

AN ABSTRACT OF THE THESIS OF

Connie Landis Fisk for the degree of Master of Science in Food Science and Horticulture presented on February 24, 2006.

Title: Investigation of Postharvest Quality and Storability of Hardy Kiwifruit (*Actinidia arguta* 'Ananasnaya')

Abstract approved:

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The objectives of this project were to determine the effects of harvest maturity, packaging, and storage conditions on subsequent fruit quality of *Actinidia arguta* 'Ananasnaya' and to investigate the use of edible coatings to improve fruit quality and storage life. The influences of harvest maturity (6.0, 8.7, 9.1, and 15.1% average soluble solids content (SSC)) and storage conditions (22±1 °C and 45% RH, or 2 °C and 88% RH for three weeks followed by a ripening period at 22±1 °C and 45% RH) on the physicochemical, sensory, and nutritive qualities of 'Ananasnaya' hardy kiwifruit were investigated. The effects of refrigeration depended largely on maturity of the fruit at harvest. Chroma values of refrigerated fruit ranged from 16.4-19.1 and were similar to vine-ripened fruit (15.1% SSC). Hue angles ranged from 75.4-97.5; the only significant (p<0.05) difference found was for refrigerated fruit harvested at 9.1% SSC, which had lower hue angles than all other treatments. Refrigeration significantly reduced titratable acidity and increased SSC of ripened fruit, regardless

of harvest maturity, and reduced firmness of fruit harvested at 6.0 and 8.7% SSC. However, storage conditions had no effect on firmness of fruit harvested at 9.1% SSC. Free-choice profiling revealed that panelists perceived significant differences between refrigerated and room-stored samples in aroma and flavor descriptors as well as differences between harvest maturity treatments. Refrigerated fruit harvested at 6.0 and 8.7% SSC measured highest in total phenolics with over 2 mg gallic acid equivalents/g fresh weight. Antioxidant activity ranged from 1.6-2.3 ascorbic acid equivalents/g fresh weight with no significant effect of treatment. The postharvest physiology of fruit was monitored for three consecutive seasons, from 2003 to 2005. Fruit were packaged in low- or high-vent plastic containers and stored under room or refrigerated conditions. Calcium caseinate, chitosan, PrimaFresh™, and Semperfresh™ edible coatings were investigated for their potential to enhance the quality and extend the storage life of the fruit. Packaged fruit were exposed to an ethylene-rich environment in the third season to determine the effect of the coatings on ethylene-induced ripening. Semperfresh™-coated and uncoated fruit were evaluated by a sensory consumer panel using a hedonic scale in the third season. Low-vent packaging significantly ( $p < 0.05$ ) reduced weight loss. Refrigerated storage delayed ripening and extended storage life by four weeks. Coatings provided an attractive sheen to the fruit surface and did not impair ethylene-induced ripening. The consumer test indicated that both coated and uncoated fruit were well liked by consumers. These results demonstrated that quality of ripened hardy kiwifruit can be optimized through identification of ideal harvest date for this *Actinidia* species and by controlling storage

conditions. The results also provide important information regarding the ripening physiology of hardy kiwifruit and indicate that edible coatings may be an alternative to costly low-vent packaging for reducing moisture loss and extending storage life of fresh fruit.

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Investigation of Postharvest Quality and Storability of  
Hardy Kiwifruit (*Actinidia arguta* 'Ananasnaya')

by  
Connie Landis Fisk

A THESIS

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Connie Landis Fisk, Author

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## CONTRIBUTION OF AUTHORS

Drs. Yanyun Zhao and Bernadine Strik assisted with the experimental design, data analysis, and writing of each chapter. Dr. Mina McDaniel was involved with the design, analysis and writing of the sensory study in Chapter 3. Cindy Lederer assisted with the design, execution, and analysis of the consumer sensory study in Chapter 4 and helped with the data analysis of the sensory study in Chapter 3. Alissa Silver performed all of the 2003 season fruit preparation and physicochemical analyses reported in Chapter 4 and Dr. Su-il Park assisted with coating material preparation in Chapter 4.

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# **Investigation of Postharvest Quality and Storability of Hardy Kiwifruit (*Actinidia arguta* ‘Ananasnaya’)**

## **CHAPTER 1**

### **Introduction**

Hardy kiwifruit (*Actinidia arguta* [Sieb. et Zucc.] Planch. ex Miq.) have a smooth, edible skin and are smaller in size than fuzzy kiwifruit (*A. deliciosa*). They are marketed with berries rather than their larger kiwi relatives and are sometimes called grape kiwi because they are roughly the size of table grapes. The fruit is highly aromatic with a sweet, intense flavor that has been compared to ripe strawberry, banana, pineapple, pear, rhubarb, blackcurrant, grassy, melon, and tropical flavors (Williams et al., 2003; Matich et al., 2003). They are high in vitamin C and antioxidants, which don't appear to decrease during storage (Ferguson and MacRae, 1991). Hardy kiwifruit are grown commercially in the United States, Canada, Chile, New Zealand, and parts of Europe (Ferguson, 1999). Oregon, USA hosts over 80 acres of the cultivar Ananasnaya which develops a characteristic purple-red blush in full sun, especially when vine ripened (Strik, 2005).

The determination of maturity is an important quality criterion for hardy kiwifruit, especially since the crop does not ripen all at once and yet must be collected

through a once-over harvest. Prediction of hardy kiwifruit maturity cannot be based on skin color. Instead, growers monitor fruit maturity through color change of the seeds from white to black, by measuring fruit sugar content (°Brix) using a refractometer, and by determining the percentage of fruit prematurely softening and falling to the ground. Only fruit harvested at the right time fulfill the requirements for appearance, skin color, firmness of fruit flesh, and taste after storage that are required for successful marketing.

Hardy kiwifruit are not picked vine ripe as they would be too soft to package and ship. Instead they are picked when physiologically mature and firm, packaged in plastic clamshell containers, and stored under refrigerated conditions, with ripening triggered with ethylene gas prior to shipping. This is standard practice in the fuzzy kiwifruit 'Hayward' where the ideal harvest and storage conditions have been well researched (McDonald, 1990; Cheah and Irving, 1997). However, there is little published information, worldwide, on harvest and storage criteria for optimum quality in hardy kiwifruit. Also, in contrast to fuzzy kiwifruit, hardy kiwifruit are susceptible to dehydration during storage and shipping and can only be stored for 7 to 10 weeks (Strik, 2005).

Variable fruit quality, dehydration, and short shelf-life have been identified as the major barriers to fresh marketing in this crop. Developing knowledge on the impact of °Brix at harvest on the storage life and fruit quality of hardy kiwifruit would have a tremendous impact on this industry. Likewise, identifying ideal packaging and



storage conditions would help supply a consistently high quality product to the fresh market.

The objectives of this project were to determine the effects of harvest maturity and storage conditions on the physicochemical, sensory, and nutritive qualities of ‘Ananasnaya’ hardy kiwifruit and determine the effects of packaging and application of edible coatings on the quality and storage life of hardy kiwifruit by monitoring physicochemical parameters and by evaluating the sensory quality of Semperfresh™-coated hardy kiwifruit using a sensory consumer panel.

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## CHAPTER 2

### Literature Review

#### Introduction

Kiwifruit, or the “Monkey peach,” as it was called in classical Chinese text (Anonymous, 2000), grow wild from Siberia to Indonesia in the temperate forests and mountains of Asia and were originally brought to this country as an ornamental (Ferguson and Bollard, 1990). The first commercial orchards in New Zealand date back to early in the twentieth century where it was known as the Chinese gooseberry (Bartley and Schwede, 1989; Alvisi, 1990; Williams et al., 2003), although widespread cultivation and marketing began as recently as the 1970s (Earp, 1990). Fuzzy kiwifruit (*Actinidia deliciosa* cultivar ‘Hayward’) are now produced commercially worldwide, with the largest planted areas in Italy, New Zealand, Chile, and California, U.S.A.

Hardy kiwifruit (*Actinidia arguta* (Sieb. et Zucc.) Planch. ex Miq.) are just beginning to be grown commercially and are produced in Canada, Chile, France, Germany, New Zealand, and the United States (Ferguson, 1999). Oregon, U.S.A. currently has the largest crop in the world with more than 80 acres of the cultivar

‘Ananasnaya’ (Strik, 2005). ‘Ananasnaya’ came to North America from the Russian breeding program of Ivan Michurin during the Stalin regime and ‘Issai’, a less hardy, self-fertile cultivar came from Japan in 1986 (Kabaluk et al., 1997).

Most of the research on the harvest, handling, and storage of kiwifruit has been done on *Actinidia deliciosa* ‘Hayward’, the fuzzy kiwifruit. Many characteristics of hardy kiwifruit differ from those of fuzzy kiwifruit. For this work, it is important to consider the research techniques and findings that are important to the fuzzy kiwifruit industry as well as those regarding other berries and small fruits in order that hardy kiwifruit can be accurately examined and its quality and shelf life optimized.

### **Botanical classification and plant morphology**

Kiwifruit, classified in the genus *Actinidia*, belong to the family *Actinidiaceae* (Cheah and Irving, 1997). The most common kiwifruit grown commercially is *Actinidia deliciosa* cultivar ‘Hayward’. This is the familiar fuzzy brown kiwifruit found in grocery stores worldwide. *Actinidia chinensis*, cultivar Hort16A, trademarked as Zespri Gold, is a relatively new commercial cultivar known for its yellow flesh and sweet taste (Ferguson, 1999; Anonymous, 2000). These cultivars are not widely grown in the Pacific Northwest because the plants often suffer cold injury and the fruit do not ripen on the vine within our growing season, before fall frosts (Strik, 2005). There are other *Actinidia* species however that grow very well in our climate and they are known as hardy kiwifruit because they can withstand temperatures below -10 °F. However, even hardy kiwifruit require protection from

frost injury in the form of overhead irrigation or other frost protection strategy when temperatures are expected to drop below 0 °C after bud break (Strik, 2005).

The fruit of *A. arguta* are much smaller than ‘Hayward’ and have a smooth edible skin. The main cultivar grown in the Pacific Northwest is ‘Ananasnaya’, whose skin develops a characteristic red blush with exposure to sunlight. Its Russian name means “pineapple-like.” Other cultivars include ‘Issai’, which remains green and is more oblong than ‘Ananasnaya’, and can be found in local farmers’ markets, and ‘Ken’s Red’, a red-fleshed variety that has not been successfully marketed yet. These fruit are marketed as “baby kiwi” in Oregon and as “grape kiwi” in British Columbia (Strik, 2005), since they are about the same size as table grapes and can be eaten in a similar fashion.

The fruit is an oval, nondehiscent berry with many (up to 4000 in ‘Hayward’ and 200 in ‘Ananasnaya’) very small seeds in a fleshy pericarp that is attached to the central core (Ferguson, 1999). The kiwi plant is dioecious, meaning that for most cultivars it is necessary to have both male and female plants for fruit production. It is a deciduous, perennial vine, with a vigorous growth habit; each new cane is capable of growing up to 20 feet in one year (Strik, 2005).

### **Production System**

Similar to grapes, commercially grown plants are trained to a permanent framework, either a T-bar, or more commonly in Oregon, a pergola (solid overhead canopy). Kiwifruit grown on a T-bar trellis system hang down like table grapes, while

pergola trained kiwifruit hang from overhead in a single-layer of vegetation. The benefits of a T-bar system are less expensive construction costs, less labor-intensive pruning, and better suitability to bee pollination (Strik, 2005). The benefits of a pergola system include reduced wind damage to the fruit and reduced weed growth underneath the canopy. However, if the canopy of a pergola becomes too dense, the disadvantage is that fruit quality may be reduced as a result of premature softening (Strik, 2005).

### **Pre- and post-harvest fruit quality**

Poor pollination and fruit set, wind damage, and *Botrytis cinerea* are common defects that affect the appearance of kiwifruit. Pollination can be encouraged by supplying adequate numbers of bees. Wind damage can be minimized by tying the canes to a pergola and by planting windbreaks. *B. cinerea* can be controlled through site selection (well-drained soil), by treatment with carboxymides (Vinclozolin and others) or Fenexamid, and by summer pruning (Brigati et al., 2003).

Rapid flesh softening and sensitivity to ethylene gas are the major causes of concern during kiwifruit handling and storage (McDonald and Harman, 1982), which increases the susceptibility of fruit to handling injuries and development of various fruit rots (Mitchell, 1990). In addition, physiological pitting is positively correlated to the degree of weight loss during controlled atmosphere (CA) storage, which may be reduced by a longer delay prior to, or by a slower rate of CO<sub>2</sub> establishment (Tonini et al., 1999; Lallu et al., 2003). The rate of growth and spread of organisms such as *B.*

*cinerea* is slowed at 0 °C, the recommended temperature for kiwifruit storage (Mitchell, 1990). Tonini et al. (1998 and 1999) found that controlled atmosphere (CA) storage favors the spread of *B. cinerea*, but concluded that by delaying the establishment of CA conditions, the negative impacts can be avoided without any adverse effects on fruit firmness. *B. cinerea* can also be minimized through maintenance of vineyard cleanliness, by avoiding injuries during handling, removing dead plant material from the fruit surface, avoiding contamination with the juice of soft fruit, and cooling the fruit rapidly (Mitchell, 1992).

### **Ripening and physiology**

Fruit are able to ripen on the vine, usually 150 to 160 days after flowering in ‘Hayward’ and 90 to 105 days after flowering in ‘Ananasnaya’. However, kiwifruit are typically harvested when they are still firm to facilitate harvesting and packaging. They are picked by hand when the fruit are physiologically mature with ripening triggered during storage.

Kiwifruit are climacteric and are responsive to concentrations of ethylene as low as 0.1  $\mu\text{L liter}^{-1}$ , even under low temperatures and controlled environments (McDonald and Harman, 1982; Beever and Hopkirk, 1990). When exposed to exogenous ethylene, kiwifruit undergo more rapid and uniform ripening, which is a useful preconditioning technique employed by processors prior to shipping (Crisosto et al., 1997). The effect of endogenous ethylene on fruit softening is

negligible, as the kiwifruit does not begin to produce ethylene until it has softened to below 10 Newtons (N) (Ritenour et al., 1999).

During ripening, the flesh of kiwifruit changes from hard to soft and from acid to sweet. Firmness decreases as fruit ripen and starch is converted to sugars (Matsumoto et al., 1983; MacRae et al., 1989b). MacRae et al. (1989a and 1989b) reported a gradient in soluble solids (SS) between the two ends of 'Hayward' kiwifruit, with the blossom end containing more soluble solids and less starch than the stem end; this differential appears to increase in response to low temperature and ethylene treatment (MacRae et al., 1989b). SS content increases with ripening, but may increase or decrease during storage as carbohydrates are utilized in fruit respiration (Mitchell et al., 1991; MacRae et al., 1992). SS may also increase due to the action of sucrose-phosphate synthase (Hubbard et al., 1991, MacRae et al., 1992), which is activated by the ripening process itself, by ethylene, and by cool storage (Langenkämper et al., 1998). Organic acids are metabolized by the fruit during ripening and storage, resulting in a decrease in total acidity and a rise in pH (Matsumoto et al., 1983).

### **Chemical composition**

Within the genus *Actinidia* a range of fruit colors occurs, including green, red, purple, yellow, and orange. To date, the majority of pigment research has focused on those of *A. deliciosa* 'Hayward', whose green color is due to chlorophyll (~1 mg/100 g fresh weight (McGhie and Ainge, 2002)), which is retained during maturation and

ripening, and contains other important pigments including  $\beta$ -carotene and xanthophylls (Cano, 1991). Results reported by McGhie and Ainge (2002) show that *A. chinensis* contains similar carotenoid composition and concentration to *A. deliciosa*, with the addition of esterified xanthophylls, and with only trace amounts of chlorophyll, while *A. macrosperma* and *A. polygama* contain mostly  $\beta$ -carotene, with no chlorophyll detected. The yellow color of *A. chinensis* is mostly due to a reduction in chlorophyll, rather than an increase in carotenoid concentration (McGhie and Ainge, 2002).

Kiwifruit are known for their high vitamin C content, which is at least twice as high as that found in oranges (Ferguson and Ferguson, 2003; Strik, 2005) and doesn't appear to decrease during ripening or storage (Ferguson and MacRae, 1991). Kabaluk et al. (1997) reported vitamin C contents of  $41 \pm 2.4$  and  $155 \pm 7.7$  mg/100 g, for 'Ananasnaya' and 'Issai', respectively, and Nishiyama et al. (2004) reported  $184.6 \pm 23.4$  and  $65.5 \pm 14.2$  mg/100 g fresh weight, for 'Issai' and 'Hayward' respectively.

Similar to rhubarb, starfruit and spinach, kiwifruit contain high amounts of oxalic acid (though less in *A. arguta* than in *A. deliciosa* [Watanabe and Takahashi, 1998]), mostly in the form of raphides which may cause mechanical irritation of the mucous membranes of the mouth (Perera et al., 1990; Perera and Hallett, 1991; Ferguson and Ferguson, 2003). In addition, oxalate is known to inhibit calcium absorption and to cause stone formation in people prone to kidney stones (Libert and



Franceschi, 1987). Concentration is highest during early development, but gradually decreases during growth and storage (Watanabe and Takahashi, 1998).

Kiwifruit are excellent sources of potassium and folate, and possibly vitamins E and K (Ferguson and Ferguson, 2003). Dietary fiber may be responsible for the laxative effect of kiwifruit, though the protease, actinidin, present in kiwifruit in large amounts, may also contribute to laxation (Rush et al., 2002). The actinidin concentration and specific activity in ‘Ananasnaya’ is much higher than that of ‘Hayward’ (Yamanaka et al., 2004).

Kiwifruit is a significant allergen in some individuals and researchers have discovered correlations with latex and buckwheat allergies; research is currently being conducted to explore this relationship further (Möller et al., 1997; Lucas et al., 2004). Actinidin may be responsible for the allergic responses caused by kiwifruit, but it is not known whether kiwifruit are the primary cause of the allergic reaction, or are secondary to exposure to other allergens (Ferguson and Ferguson, 2003).

### **Factors influencing berry composition and quality**

Many factors influence berry composition and quality such as trellising system, fruit location within the canopy, nutritional status of the vine, season (year), and location. The influence of trellising system on kiwifruit quality was explored by Smith et al. (1992) who found that fruit from pergola-trained vines had greater concentrations of soluble solids after 12 weeks storage than those from T-bar trained vines.

Research on 'Hayward' kiwifruit in New Zealand (Antognozzi et al., 1995), Greece (Lionakis et al., 1994), and Italy (Tombesi et al., 1993) has demonstrated that fruit grown underneath the canopy (with reduced light intensity) showed decreased values of flesh firmness, chlorophyll, and SSC, and were therefore not suitable for long-term storage. Davidson (1977) also reported that soluble solids contents were higher in exposed fruit than in shaded fruit and Grant and Ryugo (1984) found that fruit grown above the foliar canopy (exposed) were significantly larger than fruits grown below the canopy (shaded). In addition, Snelgar and Hopkirk (1988) demonstrated that the weight of 'Hayward' fruit was reduced by shading and that harvest date was delayed. They later went on to demonstrate that long-term shading of kiwifruit vines leads to large reductions in yield due to reductions in both the number of flowers and the ability of the vines to sustain fruit growth (Snelgar et al., 1991). On the other hand, Smith et al. (1997) suggest that fruit from denser parts of the canopy close to the cordon have superior quality while fruit from the extremities of the canopy, where leaf area index is lower, develop less desirable attributes. The effect on fruit quality of shading hardy kiwifruit vines to 45% full sun was observed by Tiyyon and Strik (2004) in the Pacific Northwest. They concluded that while shading for two months before harvest significantly reduced fruit dry weight, the effect of overhead shading, as might occur with dense canopies, did not have a large impact on hardy kiwifruit quality (color, firmness, SSC, and fresh weight).

The effect of nitrogen fertilization was monitored by Costa et al. (1997) and was shown to increase yields per vine, average fruit weight and size, and the

percentage of “fan and fasciated” fruits, while having no effect on soluble solids content or flesh firmness. However, Vizzotto et al. (1999) found that vines receiving N fertilization had lower levels of ascorbic acid at harvest and throughout storage than control vines. Quality parameters during storage may be greatly affected by N fertilization. Prasad and Spiers (1991), Johnson et al. (1997), and Vizzotto et al. (1999) found high correlations between N concentration and rate of fruit softening. Boron (Smith and Clark, 1989) and chloride (Prasad and Spiers, 1991) toxicities have also been shown to cause rapid softening of kiwifruit. Gorini et al. (1987) reported that fertilization decreased the levels of sourness and consumer acceptance in Italian-grown ‘Hayward’ kiwifruit. Low calcium concentration in kiwifruit is associated with premature fruit softening (Prasad and Spiers, 1991), physiological pitting (Thorp et al., 2003) and development of bruising and water soaked patches during storage (Davie, 1997).

Seasonal and location variations have been observed by various researchers (Okuse and Ryugo, 1981; MacRae et al., 1989a; Hall and McPherson, 1997; Ferrandino and Guidoni, 1999) and attributed to differences in mean temperature during fruit growth and maturation (Walton and DeJong, 1990; Snelgar et al., 1993; Seager et al., 1996; Hall and McPherson, 1997; Ferrandino and Guidoni, 1999).

### **Fruit quality attributes and their measurement**

*Color.* Color is not as important in ‘Hayward’ as in ‘Ananasnaya’, but some consumers do seem to prefer green-skinned ‘Hayward’ to brown-skinned ‘Hayward’.

Color is much more important in varieties of *A. arguta*. Processors believe that preference varies with market – Canadian and European markets seem to prefer fruit that are green overall (i.e. ‘Issai’) while Asian markets prefer ‘Ananasnaya’ with its red blush (Peacock, personal communication).

Color change in kiwifruit during ripening can be seen by the human eye but objective measurements require analytical testing. Samples can be compared with Munsell color chips (hues 7.5GY and 5GY for ‘Hayward’ flesh [Crisosto et al., 1984]) or their L\* (lightness-darkness), a\* (redness-greenness), and b\* (yellowness-blueness) values can be measured with a colorimeter or spectrophotometer. Using these three numbers chroma  $[(a^{*2} + b^{*2})^{1/2}]$  and hue angle  $[\arctan (b^*/a^*)]$  can be calculated to compare changes in fruit color with time.

*Firmness.* Firmness is an important quality attribute in kiwifruit. At harvest, kiwifruit firmness is high (above 60 Newtons (N)) and drops to about five to eight N at the eating-ripe stage (Beever and Hopkirk, 1990). Several factors (temperature, atmosphere composition, ethylene concentration, maturity at harvest) affect the rate of softening (McDonald, 1990). Sensory evaluation has demonstrated a significant relationship between flesh firmness and overall fruit acceptability; softer fruit are perceived by consumers as being riper than firmer fruit (Stec et al., 1989).

Kiwifruit firmness has traditionally been measured destructively with a penetrometer or texture analyzer that measures the compression force or force required to penetrate the skin and/or flesh using a cylindrical punch probe. Recent advances have made possible the non-destructive measurement of kiwifruit firmness, SSC, and

acidity (Hopkirk et al., 1996; Muramatsu et al., 1997 and 1999a and b; McGlone et al., 1997a, b, and c, 1998, 1999, 2000, and 2002; Costa et al., 1999 and 2003; Terasaki et al., 2001a and b). Results have shown that electromagnetic (NIRS (near infrared spectroscopy) and NMR (nuclear magnetic resonance)), electrochemical (e-nose (electronic nose)), and electromechanical (impact, sound, laser Doppler vibrometer), and non-contact laser air-puff) methods work well and make it possible to easily determine quality traits of a large number of fruits, to repeat assays on the same set of samples, and to monitor their development during ripening and storage.

*Titrateable acidity.* Kiwifruit are relatively high in acid, with the acid content reaching nearly two percent of fresh weight at maturity and declining after harvest (MacRae et al., 1989b). Marsh et al. (2004) reported that the decline in titrateable acidity is due to acid metabolism and that storage temperature can change the balance of the three major acids in the fruit, which are citric (40-50%), quinic (40-50%), and malic (10%) (Okuse and Ryugo, 1981; Marsh et al., 2004). Quinic acid was found by Marsh et al. (2003) to have a greater impact on sensory perception of acidity than the other common acids in kiwifruit, and malic acid was perceived as more sour tasting than citric acid at equal pH (Hartwig and McDaniel, 1995; Marsh et al., 2004). Quinic acid is reportedly high during early growth, but declines as growth continues (Mitchell, 1990), while malic acid concentration can increase after harvest (MacRae et al., 1989b). Ascorbic acid (vitamin C) increases during kiwifruit growth and may reach over 1 mg per gram fresh weight by harvest (Mitchell, 1990).

TA is measured by diluting a blended fruit sample with deionized water and titrating with NaOH to a pH endpoint of 8.1 to 8.2, where the amount of acid in the sample will equal the amount of base added during the titration; this number, the molarity of the NaOH, and the equivalent weight of the most prevalent acid in the sample are entered into an equation to determine the %TA. TA can also be determined by titrating to a colorimetric endpoint using phenolphthalein as an indicator (it turns bright pink at pH 8.1), but is not widely used in kiwifruit research since the green color of the fruit may make determination of the endpoint difficult.

*Soluble solids content (SSC).* Soluble solids content (°Brix) is an important attribute of kiwifruit as SSC is associated with eating quality of ripe fruit (Mitchell et al., 1991; Crisosto, 1992) and studies have specifically shown that consumers prefer fruit with a higher ripe SSC (Rossiter et al., 2000; Burdon et al., 2004). However, McMath et al. (1991) reported that SSC was only one factor contributing to the explanation of sweetness in kiwifruit and that sweetness and acidity can be predicted by a number of components including soluble solids, fruit firmness, and some volatile flavor compounds. Rossiter et al. (2000) reported that changes in Brix did not influence “flavor intensity”, suggesting that aroma volatiles are important contributors to kiwifruit flavor intensity. Paterson et al. (1991) also observed that a high sensory score for sweetness was correlated with soft fruit and high volatile ester levels.

Soluble solids are most often measured by either squeezing juice directly onto the prism of a handheld refractometer or by macerating a fruit sample in a blender and placing a small amount on the prism, which is then looked through and the °Brix read

off of a line scale (Harman and Watkins, 1986). The refractometer works because sugars change the direction of (refract) light. Glucose, fructose, and sucrose are the major sugars reported in kiwifruit (Matsumoto et al., 1983; Mitchell, 1990) although recent research (Bieleski et al., 1997; Klages et al., 1997) has identified *myo*-inositol as a major carbohydrate in kiwifruit as well, with the amounts found in *A. arguta* being notably higher than those found in *A. deliciosa*, which may contribute to the cold-hardiness of hardy kiwifruit (Klages et al., 1998).

In kiwifruit, density measured at harvest is positively correlated with dry matter (DM) and SSC of ripe fruit (Asami et al., 1988; Richardson et al., 1997). One non-destructive method for predicting SSC and DM of ripe fruit is a density test where the fruit are allowed to float or sink in salt solutions adjusted to key densities (Jordan et al., 2000). In this manner, fruit can be sorted by their predicted eating quality. In addition, since DM is correlated with ripe fruit SSC, it is the target of near infrared (NIR) grading equipment (Jordan et al., 1997). Schaare and Fraser (2000) reported the relative accuracy of reflectance, transmission, and interactance modes of NIR spectroscopy for estimating SSC, density and flesh hue of *A. chinensis* and found good calibrations in each case. Their results as well as those of Slaughter and Crisosto (1998) support the use of NIR spectroscopy for the rapid and non-destructive evaluation of internal fruit quality.

*Kiwifruit volatiles.* Experiments on *A. deliciosa* and *A. chinensis* have identified three volatile compounds, ethyl butanoate (fruity, strawberry), E-2-hexenal (fruity, strawberry, cherry), and hexanal (green, herbal, grass) as being likely

determinants of kiwifruit flavor (Young and Paterson, 1985; Bartley and Schwede, 1989; McMath et al., 1991; Young et al., 1995; Jordán et al., 2002). Gilbert et al., (1996) reported that ethyl butanoate increased consumer acceptability for descriptors ‘overall liking’, ‘aroma liking’, and ‘flavor liking’ and increased the perceived intensities of ‘kiwifruit aroma’ and ‘kiwifruit flavor’. E-2-hexenal increased ‘kiwifruit aroma’ intensity while decreasing consumer acceptability and hexanal increased the perceived intensity of ‘kiwifruit aroma’ (Gilbert et al., 1996). Young et al., (1992) further argue that E-2-hexenal is an important contributor to the off-flavor in kiwifruit juice. It is important to note that kiwifruit only begin to produce fruity ester volatiles (such as ethyl butanoate) once the fruit are at or near eating ripeness or are very soft and that kiwifruit stored at 0 °C have been shown to contain decreased amounts of aroma volatiles compared to ripe fruit (Young and Paterson, 1985). Another important finding is that after as little as 1 month frozen storage a severe reduction in volatile compounds (esters, aldehydes, and alcohols) is observed (Talens et al., 2003); the sensory impact of these differences is yet to be determined.

The fruit of *A. arguta* have some different aroma notes from those of *A. deliciosa* and *A. chinensis*. *A. arguta* fruit have been described as having banana, floral, fruit candy, grassy, green and melon odors and blackcurrant, fruit candy, grassy, green, melon, stalky, woody, and tropical flavors (Matich et al., 2003). Volatile sampling of *A. arguta* identified some monoterpenes, but were dominated by esters such as ethyl butanoate, hexanoate, 2-methylbutanoate, and 2-methylpropanoate, as well as aldehydes such as hexanal and E-2-hexenal (Matich et al., 2003).



*Sensory analysis.* Kiwifruit aroma and flavor impact consumer acceptance and purchase behavior. Products that do not meet consumer sensory expectations will not survive in the market.

Descriptive sensory testing supplies information about the quality attributes of a sample. Generally, panelists rate the intensities of appearance, texture, aroma, flavor, and basic taste descriptors using line or number scales. Descriptive tests can be performed using trained panels or untrained consumer panels. Training is often time-consuming and costly as panelists must come to agreement on which descriptive words to use and what constitutes high or low intensity scores. One method of descriptive testing minimizes training time by allowing panelists to use their own words to describe the samples, with the researchers then performing a lengthier statistical analysis to understand the results. This method, called Free-Choice Profiling (FCP), has been successfully used to measure the sensory attributes of complex food systems including cider (Piggott and Watson, 1992), port wine (Williams and Langron, 1984), vanilla (Heymann, 1994), coffee (Narain et al., 2003), and chocolate (McEwan et al., 1989). The idea behind the method is that everyone describes product attributes differently based on their cultural background and life experiences, with each person's perception being equally correct and important; these results are often very useful as the terminology is understood by various departments including marketing as well as laboratory personnel. The statistical analysis that makes this method useful is called Generalized Procrustes Analysis (GPA). GPA creates an attribute "map" for each panelist and then combines the maps of all

panelists, twisting and contorting them to make one overall map that represents how the samples were perceived by the whole panel (Oreskovich et al., 1991; Stucky and McDaniel, 1997).

*Nutritive qualities.* Before analysis of nutritive qualities the researcher must extract the compounds of interest from the fruit sample. Procedures have been well developed for the extraction of anthocyanins (Rodriguez-Saona and Wrolstad, 2001), antioxidants, and phenolic compounds in berries, and seem well suited for analysis of these compounds in kiwifruit. Automated systems have also been developed such as the Accelerated Solvent Extraction (ASE<sup>®</sup>, Dionex Corp., Sunnyvale, CA, U.S.A.), which extracts under pressure using a series of solvents for much greater efficiency/recovery. Extracts are then used to measure vitamin C content, antioxidant activity, and total phenolic content as well as specific compound identification and quantification using High Performance Liquid Chromatography (HPLC).

Vitamin C in kiwifruit can be measured by titration against 2,6-dichloro-indophenol (AOAC, 1984) or, more commonly today, using HPLC (Rassam and Laing, 2005).

Antioxidant activity is often measured using the fluorometric-based Oxygen Radical Absorbing Capacity (ORAC) or the spectrophotometric Ferric Reducing Ability of Plasma (FRAP). The ORAC assay depends on the free radical damage to a fluorescent probe, such as fluorescein, to result in a downward change of fluorescent intensity, while the FRAP assay uses an oxidation/reduction reaction to measure the ability of a sample to reduce iron(III) to iron(II). The ORAC determination is

regarded as a fairly direct means of measuring the ability to trap free radicals while the FRAP assay is easier to perform. Imeh and Khokhar (2002) reported FRAP values for kiwifruit (*Actinidia chinensis*) of  $0.93\pm 0.08$ ,  $1.15\pm 0.11$ , and  $1.57\pm 0.10$  for 4 min, 10 min, and 30 min, respectively. Collins et al. (2001) used the comet assay (a gel electrophoresis technique that detects strand breaks and oxidized bases in DNA) to demonstrate significant antioxidant activity of kiwifruit *ex vivo* and *in vitro*, and showed that this activity was due to more than simply the vitamin C content of the fruit. Some of the pigments found in kiwifruit, such as flavonoids, anthocyanins and carotenoids, also contribute to antioxidant activity (Ferguson and Ferguson, 2003). Another method developed by Brand-Williams et al. (1995) measures antioxidant activity as the ability of a sample to reduce 2,2-diphenyl-1-picrylhydrazyl (DPPH) (also known as 1,1-diphenyl-2-picrylhydrazyl), a free radical. This is observed spectrophotometrically at 517 nm as a color change from purple to yellow with increasing antioxidant activity. Using this test on strawberry, seedless grape, and kiwifruit (*A. chinensis*), Leong and Shui (2002) reported 434, 287, and 125 ascorbic acid equivalents per 100 grams fresh weight, respectively.

Total phenolic content can also be determined spectrophotometrically using the Folin-Ciocalteu method as described by Waterhouse (2002). This method involves reduction of the reagent by phenolic compounds, creating a blue complex whose intensity (measured at 760 nm) increases with the concentration of total phenolics in solution. Total phenol results obtained by Imeh and Khokhar (2002) using this test found that kiwifruit (*A. chinensis*) contains  $302.8\pm 11.0$  mg gallic acid equivalents

(GAE) per 100 gram fresh weight and 274.4±9.5 mg catechin equivalents per 100 grams fresh weight. Fuke and Matsuoka (1984) reported a total polyphenol content of 180-220 mg/100 g *A. deliciosa* one month after pollination, with a decrease during growth but no decrease during ripening and a similar pattern in the contents of chlorogenic acid, flavanol-tannin and leucoanthocyan. Comparison of phenolic values between studies is difficult due to differences in sample preparation and testing method, spectrophotometric standards employed and in units reported.

HPLC is useful for identification and quantification of specific compounds of interest. One study on 'Hayward' juice showed the important phenolic classes of kiwifruit to be hydroxybenzoic acids, hydroxycinnamic acids, flavonols, and flavan-3-ols (Dawes and Keene, 1999). Total phenolic content is not expected to change much with harvest maturity or storage, but has been observed to increase in fruit with greater exposure to sunlight (Brigati et al., 2003).

### **Harvesting and storage**

Most of the research on the harvest, handling, and storage of kiwifruit has been done on 'Hayward'. However, the differences between *A. deliciosa* and *A. arguta* cultivars suggest that there may exist unique production concerns that should be addressed by further research focused on *A. arguta*.

Research has shown that the most reliable and practical method of assessing fuzzy kiwifruit maturity is the measurement of the soluble solids content (SSC) of its juice. This is estimated using a refractometer and readings may be expressed as SSC

or °Brix (Harman and Hopkirk, 1984; Mitchell, 1990), although a combination of SSC and flesh firmness may provide a more accurate determination of harvest maturity (Crisosto et al., 1984; Mitchell, 1992). According to Hassall et al. (1998), this method is not a reliable indicator of harvest maturity in *A. arguta* due to the continued import of sugar/dry matter. There is interest in developing a grower-friendly visual maturity test as exists for apples. In the apple industry, apples are routinely cut in half and stained with an iodine solution to judge fruit maturity (Saltveit and Hale, 1982). The stained fruit is compared to a chart of starch-iodine staining patterns for that particular apple variety. This test is based on the conversion of starch to sugar during ripening. Nondestructive methods also exist for estimating soluble solids content in kiwifruit. Near infrared is the most promising of these techniques which estimates fruit dry matter (DM), which is correlated with ripe fruit soluble solids (Jordan et al., 1997).

Fruit size within a vine is not related to fruit maturity and most cultivars show little change in fruit appearance and color as they mature (Mitchell, 1990). So, while the fruit on a particular vine will be at differing stages of ripeness, it is unreasonable to attempt multiple harvests from a vine. Instead, growers determine when to harvest the entire field by monitoring the color change of the seeds from white to black, the increase in SSC using a refractometer, and the percentage of fruit softening or falling from the vine. The standards for 'Hayward' harvest in California require a Brix level of at least 6.5, and in Chile and New Zealand a minimum of 6.2 (Cheah and Irving, 1997; Crisosto and Crisosto, 2001), though research has shown that fruit harvested with higher sugar levels stores better (Mitchell et al., 1991; Kempler et al., 1992;

Chase, 1995). Current recommendations suggest 'Ananasnaya' be harvested between 8 and 14 °Brix. When ripe, 'Hayward' achieves about 17 °Brix and 'Ananasnaya' reaches 18 to 23 °Brix. Vine-ripened fruit become very soft, and the stem pulls from the fruit, leaving an open wound; these fruit cannot be stored.

The fruit are normally harvested by hand with care taken to avoid injury. Fruit should be harvested when the skins are completely dry; when harvested wet the fruit are at an increased risk of storage rots, especially those caused by *Botrytis cinerea* (Cheah and Irving, 1997). In addition, wet surfaces may promote physiological pitting during storage (Clark et al., 2003).

Lallu (1997) reported that precooling significantly increased the occurrence of kiwifruit breakdown symptoms, compared to passive cooling, and showed that the incidence and severity of symptoms was significantly reduced by delays at ambient conditions prior to cool storage. In contrast, Mitchell (1990 and 1992) concluded that field heat must be removed quickly from the fruit within 6 hours of harvest because the fruit will lose water quickly. After three to four percent water loss, fruit may appear shriveled, especially at the stem end (Strik, 2005). Water loss (shriveling) has been identified as the most significant cause of commercial loss in hardy kiwifruit (Hassall et al., 1998).

Chase (1992) suggests that quality may be improved if hardy kiwifruit are harvested and stored as a cluster, like grapes. The idea is that fruit will continue to draw moisture and nutrients several days after they are harvested. Research is needed to test this hypothesis.

Although fuzzy kiwifruit are sold loose, unwrapped, hardy kiwifruit are best sold in clamshell packages that maintain a higher humidity (to prevent shriveling) and prevent fruit damage (Kabaluk et al., 1997; Strik, 2005). Bhushan et al. (2002) argue that optimum storage conditions for 'Hayward' are achieved by storage in polyethylene packages having a thickness of 200 gauge with 0.5% ventilation. With this treatment, fruit had better overall quality at the end of eight weeks storage owing to the development of an optimum modified atmosphere in these packages.

Typically, kiwifruit are stored under refrigeration (0 °C, 90-95% RH), coupled with an ethylene removal system, and may be treated with ethylene blockers to delay ripening. 'Hayward' can be stored in this manner for four to six months for good quality (McDonald, 1990; Cheah and Irving, 1997), while the shelf-life of hardy kiwifruit is only one to two months. One ethylene blocker is 1-methylcyclopropene (MCP), which binds to ethylene receptors on the plant tissues and inhibits ethylene action (Sisler and Serek, 1997). When applied to kiwifruit at harvest, 1-MCP reduced respiration rate, delayed the onset of ethylene production, and reduced softening rate of fruit at 20 °C and 0 °C (Hewett et al., 1999). Fruit stored at 0 °C ripen more uniformly during and after removal from cool storage than fruit stored at 20 °C (Lallu et al., 1989) and experience enhanced flavor intensity, including a decrease in off-flavors, greenness and acidity (with a short (4-6 weeks) period of storage) (MacRae et al., 1990; Marsh et al., 2004).

Other postharvest technologies to maximize kiwifruit quality and storage life include modified atmosphere (MA) and controlled atmosphere (CA) storage. MA is

known to retard the rate of kiwifruit softening and thus extend storage life as a result of both increased levels of CO<sub>2</sub> and decreased levels of O<sub>2</sub> (Manolopoulou et al., 1997; Kitsiou and Sfakiotakis, 2003). Hertog et al., (2004) showed that the rate of gas exchange and the rate of quality loss in ‘Hayward’ kiwifruit are both affected by MA. While MA can refer to any synthetic environment, arising intentionally or unintentionally, whose composition cannot be closely controlled, CA tends to imply precise control of O<sub>2</sub> and CO<sub>2</sub> concentrations in the atmosphere. CA storage of kiwifruit has been examined by McDonald and Harman (1982), and Harman and McDonald (1983) who found that the optimum controlled atmospheres for ‘Hayward’ were 5-8% CO<sub>2</sub>, and 1-2% O<sub>2</sub> at 0 °C, which could increase storage life by 3-4 months. Harman and McDonald (1989) further demonstrated that CA treatments containing > 8% CO<sub>2</sub> and < 3% O<sub>2</sub> retarded the loss of green color in stored kiwifruit, although prolonged storage (greater than 16 weeks) of the fruit under these conditions can result in development of “hard core”, flesh breakdown, loss of normal flavor, and the development of off-flavors. Thomai and Sfakiotakis (1997a and b) also observed the accumulation of ethanol and acetaldehyde in fruits stored under low oxygen conditions. Lallu et al. (2005) also observed a greater retention of green color in CA stored fruit after 27 weeks, compared to air-stored fruit. Burdon et al. (2005) reported that CO<sub>2</sub> scrubbing systems used to maintain exact CO<sub>2</sub> concentrations during CA storage significantly affect ripe kiwifruit volatile profiles, particularly ester production, although it is unknown whether or not these differences are significant to consumers.



### **Edible coatings**

Another postharvest technology of particular interest for the hardy kiwifruit industry is the use of edible coatings. Edible coatings are thin layers of material that can be eaten by the consumer as part of the whole food product. Desirable coatings modify the fruit internal atmosphere composition and depress its respiration rate, while having little effect on transpiration rate (Banks et al., 1993). Some edible coatings that may be of use on kiwifruit include pullulan, Semperfresh™, calcium caseinate, and chitosan-, lipid-, and protein-based solutions. Each has positive and negative attributes. Polysaccharide- and protein-based films have suitable gas barrier properties but show poor water vapor properties, while lipid-based coatings help control moisture loss but tend to be brittle and prone to oxidation (Diab et al., 2001). Romanazzi et al. (2002) applied chitosan treatments to table grapes and reported a reduced incidence, severity, and nesting of the gray mold, *Botrytis cinerea*. Negative attributes include the bitterness and astringency of acid-soluble chitosan-based coatings and the lack of definitive information regarding shellfish allergenicity and Kosher certification. The bitterness and astringency associated with chitosan may be alleviated by reducing chitosan concentration or adjusting pH value of the chitosan solution to 4.6-6.3 (Rodriguez et al., 2003; Han et al., 2005).

Recent research on 'Hayward' has concluded that pullulan films increase levels of internal ethylene, leading to acceleration of ripening (Diab et al., 2001) and that chitosan coatings decrease respiration rates and inhibit fungal development (Du et al., 1997). Xu et al. (2001 and 2003) suggest an optimum edible coating composed of

soybean protein isolate, stearic acid, and pullulan, extending the shelf-life by 3 weeks compared to the control. Research on Semperfresh™ found that the coating reduced apple ripening rate as observed by several parameters including texture and color while having no significant effect on pH, acidity, SSC or sensory scores (Santerre et al., 1989). Semperfresh™ has also been shown to reduce the weight loss and increase firmness, ascorbic acid content, titratable acidity and skin color of cherries during storage time, and increase the shelf-life of cherries by 26% at 0 °C (Yaman and Bayoindirli, 2002).

### **Other uses for kiwifruit**

Often there are surplus kiwifruit as well as kiwifruit that do not meet fresh market requirements for quality. Many attempts have been made to develop kiwifruit products, however kiwifruit provide some challenges. One of the problems associated with heat processing of kiwifruit, as would be required to pasteurize a puree or juice, for example, is the color change from bright green to dull brown/olive green due to the formation of pheophytins and pyropheophytins during heat treatment (Robertson and Swinburne, 1981; Robertson, 1985; Cano and Marín, 1992). Kiwifruit products also undergo nonenzymic browning due to Maillard browning reactions and ascorbic acid browning reactions (Wong and Stanton, 1989; Wong et al., 1992). In addition, color changes are more deleterious as storage time and temperature increase, though their effects on minimally processed kiwifruit slices are lessened by the use of vacuum impregnation with a combination of sucrose, potassium sorbate, ascorbic and citric

acids, and zinc chloride (Leunda et al., 2000). Vial et al. (1991) found similar results with osmotic dehydration of kiwifruit slices where addition of ascorbic acid, as well as calcium and/or copper chlorides enriched the quality of the final product, particularly the color. This problem has been overcome in the beverage industry by addition of natural or artificial colorants or by mixing with other fruit ingredients such as strawberry or cherry juice (Crivelli et al., 1990), where a bright green color is no longer expected by consumers. However, the flavor of kiwifruit is also impacted by heat processing, resulting in a flavor similar to that of the cooked green European gooseberry (*Ribes grossularia* L.) (Luh, 1989).

Freezing is another processing option, although research has shown that kiwifruit lose aroma volatiles during freezing and frozen storage (Talens et al., 2003). Another option is dehydrofreezing, a process that combines partial dehydration and freezing, where a very acceptable product was achieved by Crivelli et al. (1990) that they recommend for use in fruit salad preparations. Air dehydration is not an acceptable processing strategy for kiwifruit as it results in color and textural defects (Crivelli et al., 1990). Techniques have been developed to produce canned, pulped, dried, and candied kiwifruit. Kiwifruit juice, nectar and wine are also produced commercially (Lodge and Robertson, 1990).

One exciting avenue for kiwifruit products is extraction of nutraceutical compounds and actinidin, the kiwifruit protease (Ferguson and Ferguson, 2003) which could find uses similar to that of papain from papaya or bromelain from pineapple

(Préstamo, 1995). In addition, the seeds of kiwifruit may be utilized by extracting their oil for use in health and beauty products.

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## CHAPTER 3

### **Physicochemical, Sensory, and Nutritive Qualities of Hardy Kiwifruit (*Actinidia arguta* ‘Ananasnaya’) as Affected by Harvest Maturity and Storage**

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## ABSTRACT

The influences of harvest maturity (6.0, 8.7, 9.1, and 15.1% average soluble solids content (SSC)) and storage conditions (22±1 °C and 45% RH, or 2 °C and 88% RH for three weeks followed by a ripening period at 22±1 °C and 45% RH) on the physicochemical, sensory, and nutritive qualities of ‘Ananasnaya’ hardy kiwifruit were investigated. The effects of refrigeration depend largely on maturity of the fruit at harvest. Chroma values of refrigerated fruit ranged from 16.4-19.1 and were similar to vine-ripened fruit (15.1% SSC). Hue angles ranged from 75.4-97.5; the only significant difference was refrigerated fruit harvested at 9.1% SSC, which had lower hue angles than all other treatments. Refrigeration significantly reduced titratable acidity and increased SSC of ripened fruit, regardless of harvest maturity, and reduced firmness of fruit harvested at 6.0 and 8.7% SSC. However, storage conditions had no effect on firmness of fruit harvested at 9.1% SSC. Free-choice profiling revealed that panelists perceived significant differences between refrigerated and room-stored samples in aroma and flavor descriptors as well as differences between harvest maturity treatments. Refrigerated fruit harvested at 6.0 and 8.7% SSC measured highest in total phenolics with over 2 mg gallic acid equivalents/g fresh weight. Antioxidant activity ranged from 1.6-2.3 ascorbic acid equivalents/g fresh weight with no significant difference between treatments. This study demonstrated that quality of ripened hardy kiwifruit can be optimized through identification of ideal harvest date for this *Actinidia* cultivar and by controlling storage conditions.

## INTRODUCTION

Hardy kiwifruit (*Actinidia arguta*) have smooth, edible skins and are smaller in size than fuzzy kiwifruit (*A. deliciosa*). The fruit are highly aromatic with a sweet, intense flavor that has been compared to ripe strawberry, banana, pineapple, over-ripe pear, rhubarb, blackcurrant, grassy, melon, and tropical flavors (Williams et al., 2003; Matich et al., 2003). The fruit contain 25-155 mg of vitamin C per 100 g of fruit (Kabaluk et al., 1997) and are relatively high in nutraceuticals. They are grown commercially in the United States, Canada, Chile, New Zealand, and parts of Europe. In Oregon, USA there are over 80 acres of *A. arguta* 'Ananasnaya', a cultivar that develops a characteristic purple-red blush in full sun, especially when vine ripened (Strik, 2005).

Hardy kiwifruit are not picked vine ripe, as they would be too soft to package and ship. Instead they are picked when physiologically mature and firm, and allowed to ripen after refrigeration (Kabaluk et al., 1997). This is standard practice for the fuzzy kiwifruit *A. deliciosa* 'Hayward' where the ideal harvest and storage conditions have been well researched (pick at 6.5% soluble solids content (SSC), store at 0 °C for up to 6 months for good fruit quality). However, there is very little published information, worldwide, on harvest and storage criteria for optimum quality in hardy kiwifruit. When growers harvested hardy kiwifruit at 6.5% SSC, the ripened fruit were described as having inadequate aroma, flavor, and sugar levels. Also, in contrast to fuzzy kiwifruit, hardy kiwifruit are very susceptible to dehydration during storage and shipping and can only be stored for 7 to 10 weeks (Strik, 2005).

The optimal date to pick fruit (the determination of maturity) is an important quality criterion for hardy kiwifruit. Only fruit harvested at the right time fulfill the requirements for appearance, skin color, firmness of fruit flesh, and taste after storage that are required for successful marketing. Variable fruit quality, dehydration, and short shelf life have been identified as the major barriers to fresh marketing in this crop. Developing knowledge on the impact of SSC at harvest on the storage life and fruit quality of hardy kiwifruit would have a tremendous impact on this industry. Likewise, identifying ideal storage conditions would help supply a consistently high quality product to the fresh market.

The objective of this study was to determine the effects of harvest maturity (% SSC at harvest) and storage conditions on the quality of ripened hardy kiwifruit by monitoring physicochemical parameters and nutritive compounds and by using descriptive sensory analysis to develop a vocabulary of hardy kiwifruit descriptors and use them to rate the intensities of sample characteristics.

## **MATERIALS & METHODS**

### **Materials**

*Fruit.* ‘Ananasnaya’ hardy kiwifruit were harvested in 2004 at four different maturity stages (average SSC of 6.0, 8.7, 9.1, and 15.1% (vine ripe)) from a mature commercial vineyard in Sheridan, OR. Vines were trained to a pergola and maintained as per standard recommendations (Strik, 2005). These harvest dates were chosen arbitrarily to represent a range of harvest maturities

from just physiologically mature to vine ripe and fell on September 13, 24, 30 and October 16, 2004. The fruit were packaged in low-vent plastic clamshell containers, eight fruit per container. Half of the fruit from the 6.0, 8.7, and 9.1% SSC harvests were stored under room ( $22\pm 1$  °C, 45% RH) conditions, while the other half were stored under refrigerated (2 °C, 88% RH) conditions for three weeks and then stored under room conditions, until ripe. Time stored at room temperature ranged from 16 to 22 d for samples stored under room conditions and from 8 to 9 d after refrigerated samples were placed under room conditions. Ripeness was determined by visual (color change and decay rate) and tactile observations (flesh firmness). Vine ripe fruit were stored overnight under room conditions before evaluation.

*Chemical reagents.* Titration was carried out using 0.1 N sodium hydroxide obtained from Mallinckrodt Baker, Inc (Phillipsburg, NJ). The phenolic and antioxidant extraction procedure used acetone and chloroform from EM Science (Gibbstown, NJ). Total phenolics were determined using Folin & Ciocalteu's Phenol Reagent, 2.0 N and sodium carbonate from Sigma-Aldrich, Inc. (St. Louis, MO) with gallic acid from EM Science (Gibbstown, NJ) used to construct a standard curve. Antioxidant activity was measured using 1,1-diphenyl-2-picrylhydrazyl (DPPH), a free radical, from TCI America (Portland, OR), dissolved in methanol from EM Science (Gibbstown, NJ), with ascorbic acid from Mallinckrodt Baker, Inc (Phillipsburg, NJ) used to construct a standard curve.

### **Physicochemical analyses**

For each replication, surface color was measured at two points, in the approximate center of the flat surface, on each of 16 individual fruit using a Hunter Labscan spectrophotometer (Model MS/S-4500L, Hunter Associates Laboratory Inc., Reston, VA, U.S.A.).  $L^*$  (lightness),  $a^*$  (greenness (-) to redness (+)), and  $b^*$  (blueness (-) to yellowness (+)) values were recorded. Calculated hue angle ( $\arctan(b^*/a^*)$ ) and chroma ( $((a^{*2} + b^{*2})^{1/2})$ ) were used for comparing color changes between samples. The same 16 fruit were then used to measure the other physicochemical parameters. Firmness was determined by measuring compression using a Texture Analyzer (TA-XT2, Texture Technologies Corp., Scarsdale, NY, U.S.A.) with a 5 mm diameter punch probe. Each fruit was subjected to a compression speed of 1 mm/s after contact and penetration to 10 mm, through the approximate center of the flat surface of the fruit. The firmness was reported as peak force and expressed in Newtons (N). Titratable acidity was determined using 5 g of fruit puree mixed with 45 mL of distilled water, titrated with 0.1 N sodium hydroxide to an endpoint of pH 8.1, and expressed as percent anhydrous citric acid. The pH of the samples was measured by a pH meter (IQ240, IQ Scientific Instruments, Inc., San Diego, CA, U.S.A.). A refractometer (RA-250, KEM, Kyoto Electronics Manufacturing Co., Ltd., Japan) was used to measure soluble solids content (SSC). Three replications were completed for each parameter measured.

## **Sensory analysis**

*Recruiting of panelists.* Permission to carry out the sensory study was approved by the Institutional Review Board for the Protection of Human Subjects at Oregon State University (OSU). Panelists experienced in the assessment of small fruit were recruited by email from the Departments of Food Science & Technology and Horticulture at OSU and screened for allergic reactions to hardy kiwifruit. Before participating in the evaluation, panelists were asked to sign a consent form, which had a clearly defined risk statement. Only those who met all the criteria were eligible.

*Sample preparation.* Previous research using whole *A. deliciosa* cv. ‘Hayward’ kiwifruit demonstrated that the natural variation between whole fruits confounds the ability to establish clear relationships between sensory attributes and suggested that using a “standardized” kiwifruit pulp would be a better approach (Paterson and others 1991). In this study, ripened hardy kiwifruit were pureed in a Stephan food processor for 5 min and then stored frozen (-32 °C) in plastic freezer bags until analysis. Samples were thawed overnight under refrigeration (2 °C) and served to panelists as 2 oz samples in teardrop shaped wine glasses with plastic covers, coded with three-digit random numbers.

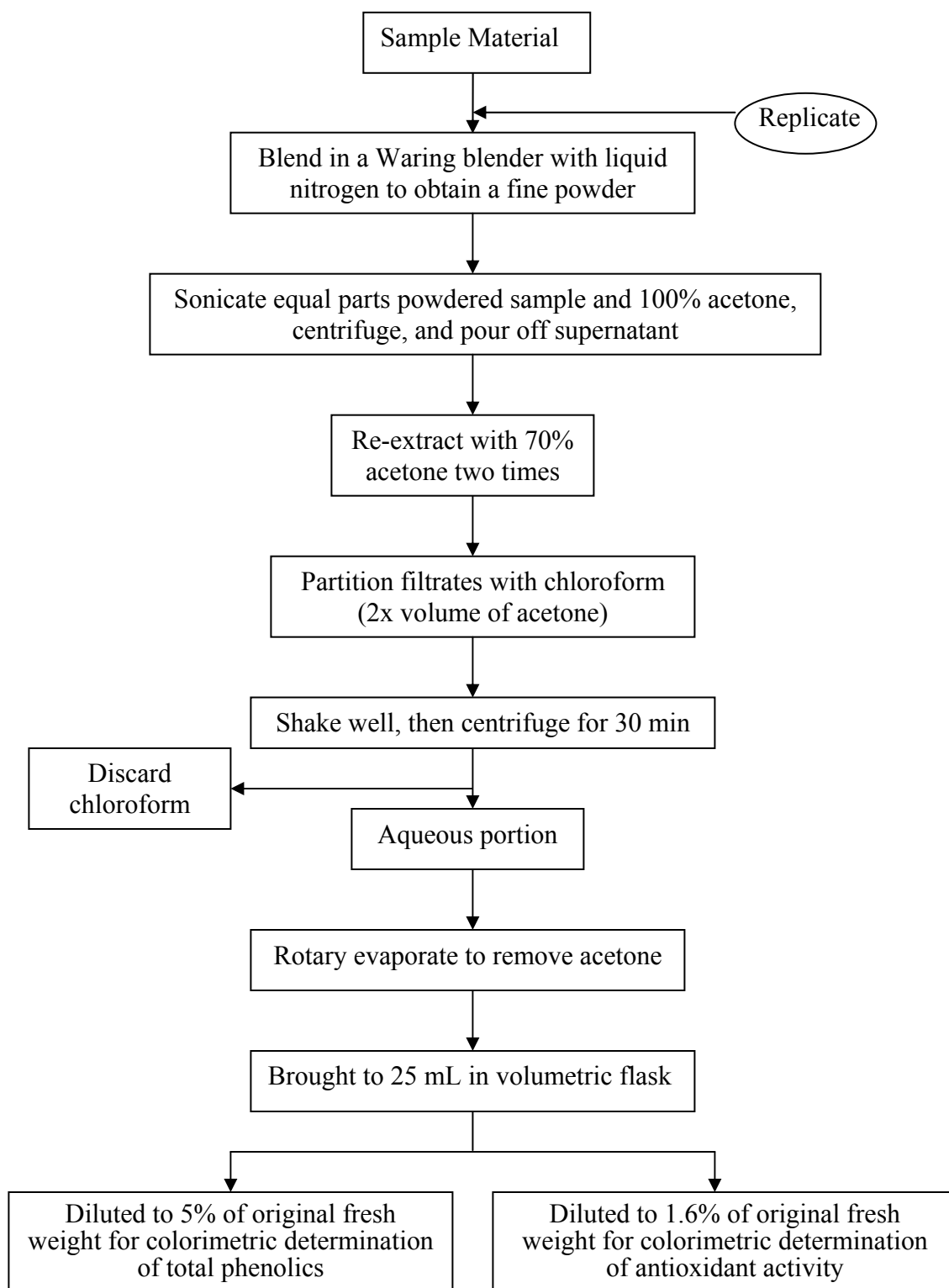
*Free-choice profiling panel.* Free-choice profiling method was chosen because it allows panelists to describe samples using their own terms. The result is a consensus map that reveals the relationships between samples based on the descriptors generated by the panelists (Stucky, 1996).



Nine panelists (8 females and 1 male, aged from 24 yr to 55 yr) met for 5 1-h sessions for familiarization with the samples and to develop consensus terms. Standards were provided for each consensus term chosen by the panel. Panelists were encouraged to use individual terms as well, so each person developed a customized ballot for subsequent testing. Panelists rated the intensity of each aroma and flavor descriptor using the 16-point intensity scale where 0 = none, 7 = moderate, and 15 = extreme intensity. Intensity standards were provided in covered wine glasses for reference including safflower oil (15 mL, Saffola Quality Foods, Los Angeles, CA, U.S.A., for an intensity of 3), Hi-C orange drink (15 mL, Coca Cola Co., Houston, TX, U.S.A., for an intensity of 7), Welch's purple grape juice (15 mL, Welch Foods Inc., Concord, MA, U.S.A., for an intensity of 11), and Big Red cinnamon gum (1 stick unwrapped, Wm. Wrigley Jr. Co., Peoria, IL, U.S.A., for an intensity of 15). Testing was performed in individual booths under red-colored incandescent lighting to disguise differences in sample color. Panelists received 5 to 6 samples on each of 4 testing days to complete 3 replications and cleansed their palates between samples by drinking spring water (Aqua Cool, Portland, OR, U.S.A.).

### **Nutritional analysis**

*Sample preparation and extraction.* Three replications of each treatment were sliced, individually quick frozen (IQF) on screens in a commercial -32 °C walk-in blast freezer, and stored frozen (-32 °C) in plastic freezer bags until analysis. Extraction was performed following the method modified from Rodriguez-Saona and



**Figure 1 - Flowchart of phenolic and antioxidant extraction (Modified from Rodriguez-Saona and Wrolstad, 2001).**

Wrolstad (2001) for berry anthocyanins. Briefly, samples were blended in a Waring blender with liquid nitrogen to obtain a fine powder before an acetone/chloroform extraction (Figure 1). Extracts were then diluted to fall within a standard curve of gallic acid or ascorbic acid for the phenolic and antioxidant measurements, respectively.

*Determination of total phenolics.* The amount of total phenolics in each extract was determined using the Folin-Ciocalteu method (Waterhouse, 2002) with some modifications. Extracts were diluted to 5% of original fresh weight using distilled water and were introduced as 0.5 mL aliquots into test tubes containing 7.5 mL distilled water and 0.5 mL Folin & Ciocalteu's reagent. Test tubes were capped, vortexed, and kept at room temperature for 10 min. Then 3 mL of 20% sodium carbonate was added and the samples were vortexed and heated in a 40 °C water bath for 20 min. The absorbance of the samples was measured at 765 nm using a spectrophotometer (UV-160U, Shimadzu, Japan) after cooling for three min in an ice bath. The total phenolic content was expressed as gallic acid equivalents (GAE) in mg/g fresh weight (FW) of material.

*Antioxidant activity.* The amount of antioxidant activity in extracts was determined using the DPPH method (modified from Brand-Williams et al., 1995). Extracts were diluted to 1.6% of original fresh weight with distilled water and were introduced as 0.75 mL aliquots into test tubes containing 1.5 mL 0.1 mg DPPH/mL methanol solution. The test tubes were capped and vortexed and the absorption at 517

nm was measured after 5 min. Antioxidant activity was expressed as ascorbic acid equivalents (AAE) in mg/g FW of material.

### **Statistical analysis**

All fruit were harvested randomly from four vines in one vineyard, with analyses performed on three separate samples for each treatment. Data were analyzed with SAS statistical software Release 8.2 (SAS Institute, Cary, NC, U.S.A.). Treatments were compared using orthogonal contrasts with vine ripe samples regarded as a control. Following analysis of variance (ANOVA), treatment means were compared using Least Significant Difference (LSD) or Tukey's "Honestly Significant Difference" (HSD). Sensory free-choice profiling data were analyzed by Generalized Procrustes Analysis (GPA) using Senstools Version 2.0 (OP&P Product Research, Utrecht, Netherlands).

## **RESULTS & DISCUSSION**

### **Physicochemical analysis**

Color measurements of ripened hardy kiwifruit harvested at four maturity levels and stored under room or refrigerated conditions are summarized in Table 1. On each fruit, color was measured on two opposite surfaces to account for the red blush that develops on the side of the fruit exposed to sunlight. So while the  $a^*$  and  $b^*$  values as well as the calculated hue angle may seem misleading (suggesting a yellow-

**Table 1 - Color measurement of ripened hardy kiwifruit harvested at four maturity levels and stored under room or refrigerated conditions\***

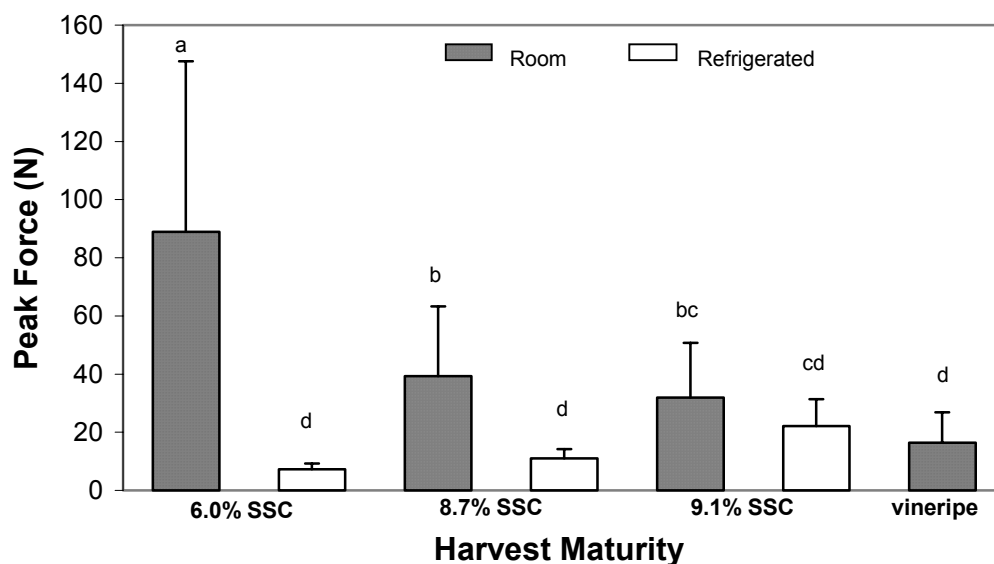
Measurements	6.0% SS		8.7% SS		9.1% SS		Vine Ripe
	Room	Refrig	Room	Refrig	Room	Refrig	
L*	45.17a (6.78)**	38.32d (5.13)	43.02ab (5.43)	41.30bc (4.73)	42.93ab (5.07)	37.13d (5.28)	39.28cd (5.26)
a*	-4.82c (6.00)	-1.18b (5.19)	-2.41b (6.25)	-1.67b (4.38)	-2.74bc (5.55)	2.31a (6.59)	-2.71bc (4.72)
b*	23.38a (6.84)	15.81c (4.95)	21.44a (5.49)	18.46b (4.48)	21.55a (5.78)	14.41c (5.47)	15.06c (6.09)
Chroma	24.71a (6.43)	16.77c (4.60)	22.57a (4.96)	19.09b (4.26)	22.51a (5.39)	16.41c (4.06)	16.01c (6.07)
Hue Angle	97.51a (19.81)	90.68a (21.25)	92.72a (19.78)	93.00a (15.62)	94.00a (18.01)	75.41b (28.62)	96.04a (20.51)

\* Color results are based on two measurements on each of 48 fruit (3 reps, 16 fruit each). The “Room” treatment refers to storage at 22±1 °C and 45% RH until ripe; “Refrigerated” treatment refers to storage at 2 °C and 88% RH for three weeks followed by storage under room conditions until ripe.

\*\* Numbers in parentheses refer to the standard deviation. Different letters within a row indicate significant differences at p<0.05 separated by Tukey’s HSD.

colored fruit while in reality most of the fruit have a red side and a green side), they are still important parameters to monitor. Harvest maturity and storage conditions both affected color of ripened fruit (i.e., the effect of refrigeration on ‘Ananasnaya’ color depends on maturity at harvest). Significant (p<0.05) differences were observed between refrigerated samples where fruit harvested at 8.7% SSC had higher L\*, b\*, and chroma values and fruit harvested at 9.1% SSC had significantly higher a\* values than samples harvest at other maturities. With respect to storage conditions, refrigerated samples generally had lower L\* and b\* values, but higher a\* values than those stored under room conditions, indicating an increase in red color, while fruit ripened under room conditions had significantly higher (p<0.05) chroma values (more vivid color, less whiteness or blackness) than refrigerated or vine ripened samples. The only significant difference in hue angle (p<0.05) was observed in fruit harvested at 9.1% SSC and refrigerated, where a significantly lower value was observed (a hue

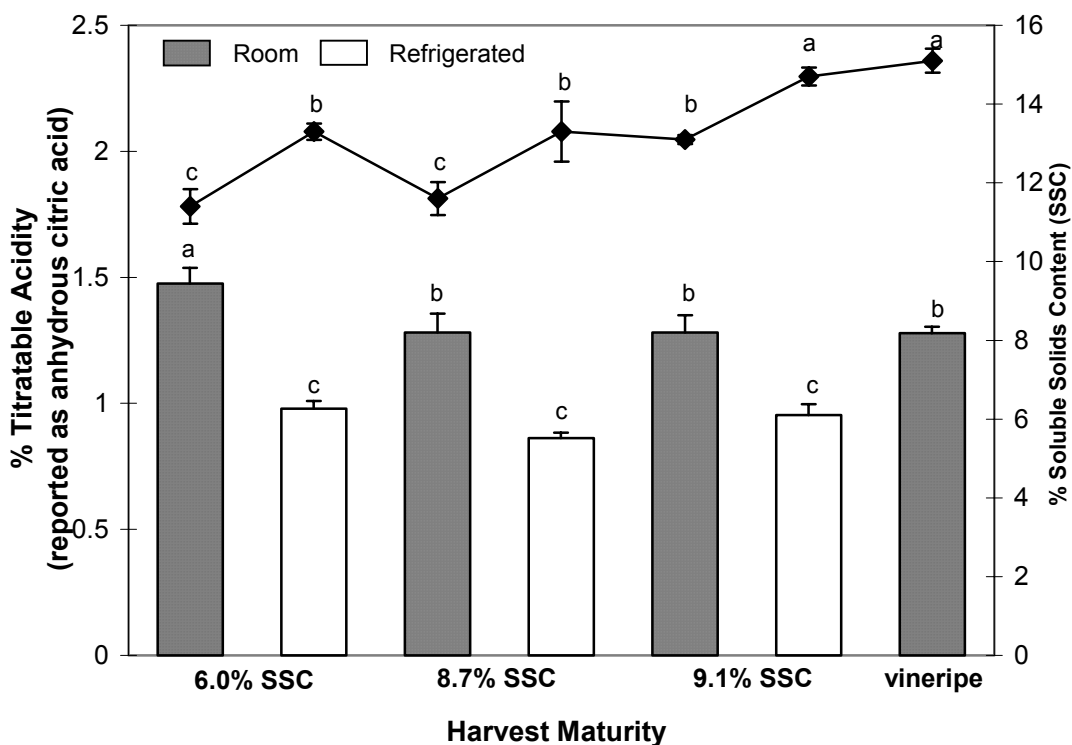
angle of 0 is red, 180 is green). This may be explained by the synthesis of anthocyanins with cold storage as reported by Holcroft and Kader (1999) for strawberry, and explains why the decrease in hue angle was not observed in vine ripened samples that would have received even more sunlight exposure and therefore greater capacity for developing red blush. Further work is needed to pinpoint the precise reason for color differences in hardy kiwifruit stored under refrigeration.



**Figure 2 - Peak force required to penetrate the skin of ripened hardy kiwifruit harvested at four different maturity levels and stored under room conditions ( $22\pm 1$  °C, 45% RH) or refrigerated (2 °C, 88% RH) for three weeks and then stored under room conditions until ripe. (Samples with different superscripts are significantly different ( $p < 0.05$ ) separated by Tukey's HSD).**

Figure 2 shows the peak force required to penetrate the skin of ripened hardy kiwifruit (firmness of the fruit). The effect of refrigeration on the firmness of ripened hardy kiwifruit depended on maturity at harvest, which corresponds to the results obtained from similar work on 'Hayward' kiwifruit (Abdala et al., 1996). Under refrigerated conditions, fruit harvested at 6.0 and 8.7% SSC significantly ( $p < 0.05$ )

decreased in firmness, while storage treatment had no effect on fruit harvested at 9.1% SSC. Antunes and Sfakiotakis (2002) showed that firmness of ‘Hayward’ kiwifruit did not decrease significantly during storage at 0 or 5 °C, but did decrease significantly upon rewarming at 20 °C. The large standard deviation seen in the 6.0% SSC fruit ripened at room temperature is due to the fact that fruit softened due to spoilage rather than ripening. Subsequent harvest dates and refrigeration produced a reduced standard deviation in peak force.



**Figure 3 - Titratable acidity and SSC at ripeness for hardy kiwifruit harvested at four different maturity levels and stored under room conditions (22±1 °C, 45% RH) or refrigerated (2 °C, 88% RH) for three weeks and then stored under room conditions until ripe. (The shaded bars represent TA; the line represents SSC; vertical bars indicate standard deviation. Samples with different superscripts are significantly different ( $p < 0.05$ ) separated by Tukey's HSD).**

Titrateable acidity (TA) and SSC at ripeness for hardy kiwifruit are shown in Figure 3. Under refrigerated conditions titrateable acidity decreased and SSC increased over all three early harvest maturities. In general, refrigeration is known to delay the ripening process (i.e., delay the decrease in TA and increase in SSC). Similar to our findings, Illeperuma and Jayasuriya (2002) reported a decrease in TA with refrigerated storage of mangoes, attributed to the initiation of ripening in the presence of ethylene that is autocatalytically stimulated by low temperatures in climacteric fruits such as mangoes and kiwifruit. The increase in SSC is expected since the fruit of *A. deliciosa* have been shown to contain sucrose phosphate synthase (SPS), a key enzyme in sucrose biosynthesis whose activity increases during ripening (MacRae et al., 1992) and in response to low temperature (Langenkämper et al., 1998). Previous research has also revealed that SSC increases further upon rewarming after exposure to 0 °C (Antunes and Sfakiotakis, 2002; Langenkämper et al., 1998). Meanwhile, refrigeration lengthened storage time by 7 to 14 days (data not shown). In this study, harvest maturity had no significant ( $p>0.05$ ) effect on final TA of ripened fruit when fruit were stored under refrigerated conditions, and only fruit harvested at 6.0% SSC had significantly ( $p<0.05$ ) higher TA from other samples stored under room conditions. In respect to the effect of harvest maturity on the SSC of ripened fruit, those harvested at 9.1% SSC and stored under refrigerated conditions reached the highest SSC at ripeness and were not significantly different ( $p>0.05$ ) from vine-ripened fruit. It is important to note that this was an atypical season, with vine ripe fruit achieving a SSC of only ~15%, when typically 'Anasnaya' reaches 18-23% SSC (Strik, 2005).



## Sensory analysis

Table 2 contains the sensory intensity ratings for consensus descriptors of hardy kiwifruit harvested at four different maturity levels and stored under room or refrigerated conditions. It is important to remember that these numbers represent

**Table 2 - Mean sensory intensity ratings for consensus descriptors of hardy kiwifruit harvested at four different maturity levels and stored under room or refrigerated conditions\***

Aroma	6.0% SSC		8.7% SSC		9.1% SSC		Vine Ripe
	Room	Refrig	Room	Refrig	Room	Refrig	
Overall Intensity	8.7 (2.1)abc	9.6 (2.3)ab	7.7 (2.2)c	9.9 (2.4)a	7.9 (2.2)bc	9.2 (2.5)abc	8.3 (2.5)abc
Overall Fruit**	6.8 (1.8)	6.6 (2.1)	6.2 (1.9)	7.3 (1.9)	6.4 (1.7)	6.6 (1.8)	6.3 (1.9)
Fuzzy Kiwi**	6.3 (1.9)	5.5 (2.0)	6.0 (2.0)	6.1 (1.9)	5.8 (1.7)	6.6 (1.9)	5.6 (2.1)
Strawberry**	3.6 (2.5)	2.9 (2.9)	3.4 (2.3)	3.4 (3.0)	3.7 (2.7)	3.5 (2.9)	3.6 (2.5)
Green Banana**	5.0 (1.8)	3.3 (2.4)	3.8 (1.9)	3.5 (2.8)	4.1 (2.0)	4.1 (2.2)	3.6 (2.2)
Overripe Fruit	1.1 (2.0)b	3.8 (3.3)a	1.3 (2.0)b	4.7 (3.7)a	1.3 (1.8)b	3.2 (3.2)ab	2.8 (2.3)ab
Overall Vegetal**	6.1 (1.7)	6.3 (2.6)	5.4 (1.6)	5.5 (2.7)	5.0 (2.2)	5.6 (1.9)	5.3 (1.6)
Green Tea**	3.1 (2.9)	2.9 (2.7)	2.4 (2.5)	2.6 (2.5)	2.6 (3.0)	2.8 (2.6)	2.5 (2.7)
Earthy**	1.6 (2.2)	2.1 (2.1)	1.9 (2.1)	1.8 (1.7)	1.5 (2.1)	1.3 (1.6)	1.6 (1.9)
<b>Flavor</b>							
Overall Intensity**	7.7 (2.2)	9.0 (2.4)	7.8 (2.0)	8.7 (2.5)	8.1 (2.5)	8.7 (2.5)	8.2 (2.5)
Overall Fruit**	6.1 (2.0)	6.4 (3.0)	6.7 (1.7)	7.0 (2.4)	7.1 (1.7)	7.6 (2.0)	7.6 (1.6)
Fuzzy Kiwi**	5.8 (1.6)	5.7 (2.3)	6.3 (1.5)	6.3 (2.2)	6.6 (1.8)	6.8 (2.1)	6.2 (1.9)
Overall Citrus**	2.9 (2.6)	2.1 (2.3)	2.8 (2.1)	2.1 (2.3)	2.9 (2.2)	1.7 (2.0)	2.8 (2.3)
Green Banana**	4.3 (2.0)	3.2 (2.1)	4.4 (1.9)	3.2 (1.9)	3.7 (2.1)	3.8 (2.0)	3.8 (2.2)
Ripe Banana	2.2 (2.1)bc	3.1 (2.6)bc	3.0 (2.4)bc	3.8 (2.1)ab	3.7 (2.5)ab	5.2 (2.5)a	4.4 (2.6)ab
Overall Vegetal**	5.4 (1.8)	5.6 (2.7)	5.1 (1.8)	4.9 (2.5)	4.9 (1.8)	5.1 (1.9)	5.0 (1.7)
Grassy**	4.8 (2.1)	4.4 (2.8)	4.9 (2.1)	4.0 (2.7)	4.2 (2.2)	4.3 (2.5)	4.4 (2.3)
Earthy**	1.2 (1.6)	2.0 (2.6)	1.0 (1.6)	2.1 (2.1)	1.4 (2.1)	1.6 (1.6)	1.2 (1.5)
<b>Basic Taste</b>							
Sweet	4.7 (1.7)c	5.4 (2.1)bc	5.5 (1.5)bc	6.3 (2.1)ab	5.4 (2.0)bc	7.3 (1.4)a	6.3 (1.5)ab
Sour	5.3 (1.9)a	4.1 (2.2)ab	5.0 (2.0)a	3.4 (1.4)b	4.6 (1.8)ab	3.4 (1.6)b	4.4 (1.6)ab
Astringent**	4.7 (1.4)	5.0 (2.1)	4.2 (1.3)	4.4 (1.8)	4.3 (1.5)	3.8 (1.6)	3.9 (1.5)

\* Mean of 9 panelists x 3 replications; numbers in parentheses refer to standard deviation; different letters within a row indicate significant differences at  $p < 0.05$  separated by Tukey's HSD. Sixteen-point intensity scale: 0 = none, 7 = moderate, 15 = extreme. The "Room" treatment refers to storage at  $22 \pm 1$  °C and 45% RH until ripe; "Refrigerated" treatment refers to storage at 2 °C and 88% RH for three weeks followed by storage under room conditions until ripe. Only consensus descriptors that had a GPA correlation  $> 0.40$  (absolute value) are shown.

\*\* No significant ( $p > 0.05$ ) difference between the treatments.

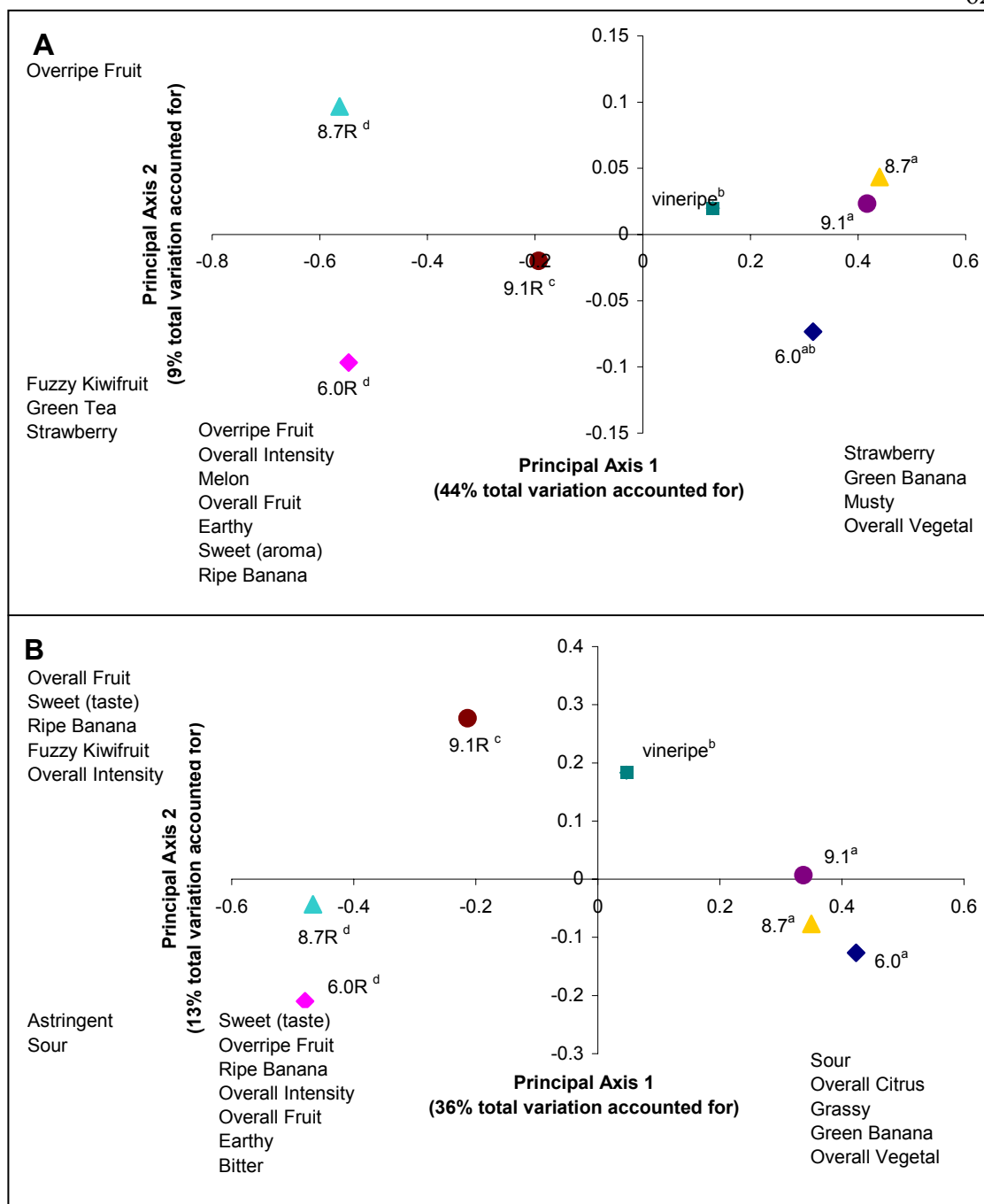
mean ratings averaged across all panelists. These standard deviations (SD) may seem high compared to those seen in trained descriptive panel work but are comparable to SD reported in other free-choice profiling studies (Hjorth, 2002). ANOVA results for

consensus descriptors showed significant differences ( $p < 0.05$ ) between samples in overall intensity and overripe fruit aromas, in ripe banana flavor, and in sweet and sour tastes. In general, fruit stored under refrigerated conditions received higher intensity ratings in aroma and flavor than those stored under room conditions. This is in agreement with work done on 'Hayward' kiwifruit where fruit stored under refrigerated conditions for longer periods of time had more intense aroma and flavor, especially in sweet, fruity notes and off-odors (rancid, earthy) than fruit stored under refrigeration for shorter periods of time (MacRae et al., 1992). Harvest maturity did not show significant ( $p > 0.05$ ) effects on the mean intensity of the sensory descriptors although there was a trend for refrigerated samples where increasing fruit harvest SSC increased intensity in some sensory descriptors, such as fuzzy kiwi and strawberries in aroma, overall fruit, fuzzy kiwi, and ripe banana in flavor, and sweet in basic taste. In this study, the intensity ratings for the basic tastes of sweet and sour correlated,  $R^2 = 0.625$  ( $P < 0.05$ ) and  $R^2 = 0.8819$  ( $P < 0.01$ ), respectively, well with SSC and TA at ripeness.

Panelists generated 11 consensus aroma descriptors, 11 consensus flavor descriptors, and 3 consensus basic taste descriptors during training. Individual panelist descriptors were also generated ranging from 7 to 15 terms/panelist, with an average of 11 terms/panelist. Individual descriptors included apple, orange, lemon, pineapple, cucumber, menthol/eucalyptus, pine, and vinyl. Only consensus descriptors that had a GPA correlation  $> 0.40$  (absolute value) are shown in Table 2. A GPA correlation  $> 0.40$  (absolute value) indicates that the descriptor was important

for describing the differences between samples for at least one panelist and therefore significantly affected the resulting GPA map (Figure 4). Sample consensus plots following generalized procrustes analysis (GPA) of the free choice profiling intensity ratings are shown in Figure 4. For both aroma and flavor, refrigerated samples were significantly different ( $p < 0.05$ ) from samples stored under room conditions on Principal Axis (PA) 1. With respect to aroma, refrigerated samples had higher intensities in overripe fruit, overall intensity, overall fruit, and sweetness, while fruit stored under room conditions had higher intensities in strawberry, green banana and overall vegetal descriptors; the vine ripe sample fell in between the two storage treatments on PA 1, lying close to the y-axis. Samples were separated more according to harvest maturity than storage condition on PA 2. Vine ripe fruit and samples harvested at 8.7 and 9.1% SSC had higher ratings in the aroma descriptor of overripe fruit, with the 6.0% SSC harvest rating highest in fuzzy kiwifruit, green tea, and strawberry. Note that only 9% of the total variation was accounted for on PA 2 for aroma; the difference in PA 2 was not as significant as PA 1 (44% total variation accounted for). The results seen with respect to overall and overripe fruit with increasing harvest maturity and refrigerated storage (and their accompanying softness) are expected since the volatile profile of 'Hayward' kiwifruit has been shown to change from aldehyde (greenness) dominance to ester (fruitiness) dominance during softening (Young and Paterson 1985).

With respect to flavor on PA 1, refrigerated samples had higher intensities in sweet taste, overripe fruit, and ripe banana descriptors, while fruit stored under room

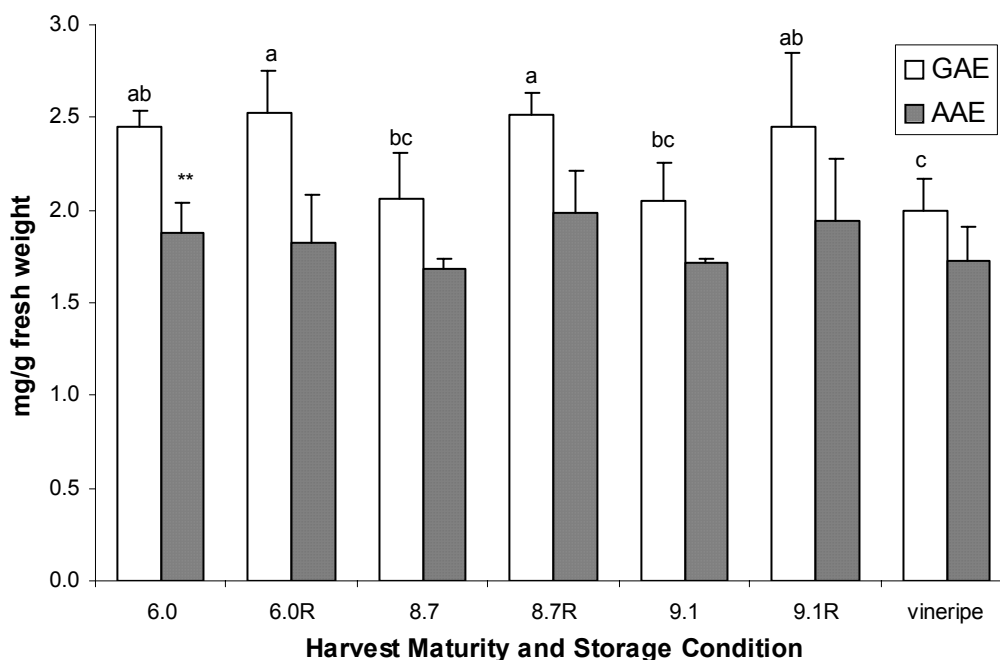


**Figure 4 - Consensus plots following generalized procrustes analysis (GPA) for free choice profiling of hardy kiwifruit harvested at four maturity levels and stored under room conditions (22±1 °C, 45% RH), or refrigerated (with symbol “R”, 2 °C, 88% RH) for 3 weeks and then stored under room conditions, until ripe: (A) aroma, PA 1 vs 2; (B) flavor, PA 1 vs 2. (Samples with different superscripts are significantly different (p<0.05) on PA 1 separated by Tukey’s HSD).**

conditions had higher intensities in sour taste, overall citrus, grassy, and green banana descriptors. Similar findings were reported by McMath and others (1991) for 'Hayward' kiwifruit where fruit stored under refrigeration scored higher in sweet flavor and lower in tangy/acid flavor. On PA 2, vine ripe and 9.1% SSC harvested fruit were higher in overall fruit, sweet taste, and ripe banana intensity, while 6.0 and 8.7% SSC harvested fruit were higher in astringency and sour taste. McMath and others (1991) also reported an increase in sweetness with later harvest dates.

### **Nutritional analysis**

The effect of harvest maturity and storage conditions on total phenolics and antioxidant activity are shown in Figure 5. Harvest maturity and storage conditions significantly affected total phenolics; samples stored under refrigerated conditions generally had higher amounts of phenolic compounds than those stored under room conditions, and fruit harvested at 6.0 and 8.7% SSC stored under refrigerated conditions achieved the highest amount, over 2.0 mg GAE/g FW. There was no significant difference ( $p>0.05$ ) between vine ripe samples and those harvested at 8.7 and 9.1% SSC ripened under room conditions in total phenolics, and they were significantly lower ( $p<0.05$ ) than other samples. Preliminary HPLC analysis (data not shown) suggested that while there were only small differences in total phenolic content, the change in phenolic composition during refrigerated storage should be investigated further. The antioxidant activity for hardy kiwifruit evaluated in this study was in the range of 1.7-1.9 mg ascorbic acid equivalents/g FW. Harvest



**Figure 5 - Effect of harvest maturity and storage conditions on total phenolics and antioxidant activity. (Total phenolics expressed as mg Gallic Acid Equivalents (GAE) per g fresh weight; antioxidant activity expressed as mg Ascorbic Acid Equivalents (AAE) per g fresh weight. Samples were either stored under room conditions (22±1 °C, 45% RH) or refrigerated (with symbol “R”, 2 °C, 88% RH) for three weeks and then stored under room conditions until ripe. Vertical bars represent standard deviation over three replications. Bars showing the same index are not significantly different (p>0.05) separated by “Least Significant Difference”.**

**\*\* Not significantly different in antioxidant activity between treatments.)**

maturity and storage condition had no significant (p>0.05) effect on antioxidant activity. This is expected since ascorbic acid (vitamin C) plays a large antioxidant role and research on ‘Hayward’ kiwifruit has shown that there is little effect of maturity at harvest and only negligible effect of refrigerated storage on ascorbic acid concentrations (Ferguson and MacRae, 1991; Okuse and Ryugo, 1981).

Comparison of antioxidant activity observed in this study with that of other studies would be important; however, differences in method of measurement and in

units reported makes direct comparison difficult. Leong and Shui (2002) measured the antioxidant activity of various fruits using the DPPH method and reported that strawberry had 4.72 mg/g AAE and kiwifruit had 1.36 mg/g AAE.

To our knowledge, this is the first study to present findings on the total phenolics and antioxidant activity of hardy kiwifruit. One study on fuzzy kiwifruit juice by Dawes and Keene (1999) reported that phenolic compounds present in clarified kiwifruit juice were at levels <1.7 mg/L while Imeh and Khokhar (2002) reported 3.0 mg/g FW total phenols in the edible portion of commercial kiwifruit. Moyer and others (2002) explored total phenolic content for a variety of berry crops and reported 1.7-9.6 mg GAE/g *Vaccinium* blueberries and huckleberries, 1.3-10.8 mg GAE/g *Rubus* blackberries, raspberries, and black raspberries, and 1.9-17.9 mg GAE/g *Ribes* gooseberries, currants, and jostaberries. Other studies have measured vitamin C content in kiwifruit. Rassam and Laing (2005) reported that levels of whole fruit mean ascorbic acid in six genotypes of *Actinidia chinensis* ranged from 0.98 to 1.63 mg/g FW and mean oxalic acid varied between 0.18 and 0.45 mg/g FW. Nishiyama et al. (2004) indicated that there was a wide variation in vitamin C content in *A. arguta* fruit, ranging from 0.37 to 1.85 mg/g FW, and fruit from *A. arguta* cv. Gassan, Issai, and Mitsuko had much higher vitamin C contents than 'Hayward', suggesting that some *A. arguta* cultivars may be useful genetic resources. Our results on the phenolic content and antioxidant activity of *A. arguta* 'Ananasnaya' further support the significant health benefits of hardy kiwifruit.

## CONCLUSIONS

This study demonstrated that storage conditions and maturity of fruit at harvest affect the quality of ripened 'Ananasnaya' hardy kiwifruit. Fruit ripened under refrigerated conditions were more similar to vine ripened fruit than fruit ripened under room conditions in basic physicochemical properties. In general, refrigerated samples received high aroma and flavor intensities and have higher total phenolic content than room temperature ripened samples. The results further support industry observation that hardy kiwifruit harvested at 6.0% SSC do not develop adequate quality and often spoil before ripening. Data suggest that 'Ananasnaya' hardy kiwifruit should be harvested at greater than 8% SSC and stored under refrigeration to achieve high quality. Due to seasonal variation, further work is needed to identify the precise SSC at harvest required to achieve optimum quality in ripened fruit.

## ACKNOWLEDGEMENTS

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## CHAPTER 4

### **Quality of Hardy Kiwifruit (*Actinidia arguta* ‘Ananasnaya’) Associated with Packaging and Storage Conditions**

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## ABSTRACT

Limited information exists regarding the ripening physiology of hardy kiwifruit (*Actinidia arguta*) or the ideal packaging and storage conditions for optimum quality and storage life. In this study, the physicochemical properties (°Brix, titratable acidity, pH, firmness, color, weight loss, and respiration) of hardy kiwifruit cv. Ananasnaya were monitored for three consecutive seasons, from 2003 to 2005. Fruit were packaged in low- or high-vent plastic containers and stored under room ( $22\pm 1$  °C, 45% RH) or refrigerated (2 °C, 88% RH) conditions. Calcium caseinate, chitosan, PrimaFresh™, and Semperfresh™ edible coatings were investigated for their potential to enhance the quality and extend the storage life of the fruit. Packaged fruit were exposed to an ethylene-rich environment in the third season to determine the effect of the coatings on ethylene-induced ripening. Semperfresh™-coated and uncoated fruit were evaluated by a sensory consumer panel using a hedonic scale in the third season. Low-vent packaging significantly ( $p<0.05$ ) reduced weight loss. Refrigerated storage delayed ripening and extended storage life by 4 weeks. Coatings provided an attractive sheen to the fruit surface and did not impair ethylene-induced ripening. The consumer test indicated that both coated and uncoated fruit were well liked. These results provide important information regarding the ripening physiology of ‘Ananasnaya’ hardy kiwifruit and indicate that edible coatings may be an alternative to costly low-vent packaging for reducing moisture loss and extending storage life of fresh fruit.

## INTRODUCTION

Hardy kiwifruit (*Actinidia arguta*) have smooth, edible skins and are smaller in size than fuzzy kiwifruit (*A. deliciosa* 'Hayward'). They are not picked vine ripe, as they would be too soft to package and ship. Instead they are picked when physiologically mature and firm, and are stored under refrigeration (0 °C, 90-95% RH), and may be treated with ethylene blockers to delay ripening. 'Hayward' can be stored in this manner for four to six months with good quality (McDonald, 1990; Cheah and Irving, 1997), while the storage life of hardy kiwifruit is only one to two months.

One postharvest technology of particular interest for the hardy kiwifruit industry is the use of edible coatings. Edible coatings are thin layers of material that can be eaten by the consumer as part of the whole food product. Coatings have the potential to reduce moisture loss, restrict oxygen entrance, lower respiration, retard ethylene production, seal in flavor volatiles and carry additives (such as antioxidants) that retard discoloration and microbial growth (Baldwin et al., 1995). In addition to increasing shelf life and prolonging senescence, some coatings, depending on the type of materials used, add shine and luster to commodities, thus making them more attractive and appealing to consumers (Kaplan, 1986). Edible coatings on fresh produce provide an alternative to modified atmosphere packaging and reduce quality changes and quantity losses through modification and control of the internal atmosphere of the individual fruit. This modified atmosphere can protect the food from the moment it is applied, through transportation to its final retail destination, and in the home of the consumer (Smith et al., 1987).

Some edible coatings that have been tried on kiwifruit include pullulan, Semperfresh™, calcium caseinate, and chitosan-, lipid-, and protein-based solutions. Each has positive and negative attributes. Polysaccharide- and protein-based films have suitable gas barrier properties but show poor water vapor properties, while lipid-based coatings help control moisture loss but tend to be brittle and prone to oxidation (Diab et al., 2001).

Recent research on ‘Hayward’ has concluded that pullulan films increase levels of internal ethylene, leading to acceleration of ripening (Diab et al., 2001). Xu et al. (2001 and 2003) suggested an optimum edible coating for ‘Hayward’ composed of soybean protein isolate, stearic acid, and pullulan, extending the shelf life by 3 weeks compared to the control.

A number of cellulose-derived coatings are available commercially, most taking advantage of the modified atmosphere effect of the barriers. They are non-phytotoxic, tasteless, odorless and effective in preserving many kinds of fruit. TAL Pro-long™ and Semperfresh™ are examples of water-soluble composite coatings comprised of sodium salts of carboxymethylcellulose and sucrose fatty acid esters, and have been commercially available for coating fruits and vegetables since the 1980s. Research on Semperfresh™ found that the coating reduced apple ripening rate as observed by several parameters including texture and color while having no significant effect on pH, acidity, SSC or sensory scores (Santerre et al., 1989). Semperfresh™ has also been shown to reduce the weight loss and increase firmness, ascorbic acid

content, titratable acidity and skin color of cherries during storage time, and increase the shelf-life of cherries by 26% at 0 °C (Yaman and Bayoindirli, 2002).

Another suggestion (Zhang and Quantick, 1998) is that chitin and chitosan (deacylated chitin) from marine invertebrates could be used to make a transparent film for application as an edible coating on fruits and vegetables. One of the main advantages of using chitosan for berry fruits is its antifungal ability against *Botrytis cinerea* and *Rhizopus* spp., the two main fungi causing decay in strawberries and raspberries. According to researchers (El Ghaouth et al., 1991; Zhang and Quantick, 1998) a 1 to 2% chitosan solution can decrease *B. cinerea* and *Rhizopus* decay incidence of inoculated strawberries or raspberries significantly at 13 °C. Romanazzi et al. (2002) applied chitosan coating to table grapes and reported a reduced incidence, severity, and nesting of *B. cinerea* gray mold. Negative attributes include the bitterness and astringency of acid-soluble chitosan-based coatings and the lack of definitive information regarding shellfish allergenicity and Kosher certification. The bitterness and astringency associated with chitosan may be alleviated by reducing chitosan concentration or by adjusting the pH of the chitosan solution to 4.6-6.3 (Rodriguez et al., 2003; Han et al., 2005).

Wax and sucrose fatty acid ester mixtures are the most widely used edible coatings for fruits and vegetables. But they are not equally effective for all produce. The effects of edible coatings on internal gas composition and their interactions with quality parameters must be determined for coated fresh produce. For example, color

change, loss of firmness, ethanol fermentation, decay ratio, and weight loss of edible film coated fruit are each important qualities that must be monitored.

The objectives of this study were to determine the effects of packaging and application of edible coatings on the quality and storage life of hardy kiwifruit by monitoring physicochemical parameters in three consecutive seasons, from 2003 to 2005, and by evaluating the sensory quality of Semperfresh™-coated hardy kiwifruit using a sensory consumer panel.

## **MATERIALS & METHODS**

### **Materials**

Coating materials used in this study were Semperfresh™ (SF: AgriCoat Industries Ltd., England; distributed by Pace International, Seattle, WA), calcium caseinate (CC: Alanate 385, NZMP, Santa Rosa, CA; 92.9% protein and 1.4% calcium), chitosan (CH: Vanson Inc., Redmond, WA; 89.8% deacylated), and PrimaFresh 50-V™ (PF: Pace International, Seattle, WA; a vegetable-oil based coating). Other materials include stearic acid (Integra Chemical Company, Renton, WA), glycerol (Fisher Scientific Inc., Fairawn, NJ), and analytical grade glacial acetic acid (Baker Adamson, Morristown, NJ). All materials were food-grade.

### **Preparation of coating solutions**

The Semperfresh (SF) coating solution was prepared by diluting 50% Semperfresh™ concentrate with deionized water to 1%. The chitosan (CH) solution



(3% w/v) was prepared by dissolving chitosan in 1% aqueous acetic acid with 10% glycerol (w/w with chitosan), heating to 80 °C, adding 25% stearic acid (w/w with chitosan) preheated to 80 °C, homogenizing (Polytron PT 10-35, Kinematica AG, Littau, Switzerland) for 90 s at 3000 rpm, and then storing overnight at room temperature. The calcium caseinate (CC) solution (1% in deionized water) was prepared by homogenizing for 1 min at 3000 rpm and then shaking in 60 °C water bath for 30 min, followed by cooling to room temperature. The PrimaFresh (PF) coating solution was prepared by diluting PrimaFresh 50-V™ concentrate 1:6 with deionized water.

### **Sample preparation**

*2003 Season.* Hardy kiwifruit (*Actinidia arguta*) cv. 'Ananasnaya' were harvested in 2003 at 10-13 °Brix from a commercial vineyard in Independence, OR. Vines were trained to a pergola and maintained as per standard recommendations (Strik, 2005). Hardy kiwifruit were selected for uniform size and absence of visible defects, transported to the Value Added Fruit and Vegetable Products Lab at Oregon State University, Corvallis, OR and immediately coated. Individual fruit were randomly assigned to a coating treatment (SF or CC), or the deionized water control (uncoated) treatment. Samples were dipped in coating solution for 30 s and dried on a stainless steel screen under fans for 30 min, dipped a second time for 30 s and dried again to ensure surface dryness. Dry hardy kiwifruit were then packed 8 per package (approximately 100 g per pack) in plastic clamshell containers (high vent (HV),

standard berry containers with many air vents, or low vent (LV), containers made specifically to hold 8 hardy kiwifruit (~100 g) in individual wells with 2 small open air vents) and stored under room (room temperature (RT),  $22\pm 1$  °C, 45% RH) or refrigerated (cooler temperature (CT), 2 °C, 88% RH) conditions, in the dark.

*2004 Season.* ‘Ananasnaya’ hardy kiwifruit were harvested in 2004 at 8-10 °Brix from a commercial vineyard in Sheridan, OR. Vines were trained to a pergola and maintained as per standard recommendations (Strik, 2005). Fruit were transported, sorted, and coated as in the 2003 season. Individual fruit were randomly assigned to the coated (SF) treatment or the deionized water control (uncoated) treatment. Dry fruit were packaged in LV plastic containers and stored under refrigerated conditions, in the dark.

*2005 Season.* Fruit were harvested at 8-10 °Brix from the same vineyard as the 2004 season and transported, sorted and coated as in the previous two years. Individual fruit were randomly assigned to a coating treatment (SF, CH, or PF) or to the deionized water (uncoated) control treatment. Dry fruit were packaged in LV plastic containers and stored under refrigerated conditions, in the dark, in an ethylene-rich environment to determine the effect of coatings on ethylene-induced ripening.

### **Physicochemical analyses**

Firmness was determined by measuring compression using a Texture Analyzer (TA-XT2, Texture Technologies Corp., Scarsdale, NY) with a 5 mm diameter punch probe. Each fruit was subjected to a compression speed of 1 mm/s after contact and

penetration to 10 mm, in the approximate center of the flat surface of the fruit. The firmness was reported as the average peak force of 24 fruit and expressed in Newtons (N). Titratable acidity was determined using 5 g of fruit puree mixed with 45 mL of distilled water, titrated with 0.1 N sodium hydroxide (Mallinckrodt Baker, Inc., Phillipsburg, NJ) to an endpoint of pH 8.1, and expressed as percent anhydrous citric acid. The pH of the samples was measured by a pH meter (IQ240, IQ Scientific Instruments, Inc., San Diego, CA). A refractometer (RA-250, KEM, Kyoto Electronics Manufacturing Co., Ltd., Japan) was used to measure soluble solids content (SSC). Three replications were completed for each parameter measured.

For respiration measurements, 8 fruit were placed into a half pint canning jar as one replicate, with two replicates used per treatment. After 1 h at room temperature, a 0.5 mL sample was taken through a rubber septum in the jar lid and immediately injected into a Carle model 311 Gas Chromatograph (EG&G Chandler Engineering, Tulsa, OK), with thermal conductivity detector connected to a Shimadzu CR3A Chromatopac recording integrator (Shimadzu Scientific Instruments, Columbia, MD). CO<sub>2</sub> and O<sub>2</sub> evolution were determined by comparing ratios of their curve areas, accounting for the weight of the fruit sample.

Color was measured in the center of the flat surface of 24 fruit using a Hunter Labscan spectrophotometer (Model MS/S-4500L, Hunter Associates Laboratory Inc., Reston, VA). L\* (lightness), a\* (greenness [-] to redness [+]), and b\* (blueness [-] to yellowness [+]) values were recorded. Calculated hue angle ( $\arctan(b^*/a^*)$ ) and chroma ( $((a^{*2} + b^{*2})^{1/2})$ ) were used for comparing color changes between samples.

### **Sensory analysis in the 2005 season**

*Recruiting of panelists.* Permission to carry out the sensory study was approved by the Institutional Review Board for the Protection of Human Subjects at Oregon State University (OSU). Consumers were recruited by emails using the Sensory Science Laboratory database, OSU, Corvallis, OR, U.S.A. They were screened for allergic reactions to kiwifruit and to the ingredients used in Semperfresh™. Recruitment criteria excluded individuals that did not consume fresh berries, grapes, or kiwifruit on a regular basis. Before participating in the evaluation, consumers were asked to sign a consent form, which revealed all ingredients used and had a clearly defined risk statement. Only those who met all of the criteria were eligible.

*Sample preparation.* Samples were taken out of refrigeration 24 h before the start of the evaluation to equilibrate to room temperature. The presentation order of the samples was balanced so that each sample appeared in the same position an equal number of times, to minimize any bias caused by presentation order.

*Consumer panel.* The consumer panel consisted of 91 consumers (45 females and 46 males, aged 18 to 65 y). In a separate room panelists were asked to observe and then rate the overall appearance of the samples using a 9-point hedonic scale (1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely). Two LV containers, one containing 8 whole hardy kiwifruit and one containing halved fruit open to expose the cut surface, randomly selected from each treatment and labeled with 3-digit random numbers, were presented to the panelists. The panelists observed

and rated the overall appearance of cut and uncut kiwifruit as well as outside color of the samples. Following the appearance test, consumers entered individual sensory booths and were served the samples in paperboard dishes, three whole fruit per sample. Overall liking, flavor, sweetness, sourness, texture and aftertaste liking were rated by the panelists using the same 9-point hedonic scale as above.

Demographic data were obtained regarding gender, age, likeliness to consume, purchase intent, etc. Likeliness to consume and purchase intent questions were based on a 5-point scale where 1 = definitely would not consume (purchase), 3 = may or may not consume (purchase), 5 = definitely would consume (purchase).

### **Statistical analysis**

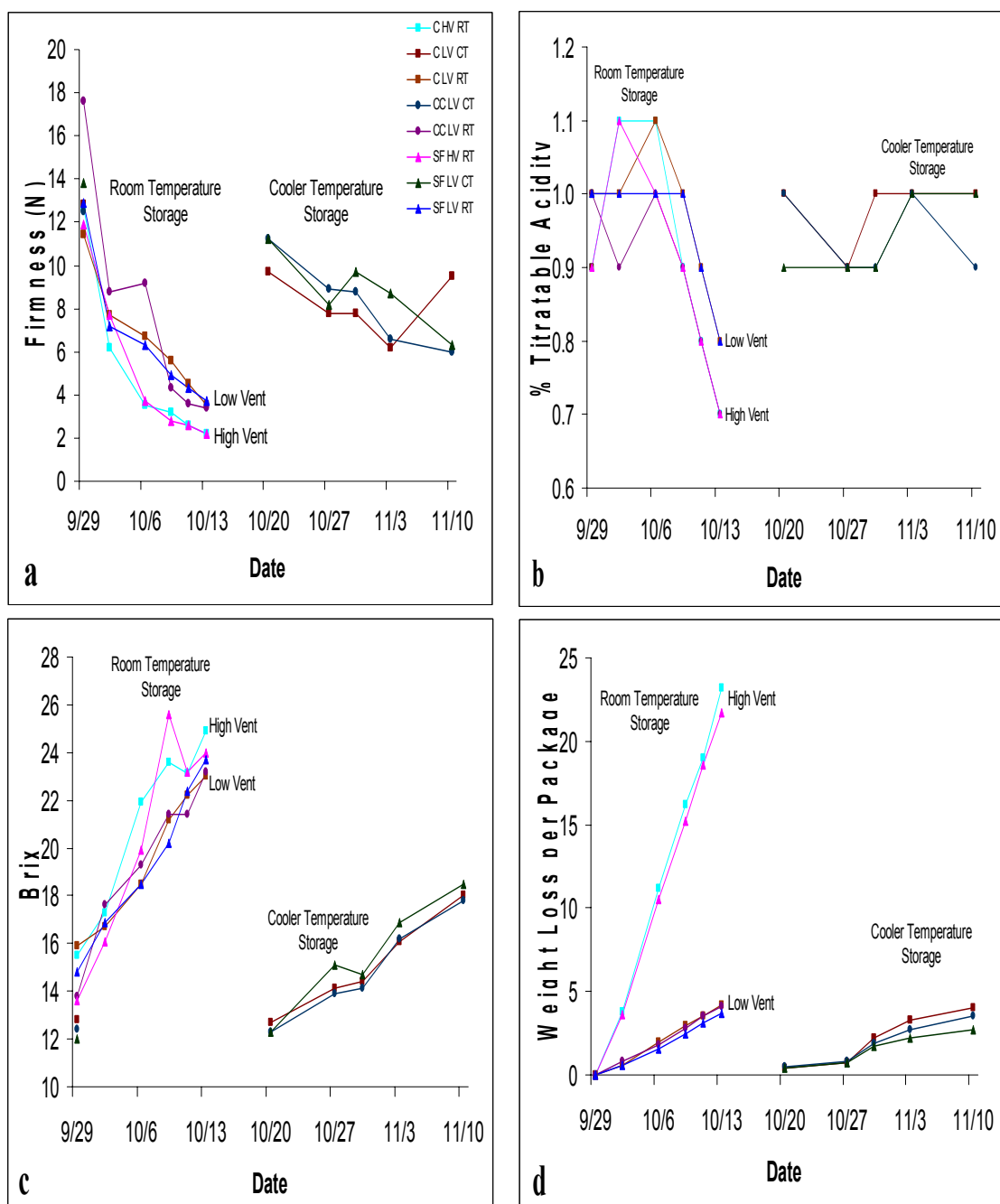
Physicochemical data were analyzed with SAS statistical software Release 8.2 (SAS Institute, Cary, NC). Treatments were arranged in a completely randomized design in the 2003 and 2004 seasons. In the 2005 season, a split-plot design was used. Treatments were compared using PROC GLM, with weekly color and weight loss data treated as repeated measures, and with treatment means compared using Least Significant Difference (LSD).

For consumer tests, differences among treatments were analyzed using univariate analysis of variance (ANOVA) per attribute. Significant differences detected by ANOVA were subjected to post hoc Tukey's Honestly Significant Difference (HSD) to test treatment means at the  $p < 0.05$  significance level (Compusense Five, Version 4.6., Compusense Inc., Guelph, Ontario, Canada).

## RESULTS & DISCUSSION

### 2003 Physicochemical Results

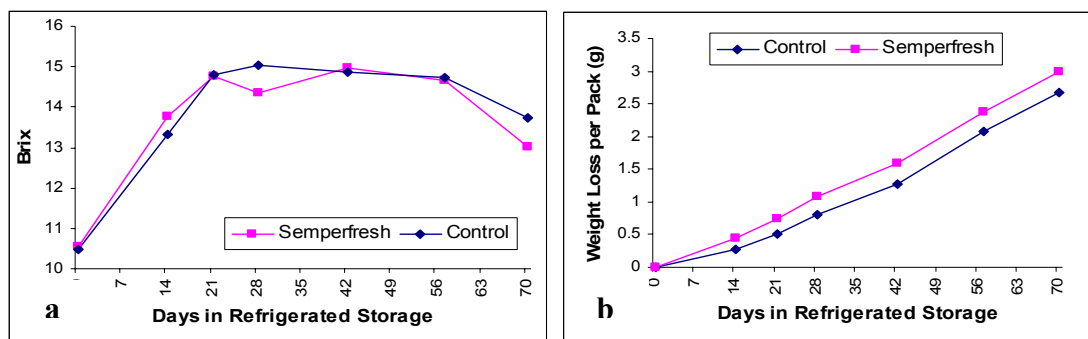
Figure 1 displays the effects of coating, packaging, and storage conditions on a) firmness, b) titratable acidity, c) Brix, and d) weight loss of 'Ananasnaya' hardy kiwifruit. In general, RT-stored fruit were less firm than CT-stored fruit, and fruit stored in HV packaging were less firm than fruit stored in LV packaging. There was no significant difference ( $p>0.05$ ) between coating treatments or the control for firmness. TA was significantly ( $p<0.05$ ) affected by coating treatment and by packaging, but not by storage conditions. CC-coated fruit had significantly ( $p<0.05$ ) lower TA than SF or the control. Brix was significantly ( $p<0.05$ ) affected by choice of packaging and storage conditions, but not affected by coating treatment, although there was a trend that CC-coated fruit had lower Brix values than SF or the control. Choice of packaging significantly ( $p<0.05$ ) affected weight loss, with no differences between coatings or storage conditions. CT storage effectively delayed weight loss by 4 weeks, extending the storage life of the fruit. Coatings provided an attractive sheen to the fruit surface and reduced incidence of physiological pitting (data not shown). These results indicate that coatings may be a good alternative to costly LV packaging and that the two strategies do not seem to have an additive effect on improving quality or lengthening shelf life, therefore processors have the option of choosing one or the other.



**Figure 1. Effect of coating, packaging, and storage conditions on a) firmness, b) titratable acidity, c) °Brix, and d) weight loss of hardy kiwifruit in 2003. Coatings: C (Control), CC (Calcium caseinate), and SF (Semperfresh™) Packaging: LV (low vent), HV (high vent); ~100 g starting weight per pack Storage: RT (room conditions), CT (cooler/refrigerated conditions)**

## 2004 Physicochemical Results

There were no significant differences ( $p>0.05$ ) between SF and control fruit for firmness, TA, Brix, pH, or weight loss in the 2004 season. Figure 2 displays the a) °Brix and b) weight loss of ‘Ananasaya’ during refrigerated storage. °Brix of the coated and uncoated fruit remained similar throughout the storage period. While the decrease in °Brix at the end of the storage period was not predicted, kiwifruit research has demonstrated that while °Brix increases with ripening, it may increase or decrease during storage as carbohydrates are utilized in fruit respiration (Mitchell et al., 1991; MacRae et al., 1992). Table 1 contains the average firmness, TA, pH and color measurements observed throughout refrigerated storage. The high standard deviations are due to the highly variable nature of the individual fruit. Treatment with ethylene, as is done commercially to enhance ripening, would likely reduce this variation so that each fruit in a lot reaching the marketplace would be at a similar ripeness level. Color measurements showed a trend ( $p<0.1$ ) for control fruit appearing lighter than SF-coated fruit after 28 days of storage and that SF-coated fruit had higher  $b^*$  (yellowness)



**Figure 2. Effect of 10 weeks refrigerated storage on a) Brix and b) weight loss in 2004.**



values than control fruit. There were no significant differences between the two treatments on  $a^*$ , hue angle, or chroma.

**Table 1. Physicochemical measurements of ‘Ananasnaya’ observed during refrigerated storage (2 °C) in the 2004 season.**

		Day 0	Day 14	Day 21	Day 28	Day 42	Day 57	Day 70
<b>Firmness<sup>a</sup></b>	<i>SF</i>	331.02 (147.7)	61.5 (30.1)	30.0 (12.9)	32.1 (13.7)	4.9 (1.7)	4.5 (2.2)	24.5 (38.5)
	<i>Control</i>	342.0 (159.1)	56.9 (27.5)	22.3 (8.5)	36.7 (13.7)	4.9 (1.7)	5.3 (2.6)	64.6 (29.5)
<b>TA<sup>b</sup></b>	<i>SF</i>	1.49 (0.04)	1.07 (0.05)	1.01 (0.02)	0.93 (0.03)	0.71 (0.04)	0.62 (0.06)	0.52 (0.05)
	<i>Control</i>	1.50 (0.06)	1.08 (0.02)	1.01 (0.04)	0.95 (0.04)	0.68 (0.01)	0.58 (0.03)	0.46 (0.02)
<b>pH<sup>b</sup></b>	<i>SF</i>	3.40 (0.04)	3.49 (0.02)	3.52 (0.02)	3.52 (0.04)	3.87 (0.04)	4.04 (0.05)	4.03 (0.10)
	<i>Control</i>	3.39 (0.02)	3.46 (0.03)	3.54 (0.02)	3.52 (0.03)	3.88 (0.02)	3.99 (0.00)	4.12 (0.03)
<b>L*<sup>c</sup></b>	<i>SF</i>	42.5 (4.54)	36.5 (7.86)	35.4 (7.86)	33.8 (8.03)	32.9 (7.55)	35.6 (7.20)	33.5 (6.96)
	<i>Control</i>	43.2 (4.05)	37.2 (6.47)	37.6 (6.10)	37.2 (5.49)	35.6 (5.62)	37.5 (6.16)	36.0 (5.76)
<b>a*<sup>c</sup></b>	<i>SF</i>	-1.65 (4.99)	0.75 (9.39)	1.50 (9.25)	1.46 (8.86)	2.53 (8.67)	2.59 (7.59)	2.41 (6.51)
	<i>Control</i>	-1.32 (4.15)	3.14 (8.03)	2.63 (7.49)	2.69 (6.96)	3.54 (6.62)	3.26 (6.27)	4.01 (6.48)
<b>b*<sup>c</sup></b>	<i>SF</i>	16.3 (7.74)	27.1 (5.59)	23.2 (6.67)	23.1 (5.80)	20.8 (5.47)	17.1 (5.26)	16.4 (5.22)
	<i>Control</i>	17.3 (6.04)	23.8 (5.59)	21.4 (5.09)	19.2 (4.94)	18.2 (5.11)	17.2 (4.85)	15.8 (4.46)
<b>Hue<sup>c</sup></b>	<i>SF</i>	-0.31 (1.25)	-0.26 (1.27)	-0.29 (1.22)	-0.34 (1.23)	-0.26 (1.23)	-0.23 (1.21)	0.03 (1.28)
	<i>Control</i>	-0.48 (1.24)	0.15 (1.29)	-0.04 (1.30)	-0.06 (1.29)	0.09 (1.27)	0.10 (1.29)	0.26 (1.25)
<b>Chroma<sup>c</sup></b>	<i>SF</i>	17.3 (7.40)	28.8 (4.60)	25.2 (6.09)	24.9 (5.15)	22.7 (5.23)	19.0 (4.70)	17.8 (4.86)
	<i>Control</i>	17.9 (5.83)	25.6 (4.25)	23.0 (3.63)	20.9 (3.39)	20.0 (3.74)	18.9 (3.42)	17.7 (3.64)

<sup>a</sup> mean and SD of 48 fruit; SF = Semperfresh™

<sup>b</sup> mean and SD of 3 commingled samples of 8 fruit each

<sup>c</sup> mean and SD of 24 fruit, 2 measurements each

TA = titratable acidity, L\* = lightness, a\* = green to red, b\* = blue to yellow

## 2005 Physicochemical Results

There were no significant differences ( $p > 0.05$ ) between coating treatments for TA, Brix, and pH (Table 2), or respiration (data not shown) in the 2005 season,

suggesting that none of the coatings tested impair ethylene-induced ripening. There was a significant coating by week interaction for firmness ( Figure 3). While there was an initial difference in firmness between coating treatments, there was no significant difference between coating treatments from week 2 on. Figure 4 contains the effect of coating treatments on weight loss in ethylene-treated hardy kiwifruit. Coated fruit lost significantly more weight than the control fruit. This result is consistent with that obtained in the 2004 season, and may be due to disruption of the natural fruit wax surface properties. Applying the coating using a method other than dipping, such as spraying or drip application, may minimize this disturbance. There

**Table 2. Physicochemical measurements of ethylene-exposed hardy kiwifruit in 2005\*.**

		<b>Week 1</b>	<b>Week 2</b>	<b>Week 4</b>	<b>Week 5</b>	<b>Week 6</b>
<b>TA</b>	<i>Control</i>	1.26 (0.05)	1.15 (0.04)	1.10 (0.02)	1.07 (0.03)	0.91 (0.02)
	<i>SF</i>	1.25 (0.09)	1.17 (0.06)	1.10 (0.05)	1.05 (0.05)	0.96 (0.02)
	<i>PF</i>	1.21 (0.06)	1.16 (0.06)	1.08 (0.01)	1.01 (0.03)	0.98 (0.00)
	<i>CH</i>	1.26 (0.06)	1.15 (0.06)	1.08 (0.03)	1.04 (0.01)	0.92 (0.01)
<b>Brix</b>	<i>Control</i>	15.7 (0.44)	15.27 (1.04)	14.93 (0.72)	15.27 (0.76)	14.87 (0.47)
	<i>SF</i>	15.10 (0.92)	15.10 (0.44)	15.80 (0.62)	14.47 (0.67)	14.20 (0.56)
	<i>PF</i>	14.60 (0.75)	15.57 (0.47)	16.30 (0.95)	14.80 (0.26)	13.50 (0.26)
	<i>CH</i>	14.43 (0.51)	15.83 (0.25)	15.93 (0.90)	14.20 (0.36)	13.97 (0.35)
<b>pH</b>	<i>Control</i>	3.56 (0.18)	3.52 (0.13)	3.67 (0.04)	3.76 (0.04)	3.79 (0.09)
	<i>SF</i>	3.65 (0.09)	3.52 (0.06)	3.75 (0.04)	3.64 (0.10)	3.75 (0.04)
	<i>PF</i>	3.63 (0.04)	3.53 (0.03)	3.72 (0.07)	3.80 (0.02)	3.71 (0.07)
	<i>CH</i>	3.63 (0.02)	3.61 (0.04)	3.80 (0.04)	3.71 (0.04)	3.77 (0.06)

\* mean and SD of 3 commingled samples of 8 fruit each; SF = Semperfresh™, PF = PrimaFresh 50-V™, CH = chitosan

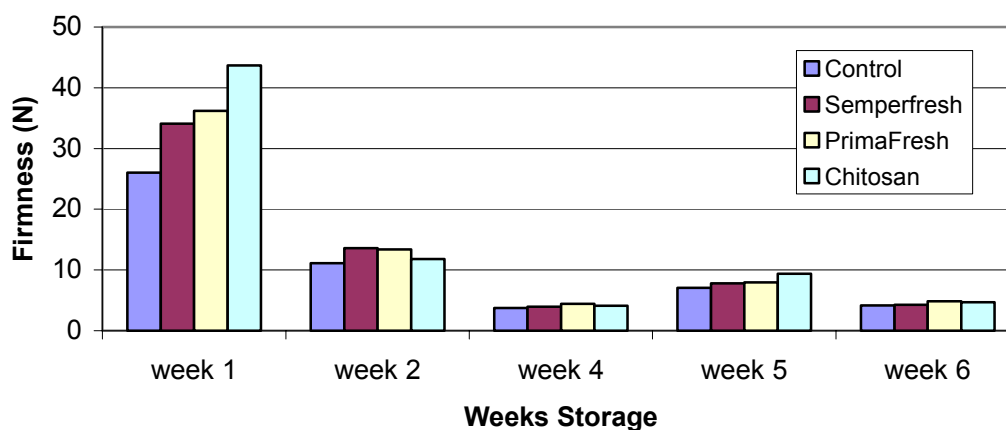


Figure 3. Firmness of ethylene-exposed 'Ananasnaya' stored at 2 °C (n=24).

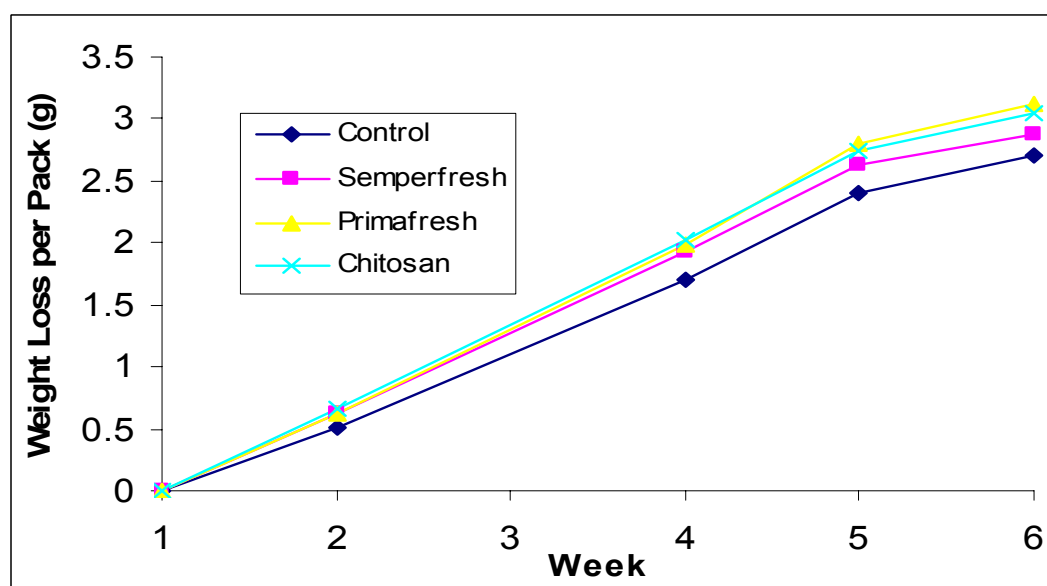


Figure 4. Weight loss of ethylene-exposed 'Ananasnaya' (per pack of 8 fruit, starting weight ~100 g) stored at 2 °C.

were no significant differences between coating treatments for  $a^*$  or hue angle, although the treatment orders arranged by LSD for hue remained the same each week, suggesting a trend of control, PF, CH, SF, from low to high, in hue angle. The effect of coating treatments on lightness,  $b^*$ , and chroma, were significantly affected by

week measured. This is partly due to the fact that the CH coating was white and somewhat uneven on the fruit surface. Further work should be conducted with care paid to ensure consistent coating color and thickness across treatments.

While none of the coating treatments displayed high incidence of mold or rot, coatings would be expected to be of benefit in seasons where mold and rot are prevalent, especially when using coating materials such as chitosan, which is known for its natural anti-fungal ability. Further research should address the ability of coatings to impair mold and rot on artificially inoculated fruit.

### Sensory analysis

Table 3 shows the results of the sensory consumer test. There were no significant differences between Semperfresh™-coated fruit and the water-coated control for consumer acceptance over all attributes. In general, both coated and

**Table 3. Sample "liking" means, standard deviations, and significance (n=91) of the 2005 sensory consumer test for control and Semperfresh (SF)-coated 'Ananasnaya' fruit.**

<i>Attribute</i>	<i>Control Sample Mean</i>	<i>SF-Coated Sample Mean</i>	<i>p-value</i>
<b>Appearance<sup>NS</sup></b>	7.6 (0.9)	7.4 (1.1)	0.1866
<b>Color<sup>NS</sup></b>	7.4 (1.0)	7.4 (1.0)	0.9257
<b>Overall Liking<sup>NS</sup></b>	7.3 (1.1)	7.0 (1.7)	0.0823
<b>Flavor<sup>NS</sup></b>	7.1 (1.5)	7.0 (1.8)	0.3092
<b>Sweetness<sup>NS</sup></b>	7.2 (1.5)	7.0 (1.8)	0.2627
<b>Sourness<sup>NS</sup></b>	6.4 (1.8)	6.2 (1.9)	0.3245
<b>Texture<sup>NS</sup></b>	6.9 (1.7)	6.7 (1.9)	0.4278
<b>Aftertaste<sup>NS</sup></b>	6.0 (2.0)	5.6 (2.2)	0.1518

Nine point liking (acceptance) scale where:

1=dislike extremely, 5=neither like nor dislike, 9=like extremely

<sup>NS</sup>Attribute *not significant* at  $p < 0.05$  level

uncoated fruit were well liked by consumers, as indicated by their mean ratings. Table 4 displays the consumer responses for intent to consume/purchase hardy kiwifruit.

This is important information for growers who currently ship most of their product to markets in Asia or tourist destinations such as Hawaii. Consumers in Corvallis, OR, like the fruit and would purchase and consume it, therefore producers should proceed with marketing efforts in their local area.

**Table 4. Consumer sensory panelist intent to consume/purchase hardy kiwifruit\***

	Definitely would	Probably would	May or may not	Probably would not	Definitely would not
Consume	51.7%	29.7%	14.3%	3.3%	1.1%
Purchase	42.9%	31.9%	18.7%	5.5%	1.1%

\*In response to the question, “Overall, based on your appearance and tasting experience, how likely would you be to consume (purchase) hardy kiwifruit?”

## CONCLUSIONS

Year-to-year variation is readily apparent in this crop. Ripening physiology is altered by choice of packaging, application of edible coatings, and by storage conditions. The vine ripe °Brix for hardy kiwifruit is reportedly 18-23 °Brix (Strik, 2005). The results of this study show a °Brix of as much as 24 in RT-stored fruit but only 15-18 °Brix in refrigerated fruit. Current storage life recommendations are 7-10 weeks. When hardy kiwifruit were packed in traditional HV clamshell containers or exposed to ethylene during storage the results of this study validated that recommendation. However, observations in the 2004 season suggest that the storage life of hardy kiwifruit may be extended to as many as 14 weeks through the use of LV packaging combined with edible coatings. More work is needed to test this hypothesis

directly. While LV packaging is costly, edible coatings are quite economical considering their ability to improve appearance and control moisture loss, thereby extending storage life. Therefore edible coatings may be of particular interest to producers who wish to improve their product quality while continuing to use HV packaging.

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## Chapter 5

### General Conclusion

Storage conditions and maturity of fruit at harvest affected subsequent quality of ripened 'Ananasnaya' hardy kiwifruit. Fruit ripened under refrigerated conditions were more similar to vine ripened fruit than fruit ripened under room conditions in basic physicochemical properties. In general, refrigerated samples received high sensory intensity scores in aroma and flavor and had higher total phenolic content than room temperature ripened samples. The results support industry observation that hardy kiwifruit harvested at 6.0% SSC do not develop adequate quality and often spoil before ripening. Data suggest that 'Ananasnaya' hardy kiwifruit should be harvested at greater than 8% SSC and stored under refrigeration to achieve the highest quality. Due to seasonal variation, further work is needed to identify the precise SSC at harvest required to achieve optimum quality in ripened fruit.

Ripening physiology is altered by choice of packaging, application of edible coatings, and by storage conditions. The results show a °Brix of as much as 24 in RT-stored fruit but only 15-18 °Brix in refrigerated fruit. Current storage life recommendations are 7-10 weeks. When hardy kiwifruit were packed in traditional



HV clamshell containers or exposed to ethylene during storage, results validated that recommendation. However, observations in the 2004 season suggest that the storage life of 'Ananasnaya' hardy kiwifruit may be extended to as many as 14 weeks through the use of LV packaging combined with edible coatings. More work is needed to test this hypothesis directly. While LV packaging is costly, edible coatings are quite economical considering their ability to improve appearance and control moisture loss, thereby extending storage life. Therefore edible coatings may be of particular interest to producers who wish to improve their product quality while continuing to use HV packaging.

Additional research should be conducted to find a grower friendly test for predicting optimum harvest date (Appendix), to further explore postharvest physiology, and to investigate other coating application methods such as spray and drip application. Research regarding processed hardy kiwifruit products that retain the characteristic green color would also be of great benefit to the industry.

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**APPENDIX**

**APPENDIX**

**Iodine Staining of Starch in ‘Ananasnaya’ Hardy Kiwifruit is  
Not Useful as an Indicator of Harvest Maturity**

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## ABSTRACT

Iodine staining of starch was explored to determine its usefulness as a harvest index for hardy kiwifruit (*Actinidia arguta*). Weekly from 2 Sept. to 14 Oct. 2005, the cut surfaces of 20 halved fruit were dipped in an iodine solution and the staining intensity measured using digital photography and color analysis. Harvest date had a significant effect on °Brix and all color readings (L\*, a\*, b\*, and chroma) before and after staining. Fruit harvested later in the season had less starch and thus were lighter. However, an easily observable color difference was only apparent weeks after commercial harvest is recommended based on °Brix. Therefore, while the technique can be successfully used to observe the conversion of starch to sugar in ‘Ananasnaya’ hardy kiwifruit, it will have little usefulness as a harvest index.

## INTRODUCTION

‘Ananasnaya’ is the most widely grown cultivar of hardy kiwifruit (*A. arguta*) in the world. Hardy kiwifruit may also be known or marketed under alternate names including “baby kiwifruit”, “grape kiwi”, “wee-kee”, and “cocktail kiwi”. There were 42 ha (100 acres) of ‘Ananasnaya’ planted in Oregon in 2002 (Tiyayon and Strik, 2003) and Williams et al. (2003) estimated that about 100 ha (247 acres) were grown commercially in the United States (Ore., Pa., N.Y., and Wash.), New Zealand, Canada (B.C. and Ont.), Chile, Italy, France, Germany, and The Netherlands.

The fruit of ‘Ananasnaya’ is a medium-sized, ovoid, 3.5 cm long x 2.5 cm wide (1.5 x 1 in.) berry. Fruit weight ranges from 2 to 14 g, averaging 6.9 g (Pescie and Strik, 2004) or 7.3 g per vine (Tiyayon and Strik, 2004).

‘Ananasnaya’ has female flowers that bloom for about 10 days in late May to early June. Fruit go through an initial phase (35 to 40 days after flowering) of rapid increase in fruit volume, followed by a period of reduced growth, which may coincide with seed hardening (from 35 to 50 days after flowering). Fruit thereafter continue to increase in volume and reach maximum size approximately two weeks to one month prior to harvest, depending on harvest criteria (Pescie and Strik, 2004). Hassall et al. (1998) reported that *A. arguta* in New Zealand reached 80% of final size by 40 days after flowering. Fruit mature in late summer to autumn, 100 to 110 days after flowering, depending on region, with firmness decreasing in the later stages of ripening (Kabaluk et al., 1997; Strik, 2005). ‘Ananasnaya’ produces a green to red blushed berry with a smooth, edible skin. The flesh is light-green, juicy, and has a sweet-tart taste with a rich, aromatic flavor that has been compared to ripe pineapple, strawberries, bananas, European gooseberries, over-ripe pears, or rhubarb (Ferguson and Ferguson, 2003). The sliced fruit has a similar internal appearance to that of the more typical “fuzzy” kiwifruit ‘Hayward, *A. deliciosa* (Ferguson, 1984).

Commercially, fruit are generally once-over hand harvested when fruit are at an average percent soluble solids (°Brix), of 8-10 in Oregon (Strik, 2005; Tiyayon and Strik, 2003). In New Zealand new selections of hardy kiwifruit were found to be ideally harvested at 20% dry weight – fruit harvested earlier developed storage

disorders and did not reach as high °Brix when ripened (Williams et al., 2003). When harvesting at average 8-10 °Brix most fruit are still green and firm, although a small percentage (generally less than 4% of total yield) are very soft and unusable (Tiyayon and Strik, 2003). Hassall et al. (1998) reported *A. arguta* in New Zealand were harvested when about 10% of the fruit on a vine were soft to the touch. Fruit cannot be harvested vine ripe as it is then too soft to handle or store and often the fruit tears at the pedicel-fruit juncture when harvested. In Aurora, Ore. fruit reached a typical commercial harvest °Brix (8 to 10) on 21 Sept. However, vine-ripened fruit continued to increase in °Brix to 21 to 23%, depending on cultivar (Strik and Hummer, 2006).

A commercial grower's decision to harvest is influenced by seed color (all seeds must be black), average °Brix, and percent of fruit prematurely softening. Unfortunately, hardy kiwifruit do not ripen uniformly on the vine, making determination of optimum harvest date difficult for growers. Dry weight of fruit continues to increase after or without a sharp rise in content of soluble solids (Hassall et al., 1998). Also, the fruit change little in external color during the optimum harvest period. Variable fruit quality due to range in fruit size, °Brix, firmness, and subsequent flavor is considered an important production problem in this crop.

While a refractometer is useful for measuring °Brix, not all growers have access or desire to use one. Therefore, development of a rapid, in-field test for predicting optimum harvest date would be of great benefit to the hardy kiwifruit industry. Iodine staining of starch has been used to help judge maturity in apples (Saltveit and Hale, 1982), pears (North, 1961), and bananas (Blankenship et al., 1993).

In 'Hayward' kiwifruit, starch content of fruit declines as seeds change from brown to black and as fruit ripens with a consequent increase in sugars (Beever and Hopkirk, 1990). Iodine staining of starch is thus closely correlated with °Brix and may be useful in hardy kiwifruit. Producing a color reference chart of staining patterns that could be taken into the field and compared to stained fruit may help growers predict optimum harvest date. The purpose of this study was to determine if a useful iodine-starch staining test could be developed in 'Ananasnaya' to estimate °Brix and thus optimum harvest date.

## **MATERIALS & METHODS**

*Fruit Material.* Hardy kiwifruit cv. Ananasnaya were harvested weekly from 2 Sept. to 14 Oct. 2005 from a mature commercial vineyard in Sheridan, Ore. Twenty representative fruit were picked each week from 4 plants trained to a pergola, with care paid to harvest from various locations in the canopy. The fruit were immediately transferred to the Value Added Fruit and Vegetable Processing Lab at Oregon State University, Corvallis and were allowed to come to room temperature before analysis. Fruit were cut in half in cross section, with one half subjected to measurement of percent soluble solids (°Brix; refractometer RA-250, KEM, Kyoto Elec. Manuf. Co., Ltd., Japan) and the other half used for iodine-starch staining and color measurement. Measurement of °Brix was done on the half proximal to the pedicel on half of the sampled fruit and distal to the pedicel on the other half, in case °Brix varied from the

pedicel to the calyx end of the fruit (MacRae et al., 1989a; 1989b). Juice was extracted from the sliced fruit by squeezing.

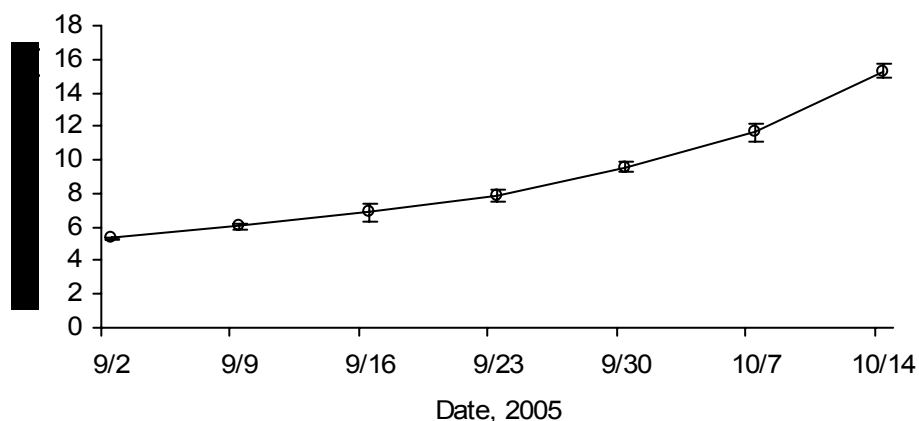
*Iodine-starch staining.* The iodine staining solution (1.0% potassium iodide, 0.1% iodine; Mallinckrodt Baker, Inc., Phillipsburg, N.J.) was prepared as described by Saltveit and Hale (1982). Briefly, potassium iodide was dissolved in a small amount of deionized water before addition of iodine, and then deionized water to make 1 L. One half of each fruit was placed cut side down in 5 mm of staining solution for one minute. Fruit were then gently rinsed with deionized water and blotted with tissue paper to remove excess moisture. Samples were allowed to dry briefly before color measurements and digital photographs were taken.

*Color analysis.* The flesh color of each sliced fruit was measured before and after staining using a Hunter Labscan spectrophotometer (Model MS/S-4500L, Hunter Assoc. Lab. Inc., Reston, Va.). The L\* (lightness), a\* (redness-greenness), and b\* (yellowness-blueness) values were recorded. Calculated chroma ( $(a^{*2} + b^{*2})^{1/2}$ ) values were also used for comparing color changes between samples. Digital photographs were taken using a Sony model DSC-S85 camera (Sony Corp., Japan).

Data were analyzed using SAS (SAS Institute, 1999, Cary, NC, U.S.A.). Color readings, before and after iodine staining, were analyzed using a paired t-test. The effect of harvest date on °Brix and color readings was analyzed using PROC GLM. Correlation analysis was used on all variables and regression was used to determine the relationship between color readings and °Brix.

## RESULTS & DISCUSSION

Harvest date had a significant effect on all measured variables, °Brix and all color readings, before and after staining ( $P < 0.0001$ ). Changes in °Brix over the harvest period are presented in Fig. 1 and were similar to what has been reported



**Fig. 1. The effect of harvest date on percent soluble solids (°Brix) of 'Ananasnaya' fruit (n=20; mean ± SE per date).**

elsewhere for this cultivar of hardy kiwifruit (Kabalak et al., 1997; Strik and Hummer, 2006; Tiyyon and Strik, 2004).

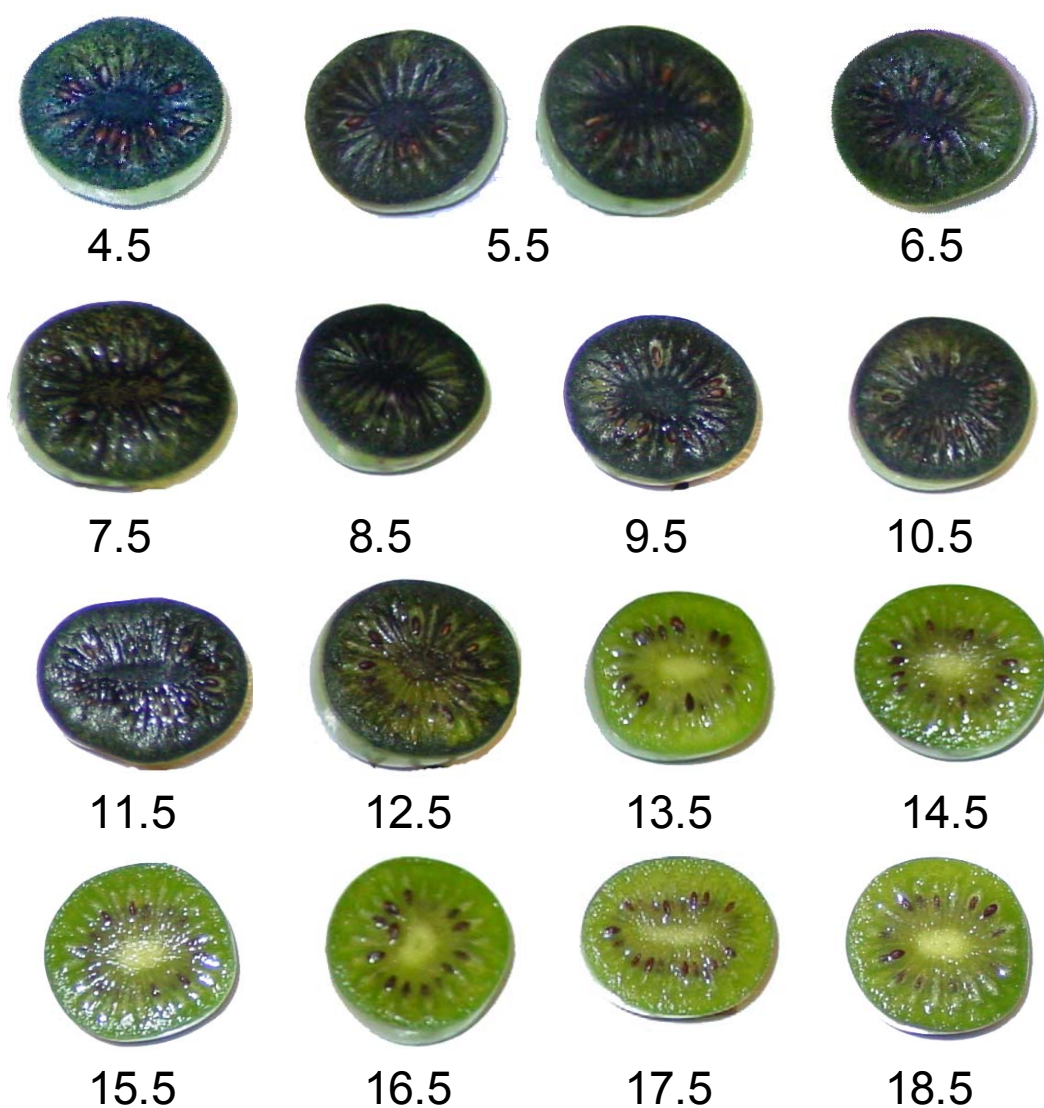
The appearance of sliced fruit after staining with iodine was affected by °Brix (Fig. 2). Fruit that were more ripe (higher °Brix) had less starch and thus showed less purple color after staining with iodine. The lightness score ( $L^*$ ),  $a^*$ ,  $b^*$ , and chroma values were significantly affected by staining ( $P < 0.05$ ) even on the last fruit harvest date when °Brix averaged 15.3 (Fig. 1) and there was little visual change in appearance after staining (Fig. 2).

The positive relationship between  $L^*$  after staining and °Brix was thus affected by harvest date (Fig. 3). Fruit harvested later in the season had less starch and thus

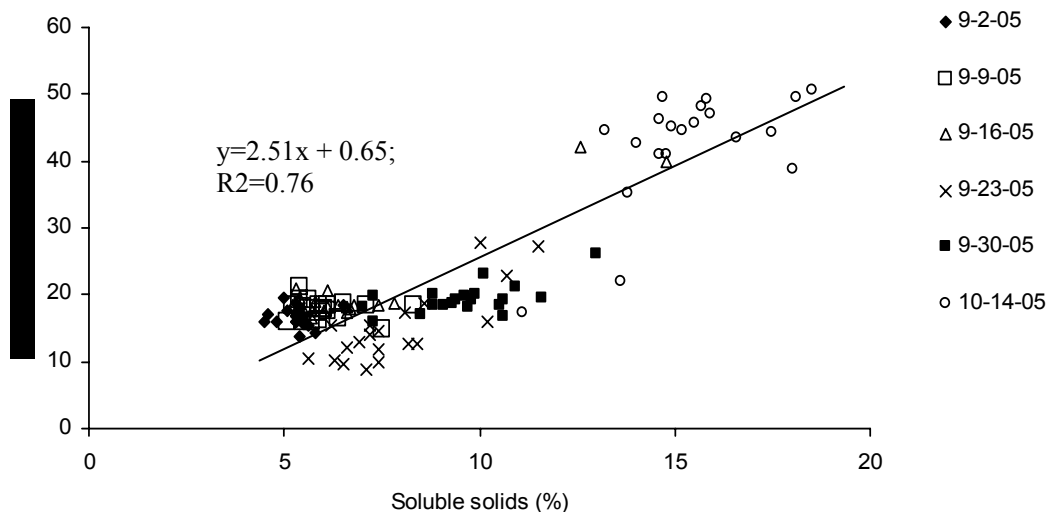


were lighter after staining (Fig. 2 and 3). At a 13.5 °Brix, fruit had visually lost evidence of staining (Fig. 2).

On 30 Sept., when °Brix was within the present commercial standard for harvest, 8-10 (Fig. 1), °Brix was significantly correlated ( $P < 0.05$ ) with  $L^*$  ( $r = -0.465$ ) and  $a^*$  ( $r = 0.541$ ) before staining and  $L^*$  ( $r = 0.601$ ),  $b^*$  ( $r = 0.591$ ), and chroma ( $r = 0.495$ )



**Fig. 2.** Visual appearance of 'Ananasnaya' fruit, ranging from 4.5 to 18.5 °Brix, after staining with iodine.



**Fig. 3. The effect of harvest date on the relationship between lightness ( $L^*$ ) after iodine staining and percent soluble solids ( $^{\circ}$ Brix) of 'Ananasnaya' fruit (n=20 per harvest date).**

after staining. Similar correlations were observed for the 23 Sept. harvest date (data not shown). All variables were correlated with  $^{\circ}$ Brix for fruit harvested 16 Sept. However, there were no significant correlations between  $^{\circ}$ Brix and color variables before or after staining for fruit harvested on 2 or 9 Sept. when  $^{\circ}$ Brix was 5-6 (data not shown).

There was no clear pattern to which parts of the sliced kiwi were more stained than others. In apple the core loses staining ability last (Saltveit and Hale, 1982) and in banana starch (and staining) is lost from the center of the fruit outward (Blankenship et al., 1993). In our study, fruit at all  $^{\circ}$ Brix levels could show spots that did not stain, but the locules in particular were less stained than the columella (core; Fig. 2).

## CONCLUSIONS

Results demonstrate that 'Anansnaya' hardy kiwifruit can be successfully stained using the iodine staining technique. However, although color variables ( $L^*$ ,  $a^*$ ,  $b^*$ , and chroma) were correlated with °Brix, it was difficult to discriminate color change visually at a desirable harvest °Brix. By the time significant color change can be seen visually the fruit should have already been harvested. Therefore, while the technique is useful for observing the conversion of starch to sugar in 'Ananasnaya' hardy kiwifruit, growers should continue to use a refractometer for measuring °Brix when determining harvest date in this crop.

## ACKNOWLEDGEMENTS

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