences and 25% could be explained by cultivar differences.

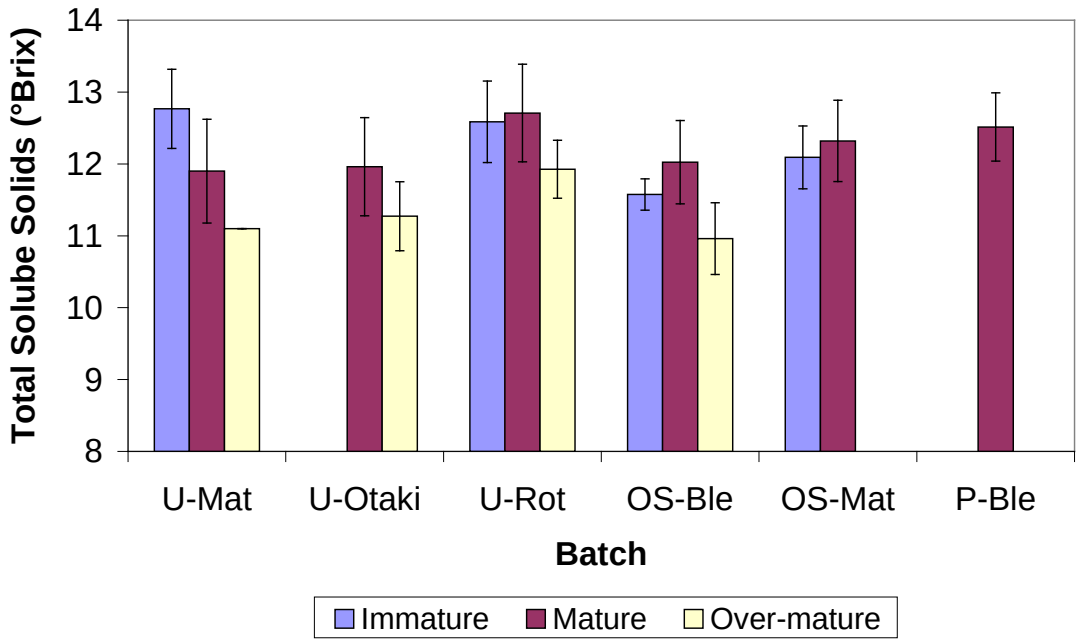


Figure 3.10 Average total soluble solids of different feijoa cultivars grown in different regions. Where U= 'Unique', OS= 'Opal Star', and P= 'Pounamu' cultivars. Mat= Matamata, Otaki= Otaki and Ble= Blenheim regions. Bars represent SDEV values.

Table 3.8 Total soluble solids of 'Unique' and 'Opal Star' feijoa fruit from different regions and at different stages of maturity.

Cultivar	Unique								
Maturity	Regions (R)								Maturity
(M)	Matamata	n	Otaki	n	Rotorua	n	Blenheim	n	means
Immature	12.77	15			11.59	23	-	-	12.66^{NS}
Mature	11.90	93	11.96	49	12.71	73	-	-	12.19
Overmature	11.10	1	11.27	11	11.93	11	-	-	11.58
Region means	12.01^{NS}		11.84		12.60		-	-	
M x R	^{NS}								
s^2	1.77								
	Opal Star								
Immature	12.09	24	-	-	-	-	11.58	4	12.02^{***}
Mature	12.32	69	-	-	-	-	12.02	64	12.18
Overmature	-	-	-	-	-	-	10.96	23	10.96
Region means	12.26^{NS}		-		-		11.74		
M x R	^{NS}								
s^2	1.18								

$^{*, **, ***, NS}$ Significant at the 5%, 1%, or 0.1% levels or not significant, respectively.
n: number of observation.
S^2: Error Mean Square.

3.3.8. Titratable Acidity (TA)

Titratable acidity in feijoa fruit is mainly dominated by malic and citric acid in an equal ratio of 1:1 (Harman, 1987). There was a similar pattern for all cultivars tested where acidity decreased as maturity advanced. TA of mature fruit ranged between 1.5 – 3.0 g malic acid / 100 ml feijoa (Table 3.9). For both 'Unique' and 'Opal Star' there was no interaction between region and maturity, but there was a significant effect of region and a consistent reduction with maturity. For 'Unique' fruit the main effect was dominated by both region and maturity. There was a significant difference between all regions tested and between all maturity stages. In 'Opal Star' however, the dominant effect was due to the region. Fruit from Matamata region had the highest acidity (Figure 3.11). TA of fruit generally decreases as fruit ripens. However, in some fruit such as in kiwifruit, TA may remain stable during storage and ripening (MacRae et al., 1989) or decline (Crisosto and Crisosto, 2001) depending on growing location.

Table 3.9 Titratable acidity (g/100 ml) of 'Unique' and 'Opal Star' feijoa fruit from different regions and at different stages of maturity.

Cultivar	Unique								
Maturity	Regions (R)								Maturity
(M)	Matamata	n	Otaki	n	Rotorua	n	Blenheim	n	means
Immature	4.06	12	-	-	3.33	6	-	-	3.81***
Mature	2.67	73	1.79	25	1.78	20	-	-	2.33
Overmature	1.79	1	0.92	5	1.46	3	-	-	1.20
Region means	2.85*		1.64		2.07		-	-	
M x R	NS								
s^2	0.43								
	Opal Star								
Immature	3.36	14	-	-	-	-	-	-	3.36**
Mature	2.77	52	-	-	-	-	1.94	22	2.52
Overmature	-	-	-	-	-	-	1.00	6	1.00
Region means	2.89***		-		-		1.73		
M x R	NS								
s^2	0.59								

*, **, ***, NS Significant at the 5%, 1%, or 0.1% levels or not significant, respectively.
n: number of observation.
S^2: Error Mean Square.

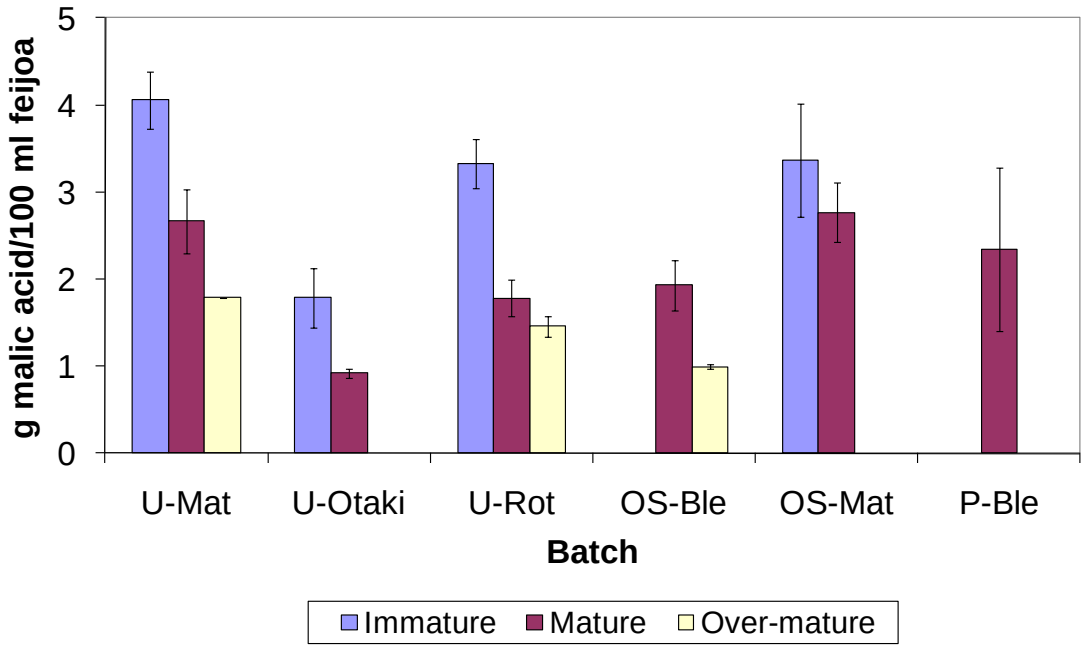


Figure 3.11 Average titratable acidity of different feijoa cultivars grown in different regions. Where U= 'Unique', OS= 'Opal Star', and P= 'Pounamu' cultivars. Mat= Matamata, Otaki= Otaki and Ble= Blenheim regions. Bars represent SDEV values.

3.3.9. Flotation

Unfortunately flotation was unsuitable for the separation of different maturity stages of both cultivars 'Unique' and 'Opal Star' feijoa as all fruit tested floated. In fact detailed measurements for respiration showed feijoa density = 0.98. A similar result was reported with 'Apollo' feijoa (Clark et al., 2005). The variable amount of intercellular airspaces in the flesh of feijoa fruit (Clark et al., 2005) probably caused this problem in the present results. In other fruit such as avocado, variation in seed to flesh volume ratio, and the variable composition of oil constituents precluded density sorting as a useful technique in some products (Clark et al., 2007). In addition, 'Opal Star' is self-sterile and needs cross pollination; it has more problems of hollow locules than other cultivars tested (Figure 3.12). Hollow locules were not a significant problem in 'Unique'.

Figure 3.12 Hollow locules in 'Opal Star' cultivar resulting from poor pollination.

3.3.10. Relationship of Visual Grading with Different Quality Attributes

3.3.10.1. TSS

As feijoa fruit develop on the tree, many attributes change including size, chemical composition and respiration rate. There was a very weak relationship between TSS and internal maturity rating for both cultivars (Figure 3.13). El Bulk et al., (1997) mentioned that for guava Brix value could not be used to indicate actual sugar content of fruit, as Brix is affected by many compounds in the juice. TSS is not a simple indicator of sweetness only, acids, salts, nitrogenous compounds and other minor soluble such as water-soluble vitamins may also be present. Thus TSS is not always helpful in determining the actual sugar content. As TSS remained unchanged with

maturity stage in feijoa, TSS could not be used as a maturity index, a result that agrees with Gaddam et al., (2004).

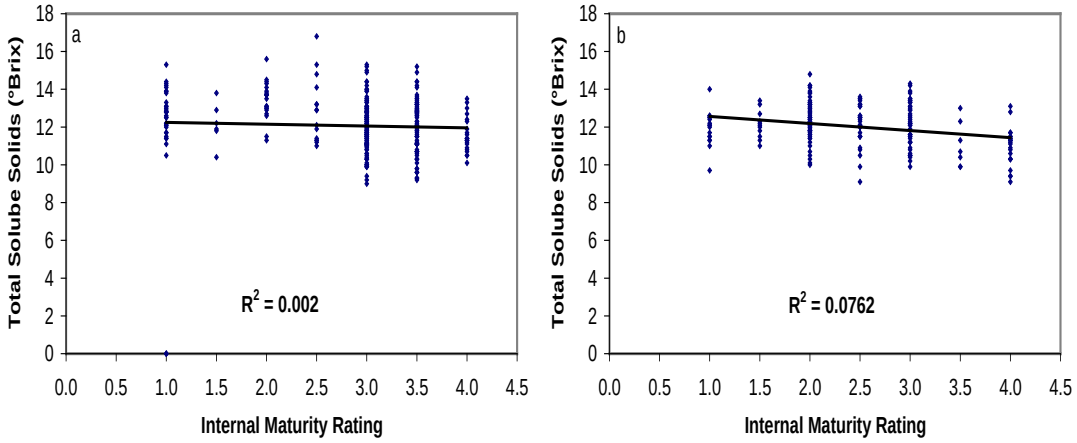


Figure 3.13 Relationship between internal maturity rating and total soluble solids of (a). 'Unique' and (b). 'Opal Star' from different regions.

3.3.10.2. Acidity

As there is a clear effect of fruit maturity on titrable acidity (section 3.2.8), it is justified in doing more detailed analysis of all measured fruit by internal visual grading. Reduced acidity correlated with increased internal maturity rating (Figure 3.14), but the correlation was weak. The correlation for 'Unique' (R^2 = 0.52) was better than for 'Opal Star' (R^2 = 0.32). Despite these correlations the wide spread of acidity between individual fruit at the same maturity prevents titratable acidity from being used as a maturity index. According to Wiryawan et al., (2002), 70% of the variation in titratable acidity in feijoa is a result of batch to batch difference, and 30% because of individual fruit difference. Therefore TA is not likely to be worth developing into a non-destructive test of maturity. However, TA in combination with firmness might improve the estimate of maturity if it could be measured non-destructively. It is possible that NIRS could be used to measure the compounds responsible for TA; so this technique needs to be tested in the future for feijoa fruit.

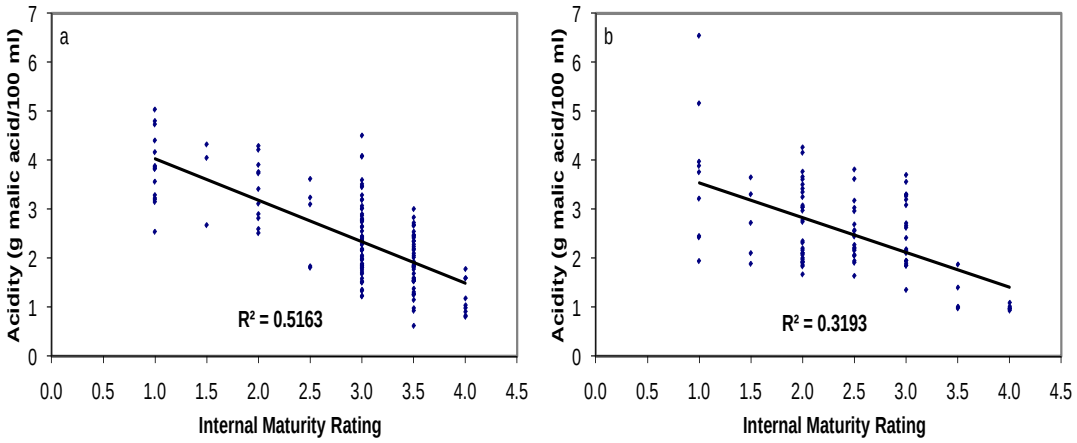


Figure 3.14 Relationship between internal maturity rating and acidity of (a). 'Unique' and (b). 'Opal Star' from all regions.

3.3.10.3. Firmness

Many studies have used acoustic firmness to measure fruit quality e.g. for apple representative studies include those of Cooke (1970), Finney (1971) Yamamoto et al., (1980), Chen and De Baerdmaeker (1993), De Belie et al., (2000) and Harker et al., (2008). According to Chen and Sun (1991) and Tollner et al., (1993) there was a high correlation between resonance frequency and quality and maturity of fruit. In this study, the correlation between combined data for 'Unique' and 'Opal Star' sourced from different regions for both compression and acoustic firmness indicated that the R^2 of 'Unique' was higher than for 'Opal Star' using both devices (Figure 3.15). The R^2 of compression firmness was higher than acoustic firmness for both cultivars.

There was a reasonable correlation between the two methods for both cultivars (R^2 = 0.6 and 0.5) for 'Unique' and 'Opal Star' respectively (Figure 3.16). Similar results have been reported for kiwifruit (Schotsmans and Mawson, 2005) where the correlation was R^2 = 0.73. It appears that compression tests with firmer fruit give more relevant results than acoustic firmness. Acoustic firmness has previously been found to be more reliable in evaluating changes in tissue firmness during long-term storage (Molina-Delgado et al., 2009).

To determine if fruit from each region followed an established pattern, a detailed analysis of all cultivars from each region was undertaken. The relationships between

acoustic firmness (AF), compression firmness (CF) and maturity index (visual grading) varied greatly between the batches (Figure 3.17). This variation could arise from many factors such as cultivar differences in cellular organisation and fruit size, cell composition and turgor. The compression firmness analyser was more reliable in determining fruit maturity than acoustic firmness especially with 'Unique' sourced from Rotorua and Matamata. All cultivars from different regions followed a similar trend for both compression and acoustic firmness except for 'Opal Star' from Matamata where the correlation between acoustic firmness and internal maturity was very low ($R^2 = 0.0008$), this may have been because of the inappropriate method used to measure acoustic firmness as explained earlier. In terms of 'Opal Star', acoustic firmness after modification could estimate fruit firmness from Blenheim ($R^2 = 0.511$). This could be due to better sensitivity of the device towards maturity in the larger 'Opal Star' fruit sourced from Blenheim, (average fruit weight (91 g) compared with (61 g) from Matamata).

A low or moderate correlation using acoustic or compression firmness analyser does not necessarily mean these techniques are impractical for measuring fruit maturity; more detailed studies need to be carried out to understand the reasons behind the variability obtained before they should be discarded. Gaddam et al., (2004) found a reasonable correlation between acoustic firmness and maturity index ($R^2 = 0.59$) with 'Unique' fruit from Taranaki. In 2008, a weak correlation was found with 'Unique' using three devices; Sinclair, acoustic and compression firmness (Figure 3.18). Compression firmness and acoustic firmness appeared better correlated ($R^2 = 0.50$) than did compression firmness and the Sinclair device ($R^2 = 0.47$) (Figure 3.19). The bench top low-mass impact firmness device (Sinclair) showed potential to assess fruit quality of avocado (Shmulevich et al., 2003) and stone fruit (Valero et al., 2007) non-destructively. The Sinclair method seems particularly promising for stone fruit, and it was used to classify fruit such as plums, nectarines and peaches into two categories of firmness ("ready to eat" and "others" or "mature and immature" and "others") but when three categories of firmness was used fruit segregation was reduced (Valero et al., 2007). However in this study, Sinclair was not useful in determining maturity stages of feijoa fruit and this may have been because of the small fruit mass of feijoa.

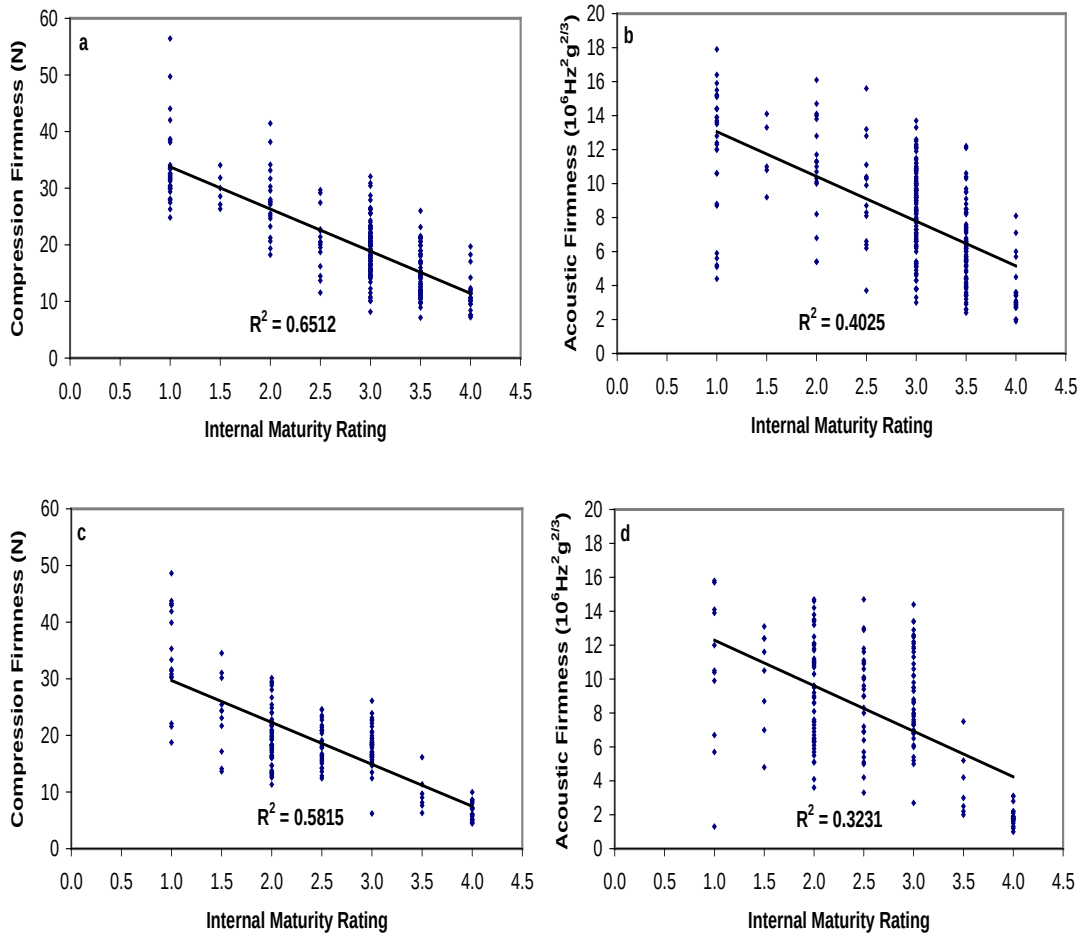


Figure 3.15 Relationship between compression firmness (a and c) and acoustic firmness (b and d) with internal maturity rating of two cultivars sourced from different regions: (a and b) 'Unique' sourced from Matamata, Otaki and Rotorua, (c and d); 'Opal Star' from Blenheim and Matamata.

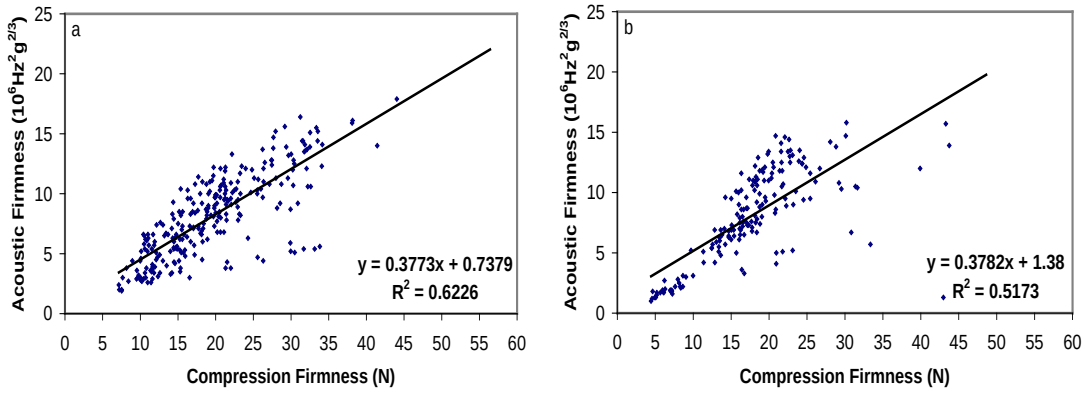


Figure 3.16 Relationship between compression firmness and acoustic firmness of two cultivars; (a). Unique and (b). Opal Star sourced from different regions.

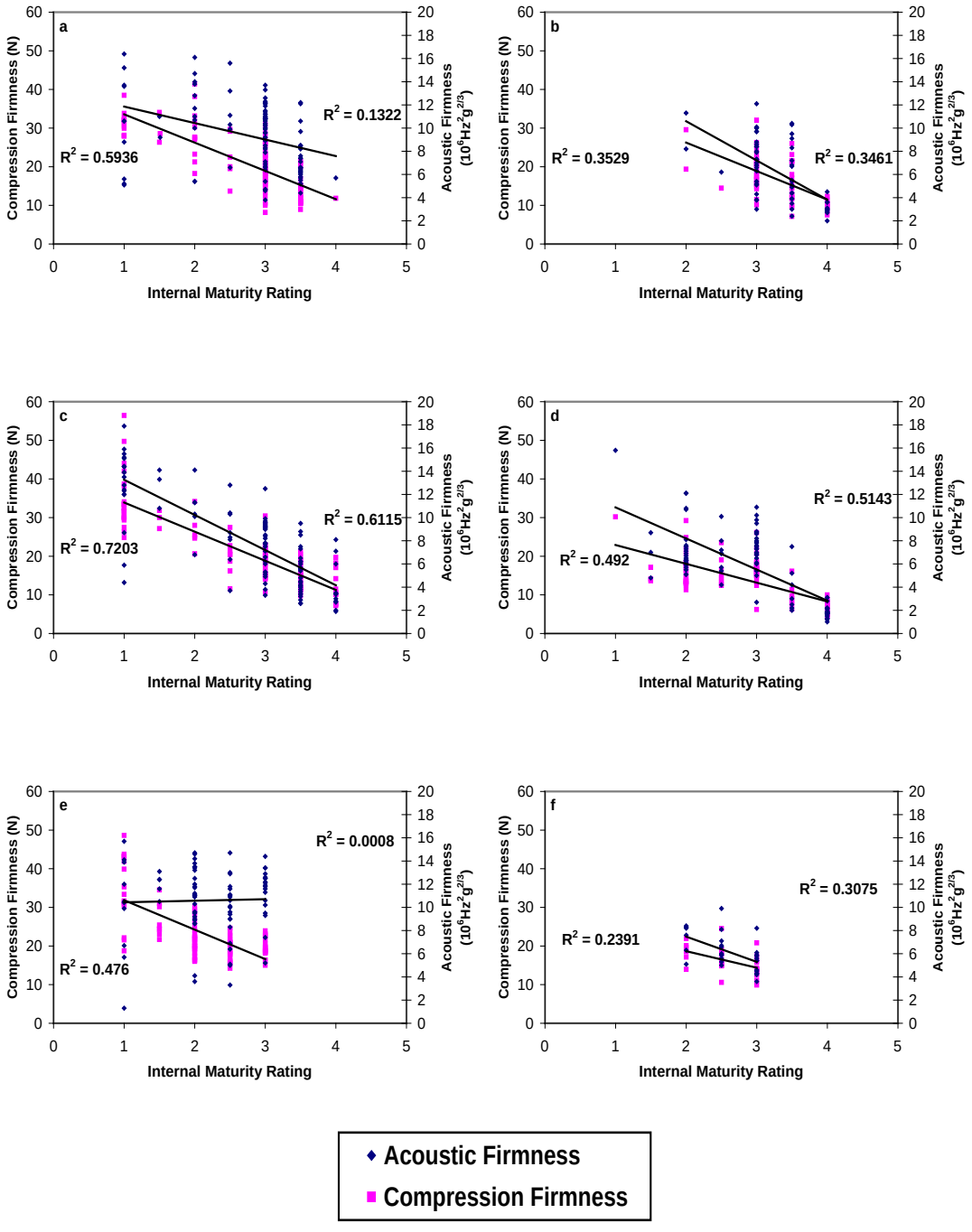


Figure 3.17 Relationship between acoustic firmness, compression firmness with internal maturity rating of different cultivars sourced from different regions; (a). Unique-Matamata, (b). Unique-Otaki, (c). Unique-Rotorua, (d). Opal Star-Blenheim, (e). Opal Star-Matamata, (f). Pounamu-Blenheim.

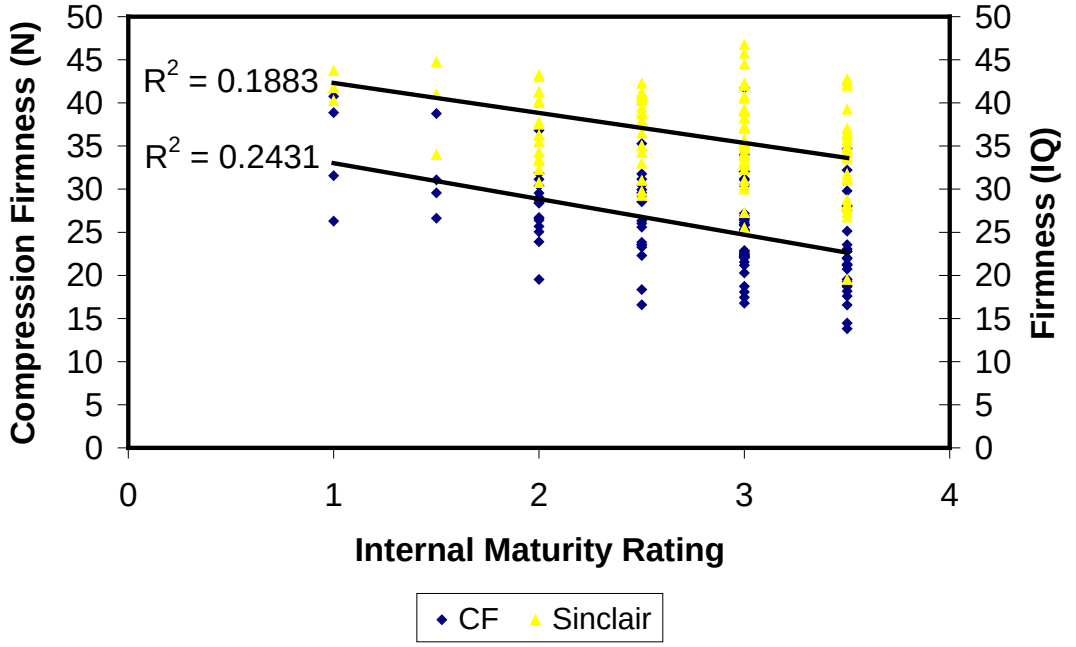


Figure 3.18 Relationship between compression firmness and Sinclair with internal maturity rating of 'Unique' cultivar sourced from Matamata.

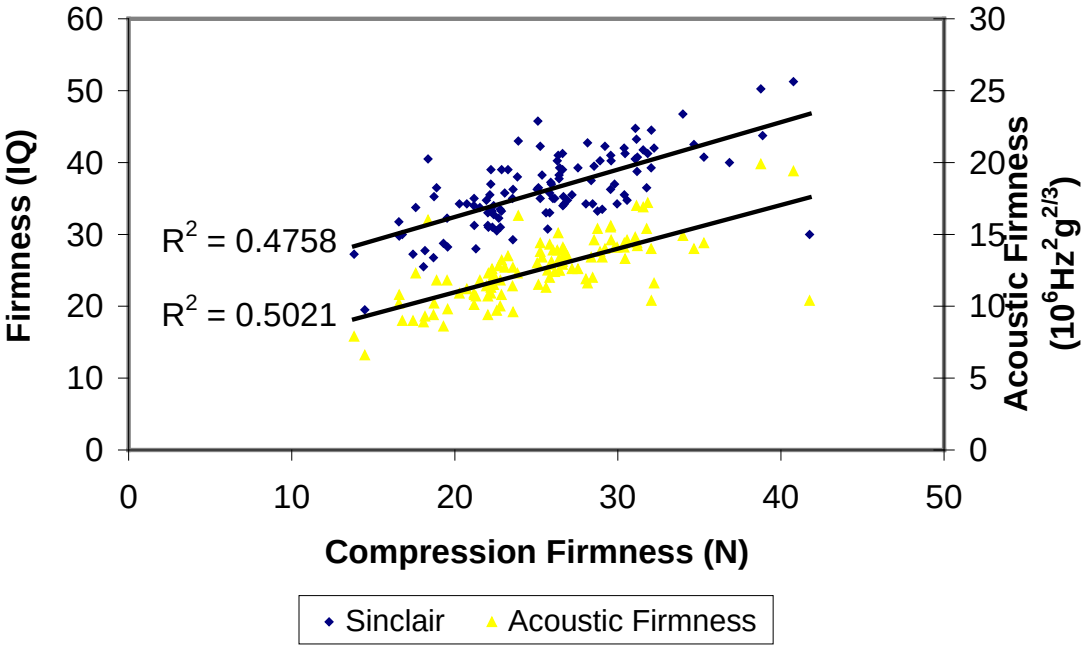


Figure 3.19 Correlation between compression firmness with Sinclair and acoustic firmness of 'Unique' cultivar sourced from Matamata.

3.4. CONCLUSIONS

There are many factors leading to heterogeneity of fruits within a tree that may arise because of size, colour, chemical composition and physiological stage. Some of these factors are: positioning of fruit along the shoot, number of leaves per fruit, light intensity and flowering time and fruit set (Zerbini, 2008). In feijoa, there is usually a large variation among individual fruit. This variation could be attributed to the relatively long time of fruit set that leads to great variation in fruit maturity.

Differences were found between the pickers for commercial pack houses to identify the optimum harvest maturity of feijoa fruit. Thus it is very important to find a non-destructive and objective tool to assess fruit maturity. Compression firmness was more reliable than acoustic firmness in determining maturity stages of different feijoa cultivars. Acoustic firmness was found to be reliable for some feijoa cultivars. The Sinclair device was not suitable for measuring maturity index of feijoa fruit tested. Investigative work with MRI gave a good indication of the potential of this technique to identify maturity stages of fruit. Significant changes in T_2 and ΔH_2 did occur; if a device could be designed that allowed a rapid test to measure these properties, then it is possible that it could be used to identify maturity. In general, non-destructive techniques used in this research highlighted the need for further work to understand why such large differences between cultivars and regions occurred. Total soluble solids, dry matter and titratable acidity were not helpful in determining maturity stages of feijoa fruit. There was no significant reduction in TSS or dry matter with maturity, but there was a clear reduction in titratable acidity similar to other fruit. If significant compositional changes do occur with advancing fruit maturity, then it is possible that a non-destructive technique such as Near Infrared Spectroscopy (NIRS) may be able to detect such changes but further studies are required to establish a meaningful relationship.

CHAPTER 4
INVESTIGATIONS ON EXTENDING SHELF LIFE OF FEIJOA FRUITS WITH COOL STORAGE CONDITIONS

4.1. INTRODUCTION

Cool storage plays a very important role in extending storage life of horticultural produce by reducing rates of respiration, transpiration and metabolic activity. In order for feijoa to be exported to distant countries it must be stored for relatively long times required for transport by sea freight rather than the more expensive air freight. Storage temperature is the key factor in maintaining the quality and extending storage life of feijoas by preventing deterioration and avoiding chilling injury. It is very important to determine the length of time that quality of feijoa cultivars can be maintained when stored at low temperatures. The recommended storage temperature for feijoa is 5 ± 1°C (Kader, 2006). Feijoa fruit stored at 4°C can be stored for 4 weeks with a subsequent shelf life of 5 days at 20°C (Klein and Thorp, 1987). Different feijoa cultivars have different storage potential. Klein and Thorp (1987) found that 'Unique' fruit did not store well at 4°C and develop flesh browning after 7 days of storage whereas other cultivars such as 'Apollo', 'Gemini', 'Opal Star', 'Pounamu' and 'Triumph' stored well for 4 weeks and with 5 days of subsequent shelf life. Despite the good external appearance of the fruit, fruit maybe over-mature when cut open. Feijoa fruit stored at 0°C exhibited chilling injury, which manifested as discoloration of the fruit surface from green to brown to black with sunken tissue followed by internal browning of flesh (Klein and Thorp, 1987). The objective of this study was to investigate the response of different cultivars of feijoa sourced from different regions/growers to cool storage at 4°C and assess their shelf life at ambient temperature.

4.2. MATERIALS AND METHODS

Three cultivars of feijoa fruit, 'Unique', 'Opal Star' and 'Pounamu', were selected from three different production regions within New Zealand: Matamata, Otaki and Blenheim. The cultivars were harvested on different days (Table 2.2) and it took 1-2 days for fruit to be transported by courier to the laboratory at Massey University, Palmerston North. Fruit were harvested by experienced pickers using the touch pick method in an attempt to ensure optimum harvest maturity. For each cultivar/region 180-234 fruit were harvested. Each batch of 30-39 graded mature fruit/cultivar/region was stored at 4°C for varying periods and then assessed for shelf life at 20°C. The storage periods tested were 2, 4, 6, 8 and 10 weeks of storage. During shelf life assessment, fruit were held at 20°C and 10-13 fruit from each batch of 30-39 fruit were assessed after 1, 4 or 7 days at 20°C.

Assessment included non-destructive measurements such as mass, acoustic firmness, and compressive firmness, and destructive measurements such as total soluble solids and visual grading (internal maturity rating) as outlined in chapter 2.

4.3. RESULTS AND DISCUSSION

4.3.1. General Observations

Feijoa fruit showed no signs of chilling injury when stored at 4^{o}C for 10 weeks, indicating that this temperature could be used safely for storing feijoa fruit as reported by Klein and Thorp (1987). Additionally, there were less than 13% of fruit with external disorders such as decay, fruit softening and skin deterioration after 6 weeks storage. Different cultivars responded differently to the low temperature: after 6 weeks of storage at 4^{o}C followed by 1 day at 20^{o}C, some rots were seen in 'Opal Star' and 'Pounamu' sourced from Blenheim, whereas no rots appeared on the same cultivars from other regions. This difference may have occurred because of the differences in the extent of physical damage sustained to fruit during harvesting and handling on the different orchards. Total soluble solids (TSS) decreased slowly during the shelf life assessment period at 20^{o}C. Colour of fruit did not change during cool storage at 4^{o}C. However, in cultivars such as 'Unique' and 'Opal Star' there was an observable change in colour from dark green to yellow green in fruit from

Matamata removed from 4°C at week 4 and held for 7 days at 20°C (Figure 4.1), in other cultivars and regions the change in colour was less obvious.

Figure 4.1 Change in colour from dark green to light green or yellow green in 'Opal Star' fruit stored at 4°C for 4 weeks followed by 7 days at 20°C.

4.3.2. Weight loss

Weight loss is an important contributor to quality deterioration during storage. There was a significant difference in fruit weight of the same cultivar delivered from different regions ($P < 0.0001$), and variation within batches was also large. During storage at 4°C total weight loss increased with time from less than 1% during the first week to about 5% after 6 weeks (Figure 4.2). When fruit were transferred to 20°C, weight loss rapidly increased to more than 5% from day 1 to day 7. This increase in weight loss within a short period of time after the fruit has been transferred could be due to an adverse effect of higher temperature on cellular integrity thus increasing the membrane permeability (Saltveit and Morris, 1990) or could also be due to the increased driving force (differences in vapour pressure attributed to the temperature and relative humidity). According to Kader (1992) fruit such as tomato become softer and less juicy when they lose more than 5% of their weight. For feijoa, fruit become softer but there was no obvious change in amount of juice. It is worth to test in the future if weight loss has an effect on amount of expressible juice. Different cultivars sourced from different regions or growers exhibited a similar trend in percentage weight loss during subsequent shelf life assessment at 20°C for day 1, 4 and 7 (Figure 4.2).

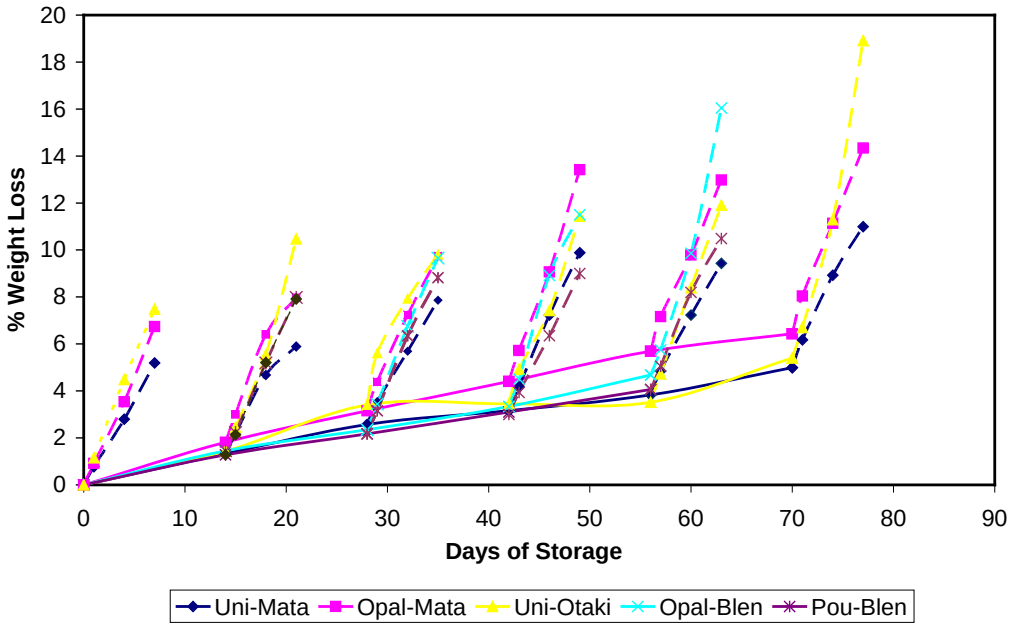


Figure 4.2 Weight loss of different cultivars of feijoa during storage at 4°C (continuous lines) and after 1, 4 and 7 day (dotted lines) at 20°C. Each data point on the continuous line represents an average of 30-39 fruit, while the dotted line represents an average of 10-13 fruit.

4.3.3. Internal Maturity Rating

Comparison of the rates of change of internal maturity rating among different cultivars from different growers indicates that the rate of change of internal maturity rating of feijoa fruits increased slowly during subsequent shelf life assessment in the first few weeks and increased rapidly after 6-8 weeks in storage (Figure 4.3) presumably as respiration rate and ethylene production also increased leading to enhanced ripening and deterioration of the fruit.

If we assign internal maturity rating of 4 to be the limit of acceptability then the maximum storage period differs between the cultivars. The internal maturity rating of 4 was selected because fruit eating quality is considered to be the best at this stage; fruit above 4 rating are over-mature and tend to turn brown in some cultivars. For instance, 'Unique' and 'Opal Star' from Matamata could be stored up to 42 days (six weeks) with seven days of subsequent shelf life (Figure 4.3 a & b), whereas 'Opal Star' and 'Pounamu' from Blenheim could be stored for only 28 days (four weeks) and still retain seven days of subsequent shelf life (Figure 4.3 c & d). 'Unique' from

Otaki could only be stored up to 14 days (two weeks) (Figure 4.3 e). These batch differences in length of storage could be due to the different history of the fruit before storage, as it is well known that cold storage can only maintain and extend the storage life of good quality fruits. Extending the shelf life of horticultural commodities depends mainly on production history, maturity stage at harvest and environmental conditions (Kader, 1999).

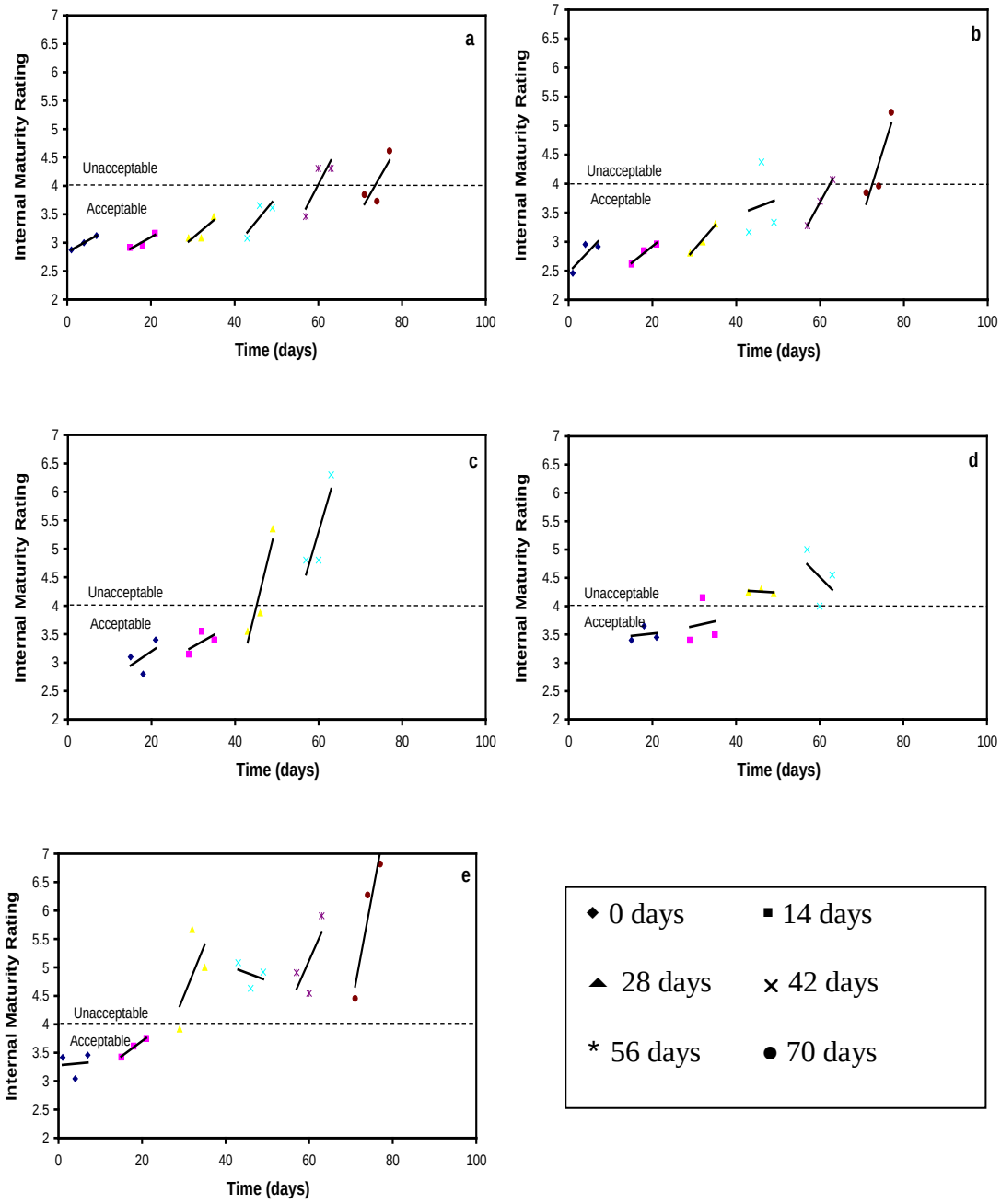


Figure 4.3 Internal maturity ratings of feijoa cultivars sourced from different regions / growers during shelf life assessment at 20°C after storage at 4°C for 0,2,4,6,8 or 10 weeks. (a). Unique-Matamata, (b). Opal Star-Matamata, (c). Opal Star-Blenheim, (d). Pounamu-Blenheim, (e). Unique-Otaki. Each data point represents the average of 10-13 fruit.

4.3.4. Firmness

Acoustic firmness and compression firmness readings produced a consistent softening trend with time of storage at 4°C (Figure 4.4). This is a normal phenomenon as the integrity of cells will be affected at higher temperature and fruits will become softer. Also, fruits ripen more quickly at higher (ambient) temperatures. During shelf life assessment at 20°C, fruit firmness decreased more from day 4 to day 7 than from day 1 to day 4. There were significant differences between the same cultivar sourced from different regions in terms of acoustic and compression firmness ($P < 0.0001$), the differences were also observed during the storage period.

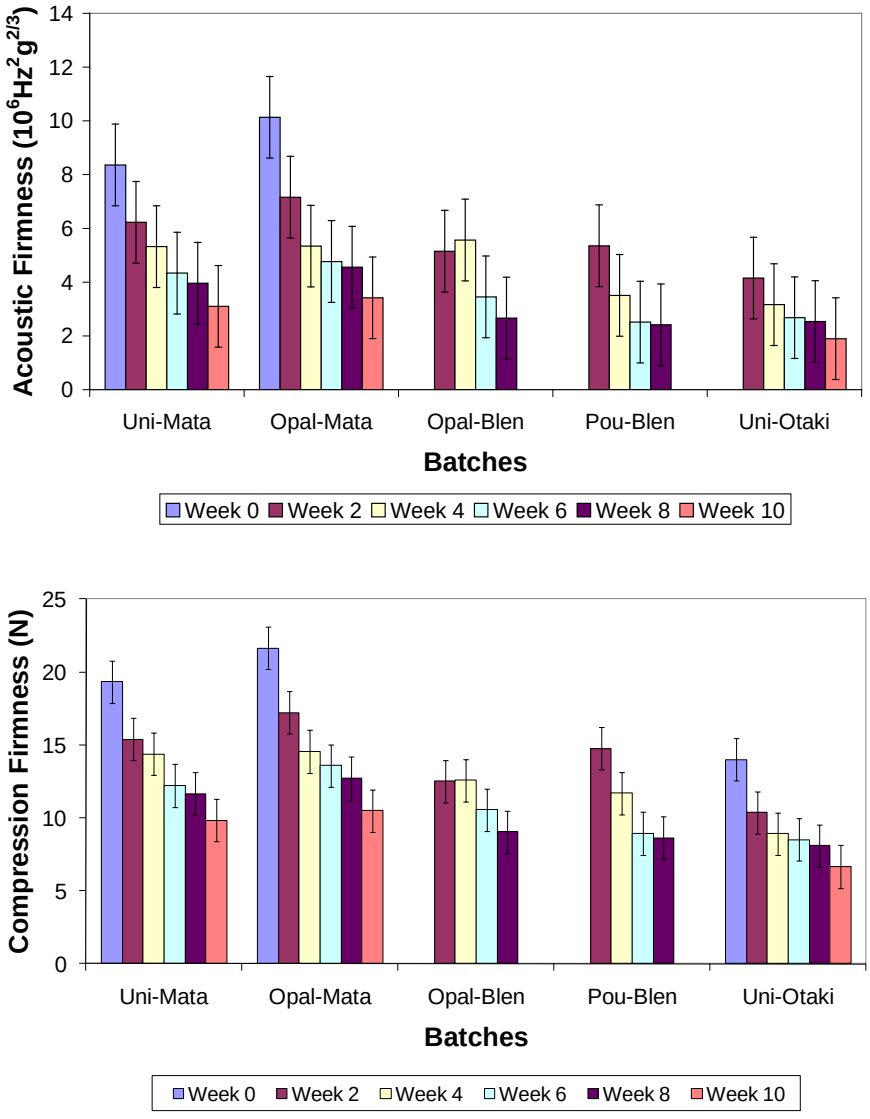


Figure 4.4 Average acoustic and compression firmness of different cultivars of feijoa stored at 4°C followed by 1 day at 20°C. Each bar represents average of 30-39 fruit. Vertical bars represent $LSD_{0.05}$.

4.3.5. Total Soluble Solids

There was an apparent trend of slight reduction in TSS during storage at 4°C and subsequent shelf life assessment at 20°C for the entire period of storage, from approximately 12 to 10 °Brix, but this difference was not statistically significant (Figure 4.5). Similar results were obtained by Gaddam et al., (2004), where there was no significant difference between TSS among different stages of maturity.

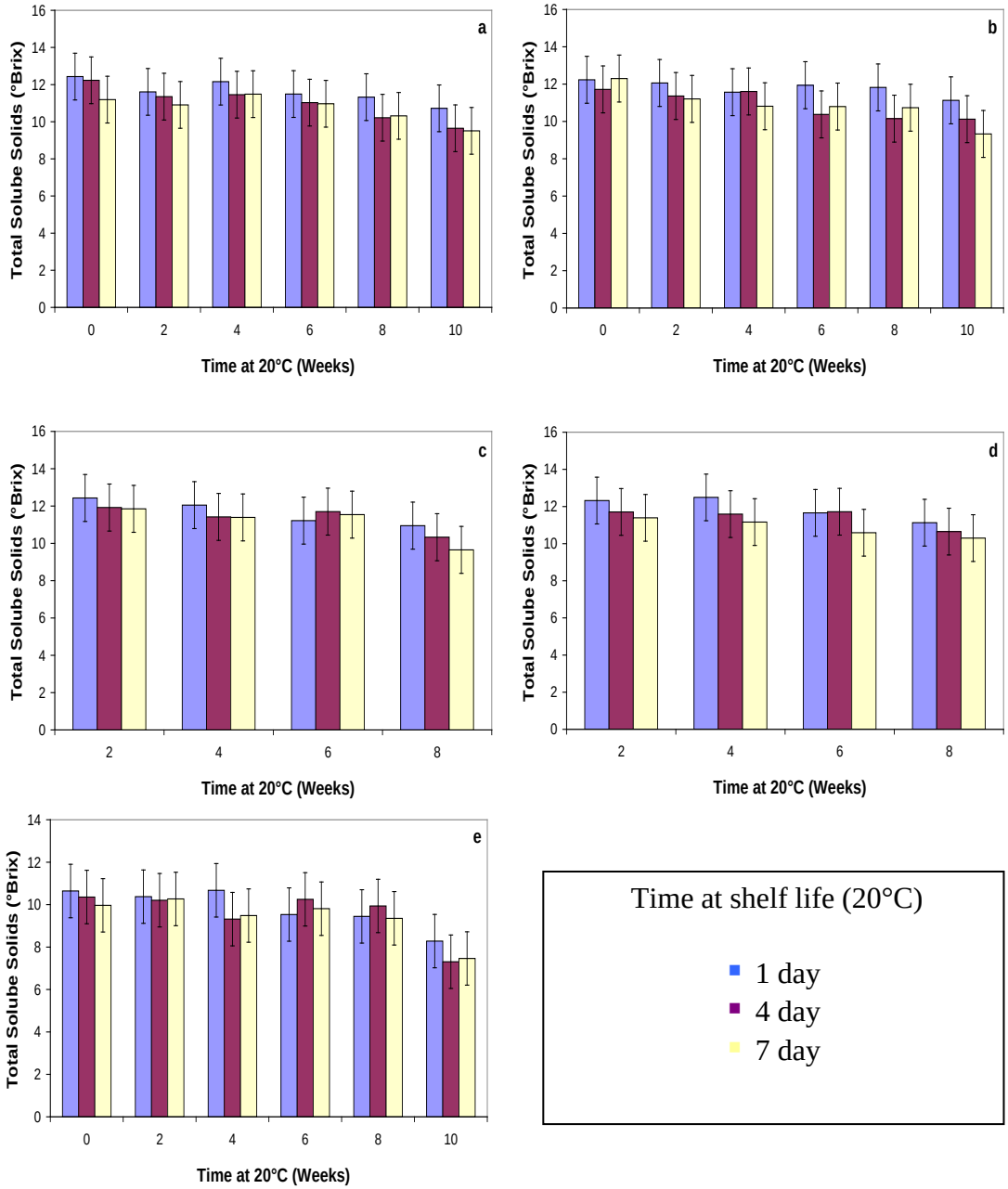


Figure 4.5 Changes in total soluble solids of different cultivars of feijoa stored at 4°C followed by 1, 4 and 7 days shelf life at 20°C. Each bar represents the average of 10-13 individual fruit. (a). Unique-Matamata, (b). Opal Star-Matamata, (c). Opal Star-Blenheim, (d). Pounamu-Blenheim, (e). Unique-Otaki. $LSD_{0.05}$ = 2.516.

4.4. CONCLUSIONS

Feijoa fruit stored at 4°C maintained better quality for longer period of time compared to storage at ambient temperature (20°C). At 4°C, the weight loss of different feijoa cultivars performed similarly, with slow increases from 1% to 5% from week one to week six. At 20°C there was a rapid increase in weight loss to more than 5% within one week of storage. The rate of change of internal maturity rating also increased progressively during shelf life assessment at 20°C after 6-8 weeks of storage. Both acoustic and compression firmness values decreased with time. There was a trend for a reduction in TSS during storage at 4°C and subsequent shelf life assessment at 20°C, but this was not statistically significant in this experiment. Although fruit showed no sign of internal chilling injury symptoms for the entire period of storage as in Thorp and Bieleski (2002), there was a small percentage of external deterioration recorded towards the end of the storage period.

The maximum length of storage before unacceptable loss of quality varies between cultivars sourced from different regions depending upon pre-and post-harvest production history, environmental condition and maturity stage of fruit at harvest. Thorp and Klein (1987) were able to store some commercial New Zealand feijoa cultivars at 4ºC for up to 4 weeks and retain subsequent shelf life of 5 days at 20°C, including 'Apollo', 'Gemini', 'Marion', and 'Triumph', whereas they claimed 'Unique' developed discolouration of flesh around the locules after only one week of storage at 4ºC and one day at 20ºC. In this experiment 'Unique' could be stored for longer periods depending upon the condition of the fruit before storage. Different cultivars show different response to cold storage. Some cultivars such as 'Opal Star' have the potential to be stored for six weeks or more. 'Unique' also has the potential to be stored for up to four weeks without internal browning. More advanced techniques, such as controlled or modified atmosphere, need to be explored in order for feijoa fruit to be exported to international markets.

CHAPTER 5
EFFECT OF CONTROLLED ATMOSPHERE STORAGE ON QUALITY CHANGES OF FEIJOA FRUIT

5.1. INTRODUCTION

The importance of controlled atmosphere (CA) or modified atmospheres (MA) in maintaining quality during prolonged postharvest storage of many fruits and vegetables by reducing respiration rate, endogenous ethylene production and other metabolic activities is well known. CA can very effectively retard fruit ripening, but the choice of atmosphere is very important. For example CA conditions ideal for 'Gala' apples are inappropriate for 'Braeburn' apples (Kupferman, 2001), and CA varies for cultivars grown in different ecological conditions (Erkan and Wang, 2006). It is therefore essential to determine the best CA conditions for each variety of fruit.

Feijoa (*Acca sellowiana*) is a distinctive subtropical fruit grown in most parts of New Zealand. There are approximately 200 commercial orchards producing 500 tonnes of fruit for the fresh and processing markets. Export of feijoas is limited by the need to use air freight. The ability to export by sea would reduce transport costs and allow export of larger volumes of product. Feijoa fruit lose quality rapidly after harvest and fruit are sensitive to chilling temperatures. Guava (*Psidium guajava* L.) is similar to feijoa in size, shape and taste and both fruit are considered to be very sensitive to injuries that occur during postharvest operations. Current best storage practice is to keep fruit at 5°C ± 1°C with optimum relative humidity of 90 to 95% (Kader, 2006). In order for feijoa to maintain quality during long distance sea freight, a consistently reliable storage period of at least six weeks is required.

Controlled or modified atmosphere storage provides an option to extend the storage life of subtropical and tropical fruits (Erkan and Wang, 2006, Yahia, 2006, Kader, 2003, Yahia, 1998). Both technologies have been adopted for commercial storage of some horticultural commodities (Erkan and Wang, 2006, Yahia, 2006). Very little published information is available on responses of feijoa to CA. Thorp and Bieleski

(2002) reported that ripening was delayed during storage and subsequent shelf life assessment at room temperature, when feijoa cultivar 'Triumph' was stored at two levels of CA (2.1 or 4.8% O_2 with 0% CO_2). In another work by Galvis-Venegas (2003), feijoa fruit showed potential to maintain fruit quality for longer periods after harvest when stored in modified atmosphere packages flushed with 8% O_2 and 5% CO_2 at 6°C. In work carried out after the current study, East et al., (2009) found that for 'Unique' feijoa, storage at low O_2 and low CO_2 was the best treatment to reduce weight loss and delay colour change compared to regular air at 5°C. Overall scarcity of information on responses of feijoas to CA storage has led to this study of the influence of five different CA mixtures on feijoa, (cv. 'Unique' and 'Opal Star') stored at 4°C. The objective was to quantify the response of 'Opal Star' and 'Unique' feijoa to CA at 4°C using O_2 concentrations as previously tested (Thorp and Bieleski, 2002), but adding 0 or 3% CO_2 which has been tested before for guava (Singh and Pal, 2008). The outcome should assist producers to export feijoa fruit longer distances by sea freight to international markets.

5.2. MATERIALS AND METHODS

This experiment was conducted in 2008 to study the influence of selected concentrations of O_2 and CO_2 on postharvest quality of feijoa. Fruit were harvested in early April for 'Unique' and late April for 'Opal Star' and transported in unlined trays of 30-39 fruit to the laboratory, Massey University, Palmerston North on the following day. Fruits were then randomized between treatments and initial fruit measurements were taken before subjecting them to different CA concentrations in PVC tubes (volume = 0.0135 m^3) at 4°C (Figure 5.1).

Five replicates each of 12-15 fruit of 'Opal Star' (≈ 70 g weight) or 'Unique' (≈ 55 g weight) feijoa, were placed into loose nylon mesh bags that facilitated removal of fruit samples from the tube. The bags were then placed into one of fifty PVC tubes. Tubes were exposed to one of 5 different atmospheres: (0% CO_2; 2% O_2), (3% CO_2; 2% O_2), (0% CO_2; 5% O_2), (3% CO_2; 5% O_2) and air. Gas mixtures were generated by mixing flows of dry air (as a source of O_2), nitrogen (N_2) and carbon dioxide (CO_2, BOC, Palmerston North, New Zealand). Before entering the PVC containers, the gas

mixtures were humidified by bubbling through jars containing glycerol and water solutions to deliver gas at approximately 95% RH and a flow rate of 0.2 $L.min^{-1}$.

Fruits were stored at 4°C for up to 10 weeks. One bag (12-15 fruit) of feijoas from each treatment was removed from the PVC tubes after weeks 4, 6, 8 and 10 and placed at 20°C for 7 days to evaluate fruit quality.

Quality assessments included non-destructive measurements such as mass, respiration rate, ethylene production, acoustic firmness, and compression firmness, and destructive measurements such as total soluble solids (TSS) and visual grading as mentioned in chapter 2. Some fruit were stored in their trays without liners in the same cold room to observe weight loss under commercial storage conditions.

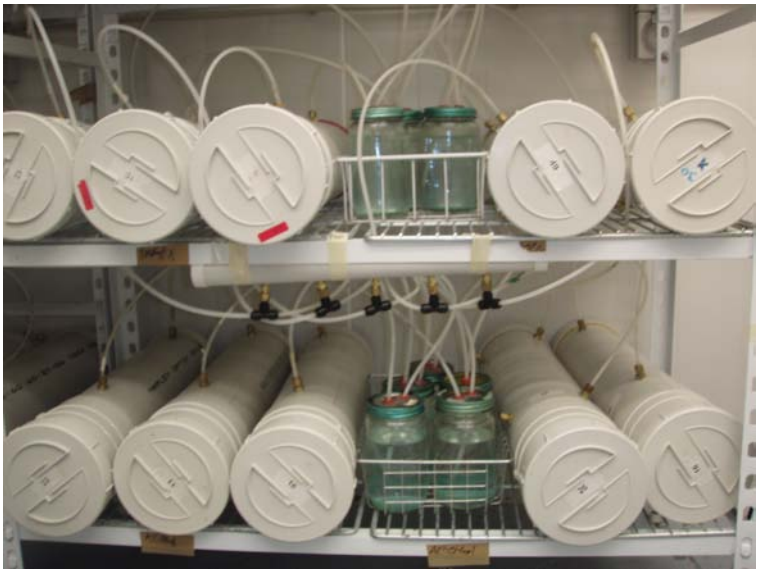


Figure 5.1 PVC tubes used to store feijoa under CA condition.

5.3. RESULTS AND DISCUSSION

5.3.1. Weight Loss

Postharvest weight loss results from a combination of transpiration and respiration, and is dependent on the ratio of fruit surface area to volume, permeability of skin to water vapour, relative humidity and temperature (Maguire et al., 2001). An effective method to reduce water loss from produce is by reducing the vapour pressure difference between the produce and the air by increasing the relative humidity of the

air (Wills et al., 2007). Therefore it is not surprising that all fruit stored in PVC tubes with humidified flow lost less weight (1.5-2%) than fruit in commercial trays without liners (5-6% weight loss) over the same storage period. For the entire period of storage (10 weeks) at CA conditions, there was about 1.5-2% of fruit weight lost at 4°C (Figure 5.2). The weight loss varied depending on the CA conditions applied. The fruit weight loss of 'Opal Star' appeared slightly higher (1.9%) than 'Unique' (1.6%) at 10 weeks of storage averaged across all the treatments (Figure 5.2) which could be due to differences in fruit size, texture and water vapour permeability. 'Opal Star' fruit are medium to large in size with a smooth skin, whereas 'Unique' fruit are small to medium in size with a rough skin (Figure 5.3) (Thorp and Bieleski, 2002), so weight loss differences may be because of differences in fruit size and water vapour permeability of the skin. Small fruit have a higher surface area to volume ratio and hence lose water faster than a larger fruit if all other factors are equal (Wills et al., 2007). However, fruit size did not appear to be the reason for different weight losses in this study as 'Opal Star' (the larger fruit) lost proportionally more weight than 'Unique' suggesting that there may be a difference in water vapour permeability between the two cultivars.

The weight loss in air (control treatment) in both cultivars was significantly higher than all CA treatments at week 8 (Figure 5.2) and during subsequent period at 20°C (Figure 5.4). CA when combined with low temperature led to reduced respiration and ethylene production, a delay in softening and reduced compositional changes related to ripening and senescence (Erkan and Wang, 2006).

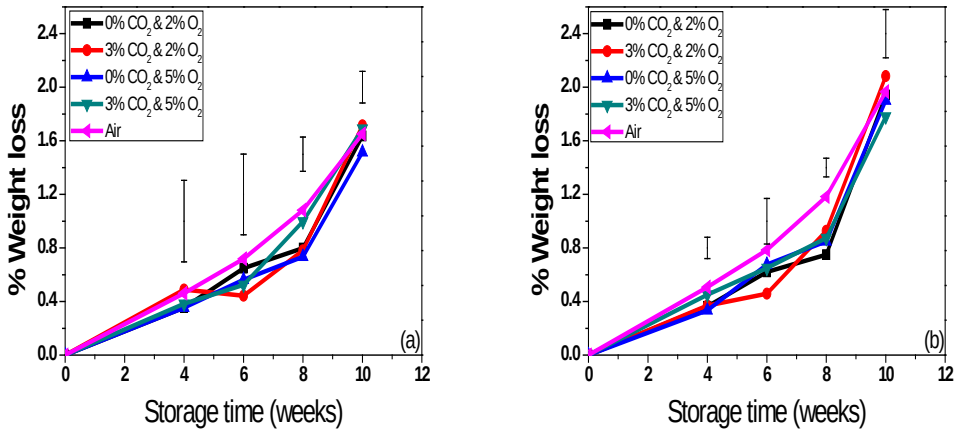


Figure 5.2 Weight loss in two feijoa cultivars (a). 'Unique' and (b). 'Opal Star' stored at 4°C in five different controlled atmosphere conditions. Each data point represents 25 and 20 fruit for 'Unique' and 'Opal Star' respectively. Bars represent $LSD_{0.05}$.

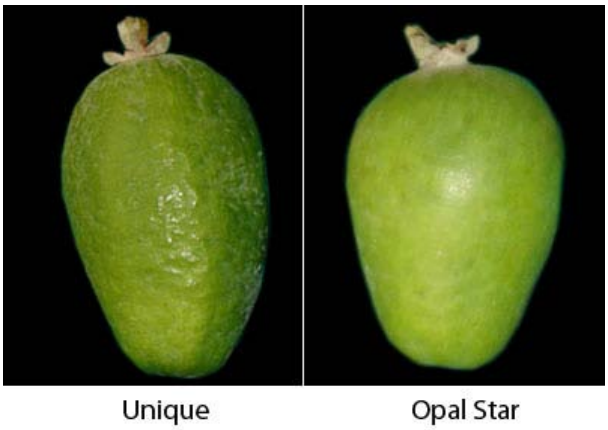


Figure 5.3 Differences between 'Unique' and 'Opal Star' in surface texture.

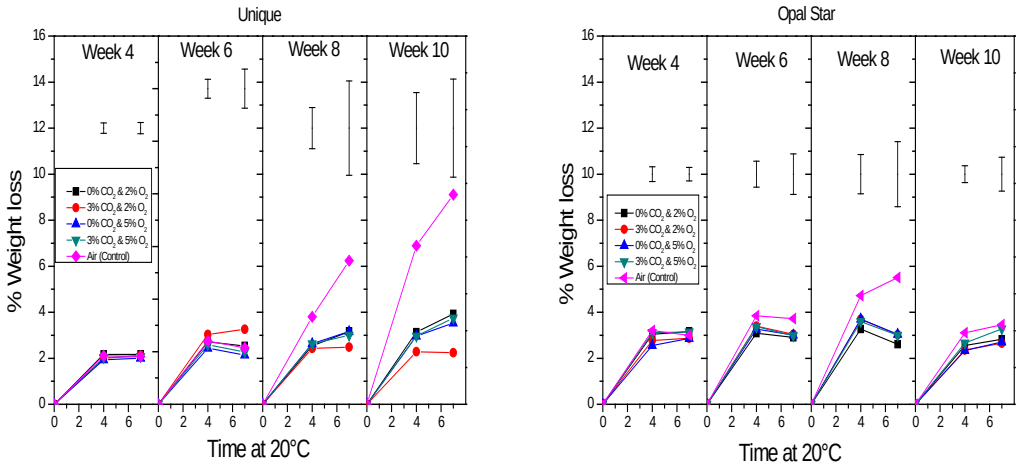


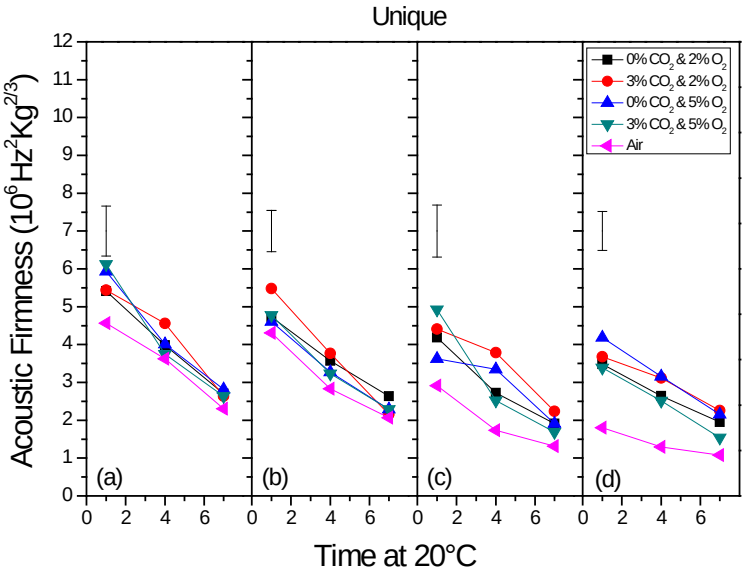
Figure 5.4 Weight loss in ('Unique' and 'Opal Star' feijoa cultivars) at 20°C after storage for 4-10 weeks at 4°C in different controlled atmosphere conditions. (The % weight loss at days 4 and 7 were relative to fruit weight at day 1 after removal from cold store at 4°C). Each data point represents 25 and 20 fruit for 'Unique' and 'Opal Star' respectively. Bars represent $LSD_{0.05}$.

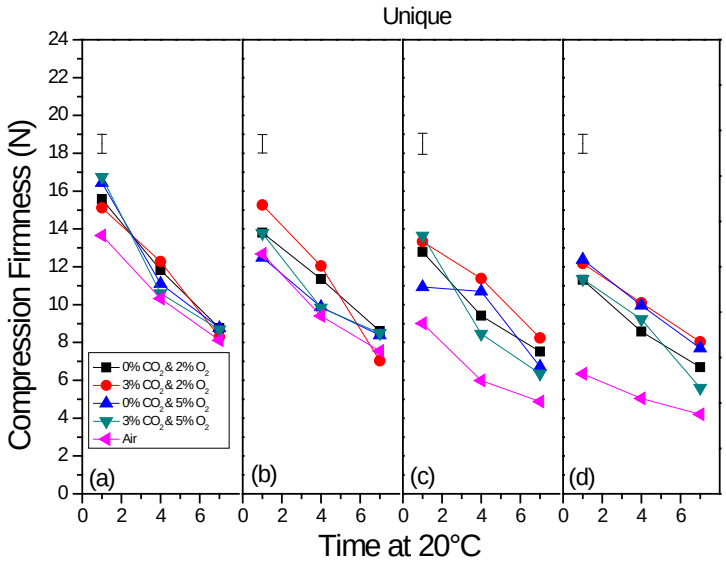
5.3.2. Firmness

Similar trends occurred for acoustic firmness and compression firmness measurements for both cultivars when removed from 4°C and placed at 20°C (Figure 5.5). Fruit firmness declined in all treatments over the storage period. Firmness of fruit stored in air declined at a higher rate than fruit in all CA treatments. For example, compression firmness of cultivar 'Unique' fruit in air at 20°C declined from about 14 N after 4 weeks to 7 N after 10 weeks compared with the change in all CA treatments (16 N to 12 N). For 'Opal Star' on the other hand, the firmness decline in air was from 17 N to 7 N over the same period. Similar reductions in firmness during storage have been reported for the closely related guava fruit (Singh and Pal, 2008, Pal et al., 2007, Abu-Goukh and Bashir, 2003). Compression firmness changes during storage in this experiment were in a lower range (≈ 18-20 N to 9-12 N) from week 4 to week 10 than those reported for 'Unique' feijoa (31 N to 14 N) by East et al., (2009) which presumably relates primarily to the initial firmness differences of the fruit.

Firmness of the fruit stored at 4°C in all treatments decreased when fruit were transferred to 20°C regardless of previous atmospheric conditions. In 'Unique' no significant differences between firmness values occurred in fruit from different CA

treatments. However in 'Opal Star' fruit, there was a significant difference in firmness between treatments at 8 and 10 weeks of storage, with 0% CO_2 being the most firm. A similar sensitivity to high CO_2 concentrations was reported for 'Unique' stored at 0.2% and 4% CO_2 mixed with a range of (3-21%) of O_2 concentrations (East et al., 2009). There was a close correlation between increased weight loss and decreased fruit firmness. A relationship between the firmness and the structure and composition of the cell wall has been found by Hertog et al., (2004) as well as the water status or the turgor pressure in the cells (Wills et al., 2007). In this experiment, we did not determine whether the correlation observed between decreases in firmness and weight loss increases was more dependent on changes in cell wall structure or loss of turgor pressure.





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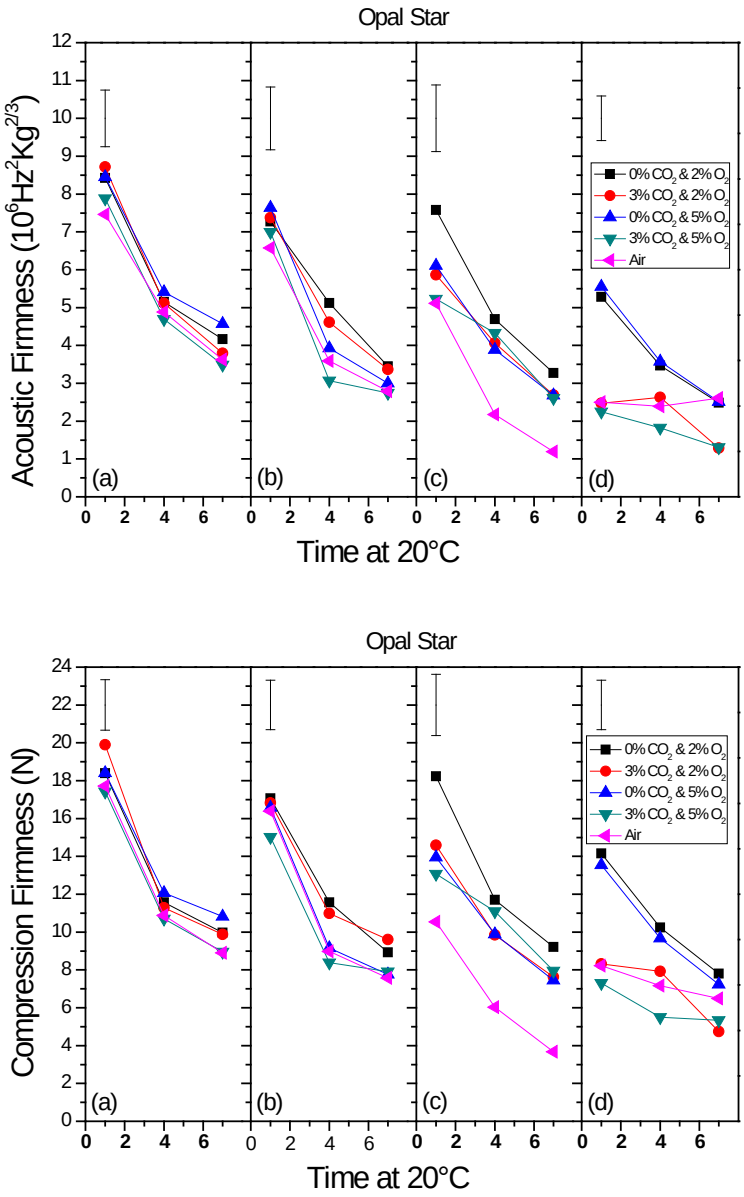

Figure 5.5 Acoustic and compression firmness of feijoa at 20°C followed removal from 4°C under different controlled atmosphere conditions. (a). 4 weeks, (b). 6 weeks, (c). 8 weeks, (d). 10 weeks. Bars represent $LSD_{0.05}$.

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5.3.3. Skin Colour Changes

Feijoa fruit are olive greenish in colour and do not change colour dramatically as they ripen, although some cultivars ripen from dark green to light green (Kader, 2006). In 'Unique' there was no significant difference in skin colour between CA and air after 10 weeks at 4°C followed by 1 week at 20°C (Table 5.1). According to work by Singh and Pal (2008) with guava, and East et al., (2009) in 'Unique' feijoa, rate of colour changes should be reduced when fruit are stored under low O_2. However, this

wasn't the case in 'Unique' used in this experiment. The insignificant changes in values of a, b, L and h° in CA compared to air indicated that the CA atmospheres used here had no benefit in retaining colour in the 'Unique' cultivar.

Despite being green initially, 'Opal Star', fruit underwent a significant colour change after the 10 weeks at 4°C followed by 1 week at 20°C. Under CA, colour change (hue°) was slower than when fruit were stored in air. The lightness (L) value of fruit in the air treatment was significantly greater than that from fruit from CA treatments, indicating changes in colour from dark green to light green. Similar results were reported for the closely related guava when measured at different stages of maturity (Soares et al., 2007) or during growth and development (El-Buluk et al., 1995) where the loss of green colour was associated with decreased chlorophyll and increased carotenoid content. Although some individual fruit appeared quite pale, the statistically significant difference (Table 5.1) was not clearly visible by eye, more obvious changes were seen in surface discolouration or injury (Figure 2.4).

Table 5.1 Colour of 'Unique' and 'Opal Star' feijoa after 10 weeks at 4°C under different controlled atmosphere conditions followed by 7 days at 20°C. Data are means of different numbers of replications (n). Significant differences ($P \leq 0.05$) for means within a column are indicated by different letters.

Treatments	Unique				Opal Star			
	n	L	C	h	n	L	C	h
0% CO_2;2 %O_2	11	45.64 [a]	29.91 [a]	110.22 [a]	9	44.89 [b]	28.59 [b]	109.67 [b]
3% CO_2;2% O_2	14	45.60 [a]	29.95 [a]	109.96 [a]	7	46.41 [b]	31.54 [b]	108.66 [b]
0% CO_2;5% O_2	11	46.97 [a]	29.64 [a]	109.66 [a]	12	45.13 [b]	29.25 [b]	108.99 [b]
3% CO_2;5% O_2	10	46.48 [a]	30.62 [a]	108.77 [a]	9	46.03 [b]	31.16 [b]	107.35 [b]
Air	6	45.28 [a]	28.08 [a]	109.66 [a]	7	50.87 [a]	36.04 [a]	103.27 [a]
S^2		12.00	12.50	6.88		10.05	14.21	9.06
Df		47	47	47		39	39	39

5.3.4. Total Soluble Solids (TSS)

There was a decrease in total soluble solids both at 4°C and after removal to 20°C in all treatments (Figure 5.6). For 'Unique' there was no difference between treatments ($P > 0.05$). However, significant differences were measured in fruit removed after different periods at 4°C with fruit stored for a longer time having a lower TSS. For 'Opal Star' there was a significant difference between the treatments, during time at 4°C and then at 20°C ($P < 0.0001$). Similar results have previously been found for 'Apollo' and 'Gemini' feijoa where soluble solids declined clearly after 4 weeks storage at 4°C followed by 5 days at 20°C irrespective of fruit retention force at harvest (Downs et al., 1988). Similar results were also reported with guava fruit at the end of growth period (Soares et al., 2007). The decrease in TSS most likely occurs as a result of postharvest utilisation of sugars through respiration (Sharaf and El-Saadany, 1986).

Even though a decreasing trend can be seen in TSS with storage time, TSS does not decrease as internal maturity rating increases (Figure 5.7). A large variation in TSS existed at each internal maturity stage. The correlation between internal visual rating with TSS is very weak; $R^2 = 0.067$ and $R^2 = 0.13$ for 'Unique' and 'Opal Star' respectively (Figure 5.7). 'Opal Star' has a higher TSS than 'Unique' (≈ 12 and 10 respectively). Variability of TSS appears to increase as fruit mature for 'Unique' (Figure 5.7a); this could result from the relatively few fruit at the lower internal maturity rating. However, the variation in TSS remains consistent for 'Opal Star' feijoa at any maturity stages (Figure 5.7b). Thus TSS is not a good method to distinguish between different maturity stages or internal maturity rating does not adequately describe the physiological changes in the fruit that occur during storage.

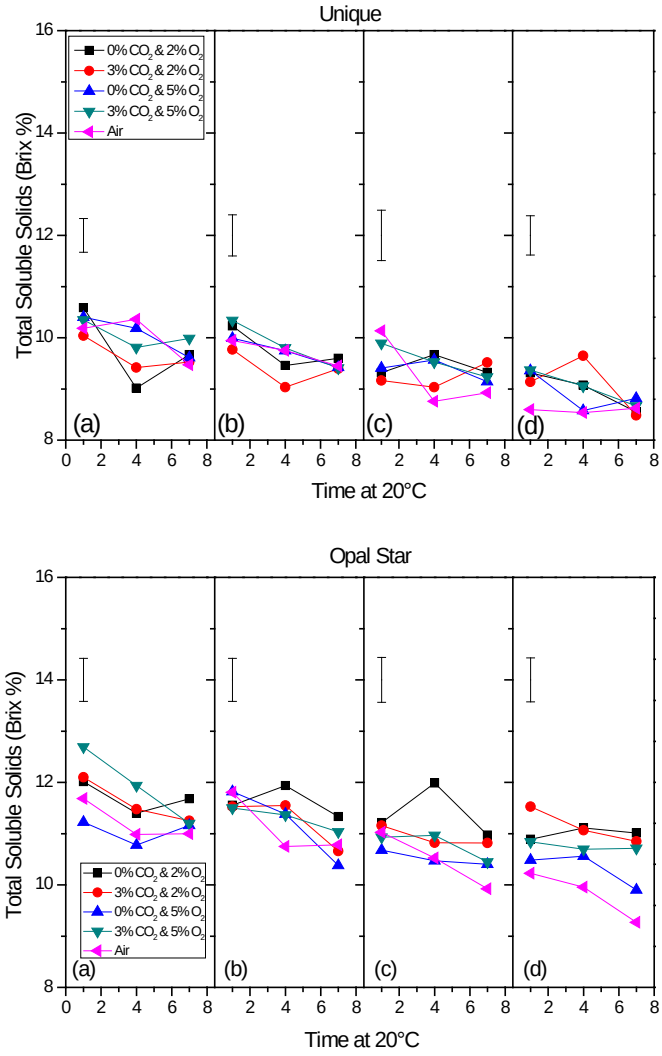


Figure 5.6 Total soluble solids of 'Unique' and 'Opal Star' feijoa treated with different controlled atmosphere conditions at 4°C for (a). 4 weeks, (b). 6 weeks, (c). 8 weeks and (d). 10 weeks and subsequent removal to 20°C. Each data point represents 25 and 20 fruit for 'Unique' and 'Opal Star' respectively. The vertical bars represent the $LSD_{0.05}$ after storage.

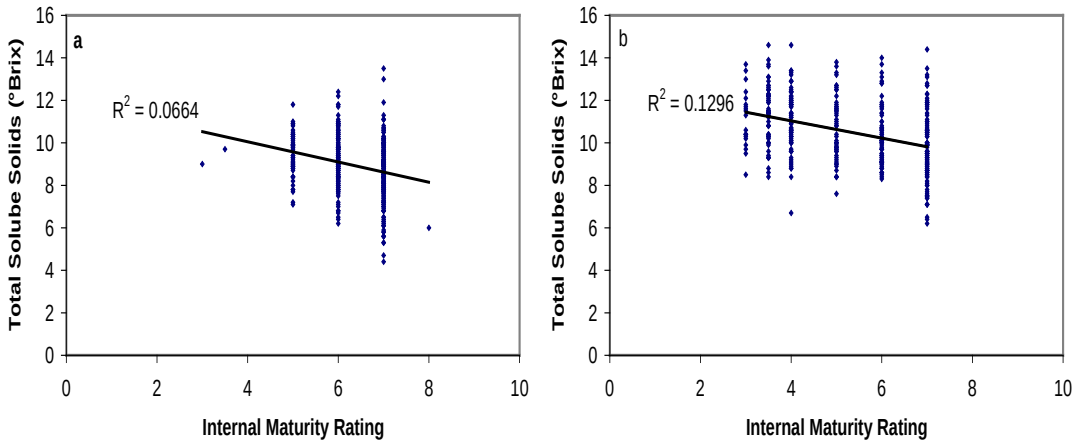


Figure 5.7 Correlation of total soluble solids with internal maturity rating of (a). Unique cultivar and (b). Opal Star feijoas treated with different controlled atmosphere conditions. Each data point represents a single fruit.

5.3.5. Correlation between AF and CF

There was a reasonable correlation between acoustic firmness and compression firmness for both cultivars (Figure 5.8), being better with 'Unique' cultivar than 'Opal Star'. There was no difference between the effectiveness of acoustic and compression firmness measurements in identifying the relationship with internal maturity rating of feijoa fruit stored under CA conditions (Figure 5.9). Acoustic firmness appeared more accurate in identifying maturity stages of long stored fruit. Molina-Delgado et al., (2009) found acoustic measurements to be a good tool to evaluate firmness changes during long term storage of apple fruit. Fruit firmness of 'Unique' apparently decreased rapidly during the storage period at 4°C and shelf life assessment period at 20°C compared to 'Opal Star', but this difference is strongly influenced by the low fruit number of 'Unique' fruit at internal maturity rating of 3 and 4.

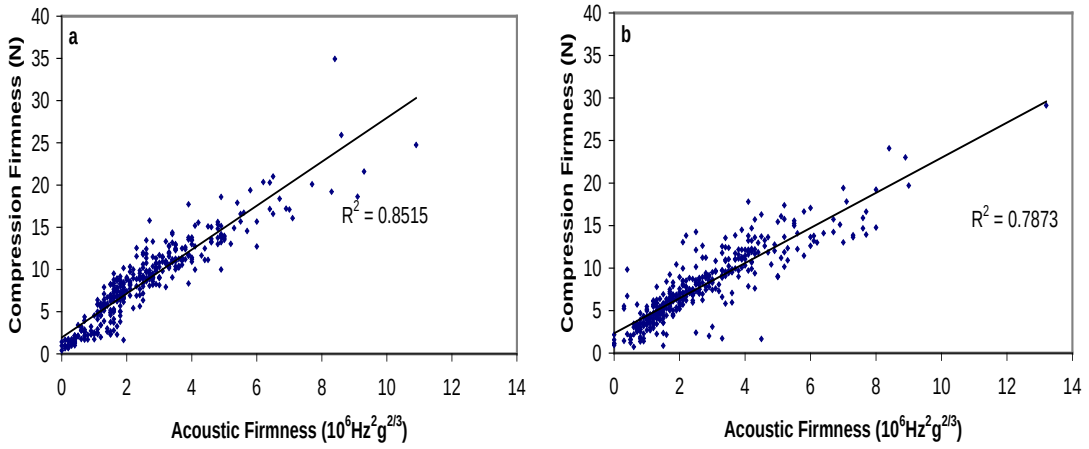


Figure 5.8 Correlation between acoustic firmness and compression firmness of two cultivars (a). 'Unique' and (b). 'Opal Star'. Each data point represents a single fruit.

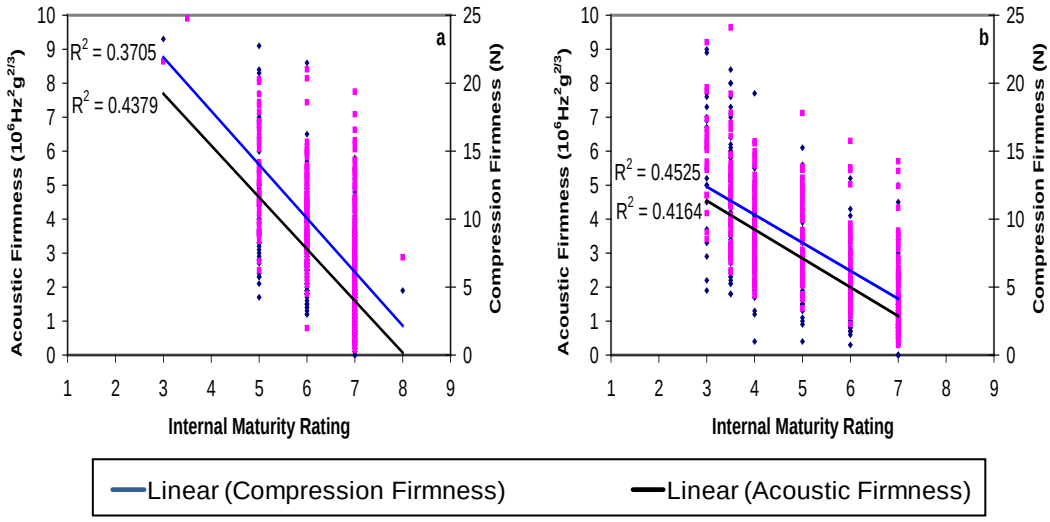


Figure 5.9 Correlation between acoustic firmness and compression firmness with internal visual grading of two cultivars (a). 'Unique' and (b). 'Opal Star' at 20°C. Each data point represents a single fruit.

5.3.6. Internal Maturity Rating

The internal maturity in both cultivars increased with time at 4°C and subsequently at 20°C in all CA conditions, with a more rapid increase in internal maturity rating in the air treatment (Figure 5.10).

For 'Unique' a more rapid increase in internal maturity ratings occurred in the air stored treatment after six weeks at 4°C. Significant differences ($P < 0.0001$) between

treatments were clear for fruit removed from 4°C after week 8. Significant differences between storage period at 4°C and subsequent shelf life at 20°C were also observed. For 'Unique' the rate of ripening increased rapidly after 4 weeks of storage. Internal maturity stage 4 is characterised by browning of the locule gel. Cultivars vary in the rate of change of gel colour, depending on the amount of polyphenol oxidase (PPO) within the fruit. Feijoa cultivars such as 'Gemini' and 'Marian' are known to have low levels of PPO activity (Zhu Jun-sheng, 1987) compared to 'Apollo' (Thorp and Bieleski, 2002) and thus tend to show less flesh browning. PPO causes enzymatic browning in many fruit and vegetables. Fruit become more susceptible as they ripen, in apple and peach for example, the enzymatic browning depends on the ripening stage (Brandelli and Lopes, 2005, Murata et al., 1995). The browning can cause deterioration and economic losses.

On the other hand, for 'Opal Star', more rapid internal maturity rating development was observed in air treatment after 8 weeks cold storage. Significant differences ($P < 0.0001$) between treatments could be seen clearly after week 8, with air stored fruit at a higher maturity. Significant difference between storage period at 4°C and subsequent shelf life at 20°C was also observed.

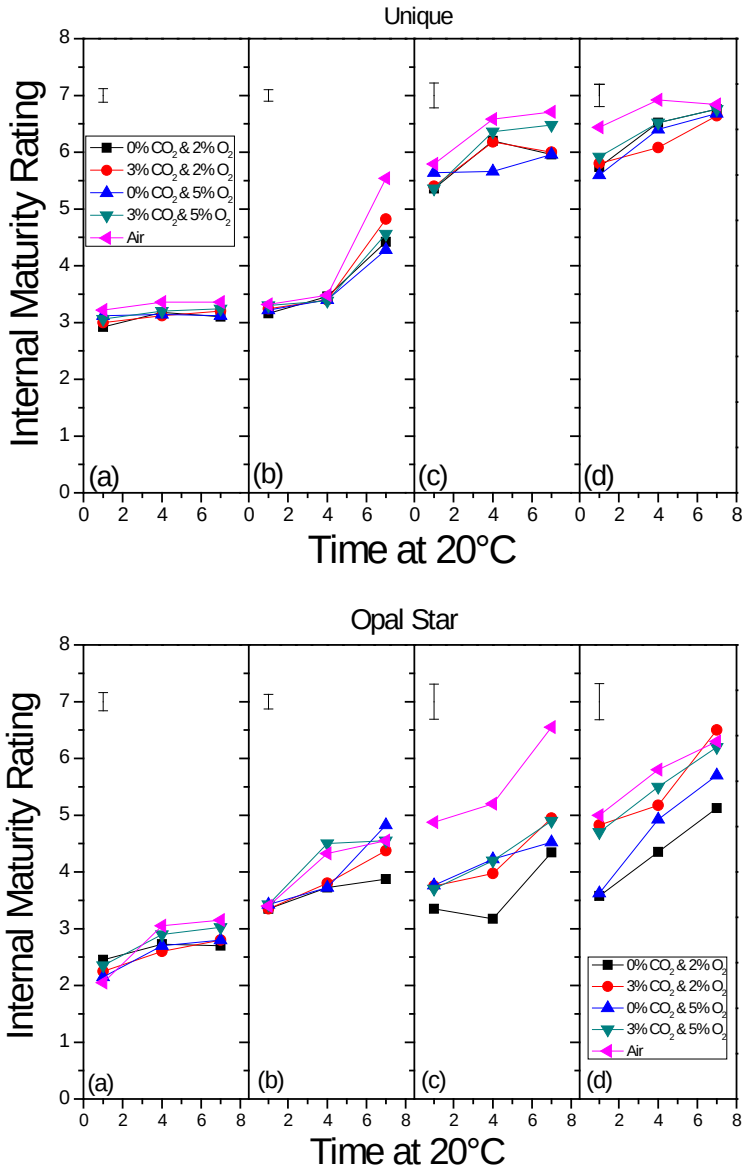


Figure 5.10 Average maturity index of 'Unique' and 'Opal Star' feijoa treated with different controlled atmosphere conditions for a, b, c, d = 4, 6, 8, 10 weeks at 4°C then removal to 20°C in air. Each data point represents 25 and 20 fruit for 'Unique' and 'Opal Star' respectively. Vertical bars represent the $LSD_{0.05}$ after storage.

5.3.7. Fruit Acceptability Depending on Maturity Index

Fruit rated as 2-4 (A to D) using the industry quality rating were judged as being commercially acceptable. The percent acceptance was pooled for the entire period of shelf life. 'Opal Star' remained moderately acceptable (more than 60% of fruit) for up to 8 weeks at 4°C and took 4-7 days at 20°C before they were fewer than 80% fruit acceptable, whereas less than 20% of fruit were acceptable after 6 weeks at 4°C in

'Unique' fruit (Figure 5.11). This indicates that 'Opal Star' had a good storage life (Thorp and Bieleski, 2002) while 'Unique' fruit did not store well for more than 4 weeks under the conditions tested. 'Opal Star' was very sensitive to CO_2; with no CO_2 (2% O_2 and 5% O_2) the percentage of acceptable fruit was better than with 3% CO_2 (Figure 5.11). Conversely, 'Unique' performed relatively better at the atmosphere with the higher CO_2 concentration.

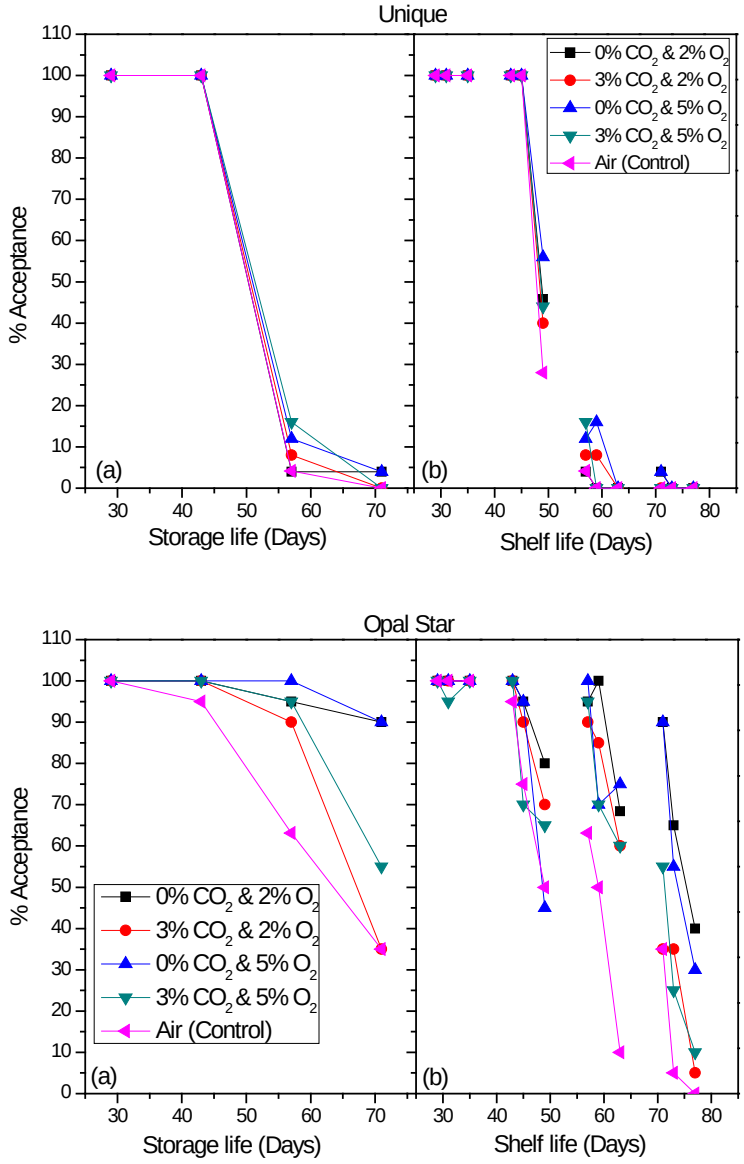


Figure 5.11 Acceptability 'Unique' and 'Opal Star' feijoa exposed to different controlled atmosphere conditions (the acceptability of the fruit was calculated by accepting any fruit at the rate of 2-4 in industry rating).

a. Percentage fruit acceptance after one day from removal from 4°C.

b. Percentage fruit acceptance after day 4 and 7 at 20°C.

5.3.8. Injury Incidence

The minimum storage duration required to ship feijoa fruit from New Zealand to international markets is about 6 weeks. Fruit surface discolouration developed during CA consisted of substantial browning of the skin. Incidence of injuries increased with time in storage.

In 'Unique', the first signs of injury appeared after 4 weeks of storage. After 6 weeks storage, fruit stored in 0% CO_2 and 2% O_2 showed the most injury and hence lowest fruit acceptability compared with the other CA treatments (Figure 5.12a). After 8 weeks ≈ 40% of stored fruit had surface discoloration.

For 'Opal Star' there were few signs of any injury on fruit removed after 8 weeks at 4°C, first signs of injury appeared in air stored fruit with ≈ 50% affected within 1 day at 20°C (Figure 5.12b). By week 10, the difference in injury between CA treatments was very clear; CA treatments without CO_2 (combined with either 2 or 5% O_2) had a lower incidence (≈ 90% without major discoloration) compared to fruit stored in air or in 3% CO_2. 'Opal Star' showed less fruit injury after CA storage than 'Unique'. The reduction in injury incidence and severity caused by CA conditions with low CO_2 atmospheres agrees with the findings of East et al., (2009) working with 'Unique' feijoa. On the other hand, 'Unique' in this experiment was not consistently harmed by high CO_2; 3% CO_2 and 5% O_2 was harmful but 3% CO_2 and 2% O_2 was as good as the 0% CO_2 treatments (Figure 5.12a).

In both cultivars, the degree of injury became more prevalent when fruit were transferred to ambient conditions (Figure 5.13 and 5.14). This seems to be a similar phenomenon to classic chilling injury symptoms in other fruit, which maybe undetectable after removal from cold storage, but become progressively more visible during shelf life assessment at 20°C (Morris, 1982). 'Unique' fruit previously stored in CA showed a lower area of skin discoloration compared to air (Figure 5.15). However, the CA storage treatments used for 'Unique' did not appear to offer a significant benefit in terms of overall consumer acceptability.

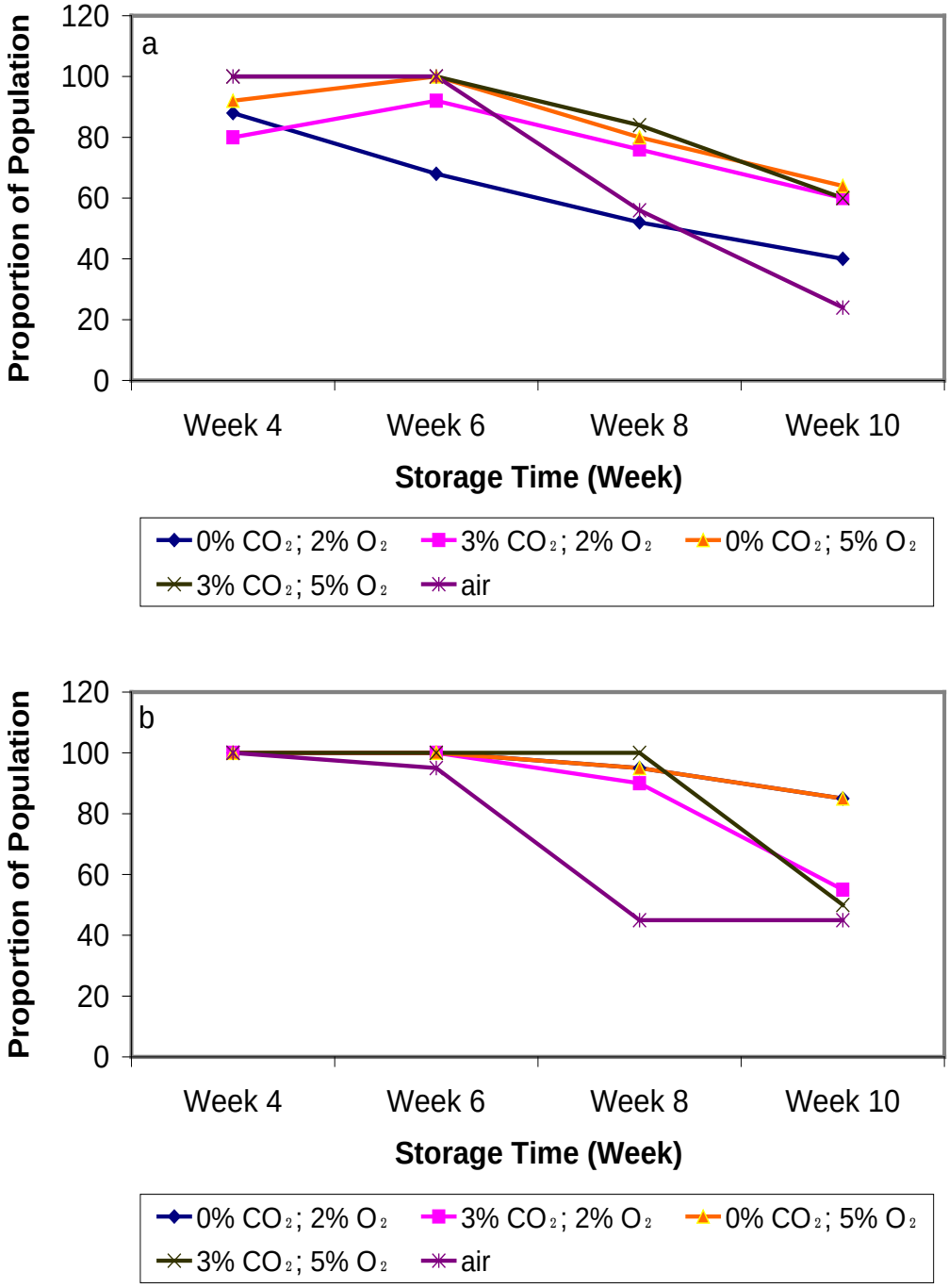


Figure 5.12 Proportion of saleable fruit of (a). Unique and (b). Opal Star feijoas after different times at 4°C and 1 day at 20°C.

Figure 5.13 Effects of CA treatments or air storage on skin discolouration in 'Unique' fruit during shelf life assessment 1, 4 and 7 days at 20°C after (a). 4 weeks (b). 6 weeks (c). 8 weeks and (d). 10 weeks.

Figure 5.14 Effects of CA treatments or air storage on skin discolouration in 'Opal Star' fruit during shelf life assessment 1, 4 and 7 days at 20°C after (a). 4 weeks (b). 6 weeks (c). 8 weeks and (d). 10 weeks.

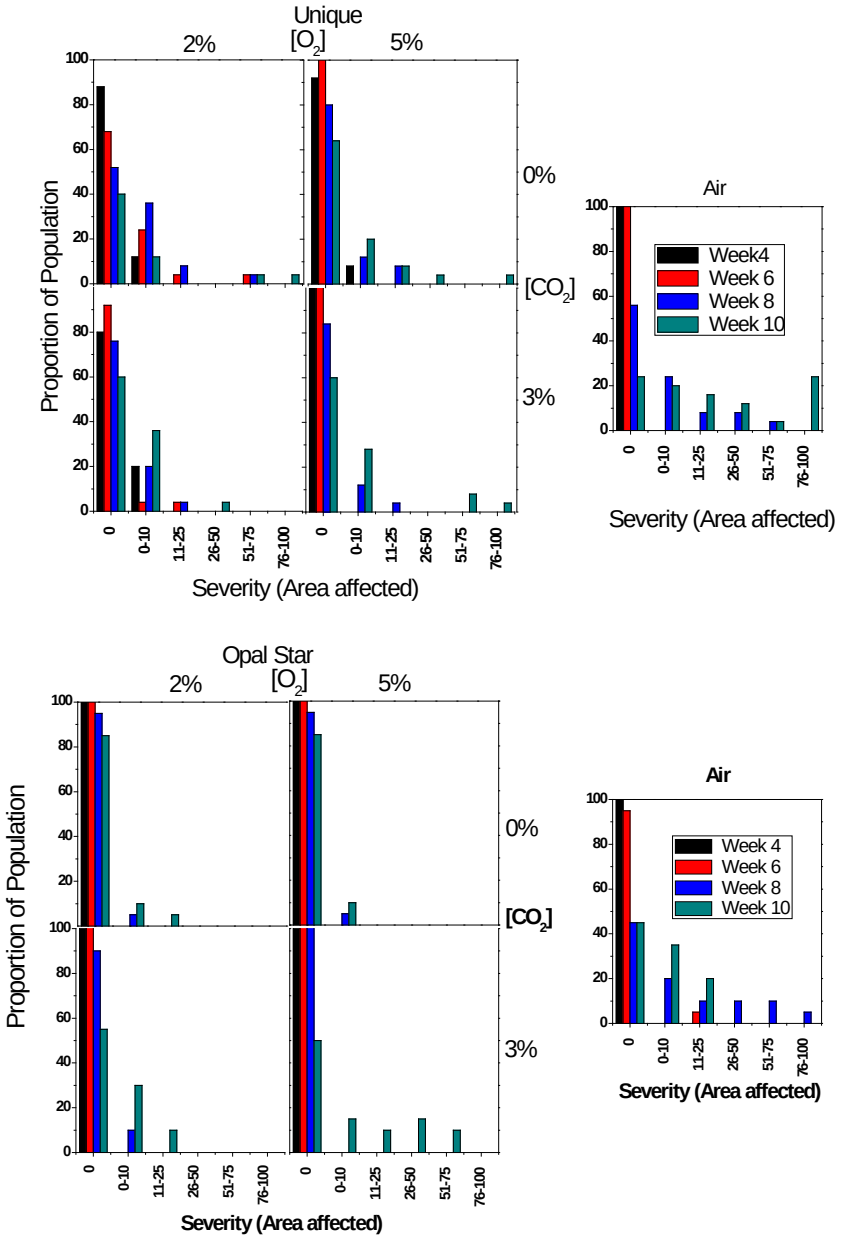


Figure 5.15 % area of skin discolouration of 'Unique' and 'Opal Star' cultivar treated with different controlled atmosphere conditions for 4-10 weeks at 4°C.

5.3.9. Fruit saleability

Taking into account the importance of both external (fruit discoloration) and internal (fruit maturity index) features for fruit marketability, "saleability" in this section refers to fruit with less than 10% external damage and with a maturity index of 2-4.

For 'Unique' fruit, segregation between treatments of the proportion of sealable fruit after different times at 4°C followed by one day at 20°C occurred after 4 weeks at 4°C

(Figure 5.16). On the other hand, segregation between CA treatments for 'Opal Star' fruit occurred from week 8. The fruit measured after different time at 20°C were averaged across the storage period. More than 60% of the 'Unique' fruit from all CA treatments appeared to be in good condition up to 8 weeks, although some injuries were apparent in all treatments. This was true only if we accept the fruit according to external fruit appearance (no damage or injury); however, almost all of these fruit were above the acceptable maturity index 2-4 (Figure 5.16). For 'Opal Star' the segregation between CA and air was very clear after 8 weeks, when all CA treatments had more than 75% fruit in saleable condition (Figure 5.16), and after 10 weeks the low O_2 and no CO_2 treatment still had more than 60% of fruit in saleable condition.

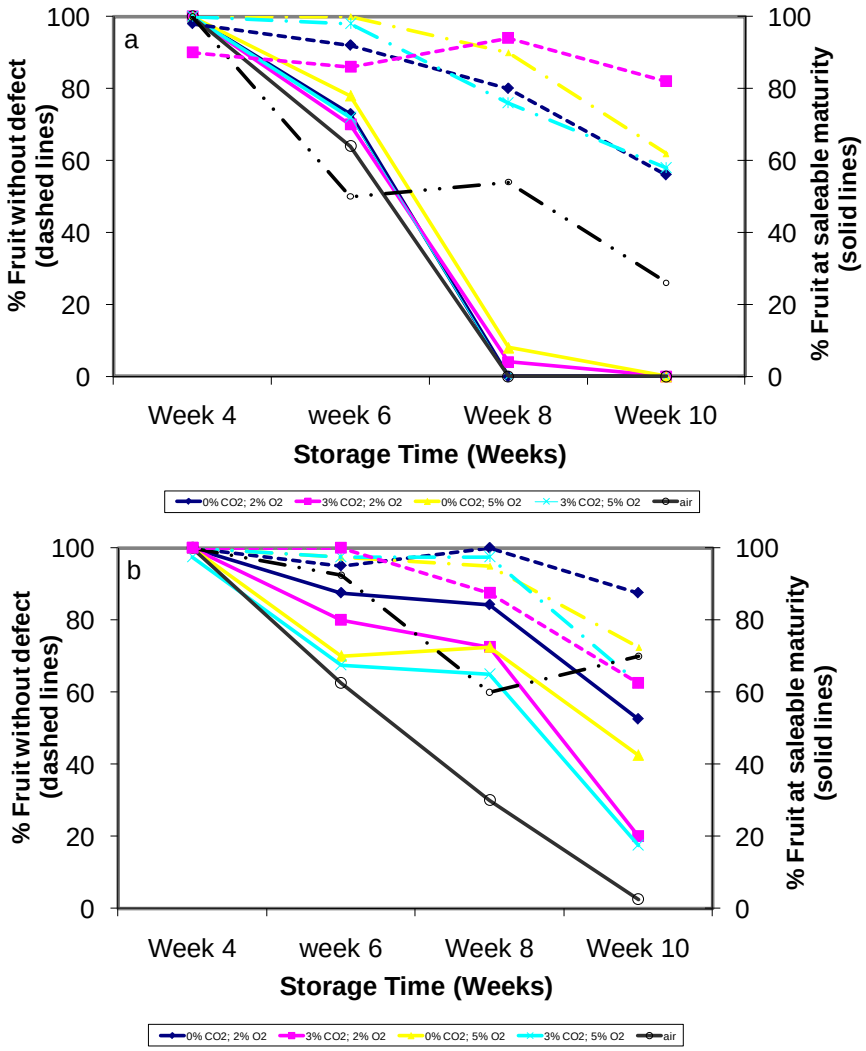


Figure 5.16 Proportion of saleable fruit of (a). 'Unique' and (b). 'Opal Star' feijoas after storage in different controlled atmosphere conditions and shelf life averaged across 1-4 day at 20°C.

5.4. CONCLUSIONS

Future success of the New Zealand feijoa export industry depends on the ability to ship feijoa by sea to remote markets in USA, Europe and Japan. The ability to store fruit for longer periods under low temperatures will be the basis of future industry success. Controlled atmosphere storage seems to be promising to extend the shelf life and enhance the quality of feijoa fruit. The most significant effect of CA in feijoa included delayed ripening, reduced weight loss, reduced external colour change and maintained fruit firmness. In 'Unique' CA treatments did increase fruit acceptability during shelf life assessment after 4 weeks of storage. Despite these small beneficial effects of CA, CA conditions used in this experiment did not add a significant value for 'Unique'; as all fruit were rated over-mature after 6 weeks of storage. In order to survive long distance sea freight, New Zealand fresh produce requires a reliable storage period of at least six weeks, and no treatments were found to give acceptable fruit at this time. On the other hand, controlled atmosphere storage shows promise for extending the storage life of 'Opal Star' feijoa fruit. In this trial CA storage of 'Opal Star' feijoa resulted in reduced weight loss, reduced loss of firmness, delayed ripening, and reduced injury incidence. Atmospheres that combined low CO_2 (0%) and low O_2 (2% and 5%) were more effective than atmospheres that combined low O_2 with 3% CO_2. Results from this study agreed with that found previously by East et al., (2009) for 'Unique' feijoa suggesting that low CO_2, low O_2 controlled atmospheres may be favourable for feijoa storage.

CHAPTER 6
RESPONSE OF FEIJOA FRUIT TO EXOGENOUS ETHYLENE AND PROPYLENE APPLIED AT DIFFERENT STAGES OF MATURITY

6.1. INTRODUCTION

It is claimed that feijoa is a climacteric fruit with ripening advanced by exposure to ethylene (Akerman et al., 1993). Ethylene, as a natural plant hormone, plays a vital role in the initiation of ripening in many climacteric fruit (McGlasson et al., 1975). The response of plant species to exogenous ethylene application may vary greatly. In fruit such as apple, avocado, banana, mango, pear and tomato ripening is influenced by the endogenously produced ethylene. However, in other fruits such as citrus and grapes where endogenous ethylene seems to play little if any role, exogenous application of ethylene can still promote some ripening characteristics (Cara and Giovannoni, 2008). Fruit vary in the relationship between ethylene and respiration. Biale et al., (1954) classified fruit into three groups in relation to ethylene production: 1- Climacteric fruit with significant production of ethylene, such as apple or pear. 2- Climacteric fruit but lacking ethylene emanation such as mango. 3- Non-climacteric fruit with no ethylene production under normal conditions such as lemon and orange. Biale (1964) later classified fruit into two groups, climacteric and non-climacteric, according to their respiratory patterns. Fruit in the climacteric group showed an increase in respiration and ethylene production to a peak during ripening whereas non-climacteric fruit showed no change in either. During the post-climacteric phase ethylene production decreased (Hoffman and Yang, 1980). In this group, ethylene is considered a key factor in stimulating the biochemical changes that occur during ripening (Giovannoni, 2001, Lelièvre et al., 1997). Apple, banana, peach and tomato are examples of this group. Non-climacteric fruit such as citrus, grape and strawberry do not produce high levels of ethylene or have a high respiration rate during ripening. Some fruit genera such as melon and capsicum may have species or cultivars that are either climacteric or non-climacteric (Barry and Giovannoni, 2007).

McMurchie et al., (1972) identified two systems of ethylene production in climacteric fruit. System 1 occurs during the pre-climacteric phase or during normal growth and development, where low levels of ethylene are produced. System 1 ethylene production is auto-inhibited by exogenous ethylene. System 2 occurs during fruit ripening where high levels of ethylene are produced and this production is stimulated by ethylene i.e. it is autocatalytic. In recent years, the main difference between the 'climacteric' and 'non-climacteric' fruit has become dependent on their catalytic production of ethylene in response to exogenous ethylene (Ludford, 2003). In other words, application of exogenous ethylene can be used to distinguish between climacteric and non-climacteric fruits (McMurchie et al., 1972). In climacteric fruit, exogenous application of ethylene at the right maturity stage leads to an increase in respiration and ethylene production, whereas in non-climacteric fruit exogenous application of ethylene leads to a temporary increase in respiration followed by a decrease (Bufler, 1986).

Treating fruit with propylene usually gives information about biogenesis of ethylene (McMurchie et al., 1972) and stimulates endogenous ethylene production. 1300 ppm propylene is biologically equivalent to 100 ppm ethylene (Sfakiotakis et al., 1989). Climacteric fruit such as banana, treated with propylene, show a typical respiratory increase and ethylene rise, whereas in non-climacteric fruit such as lemon and oranges only a climacteric-like rise in respiration was seen (McMurchie et al., 1972). Many studies have been conducted using 10-1000 ppm ethylene or propylene to enhance ripening. For example, exogenous propylene treatment at 500 ppm stimulates both ethylene production and fruit softening in apricots in parallel with the stimulation of β-D-galactosidase, α-L-arabinofuranosidase, β-D-xylosidase, α-D-mannosidase, and PME activity (Cardarelli et al., 2002). Apricots cv. 'Bebecou' treated with 100 or 1000 ppm propylene at 25°C showed enhanced ethylene production and there was no autocatalytic ethylene production in the absence of propylene (Nanos et al., 1999). In avocado, the exogenous application of ethylene (10 ppm) or propylene (1000 ppm) hastened the ripening response at 20, 25, 30 and 35°C (Eaks, 1978). Kiwifruit cv. 'Hayward' treated with 1000 ppm propylene for 24 hours at 20°C started autocatalytic ethylene production, but when propylene concentration was reduced to 400 or 100 ppm, 72 hours were needed to initiate ethylene production (Antunes et al., 2000). In another study, ethylene biosynthesis and fruit ripening were stimulated when kiwifruit

was exposed to a low concentration of propylene (130 ppm) under 1, 5, 10, 13, 16 and 21% O_2 gas mixture in a continuous flow-through system at 20°C (Stavroulakis and Sfakiotakis, 1997).

Previous studies indicated that feijoa was a climacteric fruit (Akerman et al., 1993, Reid, 1975, Biale et al., 1954). Only one study was found that investigated response of feijoa fruit to exogenous ethylene, where treated feijoa fruit with 100 ppm ethylene for 48, 72 or 96 hour or heated at 38 or 42°C for 48 hour showed significant stimulation of respiration and ethylene production during storage (Akerman et al., 1993). The guava, which is related to feijoa has been classified as climacteric (Brown and Wills, 1983, Akamine and Goo, 1979), non-climacteric (Kuo and Ke, 2006, Biale and Barcus, 1970) or both (Azzolini et al., 2005). These differences may be due to varietal characteristics or may relate to the complexity of the climacteric response.

Up to date, very little research has been done on the respiration pattern and the role of ethylene in the ripening of feijoa fruit. Biale et al., (1954) worked with the feijoa cultivar 'Coolidge' and reported rates of respiration and ethylene production as 73 ml (CO_2) $kg^{-1}.h^{-1}$ and 50 $\mu l.kg^{-1}h^{-1}$ respectively. In that work, the rise in respiration rate preceded the rise in ethylene production and it was concluded that feijoa fruit were climacteric, based on the classical definition, because they were capable of producing significant quantities of ethylene. Kader (2006) reported that respiration rate of feijoa fruit was 10-15 ml (CO_2) $kg^{-1}.h^{-1}$, rising to 20-25 ml (CO_2) $kg^{-1}.h^{-1}$ at climacteric maximum at 20°C, while the rate of ethylene production rose from 0.1-0.4 $\mu l.kg^{-1}.h^{-1}$ to 40 - 50 $\mu l.kg^{-1}.h^{-1}$ at the climacteric maximum. The primary objectives of this study were to understand the ripening physiology of 'Unique' and 'Opal Star' feijoas at three different stages of maturity and to study the effect of different concentrations of ethylene and propylene on the ripening of those two cultivars, in order to understand whether these two cultivars are best defined as 'climacteric' or 'non-climacteric'. Propylene as an active analogue of ethylene was used in this study to enable measurement of endogenous ethylene produced by treated fruit.

6.2. MATERIALS AND METHODS

6.2.1. Ethylene and Propylene Treatment

Feijoa fruit at different maturity were stored in 7 litre air tight perspex boxes (Figure 6.1) at room temperature (20°C) and exposed to one of three different concentrations of ethylene (10, 100 and 1000 ppm), or propylene (1300 ppm) or air (control) in a synthetic air mixture at a constant flow of 0.2 $L.min^{-1}$ for 24 hours. Different concentrations of gases were generated by mixing ethylene (0.5% in air) or propylene (0.13% in air) with air from cylinders (BOC Gases New Zealand Limited, Palmerston North) using a gas mixer. Each gas concentration was humidified with water before entering the storage unit ensuring 95% RH. Each treatment consisted of 3 replicates each of 15 fruit. A total of 225 fruit of each maturity stage of each cultivar were used. After the treatments, fruit were ventilated with humidified air for 4 hours and then left at 20°C for 24 hours. Fruit firmness, fruit weight, fruit colour and ethylene production and respiration rate were measured as described in chapter 2 (Sections 2.3.1.2, 2.3.3, 2.3.10 and 2.3.12 respectively). Flow rates were monitored by digital flow meter (J & W Scientific, CA, USA). Ethylene and propylene concentrations were monitored using a GC (Varian model 3400 equipped with a 1/8 in alumina packed column).

Figure 6.1 Perspex box used to store feijoa fruit under ethylene and propylene treatments.

6.3. RESULTS AND DISCUSSION

6.3.1. Ripening of Feijoa Fruit at Different Maturity Stages

6.3.1.1. Respiration and Ethylene Production During Ripening

Ethylene production of 'Opal Star' feijoa increased as fruit ripened (Figure 6.2). For 'Unique' the increase in ethylene production was only consistent for mature fruit, with the other two maturities the measured fluctuation was considerable. There was no change in respiration rate for 'Opal Star' fruit at different stages of maturity. However, for 'Unique' a trend of decreased respiration as maturity increased was observed. 'Unique' was found to have a shorter storage life than 'Opal Star' (Chapter 4), so it could be that 'Unique' fruit had already reached their climacteric peak at harvest. The decrease in the respiration rate during ripening may represent the inability of mitochondria to maintain cell homeostasis (Romani, 1984), which decreases the ability of the fruit to be stored for a long period

According to the classic definition of climacteric (increased ethylene production during ripening and concomitant increase in respiration), feijoa can be considered a climacteric fruit. In this experiment ethylene production increased from 0.2 $\mu l.kg^{-1}.h^{-1}$ at harvest in immature fruit to 30 $\mu l.kg^{-1}.h^{-1}$ in mature fruit and the rate of respiration was in the range of 26-78 $ml.kg^{-1}.h^{-1}$. Previously Biale et al., (1954), found that a rise in ethylene production followed a rise in respiration rate for 'Coolidge' feijoa. Ethylene production of 'Coolidge' feijoa was 50 $\mu l.kg^{-1}.h^{-1}$ and respiration rate was 73 $ml.kg^{-1}h^{-1}$. The increase in ethylene production followed the shallow rise in respiration. The rates of ethylene production and respiration measured here are exactly in the range previously described (Kader, 2006, Biale et al., 1954).

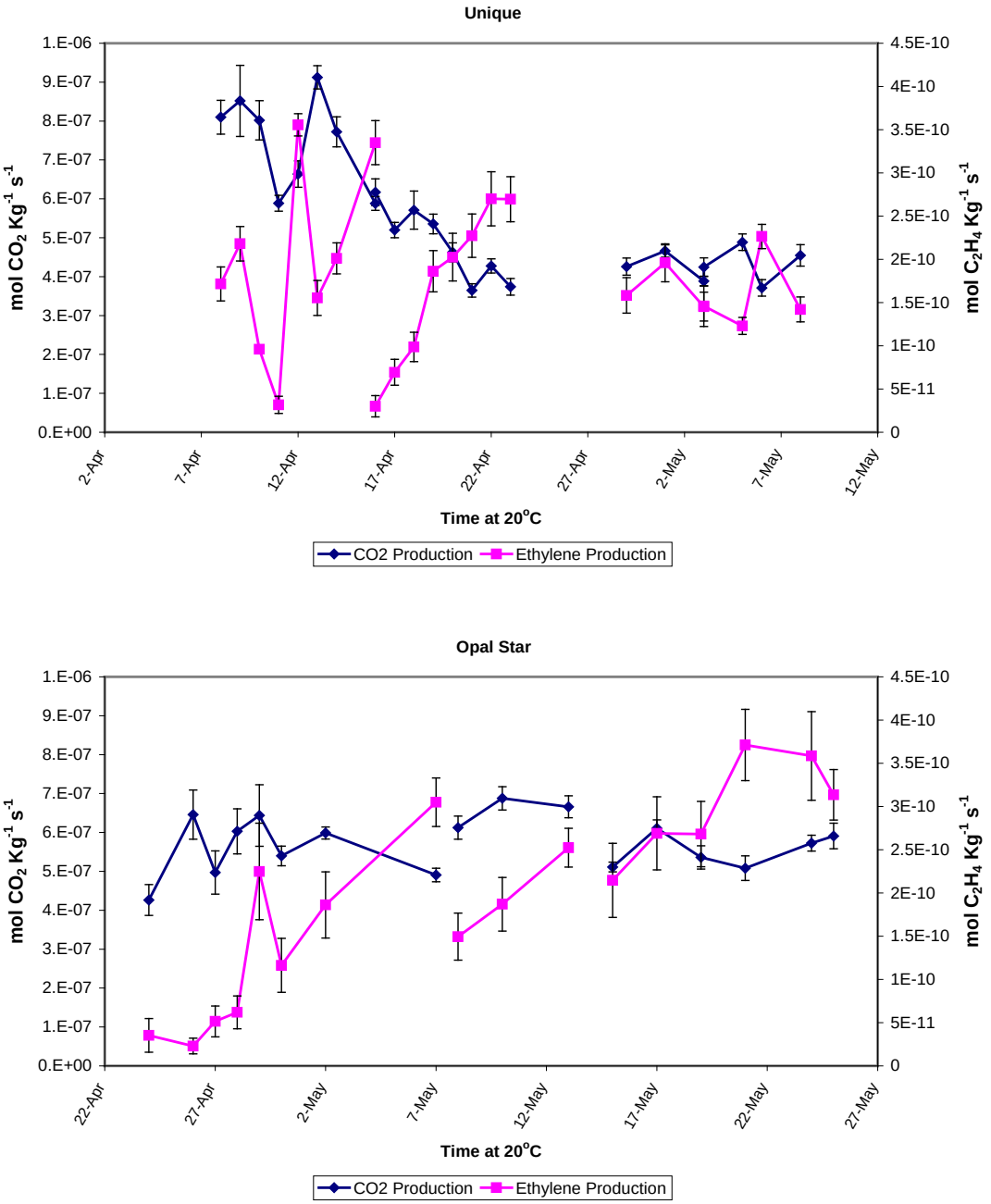


Figure 6.2 Respiration rate and ethylene production of two feijoa cultivars at 20°C of three maturity stages. Each data point represents 15 fruit. Vertical bars represent SE.

6.3.1.2. Ethylene Production and Skin Colour

No clear relationship existed between ethylene production of individual fruit and skin colour (h°) changes in either 'Unique' or 'Opal Star' at three harvest dates (Figure 6.3). No detectable ethylene was noted in 'Unique' from 120 (h°) to 115 (h°). For both cultivars, fruit developed the capacity to produce higher quantities of ethylene at around 115 (h°) but there was a large individual variability in ethylene production as

hue angle decreased. While some fruit produced increasing ethylene as hue angle decreased, an increasing proportion of more mature fruit tended to produce barely detectable amounts of ethylene throughout the colour change process. For 'Opal Star' fruit with the highest ethylene production were all in the late harvest batch. However, there was no clear distinction between early harvest and optimum harvest in terms of skin colour and ethylene production for both cultivars. This suggests that colour change is independent of ethylene production in feijoa.

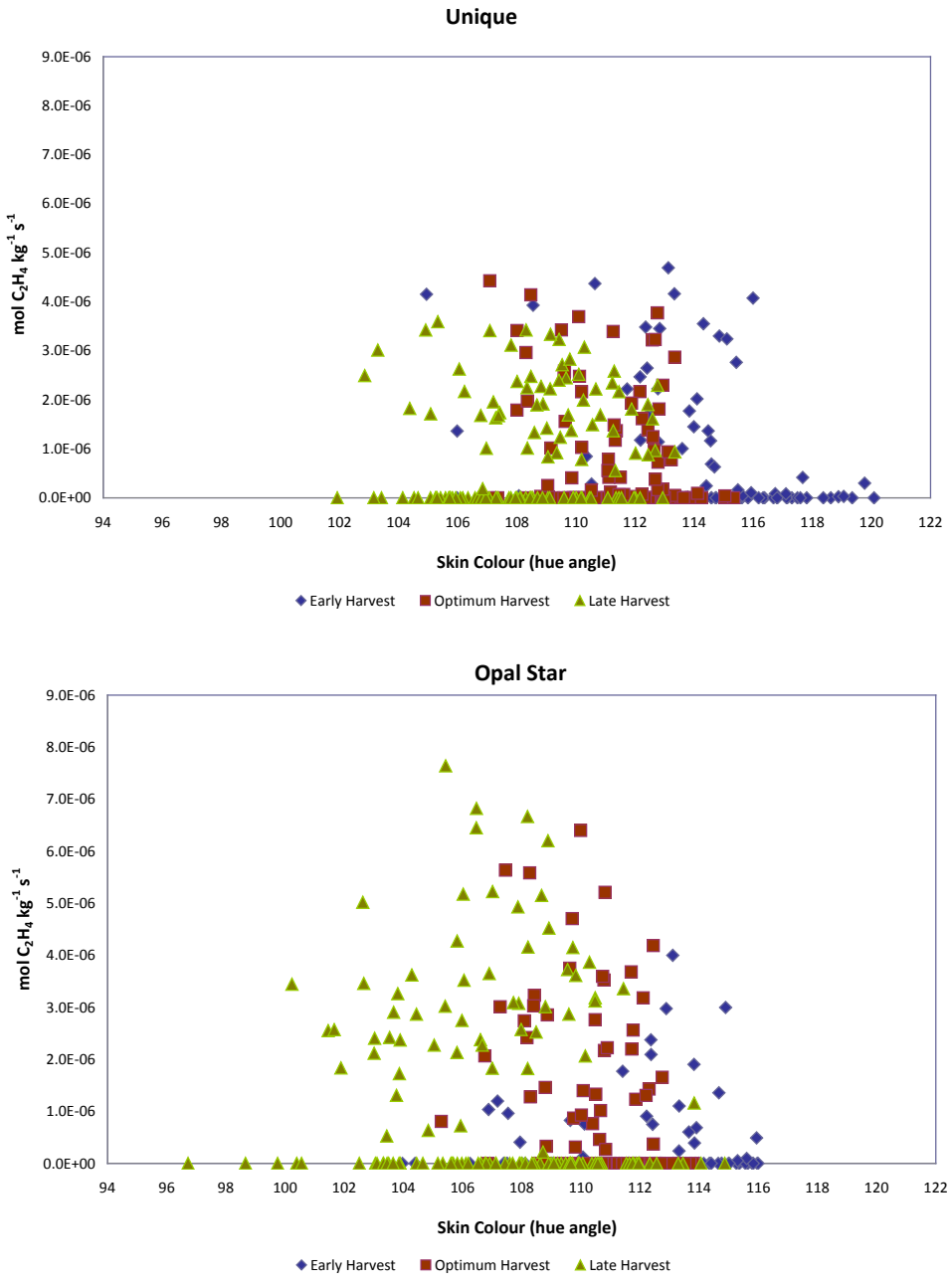


Figure 6.3 Ethylene production and skin colour (h°) of 'Unique' and 'Opal Star' feijoa cultivars harvested at three maturity stages and stored at 20°C. Each data point represents an individual fruit.

6.3.1.3. Ethylene Production and Firmness

Virtually no detectable ethylene was produced as feijoa fruit softened from about 45 N to 23 N for 'Unique' and 24 N for 'Opal Star' (Figure 6.4). Both cultivars showed a steady increase below 25 N in ethylene production, indicating a weak correlation between ethylene production and fruit softening. There was a high variability between individual fruit, and some fruit with undetectable ethylene production were able to soften. It is not clear whether ethylene production is causing softening in both tested cultivars, but there is an indication that very firm fruit are not producing detectable concentration of ethylene, whereas softer fruit in general show a higher production.

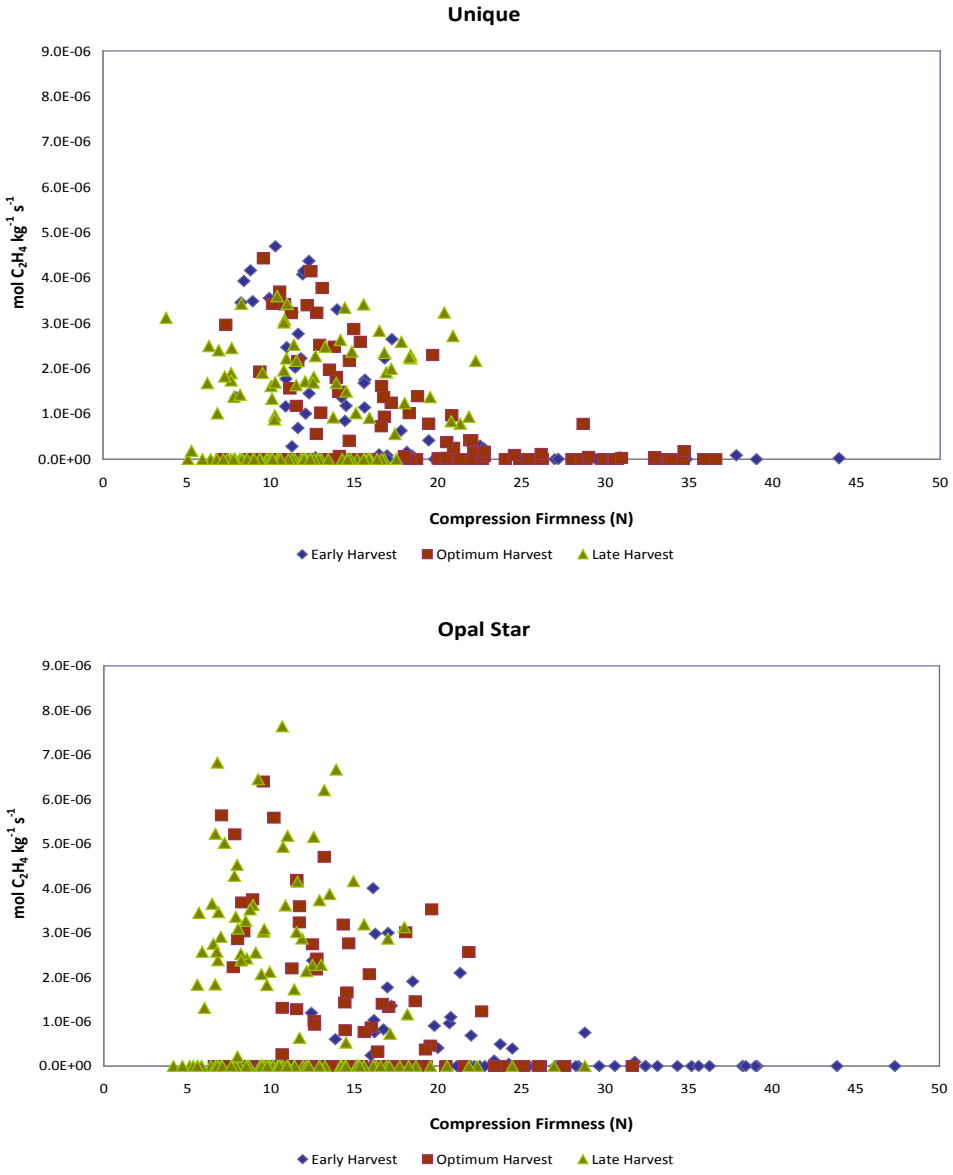


Figure 6.4 Ethylene production and fruit firmness of 'Unique' and 'Opal Star' feijoa cultivars harvested at three maturity stages stored at 20°C. Each data point represents individual fruit.

6.3.1.4. Respiration and Colour

There is high variability in the respiration rates of individual feijoa fruit, but some general observations can be made. In both cultivars, late harvested fruit produced less CO_2 than optimum or early harvest fruit (Figure 6.5). Fruit harvested at different dates seem to group together by colour as fruit mature. For 'Unique' the relationship between the average CO_2 production and colour showed that the maximum climacteric peak occurred in fruit from the early harvest whereas for 'Opal Star', the maximum climacteric peak occurred in fruit at optimum harvest (Figure 6.5 inset). Although the variability is high, this is consistent with 'Unique' fruit having on earlier respiratory climacteric than 'Opal Star' fruit.

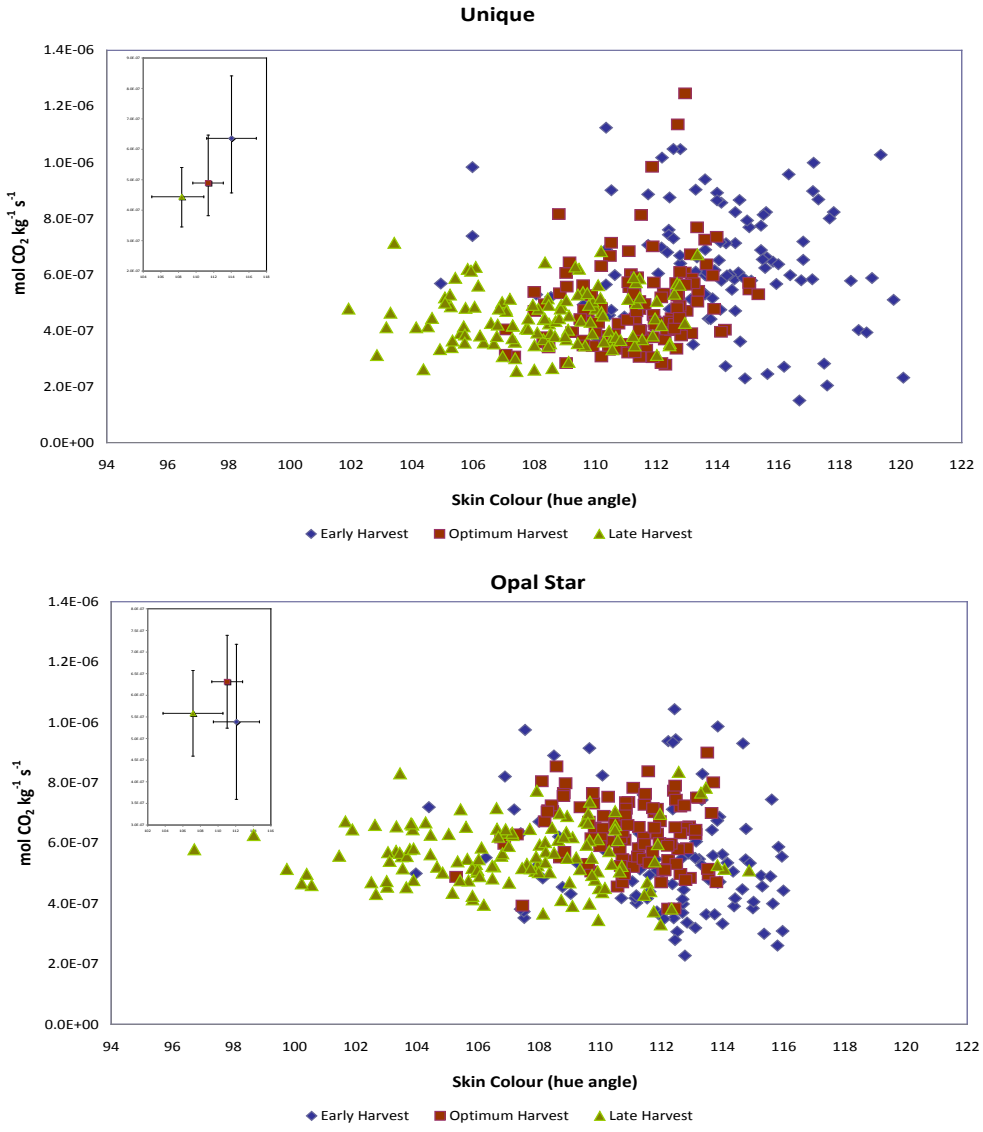
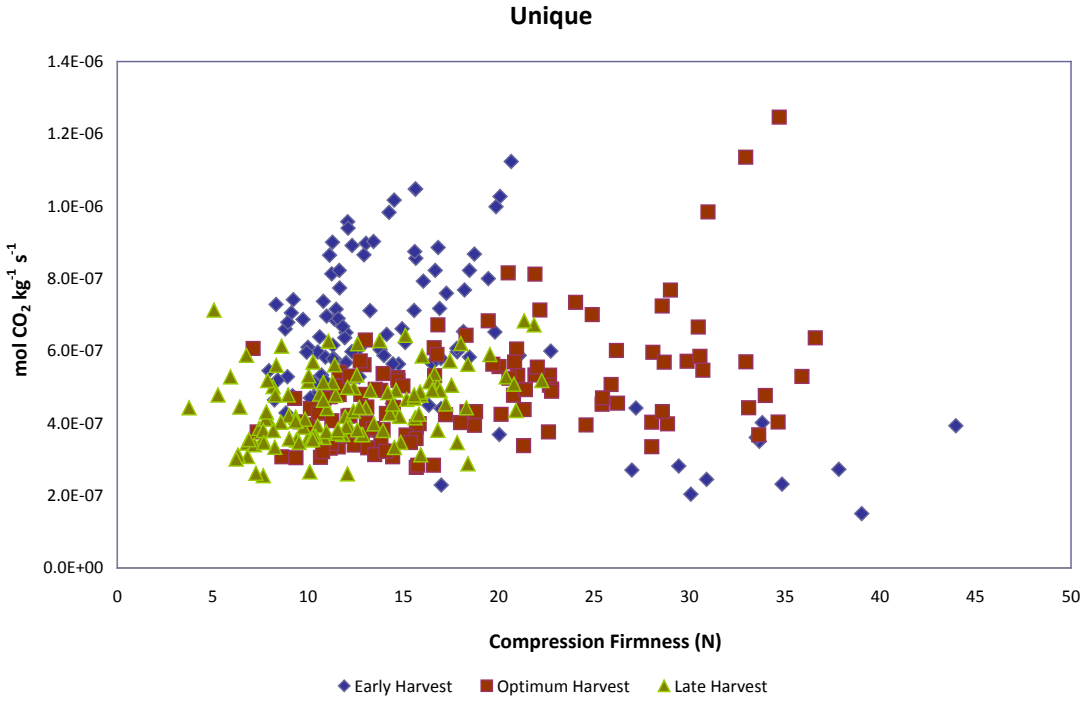


Figure 6.5 CO_2 production and skin colour of 'Unique' and 'Opal Star' feijoa cultivars harvested at three maturity stages and stored at 20°C. Each data point represents an individual fruit. Inset graphs show mean colour and CO_2 production for each harvest.

6.3.1.5. Respiration and Firmness

Respiration rate (RR) of early harvest 'Unique' fruit increased steadily as fruit matured and softened (Figure 6.6). At optimum harvest maturity, fruit was already rapidly respiring on the tree before harvest, and after harvest the respiration rate tended to decrease as fruit matured. Respiration rate in late harvest fruit was less than that in fruit from both earlier harvests. 'Unique' fruits at early and optimum harvest showed a greater range of CO_2 production than late harvested fruit. This is consistent with a small respiratory climacteric being reached after the early harvest fruit are picked, or at the time of harvest for optimum harvest fruit. If this is correct, then late harvest fruit could be classified as "Post climacteric". On the other hand, 'Opal Star' had similar trend, but a climacteric peak (if any) can be seen in the optimum harvest. There was no clear distinction between early harvest, optimum and late harvest in terms of fruit firmness and respiration, as there was a great variability between individual fruit.



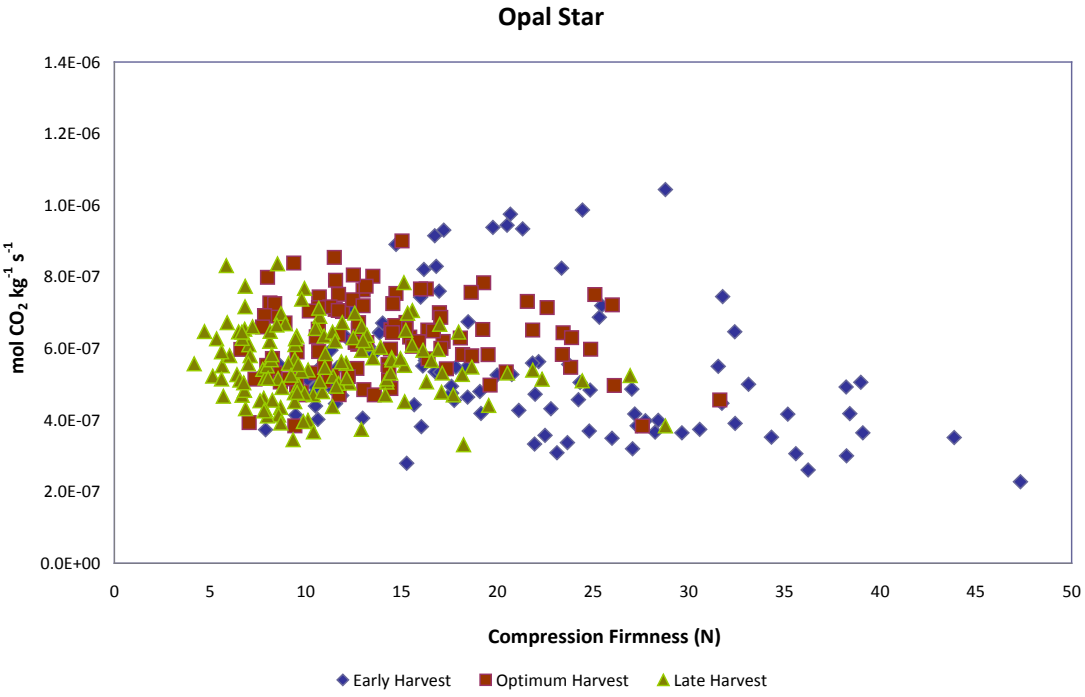


Figure 6.6 CO_2 production and fruit firmness of 'Unique' and 'Opal Star' feijoa cultivars harvested at three maturity stages stored at 20°C. Each data point represents individual fruit.

6.3.2. Response of Feijoa Fruit to Exogenous Ethylene and Propylene

6.3.2.1. Variation in Starting Material

There was a significant difference in fruit weight of the batches delivered. Immature fruit ranged between 60-70 g and 75-85 g for 'Unique' and 'Opal Star' respectively. It was very difficult for pickers to pick fruit with similar size and weight at early stage of maturity because harvesting feijoa fruit depends on retention force and is a labour-intensive exercise. 'Unique' is an early cultivar. Fruit reach optimum maturity stage just a few days prior to natural fruit drop, thus no significant differences were found between mature and over-mature fruit (average fruit weight 65-75 g). In 'Opal Star' there was a clear trend of reduction in fruit weight as fruit matured. This counter-intuitive observation can be explained by the fact that 'Opal Star' is a late cultivar, and the harvesting period is very short (2-3 weeks), thus pickers tended to harvest larger fruit before smaller fruit at early maturity leading to a reduction in number of larger fruit remaining at the end of harvest. Thorp and Bieleski, (2002) found that for early cultivar 'Gemini', harvested over a period of 2-3 weeks from early April till mid April, there was an apparent increase in fruit weight followed by a sudden decrease

afterwards; this was probably a result of pickers' selection where they tend to harvest larger fruit at early harvest. In this experiment the 'Unique' cultivar was harvested in early April for the immature stage, mid April for mature fruit and late April for over-mature fruit.

There was no significant influence of ethylene/propylene treatments on weight loss of feijoa. Rate of weight loss was similar for all treatments at the same stage of maturity and increased dramatically during shelf life assessment (data not shown).

6.3.2.2. Fruit Firmness

Ethylene and propylene treatments of feijoa had no effect on firmness change across all fruit maturities (Figure 6.7). However, rate of softening at 20°C after treatments was highest for immature fruit compared with mature and over-mature fruit. This difference could be due to many factors, such as water loss, cell wall degradation as fruit mature and internal physiological changes such as locule formation. There was a significant difference between fruit firmness at different maturity stages and during shelf life assessment as the fruit ripened. Many factors are involved in the response of harvested fruit to applied ethylene such as cultivar, fruit maturity stage at harvest, exposure time and ethylene concentration (Liu et al., 1999) but in this experiment firmness loss was very consistent and completely unaffected by ethylene or propylene. Exogenous application of ethylene can affect firmness of many fruit and vegetables, whether or not they are climacteric. For example, addition of ethylene to cucumber and peppers may advance unwanted excessive softening, whereas in climacteric fruit such as apricot, avocado, melons, pears and tomato firmness will be reduced as fruit ripening is stimulated (Saltveit, 1999). Some fruit such as kiwifruit are very sensitive to low concentrations of ethylene (30 ppb). In guava fruit treatment with 100 ppm ethylene at 20°C for 24 hours increased skin yellowing and softening of immature-green fruit, but there was no effect on mature-green and quarter-yellow fruit (Reyes and Paull, 1995). In the present experiment, neither feijoa cultivar showed any response to the different concentrations of ethylene and propylene applied. This suggests that 'Unique' and 'Opal Star' fruit are not very sensitive to ethylene or propylene treatments since the pattern of the rate of softening was so similar between

treated and untreated batches. However, there is another possible interpretation which will be discussed below.

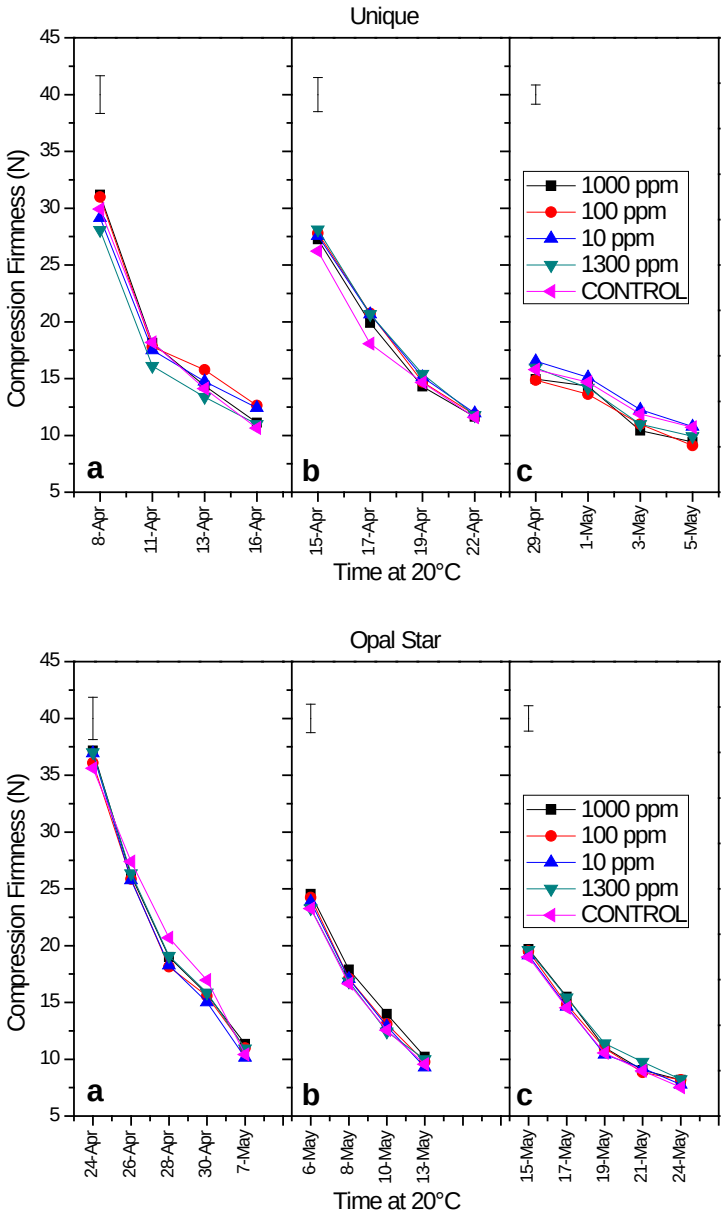


Figure 6.7 Firmness of 'Unique' and 'Opal Star' feijoa treated with either ethylene (10, 100 and 1000 ppm), propylene (1300 ppm) or air (control) for 24 h prior to storage at 20°C. Fruit from three different stages of maturity were assessed: (a). immature, (b). early harvest and (c). late harvest fruit. Each data point represents 45 fruit. The error bars represent the LSD $_{0.05}$.

6.3.2.3. Skin Colour Changes

As fruit mature, significant changes occurred in L, C, and h° values, indicating that both 'Unique' and 'Opal Star' colour changed from dark green to light green. There was no significant difference in skin colour between treated and untreated fruit at the same stage of maturity. More rapid skin colour changed in fruit at the over-mature stage. The rate of changes between colours was similar between treated and untreated fruit (Figure 6.8). Skin colour was not affected by application of ethylene or propylene suggesting that neither 'Unique' nor 'Opal Star' was climacteric fruit.

Exposure of climacteric fruit to ethylene may induce chlorophyll degradation (Alexander and Grierson, 2002). However, in this study the different concentrations of ethylene or propylene used had no affect on chlorophyll degradation. There are many factors that might be involved in the response of harvested fruit to applied ethylene such as cultivar, fruit maturity stage at harvest, exposure time and ethylene concentration (Lagunes et al., 2007). Since three different concentrations of ethylene ranging from 10-1000 ppm and propylene at 1300 ppm were used with three different maturity stages, the main reason for not observing a response could be due to cultivar characteristics i.e. these cultivars truly do not respond to ethylene; or, as for softening there may be an alternative explanation, discussed later in this chapter. A 24 hour ethylene treatment with the concentration range used in this experiment was sufficient to enhance yellowing in other climacteric fruits. For the closely related guava, treatment with 100 ppm ethylene at 20°C for 24 hours increased the skin yellowing of immature-green fruit, but had no effect on mature-green and quarter-yellow (Reyes and Paull, 1995). For papaya, exogenous application of ethylene (100 ppm) enhanced skin colour degreening (An and Paull, 1990). In many fruit the stage of maturity can determine response of fruit to ethylene application. In avocado for instance, the more mature fruit, the faster its response to ethylene (Pesis et al., 1978). For 'Unique' and 'Opal Star' feijoa neither stage of maturity nor concentration of ethylene had an effect on feijoa skin degreening.

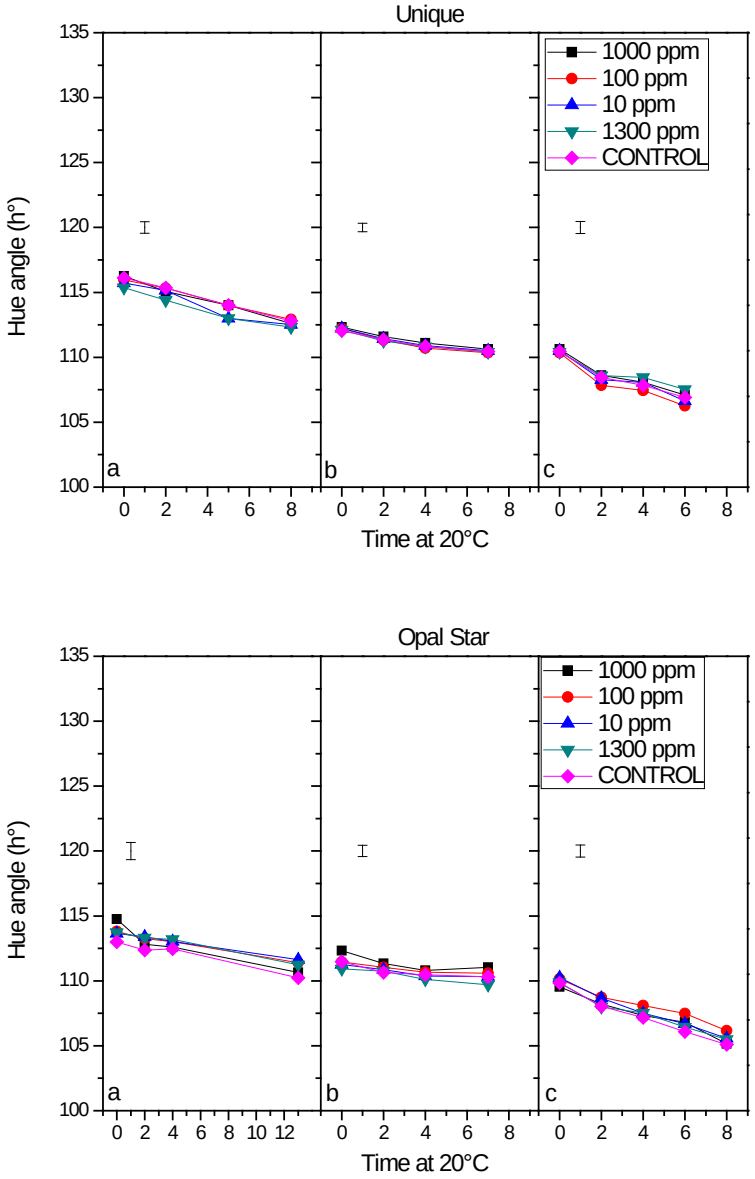


Figure 6.8 Hue angle of feijoa fruit harvested at three different maturity stages: (a). Immature, (b). mature early harvest and (c). mature late harvest treated with different concentrations of ethylene (10, 100 and 1000 ppm), propylene (1300 ppm) and control and maintained at 20°C. Each data point represents 45 fruit. Error bars represent $LSD_{0.05}$ at shelf life 20°C.

6.3.2.4. Ethylene Production and Respiration

There were no significant differences in ethylene production and respiration rate between ethylene and propylene treated and untreated fruit at any stage of maturity. Previous reports of applied ethylene stimulating respiratory rate and hastening ripening are numerous for many fruit such as mango (Lalel et al., 2003), but no such effect was found for feijoa fruit of 'Unique' and 'Opal Star' cultivars. This

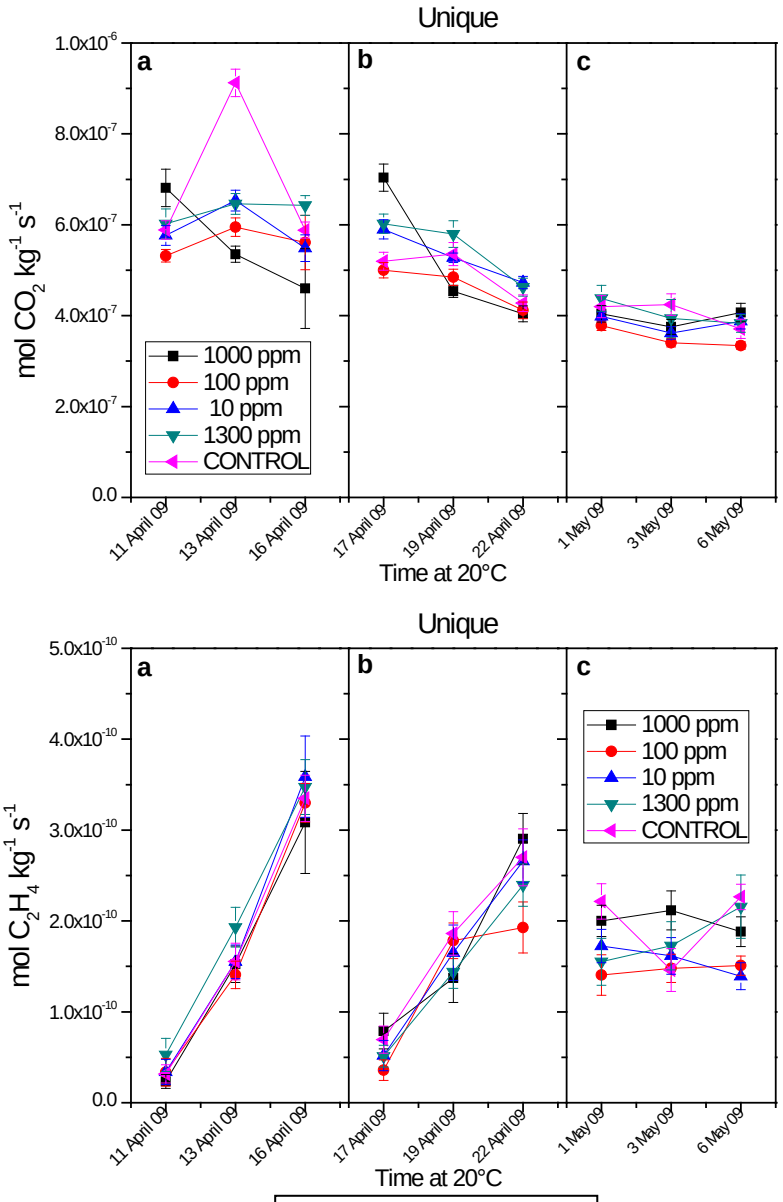
apparently indicates that feijoa is non-climacteric with respect to the definition of McMurchie et al., (1972), and is insensitive to exogenous application of ethylene and propylene.

Feijoa fruit are therefore behaving quite enigmatically with respect to their climacteric status. Fruit softening but not degreening is clearly accompanied by increasing ethylene production. There is some evidence for an earlier respiratory climacteric preceding the increased production of ethylene, but there is absolutely no response to added ethylene or propylene at a range of concentrations and three different fruit maturities. According to McMurchie et al., (1972) one would therefore have to label the fruits as non-climacteric, despite the clear evidence for increasing ethylene production during ripening and softening. An alternative explanation for these observations does exist and data from research on the related species guava is highly relevant. In guava, the addition of 1-MCP was sufficient to prevent ripening-related softening (Azzolini et al., 2005). If this proves to be true for feijoa as well then we can postulate a new hypothesis that fits all the data in this thesis. This hypothesis is that addition of ethylene or propylene does not accelerate softening because the tissue is already saturated by its own ethylene production at rates below those measurable with our conventional GC equipment. Wills et al., (2001) has proposed that there may be no lower threshold of ethylene responsiveness for some horticultural crops after harvest.

It is concluded that the feijoa cultivars tested here are sensitive to ethylene and produced increased ethylene during ripening and softening, but the amount produced maybe so low in firmer fruit that it is below the detection limit for the equipment used. Adding more ethylene did not accelerate ripening because the receptors were already saturated. This hypothesis could be tested by treating fruit with 1-MCP at an early stage of fruit maturation and monitoring change in quality attributes including reduction in softening, or by using much more sensitive ethylene sensing equipment such as the laser system which may reveal a much stronger association between fruit softening and ethylene production than demonstrated here.

The results of this experiment contradict those reported by Akerman et al., (1993), in which feijoa fruit treated with 100 ppm ethylene for 48, 72 or 96 hour showed

significant stimulation of respiration rate and ethylene production during storage. Different varieties and cultivars may exhibit different responses to ethylene. Different varieties of the same fruit may have both climacteric and non-climacteric behaviour (Toivonen, 2007). However, the detail of Akerman et al., (1993) was not published to review the method used. However, 1-MCP treatment has to be tested, to further investigate the role of ethylene in ripening and senescence in feijoas. 1-MCP prevents or delays ethylene production and reduces internal ethylene concentration of many fruit including apple (Watkins and Nock, 2005). 1-MCP delayed ripening after ethylene treatment only if applied before fruit softening (Jeong and Huber, 2004), so it would probably need to be applied to feijoas at the immature stage in order to obtain a response.



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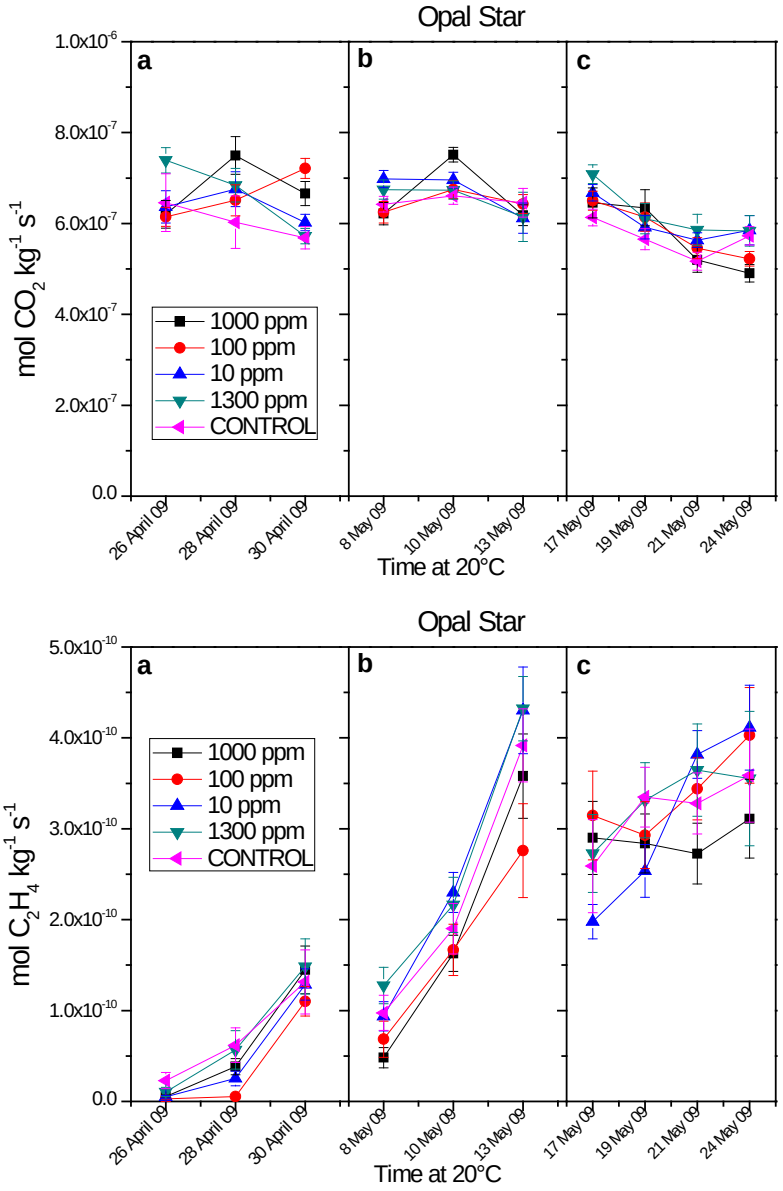

Figure 6.9 Average respiration rate and ethylene production of two feijoa cultivars treated with three concentrations of ethylene (10, 100 and 1000 ppm), propylene (1300 ppm) and control at different stages of maturity: (a). immature (b). mature and (c). over-mature. Vertical bars represent ± SE and each data point represents 15 fruit.

6.4. CONCLUSIONS

Feijoa fruit harvested at different stages of maturity continue to ripen without significant acceleration by ethylene or propylene treatments. Application of different concentrations of exogenous application of ethylene and propylene did not effect fruit firmness and colour changes. This could mean that both cultivars were non-climacteric fruit according to the McMurchie et al., (1972) classification. However,

this may also indicate that the fruit are already saturated with ethylene at an early harvest stage. Other studies have shown that 1-MCP treatment can reduce rate of ripening in guava, while application of ethylene did not promote this process (Azzolini et al., 2005). Hence, it is very important to study the effect of 1-MCP on feijoa fruit.

In 'Unique' highest ethylene production rates occur with early season fruit as they soften. Fruit from the late harvest seemed to be past the climacteric. In 'Opal Star' highest ethylene production occurred in late season fruit, which may imply that the climacteric peak occurred around the eating ripe stage. There was no consistent relationship between ethylene production and colour. However, colour does change as ethylene production increases, in each harvest.

This study suggests that feijoa cultivar 'Unique' and 'Opal Star' do not present typical climacteric respiratory activity. This study supports the idea of Azzolini et al., (2005) that the climacteric and non-climacteric classification is relatively general and unsuccessful by not taking into account the peculiarities of each species.

CHAPTER 7
VOLATILE FLAVOUR COMPOSITION OF FEIJOA FRUIT AT DIFFERENT STAGES OF MATURITY

7.1. INTRODUCTION

Flavour is often considered as a combination of taste and aroma (smell) (Laing and Jinks, 1996). Taste of food is determined by five components of sweet, sour, bitter, salty and savoury (umami) which can be detected by tongue. Aroma on the other hand is the main determinant of food flavour. Aroma can be sensed by nasal receptors during smelling or eating. But flavour perception is complex and challenging and in addition to flavour (taste and smell), appearance (sight) and texture (hearing, touch and kinesthesis) have a significant impact on the perception of flavour (Buettner and Schieberle, 2000). Therefore the human brain has to process many sensory inputs to result in flavour perception.

Feijoa has a distinctive fruity and perfumed aroma that is attractive to consumers. Feijoa imparts a distinctive aroma to many manufactured commercial processed products such as fruit drinks, jam, ice-cream, chutney, wine and fruit smoothie. Hardy and Michael (1970) identified 16 compounds from feijoa that contributed to whole fruit flavour using a vacuum steam distillate in which methyl and ethyl benzoate constituted 90% of GC profile by area. These two compounds are considered to be the primary reason for the strong aroma of feijoas. In subsequent work by Shiota et al., (1980) 57 compounds were identified in feijoa of which octan-3-one, methyl benzoate, ethyl benzoate and linalool comprised 70% by area of the GC profile, and ethyl benzoate was considered the major organoleptically important constituent of feijoa. An investigation on the distribution of volatile flavour profile in the headspace from different parts of the fruit, such as intact fruit or flesh of ripe fruit, identified 15 constituents of which (Z)-hex-3-enal and isopropyl benzoate were reported for the first time and methyl benzoate constituted 82% of the flavour extract (Shaw et al., 1989, Shaw et al., 1983). Ethyl benzoate was found to be associated with over-ripe fruit (Shaw et al., 1989, Shaw et al., 1983). Moreover, methyl

benzoate gives a characteristic sweet 'note' to fresh feijoa (Shaw et al., 1989). Ethyl butyrate was also considered to be contributing significantly to aroma of intact feijoa (Pesis et al., 1991, Shaw et al., 1983). Shaw et al., (1989) also investigated the volatile flavour compounds in feijoa skin using capillary GC and GC-MS. Of the 34 constituents identified, 14 were reported for the first time. (Z)-3-Hexen-1-ol, linalool and methyl benzoate constituted 53% of the oil. Hence ethyl benzoate, methyl benzoate and ethyl butyrate are considered the most important constituents of edible portion of feijoa fruit. Details of all flavour constituents compounds previously found in feijoa fruit are summarised in Table 7.1.

Although there is abundant literature on the volatile flavour constituents of feijoa fruit, there are no details on the volatile composition of NZ grown cultivars at different stages of maturity. This experiment investigated changes that occurred in important aroma constituents of feijoa fruit harvested at different stages of maturity and during subsequent shelf life. Understanding the changes in chemical composition and volatile constituents during ripening might help in developing objective and non-destructive methods to assure high quality fruit for consumption and processing. In addition, fruit after prolonged storage under cold store or modified atmosphere may have excellent appearance but the flavour might be affected, so there is a need to understand when the changes in volatile compositions occur during storage and ripening.

Table 7.1 Volatile flavour constituents of feijoa fruit.

Hardy et al (1970) [1]	Shaw et al (1989) [2]		Shaw et al (1983) [3]	
Constituent *	**Constituent**	**Relative Abundance (%)**	**Constituent**	**Relative Abundance (%)**
Ethyl Acetate	(Z)-Hex-3-en-1-ol	20.00	Methyl benzoate	81.9
Ethyl butyrate	Linalool	18.08	(Z)-hex-3-enal	2.2
Hexenal	Methyl benzoate	14.50	(Z)-Hex-3-en-1-ol	2.2
2-Hexenal	Octan-3-ol	6.45	(E)-Hex-2-enal	1.7
2- Heptanone	Germacrene-D	6.10	(E)-B-Ocimene	1.3
3-Octanone	Octan-3-one	5.80	(Z)-Hex-3-enyl acetate	0.7
Hexenyl acetate	Ethanol	3.70	Hexanal	0.5
Hexenyl propionate	B-Caryophyllene	3.40	Isopropyl benzoate	0.5
2-Nonanone	Acetaldehyde	3.05	Ethyl benzoate	0.5
Methyl Benzoate	Ethyl acetate	2.60	(Z)-Hex-3-enyl-butanoate	0.4
Ethyl benzoate	(Z)-Hex-3-enyl benzoate	2.50	Ethyl butyrate	0.3
2-Undecanone	Methyl anisate	2.10	Hexan-1-ol	0.2
Methyl p-anisate	Butyl anisate	1.46	Octan-3-ol	0.2
Ethyl p-anisate	(Z)-Hex-3-enyl-butanoate	1.44	Methyl anisate	0.2
Ethyl cinnamate	a-humulene	1.25	(Z)-Hex-3-enyl-benzoate	0.2
Hexenyl benzoate	Ethyl benzoate	0.83		
Ethyl hexanoate	Ethyl propanoate	0.80		
	Geraniol	0.80		
	Methyl acetate	0.60		
	B-Elemene	0.52		
	Heptan-2-one	0.51		
	Hexan-1-ol	0.48		
	Calamenene	0.41		
	Pentanol	0.37		
	(Z)-Hex-3-enyl-acetate	0.32		
	Hexan-3-ol	0.28		
	(E)-3-Hexenyl-acetate	0.28		
	Unknown Sesquiterpene	0.28		
	(e)-B-Ocimene	0.21		
	Undecan-2-one	0.18		
	Ethyl butyrate	0.16		
	a-Copaene	0.14		
	B-Farnescene	0.14		
	Myrcene	0.13		
	(Z)-B-Ocimene	0.13		
	Diethyl ether			

[1] whole feijoa fruit, [2] skin oil, [3] fruit flesh.

* Compounds are not in relative abundance % order.

7.2. MATERIALS AND METHODS

Feijoa cultivars 'Unique' and 'Opal Star' were harvested from an orchard in Matamata. In 2008, fruit were harvested in early and mid April. Fruit were equilibrated to room temperature before juicing. Juice was extracted (Section 2.3.13.1), and solvent extraction used (Section 2.3.13.2). In 2009, fruit were

harvested every two weeks, starting two weeks before commercial harvest and continuing until the end of the season. On arrival at the postharvest laboratory fruit were cut in half and the seed pulp was scooped out and stored at -22°C until extraction. Two methods were used to analyse volatile profiles of the collected samples, solvent extraction (Section 2.3.13.2) and headspace analysis (Section 2.3.13.3). In 2009, Selected Ion Monitoring mode (SIM) was used to improve sensitivity of the headspace method to identify the volatiles produced. The mass spectrum of the three targeted compounds was obtained after injecting the standards into GC-MS. Full scan mode range from 45 m/z to 450 m/z was used with a scan rate of 2500 ms. After each scan peak intensity was determined with three reference ions i.e. the base peak and the two fragment ions. Those three ions were used as reference ions for the key volatile compounds (Table 7.2). Retention times of the key volatiles in the three different methods based on the operating conditions specified in section 2.3.13.5 and 2.3.13.6 used are summarised in Table 7.3.

Table 7.2 The mass spectrum of the targeted compounds in feijoa.

Compounds	Base Peak (m/z)	Fragment Ion (m/z)	
Ethyl Butyrate	71	88	73
Methyl Benzoate	105	77	136
Ethyl Benzoate	105	77	122

Table 7.3 Comparison between the retention times of all methods used.

Compounds	Retention Time		
	Solvent (GC-MS)	Headspace (GC-MS)	Solvent (GC)
Ethyl Butyrate	9.172	6.136	12.963
Methyl Benzoate	15.593	16.047	14.831
Ethyl Benzoate	16.843	19.65	15.525

7.3. RESULTS AND DISCUSSION

7.3.1. Method Refinements for Headspace Equilibrium Time

When using the headspace technique, there will be a time difference between the first samples to be injected to the GC-MS and the last sample. The length of time the sample is left inside the vial following extraction may affect the volatile composition of the sample. To determine the extent of change of volatile concentrations inside vials, three headspace samples from frozen and thawed feijoa in triplicate were injected into GC-MS at different times after sample preparation. The concentration of the targeted compounds inside vials changed with time. However, there was no clear trend observed. For the 'Unique' cultivar there were small changes in ethyl benzoate and ethyl butyrate as time increased, whereas methyl benzoate appeared to increase after the first two hours of incubation (Figure 7.1). In consequence it is important to standardise the time from sample preparation to measurement.

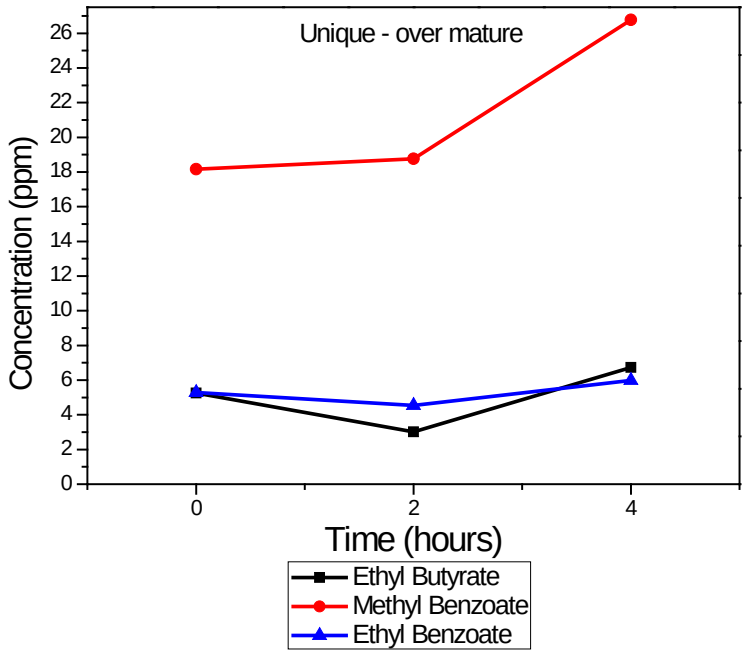

Figure 7.1 Effect of time on volatiles concentration.

7.3.2. Effect of Fruit Maturity on Volatile Constituents

In 2008, all targeted compounds were detected in solvent extractions of frozen feijoa juice. Concentration of compounds was in the following descending order: methyl benzoate, ethyl butyrate and ethyl benzoate. The 'Unique' cultivar had a higher concentration of all compounds studied than 'Opal Star' (Figure 7.2). It was very

clear that volatile concentration increased in 'Unique' as fruit ripened. Relationships between fruit maturation and volatile constituents have been found for many fruits such as tomato, mango and peach (Birtici et al., 2009, Singh et al., 2004, Do et al., 1969). Aroma of extracted juice is considered to closely resemble the aroma released and perceived by consumers when eating fruit (Tough, 1999), whereas, solvent extraction of juice provides an accurate description of the 'raw materials' that give rise to the final aroma.

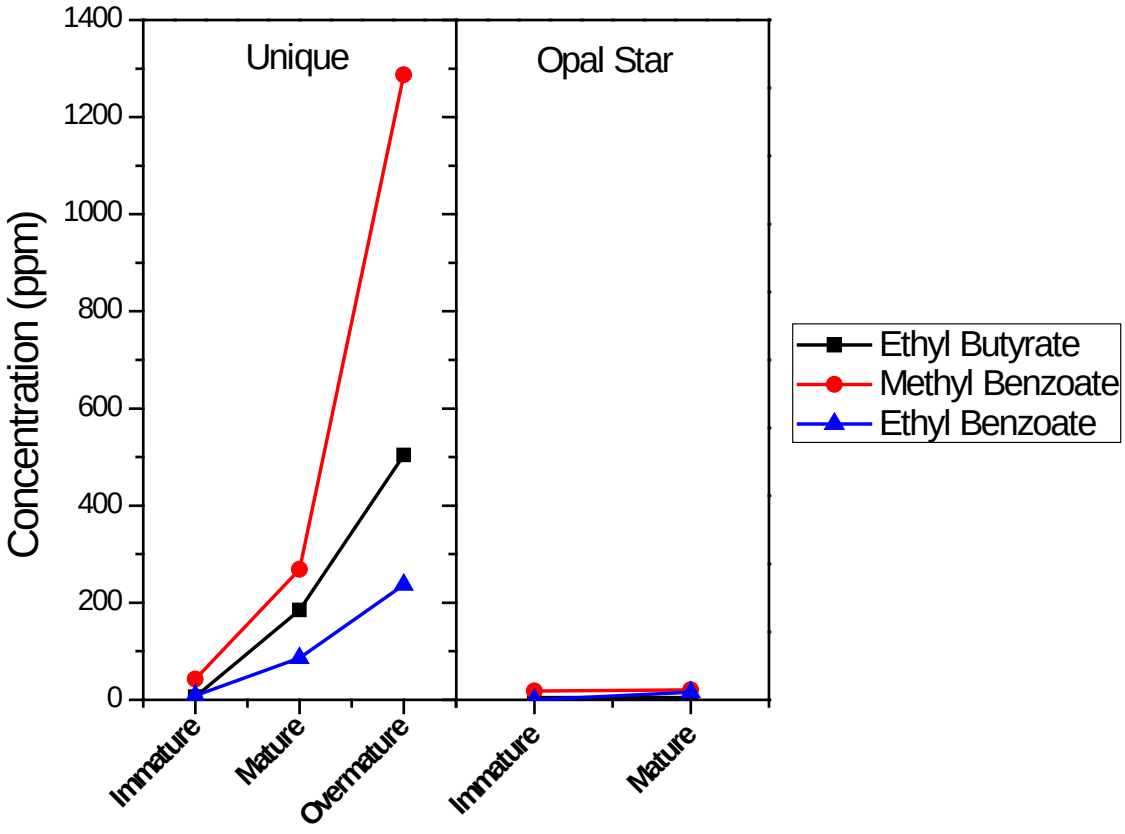

Figure 7.2 Concentration of selected volatile compounds extracted in 2008 from juice of 'Unique' and 'Opal Star' feijoa fruit of different maturity stages.

Results collected in 2009 with solvent extraction of frozen feijoa flesh displayed similar trends to that found with the juice in 2008 despite the difference in starting material and methodology. Methyl benzoate was dominant compared to the other compounds measured. However, both cultivars 'Unique' and 'Opal Star' had similar concentration of methyl benzoate (Figure 7.3) which does not agree with the previous

year's finding. The origin of sample and sample method preparation may affect the volatile results. Same fruit sourced from different regions or different cultivars may have different volatile composition (Alves and Franco, 2003). In this test, ethyl butyrate was rarely found. The concentration of all targeted compounds in the flesh in 'Unique' fruit was found to be less than juice. This may imply that the volatile compounds are more available in juice than in flesh solvent extraction, as the aroma compounds have been allowed to develop in a way most closely resembling what happens in the mouth (Tough, 1999).

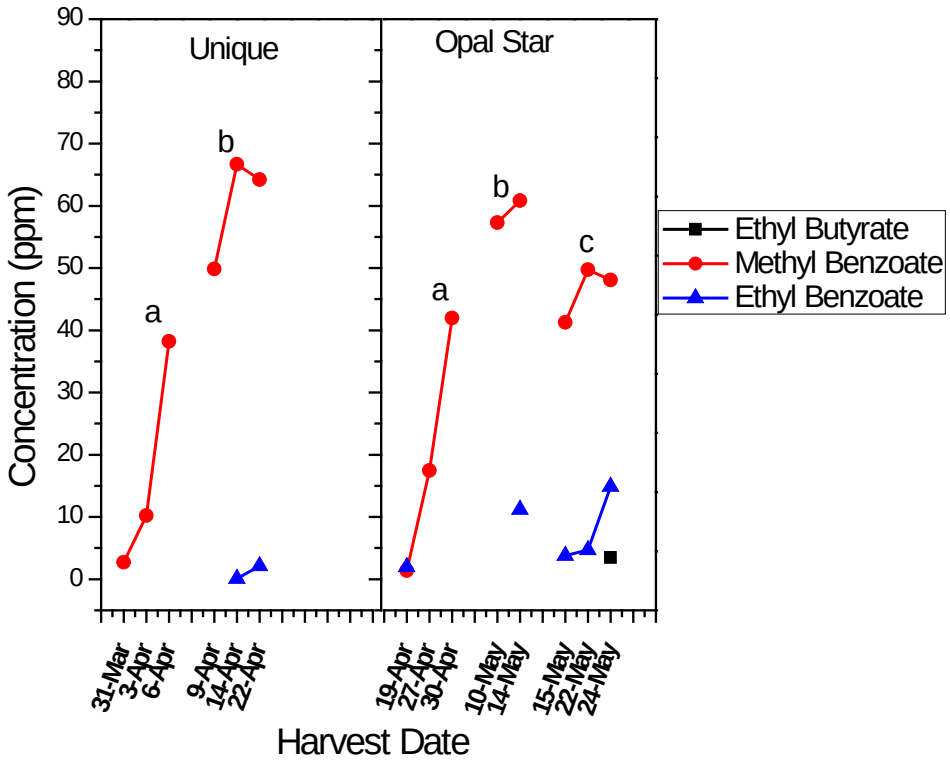

Figure 7.3 Comparison between volatile production during shelf life of two feijoa cultivars harvested at different maturity stages (a). immature, (b). mature and (c). over-mature. Volatiles were extracted from frozen flesh with solvent in 2009.

Using headspace analysis of frozen, thawed flesh, the concentrations of the three targeted compounds (methyl benzoate, ethyl benzoate and ethyl butyrate) changed as the time in storage and maturity stage increased (Figure 7.4). Both cultivars had more methyl benzoate than the other two compounds. Concentration of all targeted compounds was higher with 'Unique' than with 'Opal Star' indicating that 'Unique'

had stronger aroma volatiles than 'Opal Star'. Ethyl benzoate and ethyl butyrate was found higher in over-mature fruit, and the concentration of ethyl benzoate was lowest.

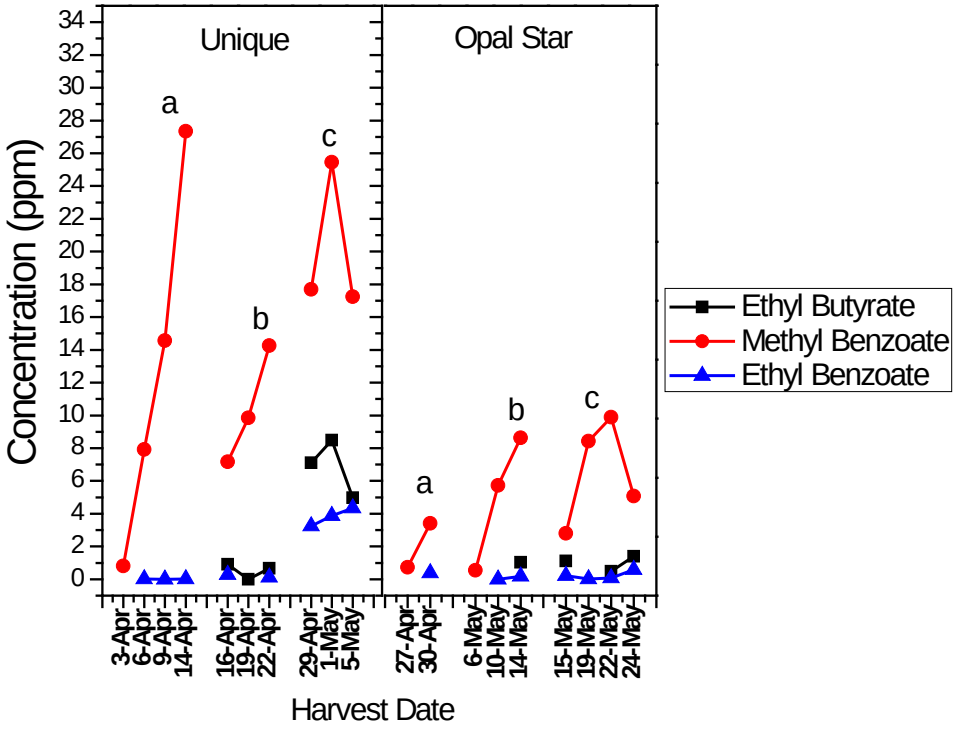

Figure 7.4 Comparison between volatile production during shelf life of two feijoa cultivars harvested at different maturity stages (a). immature, (b). mature and (c). over-mature. Volatiles measured in headspace above thawed flesh.

Similar results were also found when following the concentration changes of the targeted compounds in 'Unique' as the internal maturity rating increased (Figure 7.5). The three characteristic compounds of feijoa aroma were found more consistently in headspace analysis than the solvent extracted fruit flesh. Ethyl butyrate, regarded as an important constituent of feijoa volatiles, was not readily detected in solvent extracted flesh, whereas it was readily identified in both solvent-extracted juice and the headspace of thawed flesh. This could be because it develops during the incubation period after initial sample preparation.

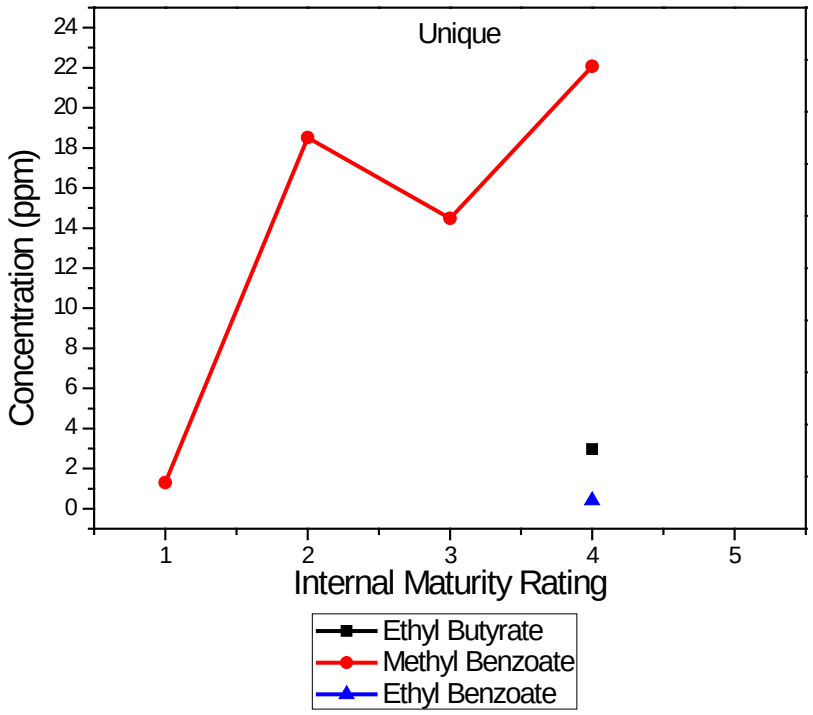

Figure 7.5 Headspace volatile concentration of feijoa 'Unique' fruit with different internal maturity ratings.

7.3.3. CA Effect on Feijoa Volatiles Production

Controlled atmosphere storage delayed ripening in feijoa (Chapter 5). However, it may also reduce the production of aroma volatiles after prolonged storage (Tough and Hewett, 2001, Dixon and Hewett, 2000). While CA successfully maintained fruit quality of both cultivars 'Unique' and 'Opal Star' it suppressed aroma production (Figure 7.6). After 4 and 6 weeks in CA with 'Unique', there was a great reduction in the targeted compounds compared to air. For 'Opal Star' only fruit at week 8 and 10 were examined and there appeared to be no significant difference between CA and air stored fruit.

After 4 weeks in CA, concentration of methyl benzoate, a dominant aroma volatile compound, was 66% less than air. However, the large reduction in aroma doesn't mean that the fruit is not acceptable. Many studies have shown that CA storage has an effect on flavour characteristics (Tough and Hewett, 2001, Dixon and Hewett, 2000). After fruit are removed from CA, the volatile production might increase (Tough, 1999, Yahia et al., 1990) but this was not tested in this study. CA

suppression of volatile production was mostly found with prolonged storage of more than 3 months, but may occur as early as 4 weeks (Tough, 1999, Yahia et al., 1990). The degree of suppression usually increases with storage time. Understanding the changes in volatile constituents during ripening might help in developing objective and non-destructive methods to assure high quality fruit for consumption and processing. A device such as the electronic nose can be used to detect and recognise the aroma and flavour. The recognition process is quite similar to human olfaction. The ability of an electronic nose to identify different stages of maturity non-destructively has been studied (Athamneh et al., 2008, Lebrun et al., 2007, Brezmes et al., 2001, Llobet et al., 1999).

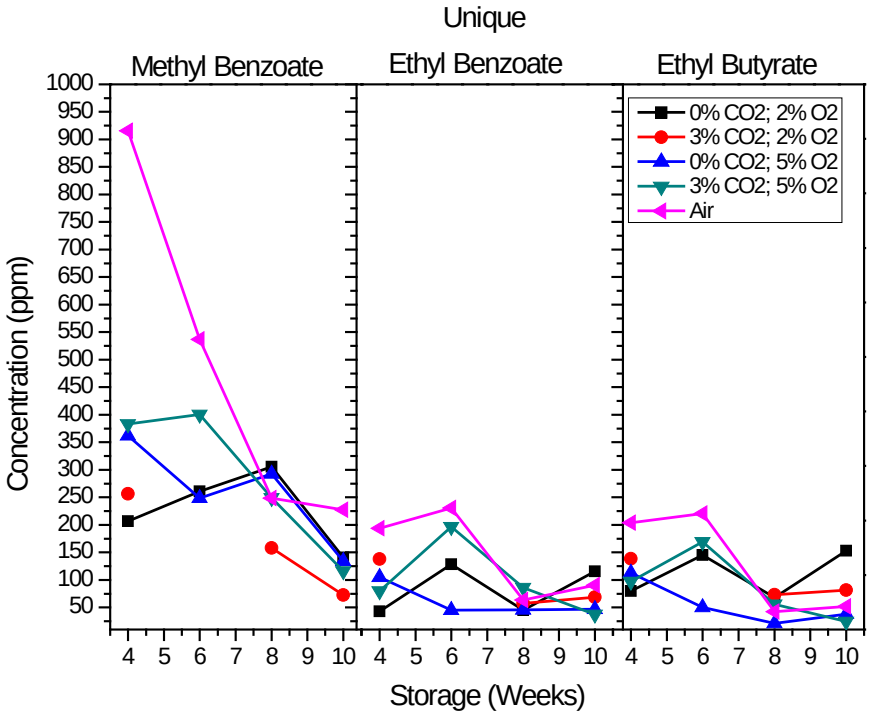

Figure 7.6 Concentration of selected solvent extracted volatiles from feijoa 'Unique' fruit juice maintained in CA conditions, (0% CO2; 2% O2), (3% CO2; 2% O2), (0% CO2; 5% O2), (3% CO2; 5% O2) and air for up to 10 weeks at 20°C from pooled single samples.

7.4. CONCLUSION

As fruit mature aroma volatile concentrations increase. 'Unique' cultivar had a higher concentration of all tested aroma volatiles than 'Opal Star'. In headspace technique, the concentration of the three targeted compounds (ethyl butyrate, methyl benzoate and ethyl benzoate) changed with time inside the vials indicating the importance of standardising the time of incubation before injecting the sample into GC-MS. Solvent extraction technique was able to detect all targeted compounds in frozen feijoa juice and they were in the following descending order: methyl benzoate, ethyl butyrate and ethyl benzoate. In flesh however, ethyl butyrate was not readily detected. The concentrations of the compounds were higher in juice than in flesh. Both cultivars 'Unique' and 'Opal Star' had more methyl benzoate than the other two compounds. Controlled atmospheres were found to suppress aroma production. Fruit ripeness determination plays a vital role in fruit quality. It is very important to find a non-destructive method to assess fruit ripeness. Aroma could be used as a fruit quality measure. A human sensory panel has been used for a long time to identify food aromas. However, this method is tiring and inconsistent. The e-nose is sensitive to many volatile emissions from fruit. The e-nose might have potential to measure changes in maturity of feijoa fruit. This technique is practical, non-destructive and cost effective and should be evaluated for feijoa fruit.

CHAPTER 8
DISCUSSION AND FURTHER RESEARCH

8.1. INTRODUCTION

In New Zealand, feijoa fruit are harvested between March and June. Exported feijoas are graded and packed in single layer trays containing 25-39 fruit and shipped to international markets. One of the essential requirements for successful marketing is consistently good fruit quality. Fruit has to reach consumers at the right stage of maturity. Immature or over mature fruit may have a bad influence on consumers' acceptance. The primary objective of this study was to develop postharvest feijoa knowledge that would assist the feijoa industry to deliver fruit of the required quality and hence improve export potential of the crop. The objective was pursued by exploring non-destructive techniques that could be used to identify maturity of the fruit (Chapter 3); investigating fruit maximum period of storage in conditions that could be used to extend the postharvest life of feijoa fruit (Chapter 4 and 5); investigating the influence of applying ethylene and propylene to feijoa fruit at different maturity stages (Chapter 6); and investigating the production of selected feijoa fruit volatiles at different maturity stages (Chapter 7).

Total planted area of feijoa has declined since the early 1980s, although it does seem to have recovered slightly from a trough in the mid 1990s to 251 ha in 2009 (Figure 8.1). Despite the interest in planting feijoa in New Zealand compared with other countries, development of a thriving feijoa industry is still inhibited by a number of constraints. These challenges are dispersed among farmers, pack houses, retailers, exporters and researchers (Figure 8.2). Researchers play a major role in resolving some of the current difficulties and problems.

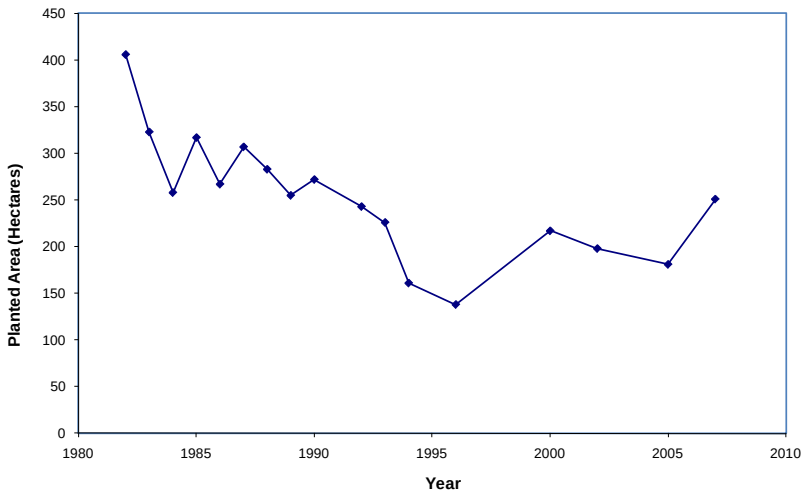

Figure 8.1 Planted area of feijoa fruit from 1980 to 2009.

Source (HortResearch, 2009, Anonymous, 2010)

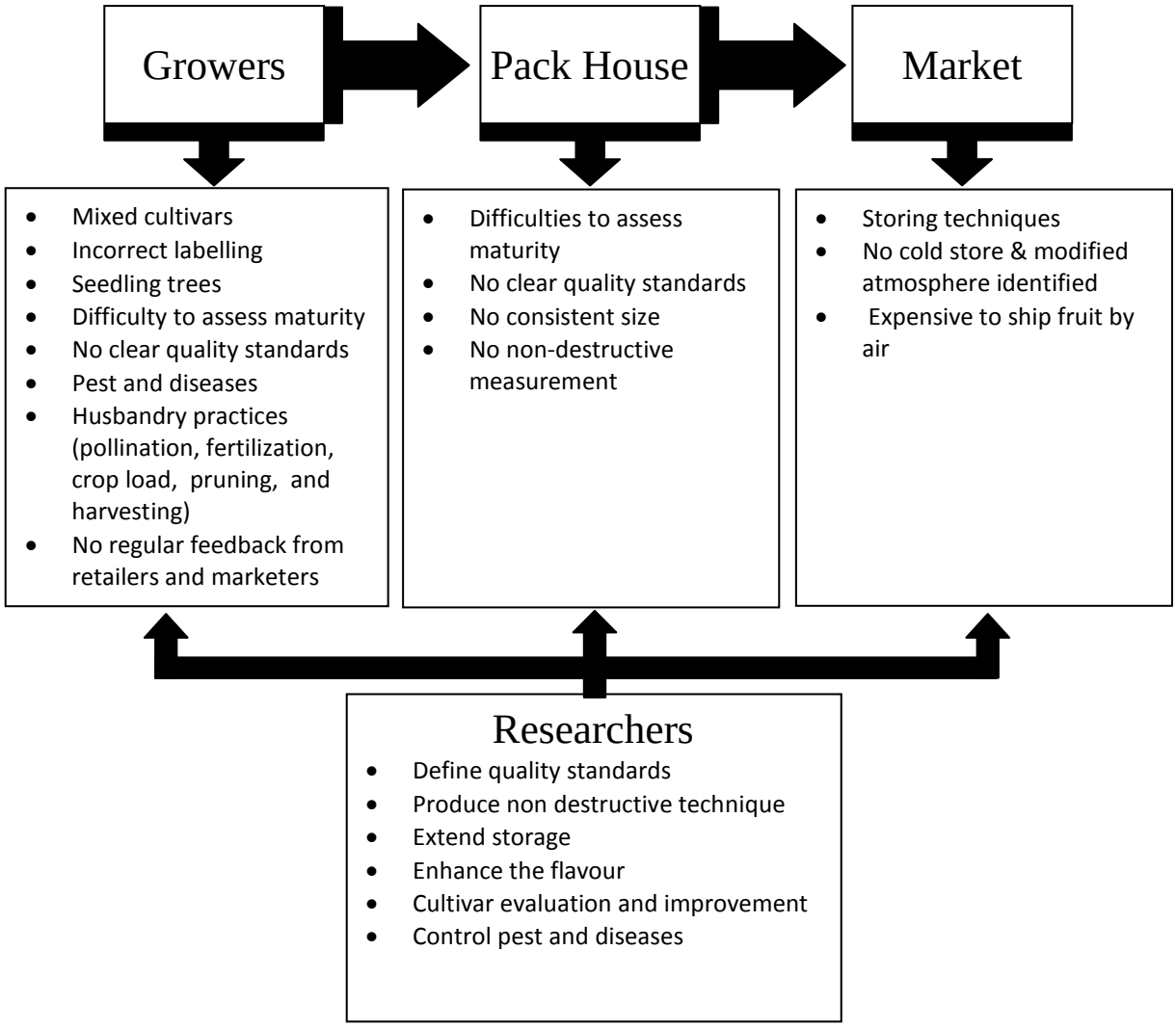

Figure 8.2 Summary of some problems experienced along the feijoa supply chain, and the research required addressing those problems.

To resolve these difficulties, all parties have to work together to determine how to overcome these constraints. Regular feedback has to come from each party, in order for the group to understand the nature of the problem. Solutions have to come from all those who will benefit from feijoa industry development. Hence it is necessary for interested parties to meet under one umbrella to identify obstacles and develop strategies and proposals for future development of the industry. A strategic plan must be developed by and for all those concerned parties in the supply chain. The annual conference of the feijoa growers association may provide an appropriate opportunity for an associated technical review meeting.

8.2. KEY FINDINGS

8.2.1. Fruit to Fruit Variation

A persistent problem that affects the feijoa industry in New Zealand is the presence of only a small quantity of good quality fruit. This is mainly attributable to the divergence in the shape and size of the fruit produced on an individual tree. In this study for example, 'Unique' fruit delivered from different regions had different shapes (Figure 3.8) and weights (Section 3.3.5). The majority of feijoa cultivars are self-sterile or partially self-fertile (self incompatibility) and failed to give satisfactory yield in the absence of good pollination. Pollination in feijoa mainly depends on bees and birds, although bees are not attracted by feijoa as flowers don't produce nectar. Depending on birds to pollinate the tree does not ensure good pollination. Having more than one cultivar in each block may also contribute to variability as there are several sources of pollen to pollinate each cultivar. Cross pollination of many cultivars such as 'Gemini', 'Triumph' and 'Mammoth' resulted in significant increase in fruit set and fruit weight than self pollination (Patterson, 1989). Therefore it is necessary to optimize the pollination practices. It has been found in this study that there was a large variation between and among cultivars; this variation might be because growers depend mainly on open pollination. Depending on open pollination is not wise as it has been found in many crops. For example, it has been found for date palm that pollination at different time of has an effect on fruit set and fruit quality, i.e. date palm pollinated before sunset produced higher fruit set than trees pollinated after sunset (Dawoud and Ahmed, 2006). It was also found that different types of pollination have an effect on fruit physical and chemical characteristics;

cross pollination in plum cultivars gave heavier and larger fruit than self pollination, cross pollination also produced fruit with round shape while self pollination produced fruit with oblong shape (Hassan et al., 2007). There is a direct effect of male parent on chemical and physical characteristics of the fruit such as fruit size, colour, fruit and seed weight, and ripening time (Nixon, 1955). The effect of pollination on fruit weight and size (El-Wakeel et al., 1974) fruit shape (Stino et al., 2001), firmness (Stino et al., 2001) and acidity (Church and Williams, 1983) were also reported with apple fruit. Fruit size is directly correlated with seed number (Pyke and Alspach, 1986). In feijoa, not all sources of pollen are equally effective in producing good seed (Thorp and Bieleski, 2002). 'Apollo' pollinated with 'Gemini' and 'Mammoth' produced better seed set than when pollinated with 'Triumph' (Patterson, 1989). For 'Apollo' percentage of fruit set, number of seed per fruit and fruit weight were greatly influenced by pollen source and this effect varied depending on the pollination source and method of pollination (Patterson, 1989). Some crops have a limited period of stigmatic receptivity that might also limit the effective pollination period. To reduce the fruit to fruit variation, it is very important to do more studies on cross pollination and pollen compatibility in feijoa; with the possible outcome of developing commercially effective artificial pollination systems.

Another reason for fruit to fruit variation might be depending on seedling feijoa trees. It is essential to depend on new registered cultivars that have the ability to produce consistent fruit characteristics. To support the feijoa industry, growers are required to provide marketers and exporters with good quality fruit of identical size and shape. This does not occur consistently at present as some growers have seedling trees (that are inherently variable), mixed and/or mislabeled cultivars that produce fruit of variable and inconsistent quality. Confirmation of the cultivars present in an orchard is a priority for commercial growers and replanting with high-quality cultivars should be considered. New varieties resulting from new selection and breeding programs must also be evaluated by growers on their properties. Selection of the cultivars must consider the importance of both external and internal features, and would ideally include assessment of their suitability for sea freight.

Because of the difficulties in assessing the fruit maturity, it is inevitable that fruit of mixed maturity will be in the same box for market. Fruit are assessed depending on

external features such as size, shape, and weight and freedom from pest and diseases. Relying on external standards only may lead to unacceptable fruit in the market because of poor internal quality. This study found that fruit without any external damage or injury may have already been beyond acceptable eating quality (Section 5.3.9). At the pack house, it is very important to handle the fruit with care as feijoa fruit has a limited storage and handling tolerance. Fruit handled properly will have better quality and shelf life.

8.2.2. Relying on Touch Picking is a Problem in Feijoa

Touch picking is a method currently used by growers in New Zealand to assess maturity of individual feijoa fruit. This technique mainly depends on how easy it is to pick the fruit from the tree. Some feijoa cultivars such as 'Triumph' are ripe at natural fruit drop (Harman, 1987) whereas others such as 'Apollo' and 'Unique' are harvested with higher retention force. Growers assume that fruit that drop to the ground are over-matured. It was very clear from the results of this study (Chapter 2), that there are difficulties in determining the stages of maturity of fruit depending on the retention force at the time of picking. It is apparent that around 30% of 'Unique' fruit thought to be harvested at optimum harvest was not (Table 3.1). Also, fruit that had fallen to the ground and was regarded as over-mature may have been perfectly suitable for sale (Table 3.3). It was very difficult for experienced pickers to assess maturity of feijoa fruit depending on 'touch picking' (Chapter 2). Fruit harvested with higher retention force were assumed to be immature, but ranged between 1-3 internal maturity ratings, whereas fruit collected from the ground and assumed to be over-mature, ranged between 2-4 internal maturity ratings. There was a large variation between and among batches. This may indicate that 'touch picking' is not a reliable method to assess maturity. The variability was not only on the internal maturity but also on physiochemical characteristics (Chapter 2). Downs et al., (1988) showed that feijoa cv. 'Apollo' and 'Gemini' fruit had similar total sugar and organic acid contents and sugar to acid ratio at harvest irrespective of retention force. Similar results were also found in this study, where fruit to fruit variation was so large irrespective of maturity stage.

It is very important that a strong, physiologically based maturity index is developed for use on the grading line so that the industry can reduce the variability inherent in touch picked fruit. For instance the breeding programs should try to identify selections that change colour regularly, or soften consistently, during ripening and link this closely with stage of maturity. It is essential that ways are developed to determine different fruit quality attributes non-destructively. Acoustic and compression firmness techniques used in this study indicates the potential for future use after further refinement to explain why differences between cultivars and regions happen. Some other techniques such as, Near-infrared spectroscopy (NIR), Nuclear Magnetic Resonance (NMR) and X-rays have to be explored. Recently NIR and NMR have shown great potential to be used on-line to sort fruit (Clark et al., 2003). NIR has potential in assessing high moisture horticultural crops non-destructively; better prediction of fruit firmness and dry matter content in cucumber were obtained with NIR (Kavdir et al., 2007). Visible NIR was recognised as a rapid and non-destructive method in determining constituents of horticultural crops. The detector records the intensity of reflected light at certain wavebands from the sample tested. It has the potential to predict moisture content, oil and crude protein content of intact sunflower seeds (Fassio and Cozzolino, 2004). It has also been used to discriminate between bruised and non-bruised apples (Xing et al., 2003). Relationship between dry matter and the ratio of the oil/water in avocado was obtained using NMR (Chen et al., 1993).

8.2.3. CA Holds Promise but Suppressed the Aroma Production in Feijoa

There is a lot of information available about the importance of CA and MA in extending the postharvest life of many fruits and vegetables based on visual appearance and physiochemical characteristics such as texture, titratable acidity and total soluble solids, but not much information about the negative effect on aroma volatiles (Pelayo et al., 2003). Feijoa is an aromatic fruit having unique flavour and aroma that add an important contribution to the eating quality. In feijoa as in many fruits, flavour is lost long before any visual deterioration can be seen (Pelayo et al., 2003, Klein and Thorp, 1987), less attention has been given to flavour life extension because the work is much more complex than traditional quality assessments (Schotsmans and Prange, 2006). In this study, it was very clear that good appearance doesn't equate to good quality in feijoa. Feijoa fruit stored at low temperature

(Chapter 4) or controlled atmosphere (Chapter 5) after 4 weeks of storage had good visual appearance; however CA effect on volatile production (Chapter 7) showed that the main volatile constituents of feijoa fruit were suppressed. Similar results were also reported with apple after 4 week in CA, a key volatile compound (butyl acetate) was only 34% that in regular air (Tough and Hewett, 2001). More studies need to be done to understand if the aroma volatile reappears during subsequent storage under ambient temperature.

Methyl benzoate, ethyl benzoate and ethyl butyrate could be appropriate ripeness indicator compounds in feijoa fruit due to their increasing concentration during storage and ripening (Figure 7.4). E-nose is a smart instrument that can be used to distinguish among complex odours. It has been used to differentiate flavour or odour of many food items such as 24 flavour notes of tea (Ampuero and Bosset, 2003). Electronic noses have provided value to a variety of commercial industries, including the agricultural, biomedical, cosmetics, environmental, food, manufacturing, military, pharmaceutical, regulatory, and various scientific research fields (Wilson and Baietto, 2009). This technique has to be tested with feijoa in the future. Research should continue, taking into account the feasibility of using these devices in terms of cost. The disadvantage of the destructive techniques used currently to identify maturity is that the samples tested cannot be exported, and quality inspection cannot be done for individual fruit. E-nose was recognized to be promising in the development of rapid test.

In general, fruit quality is influenced by the supply chain conditions from harvest till consumption. Refrigeration technology plays a role in preserving fresh produce and extending postharvest life. NZ fruit producers have the challenge of being far from the rest of the world resulting in long transport times for products. The cheapest and most environmentally sustainable way in which to export fruit and vegetables is via sea freight. In order for feijoa fruit to be shipped internationally, it must maintain acceptable quality for 4-6 weeks so this requires that it is stored at an appropriate temperature or atmosphere. This study showed that feijoa cultivars have differences in maximum period of storage; ‘Opal Star’ may be suited for sea freight (Chapter 6 and 7) as it was in a good condition after 6 weeks time. However, quality of the fruit

before storage plays a vital role in the length of storage achievable. It is also very important to realize that good appearance doesn't necessarily mean good quality. It has been found in this study that controlled atmosphere suppressed the production of volatile compounds.

8.2.4. Is Feijoa Climacteric or Non-climacteric

Feijoa is a subtropical fruit with rapid postharvest ripening. Traditionally feijoa has been classified as climacteric and a rise in respiration rate was found to precede a rise in ethylene production (Reid, 1975). It was reported that 10-100 ppm ethylene for 24 hours at 20°C will enhance loss of colour and softening (Kader, 2006). However, feijoa has been classified as low ethylene sensitivity (Marta, 2001). In modern definition, the main difference between climacteric and non-climacteric fruits lies in autocatalytic ethylene production in response to ethylene treatment (Ludford, 2003). This can be seen by treating the fruit with threshold levels of ethylene or propylene. In this study however, feijoa fruit exhibited both climacteric and non-climacteric features depending on the definition used. Feijoa harvested at three different maturity stages were able to complete their ripening process after harvest with superficial changes in skin colour and firmness. Respiratory activity was different between the maturity stages, generally reaching a maximum when fruit are ripe (Figure 6.2). There was a large variation between individual fruit in terms of respiration and ethylene production. This variation could be due to different stages of maturity within the batch as has been explained in chapter 3. When exogenous ethylene and propylene was applied to feijoa fruit, no significant differences were seen between any aspect of ripening in treated and untreated fruit. This may imply either that feijoa is not sensitive to the ethylene and propylene concentrations used or that the fruit has already been saturated with endogenous ethylene. 10, 100 and 1000 ppm ethylene or 1300 ppm propylene used in this study did not have an effect on colour change or softening. In another study with feijoa, it was found that 100 ppm ethylene applied for 48, 72 or 96 hours stimulated respiration and ethylene production (Akerman et al., 1993). Thus it may be worth trying longer time of application of ethylene and propylene.

In closely related guava exogenous application of ethylene did not promote ripening as observed for many climacteric fruit; however 1-MCP application at early stage of maturity reduced fruit firmness and maintained skin and pulp colour (Azzolini et al., 2005). In this study, ethylene production increased throughout later feijoa ripening, and may have been already increasing before it reached a concentration that was detectable with our conventional GC. It would be wise to use more advanced ethylene sensor such as 'Sensor sense' (ETD-300 ethylene detector, Netherlands) to resolve this uncertainty. The fact that exogenous ethylene or propylene was ineffective may be because the tissue was already saturated with endogenous ethylene. Thus it may be important in the future to use 1-MCP at an early stage after harvest before treating the feijoa with ethylene or propylene to further investigate the role of ethylene in ripening.

8.3. SUGGESTIONS FOR FURTHER RESEARCH

In feijoa fruit, the maturation process is complicated, but non-destructive estimation of harvest maturity needs to be developed in future based on physiological and/or biochemical indices that are consistent and robust and may include patterns of change in total soluble solids, dry matter, titratable acidity, ethylene and volatiles. Future work should be directed towards the following:

- Developing a non-destructive quality assessment technique at harvest that allows segregation of fruit into different maturity stages and quality. The non-destructive test should be done on known cultivars pollinated with a single parent to minimize the variability between the fruit produced and the study may include the following techniques:
    - X-ray tomography, a shortwave radiation that can penetrate the tissue. It has been found that this technique can detect most internal disorders, such as wooliness, hollow heart and water core of some fruit.
    - Near-infrared spectroscopy, this technique has been used to measure the SSC of many fruit.
    - Magnetic resonance.
    - Acoustic and compression firmness.
- Characterising physiological and biochemical changes of feijoa fruit on tree and after harvest in order to determine the optimum harvest maturity and

storage conditions that will allow fruit to be stored for 6 weeks and still have the capacity to maintain eating quality throughout a further seven days at 20°C. This study may include:

  - Respiration and ethylene production of fruit before and after harvest.
  - Total soluble solids, titratable acidity, PPO at different stages of maturity on and off tree.

- Further evaluate a broader range of atmospheres with potential to extend the postharvest life of feijoa.
- Evaluate the affect of 1-MCP, a potent inhibitor of ethylene action on postharvest behaviour of feijoa.
- Determine pollination compatibilities between cultivars and optimal methods for pollination to determine more uniform fruit.
- Evaluate use of an e-nose system to determine if it could reliably measure changes in ethyl butyrate, ethyl and methyl benzoate, as an aid to assessing fruit maturity at harvest, in the cool store or during retail display.

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