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 3 wk 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 16.41 to 19.09 and were similar to vine-ripened fruit (15.1% SSC). Hue angles ranged from 75.41 to 97.50; the only significant ($P < 0.05$) difference was refrigerated fruit harvested at 9.1% SSC, which had lower hue angles than all other treatments. Refrigeration significantly ($P < 0.05$) 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 ($P < 0.05$) 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 to 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* species and by controlling storage conditions.

Keywords: *Actinidia arguta*, harvest maturity, phenolics, antioxidant activity, sensory analysis

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 with ripe strawberry, banana, pineapple, over-ripe pear, rhubarb, blackcurrant, grassy, melon, and tropical flavors (Matich and others 2003; Williams and others 2003). The fruit contain 25 to 155 mg of vitamin C per 100 g of fruit (Kabaluk and others 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, U.S.A., there are more than 80 acres of *A. arguta* 'Ananasnaya', a cultivar that develops a characteristic purple-red blush in full sun, especially when vine ripened (Strik 2004).

Hardy kiwifruit are not picked vine ripe because 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 and others 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 mo 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 wk (Strik 2004).

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 and Methods

Materials

Fruit. Hardy kiwifruit (*A. arguta*) cultivar 'Ananasnaya' were harvested in 2004 at 4 different maturity stages (average SSC of 6.0%, 8.7%, 9.1%, and 15.1% [vine ripe]) from a mature commercial vineyard in Sheridan, Oregon, U.S.A. Vines were trained to a pergola and maintained as per standard recommendations (Strik 2004). These harvest dates were chosen arbitrarily to represent a range of harvest maturities from just physiologically mature to vine ripe and fell on

MS 20050563 Submitted 9/18/05, Revised 11/27/05, Accepted 12/17/05. *Authors Fisk, McDaniel, and Zhao are with Dept. of Food Science and Technology, Oregon State Univ., 100 Wiegand Hall, Corvallis, OR 97331-6602. Author Strik is with Dept. of Horticulture, Oregon State Univ., Corvallis, Oreg. Direct inquiries to author Zhao (E-mail: Yanyun.Zhao@oregonstate.edu).*

September 13, 24, 30, and October 16, 2004. The fruit were packaged in low-vent plastic clamshell containers, 8 fruit per container. Half of the fruit from the 6.0%, 8.7%, and 9.1% SSC harvests were stored under room (22 ± 1 °C, 45% RH) conditions, whereas the other half were stored under refrigerated (2 °C, 88% RH) conditions for 3 wk and then stored under room conditions until ripe. Time ranged from 16 to 22 d for samples stored under room temperature 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, N.J., U.S.A.). The phenolic and antioxidant extraction procedure used acetone and chloroform from EM Science (Gibbstown, N.J., U.S.A.). Total phenolics were determined using Folin & Ciocalteu's Phenol Reagent, 2.0 *N* and sodium carbonate from Sigma-Aldrich, Inc. (St. Louis, Mo., U.S.A.) with gallic acid from EM Science used to construct a standard curve. Antioxidant activity was measured using 1,1-diphenyl-2-picrylhydrazyl (DPPH), a free radical, from TCI America (Portland, Oreg., U.S.A.), dissolved in methanol from EM Science (Gibbstown, N.J., U.S.A.), with ascorbic acid from Mallinckrodt Baker, Inc (Phillipsburg, N.J., U.S.A.) used to construct a standard curve.

Physicochemical analyses

For each replication, surface color was measured at 2 points 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, N.Y., U.S.A.) with a 5-mm-dia punch probe. Each fruit was subjected to a compression speed of 1 mm/s after contact and penetration to 10 mm. 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 end point 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, Calif., U.S.A.). A refractometer (RA-250, KEM, Kyoto Electronics Manufacturing Co., Ltd., Kyoto, Japan) was used to measure 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 Univ. (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* cultivar '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 3-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 24 to 55 y) 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 includ-

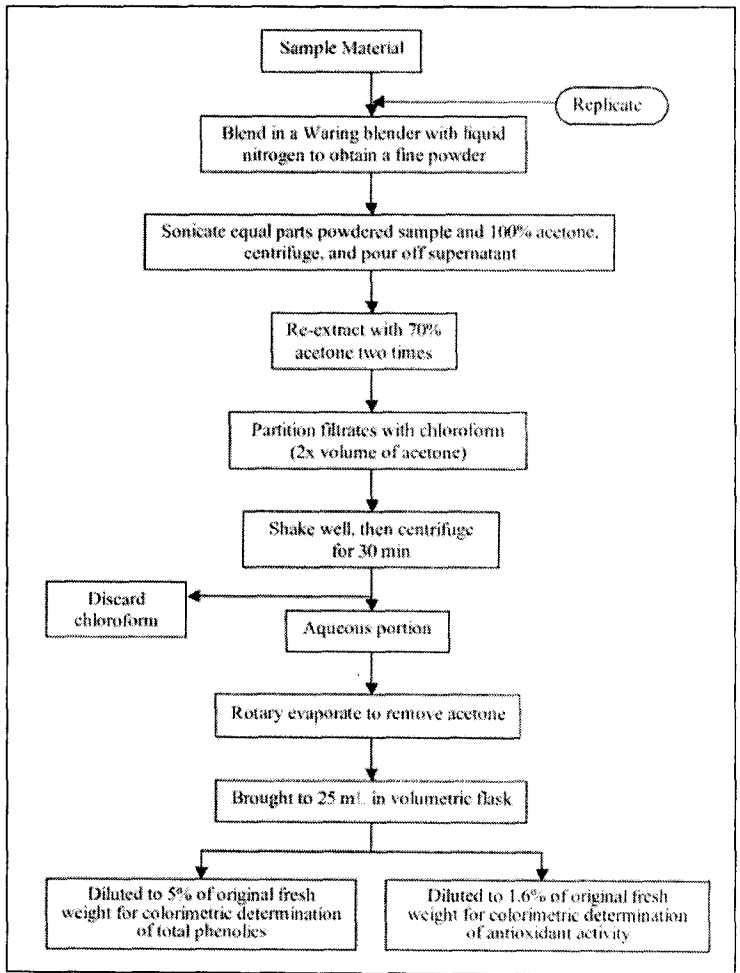

Figure 1—Flowchart of phenolic and antioxidant extraction (modified from Rodriguez-Saona and Wrolstad 2001)

Table 1—Color measurement of ripened hardy kiwifruit harvested at 4 maturity levels and stored under room or refrigerated conditions[a,b]

	6.0% SS		8.7% SS		9.1% SS		
Measurements	Room	Refrigerated	Room	Refrigerated	Room	Refrigerated	Vine ripe
*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)

[a]Color results are based on 2 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 3 wk followed by storage under room conditions until ripe.
[b]Numbers in parentheses refer to the standard deviation. Different letters within a row indicate significant differences at $P < 0.05$ separated by Tukey's Honestly Significant Difference (HSD).

ing safflower oil (15 mL, Saffola Quality Foods, Los Angeles, Calif., U.S.A., for an intensity of 3), Hi-C orange drink (15 mL, Coca Cola Co., Houston, Tex., U.S.A., for an intensity of 7), Welch's purple grape juice (15 mL, Welch Foods Inc., Concord, Mass., U.S.A., for an intensity of 11), and Big Red cinnamon gum (1 stick unwrapped, Wm. Wrigley Jr. Co., Peoria, Ill., 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 d to complete 3 replications and cleansed their palates between samples by drinking spring water (Aqua Cool, Portland, Oreg., 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 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 with the Folin-Ciocalteau 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 3 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 and others 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 4 vines in 1 vineyard, with analyses performed on 3 separate samples for each treatment. Data were analyzed with SAS statistical software Release 8.2 (SAS Inst., Cary, N.C., 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, The Netherlands).

Results and Discussion

Physicochemical analysis

Color measurements of ripened hardy kiwifruit harvested at 4 maturity levels and stored under room or refrigerated conditions are summarized in Table 1. On each fruit, color was measured on 2 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-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 (that is, the effect of refrigeration on u:'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 report-

ed 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 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 and others 1996). Under refrigerated conditions, fruit harvested at 6.0% and 8.7% SSC significantly ($P < 0.05$) decreased in firmness, whereas 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 °C 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.

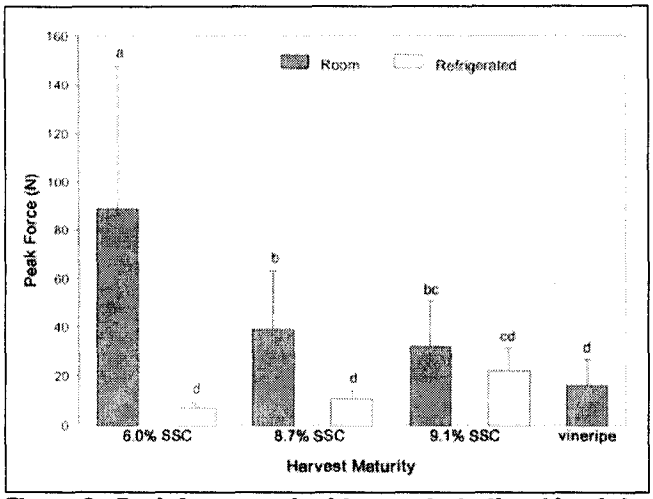

Figure 2—Peak force required to penetrate the skin of ripened hardy kiwifruit harvested at 4 different maturity levels and stored under room conditions (22 ± 1 °C, 45% RH) or refrigerated (2 °C, 88% RH) for 3 wk and then stored under room conditions until ripe. (Samples with different superscripts are significantly different [$P < 0.05$] separated by Tukey's Honestly Significant Difference [HSD].)

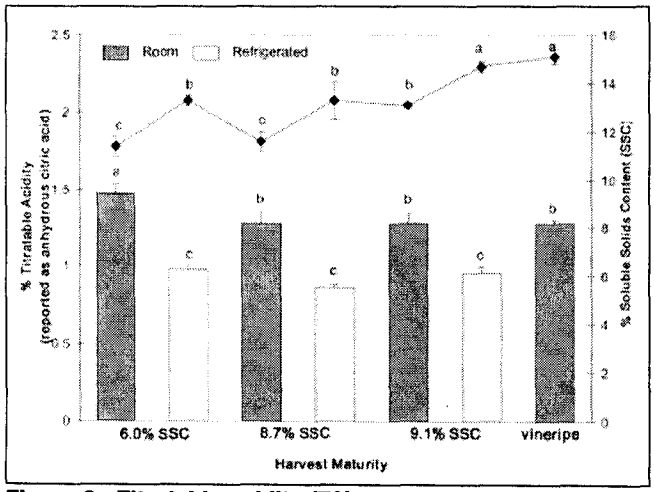

Figure 3—Titratable acidity (TA) and soluble solids content (SSC) at ripeness for hardy kiwifruit harvested at 4 different maturity levels and stored under room conditions (22 ± 1 °C, 45% RH) or refrigerated (2 °C, 88% RH) for 3 wk and then stored under room conditions until ripe. (The shaded bars represent TA; the line represents SSC; vertical bars indicate standard deviation. Samples with different superscripts are significantly different ($P < 0.05$) separated by Tukey's Honestly Significant Difference [HSD]).

Titratable acidity (TA) and SSC at ripeness for hardy kiwifruit are shown in Figure 3. Under refrigerated conditions titratable acidity decreased and SSC increased over all 3 early harvest maturities. In general, refrigeration is known to delay the ripening process (that is, 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 because 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 and others 1992) and in response to low temperature (Langenkämper and others 1998). Previous research has also revealed that SSC increases further upon rewarming after exposure to 0 °C (Langenkämper and others 1998; Antunes and Sfakiotakis 2002). Meanwhile, refrigeration lengthened storage time by 7 to 14 d (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. With 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 'Ananasnaya' reaches 18% to 23% SSC (Strik 2004).

Sensory analysis

Table 2 contains the sensory intensity ratings for consensus descriptors of hardy kiwifruit harvested at 4 different maturity levels and stored under room or refrigerated conditions. It is important to remember that these numbers represent mean ratings averaged across all panelists. These standard deviations (SD) may seem high compared with 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 in which 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 and others 1992). Harvest maturity did not show significant ($P > 0.05$) effects on the mean intensity of the sensory descriptors although a trend was observed 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 ba-

Table 2—Mean sensory intensity ratings for consensus descriptors of hardy kiwifruit harvested at 4 different maturity levels and stored under room or refrigerated conditions[a]

	6.0% SSC		8.7% SSC		9.1% SSC		
Aroma	**Room**	**Refrigerated**	**Room**	**Refrigerated**	**Room**	**Refrigerated**	**Vine ripe**
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[b]	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[b]	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[b]	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[b]	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 vegetable[b]	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[b]	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[b]	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)
Flavor							
Overall intensity[b]	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[b]	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[b]	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[b]	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[b]	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 vegetable[b]	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[b]	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[b]	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)
Basic taste							
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[b]	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)

[a]Mean of 9 panelists × 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 Honestly Significant Difference (HSD). Sixteen-point intensity scale: 0 = none, 7 = moderate, 15 = extreme. 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 3 wk followed by storage under room conditions until ripe. Only consensus descriptors that had a GPA correlation > 0.40 (absolute value) are shown.
[b]No significant ($P > 0.05$) difference between the treatments.

sic 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 1 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 2 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 because 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 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 high-performance liquid chromatography (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 fur-

ther. The antioxidant activity for hardy kiwifruit evaluated in this study was in the range of 1.7 to 1.9 mg ascorbic acid equivalents/g FW. Harvest maturity and storage condition had no significant ($P > 0.05$) effect on antioxidant activity. This is expected because 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 (Okuse and Ryugo 1981; Ferguson and MacRae 1991).

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 1st study to present findings on the total phenolics and antioxidant activity of hardy kiwifruit. One

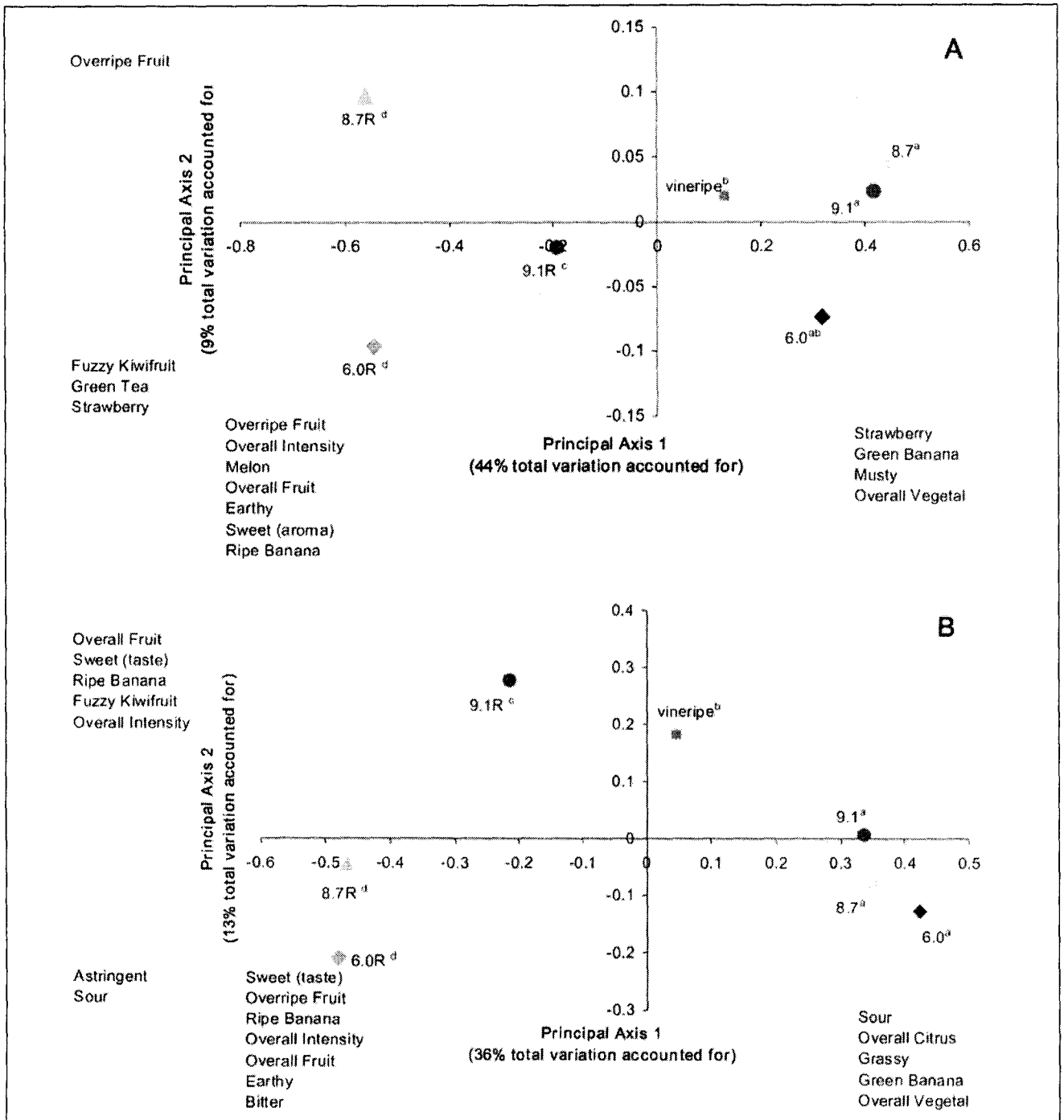

Figure 4—Consensus plots following generalized procrustes analysis (GPA) for free choice profiling of hardy kiwifruit harvested at 4 maturity levels and stored under room conditions (22 ± 1 °C, 45% RH) or refrigerated (with symbol "R," 2 °C, 88% RH) for 3 wk and then stored under room conditions, until ripe: (a) aroma, principal axis (PA) 1 versus 2; (b) flavor, PA 1 versus 2. (Samples with different superscripts are significantly different ($P < 0.05$) on PA 1 separated by Tukey's Honestly Significant Difference [HSD].)

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 whereas 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 to 9.6 mg GAE/g *Vaccinium* blueberries and huckleberries, 1.3 to 10.8 mg GAE/g *Rubus* blackberries, raspberries, and black raspberries, and 1.9 to 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 6 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 and others (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* cultivar 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.

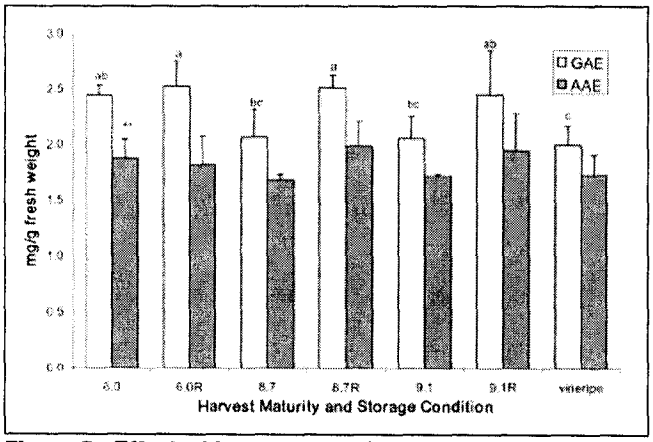

Figure 5—Effect of harvest maturity and storage conditions on total phenolics and antioxidant activity (total phenolics expressed as mg gallic acid equivalents [GAE] per g fresh weight; antioxidant activity expressed as mg ascorbic acid equivalents [AAE] per g fresh weight). Samples were either stored under room conditions (22 ± 1 °C, 45% RH) or refrigerated (with symbol "R," 2 °C, 88% RH) for 3 wk and then stored under room conditions until ripe. Vertical bars represent standard deviation over 3 replications. Bars showing the same index are not significantly different ($P > 0.05$) separated by "Least Significant Difference" (LSD). ** Not significantly different in antioxidant activity between treatments.)

Acknowledgments

The authors acknowledge the contributions of our grower cooperator Mark Hurst of Hurst's Berry Farm, Cindy Lederer for sensory study guidance and help with analysis of the Free-Choice Profiling data, and the financial support of the U.S. Dept. of Agriculture (USDA) Northwest Center for Small Fruits Research.

References

Abdala A, Gerasopoulos D, Stavroulakis G. 1996. Effects of harvest maturity and storage on ripening and membrane permeability of Hayward kiwifruit. Adv Hort Sci 10:3–7.
Antunes MDC, Sfakiotakis EM. 2002. Chilling induced ethylene biosynthesis in 'Hayward' kiwifruit following storage. Sci Hort 92:29–39.
Brand-Williams W, Cuvelier ME, Berset C. 1995. Use of a free radical method to evaluate antioxidant activity. Lebensm Wiss Technol 28:25–30.
Dawes HM, Keene JB. 1999. Phenolic composition of kiwifruit juice. J Agric Food Chem 47:2398–403.
Ferguson AR, MacRae EA. 1991. Vitamin C in *Actinidia*. Acta Hort 297:481–7.
Hjorth HB. 2002. Descriptive analysis of two consecutive vintages of Oregon Pinot noir wines as effected by irrigation, tillage and nitrogen supplementation in the vineyard [MSci thesis]. Oregon State Univ., Corvallis.
Holcroft DM, Kader, AA. 1999. Controlled atmosphere-induced changes in pH and organic acid metabolism may effect color of stored strawberry fruit. Postharv Biol Technol 17:19–32.
Illeperuma CK, Jayasuriya P. 2002. Prolonged storage of 'Karuthacolomban' mango by modified atmosphere packaging at low temperature. J Hort Sci Biotechnol 77(2):153–7.
Imeh U, Khokhar S. 2002. Distribution of conjugated and free phenols in fruits: antioxidant activity and cultivar variations. J Agric Food Chem 50:6301–6.
Kabaluk JT, Kempler C, Toivonen PMA. 1997. *Actinidia arguta*—Characteristics relevant to commercial production. Fruit Var J 51:117–22.
Langenkämper G, McHale R, Gardner RC, MacRae E. 1998. Sucrose-phosphate synthase steady-state mRNA increases in ripening kiwifruit. Plant Molec Biol 36:857–69.
Leong LP, Shui G. 2002. An investigation of antioxidant capacity of fruits in Singapore markets. Food Chem 76:69–75.
MacRae E, Quick WP, Benker C, Stitt M. 1992. Carbohydrate metabolism during postharvest ripening in kiwifruit. Planta 188:314–23.
Matich AJ, Young H, Allen JM, Wang MY, Fielder S, McNeilage MA, MacRae EA. 2003. *Actinidia arguta*: volatile compounds in fruit and flowers. Phytochemistry 63:285–301.
McMath KL, Paterson VJ, Young H, MacRae EA, Ball RD. 1991. Factors affecting the sensory perception of sweetness and acidity in kiwifruit. Acta Hort 297:489–500.
Moyer RA, Hummer KE, Finn CE, Frei B, Wrolstad RE. 2002. Anthocyanins, phenolics, and antioxidant capacity in diverse small fruits: *Vaccinium*, *Rubus*, and *Ribes*. J Agric Food Chem 50:519–25.
Nishiyama I, Yamashita Y, Yamanaka M, Shimohashi A, Fukuda T, Oota T. 2004. Varietal differences in vitamin C content in the fruit of kiwifruit and other *Actinidia* species. J Agric Food Chem 52(17):5472–5.
Okuse I, Ryugo K. 1981. Compositional changes in the developing 'Hayward' kiwifruit in California. J Am Soc Hort Sci 106:73–6.
Paterson VJ, MacRae EA, Young H. 1991. Relationship between sensory properties and chemical composition of kiwifruit (*Actinidia deliciosa*). J Sci Food Agric 57:235–51.
Rassam M, Laing W. 2005. Variation in ascorbic acid and oxalate levels in the fruit of *Actinidia chinensis* tissues and genotypes. J Agric Food Chem 53(6):2322–6.
Rodriguez-Saona LE, Wrolstad RE. 2001. Extraction, isolation and purification of anthocyanins. In: Wrolstad RE, Acree TE, An H, Decker EA, Penner MH, Reid DS, Schwartz SJ, Shoemaker CF, Sporns P, editors. Current protocols in food analytical chemistry. Hoboken, N.J.: John Wiley & Sons. F1.1.1–.11.
Strik B. 2004. Growing Kiwifruit. PNW Ext. Bull. 507. Corvallis, Oreg.: Oregon State Univ. Extension Service. p 23.
Stucky GJ. 1996. Aroma qualities of raw hops and hops in beer by trained panel free-choice profiling [MSci Thesis]. Oregon State Univ., Corvallis.
Waterhouse AL. 2002. Determination of total phenolics. In: Wrolstad RE, Acree TE, An H, Decker EA, Penner MH, Reid DS, Schwartz SJ, Shoemaker CF, Sporns P, editors. Current protocols in food analytical chemistry. Hoboken, N.J.: John Wiley & Sons. I1.1.1–.8.
Williams MH, Boyd LM, McNeilage MA, MacRae EA, Ferguson AR, Beatson, RA, Martin, PJ. 2003. Development and commercialization of 'baby kiwi' (*Actinidia arguta* Planch.). Acta Hort 610:81–6.
Young H, Paterson VJ. 1985. The effects of harvest maturity, ripeness, and storage on kiwifruit aroma. J Agric Food Chem 36:352–8.