NON-DESTRUCTIVE MEASUREMENTS OF INTERNAL MATURITY OF FEIJOA (*Acca sellowiana*)

A 90 credits thesis presented in partial fulfilment of the requirements for the Master degree of AgriScience in Horticulture at Massey University, Palmerston North, New Zealand.

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2015

ABSTRACT

Feijoa (*Acca sellowiana*) is a delicious fruit with a narrow window for harvest and a limited postharvest life. In New Zealand, feijoa fruit is required to have at least 6 weeks postharvest life in cool storage plus 6 days shelf life under room temperature in order to be exported to global markets. Slightly immature feijoa fruit (maturity stage 2) can be stored for more than 6 weeks plus few days' shelf life. However, the variation of maturity is large even among individual fruits harvested from the same tree at the same time, and currently, there is no way to segregate fruit non-destructively based on the internal maturity of feijoa at harvest time. The problem with current industry segregation practice is that the external features of feijoa, such as shape, size, and weight cannot segregate fruit with different maturity. It is inevitably that some more mature fruit will rot quickly and affect overall batch quality during storage. It is vital to have a non-destructive assessment of fruit internal maturity at harvest time. Then fruit with different maturity can be divided into different batches with more mature fruit put on sale on local market and less mature fruit put into storage. As a result, the fruit loss rate and overall fruit quality can be improved. Therefore, in this study, efforts were made to explore a non-destructive method to estimate the internal maturity of feijoa fruit and correlate that maturity with performance during storage.

The non-destructive measurements in this experiment included fruit weight, compression firmness, and skin colour. Four feijoa varieties: 'Kakariki', 'Barton', 'Anatoki', and 'Wiki-Tu' were selected for this experiment. For each variety, 945 fruit samples were harvested at approximately one week before becoming fully mature (standard commercial harvesting) and sent to the lab in Massey. All the fruit were divided into three groups based on their skin colour (from darkest green to lightest green). 45 fruit (three replicated batches of 15) from each colour group were measured immediately for weight, firmness, maturity, skin colour, Brix, and titratable acidity (TA). Then all the other fruit samples from the same colour group were randomly divided into three groups that were kept in cool storage for 4 weeks, 6 weeks and 8 weeks respectively. Once cool storage was completed, those samples

were taken out and firmness and skin colour were measured (non-destructive measurements). Then all the samples were retained at 20°C. Half of these fruits were assessed for quality attributes 3 days later, and the other half were measured 6 days after cool storage. All fruit were cut open for final visual assessment of maturity according to the maturity index developed by Plant & Food Research Institute. The data of internal maturity and initial fruit quality (weight, firmness, and skin colour) for each fruit was used to draw scatterplots in order to find out the correlation between estimated maturity at harvest, final fruit internal maturity and fruit quality after storage.

The correlation (R^2) between internal maturity and compression firmness found on 'Kakariki' was 0.6 to 0.5. The correlation for 'Barton' and 'Wiki-Tu' was weaker than that of 'Kakariki' (R^2 from 0.6 to 0.2). The correlation between firmness and internal maturity for samples of 'Anatoki' were weak. The simulated segregation based on firmness for 'Kakariki' and 'Barton' indicated that the firmness segregation at harvest time could be very useful on eliminating potentially bad fruit during cool storage. A non-destructive method for 'Kakariki' and 'Barton' fruit based on initial firmness is therefore now available that would allow successful segregation of fruit with potential for long term storage. However, this segregation would not work well on 'Anatoki'. No significant correlation was found between skin colour, fruit weight and the internal maturity of feijoa fruit either at harvest time or after storage.

There was a very large variation in fruit quality at harvest time and during the storage periods. Samples of 'Wiki-Tu' indicated that this variety could have the best storage performance among the 4 varieties testes. 'Anatoki' may also have a reasonable storage potential with less flavour.

The feijoa fruit may not be stored well when covered with polyethylene film, as it may harm the storability of the fruit. Too immature fruit should not be harvested as well, as it would never be able to ripen properly during the postharvest period.

ACKNOWLEDGEMENTS

I would like to express my great gratitude to the all the people who helped me to bring this research project into fruition. Firstly, my profound appreciation goes to my master supervisors, Professor Julian Heyes, Professor of Postharvest Technology, Institute of Food, Nutrition & Human Health, Massey University, and Dr. Andrew East, Postharvest Physiologist, Massey University. I really appreciate their consistent guidance, encouragement, professionalism and critical feedback throughout my whole master studies. There is no possibility for me to finish this thesis without their help.

All the feijoa samples for my experiment were supplied by the Southern Belle Orchard and the Kaiaponi farm. Great gratitude is also given to the general manager of Kaiaponi Scott Wilson, the grower liaison manager David Hansen, and the owner of Southern Belle Orchard Frans for their hospitality and great assistance. I also would like to thank the New Zealand Feijoa Grower Association (NZFGA) for their generous sponsorship on the fruit samples.

I would also like to thank the lab manager Sue Nicholson at Massey lab, who taught me how to use the lab facilities and instruments that I needed, and many thanks also goes to Peter Jeffery, for his professional help with computer matters during my study.

During my master degree, I received financial support from Professor Julian Heyes, Professor Ren Jizhou Scholarship and Turners & Growers Research Grant. I am very grateful for their generosity and trust. This study was based on the previous researches from Abdul-Aziz Salim Al-Harthy and Srikanth Rupavatharam. I would like to thank them for the inspiration and guidance.

Finally, I must express my very profound gratitude to my parents and to my partner for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. They are my fundamental motivation to finish this thesis.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

The feijoa, (*Acca sellowiana*), is delicious and aromatic fruit. The fruit skin is a bright or olive green, depending on cultivar (Al-Harthy, 2010; Thorp & Bieleski, 2002). A heavy wax bloom overlays the whole surface of the fruit. The cream-coloured flesh under the skin surrounds a transparent seed pulp, which is juicy, refreshing, and highly aromatic (Thorp & Bieleski, 2002).

This fruit is originally grown in the southeastern region of Brazil and Uruguay, where the climate ranges from subtropical to temperate. To fulfil the soaring appetite of modern consumers towards 'exotic' flavours and new tasting experiences, the feijoa has been introduced to several countries across the world including New Zealand (Thorp & Bieleski, 2002) as a potential horticultural crop.

The horticultural industry has contributed greatly to the national economy of New Zealand. Annual horticultural exports have climbed up to 3.6 billion dollars representing 8 % of New Zealand's total exports (Anon, 2014). The export revenue of another introduced plant, kiwifruit is worth $934M (Anon, 2014), being approximately 26% of the total horticultural export. However, the export value for feijoa is only $200K and $1.7M in the domestic market in 2009. This small economic exploitation seems to be unusual especially when you consider the rich nutrient content and unique aromatic flavour that feijoa has and the fact that both kiwifruit and feijoa were introduced to New Zealand at almost the same time.

To understand this 'puzzle', first of all, it requires a clear understanding of the biological characteristics of feijoa. The length of pollination and fruit set for feijoa is relatively long (Thorp & Bieleski, 2002). Consequently, it causes a tremendous variation in terms of fruit size, skin colour, and fruit internal maturity. The internal maturity of each feijoa fruit could vary greatly from the others, even if they are picked from the same tree at the same time with similar external appearance. Currently, the only accurate way to evaluate the internal maturity of each feijoa is by cutting the fruit into halves at the equator of the fruit and comparing the internal features with the maturity index chart developed by Plant & Food Research Institute. However, this is a destructive method, which cannot be used to predict the maturity condition of other feijoa fruits. Secondly, the picked feijoa fruit is highly perishable and prone to bruising. The optimal period to eat feijoa in ideal ripeness and flavour is also very limited. Air transport can deliver fresh New Zealand feijoa fruit to the rest of the world efficiently without compromising the fruit quality, but the transportation cost is expensive and volumes are limited. Cool storage can be applied to maintain fruit quality and extend the postharvest life of feijoa greatly. Fruit from some cultivars have been reported to survive after 6 or even 8 weeks' cool storage and still have another few days' shelf life (Al-Harthy, 2010). The relative low cost of on-boat refrigerated transport provides significant economic benefit and enables sea-freight based industries to develop much larger scale. However, the fruit loss rate can be high after shipping due to varying maturity among individual fruit. Fruit of late maturity would rot quickly and harm the fruit quality of the whole batch. Other issues like marketing, seasonality and poor shelf presence (being green and uninviting) may also be limiting the export potential, but nevertheless, these are not the focus of this study.

Although the development of feijoa industry is currently constrained, a tremendous potential of this fruit remains. If the dramatic maturity variations among individual batches of feijoa fruit could be minimised, the fruit quality and storage potential of each batch are likely to be more manageable, potentially enabling seafreight as an export option.

There are several options for reducing the maturity variations among individual fruit. The use of natural or synthetic plant growth regulators on fruits is industrial practice for many fruits. However, previous application of ethylene on feijoa failed to produce stimulatory ethylene production (Velho, Argenta, Amarante, & Steffens, 2008; Al-Harthy, 2010).

In the majority of cases, application of 1-MCP to feijoa has resulted in no observed quality effects (Velho et al., 2008; Schotsmans, East, Thorp, & Woolf, 2011;

Rupavatharam, East, & Heyes, 2015), which is probably because most of these studies were carried out at touch-picking maturity. Application to early harvested feijoa was made by Rupavatharam et al (2015), which concluded that treatment of 1-MCP is only effective for earlier than commercial touch-picking maturity, resulting in suppressed respiration rate, softening and losses in flesh colour. This validates the possibility of earlier harvest combined with 1-MCP treatment to extend postharvest life.

Application of plant growth regulators on flowers also has the potential of reducing maturity variation. For example, hydrogen cyanamide (HC) was able to advance flower bud initiation, differentiation and development (Engin, Gokbayrak, & Dardeniz, 2010).

It is also possible to manipulate the pollination process so that a whole batch of fruits is pollinated at the same time, reducing maturity variation.

Other more sophisticated solutions involve breeding a new cultivar that has a short period of flowering and pollination and the ability to produce fruits with consistent and uniform qualities. However, this process is likely to take longer time, therefore is less appropriate compared to other solutions that can be achieved in reasonably smaller amount of time.

An alternative approach to minimise variability in a harvest horticultural product is to establish a non-destructive maturity index. Estimating the maturity of feijoa fruit at harvest may assist prediction of the storage potential and shelf life for each fruit. If this is achievable, then it may be possible to divide the fruit into different batches at harvest according to their maturity stages. This may improve the fruit quality after the cool chain distribution and make exporting a portion of the feijoa crop to distant markets practical and profitable.

The research on developing non-destructive methods to estimate the internal maturity of feijoa is still very limited. Previous studies on feijoa have suggested the potential of using skin colour or firmness to estimate the maturity of feijoa cultivars ‘Opal Star’ and ‘Unique’ (Rupavatharam et al, 2015; Al-Harthy, East, Hewett, Heyes, & Mawson, 2009; Gaddam, Mawson, Schotsmans, & Hewett, 2005; Wiryawan et al., 2005; Clark, White, Woolf, & Domijan, 2005).

Therefore, the main objective of this study is to identify a reliable, practical, and economical non-destructive measurement for assessing the internal maturity of feijoa fruit. This project also plans to monitor and record the changes of fruit quality during the cool storage of a number of cultivars so as to identify the cultivar(s) with best storage potential.

In the remainder of Chapter 1, basic botanical and physiological information of feijoa fruit is reviewed. Current industry practices including harvest and storage are introduced. Lastly, major non-destructive methods for assessing fruit quality are reviewed.

Chapter 2 provides the materials and methods applied in this experimental project, including the cultivars tested, different storage treatments, and laboratory techniques to measure the fruit qualities. Chapter 3 presents the results of how the fruit quality changed throughout cool storage and shelf life. Chapter 4 investigates correlations between the existing internal maturity grade and measured fruit qualities. Chapter 5 discussed the possibility of applying skin colour and firmness to assess the maturity of feijoa. It also discussed the industrial application of polythene film, the fruit quality variation among individual fruit and cultivars, and identified fruits with the best storage potentials.

1.1 BOTANICAL INFORMATION OF FEIJOA

1.1.1 Botanical description

The feijoa (*Acca sellowiana*) is a small size of evergreen tree or shrub, which belongs to the Myrtaceae plant family (Thorp & Bieleski, 2002).

Feijoa tree can reach up to 6 m high and is widely grown in Australia and New Zealand as an ornamental and hedging plant. The bark is initially light brown then changes to pale grey gradually with time. The leaves are obovate and elliptic. The leaves are thick with glossy green upper surface and silver grey or brown lower surface (Landrum, 1986).

The flower of feijoa is hermaphrodite and attractive for its special appearance. The diameter of the flower is approximately 4 cm with a large cluster of red stamens, which is surrounded by 4 to 6 fleshy petals (Schotsmans et al., 2011). The fruit of feijoa is shaped from ellipsoid to ovoid. The mature fruit size varies greatly from 3 to 10 cm long and 2 to 5 cm wide with calyx segments remains on the apex of the fruit. The fruit skin is in a bright or olive green covered with whitish wax. The texture of the fruit varies from smooth to rough, depending on cultivar (Thorp & Bieleski, 2002).

When the fruit is cut open at its equator, the cross section unveils the seed pulp, locule and seed together within the pericarp flesh. Jelly-like flesh and seed and juice fill the locule.

1.1.2 Climate

There is little research regarding the climatic requirements of feijoa. Generally, feijoa is mostly found in cool subtropical regions, with typical mean temperatures ranging from 16.5 to 18.1 °C; rainfall ranging from 1350 to 1700 mm annually and feijoa is tolerant to temperature extremes of as low as -8.5°C and as high as 40°C (Thorp & Bieleski, 2002). Research indicates that feijoa prefer cool winters, during which the winter chilling process assists good flowering (Sharpe, Sherman, & Miller, 1993). Feijoa matures earlier if grown in warm locations, and such differences can be as large as 8 weeks (Thorp & Bieleski, 2002).

1.1.3 Soil

Feijoa can adapt to a wide range of soil types. For example, in the wild, feijoa is found in soil types like highly acid basalt soil in Africa, crystalline soils and sandy soils soil in Uruguay. It is generally believed that a fertile soil with pH between 6.0 and 6.5 is the most optimum soil for feijoa (Thorp & Bieleski, 2002; Fisher, Miranda, Cayon, & Mazorra, 2003). Alkaline soil may induce problems like leaf yellowing and poor shoot growth (Thorp & Bieleski, 2002). Feijoa prefer soils that are well drained, therefore, heavy soil with fine particle is quite good for feijoa (Morton, 1987). However, feijoa grown on sandy soils can produce excessive shoot growth, which could be as long as 1.5 m in length, in which case, constant cutting and pruning is required, which is often at the expense of fruiting resulting in lower yield (Thorp & Bieleski, 2002).

1.2 FRUIT DEVELOPMENT

1.2.1 Flowering

Feijoa has iconic bright red and white flowers. The feijoa flower buds start to grow just before the rapid shoot growth phrase, which is also accompanied by the flush of leaf. They start from the base of new season shoot growth, usually in the axils of leaf bracts that form opposite in the overwintering apical buds. Flowers open in November (in South hemisphere), around 70 days after the initial shoot growth (Thorp & Bieleski, 2002). The whole flowering period lasts around 4 to 6 weeks, within which full bloom only lasts 1 to 2 days (Thorp & Bieleski, 2002).

Feijoa flowers feature 4 to 6 red and white petals surrounding several red stamens. As the flower develops, the ovary wall swells and the flowering part is pushed to the far end of the flower. The petals are edible, and during full blossom, birds eat the pedals and leave the stamens, which also help pollination (Thorp & Bieleski, 2002).

1.2.2 Pollination

Feijoa flowers are hermaphroditic yet self-sterile, the male pollen and female ovules are self-incompatible. Therefore there is a need to be pollinated with other cultivars. Two or more different cultivars should be planted close to each other to allow pollination between them.

Since the feijoa flower does not produce any nectar, they are not particularly attractive to bees. The edible petals and brightly coloured stamens attract birds that assist transferring pollen between plants. In New Zealand, blackbirds and mynas are the two main bird species responsible for pollinating feijoa flowers. The sugar content in feijoa petals increase rapidly just before and during flower opening, encouraging birds to visit when they are ready to be pollinated, maximizing the chance of pollination.

However, natural pollination is neither dependable nor efficient for commercial production of superior fruit. Research has shown that fruit set can be as low as 30% with open pollination (Thorp & Bieleski, 2002), and hand pollination produce superior fruit set, with an increase of 100% fruit set, plus the bonus of increased fruit size and quality (Patterson, 1989).

1.2.3 Fruit Growth and composition change

The fruit will begin to grow within a few weeks after adequate and successful pollination has been made. The fruit growth process starts from January in New Zealand and ends around May. However, there can be large difference in the ripening time among early maturing cultivars and late ones, as early cultivars ripen as early as February.

The initiation of fruit growth is noticeable by the visible sign of shoot growth and unpollinated or poorly pollinated flowers shed.

A three-stage development process is observed in the fruit growth (Harman, 1987). At first, a slow growth period starts after pollination, which usually last to 70 days after anthesis, in this period, the growth appears to be linear. After this period, growth rate declines, which is the second stage from 70 to 95 days. The last stage is evidenced with growth acceleration, starting from 95 days after anthesis to 120-140, depending on different cultivars.

Feijoa is rich in fibre and vitamin C, contains high amounts of mineral with low calories (Weston, 2010). Morton (1997) stated that K, Na, Ca, Mg, P, and Fe contents of feijoa fruit were 0.166%, 0.5%, 0.4%, 0.8%, 0.1%, 50 ppm, respectively. Vitamin C level of the fruit was recorded as 8.75 mg/100 g (Salvo, Toscano, & Dugo, 1987).

During growth and maturation the chemical composition of feijoa undergoes great changes. The sugar contents are in the form of fructose, glucose and sucrose. The sugar content remains around 10 mg/g (dry weight) before increasing rapidly from around 80 days after flowering, reaching 80 to 160 mg/g depending on different cultivars (Harman, 1987). The starch content remains low (0.6-1.5% of the dry weight) and unchanged during maturation. It is assumed that the rapid increase of sugar is a result of the translocation of sugar from the wood or leaves (Harman, 1987).

Malic and citric acids are the main non-volatile organic acids in feijoa fruit, which remain at 1 percent of the dry weight until entering a rapid growth from 90 days after anthesis, reaching to 7-13% (Harman, 1987). The sugar: acid ratio of feijoa drops slightly (0.5%) around 75-80 days but increases thereafter.

The other mineral contents such as calcium and magnesium are similar to apples and peaches. Feijoa is lower in calcium, magnesium and potassium contents than guava fruit, which is closely related to feijoa (Watt & Merrill 1975). The calcium, magnesium in the fruit declined during initial stages of fruit growth (40 -80 days after anthesis), but such decline was slowed down or stopped during the rapid fruit growth period. Potassium remained constant during the whole growth.

During maturation, feijoa also undergo great textural characteristic changes in the pulp. Action of the hyrolases on the pectin of the cell wall renders the texture softer. Because the activity of polygalacturonase is higher in the centre of the mesocarp, feijoa fruit softening starts from the inside out (Fisher et al., 2003).

The significant development of the typical feijoa aroma and flavour also happens during the late stage of maturation. The characteristic feijoa aroma is mostly from the volatile esters, methyl benzoate, ethyl benzoate and ethyl butanoate (Nagy, 1998), and feijoa is characterised with the unique feature of high concentration of methyl benzoate (Young and Paterson, 1990). Ethyl benzoate concentrations may be useful in the determination of optimum ripeness (Sharpe et al., 1993).

1.2.4 Fruit maturity and ripening

Fruit maturation is the stage of development leading to the attainment of physiological or horticultural maturity (Watada, Herner, Kader, Romani, & Staby, 1984) . Although the periods of time overlap, physiological maturity and horticultural maturity are two very different concepts from two different perspectives.

Physiological maturity is the stage of development when a plant or plant part will continue ontogeny even if detached, while horticultural maturity is the stage of development when a plant or plant part possesses the prerequisites for utilization by consumers for a particular purpose.

Ripening is the composite of the processes that occur from the latter stages of growth and development through the early stages of senescence and that results in characteristic aesthetic and/or food quality, as evidenced by changes in composition, colour, texture, or other sensory attributes (Watada et al., 1984).

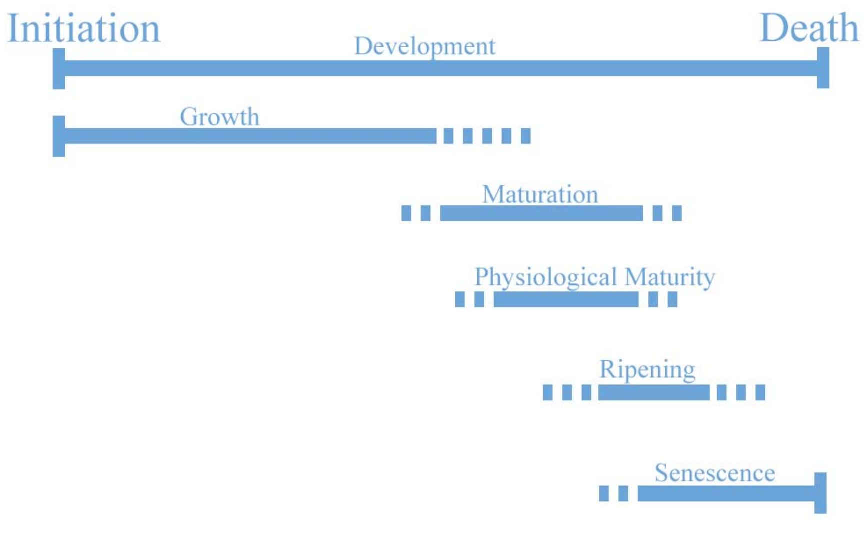


Figure 1.1 Fruit development stages

With the exception of a few fruits, such as pear, banana and avocado, almost all fruits reach the best eating quality when ripened on the plant naturally. Yet, for commercial growers, fruit are often picked before reaching horticultural maturity, to withstand long distance shipment and extend shelf life. At this stage, fruits are usually unripe enough to extend storage life but mature enough to reach horticultural maturity when arriving at retailers. A compromise is usually made between eating quality and flexibility in the marketing.

For consumers, feijoa fruits are good to eat when they are slightly soft, when the strong characteristic aroma and flavour reach maximum (Thorp & Bieleski, 2002), which is reflected in the composition changes and subtle reduction in firmness and skin colour (Clark et al., 2005).

Harvesting feijoa fruits at an appropriate time ensures optimum fruit quality, which is an important determiner for export. The harvest timing is crucial for growers. Harvesting too early may result in fruits never ripening, while harvesting too late may shorten the storage life and subsequent shelf life.

Therefore, being able to assess maturity non-destructively can provide valuable information to growers and render their decisions in harvest timing easier and more reliable.

1.3 FRUIT STORAGE

Feijoas are harvested at the point where they are approaching physiological maturity, but not yet reached full horticultural maturity. At harvest, they are generally graded based on size and shape, placed into trays, and put through cool storage to ship to the market. Recommended industry practice is to store feijoa fruit at 4°C (Klein & Thorp, 1987).

Storage life varies greatly between cultivars. For example, ‘Apollo’, ‘Opal Star’, ‘Triumph’ can last 4 weeks in cool storage and retain 5 days of shelf life at 20°C, while ‘Unique’ only lasted 1 week in cool storage with 1 day shelf life at 20°C afterwards (Thorp & Bieleski, 2002). More recent researches have achieved longer, yet, still varied cool storages for different varieties, for example, 4 weeks cool storage for ‘Unique’ (Al-Hearthy, 2010), 6 weeks for ‘Wiki-Tu’.

Prolonged cool storage will induce pulp browning and change in flavour, rendering fruit to be unacceptable for consumers (Klein & Thorp, 1987).

1.3.1 Fruit quality changes during storage

Fruit quality still declines during cool storage and subsequent shelf life, although at a much slower rate than at ambient temperature. Common changes in quality during storage include flavour, firmness, skin colour, weight loss, pulp browning.

In the postharvest life, flavour is the first to change, which is a result of slow decrease in titratable acidity and higher pH and lower soluble solids concentration (Klein & Thorp, 1987; Gaddam et al., 2004; Al-Harthy, Mawson, & East, 2008). Reduction in firmness is also usually reported during storage (Downs, Pickering, Reihana, O'donoghue, & Martin, 1988; Clark et al., 2005; Wiryawan et al., 2005; Al-Harthy, 2010). The slight change of skin colour is usually also observed, where the skin colour turns from dark green to light green or a little bit yellow. However, such change is difficult to distinguish by naked eye (Al-Harthy, 2010). Weight loss can be quite significant if fruits are left at ambient temperature or unprotected by polylined package, as high as 5.5% of initial weight, as reported by Hoffman et al (1994). But reported weight loss for polylined packaged fruit is around 0.75% per week (Al-Harthyet al, 2008) or 1.25% per week (Hoffman, Nachtigal, Kluge, & Bilhalva, 1994) at low temperature storage condition of 0-4°C.

Prolonged storage induces pulp browning, rendering feijoa fruits inedible for consumers. The pulp browns at different rates for each cultivar. The enzyme polyphenol oxidase (PPO) within the fruit causes browning (Zhu, 1987). With lower PPO activity, fruit show less internal browning during storage.

Other problems may also occur during cool storage. For example, chilling injury is found on feijoa fruits stored at 0°C, with sunken tissue at the stem end, which is followed by internal browning of the vascular elements. Fruits suffering from chilling injury are usually inedible, even at an early stage.

1.3.2 Different approaches to extend storage life

Many researches have tried different approaches to extend storage life of feijoa. Earlier research showed little success, including low temperature storage (Klein & Thorp, 1987), calcium chloride application (Ramirez, Galvis, & Fischer, 2005), and pre-storage hot water treatment (Woolf et al., 2006).

Controlled or modified atmosphere storage is widely used to extend the storage life of subtropical and tropical fruits (Kader, 2003). Preliminary study (Thorp & Bieleski, 2002) of controlled atmosphere application held feijoa fruits in a range of low oxygen and low carbon dioxide atmospheres, and reported delayed ripening which is evidenced in delayed colour changes in both skin and pulp. And it was also suggested that low oxygen (2.1%) and no carbon dioxide were better for the fruit. Low oxygen, low carbon dioxide controlled atmosphere is also confirmed as favourable for 'Unique' cultivar (East, Araya, Hertog, Nicholson, & Mawson, 2009) and 'Opal Star' (Al-Harthy, East, Hewett, & Mawson, 2009).

The application of 1-methylcyclopropene delays ripening of many different kinds of horticultural crops (Watkins, 2006). Amarante, Steffens, Ducroquet and Sasso (2008) treated feijoa fruits with 1-MCP and evaluated the respiration, ethylene production, skin colour, and reported that 1-MCP application delayed ripening of 'Brazilian' feijoa. Most other research resulted in no significant effects of 1-MCP on feijoas (Velho et al., 2008; Schotsmans et al., 2011; Rupavatharam et al., 2015). The fact that postharvest 1-MCP application delayed ripening of early harvested fruit while having no impact on touch picked fruit (Rupavatharam et al., 2015) suggests maturity plays an important role in the effect of 1-MCP on feijoa fruits.

Treatment with exogenous ethylene was mostly not effective (Velho et al., 2008; Al-Harthy, 2010; Rupavatharam et al., 2015). Only Akerman, Zauberman, and Fuchs (1993) reported physiological stimulation after applying 100 $\mu L L^{-1}$ ethylene for 96 h at 22◦C.

1.4 CURRENT INDUSTRIAL HARVEST PRACTICES

Unlike most fruit that go through a drastic skin colour change during ripening, feijoa remain green for the whole eating process, which makes it difficult to determine whether feijoa are ripe or not. Currently feijoa fruits are harvested using touch picking or net harvesting.

1.4.1 Touch picking

Touch picking is a technique that involves gently pulling feijoa sideways and harvesting only those that come away easily. This technique relies on the fruit retention force, which is the strength of the bond between the fruit and fruit stalk (Downs et al., 1988). This force is known to drop drastically as fruit ripen. It is neither practical nor possible to have a set retention standard to refer to when hand harvesting feijoa. In the feijoa industry, the fruit harvesting must be operated by experienced pickers. Touch picking is however a very labour intensive exercise, imparting a high labour cost, and a great initial cost during picker training. It usually takes one season to fully train a reliable feijoa picker. Even after the training, the standard of the retention threshold may vary among individual trained pickers.

1.4.2 Net harvesting

An alternative method to harvest is called net harvesting. A catching net is attached to a permanent frame and the net opens out under the canopy during harvest season and can be retracted after harvest season. Some growers shake the main trunk to shake off fruits with lower retention force before natural drop. The net provides a safe cushion, which avoids bruising, puncture from hard-edged mulch and contamination. Although net harvesting solves the problem of heavy labour cost in touch picking, vigorously shaking tree trunk carries significant risks in injuring the tree and its root system. Although safe cushion is applied, this technique has the potential to increase the incidence of fruit bruising compared to touch picking, as when a fruit drops, it might collide with the plant or other fruits on the net. The other problem with net harvesting is that when a force is applied to the tree, the force delivered to each part of each branch of the tree will be different. Since each fruit was given a different level of force, some immature fruit may drop as well if they were given greater force.

However, assessment by Andrew East did not find marked maturity differences or storage performance between touch-picked and machine-harvested feijoas in adjacent blocks in Gisborne in a small commercial trial (personal communication, October 5, 2014).

Both major industrial practices for harvesting feijoa possess disadvantages. Irrespective of the harvest method used, the resulting crop will be of mixed maturity, with different storability. Therefore, practical methods of assessing the fruit maturity of feijoa and separating those fruits that are ready to eat from those which can withstand a period of storage are urgently needed.

1.5 NON-DESTRUCTIVE METHODS FOR ASSESSING THE FRUIT QUALITY

Fruit quality is defined by natural attributes, such as size, flavour, taste, texture, shape, colour, and aroma. The quality of a horticultural product is vital to growers and retailers if a sustainably profitable business is to be created. It is essential to preserve fruit in good condition for consumption. The most accurate and easiest way to assess fruit properties including the internal maturities of each fruit are conducted in a destructive manner. However, that would compromise the value of the tested fruit as a horticultural product.

There has been much research investigating non-destructive methods to assess fruit quality. Some outcomes from this research have been successfully transferred into commercial practices to assess the internal maturity of some fresh horticultural products. In the following sections, some of these non-destructive measurement techniques will be evaluated for suitability to investigate the potential as a non-destructive approach to assessing the internal maturity of feijoa.

1.5.1 Density

During maturation and postharvest storage, most fruits and vegetables undergo changes in density, as a result of changes in cell structure and chemical contents such as changes in soluble solids, water content and effects of damage. A systematic review (Zaltzma, Verma, & Schmilovitch, 1987) of density-maturity relationship classified these studies and techniques into three categories: flotation, fluidized-bed technology and machine vision.

Flotation of fruit and vegetables is based on density, which is affected by the internal characteristics such as dry matter, soluble or defects (Clark, White, Jordan & Woolf, 2007). Many researchers had tried this technique on different kinds of horticultural products, including sweet potato (Bryant, 1942), potato (Kunkel, Gifford, Edgar, & Binkley, 1951), and grape (Coleman, Wagner, & Berry, 1983). The flotation method has been tried on 'Apollo' feijoa yet was not successful because of the low density from the high volume of intercellular air spaces (Clark et al., 2005). The same method was unsuccessful on 'Unique' and 'Opal Star' feijoa for the same reason (Al-Harthy, 2010).

Fluidized-bed technology utilizes a suspended bed of granular particles, which is achieved by forcing air through these particles to produce enough buoyant forces against the weight. Zaltzman, Schmilovitch and Mizrach (1985) developed a fluidized-bed for separating potato tubers from clods and stones in a continuous separation process with 99.9% separation efficiency. This technology has some potential for sorting horticultural products.

The density can also be obtained by getting the weight and estimated volume of the product, using automatic weighing and volume estimation from camera images. However because the accuracy is low (Miller & Verba, 1987), machine vision technique is not commonly used.

1.5.2 Mechanical Force

Under mechanical force loading, most fruit and vegetables show viscoelastic behaviour, exhibiting both viscous and elastic characteristics. This viscoelastic behaviour is usually used as the base for mechanical measurement, which measures firmness. For most fruits and vegetable, as they become more mature, the firmness gradually decreases. The reduction in firmness during maturation and storage was commonly observed in feijoa fruits (Downs et al., 1988; Clark et al., 2005; Wiryawan et al., 2005; Al-Harthy, 2010). Lower firmness is also common in the overripe and damaged fruits. Therefore, firmness is commonly used as a tool to sort and grade horticultural commodities.

Depending on the loading, firmness measurement can be destructive or non-destructive. In a typical force-deformation curve, the product undergoes elastic deformations before reaching a noticeable stop, after that comes the bioyield point (Mohsenin, 1986), at which the tissue start to rupture and the tissue microstructure start to fail. Generally, non-destructive firmness measurement should limit the force or deformation level to before the noticeable stop, and far before the bioyield point to preserve the structural integrity, and prevent any tissue damage or bruising (Abbot, Lu, Upchurch, & Stroshine, 1997). Many non-destructive methods of mechanical measurement have been developed for the purpose of assessing the firmness of horticultural products.

1.5.2.1 Deformation

Deformation or displacement of the product is measured imposing a constant loading for a specific period of time. This technique has been used on many soft commodities such as tomato, kiwifruit, and many berries. Some attempts have been made by Hamson (1952) on tomato, by applying a constant force with an 11.1 mm diameter flat-headed plunger and read compression. This was not successful due to the heterogeneity of fruit structure. Kattan (1957) designed an improved multipoint-compression technique in the hope of reducing the effects of loading position, which became the base of Asco Firmness Meter that uses the same principle. Some portable tomato testers that utilized the same principle were developed by Shafshak and Winsor (1964) and Diener, Sobotka and Watada (1971). Perry (1977) designed a non-destructive device to measure peach firmness using a constant air pressure, and recording the deformation with dial gauge. A more recent development in using a puff of pressured air as force and measure deformation with laser proves to be promising for measuring maturity and sorting horticultural products with high precision. Such high precision may mean great potential in commercial use.

Feijoa fruit firmness is also linked to the translucent ratio, which is a reflection of maturity (Wiryawan et al, 2005), suggesting non-destructive firmness measuring techniques may be applicable for maturity assessment and sorting.

Firmness of 'Unique' and 'Opal Star' feijoa fruits reduced as maturity stages increased (Al-Harthy, 2010). The author also concluded that that compression firmness was more reliable in determining maturity changes than acoustic firmness.

1.5.2.2 Impact Force

The impact is the moment when two objects collide for a brief period of time. The impact response is associated with the mechanical properties, and therefore impact technique can be used to assess horticultural products' firmness. The impact process can be divided into several phrases, including initial elastic deformation, permanent deformation and final elastic recovery (Mohsenin, 1986).

There are a few different impact techniques that have been developed, among which the most commonly used is the drop-test method. A drop test involves free dropping a product onto a sensing device, which records the impact response for computer analysis. Rohrbach (1981) developed an impact system that was used to sort blueberries dropping from 40 mm height, which achieved only 75% accuracy. The validity of this method is also confirmed by Delwich, Tang, and Rumsey (1987), who investigated the impact response of peach and concluded that impact response is relatively independent of fruit size. Some experiments show that there is a high linear relationship between average contact time and berries' softness. Therefore, contact time can be an important parameter for measuring firmness.

However, one important defect of drop-test is the possible bruising of the fruit during impact. Some softer sensing surfaces were experimented, for example, a modified intercom speaker was used as impact surface in Younce and Davis (1995)'s experiment, which measures the voltage signal related to the firmness. A soft foam sensor (Thai, 1994) was tested for measuring apple and tomatoes. Other techniques like impact-probe, where the rigid impact sensor strikes the fruits instead of the other way around were also tried. It may reduce some handling problems after the impact.

1.5.3 Sonic properties

Acoustic vibration is a method that utilizes resonance phenomenon to detect mechanical properties. The audible frequencies range from 20 Hz to 15000 Hz. By locating the resonance frequency at which the maximum amplitude is observed, the mechanical properties can be obtained because these two are closely associated.

This method has been used for a long time. As early as 1942, Clark and Mikelson (1942) had found the link between the textural characteristics of fruits and the vibrational prosperities. They also observed the changes in the vibration frequency as fruit ripen. A more comprehensive study (Abbott, Bachman, Childers Fitzgerald, & Matusik, 1968) examined the vibrational prosperities of excised and whole apples at successive frequencies from 20 to 4000 Hz, which reported that the lowest resonant frequencies of whole apples were significantly influenced by maturity and firmness. They later proposed stiffness coefficient f^2m, where f is the second resonant frequency and m is mass, to measure firmness of horticultural commodities (Abbott et al., 1968). The coefficient is highly correlated with the elastic modulus of the flesh tissue.

Many other researchers have measured the firmness of horticultural products using acoustic vibration. Some devices and instruments and machines have also been developed, both contacting and non-contacting. However, previous studies on feijoa have suggested that accuracy of applying compression firmness was higher than that of acoustic firmness on ‘Unique’ and ‘Opal Star’ (Al-Harthy, 2010). Although Gaddam et al. (2004) used acoustic firmness to assess maturity of ‘Unique’ feijoa obtained from Taranaki, NZ, acoustic vibration may be a less promising method.

1.5.4 Optical properties

Optical properties refer to the response of an object to visible light wavelengths, which range from 380 to 770 nm. However, the application of optical properties has been frequently extended to the region of ultraviolet and infrared wavelengths (Abbott et al., 1997). The principle of applying optical properties is based on the reflectance, transmittance, absorbance, or scatter of radiation in the near-infrared (NIR), visible, ultraviolet (UV) regions of the electromagnetic spectrum.

The main purpose of this project is to find a commercially practical, efficient, and inexpensive non-destructive method to estimate the internal maturity of feijoa. The results and suggestions from previous studies (Al-Harthy, 2010; Rupavatharam et al., 2015) suggest a small but statistically significant correlation between the fruit maturity and the absorbance wavelengths at 550 nm on 'Unique' (a common feijoa variety). Considering the concerns on safety and expense of the application of radioactive methods, this section will be focusing on exploring the potential of applying optical properties on feijoa.

The judgment of a consumer towards the quality of a horticultural product is mainly dependent on the external appearance of that produce. Usually, the visual skin colour of a fruit could suggest some information of the produce's condition. Therefore, the external skin colour of a horticultural product is commonly utilized by the consumers to assess the internal fruit quality. Although this visual inspection is a quick and simple method to get a rough understanding of the fruit quality and maturity, it is very inaccurate. One reason is that the differences of skin colour between individual fruit can be difficult for human eyes to distinguish, but more importantly, it is because the 'colour' that human are capable to see is only a very narrow segment of the whole spectrum. Some spectral wavelengths regions that fruit quality characteristics respond to, such as the near-infrared and ultraviolet are beyond the human visible observation (Abbott et al., 1997). With intensive development and research in optical characteristics and quality of horticultural products, optical non-destructive assessment of fruit maturity, quality, defects and contamination, and mechanical injuries on fruit have become reality and been regarded as one of the most successful and promising approaches to evaluate the fruit quality accurately.

When a light strikes a horticultural product, about 4% of the incident radiation will be immediately reflected off the surface as regular reflectance (Chen & Sun, 1991). After transmitting through the surface, the rest of incident radiation then scatters in all direction in the cellular structure, where small interfaces are encountered. Subsequently, the majority of the radiation will be scattered outside of the fruit near the spot where the incidence was applied. This type of reflection is recognized as ‘body reflectance’ (Birth, 1976). Meanwhile, the remaining scattered light travels further under the fruit surface randomly. When the light transmits within the fruit, a certain portion of the light will be absorbed by multiple constituents of the fruit. The effect of absorption is influenced by the constituents, the wavelength and path length of the light. Since the energy from the light will be transformed into other forms of energy (e.g. fluorescence and delayed-light emission) once absorbed, there is a possibility that the released radiation from the fruit surface may consist of various combinations of regular reflectance, body reflectance, transmittance, fluorescence, phosphorescence, and delayed-light emission.

Because the feature of the radiation released from the fruit surface is affected by the constituents of the horticultural product and the incident radiation, determining such optical features of a horticultural product could provide a pathway to estimate fruit quality.

1.5.4.1 The principle of quality index

To assess fruit quality by using optical property, a quality index should be developed. The selection of suitable optical properties is vital when establishing a quality index (quantitative values ranging from one to multiple optical readings) for a horticultural product. An excellent quality index should satisfy the several requirements listed below (Chen & Sun, 1991):

- It should present a good correlation with the quality factor being assessed.
- It should not have many interactions with other physical parameters of the product.

- It should vary little with apparatus variables, such as light-source intensity, light detector sensitivity, and variation of the system response.

The initial procedure for the selection of an optical index is monitoring the spectral responses of the horticultural product at a wide range of wavelengths. Then, choose the region or series of regions of wavelengths, where the correlation with the fruit quality emerges (Chen & Sun, 1991; Abbott et al., 1997).

The magnitude of the reflectance (*R*) or transmittance (*T*) at a specific region of wavelength (e.g., R_{670} or T_{670}) is the simplest optical index (Abbott et al., 1997). However, the accuracy of this index can be interfered by the changes in geometry of the horticultural product and instrumentation. Another quality index can be formed according to the general slope of the spectral curve in the region between the two wavelengths (e.g. R_{670}-R_{730}) (Abbott et al., 1997). This method is able to limit the negative impacts from instrument and geometric variability (Abbott et al., 1997). The other optical index is based on the ratio between two wavelengths (e.g., R_{670}/R_{730}).

The colour created by the diffuse reflectance in the region of wavelengths from 400 to 700 nm has been frequently utilized to estimate the fruit quality (Abbott et al., 1997). The colour of an object can be described by different categories of colour coordinate systems. For example, RGB (red, green, and blue) is one of the most popular systems, which is applied in coloured video monitors. Hunter Lab, CIE (Commission International de l'Eclairage) L*a*b* is also commonly used. Besides, there are CIE L*u*v*, CIE Yxy, CIE XYZ, and CIE LCH (Hunter & Harold, 1987).

In the L C H system, the *L* stands for the lightness or brightness of the object. The C is for chroma, which describes the vividness of the colour. The colour is defined by the hue angle H, for example, 0° (red), 90° (yellow), 180° (green), and 270° (blue). Conversions can be made among the various colour systems (Judd & Wyszecki, 1963).

Hue can be calculated with chroma by converting theses coordinates from rectangular form (L, a, b) to polar form (L, C, H). In the polar coordinate system, hue is the angular coordinate while chroma is radial component.

1.5.4.2 The application of optical properties in horticulture industry

There has been intensive research conducted studying the optical properties of various horticultural products. The outcomes are rewarding with numerous correlations established between optical characteristics and the fruit quality features of many kinds of horticultural commodities (Chen & Sun, 1991).

Colour coordinates themselves are important factors assessing fruits and vegetables. Aulenbach and Worthington (1973) found that G (green) tristimulus values correlate highly with visual colour and indicated ripeness of tomato and peach. The a* coordinate was utilized to separate peaches into different maturity classes after harvest (Delwiche and Baumgardner, 1983). Colour development during ripening of peach (Thai & Shewfelt, 1991a) and tomato (Thai & Shewfelt, 1991b) was linearly related to the hue angle ($H = \tan^{-1} a^*/b^*$) calculated from tristimulus colour measurements.

Reflectance at one or more wavelengths is probably a more important measurement for quality classification. The spectral composition of the body's reflectance has been widely used as an indicator of maturity for fruits and vegetables. Reflectance for apples at 670 nm increased with maturation (Bittner & Norris, 1976). This increase in reflectance in the 670 nm region coincided with the decrease of chlorophyll. A reflectance ratio R_{580}/R_{620} was suggested as a maturity indicator for apple (Bittner & Norris, 1976). Maturity of peach was also estimated by the reflectance ratio R_{670}/R_{800} (Upchurch, Delwiche, & Peterson, 1990).

The application of optical properties seems to be very promising and have many merits including the equipment is usually inexpensive and can be portable, the measurement is simple and fast, and it is totally harmless to the fruit. Since transmittance usually requires the fruit to be cut, which is not in accordance with the objective of this project, so the optical measurement for feijoa is based on 'body reflectance’. The visible skin colour of feijoa will be measured, and the reflectance from 360 nm to 740 nm will be reviewed to examine if there is any correlation between these optical properties with the internal fruit maturity, and more importantly, with fruit quality after storage.

1.5.5 Other techniques

1.5.5.1 Ultrasonic sensing

Ultrasonic sensing utilizes inaudible sound waves that are above 20,000 Hz. Sound waves are put into the products and the transmission, refraction, diffraction, interference, scattering, reflection and dispersion are analysed, which can reflect the internal quality (Abbott et al, 1997). Sarkar and Wolfe (1983) measured the attenuation coefficient of potato, cantaloupe and apple at the 500 to 1000 kHz frequency range, and concluded that the coefficient was extremely high. A through-transmission system at 25 kHz was developed by Cheng and Haugh (1994), which successfully detected hollow heart in potatoes. Some progress has been made in measuring apple firmness (Mizrach et al., 2001), obtaining good results with one variety, but not the other variety. The ultrasonic sensing may have some potential in measuring certain fruits and vegetable’s firmness and maturity, but some challenges remain.

1.5.5.2 MRI

Magnetic resonance imaging has been used in non-destructive sensing of horticultural products. Magnetic resonance imaging at 30 MHz was used to distinguish small and fine flesh segments in apple, orange and plum (Hinshaw et al., 1979). More comprehensive study (Chen, Baerdemaeker, & Vervaeke, 1992) has been done on apple, peach, pear, onion, orange, olive, tomato, prune, pineapple, cucumber and avocado, obtaining images of seeds, voids, worm damage, bruises and dry regions and even the increases in free water within the ripening process of avocado. MRI was used to evaluate the internal quality of two feijoa cultivars ‘Unique’ and ‘Opal Star’ at different maturity (AI-Harthy, 2010) and the result suggested that MRI could be used to assess feijoa internal quality.

However, many factors like high expense, slow imaging speed and the need of stable environment render magnetic resonance imaging a less practical option at present.

1.5.5.3 X-ray and Gamma ray

Electromagnetic waves with very short wavelengths can penetrate objects, and therefore have been widely used in medical and engineering industries. X-rays and gamma rays are partially absorbed by moisture content and water when traveling through the products. The extent of the absorbance is associated with the tissue density and water content, providing possibilities for measuring the internal quality and maturity of fruits and vegetables.

Some research on lettuce heads has been able to assess the maturity of the lettuce (Lenker & Adrian, 1971). Because the change in density is also reflected in other defects, many applications of X-rays in horticultural products were tested, including detecting hollow hearts in potatoes (Finney & Norris, 1973), bruises on apple (Ziegler & Morrow, 1970) and freeze damage in citrus (Johnson, 1985), and detecting insect infestation (Keagy, Parvin, & Schatzki, 1996). The commonly used radiography utilizes a linescan similar to the airport baggage screening system. Inspection of hollow hearts in potatoes has been used commercially in packinghouse. With improved technology, this method could be efficient and has great potential for measuring defects and assessing maturity in horticultural products.

1.6 NON-DESTRUCTIVE MEASUREMENTS APPLICATION

This research project explores the link between skin colour and maturity in the hope of finding a reliable non-destructive method to assess the maturity of feijoa fruits. A skin colour index is to be established and it may be used to predict storability or segregate produce.

1.6.1 Storability prediction

Fruit storability is highly dependent on fruit maturity at harvest. Monitoring feijoa fruit maturity non-destructively through a skin colour or a fruit skin firmness device can provide orchards with the capacity to manage the storability of the harvested fruit through harvesting them at proper timings.

Fruit storability prediction can be achieved by time-series observation of fruit quality changes during storage. Many postharvest researchers in feijoa have observed quality changes during cool storage (Clark et al., 2005; Wiryawan et al., 2005; Al-Harthy, 2010;). What's lacking is turning such observations into prediction model.

Wilcke (1992) developed a model describing changes in internal quality of apples during storage, enabling prediction of possible storage duration and eating quality from the quality analysis at the beginning of storage. Such regression model can also be developed for feijoa. Specific storability is different with different cultivars. Therefore, experiments have to be done on each specific cultivar to establish a unique storability prediction model.

This research project tries to establish the link between fruit quality attributes and maturity, and further research is needed to explore the possibility of establishing a model that predicts storability.

1.6.2 Produce segregation

Knowledge of the storage potential of the feijoa fruit can also permit produce segregation.

Non-destructive optical and mechanical sensory may provide fast accurate on-line maturity evaluation. Combined with storability prediction model, such maturity evaluation can be applied to produce segregation, dividing fruits into different storability categories. Based on the marketing needs of feijoa fruits, they can be segregated into short-, mid-, long-term storability, catering to local, national and export markets.

1.7 CONCLUSION

Feijoa is a fruit with enormous commercial potential gifted from its natural attractive aroma, taste and incredible nutritional value. Fruit like feijoa deserves a solid place in the tremendous but still rapidly expanding international fresh fruit market rather than just being sold within New Zealand and few countries in South America. The marketing of New Zealand feijoa in the international market is heavily restrained by several factors. One of the major issues is the huge variation on fruit qualities among individual feijoa fruit. The variation is contributed by the dramatic genetic diversity and amplified by the long period of flowering and open pollination.

The most urgent action needed now is establishing a non-destructive maturity index to estimate the maturity of feijoa fruit at harvest and predict its potential storage and shelf life, as there is still no objective and practical non-destructive method to measure the fruit maturity of feijoa. The only unambiguous method for evaluating the maturity of feijoa is internal visual grading based on destructive measure.

Based on the results from previous study on feijoa, the potential non-destructive methods for assessing the internal maturity were narrowed down to the application of optical properties and compression force. The utilization of optical properties has great potential; the equipment is not expensive, the measurement is really fast, it does no damage to the fruit. The application of compression force in commercial practice may be less appealing as the machine is usually expensive and the measurement is less efficient. However, the application of compression force was reported to have a very reasonable correlation with the internal maturity, while there is no solid evidence suggesting the correlation between the optical properties and the internal maturity.

Therefore, in this experiment, the correlation between optical properties and the internal maturity, and the correlation between compression force and the internal maturity will be examined to see if such correlations exist among different cultivars and how strong the correlations are; and tested for their potential in segregating fruit by its storage potential.

2 MATERIALS AND METHODS

2.1 INTRODUCTION

This experiment was conducted in 2014, at Massey University Palmerston North. All experiment measurements were accomplished at the postharvest lab, Riddet Complex, Massey University Palmerston North.

2.2 MATERIALS

Four feijoa cultivars were chosen for this experiment, which are ‘Kakariki’, ‘Barton’, ‘Anatoki’ and ‘Wiki-Tu’. ‘Kakariki’ and ‘Anatoki’ were sourced from Kaiaponi farm in Gisborne. ‘Barton’ and ‘Wiki-Tu’ were collected from Southern Belle Orchard in Matamata.

The four cultivars represent the wide variation of feijoa. ‘Kakariki’ is an early ripening variety with large fruit size. ‘Anatoki’ has small fruit size, smooth and soft skin, and it ripens in early season. ‘Barton’ is an old cultivar, which produces around mid-season. ‘Wiki-Tu’ is a new variety that ripens in mid to late season. Two growing regions reflect different environment conditions. The region of Gisborne has a sunny climate with abundant sunshine hours. The annual average sunshine hours are 2,200 hours. The yearly rainfall varies from 1000 mm in the coastal area to 2500 mm in higher country. Gisborne tends to have a warmer summer (average 23°C) and cooler winter (average 12°C) than most other regions in the North Island (Anonymous, 2015a). The region of Matamata has an annual average rainfall around 1373 mm. The yearly average temperature is 14°C (Anonymous, 2015b).

In addition, Kaiaponi farm uses ‘net harvesting’ to harvest fruits, which involves applying force to shake the branches of feijoa tree and pick the fruits that drop on the pre-set net under the canopy. Southern Belle Orchard uses ‘touch-picking’ to harvest fruits, which is based on professional feijoa pickers’ feeling towards the retention force of the fruit at harvest time.

For each variety, fruit sampling was conducted at the beginning of its commercial harvest time. There were 945 fruit in total contributed from three replications of harvest for each cultivar. Fruit from different replications were harvested from different rows in the orchard. Fruit were supplied by the owner under their commercial harvest standard. Over mature fruit was excluded. Additional immature fruit were pulled from the trees deliberately to offer a broad range of maturities and test the possibility of early harvesting for exporting market. After the harvest, samples were cleaned by the rinse and brush machines in Kaiaponi farm but not in Southern Belle Orchard. All samples were then packed in the standard feijoa tray (30 fruits) covered with polyethylene film. Before transfered to Massey, samples were kept at 8 °C in Kaiaponi farm and 4 °C in Southern Belle Orchard. The specific dates for fruit harvest and sample collection are listed below:

Table 2.1 The commercial harvest date and fruit samples collection date of each variety

Variety	Harvest date	Collection date
Kakariki	12th March, 2014	14th March, 2014
Barton	27th March, 2014	28th March, 2014
Anatoki	27th March, 2014	29th March, 2014
Wiki-Tu	22nd April, 2014	23rd April, 2014

2.3 METHODS

After the collection, samples were transported to the postharvest lab in Massey immediately. The temperature and humidity of the storage room was set at 4°C and 85% respectively. Every individual fruit was marked with a unique number at the proximal end of each fruit (the opposite side to the flower part). Subsequently, all the fruits of each cultivar were measured for skin colour and divided into three even groups from darkest green to lightest green (to reduce the potential of ethylene produced by from mature feijoas affecting less mature feijoa fruit). For each colour group in each replication, some samples were picked randomly and put into three and half trays (105 fruits). All these fruit were measured non-destructively for firmness, skin colour, and weight. The three full trays were then put into the cool storage room for four weeks, six weeks, and eight weeks respectively. Meanwhile, fruit from the half tray were measured for brix, titratable acidity and internal maturity immediately. When cool storage was completed, the fruit trays were taken out and left open at 20°C overnight. Samples were measured for firmness, skin colour, and weight non-destructively 14 hours after cool storage to ensure the elimination of water condensation. In the 3rd day of the ambient temperature storage, half of the fruit from the each tray was measured for firmness, skin colour, weight, brix, titratable acidity and internal maturity. The other half of the fruit was treated exactly the same in the 6th day of the ambient temperature storage.

2.4 QUALITY MEASURES

2.4.1 Firmness

Firmness was measured non-destructively by using the compression firmness analyzer (TA-XT-Plus, Stable Micro System, USA). When measuring the compression firmness, sample of feijoa were placed into the analyzer with number marked side up. Then the equator of that fruit was pressed by a flat probe to 2 mm depth at a speed of 1 mm.s^{-1}. The largest force applied to reach that 2 mm point was recorded as the reading for firmness.

2.4.2 Skin Colour

A reflectance spectrophotometer (CM-2600D, Konica Minolta, Albany, New Zealand) was used to measure the skin colour of feijoa. Measurements were conducted at three random spots around the fruit equator, ignoring any discoloured areas. Raw data were calculated by using Spectramagic NX software (CM-S100w 1.33, Konica Minolta, Albany, New Zealand) which output the average values of L*, a*, b*, C* and h°. The reflectance at spectral wavelengths from 360 nm to 740 nm of each sample was also collected. All the data contains both SCI and SCE readings (spectral component). The h° value was used to sectionalize fruits into three colour groups.

2.4.3 Weight

All the samples were weighed individually by a Mettler Toledo balance, (PG 503-S, accuracy ± 0.001 g, Switzerland).

2.4.4 Inner maturity assessment

To assess the inner maturity of each sample, each fruit was cut in half along its equator. Cut fruit (the side without number) were placed in order on an A4 3M transparency film, with 15 pre-drawn cells for each cut sample. Then cut surface of samples were scanned and stored as high-resolution pictures. The inner maturity assessment was conducted visually according to the maturity scale developed by Plant & Food Research, Mt Albert, NZ. Fruit with rating of 1 (or A for the industry) were immature fruit; rating of 2 (B) were modestly acceptable for consumption; rating of 3 (C) were most desirable fruit for eating; fruit with rating of 4 (D) were overly mature but still might be valuable for processing; Any fruit with maturity rating over 5 (E) has no commercial value any more. Any fruit with external deterioration and internal browning were marked as 6 (F). The maturity condition of the fruit can be in between two ratings. To increase the accuracy of maturity assessment, the maturity rating in this experiment was sub-divided into two sub-categories. For instance, the internal maturity of a fruit was between stage 2 and stage 3, it would be classified as 2.4 if it were more on the side of stage 2. Otherwise it would be marked as 2.6 as it is closer to the stage 3. If high accuracy is not required, the maturity rating of the fruit can be rounded down or rounded up to the nearest whole number by computer based rounding.

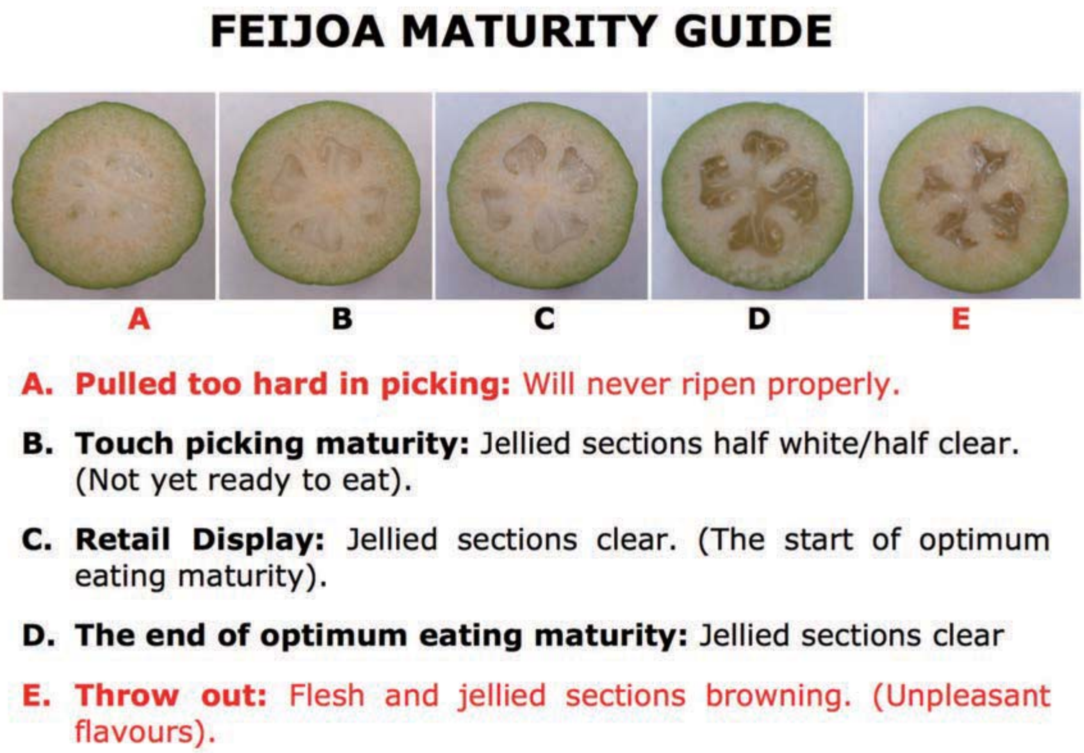


Figure 2.1 The inner maturity index for feijoa

2.4.5 Brix

When scanning the cut surface of each fruit, the other half cut sample was squeezed to get some juice on the detector screen of a refractometer (RFM 330 Refractometer, Bellingham + Stanley Ltd, UK) to get the value of brix for each fruit. Device was calibrated with distilled water. After the operation for each fruit, device was rinsed by distilled water and cleaned by tissue.

2.4.6 Titratable Acidity (TA)

After the scanning, the pulp of every five fruits were scooped and put together into a plastic bottle (making three samples from 15 fruits in total for each treatment). Then samples were frozen by liquid nitrogen and stored in the freezer at -40°C until measurement. When this experiment was almost completed, the samples were taken out and defrosted. 1 ml juice was extracted from each bottle and diluted with 50 ml distilled water. The liquid was titrated against 0.1 N NaOH, then the titratable acidity was measured by a Mettler DL21 Titrator, (Zurich, Switzerland). The value of acidity was calculated according to the following equation:

Equation 1 $N_1 \times V_1 = N_2 \times V_2$

Food acid was calculated as a percentage of total samples using the following equation:

Equation 2

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

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

2.5 THE ACTUAL TIME TABLE FOR MEASUREMENT

Compromises were made to the theoretical measurement timings due to the heavy workload and overlapping measuring date of different cultivars. The actual dates of measurement were listed below (Table 2.2). Samples of 'Wiki-Tu' for 8 weeks were totally ruined by cool storage failure.

Table 2.2 The actual dates (days after sampling) of each measurement for each variety compared with the theoretical timings for that measurement

Measurements	'Kakariki'	'Barton'	'Anatoki'	'Wiki-Tu'	Theory
Mark number	1	1	1	1	1
Skin colour	3	5	5	2	2
Grouping	4-5	6	6	3	3

Firmness	6	7	7	4	4
Weight	7	8	8	5	5
Maturity & Brix & TA	8	9	9	6	6
First day of week 4	32	31	31	26	28
Third day of week 4	34	33	33	28	30
Sixth day of week 4	36	36	36	31	33
First day of week 6	40	45	45	40	42
Third day of week 6	42	47	47	42	44
Sixth day of week 6	44	50	50	45	47
First day of week 8	54	59	59	/	56
Third day of week 8	56	61	61	/	58
Sixth day of week 8	58	64	64	/	61

2.6 STATISTICAL ANALYSIS

The experiments followed completely randomized design. All the data were processed by SPSS statistics (version 20) and Microsoft Excel 2010.

The Microsoft Excel was used to record all the original raw data and SPSS was used to process the original data, such as calculation and analysis of variance (ANOVA). The ANOVA follows least significant differences (LSD) with a significance level of $P < 0.05$. 'General linear methods' for analysis of variance were used whenever sample sizes were not balanced, such as comparing fruit quality attributes of fruits with same maturity level from four different feijoa varieties (Table 3.4-3.5).

3 FRUIT QUALITY AT HARVEST TIME AND POST-HARVEST PERIODS

3.1 Fruit Weight

At harvest, samples of 'Kakariki' had the highest average weight (110 g) among the 4 varieties (Table 3.1). Samples of 'Kakariki' were normally distributed but skewed above 100 g because particularly small feijoa (<30 g) were excluded from analysis. For samples of 'Barton', the mean weight was 92 g. Samples showed roughly normal distribution with wider distribution beyond 85 g than below due to the same reason. The mean weight of 'Anatoki' was 71 g, which was the lowest among all the varieties tested. The mean weight of 'Wiki-Tu' was 92 g. All varieties were significantly different (P<0.05) from each other, except between 'Barton' and 'Wiki-Tu'.

Table 3.1 The mean weight of samples from 4 feijoa varieties at the harvest time

Variety	Fruit number	Mean weight (g)	Std. Deviation
Kakariki	945	109.56[a]	39.92
Barton	945	92.47[b]	22.19
Anatoki	945	71.20[c]	20.80
Wiki-Tu	945	91.68[b]	24.37

[a,b,c]: those with a different letter in the column differ significantly (P<0.05)

3.1.1 Fruit weight loss during the cool storage and the room temperature

Samples of 'Kakariki' suffered the highest weight loss during the whole cool storage periods (Figure 3.1). Samples of 'Anatoki' had the second highest weight loss during the three different lengths of cool storages. After 4 weeks' storage (the actual date for each variety is listed in Table 2.2), the weight loss percentages of all varieties were significantly different ($P<0.05$) from each other, except between 'Barton' and 'Anatoki'. After 6 weeks' and 8 weeks' cool storage, the weight loss percentages of all varieties were significantly different ($P<0.05$) from each other with no exceptions. Samples of 'Barton', 'Anatoki', and 'Wiki-Tu' had a relatively small increase rate of weight loss during the whole cool storage periods.

When samples of four varieties were stored under ambient temperature (20°C) after the cool storage, the fruit weight loss all increased dramatically (Figure 3.1). Although, samples of 'Kakariki' had the highest weight loss rate during the whole cool storage periods, the weight loss under ambient temperature was not elevated as much as the other varieties. Samples of 'Anatoki' suffered the most serious weight loss under room temperature after 6 weeks' and 8 weeks' cool storage.

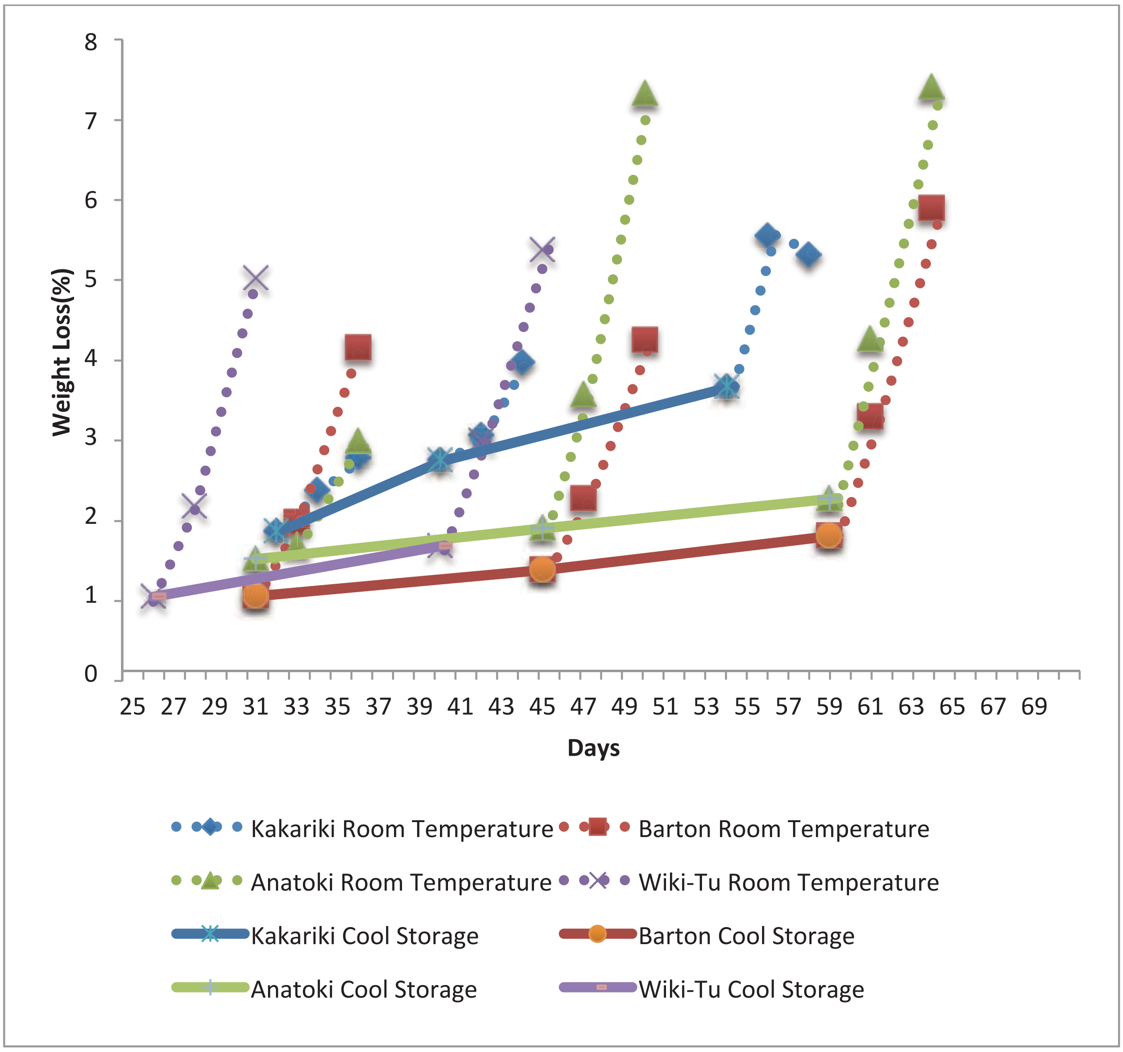


Figure 3.1 The average weight loss (%) of 4 feijoa cultivars after different lengths of cool storage and ambient temperature storage

3.2 Compression Firmness

At harvest time, the compression firmness of 'Kakariki', 'Barton', 'Anatoki' and 'Wiki-Tu' were 30 N, 33 N, 16 N and 31 N respectively (Table 3.2). All varieties were significantly different ($P<0.05$) from each other, except between 'Kakariki' and 'Wiki-Tu'. The firmness of samples of 'Anatoki' was much lower than the other three cultivars.

Table 3.2 The mean area force of four feijoa varieties at harvest time

Variety	Fruit number	Mean area force (N)	Std. Deviation
Kakariki	945	30.16[a]	11.38
Barton	945	32.75[b]	10.05
Anatoki	945	16.34[c]	4.12
Wiki-Tu	945	30.76[a]	6.86

[a,b,c]: those with a different letter in the column differ significantly (P<0.05)

There was a huge variation on the firmness among 'Kakariki', 'Barton', and 'Wiki-Tu' (Figure 3.2). Samples from 'Anatoki' and 'Wiki-Tu' showed roughly normal distribution with wider distribution on the right side beyond the peak.

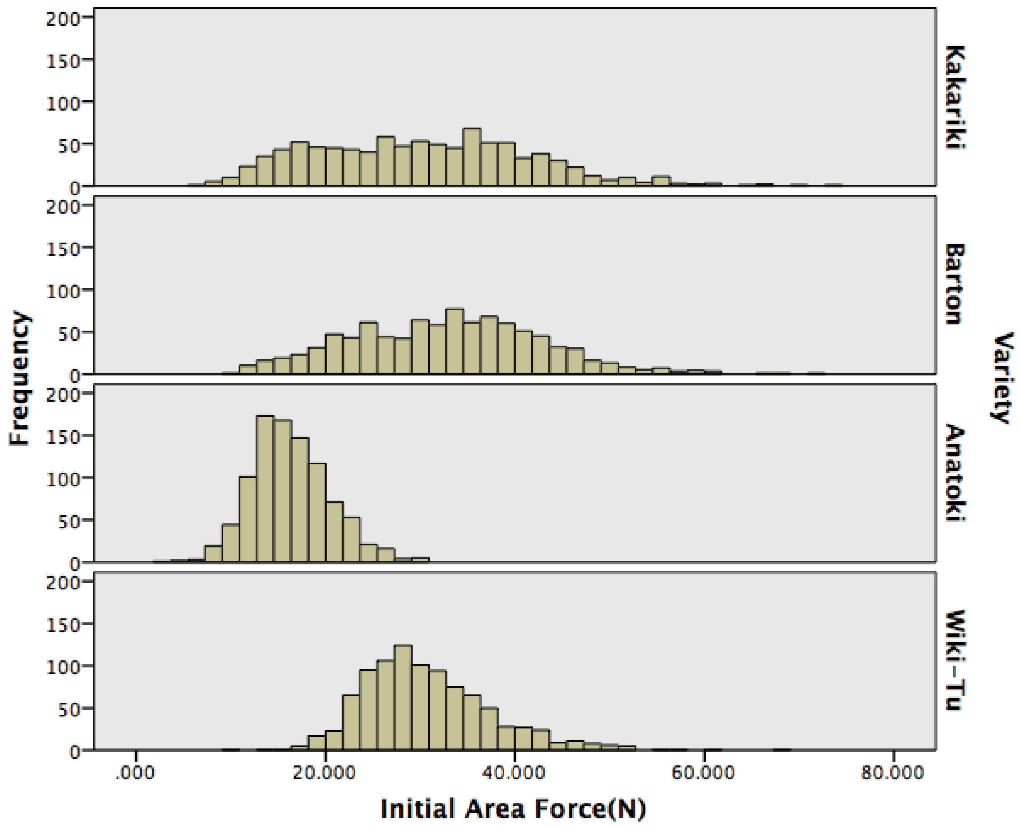


Figure 3.2 The histogram of firmness of four varieties at harvest time

3.2.1 Firmness change and storage effects

The final compression firmness of each sample from all the varieties was reasonably related to its initial compression firmness to various degrees (Table 3.3). The correlation coefficient (R^2) of initial and final compression firmness of ‘Kakariki’ was from 0.677 to 0.423 during cool storages and ambient temperature storages. The R^2 of initial and final firmness of ‘Barton’ was also reasonably high (from 0.505 to 0.686). The R^2 of ‘Anatoki’ and ‘Wiki-Tu’ were not stable, the R^2 fluctuated along the cool storages and ambient temperature storages. There is a strong trend for a better correlation after 3 days’ ambient temperature storage than that of 6 days, suggesting that firmness at harvest is correlating well with firmness 3 days after cool storage for up to 8 weeks

Table 3.3 The correlation coefficient of initial compression firmness and final compression firmness for four varieties during the cool storages and ambient temperature storages

Correlation coefficient (R^2)				
Cool storage weeks & ambient temperature storage days	‘Kakariki’	‘Barton’	‘Anatoki’	‘Wiki-Tu’
4 Weeks & 3 Days	0.677	0.631	0.584	0.482
4 Weeks & 6 Days	0.622	0.505	0.273	0.273
6 Weeks & 3 Days	0.503	0.651	0.377	0.53
6 Weeks & 6 Days	0.527	0.576	0.294	0.365
8 Weeks & 3 Days	0.556	0.686	0.402	/
8 Weeks & 6 Days	0.423	0.678	0.111	/

3.3 Skin Colour

At harvest time, the skin colour (hue) of each cultivar varied. The skin colour of each variety was significantly different from the others ($p<0.05$). Samples of ‘Barton’ had the darkest green skin colour, followed by ‘Wiki-Tu’. The skin colour of samples of ‘Anatoki’ was lighter green (Figure 3.3).

The impact of storage under ambient storage was significant on the skin colour changes for all four varieties (Figure 3.3). The skin colour hue value of all varieties dropped sharply. Samples of ‘Anatoki’ had the largest change in hue value.

Generally, the skin colour of feijoa does not change dramatically and stays olive green as they ripen. Some cultivars turn into light green from dark green when they become more mature (Kader, 2006). For 'Kakariki', 'Barton', and 'Wiki-Tu', the skin colour (hue) of these three varieties only change slightly during cool storage. However, the skin colour of 'Anatoki' changes dramatically during the cool storage and ambient temperature storage.

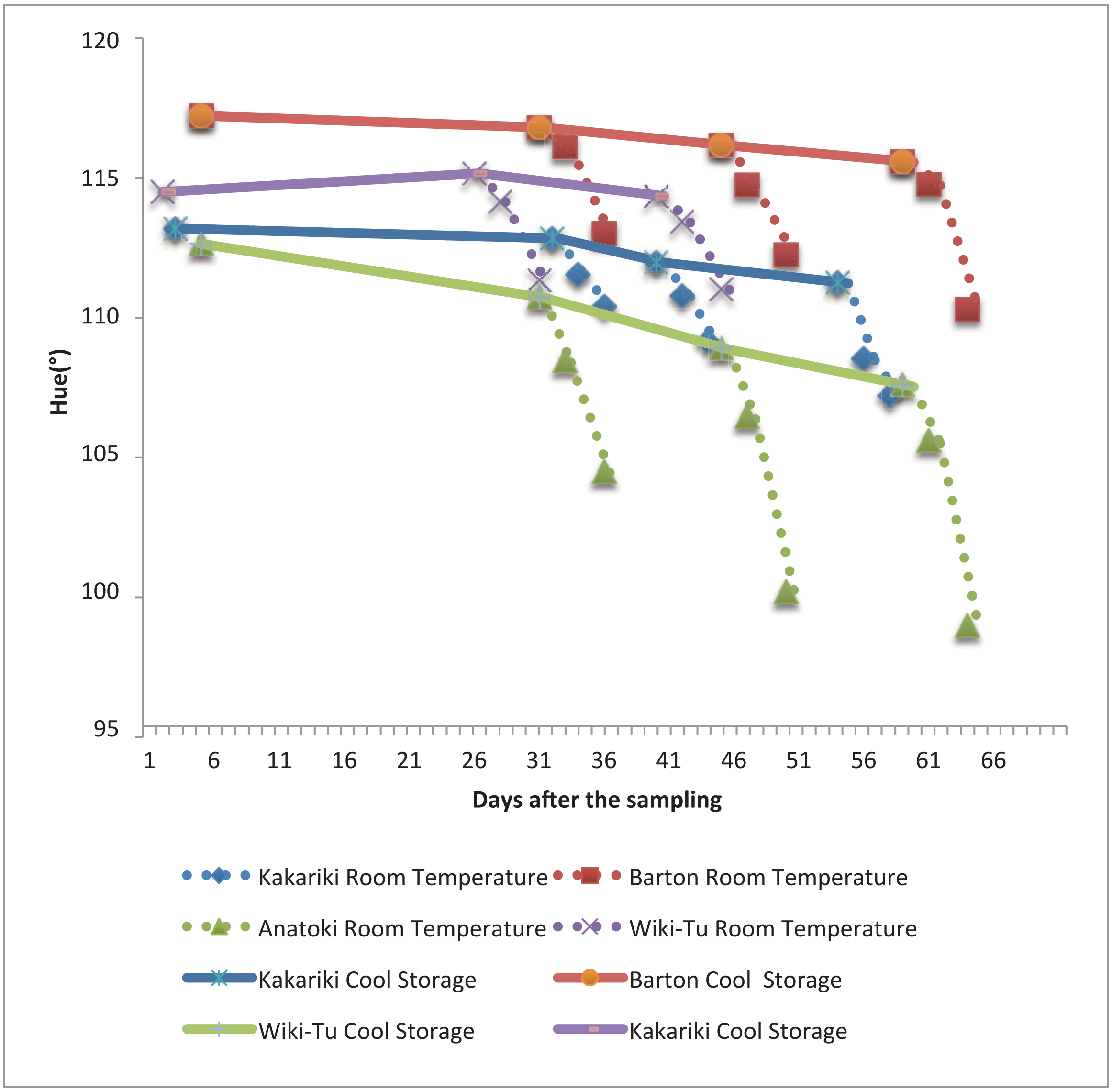


Figure 3.3 The average hue value of different feijoa varieties at harvest time and different lengths of cool storage and ambient storage

Obvious reflectance peaks were observed among 4 varieties at the spectral wavelength of 550 nm (Figure 3.4 to Figure 3.7). However, some samples from

‘Anatoki’ and ‘Wiki-Tu’ had a weak reflection response at 550 nm. The reflectance value of the spectral wavelength of 670 nm for 4 varieties started to climb up consistently and reached the peak at 740 nm, as 670 nm is the chlorophyll absorbance maximum.

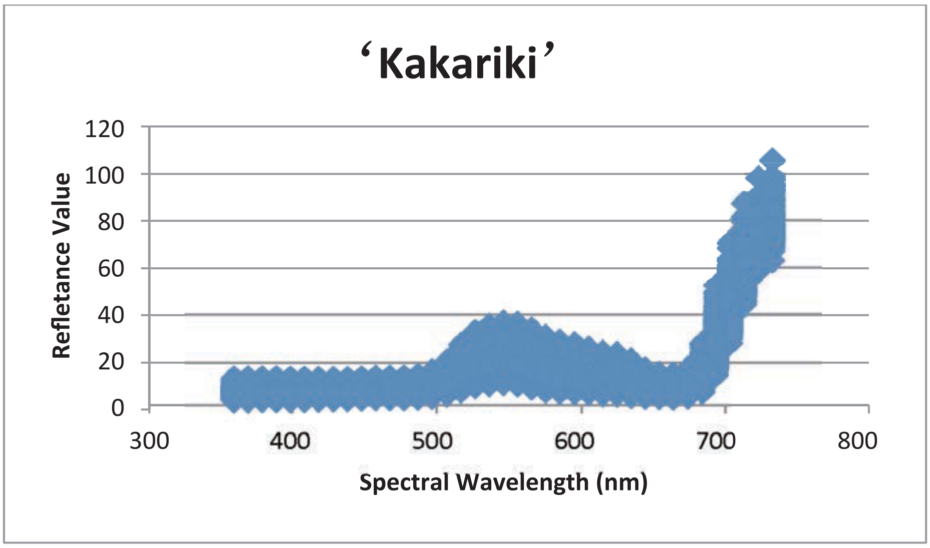


Figure 3.4 The spectral response of ‘Kakariki’ between 360 nm and 760 nm at harvest time

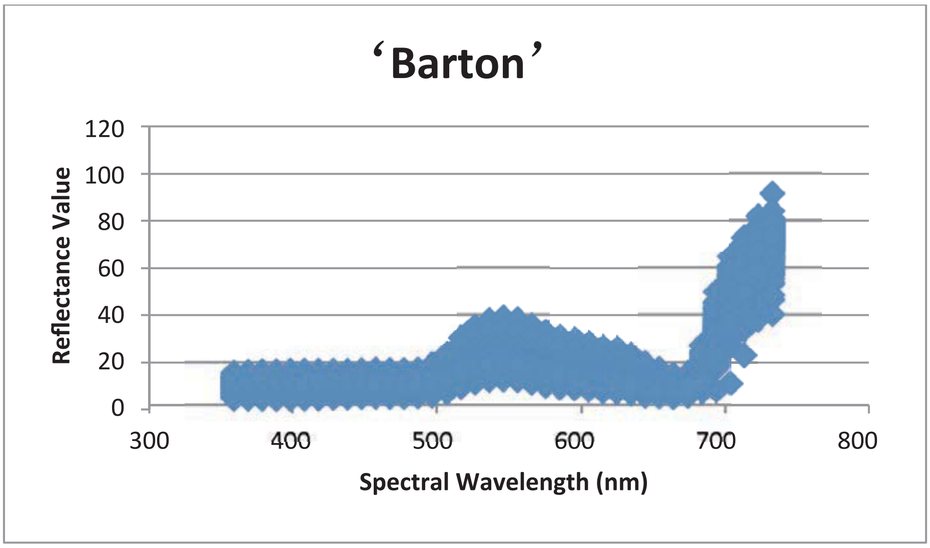


Figure 3.5 The spectral response of ‘Barton’ at harvest time between 360 nm and 760 nm

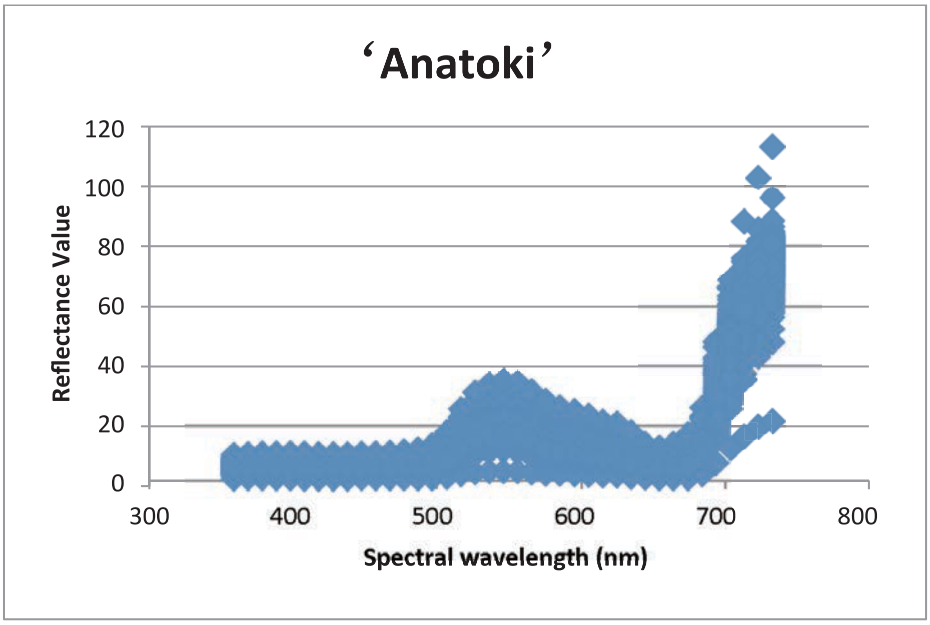


Figure 3.6 The spectral response of ‘Anatoki’ between 360 nm and 760 nm at harvest time

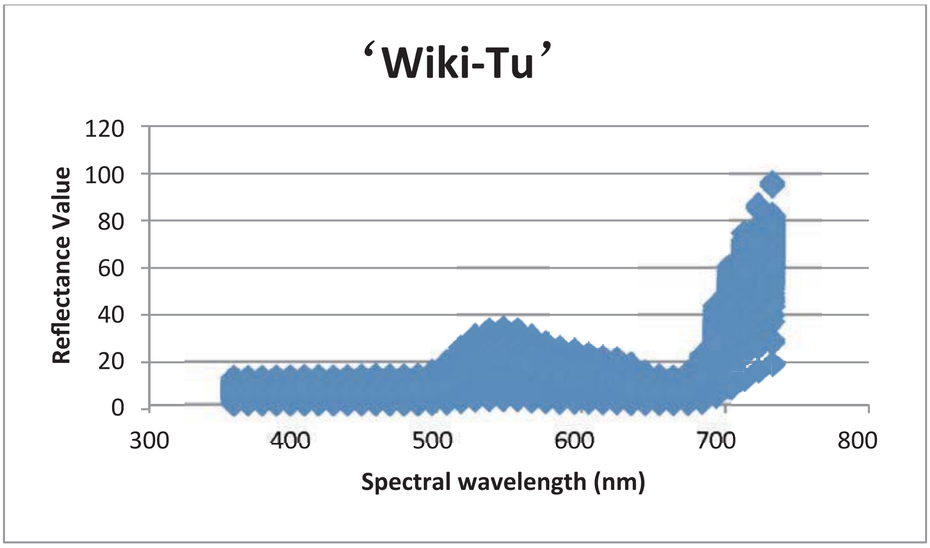


Figure 3.7 The spectral response of ‘Wiki-Tu’ between 360 nm and 760 nm at harvest time

3.4 Fruit maturity

Usually, the internal maturity rating of 3 (Figure 2.1) is recognized as the most desirable stage for consumption. Internal maturity rating of 1 is too immature for eating. Internal maturity rating of 4 is at the other end of the edible period of feijoa as the fruit flesh tends to turn brown in some cultivars (Al-Harthy, 2010) and can only be suitable for process fruit or animal feed. Any feijoa fruit with internal maturity rating beyond 4 has no commercial value anymore.

At harvest, samples of ‘Anatoki’ had the highest average internal maturity rating of 2.10. The samples of ‘Kakariki’, ‘Barton’, and ‘Wiki-Tu’ had lower average maturity rating with 1.74, 1.43, and 1.56 respectively.

From visual observation, it was also easy to distinguish that the average maturity stages of ‘Anatoki’ and ‘Kakariki’ were higher than that of ‘Barton’ and ‘Wiki-Tu’, which were sourced from the Southern Belle Orchard in Matamata (Figure 3.8). There were very few mature fruit samples found in samples of ‘Barton’ and ‘Wiki-Tu’. However, it was not difficult to find the mature samples (maturity rating of 3) in ‘Kakariki’ and ‘Anatoki’. Besides, samples of ‘Anatoki’ had the most smooth skin surface, and then followed by ‘Kakariki’. Samples of ‘Barton’ had the most uneven surface.

Figure 3.8 The samples of ‘Kakariki’ with maturity rating of 1, 2, and 3 at harvest time

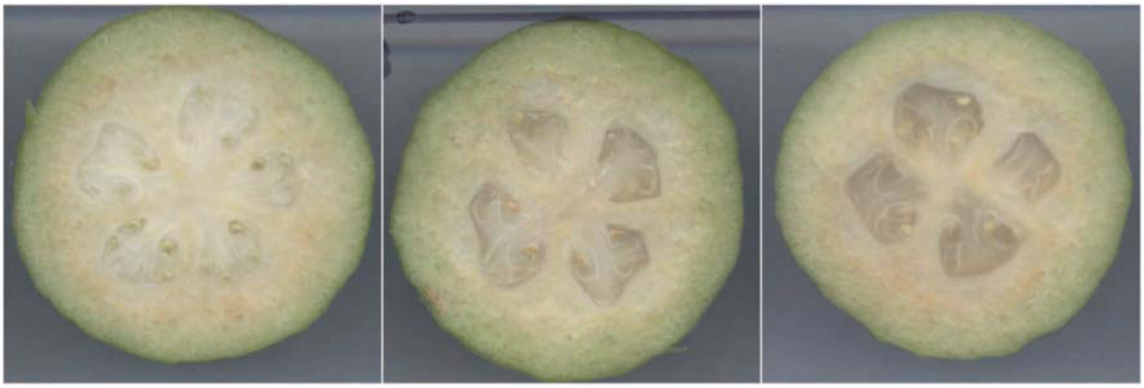


Figure 3.9 The samples of ‘Barton’ with maturity rating of 1, 1.6, and 2 at harvest time

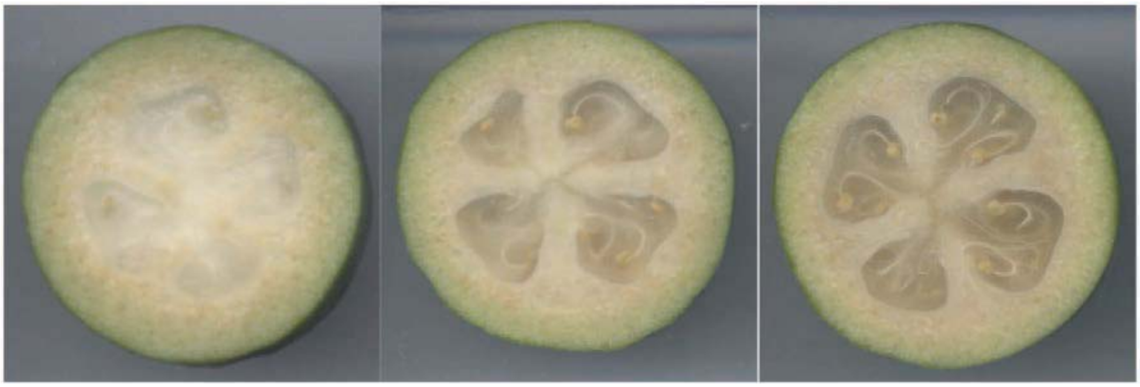


Figure 3.10 The samples of ‘Anatoki’ with maturity rating of 1, 2, and 3 at harvest time

Figure 3.11 The samples of ‘Wiki-Tu’ with maturity rating of 1, 1.6, and 2.6 at harvest time

The figures from 3.12 to 3.15 illustrate great variation of fruit maturity among individual fruit samples of four feijoa varieties at harvest time. The variation kept expanding during the subsequent cool storage and ambient temperature storage. Generally, samples of ‘Kakariki’ had the greatest variation, and then followed by ‘Barton’. Samples of ‘Anatoki’ had the least variation.

A very small proportion of rotten fruit (maturity rating over 5) was observed after 4 weeks’ cool storage plus the following storage under room temperature in all varieties except ‘Wiki-Tu’. After 4 weeks’ cool storage plus 6 days’ storage at ambient temperature, the average maturity ratings of both ‘Kakariki’ and ‘Anatoki’ had climbed up rapidly to 3. Around one third of samples of ‘Kakariki’ had become undesirable for consumption after 6 weeks’ cool storage, but the majority of ‘Anatoki’ were still visually acceptable for consumption or processing after 8 weeks’ cool storage. Samples of ‘Wiki-Tu’ seemed to have a very good storage performance (no rotten fruit) after 4 weeks cool storage plus 6 days storage under room temperature, the fruit quality of only a few individual fruits were compromised after 6 weeks’ cool storage.

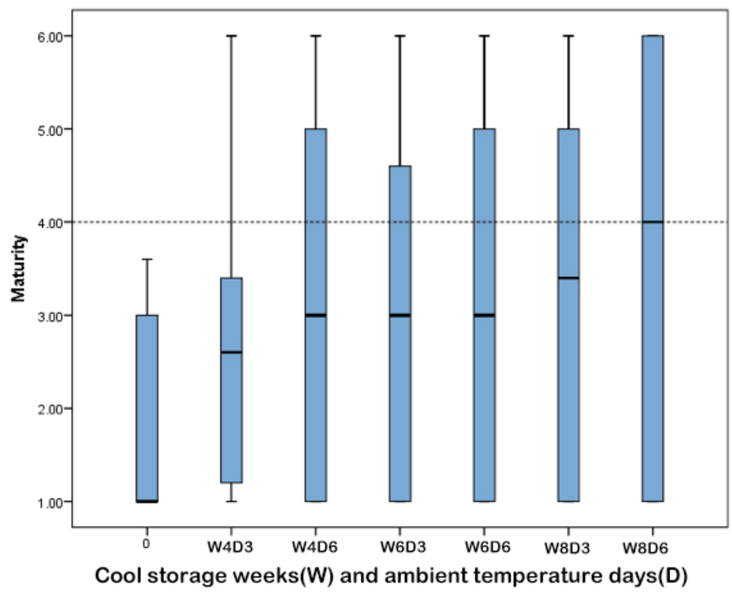


Figure 3.12 Boxplot of maturity distribution for ‘Kakariki’ during the cool storage and subsequent storage under room temperature

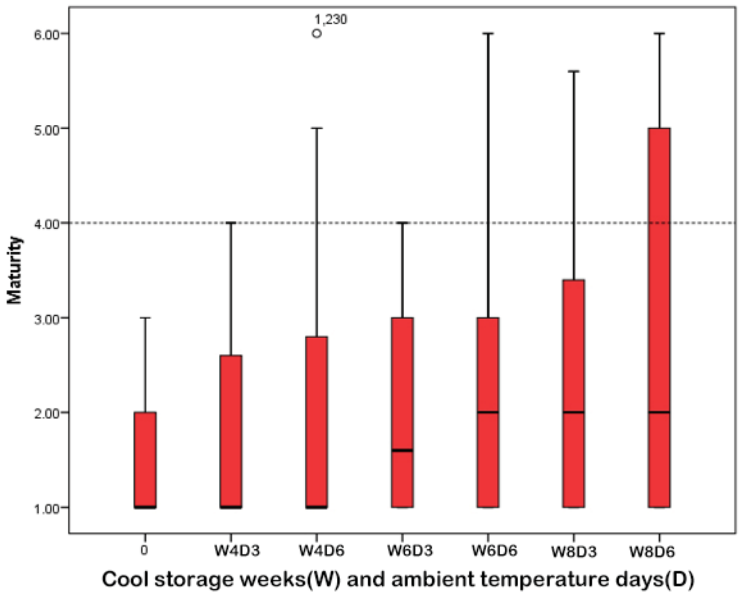


Figure 3.13 Boxplot of maturity distribution for 'Barton' during the cool storage and subsequent storage under room temperature

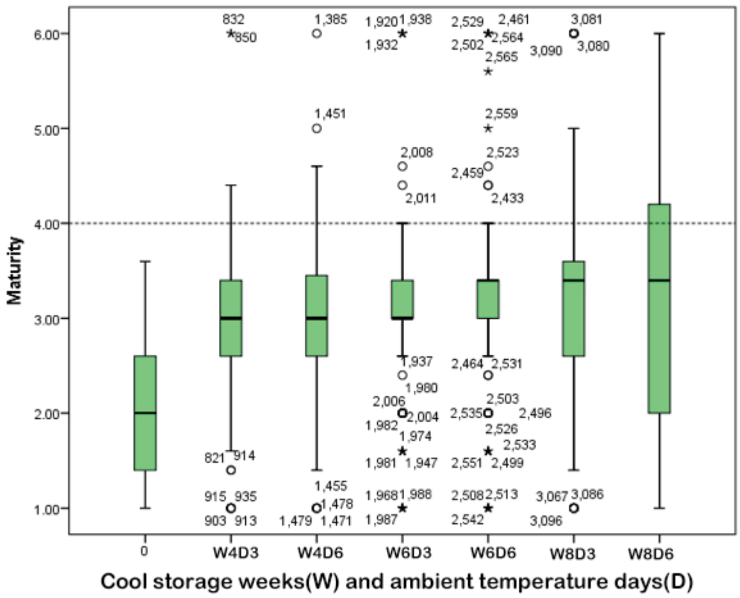


Figure 3.14 Boxplot of maturity distribution for 'Anatoki' during the cool storage and subsequent storage under room temperature

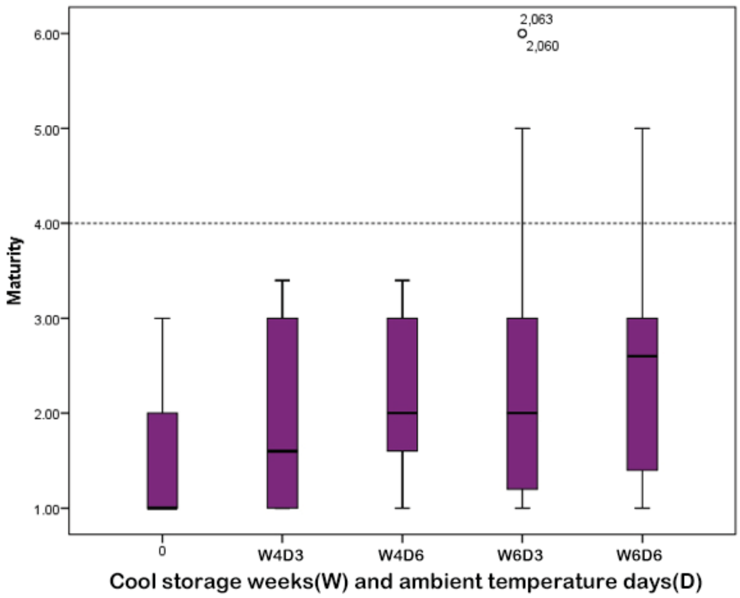


Figure 3.15 Boxplot of maturity distribution for 'Wiki-Tu' during the cool storage and subsequent storage under room temperature

Most of the samples of 'Kakariki' were either still immature (failed to ripen) or overripe after 6 weeks cool storage plus 3 days' ambient temperature storage (Figure 3.16). The overripe samples had serious internal flesh browning with some external damages. Therefore, these samples have very limited commercial value. The samples of 'Barton' were at the end of the stage for consumption. However, external defects of these samples were rarely observed. These fruit still had the potential to be sold at lower price or sold to factories for processed fruit.

A small proportion (around 1or 2 out of 15) of 'Anatoki' had surface defects that lead to deterioration (Figure 3.17). Most of the samples were still visually acceptable but with less desirable appearance. Although around half of the samples of 'Wiki-Tu' were still immature, the rest of the fruits were perfectly good for consumption after six weeks' storage and 6 days storage at room temperature.

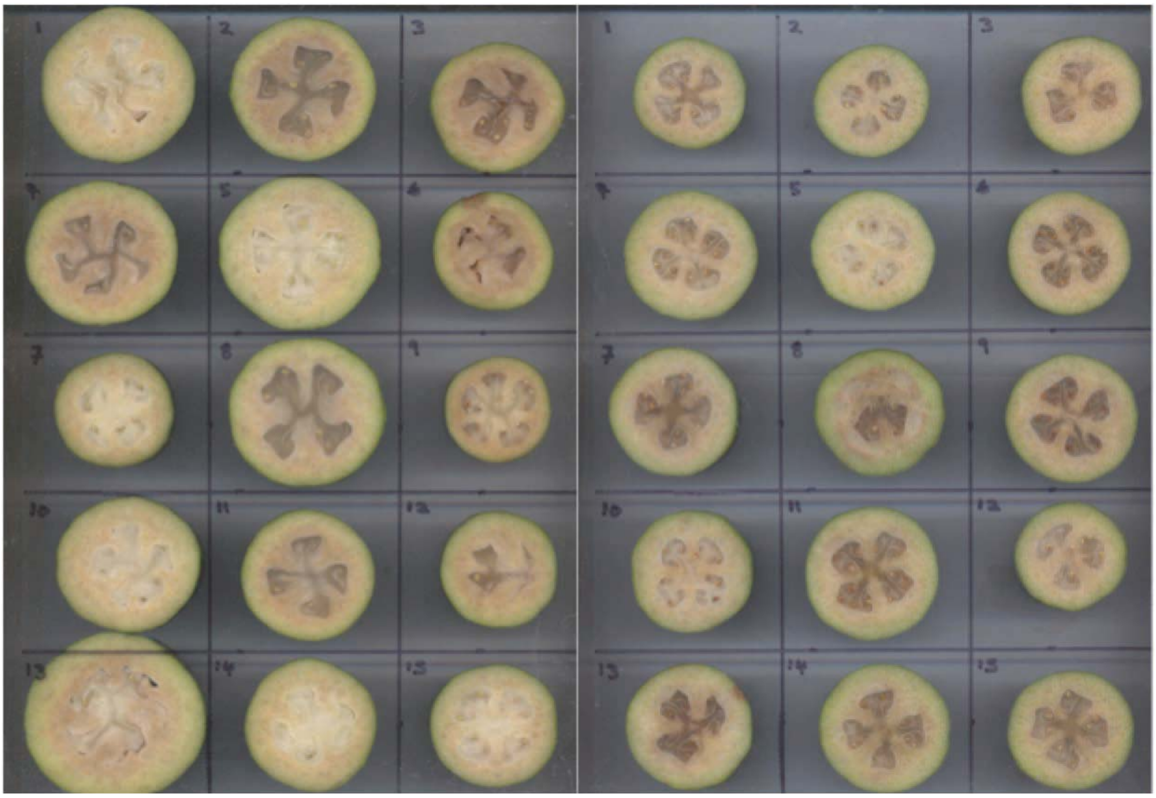


Figure 3.16 The internal maturity condition of samples of 'Kakariki' (left) and 'Barton' (right) after 6 weeks' cool storage and 3 days' ambient temperature storage

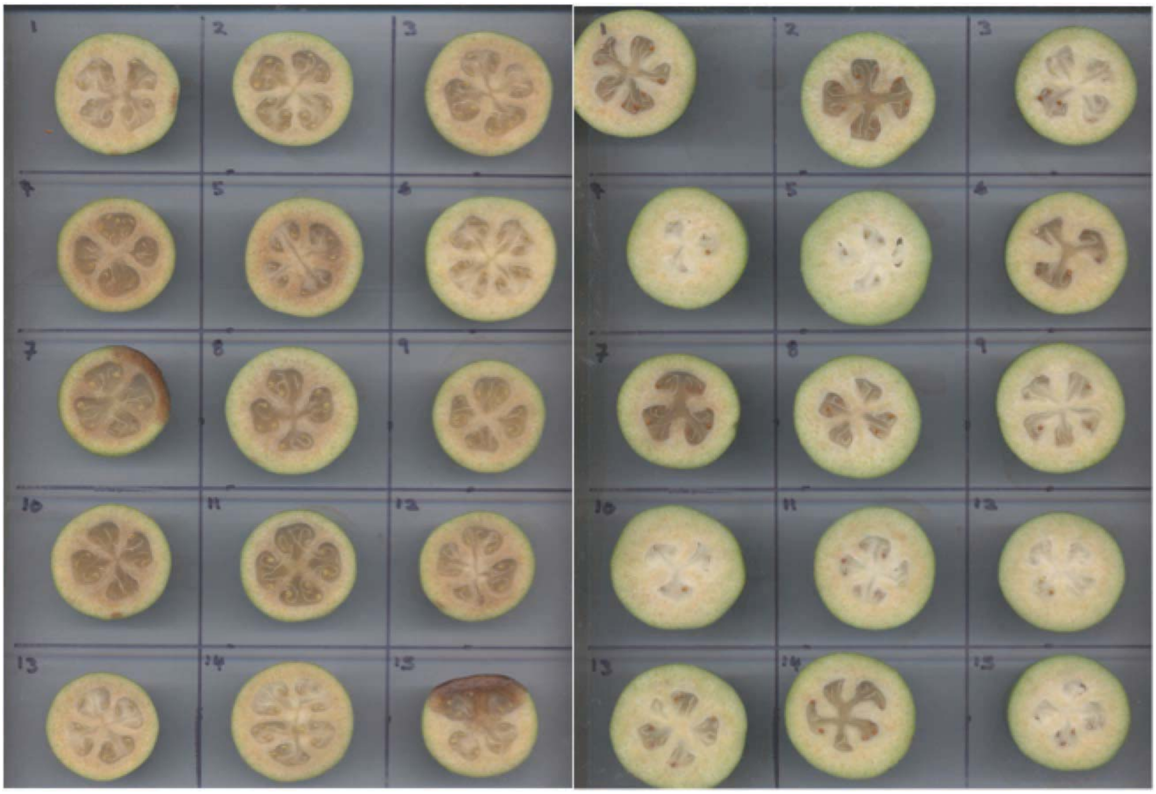


Figure 3.17 The internal maturity condition of samples of 'Anatoki' (left) and 'Wiki-tu' (right) after 6 weeks' cool storage and 3 days' ambient temperature storage

3.5 Total Soluble Solids (TSS)

For feijoa, total soluble solids (TSS) is used as an indication of fruit sweetness. TSS mainly consists of fructose, glucose and sucrose (Harman, 1987).

The average TSS at harvest time of the four varieties ranges from 10 to 12° Brix (Figure 3.18). There were significant differences ($P<0.05$) in the TSS among 4 verities, except between 'Barton' and 'Wiki-Tu'. Throughout the harvest time and cool storage periods with different lengths of storage at ambient temperature, samples of 'Wiki-Tu' always had the highest TSS content then followed by 'Barton', and 'Kakariki'. Samples of 'Anatoki' had the lowest TSS content consistently.

There was a trend of decrease in TSS during the cool storages. The TSS contents of samples from all varieties decreased during the storage under ambient temperature.

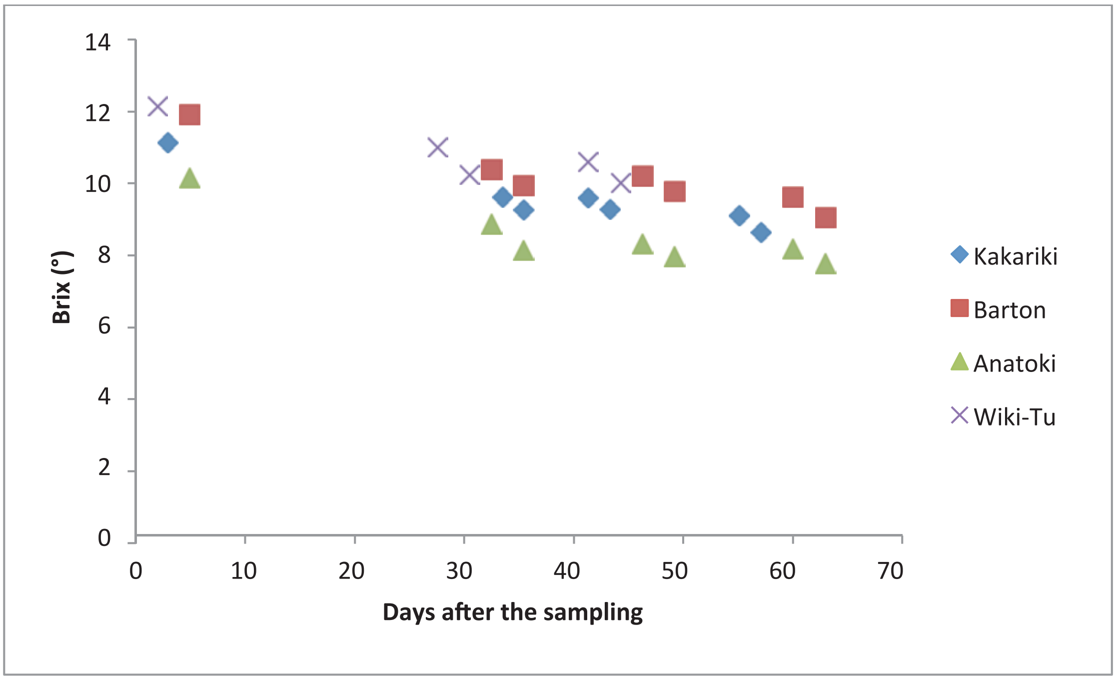


Figure 3.18 The average total soluble solids of different feijoa varieties at different lengths of ambient temperature storage.

There is a very weak correlation (R^2 from 0.007 to 0.095) between the TSS and the internal maturity at harvest time among 4 varieties (Figure 3.9). Similar results were found by Al-Harthy (2010) who reported the correlation coefficient (R^2) of TSS and the internal maturity was 0.002 for 'Unique' and 0.0762 for 'Opal Star'.

It was suggested that the Brix value is not a useful indicator for evaluating the actual sugar content of guava (El-Bulk, Babiker, & El-Tinay, 1997). There are many compounds in the juice that could have impacts on the Brix value. Since the TSS does not change significantly with the maturity stage in feijoa, TSS cannot be identified as a maturity index for feijoa. This conclusion was also supported by Gaddam et al. (2004).

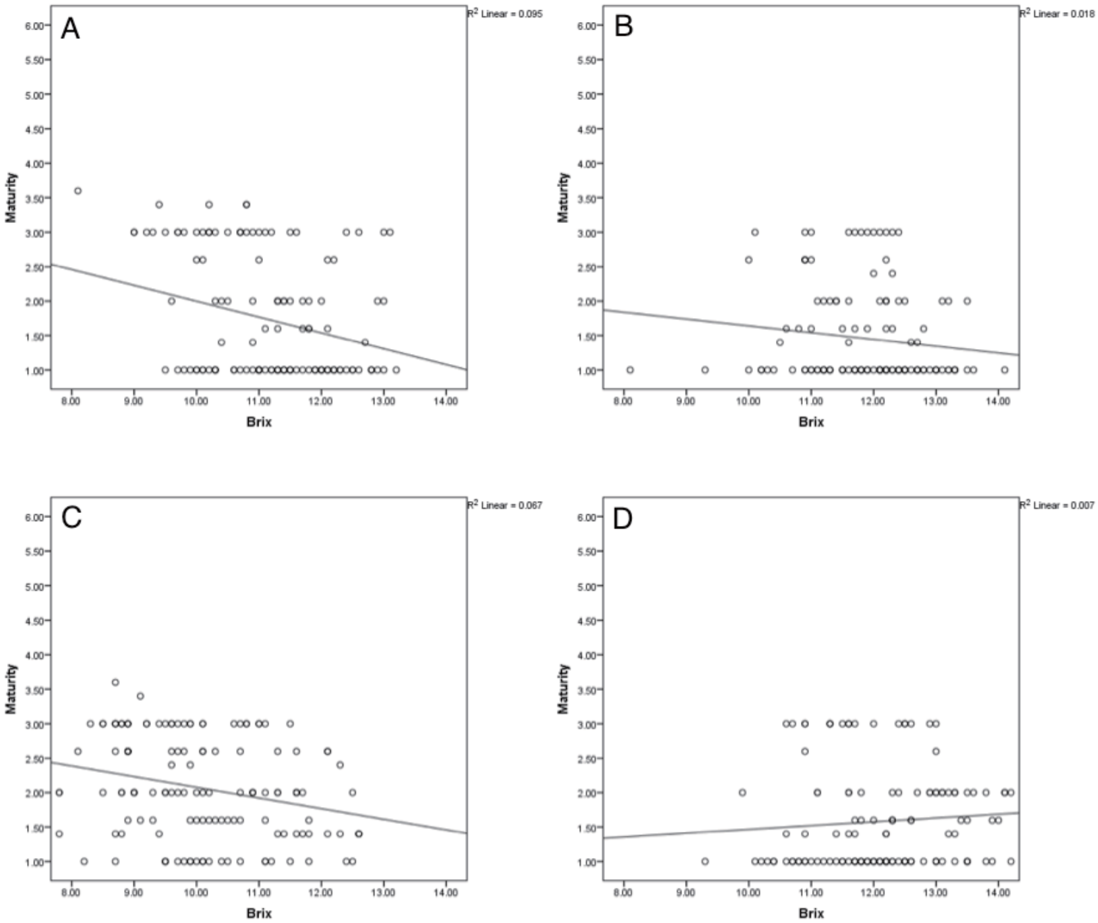


Figure 3.19 The scatterplot of TSS and fruit maturity at harvest time for four feijoa varieties: 'Kakariki' (A), 'Barton' (B), 'Anatoki' (C), and 'Wiki-Tu' (D)

3.6 Titratable Acidity (TA)

The main acids that contribute to the titratable acidity in feijoa are malic and citric acid with a ratio of 1:1 (Harman, 1987). There were significant differences ($P<0.05$) in the TA among samples of four varieties at harvest time, except between 'Barton' and 'Wiki-Tu'. Samples of 'Barton' and 'Wiki-Tu' had relatively higher TA value than that of 'Anatoki' and 'Kakariki' (Figure 3.20). The TA decreased with cool storage and ambient temperature storage.

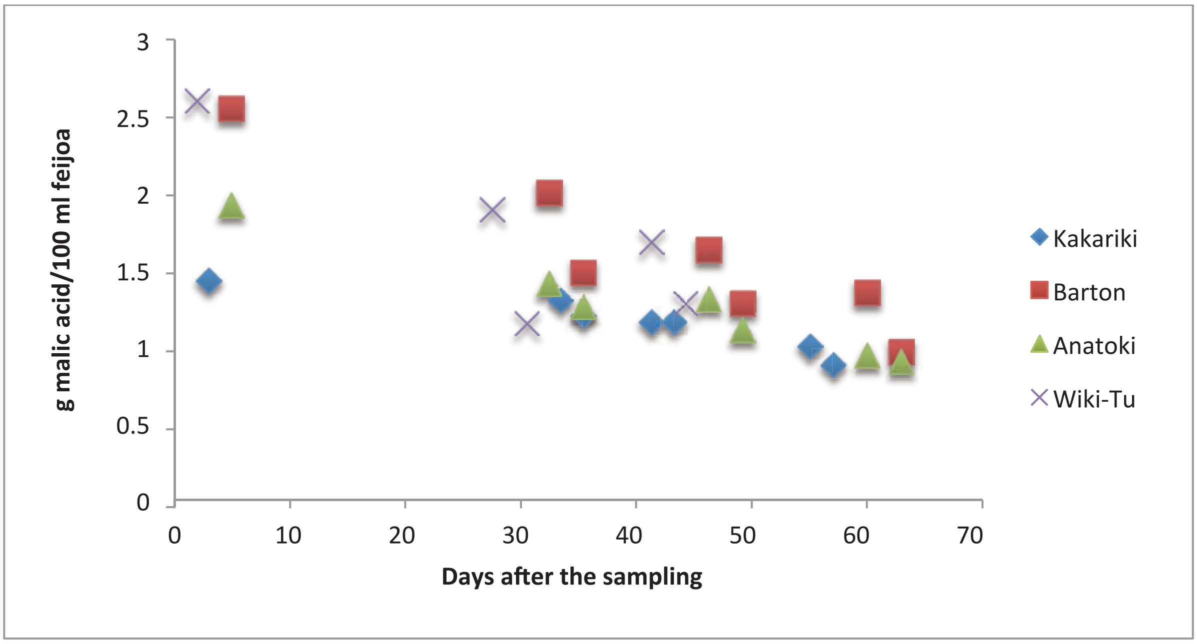


Figure 3.20 The average TA value of different feijoa varieties at different lengths of ambient temperature storage

3.7 The quality attributes of fruit from different varieties with same maturity rating

When the fruit were harvested, the physiological maturity conditions of fruits from different varieties were different. To identify the differences of quality attributes among different varieties, the samples were re-grouped according to their maturity ratings.

For both very immature and mature fruit, samples of 'Anatoki' had the lowest value of skin firmness, skin colour, weight, and Brix (Table 3.4 and Table 3.5). Samples of 'Wiki-Tu' had a high value of Brix and TA, suggesting that these fruit had a nice flavour. Samples of 'Barton' had the darkest green skin colour. Samples of 'Kakariki' had the largest fruit. Although, these quality attributes can be affected by growth region, growers' selection, and other factors, these results were still valuable for us to have a better understanding of the differences of intrinsic attributes between different feijoa varieties.

Table 3.4 The quality attributes of very immature fruit (maturity rating 1 or A) of 4 varieties at harvest time. Significant differences (P ≤ 0.05) for means within a column are indicated by different letters.

Varity	Number	Firmness (N)	Skin hue (°)	Weight (g)	Brix (°)	TA (g malic acid/100 ml)
Kakariki	319	39.2[a]	114.0[a]	100.9[a]	9.9[a]	1.4[a]
Barton	445	38.7[a]	117.9[b]	91.0[b]	10.0[a]	1.9[b]
Anatoki	75	20.8[b]	112.8[a]	67.9[c]	8.8[b]	1.4[c]
Wiki-Tu	219	36.0[c]	115.5[c]	85.1[d]	10.4[c]	2.0[d]

Table 3.5 The quality attributes of mature fruit (maturity rating 3 or C) of 4 varieties at harvest time. Significant differences (P ≤ 0.05) for means within a column are indicated by different letters.

Varity	Number	Firmness (N)	Skin hue (°)	Weight (g)	Brix (°)	TA (g malic acid/100 ml)
Kakariki	93	27.7[a]	113.3[a]	115.7[a]	9.8[a]	1.2[a]
Barton	129	27.2[a]	116.6[b]	93.6[b]	10.4[b]	1.3[b]
Anatoki	246	16.2[b]	112.9[a]	69.5[c]	8.7[c]	1.3[a]
Wiki-Tu	190	27.0[a]	114.0[c]	93.4[d]	10.9[d]	1.5[c]

4 NON-DESTRUCTIVE MEASUREMENTS AT HARVEST TIME TO ESTIMATE THE INTERNAL MATURITY OF FEIJOA AFTER THE COOL STORAGE AND AMBIENT TEMPERATURE STORAGE

4.1 The correlation between skin colour and maturity

The spectrophotometer is able to provide various types of optical data by flashing a light on the skin of fruit. Hue is a frequent used optical property to identify the colour of an object. The spectral response was high at wavelength of 550 nm for 4 varieties. Therefore it was adopted to test the correlation with internal maturity. The reflectance at 670 nm and 720 nm has been successfully applied to assess the fruit quality of nectarines, apples and pears. They were also examined in this experiment.

Although correlations between skin colour (hue) at harvest and post-storage fruit quality for the cultivar ‘Unique’ was observed (Rupavatharam et al., 2015), there was no correlation between the hue and internal fruit maturity for all 4 varieties at harvest (figure 4.1). There was no correlation between hue and maturity in this study at any of the experimented lengths of cool storage and ambient temperature storages.

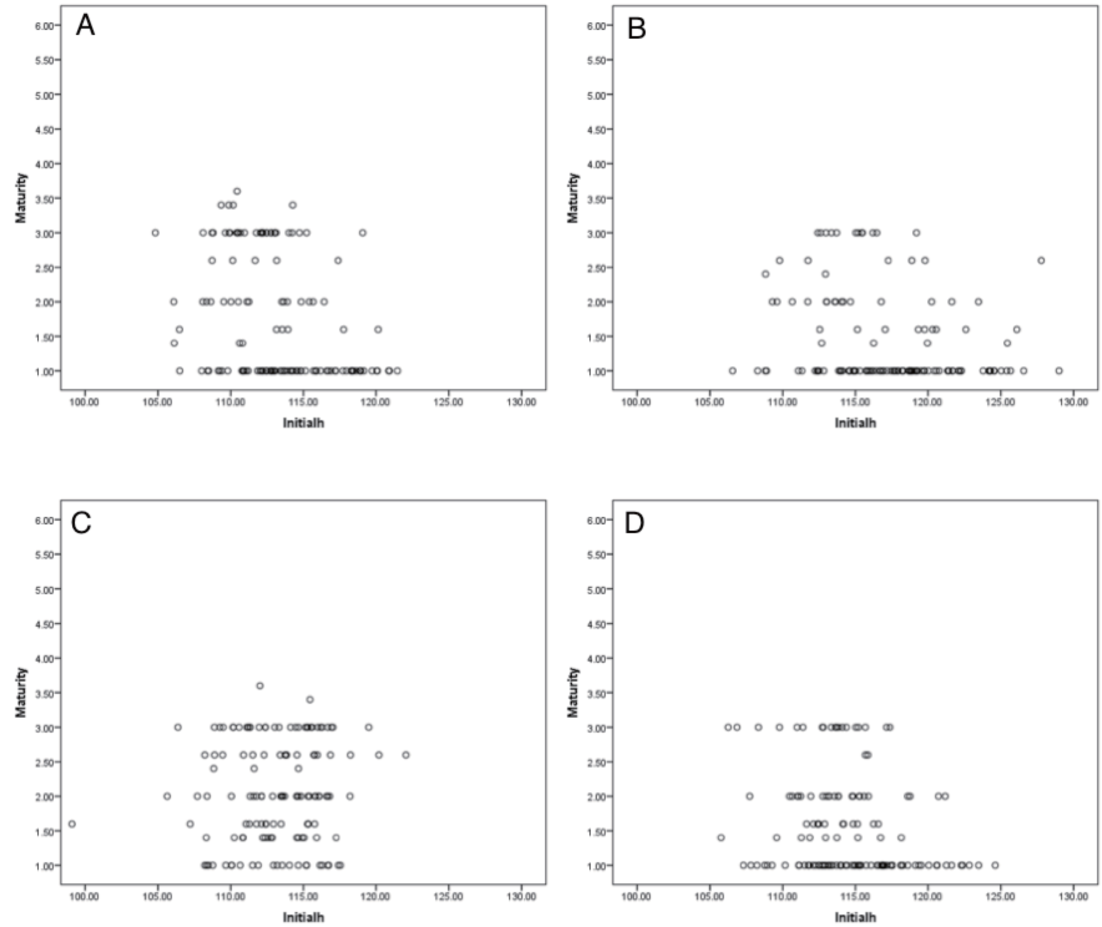


Figure 4.1 The scatterplot of hue and fruit maturity for four feijoa varieties: 'Kakariki' (A), 'Barton' (B), 'Anatoki' (C), and 'Wiki-Tu' (D) at harvest time

In this study the correlation between the reflectance at 550 nm and the internal maturity was very weak at the harvest time (R^2=0.007~0.172). Generally, the value of reflection at 550 nm increased when maturity advanced (Figure 4.2). However, the correlation vanished after the following cool storage and shelf life storage for all four varieties. However, it was suggested that the reflectance at 550nm could be a good indicator for maturity in 'Unique' (Rupavatharam, 2015).

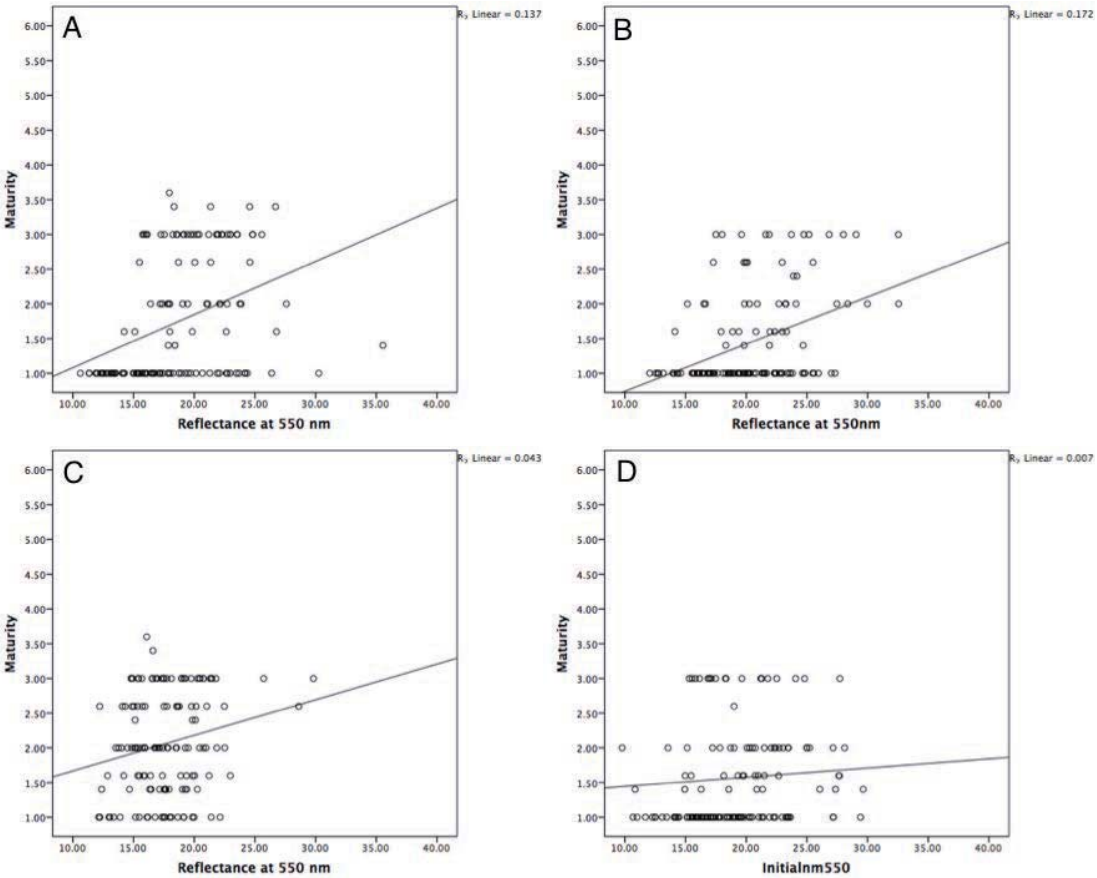


Figure 4.2 The scatterplot of reflectance at 550nm and fruit maturity at harvest for four feijoa varieties: 'Kakariki' (A), 'Barton' (B), 'Anatoki' (C), and 'Wiki-Tu' (D) at harvest time

The absorption at 670nm was successfully applied to select fruit with good flavour, and predict the softening during the shelf life in nectarines, and it was also useful to estimate the internal maturity in apples and pears (Zerbini et al., 2003). However, in this study, there was no strong correlation found between the reflectance at 670 nm and the internal fruit maturity (Figure 4.3).

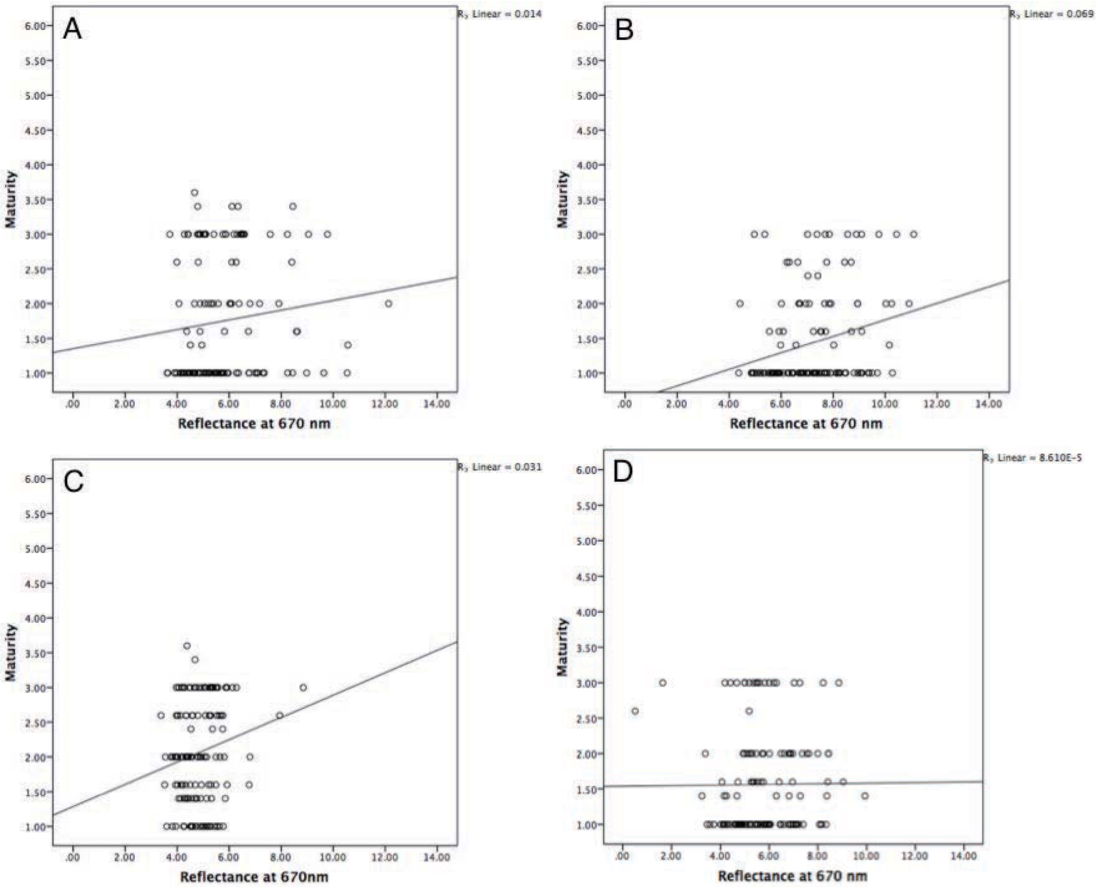
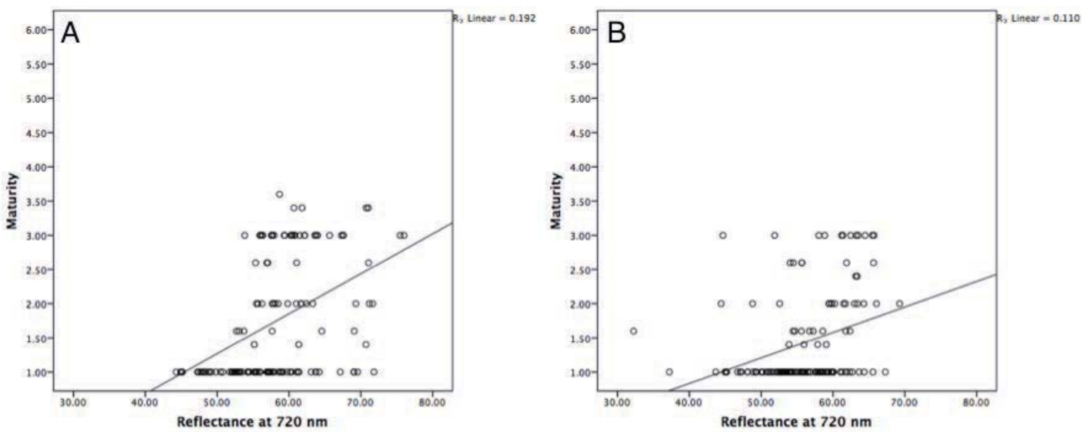


Figure 4.3 The scatterplot of reflectance at 670 nm and fruit maturity at harvest for four feijoa varieties: 'Kakariki' (A), 'Barton' (B), 'Anatoki' (C), and 'Wiki-Tu' (D) at harvest time

The absorption coefficient μa at 720 nm is mainly used to segregate the brown heart affected tissue in the intact fruit in pears (Zerbini, 2006). The reflectance at 720 nm of samples from four varieties in this study indicated that there was no strong correlation between the 720 nm and the fruit internal maturity (Figure 4.4).



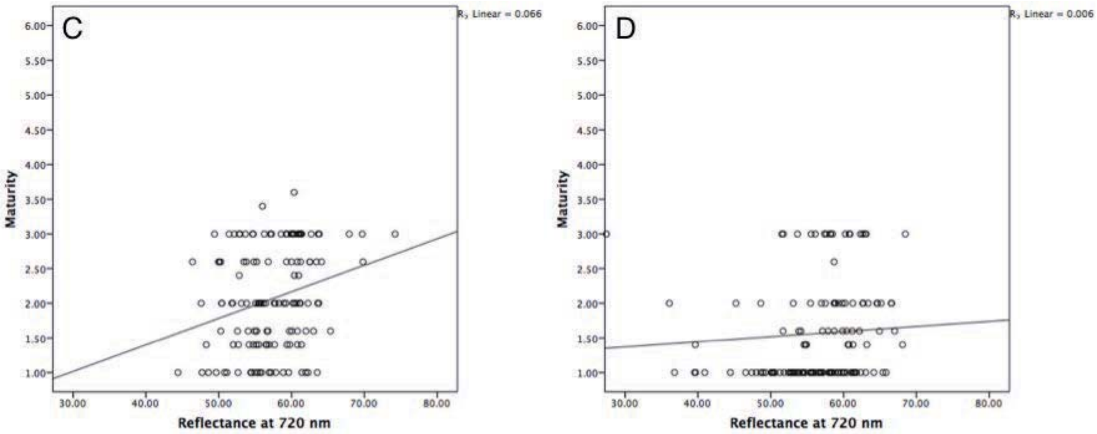


Figure 4.4 The scatterplot of reflectance at 720 nm and fruit maturity at harvest for four feijoa varieties: ‘Kakariki’ (A), ‘Barton’ (B), ‘Anatoki’ (C), and ‘Wiki-Tu’ (D) at harvest time

4.2 The correlation between compression firmness and maturity

There were numerous studies based on measuring the skin firmness to evaluate the fruit quality. The correlation between resonance frequency and internal maturity of apple is high (Cooke, 1970). Similar experiments (Schotsmans & Mawson, 2005) but measuring the compression firmness have also been done on kiwifruit where the correlation was proved strong (R^2=0.73).

Previous study on feijoa indicated that the fruit internal maturity of ‘Unique’ and ‘Opal Star’ is reasonably correlated (R^2=0.6~0.5) to the skin compression firmness (Al-Harthy, 2010). However, the accuracy of Sinclair and acoustic measurements were lower than that of compression firmness and this may have been due to the small fruit mass of feijoa (Al-Harthy, 2010).

At harvest time, for four feijoa varieties the fruit maturity and compression firmness is correlated in varying degrees (Table 4.1 & Figure 4.5). The correlation coefficients are modest (R^2=0.539 and R^2=0.414) for ‘Kakariki’ and ‘Barton’. However, the correlation coefficient is quite low for ‘Wiki-Tu’ (R^2=0.267).

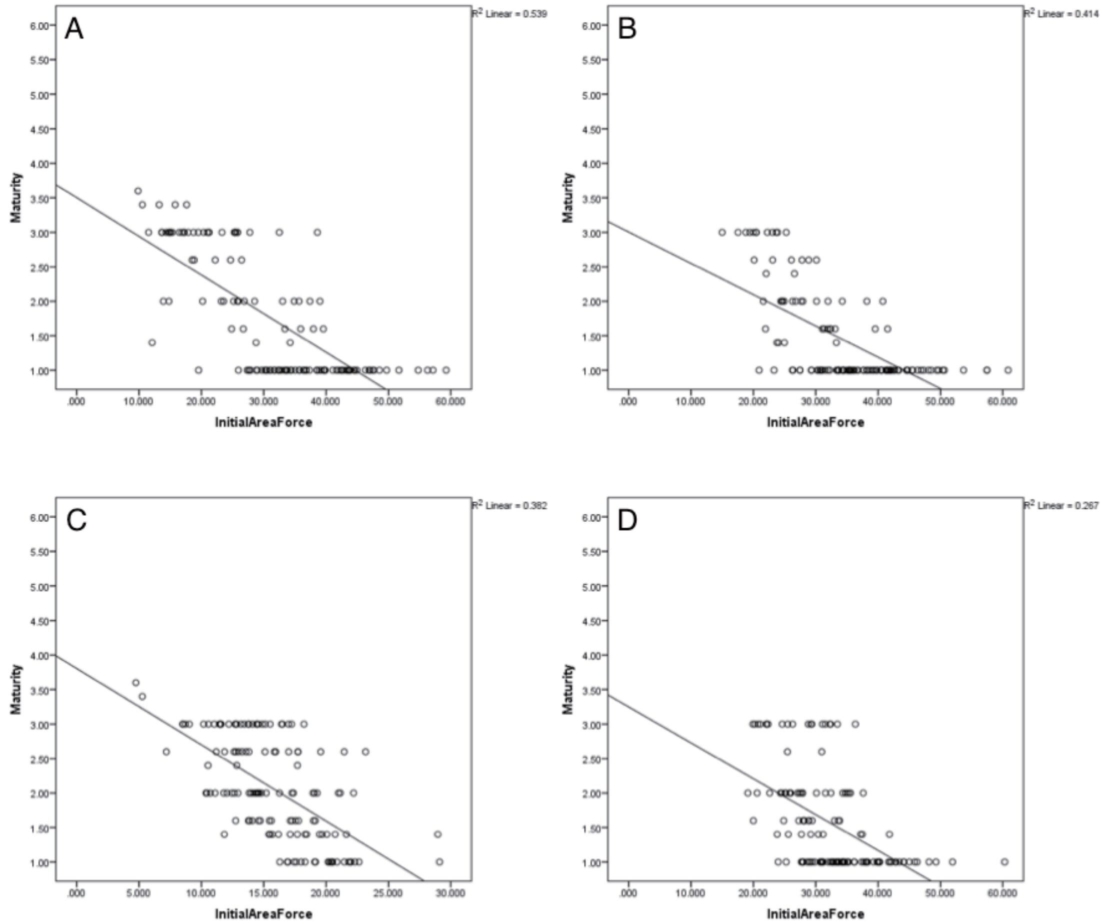


Figure 4.5 The scatterplot of initial compression force and fruit maturity at harvest for four feijoa varieties: ‘Kakariki’ (A), ‘Barton’ (B), ‘Anatoki’ (C), ‘Wiki-Tu’ (D) at harvest time

Table 4.1 The correlation coefficient of maturity after storage and initial compression firmness for four varieties

	Correlation coefficient (R^2)			
Cool storage weeks(W) and room temperature days(D)	Kakariki	Barton	Anatoki	Wiki-Tu
W0D0	0.539	0.414	0.382	0.267
W4D3	0.612	0.364	0.404	0.281
W4D6	0.598	0.492	0.288	0.318
W6D3	0.520	0.419	0.247	0.207
W6D6	0.593	0.489	0.313	0.361
W8D3	0.513	0.481	0.325	/
W8D6	0.506	0.606	0.165	/

Although for samples of 'Kakariki', the correlation coefficient declined after it reached its highest peak after 4 weeks' cool storage (Table 4.1), the correlation between the compression firmness and internal maturity of samples from 'Kakariki' was still the strongest among 4 varieties during the whole storage periods (Figure 4.6 - Figure 4.11).

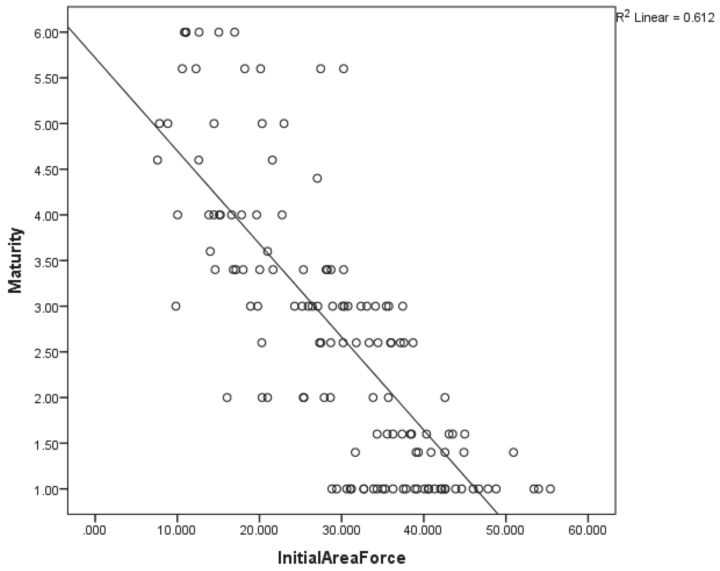


Figure 4.6 The scatterplot of initial fruit skin compression force and fruit internal maturity after 4 weeks cool storage plus 3 days' ambient temperature storage for 'Kakariki'

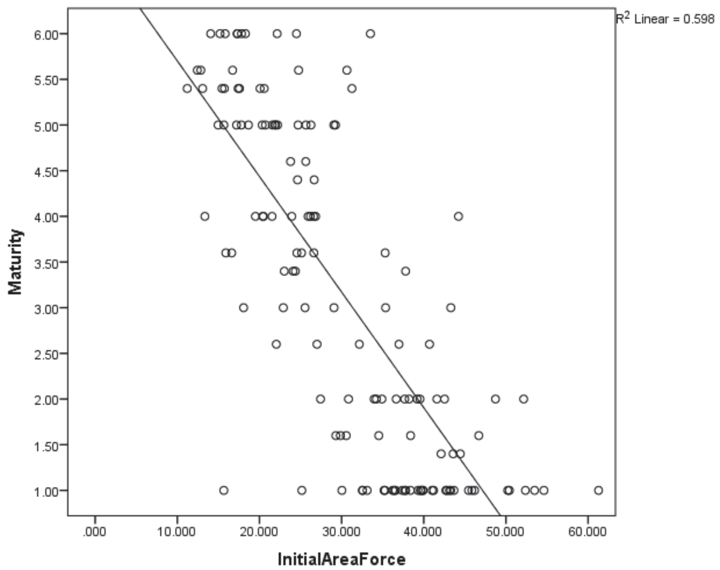


Figure 4.7 The scatterplot of initial fruit skin compression force and fruit internal maturity after 4 weeks cool storage plus 6 days' ambient temperature storage for 'Kakariki'

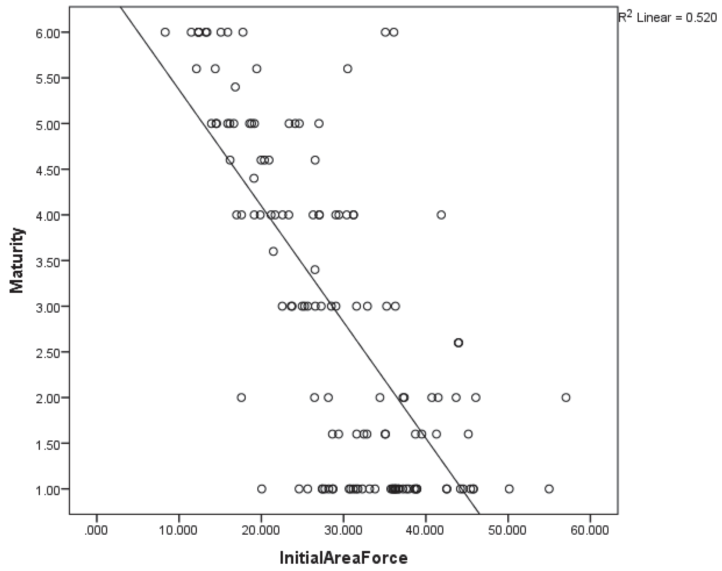


Figure 4.8 The scatterplot of initial fruit skin compression force and fruit internal maturity after 6 weeks cool storage plus 3 days' ambient temperature storage for 'Kakariki'

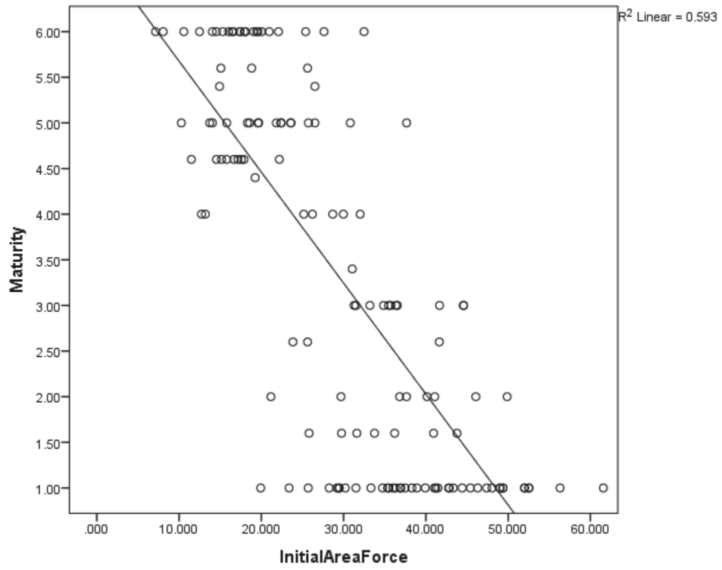


Figure 4.9 The scatterplot of initial fruit skin compression force and fruit internal maturity after 6 weeks cool storage plus 6 days' ambient temperature storage for 'Kakariki'

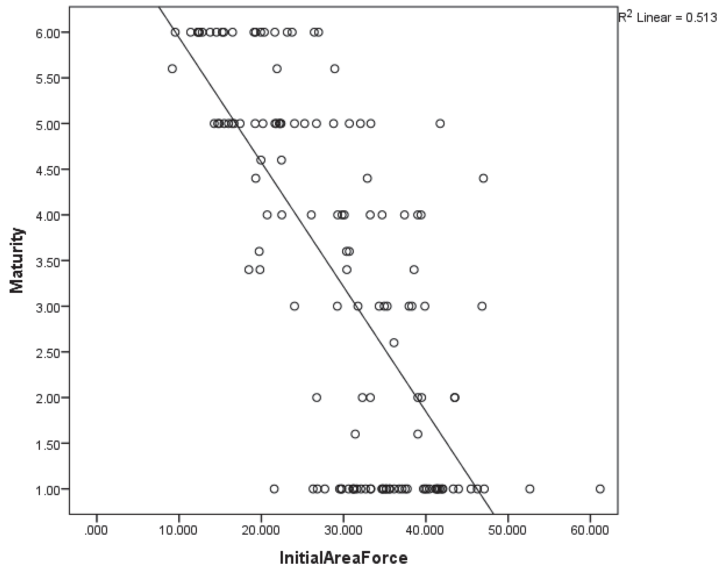


Figure 4.10 The scatterplot of initial fruit skin compression force and fruit internal maturity after 8 weeks cool storage plus 3 days' ambient temperature storage for 'Kakariki'

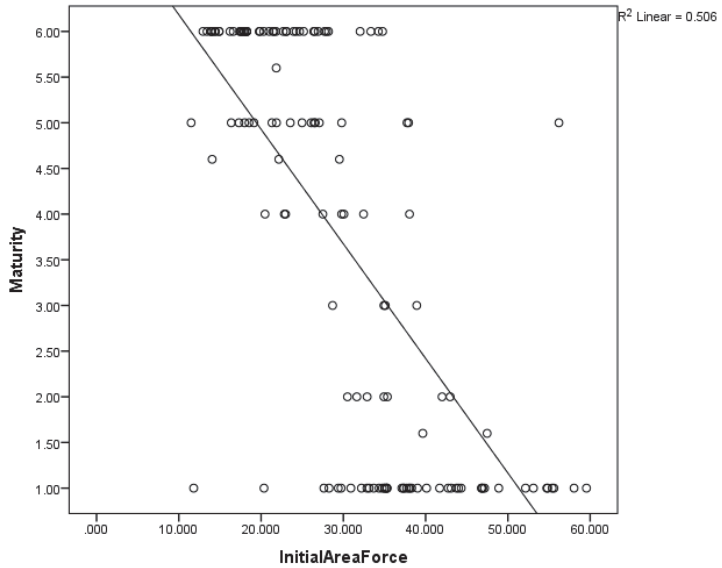


Figure 4.11 The scatterplot of initial fruit skin compression force and fruit internal maturity after 8 weeks cool storage plus 6 days' ambient temperature storage for 'Kakariki'

We have found that there is a modest correlation between initial compression firmness and final internal fruit maturity. However, we found out that the correlation got even weaker after the cool storages and shelf storages (Table 4.2) especially on 'Kakariki' and 'Barton'.

Table 4.2 The correlation coefficient of final maturity and final compression firmness for four varieties during the cool storages and ambient temperature storage

Correlation coefficient (R^2)				
Cool storage weeks & ambient temperature storage days	Kakariki	Barton	Anatoki	Wiki-Tu
4 Weeks & 3 Days	0.421	0.295	0.545	0.269
4 Weeks & 6 Days	0.330	0.270	0.276	0.311
6 Weeks & 3 Days	0.306	0.362	0.395	0.202
6 Weeks & 6 Days	0.260	0.353	0.338	0.412
8 Weeks & 3 Days	0.476	0.476	0.474	/
8 Weeks & 6 Days	0.414	0.527	0.391	/

4.2.1 Setting up a firmness threshold at harvest can help to eliminate the potential bad fruit after the storage

The variation of fruit maturity for feijoa is dramatic at harvest time. Currently in the feijoa industry, there is no reliable and quantified non-destructive method to classify feijoa fruit based on their maturity status. The industry only segregates the fruit by weight and there is no correlation between maturity and weight. So each batch of feijoa fruit stored is a combination of fruit with varying maturity. Because fruits with higher maturity status are more likely to have a shorter storage life than that of fruits with lower maturity status, some fruit will rot and some fruit will stay immature after the storage. As a result, the quality and value of a fruit batch with mixed maturity is low and inconsistent. The industry would lose money due to the fruit waste and reputation of fruit quality control would be queried.

A modest correlation between the skin firmness and fruit maturity among feijoa cultivars at harvest time was found in this experiment; mature fruits were usually softer than that of immature fruits. In this case, we could set up a threshold line according to the firmness reading of each fruit to eliminate the future potential over mature or over immature fruits at harvest time.

Segregating feijoa based on the firmness condition at harvest time could eliminate some over mature fruit that would not survive after a certain period of cool storage. These fruits should have the priority to be sold as soon as possible. Also, setting a threshold line of skin firmness at harvest time could reduce the amount of immature fruit that would never ripen during the storage. It is necessary to keep these fruit on trees until they become more mature. In this experiment, different thresholds were tested to reduce the fruit waste and increase the quality fruit batch. In the following table:

Type A is the number of successfully eliminated bad fruit (maturity stage > 3.5)

Type B is the number of falsely gained bad fruit

Type C is the number of falsely eliminated good fruit (maturity stage < 3.5)

Type D is the number of successfully gained good fruit

Table 4.3 The percentage of 4 types of fruit after the firmness segregation of 'Kakariki'

'Kakariki'					
Length of storages	Thresholds	A	B	C	D
4 Weeks + 3 Days	20N	17%	7%	6%	70%
	22N	20%	4%	10%	67%
	24N	21%	2%	10%	67%
	26N	21%	2%	14%	62%
4 Weeks + 6 Days	20N	19%	27%	1%	53%
	22N	26%	19%	1%	53%
	24N	29%	16%	4%	51%
	26N	36%	10%	7%	48%

6 Weeks + 3 Days	20N	22%	18%	1%	59%
	22N	26%	14%	1%	59%
	24N	28%	12%	4%	56%
	26N	30%	10%	7%	53%
6 Weeks + 6 Days	26N	39%	7%	5%	49%
	28N	41%	4%	5%	49%
	30N	43%	3%	10%	44%
	32N	44%	2%	14%	40%

Table 4.4 The percentage of 4 types of fruit after the firmness segregation of 'Barton'

'Barton'					
Length of storages	Thresholds	A	B	C	D
4 Weeks + 3 Days	18N	1%	2%	1%	96%
	20N	4%	0%	1%	95%
	22N	4%	0%	9%	87%
4 Weeks + 6 Days	18N	8%	6%	6%	80%
	20N	9%	5%	8%	78%
	22N	11%	3%	9%	77%
6 Weeks + 3 Days	18N	0%	1%	3%	96%
	20N	0%	1%	7%	91%
	22N	1%	1%	15%	84%
6 Weeks + 6 Days	20N	11%	4%	3%	81%
	22N	13%	3%	4%	80%
	24N	15%	1%	9%	76%
8 Weeks + 3 Days	20N	6%	10%	1%	83%
	22N	9%	7%	7%	77%
	24N	9%	7%	12%	73%
8 Weeks + 6 Days	20N	19%	16%	0%	64%
	22N	23%	13%	1%	64%
	24N	28%	7%	1%	63%

For each variety, the rate of rotten fruit increased consistently along with cool storage. The rate of deterioration accelerates dramatically when fruits were kept under room temperature (Table 4.4).

If there were no firmness segregation, the rate of rotten fruit could be spectacularly high after storage, especially for 'Kakariki' (Table 4.4). Once the fruits are segregated by firmness at the harvest time, the rate of rotten fruit after storage could be significantly reduced when comparing to that of non-segregation scenario (Table 4.4 & Table 4.5). When there was no segregation, samples from group A would be totally rotten and wasted after the storage as they are relatively more mature than the others. However, these fruit from group A could have been desirable and sold earlier to make a profit if they were segregated at harvest time.

Table 4.5 The bad fruit rate with or without the firmness segregation for 'Kakariki' after storage

Length of storage	Bad fruit rate after	Bad fruit rate without
4 Weeks + 3 Days	3.3%	23.7%
4 Weeks + 6 Days	20.0%	45.2%
6 Weeks + 3 Days	19.7%	40.0%
6 Weeks + 6 Days	5.6%	45.9%

Table 4.6 The bad fruit rate with or without the firmness segregation for 'Barton' after storage

Length of storages	Bad fruit rate after	Bad fruit rate without
4 Weeks + 3 Days	0.0%	3.7%
4 Weeks + 6 Days	3.9%	14.1%
6 Weeks + 3 Days	0.9%	1.5%
6 Weeks + 6 Days	1.0%	15.6%
8 Weeks + 3 Days	8.7%	15. 6%
8 Weeks + 6 Days	11.8%	35.6%

4.3 The correlation between fruit weight and maturity

As we can see from the figure 4.12, there is no correlation between initial fruit weight and fruit maturity at the harvest time for all the feijoa varieties. The distribution of maturity spread quite evenly along with the weight. Also there is still no correlation found in the post-harvest periods for all varieties.

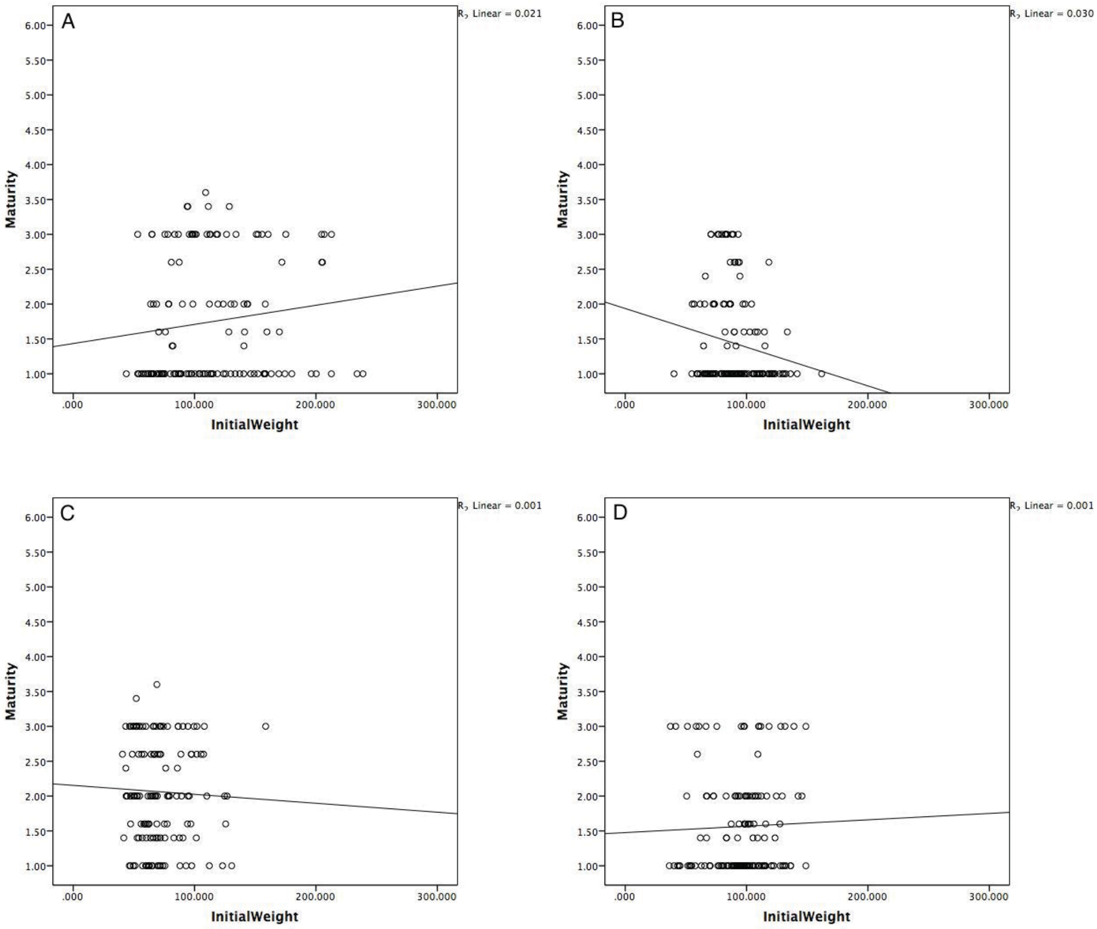


Figure 4.12 The scatterplot of initial fruit weight and fruit maturity at harvest time for four feijoa varieties: ‘Kakariki’ (A), ‘Barton’ (B), ‘Anatoki’ (C), and ‘Wiki-Tu’ (D)

5 DISCUSSION

5.1 INTRODUCTION

When delivered to the foreign consumers after the long transportation, the fruit must still remain at the desirable stage of maturity for consumption. Immature or over mature feijoa fruit will sabotage the local consumer's acceptance towards feijoa. Therefore, the feijoa fruit should be graded by their maturity stage before the transportation. Currently, the feijoa industry in New Zealand only grades the feijoa fruit by weight. However, fruit with similar fruit weight may vary greatly on fruit maturity. The main reason restraining the industry from grading by fruit maturity is that there is still no effective, reliable, and economic technique available for assessing the internal maturity for feijoa. This chapter will mainly examine the possibility of applying optical properties and skin firmness to assess the internal maturity of feijoa non-destructively in this industry. Some findings and comments during the experiment are also going to be discussed.

5.2 ASSESSING THE FRUIT MATURITY BY FIRMNESS

The correlation (R^2) between the internal maturity and compression firmness at harvest for 'Kakariki' was 0.6 to 0.5. The correlation for 'Barton' and 'Wiki-Tu' is weaker than that of 'Kakariki' (R^2 from 0.6 to 0.2). Similar experiment was done on kiwifruit and the correlation (R^2= 0.73) is high (Schotsmans & Mawson, 2005). The lower accuracy of applying compression firmness on feijoa might be because of the complex internal structure of feijoa. For each variety, some fruit has four locules, while some has three or five. The thickness of pericarp and skin also varies among individual fruit. All these variables could be the factors affecting the accuracy of the measurement.

However, it is still early to deny the potential of this technique for measuring the fruit maturity, even though the correlation was low or moderate. Previous study has suggested that the measurement of compression firmness is more reliable than that of the Sinclair and acoustic measurement for feijoa cultivars ‘Unique’ and ‘Opal star’ (Al-Harthy, 2010). Further studies are required to let us have a better understanding of the reasons behind the variability and low accuracy of applying compression firmness on feijoa.

The simulated segregation based on firmness for ‘Kakariki’ and ‘Barton’ (section 4.3.2) indicated that the firmness segregation at harvest for feijoa could be very useful and important. However, this segregation does not work well on ‘Anatoki’. The reason could be that the samples of ‘Anatoki’ were softer and more mature than the other feijoa samples. Further experiments should be conducted to find out if firmness segregation works on firmer and more immature fruits of ‘Anatoki’.

Currently, the most frequently utilized commercial on-line segregation systems are based on impact force, vibration (acoustic, ultrasonic, and mechanical), and near infra-red [NIR] (Garcia-Ramos, Valero, Homer, Ortiz-Canavate, & Ruiz-Altisent, 2005). Although the application of impact force or vibration properties seemed to be less reliable than that of compression force for feijoa, these commercial on-line segregation systems have already been made available and operating efficiently. Therefore, the feijoa industry has to weigh the advantages and disadvantages of each system and make the decision. The equipment (TA-XT-Plus, Stable Micro System, USA) used for measuring the compression force in this experiment is expensive and sophisticated. The commercial on-line segregation system based on compression force may have to compromise the high accuracy to make the system more economic. Also the on-line segregation based on the compression force much less efficient than that of impact force or acoustic, as the process of compression is much longer.

The commercial on-line firmness segregation system such as Sinclair iQ® system and portable devices such as Kiwifirm and Handy hit have already been applied in the kiwifruit industry. These techniques already existed and can be utilized on feijoa by changing the settings and parameters. However, one critical issue that must be considered is that the feijoa is very fragile and perishable. The external surface of feijoa fruit can be easily bruised and damaged. Feijoa fruit with external defects has a very limited storage potential. Therefore, further study should be conducted to assess the possibility of applying current commercial on-line system for feijoa.

5.3 ASSESSING THE FRUIT MATURITY BY SKIN COLOUR

Although the skin colour changes from dark green to light green while the fruit become more mature during the storage period, there is no significant correlation between the inner maturity and the skin colour among four feijoa varieties throughout the harvest and post-harvest periods. A fruit segregation based on fruit skin colour was also applied, but the results suggested that the segregation based on fruit skin colour couldn't separate the potential good fruit from bad fruit.

There is very little previous study over skin colour of feijoa to refer to. I believe the main reason why there is no strong correlation between skin colour and maturity is probably that the change of the skin colour is too subtle.

Crisosto, Crisosto, and Ritenour (2002) had successfully applied skin colour to segregate fruits with higher soluble solids concentration (SSC). The samples of 'Brooks' cherries with full light red (Hue = 26.15, L = 41.35, C = 42.30), 50% bright red (Hue = 21.96, L = 36.24, C = 37.69), full bright red (Hue = 16.90, L = 32.54, C = 30.79), and full dark red (Hue = 11.85, L = 29.11, C = 23.77) had significant different SSC (%) with 15.3, 16.8, 18.7 and 20.4 respectively. The change of hue between the lightest red group and the darkest red group was 14.3. The skin colour of samples of 'Brooks' cherries can also segregate firm fruit and fruit with less flavour (SSC/TA). However, the change of feijoa samples from different colour groups is relatively small (Table 5.1). Although, the skin colour change between different colour groups was statistically significant ($P < 0.05$) among different skin colour groups, the largest hue change was no more than 10 on 'Barton'. The hue change of samples of 'Anatoki' was only around 3. Therefore, the reason why skin colour cannot be used to estimate the fruit quality could be because the skin colour change among fruit with different maturity stages was too subtle.

Table 5.1 The average skin colour (Hue) of samples from different skin colour group. Significant differences ($P \leq 0.05$) for means within a column are indicated by different letters.

	'Kakariki'	'Barton'	'Anatoki'	'Wiki-Tu'
Light Green	109.8^{a}	112.5^{a}	111.5^{a}	110.8^{a}
Middle Green	112.8^{b}	117.1^{b}	113.7^{b}	114.2^{b}
Dark Green	117.1^{c}	122.1^{c}	114.4^{b}	118.5^{c}

The uneven surface of feijoa can affect the measurement of skin colour. The error of manual operation of spectrophotometer and the error from the machine itself could also contribute to low reliability of the measurement based on skin colour.

We also intended to identify a quality index that works on feijoa. However, none of them have succeeded so far. The reason might be because of the interaction of many compounds within the cells of feijoa fruit, which affect the absorbance wavelength of some constituents significantly (Norris, 1983) and caused many overlapping absorbance. The complex physical internal structure of feijoa fruit renders it an optically dense object, which is hard to penetrate and the light travelled thought can be refracted. As a result, the amount of light received from the reflection is not accurate. In addition to these, the internal and external defects such as mechanical damage can also have influence on the optical properties of a horticultural product (Abbott et al., 1997).

Therefore, skin colour is not good enough to be an indicator for estimating the inner maturity of feijoa. However, the segregation based on skin colour can still be helpful as the ANOVA tests indicate that there was a statistically significant difference ($P<0.05$) on maturity condition between the light green group (more mature) and the dark green group (less mature).

5.4 POLYETHYLENE FILM PACKAGE MAY NOT BE IDEAL FOR FEIJOA

Polyethylene films have been commonly utilized in the horticultural industry to reduce the fruit weight loss, minimize abrasion, and delay fruit ripening (Wills, McGlasson, Graham, & Joyce, 1998; Elkashif, Elamin, & Ali, 2005). The weight loss of fruit packed within carton boxes lined with perforated or sealed can be reduced by 4.5% and 9.1% respectively, compared to the control fruits (Elkashif et al., 2005; Elamine, 2006).

Feijoa is a highly perishable fruit. Grievous transportation loss and quality losses were witnessed in the market. The retail price drops if fruit quality is poor. To prevent the bruising and weight loss during the post-harvest periods, individual feijoa fruit is arranged separately in plastic trays within a one-layer carton box lined with loosely folded polyethylene films (Figure 5.1). However, some feijoa orchards complained that the polyethylene films packaging could sabotage the fruit quality.

Figure 5.1 Current common commercial packaging for New Zealand feijoa fruit

Currently, there is still no specific study on the effects of polyethylene film packaging on feijoa. The impacts of polyethylene film cover on feijoa fruit quality was also not an objective in this experiment, but serious fruit deterioration was observed during the experiment that may be contributed by the polyethylene films packaging.

Due to the heavy workload of this experiment, fruit samples were frequently shifted between cool storage room and the lab during the first week for different quality measurements. Water condensation appeared on the surface of many samples. When put back into the cool storage room, all the condensations on the fruit surface were gently wiped out, and the carton boxes were open for a few days until the water condensation was eliminated. Then the fruit trays were covered with polyethylene film films and the carton boxes were closed. After the cool storage, condensation was observed again on the inner edge of some trays. Some fruits suffered from serious decay and moulding (Figure 5.2). Similar phenomenon was also reported by Amin, Hossain, Miah, Hassan and Hoque (2014), in which water condensation appeared on guava that covered with 2% perforation polyethylene (0.05 mm) film for all treatments. The water condensation could be generated by fruit metabolism, and it accumulates due to the insufficient ventilation within the carton that covered with polyethylene films.

Figure 5.2 Samples of 'Kakariki' after 4 weeks' cool storage (left) and 8 weeks' cool storage (right)

The shelf life of guava packed in corrugated fibreboard carton with polyethylene having 2% perforation was found be poorer than that of fruit wrapped with newspaper or without any covering (Amin et al., 2014).

In terms of the industrial packaging practices for feijoa, it is very difficult to prevent fruit from bruising during the harvest and wash. After cleaning, it is also challenging to dry the fruit surface completely. During the transportation and retail, the water condensation could also be inevitable. Although the polyethylene film could reduce the water loss and fruit respiration, it also promotes the deterioration of defective fruits because it increases spreading of ethylene and germs from the rotted feijoa fruit to the healthy fruits within the sealed space. In this case, the positive effects of polyethylene film could be outweighed by the negative impacts of polyethylene film. This was also agreed by the finding of Kawada & Albrigo (1979) on grapefruit. They reported that if grapefruit in a film-lined (highly permeable, non-fogging PVC) carton decay, substances such as ethylene and mucus from the diseased fruit would accumulate. This accumulation could trigger a further decay and might affect compromise the fruits nearby.

5.5 THE HUGE VARIATION BETWEEN DIFFERENT CULTIVARS AND INDIVIDUAL FRUIT AT HARVEST TIME

A great variation in fruit quality was found in the four cultivars tested, both within cultivars and between cultivars.

For samples from the same cultivar and harvested at the same time, the variation on fruit quality was large (section 3.3.7). Fruit samples from four different varieties with the same maturity stage have varying quality features (section 3.3.4). The results of samples of ‘Anatoki’ suggested that this cultivar is significantly different from the other three cultivars, with lower Brix and TA value.

A main reason behind this variation is the pollination process. Since the majority of feijoa cultivars are self-sterile, and the successful pollination is crucial for good fruit yield. Pollination in feijoa mainly depends on bees and birds, but neither of them is dependable. Current orchards have different cultivars every 2 or 3 rows to increase chance of pollination (Thorp & Bieleski, 2002). Cross pollination of ‘Gemini’, ‘Triumph’ and ‘Mammoth’ resulted in significant increase in fruit set and fruit weight than self pollination (Patterson, 1989). It is also found that percentage of fruit set, number of seed per fruit and fruit weight were greatly influenced by pollen source for 'Apollo' (Patterson, 1989). The fact that some feijoa cultivars have a limited period of stigmatic receptivity limit the length of effective pollination period, contributing to large variation within a harvest batch.

Therefore, more research on cross pollination and pollen compatibility in feijoa is needed to reduce fruit variation at harvest. Developing a commercially effective artificial pollination technique may also be a good option.

The inherent feature of feijoa cultivar may also be responsible for the cultivar variation. Some cultivars have less consistent yield with higher variation in fruits sizes, quality and maturity levels at harvest. Cultivar selection and breeding programs may focus on the target of stable and good yield, and may include the feature of longer storage life to withstand sea freight.

5.6 VERY IMMATURE FRUIT AT HARVEST MAY NOT RIPE PROPERLY DURING THE POST-HARVEST PERIODS

Although the fruit quality is the best when harvested just prior to falling from tree by the touch picking (Fleming, 1986), the potential post-harvest life is only 4 weeks under cool storages at 4°C with 90% relative humidity and another 5-7 days' shelf life at 20°C (Klein & Thorp, 1987).

Feijoa fruit should be harvested when it almost reaches the full maturity to ensure an excellent flavour, texture and special aromas. If feijoa fruit were harvested at immature stage, the fruit appear to be less favourable and aromatic (Al-Harthy, 2010). However, this project is aiming to explore the potential of exporting the New Zealand feijoa to the international markets. The exported fruit must be able to remain in good condition after at least 6 weeks' cold storage to reach the major markets in Asian-Pacific region such as China, Japan, South Korea, west coast of USA, and India.

It is reported that feijoa ('Unique') harvested two weeks earlier than the commercial harvesting (touch picking) were visually acceptable after 6 weeks' cool storage

(Rupavatharam et al., 2015). The firmness and internal maturity tend to be still desirable for consuming. However, the lower SSC and high TA may affect the tasting experience for consumers (Rupavatharam et al., 2015). Although the fruit quality could be affected, less mature fruit tend to have a longer storage potential, which can increase the possibility of exporting feijoa. Therefore, one week before the commercial harvesting, wide ranges of immature fruit from ‘Kakariki’, ‘Barton’, and ‘Wiki-Tu’ were pulled from the trees to test the idea of early harvesting on other cultivars. The harvesting of ‘Anatoki’ was executed at normal commercial harvest timing as a control group.

As we can see that the very immature fruit from ‘Kakariki’, ‘Barton’, and ‘Wiki-Tu’ occupy a great proportion of the whole fruit samples at harvest time at 54.07%, 67.41%, and 57.78% (Table 5.2). Meanwhile, ‘Anatoki’ only has 28.15% of very immature fruit. For ‘Kakariki’, ‘Barton’, and ‘Anatoki’ there were a significant drop in the percentage of very immature fruit after 4 weeks storage. Then the proportion of very immature fruit seems to be quite stable during the rest storage and shelf life. This may indicate that if a fruit cannot ripe within 4 weeks after the harvest, it will stay immature until it decays. Since the rate of very immature fruit from ‘Anatoki’ dropped dramatically (around 74%), which was much higher than the other three cultivars, it may suggest that very immature fruit with higher mature stage would be more likely to ripe successfully after the harvest. And if there is a threshold of maturity for less immature fruit to ripe, the threshold point may be just a little earlier than horticultural mature point, but quite close to it. For ‘Barton’, the proportion of very immature fruit decreases consistently during the whole storage and shelf life periods. This is probably because this cultivar was harvested too early with a large number of very immature fruits, whose maturity levels did not hit the threshold point, thus unable to ripen properly during storage.

Table 5.2 The percentage of very immature fruit for each feijoa variety during different lengths of cool storage and ambient temperature storage

Cool storage week and ambient temperature storage days	'Kakariki'	'Barton'	'Anatoki'	'Wiki-Tu'
0 week + 0 day	54.07%	67.41%	28.15%	57.78%
4 week + 3 days	30.37%	60.00%	7.41%	39.26%
4 week + 6 days	28.89%	59.26%	5.93%	24.44%
6 week + 3 days	31.11%	48.15%	5.19%	34.07%
6 week + 6 days	31.85%	41.48%	5.93%	34.81%
8 week + 3 days	34.07%	37.04%	7.41%	57.78%
8 week + 6 days	35.56%	33.33%	13.33%	39.26%

5.7 THE POTENTIAL VARIETY FOR EXPORTING

Cool storage maintained the fruit quality greatly for samples of 'Barton', 'Anatoki', and 'Wiki-Tu'. All the fruit samples had a great visual appearance when taken out from the cool storage room. A very small amount of extra fruit samples of 'Anatoki' and 'Kakariki' was cut open just after the cool storage, and the internal condition of samples of 'Anatoki' was perfectly good. The internal condition of samples 'Anatoki' deteriorated dramatically during the storage under room temperature after the cool storage. Considering the fact that samples of 'Anatoki' had the highest rate of mature fruit at the harvest time, a relatively high percentage of over mature fruit after the storage periods was expected. However, after 6 weeks' cool storage and the subsequent storage under room temperature, more than 40% samples of 'Anatoki' was still visually eatable. Although the samples of 'Wiki-Tu' stored for 8 weeks' cool storage were destroyed due to the dysfunction of the cool temperature room, the samples of ‘Wiki-Tu’ stored for 6 weeks’ storage suggested that the ‘Wiki-Tu’ might have an excellent performance on cool storage and the subsequent ambient temperature storage. However, samples of ‘Kakariki’ stared to rot only after 4 week’s storage. This could be because of some inappropriate handing at the harvest time, relatively larger fruits, which might increase the risk of fruit brushing and extrusion within the fruit tray, or because of cultivar characteristics.

Consumer would expect the fruit to be more than just ‘looking good’. The flavour of the fruit after the storage is another vital factor. The value of Brix and TA, and the ratio of Brix/TA indicated that the samples of ‘Wiki-Tu’ and ‘Barton’ should have a better taste. The samples of ‘Anatoki’ might have less flavour.

Since the samples of ‘Wiki-Tu’ had a best storage performance after 6 weeks’ cool storage, and the flavour compounds in samples of ‘Wiki-Tu’ were abundant, ‘Wiki-Tu’ could be a promising feijoa variety for exporting. The samples of ‘Anatoki’ had a reasonable cool storage performance, especially when considered the high percentage of mature fruit at harvest time. However, the flavour of the fruit might not be satisfying. The samples of ‘Barton’ had the highest rate of very immature fruit at harvest. It is difficult to conclude that the poor storage performance is due to the variety characteristics or too early harvest.

5.8 COMMENTS AND SUGGESTIONS

The feijoa industry in New Zealand is facing a persistent problem that only a small proportion of good quality fruit remained after long cool storage. This is mainly caused by the large variation on the internal maturity between individual fruit. The variation might be the consequence of open pollination. Currently, feijoa fruit are segregated only by shape, size, and weight. However, segregation replying on external feature of the fruit cannot segregate the fruit with different maturity condition and may only lead to unacceptable fruit quality in the market due to the varying maturity.

In this study, the result suggested that non-destructive firmness measurement could produce a rough estimation of the internal maturity of feijoa. The segregation based on the firmness could deliver a good elimination of the potential bad fruit after certain period of cool storage for some feijoa varieties. Therefore, the feijoa industry might be able to improve the fruit quality and reduce the fruit lost after the storage by applying similar fruit segregations based on the fruit skin firmness prior to the storage.

One conclusion of this experiment is that the skin colour of feijoa cannot be used to predict the internal maturity of the fruit. However, in the study of Rupavatharam (2015), there is a correlation between skin colour and internal maturity for ‘Unique’.

The samples of four different feijoa varieties used in this experiment suggested that there is a large difference in the fruit quality attributes among different varieties. ‘Anatoki’ could be a variety with lower firmness. ‘Wiki-Tu’ may have a very promising storage performance.

For the further study on feijoa, more efforts should be put towards the following:

- Exploring the factors that limiting the accuracy of applying firmness to assess the maturity of feijoa.
- Assessing the possibility of applying current on-line segregation system based on acoustic or impact force to segregate feijoa fruit with different maturity at harvest time.
- Explore the potential of some other non-destructive quality assessment techniques. The promising technique could be Near-infrared spectroscopy.
- Improve the pollination practices to make the fruit maturity more unified.
- More studies on the effects of applying 1-MCP and controlled atmosphere to find out the best storage practices for feijoa.
- Consumer sensory testing of different feijoa varieties with varying maturity levels should be conducted in different overseas markets.

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