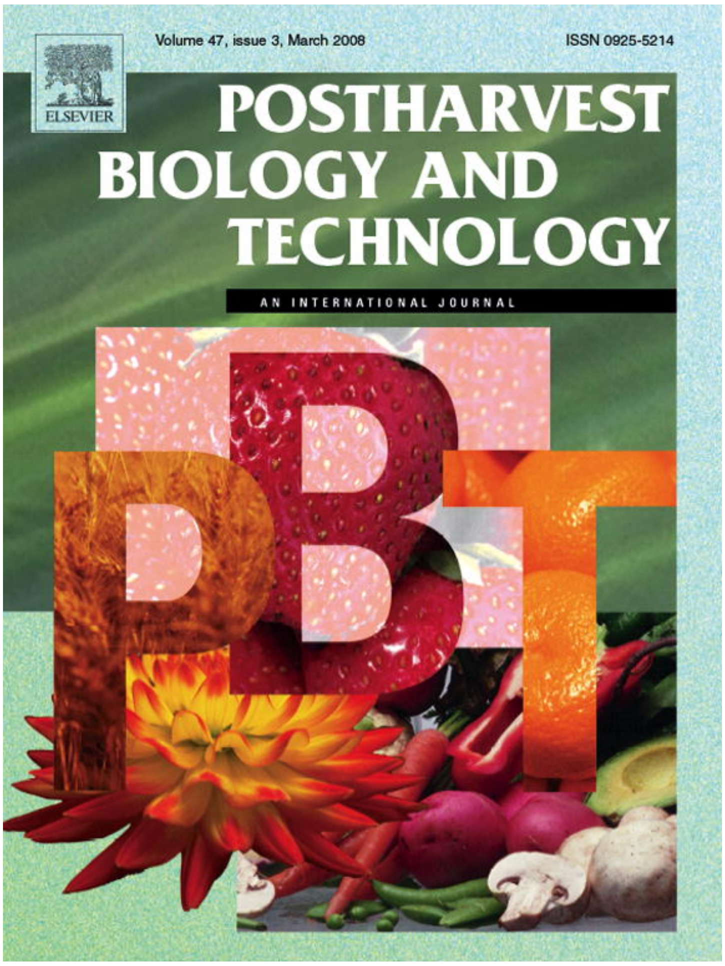
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Postharvest quality of hardy kiwifruit (*Actinidia arguta* 'Ananasnaya') associated with packaging and storage conditions

Connie L. Fisk [a,1], Alissa M. Silver [a,2], Bernadine C. Strik [b], Yanyun Zhao [a,*]

[a] *Department of Food Science and Technology, Oregon State University, 100 Wiegand Hall, Corvallis, OR 97331-6602, United States*
[b] *Department of Horticulture, Oregon State University, 4017 ALS, Corvallis, OR 97331-7304, United States*

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Abstract

Limited information exists regarding the ripening physiology of hardy kiwifruit (*Actinidia arguta* (Siebold & Zucc.) Planch. ex Miq) or the ideal packaging and storage conditions for optimum quality and storage life. In this study, the physicochemical properties (total soluble solids, titratable acidity, pH, firmness, color, weight loss, and respiration) of hardy kiwifruit cv. Ananasnaya were monitored at harvest and during storage from 2003 to 2005. Fruit were packaged in low- or high-vent clamshell containers and stored under room (22 ± 1 °C, 45% RH) or refrigerated (2 °C, 88% RH) conditions. Calcium caseinate, chitosan, PrimaFresh® 50-V, and Semperfresh™ edible coatings were investigated for their potential to enhance the quality and extend the storage life of the fruit. Semperfresh™-coated and uncoated fruit were evaluated by a sensory consumer panel using a hedonic scale in the third season. Low-vent packaging reduced weight loss. Refrigerated storage delayed ripening and extended storage life of fresh fruit compared to un-refrigerated fruit to 7–10 weeks depending on the specific packaging and other storage conditions. Coatings provided an attractive sheen to the fruit surface and did not impair 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.

Keywords: Hardy kiwifruit (*Actinidia arguta* 'Ananasnaya'); Edible coatings; Packaging; Physicochemical properties; Consumer sensory test

1. Introduction

Hardy kiwifruit (*Actinidia arguta* (Siebold & Zucc.) Planch. ex Miq)) have smooth, edible skins, and are smaller in size than 'Hayward' kiwifruit (*Actinidia deliciosa* (A. Chev.) C.F. Liang & A.R. Ferguson). They are not picked vine ripe, as they would be too soft to package and ship (Strik and Hummer, 2006). Instead they are picked when physiologically mature and firm, and are stored under refrigeration (0 °C, 90–95% RH). 'Hayward' can be stored in this manner for 4–6 months with good quality (McDonald, 1990; Cheah and Irving, 1997), while the storage life of hardy kiwifruit is only 1–2 months (Strik and Hummer, 2006).

Edible coatings have the potential to reduce moisture loss, restrict oxygen uptake, lower respiration, retard ethylene production, seal in flavor volatiles and carry additional functional ingredients (such as antioxidants and antimicrobial agents) that retard discoloration and microbial growth (Baldwin et al., 1995). Some coatings 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 (Smith et al., 1987).

In kiwifruit, pullulan, Semperfresh™, calcium caseinate, chitosan, and lipid- and protein-based solutions were evaluated as edible coatings in 'Hayward' kiwifruit (Diab et al., 2001; Xu et al., 2001, 2003). Polysaccharide- and protein-based coatings 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). Pullulan-coated 'Hayward' fruit had higher internal ethylene concentration, leading to acceleration of ripening (Diab et al., 2001). In contrast, Xu et al. (2001, 2003) reported that coatings

* Corresponding author. Tel.: +1 541 737 9151; fax: +1 541 737 1877.
E-mail address: yanyun.zhao@oregonstate.edu (Y. Zhao).
[1] Present address: Duplin County Cooperative Extension Office, North Carolina State University, 165 Agriculture Drive, Kenansville, NC 28349, United States.
[2] Present address: YoCream International, 5858 NE 87th Avenue, Portland, OR 97220, United States.

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composed of soybean protein isolate, stearic acid, and pullulan extended the shelf-life of 'Hayward' by 3 weeks compared with untreated fruit.

Semperfresh™ (SF) is a water-soluble coating comprised of sodium salts of carboxymethylcellulose and sucrose fatty acid esters, and has been commercially available for coating fruits and vegetables since the 1980s. SF reduced apple ripening rate as observed by several parameters including texture and color, but not pH, acidity, soluble solids content or sensory scores (Santerre et al., 1989). SF has also been shown to reduce weight loss and increase firmness, ascorbic acid content, titratable acidity and skin color of cherries during storage, and increase shelf-life of cherries by 26% at 0 °C (Yaman and Bayoindirli, 2002).

Another coating material that has attracted attention is chitosan, deacylated chitin from marine invertebrates (Zhang and Quantick, 1998; Han et al., 2004, 2005). 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 (Park et al., 2005). Chitosan-based coatings decreased incidence of decay caused by *B. cinerea* and *Rhizopus* in inoculated strawberries and raspberries at 13 °C (El Ghaouth et al., 1991; Zhang and Quantick, 1998; Park et al., 2005). Romanazzi et al. (2002) applied chitosan coating to table grapes and reported a reduction in *B. cinerea* gray mold. Negative attributes include the bitterness and astringency of acid-soluble chitosan-based coatings (Rodriguez et al., 2003) and the lack of definitive information regarding shellfish allergenicity and Kosher certification.

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 seasons, from 2003 to 2005, and by evaluating the sensory quality of SF-coated and uncoated hardy kiwifruit using a sensory consumer panel.

2. Materials and methods

2.1. Materials

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

2.2. Preparation of coating solutions

SF coating solution was prepared by diluting 50% Semperfresh™ concentrate with deionized water to 1%. Chitosan 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 0.835 s^{-1}, and then stored overnight at room temperature. Calcium caseinate solution (1% in deionized water) was prepared by homogenizing for 1 min at 0.835 s^{-1} and then shaking in 60 °C water bath for 30 min, followed by cooling to room temperature. PrimaFresh coating solution was prepared by diluting PrimaFresh® 50-V concentrate 1:6 with deionized water.

2.3. Fruit sample preparation

2.3.1. 2003 season

Hardy kiwifruit 'Ananasnaya' were harvested in September 2003 at total soluble solids (TSS) of 10–13% from a commercial vineyard in Independence, OR, USA. 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 the Oregon State University (OSU), Corvallis, OR, USA, 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 eight per package (∼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 eight hardy kiwifruit (∼100 g) in individual wells with two small open air vents. Fruit were then stored under room (room temperature (RT), 22 ± 1 °C; 45% RH) or refrigerated (cooler temperature (CT), 2 ± 0.5 °C; 88% RH) conditions, in the dark.

2.3.2. 2004 season

'Ananasnaya' hardy kiwifruit were harvested in late September 2004 at TSS of 9–11% from a commercial vineyard in Sheridan, OR, USA. 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 at 2 °C in the dark.

2.3.3. 2005 season

Fruit were harvested at TSS of 8–10% from the same vineyard as the 2004 season and transported, sorted and coated as in the previous 2 years. Individual fruit were randomly assigned to a coating treatment (SF, CH, or PF) or the deionized water (uncoated) control treatment. SF and CH are coating materials that showed their effectiveness for controlling weight loss and respiration of berries in our previous studies, and PF is a relatively new coating material for fruit with hydrophobic nature, thus tested in this study. Dry fruit were packaged in LV plastic containers and stored under refrigerated conditions, in the dark. The refrigerated storage room contained a large quantity of fresh pears during the 2005 season, therefore, may have been an ethylene-rich environment. However, the actual concentration of ethylene inside the room was not measured.

2.4. Physicochemical analyses

Firmness was determined by measuring compression using a Texture Analyzer (TA-XT2, Texture Technologies Corp., Scarsdale, NY, USA) 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 Newton. Approximately 100 g of fruit (8 fruit) was weighed at the time of packaging and throughout storage period to calculate percentage weight loss as: [(weight at beginning − weight at each sampling time)/weight at beginning] × 100. Titratable acidity was determined using 5 g of fruit puree from eight fruit mixed with 45 mL of distilled water, titrated with 0.1 mol L^{-1} sodium hydroxide (Mallinckrodt Baker, Inc., Phillipsburg, NJ, USA) to an endpoint of pH 8.1, and expressed as percent anhydrous citric acid since anhydrous citric acid is the dominant acid in kiwifruit (Marsh et al., 2004). Hence only the anhydrous citric acid content was measured and reported in this study. The pH of the samples was measured by a pH meter (IQ240, IQ Scientific Instruments, Inc., San Diego, CA, USA). A refractometer (RA-250, KEM, Kyoto Electronics Manufacturing Co., Ltd., Japan) was used to measure total soluble solids in percent. Three replications were completed for each parameter measured.

For respiration measurements, eight fruit were placed into a half pint glass jar as one replicate, with two replicates used per treatment. After 1 h at 22 °C, a 0.5 mL headspace gas 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, USA), with thermal conductivity detector connected to a Shimadzu CR3A Chromatopac recording integrator (Shimadzu Scientific Instruments, Columbia, MD, USA). CO_2 and O_2 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, USA). 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 among the treatments.

2.5. Sensory analysis in the 2005 season

2.5.1. Recruiting of panelists

Permission to carry out the sensory study was approved by the Institutional Review Board for the Protection of Human Subjects at OSU. Consumers were recruited by emails using the Sensory Science Laboratory database, OSU, Corvallis, OR, USA. Panelists were screened for allergic reactions to kiwifruit and to the ingredients used in Semperfresh^{TM}. 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.

2.5.2. Sample preparation

Ripened fruit were used for the sensory consumer test. Samples were in storage for 3 weeks and reached an average TSS of 15% before evaluation. Samples were taken out of refrigeration 24 h before the start of the evaluation to equilibrate to 22 °C. 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.

2.5.3. Consumer panel

The consumer panel consisted of 91 consumers (45 females and 46 males, aged 18–65 years). 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, and 9 = like extremely). Two LV containers, one containing eight 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), and 5 = definitely would consume (purchase).

2.6. Statistical analysis

Physicochemical data were analyzed with SAS statistical software Release 8.2 (SAS Institute, Cary, NC, USA). 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 sensory 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).

3. Results

3.1. Results of 2003 trials

Total soluble solids were significantly affected by choice of package and storage conditions, but not by coating treatment; thus results are reported averaged over coating treatment (Fig. 1a). TSS of the fruit increased to about 18 and 24% during storage at 2 and 22 °C, respectively, at the end of storage, determined as the time when the fruit would no longer be commercially acceptable (Fig. 1a). TA was affected by coating treatment and package type at 22 °C storage, where CC-coated fruit had significantly lower TA (mean = 0.9%) than SF-coated or control fruit (mean = 0.96%), and HV packed fruit had significantly lower TA than those packed in LV packaging (Fig. 1b). There was no effect of coating on TA of fruit stored at 2 °C with a mean of TA = 0.95% (Fig. 1b).

Cold temperature storage at 2 °C effectively delayed weight loss of fruit compared to fruit held at 22 °C (Fig. 2a). Fruit in LV packaging had reduced weight loss than fruit in HV packaging when stored at RT (Fig. 2a). Coatings provided an attractive sheen to the fruit surface, but had little impact on weight loss (data not shown).

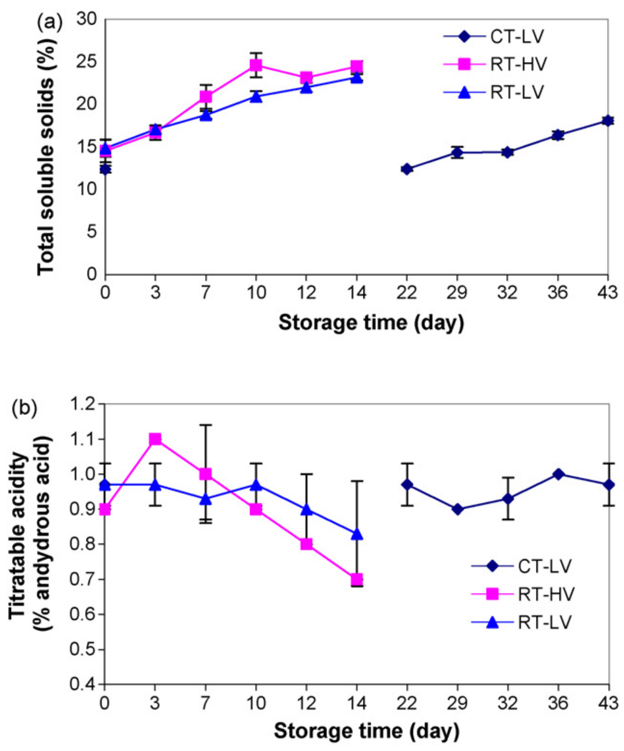

Fig. 1. Effect of packaging and storage conditions on ‘Ananasnaya’ hardy kiwifruit in 2003: (a) total soluble solids and (b) titratable acidity. Fruit were stored at cold temperature (CT; 2 °C) or room temperature (RT) in low-vent (LV) or high-vent (HV) packaging where data are averaged over coating treatment. Samples stored at CT were all in LV packaging (mean ± S.D.).

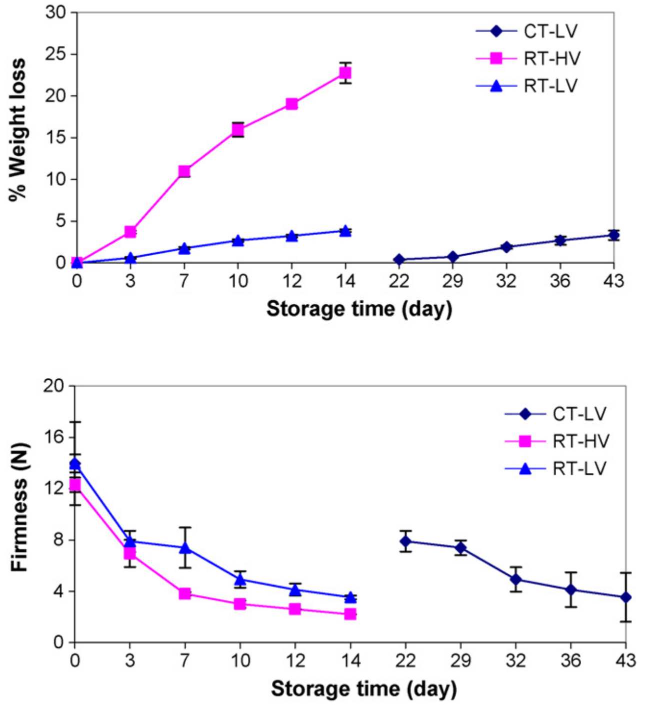

Fig. 2. Effect of packaging and storage conditions on ‘Ananasnaya’ hardy kiwifruit in 2003: (a) percent weight loss and (b) firmness. Fruit were stored at cold temperature (CT; 2 °C) or room temperature (RT) in low-vent (LV) or high-vent (HV) packaging where data are averaged over coating treatment. Samples stored at CT were all packed in LV packaging (mean ± S.D.).

In general, RT-stored fruit were less firm than CT-stored fruit, and fruit stored in HV packaging were less firm than those stored in LV packaging (Fig. 2b). Fruit stored at RT lost firmness dramatically after 3 days. CC-coated fruit initially had greater firmness than other fruit coating treatments, but there were no significant differences between coating treatments or the control for fruit firmness after the initial 3 days of storage (data not shown).

These results indicate that CT storage and use of LV packaging could significantly delay ripening (reducing the rate of TSS increase), reduce weight loss and retain firmness of fresh hardy kiwifruit during storage, thus effectively extending shelf-life. RT-stored fruit became shriveled and/or molded after 2 weeks of storage, and thus were not considered marketable.

3.2. Results of 2004 trials

Overall, there were no significant differences between SF-coated and control fruit for TSS, TA, pH, weight loss and firmness in the 2004 season trial; thus means are presented in Fig. 3. TSS increased significantly during the first 2 weeks of refrigerated storage (from about 10.5 to 15%), remained relatively stable the following 4 weeks, and then decreased the last 2 weeks of storage (Fig. 3a). While the decrease in TSS at the end of the storage period was not predicted, kiwifruit research has demonstrated that while TSS 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). As expected, TA of fruit decreased (Fig. 3b) and pH increased

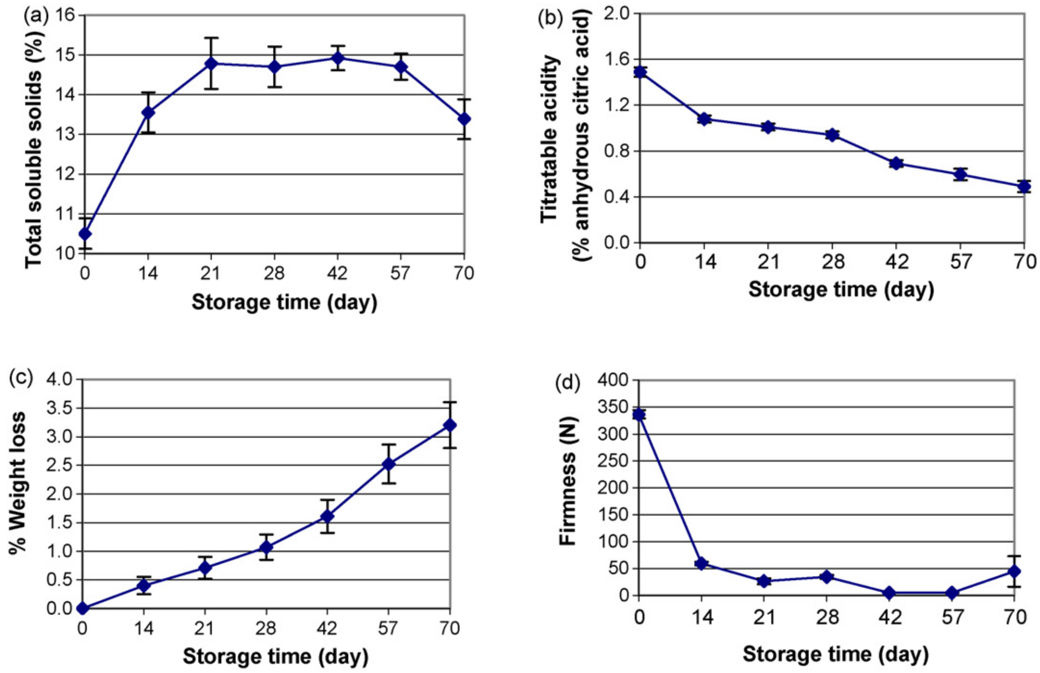

Fig. 3. Effect of 10 weeks of cold storage (2 ± 0.5 °C and 88% RH) on: (a) total soluble solids, (b) titratable acidity, (c) weight loss, and (d) firmness of 'Ananasnaya' hardy kiwifruit in 2004. There was no effect of coating treatment so data represent an average of control and coated fruit (mean ± S.D.). All fruit were in LV packaging.

(from 3.4 to 4.2; data not shown) with storage time. Again, the percentage of weight loss of fruit increased with storage time with no significant effect of coating (Fig. 3c). Fruit firmness decreased during storage (Fig. 3d).

Color measurements (Table 1) showed a trend ($p < 0.1$) for control fruit appearing lighter than SF-coated fruit after 4 weeks of storage. There were no significant differences between the two treatments on hue angle or chroma.

By the end of week 10 of storage, the fruit were still considered marketable based on observations of their surface appearance, especially for the SF-coated fruit, where no significant shriveling and mold growth were observed (data not shown), and fruit had an attractive surface sheen.

3.3. Results of 2005 trials

By the end of 7 days of storage, all fruit reached TSS of about 14–15%, and there was no further increase during the following 4 weeks of cold storage. As expected, the TA of fruit continuously decreased throughout storage, from about 1.26% anhydrous citric acid at 7 days of storage to less than 1% at the end of 42 days, and pH continuously increased from an initial level of about 3.61 to 3.75. There were no significant differences between coating treatments for TSS, TA and pH. Treatment did not affect the headspace CO_2 to O_2 ratio (Fig. 4). This result was to be expected, because the likely presence of ethylene caused kiwifruit to undergo more rapid and uniform ripening, which is often used as a preconditioning technique by processors prior to shipping kiwifruit (Crisosto et al., 1997).

Percent weight loss of fruit in 2005 was not affected by coating treatment and responded similarly to that reported for 2004. By the end of 6 weeks of storage, the average weight loss reached about 3.7%. While fruit with any edible coating were 44% firmer, on average, than untreated, control fruit at 7 days of storage, there was no coating effect from 14 to 42 days of storage (data not shown).

Table 1
Changes in color of 'Ananasnaya' hardy kiwifruit during 10 weeks of storage at 2 °C in 2004[a]

Quality parameters	Treatment	Storage time (day)						
		0	14	21	28	42	57	70
L^*[b]	SF	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)
	Control	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)
Hue[b]	SF	−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)
	Control	−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)
Chroma[b]	SF	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)
	Control	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)

[a] Fruits were packed in low-vent (LV) containers.
[b] Mean and S.D. of 24 fruit, 2 measurements each. L^*: lightness, hue = $\arctan(b^*/a^*)$, and chroma = $(a^{*2} + b^{*2})^{1/2}$.

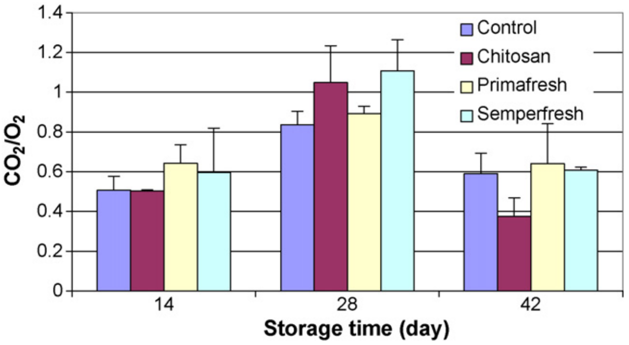

Fig. 4. Headspace CO_2/O_2 ratio of 'Ananasnaya' hardy kiwifruit as affected by coating treatment during 6 weeks of storage at 2 °C in 2005 (mean ± S.D.). Coatings—control: uncoated; SF: Semperfresh™, ester-based coating; PF: PrimaFresh® 50-V, vegetable-oil-based coating; and CH: chitosan-based coating. Fruit were in LV packaging.

Table 2
Sample 'liking' means, standard deviations, and significance ($n = 91$) of the 2005 season sensory consumer test for control and Semperfresh™ (SF)-coated ripe 'Ananasnaya' hardy kiwifruit after storage at 2 °C for 3 weeks[a]

Sensory attributes	Control sample mean	SF-coated sample mean	p-Value
Appearance[NS]	7.6 (0.9)	7.4 (1.1)	0.1866
Color[NS]	7.4 (1.0)	7.4 (1.0)	0.9257
Overall Liking[NS]	7.3 (1.1)	7.0 (1.7)	0.0823
Flavor[NS]	7.1 (1.5)	7.0 (1.8)	0.3092
Sweetness[NS]	7.2 (1.5)	7.0 (1.8)	0.2627
Sourness[NS]	6.4 (1.8)	6.2 (1.9)	0.3245
Texture[NS]	6.9 (1.7)	6.7 (1.9)	0.4278
Aftertaste[NS]	6.0 (2.0)	5.6 (2.2)	0.1518

[NS] Attribute not significant at $p > 0.05$ level.
[a] Nine point liking (acceptance) scale where 1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely.

3.4. Consumer sensory results

Table 2 shows the results of the sensory consumer test on ripened fruit. SF-coated and uncoated fruit had similar acceptance over all eight sensory attributes. In general, both coated and uncoated hardy kiwifruit were well liked by consumers as indicted by their mean ratings for Appearance Liking, Color Liking, Overall Liking, Flavor Liking, and Sweetness Liking (means ranged from 7.0 to 7.6; 7 = like moderately and 8 = like very much) (Table 2). The Sourness Liking and Aftertaste Liking means ranged from 5.6 to 6.2 (5 = neither like nor dislike and 6 = like slightly) (Table 3). Texture ratings were 6.7 (coated) to 6.9 (uncoated) (6 = like slightly and 7 = like moderately). Table 3 displays the consumer responses for the intent to consume/purchase hardy kiwifruit. Over half (51.7%) of the consumers indicated that they 'definitely would' consume hardy kiwifruit, and 29.7% 'probably would' consume; 42.9 and 31.9% would 'definitely' or 'probably' purchase hardy kiwifruit, respectively. Only less than 5% of the consumers tested would 'probably not' or 'definitely not' consume hardy kiwifruit. Hardy kiwifruit is a relatively new berry crop in the US market, so few consumers are acquainted with the product. The information generated from this sensory consumer study would be very important for growers who currently ship most of their fruit to markets in Asia or tourist destinations such as Hawaii. Consumers in Corvallis, OR, USA, like the fruit and would purchase and consume it. Therefore, producers should proceed with marketing efforts in their local and other US areas.

4. Discussions

4.1. Seasonable variations

Postharvest ripening of hardy kiwifruit from the three seasons, 2003–2005, showed significant differences. Harvest maturity (TSS) of the fruit, edible coatings, package and storage conditions, as well as weather conditions during fruit growth, especially close to harvest date, could all have been significant factors impacting the ripening process of the fruit. For example, in 2003, fruit at the final ripe stage reached TSS of about 18%, compared with only about 15% in 2004, under the same refrigerated storage conditions. In 2003, fruit TA retained relatively stable during 6 weeks of refrigerated storage (0.9–1.0% anhydrous citric acid), but decreased in 2004 (from about 1.5 to 0.7% during the same 6 weeks of storage). Possible explanations may be the difference in harvest maturity (TSS) of the fruit, where it was about 12.5% in 2003, but ∼10.5% in 2004, or the fact that the fruit harvested in 2003 were from a different vineyard than those harvested in following years. Fisk et al. (2006) investigated the influences of harvest maturity (TSS of 6.0, 8.7, 9.1, and 15.1%) and storage conditions (22 ± 1 °C and 45% RH, or 2 °C and 88% RH for 3 weeks followed by a ripening period at 22 ± 1 °C and 45% RH) on the physicochemical, sensory, and nutritive qualities of 'Ananasnaya' hardy kiwifruit. Harvest maturity of fruit and storage conditions significantly affected fruit physicochemical, nutritive and sensory quality, and they suggested that 'Ananasnaya' should be harvested at greater than TSS of 8% and stored under refrigeration to achieve high quality. In addition, weather conditions differed between the three harvest seasons. It was relatively warm and dry in 2003, but cold and rainy in 2004 and 2005, before fruit harvest (data not shown). Differences in weather may have affected the appearance or quality of the fruit; more mold growth was observed on fruit during postharvest stor-

Table 3
Consumer sensory panelist intent to consume/purchase ripe 'Ananasnaya' hardy kiwifruit after storage at 2 °C for 3 weeks[a]

Decision	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

[a]Mean of 91 consumer responses to the question, 'Overall, based on your appearance and tasting experience, how likely would you be to consume (purchase) hardy kiwifruit?'

age in 2004 and 2005 than in 2003 (data not shown). Weather may also have affected fruit ripening and harvest date, as well as basic physicochemical properties, such as TA and firmness. Even given the different growing conditions, the fruit harvested in 2004 remained marketable throughout 10 weeks of storage when packed in LV containers with edible SF-based coatings.

In 2005, fruit were harvested at TSS of 8–10% and stored at 2 °C and ∼88% RH in the presence of pears, and thus were likely exposed to an ethylene-rich environment. Under these conditions, fruit ripened quickly, reaching about TSS of 15% after 1 week of storage, with no further increase in TSS during the following 5 weeks of cold storage, while the TA continuously decreased during storage as expected. Fruit reached a similar final TSS and had the same trend in TA changes as those in 2003. It is well known that ethylene accelerates the fruit ripening process and that kiwifruit are responsive to concentrations of ethylene as low as 0.1 $\mu L\,L^{-1}$, even under low temperature and controlled environments (McDonald and Harman, 1982; Beever and Hopkirk, 1990). Ethylene treatment has been commercially utilized to accelerate the ripening process of kiwifruit, and is known to reduce variation among fruit so that each fruit in a lot reaching the marketplace would be at a similar ripeness level (Crisosto et al., 1997).

4.2. Coating effects

Weight loss by moisture evaporation through the fruit surface is determined by the resistance of the fruit skin to vapor diffusion and the strength of pressure differences between fruit tissues and surroundings (Patterson, 1987). SF and CH are all polysaccharide-based materials with β (1–4) linked polymeric backbone structures. Polysaccharide-based coatings have been mainly applied to intermediate or dry food products due to the hydrophilic nature compared to the more hydrophobic wax coatings. Protein-based coatings, such as CC are also known as poor barriers for moisture transfer (Baldwin, 1994). It was expected that these polymers would provide some barrier by forming a water-holding layer on the fruit surface, decreasing respiration rate and increasing the resistance of the fruit skin to gas and water vapor diffusion. However, we did not observe a benefit of these coatings on weight loss of hardy kiwifruit in either 2004 or 2005. This may be the result of increased water penetration through the protective cuticular layer of the fruit.

CH coatings on other fruits, such as raspberries and strawberries have successfully reduced weight loss (Zhang and Quantick, 1998; Han et al., 2004). The effectiveness of coatings on controlling moisture loss is associated with the properties of the natural protective layers of each type of fruit. The fruit outer protective layer, which plays an important role in hardy kiwifruit weight loss, is composed of cuticle, epidermal cells, stomata, and lenticels. The cuticle is a thin natural waxy covering on the fruit surface. Hardy kiwifruit has a very thin cuticle layer which is very susceptible to external damage and environment conditions. Perhaps the structural integrity of the thin cuticle layer was weakened by the coating material which may have penetrated the fruit skin causing ionic interactions with charged membrane components. Another possibility is that the application of the coating solution may have damaged the natural waxy layer, thus enhancing weight loss. Hence, the selection of appropriate coating materials and methods of application are critical for their success in controlling moisture loss of fresh hardy kiwifruit.

While coatings showed no significant benefit for controlling weight loss in our study, they may reduce incidence of mold, especially when using chitosan coatings which have a natural anti-fungal ability (Zhang and Quantick, 1998; Han et al., 2004). In addition, coated fruit appeared to have a shiny and uniform surface appearance as commented by consumers in the sensory consumer test.

As demonstrated in 2003, the LV packaging was extremely beneficial in reducing weight loss of hardy kiwifruit in comparison with traditional HV clamshell containers used for other berry crops. However, the LV package is considerably more expensive than the traditional HV package. In this case, coatings, especially at 22 °C storage conditions, may be a good alternative to cost-effectively replace LV package.

5. Conclusion

Year-to-year variations in the postharvest ripening and some basic physicochemical properties were readily apparent in ‘Ananasnaya’ hardy kiwifruit. However, their response to packaging, storage conditions and coating treatment are reproducible, offering postharvest treatments that enhance quality and extend shelf-life of the fruit. Although TSS of the vine ripe for hardy kiwifruit was reportedly 18–23% (Strik and Hummer, 2006), the results of this study show as much as 24% in room temperature stored fruit, but only 15–18% in refrigerated fruit. When hardy kiwifruit were packed in traditional high-vent clamshell containers or exposed to ethylene during storage, the storage life of the fresh fruit was about 7–10 weeks, validating current recommendations for storage life of this crop. However, observations in 2004 suggest that the storage life of hardy kiwifruit may be extended to as many as 14 weeks through the use of low-vent packaging combined with edible coatings. When appropriate coating materials are chosen, edible coatings can significantly improve the surface appearance of the fruit. Since low-vent packaging is costly, edible coatings may be of particular interest to producers who wish to improve their product quality while continuing to use high-vent packaging.

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References

Baldwin, E.A., 1994. Edible coatings for fresh fruits and vegetables: past, present and future. In: Krochta, J., Baldwin, E., Nisperos-Carriedo, M. (Eds.), Edible Coatings and Films to Improve Food Quality. Technomic Publ. Co., Basel, Switzerland, pp. 25–65.

Baldwin, E.A., Nisperos-Carriedo, M.O., Baker, R.A., 1995. Use of edible coatings to preserve quality of lightly (and slightly) processed products. Crit. Rev. Food Sci. Nutr. 35, 509–524.

Beever, D.J., Hopkirk, G., 1990. Fruit development and fruit physiology. In: Warrington, I.J., Weston, G.C. (Eds.), Kiwifruit Science and Management. Ray Richards Publisher, Auckland, NZ, pp. 97–126.

Cheah, L.H., Irving, D.E., 1997. Kiwifruit. In: Mitra, S.K. (Ed.), Postharvest Physiology and Storage of Tropical and Subtropical Fruits. CAB International, New York, pp. 209–227.

Crisosto, C.H., Garner, D., Crisosto, G.M., Kaprielian, R., 1997. Kiwifruit preconditioning protocol. Acta Hort. 444, 555–559.

Diab, T., Biliaderis, C.G., Gerasopoulos, D., Sfakiotakis, E., 2001. Physicochemical properties and application of pullulan edible films and coatings in fruit preservation. J. Sci. Food Agric. 81, 988–1000.

El Ghaouth, A.E., Arul, J., Ponnampalam, R., Boulet, M., 1991. Chitosan coating effect on storability and quality of fresh strawberries. J. Food Sci. 56, 1618–1620.

Fisk, C.L., Strik, B.C., McDaniel, M.R., Zhao, Y., 2006. Physicochemical, sensory, and nutritive qualities of hardy kiwifruit (*Actinidia arguta* 'Ananasnaya') as affected by harvest maturity and storage. J. Food Sci. 71, S204–S210.

Han, C., Zhao, Y., Leonard, S.W., Traber, M.G., 2004. Edible coatings to improve storability and enhance nutritional value of fresh and frozen berries. Postharvest Biol. Technol. 33, 67–78.

Han, C., Lederer, C., McDaniel, M., Zhao, Y., 2005. Sensory evaluation of fresh strawberries (*Fragaria ananassa*) coated with chitosan-based edible coatings. J. Food Sci. 70, 172–178.

Kaplan, H.J., 1986. Washing, waxing, and color adding. In: Wardowski, W.F., Nagy, S., Grierson (Eds.), Fresh Citrus Fruits. Avi Publishing Company, Inc., Connecticut, pp. 379–395.

MacRae, E., Quick, W.P., Benker, C., Stitt, M., 1992. Carbohydrate metabolism during postharvest ripening in kiwifruit. Planta 188, 314–323.

Marsh, K., Attanayake, S., Walker, S., Gunson, A., Boldingh, H., MacRae, E., 2004. Acidity and taste in kiwifruit. Postharvest Biol. Technol. 32, 159–168.

McDonald, B., 1990. Precooling, storage, and transport of kiwifruit. In: Warrington, I.J., Weston, G.C. (Eds.), Kiwifruit: Science and Management. Ray Richards Publisher, Auckland, NZ, pp. 429–459.

McDonald, B., Harman, J.E., 1982. Controlled-atmosphere storage of kiwifruit. 1. Effect of fruit firmness and storage life. Sci. Hort. 17, 113–123.

Mitchell, F.G., Mayer, G., Biasi, W., 1991. Effect of harvest maturity on storage performance of 'Hayward' kiwifruit. Acta Hort. 297, 617–625.

Park, S.I., Stan, S.D., Daeschel1, M., Zhao, A.Y., 2005. Antifungal coatings on fresh strawberries (fragaria × ananassa) to control mold growth during cold storage. J. Food Sci. 70, M197–M201.

Patterson, M.E., 1987. Factors of loss and the role of heat removal for maximum preservation of sweet cherries. Postharvest Pomol. Newslet. 5, 3–9.

Rodriguez, M.S., Albertengo, L.A., Vitale, I., Agullo, E., 2003. Relationship between astringency and chitosan–saliva solutions turbidity at different pH. J. Food Sci. 68, 665–667.

Romanazzi, G., Nigro, E., Ippolito, A., DiVenere, D., Salerno, M., 2002. Effects of pre- and postharvest chitosan treatments to control storage grey mold of table grapes. J. Food Sci. 67, 1862–1867.

Santerre, C.R., Leach, T.F., Cash, J.N., 1989. The influence of the sucrose polyester, Semperfresh™, on the storage of Michigan grown "McIntosh" and "Golden Delicious" apples. J. Food Process. Preserv. 13, 293–305.

Smith, S., Geeson, J., Stow, J., 1987. Production of modified atmospheres in deciduous fruits by the use of films and coatings. Hort. Sci. 22, 772–776.

Strik, B., 2005. Growing Kiwifruit. PNW Ext Bull 507. Oregon State University Extension Service, Corvallis, OR, p. 23.

Strik, B., Hummer, K., 2006. 'Ananasnaya' hardy kiwifruit. J. Am. Pom. Soc. 60, 106–112.

Xu, S., Chen, X., Sun, D.-W., 2001. Preservation of kiwifruit coated with an edible film at ambient temperature. J. Food Eng. 50, 211–216.

Xu, S., Xu, L.D., Chen, X., 2003. Determining optimum edible films for kiwifruits using an analytical hierarchy process. Comp. Oper. Res. 30, 877–886.

Yaman, Ö., Bayoindirli, L., 2002. Effects of an edible coating and cold storage on shelf-life and quality of cherries. Lebensm. Wiss. u Technol. 35, 146–150.

Zhang, D., Quantick, P., 1998. Antifungal effects of chitosan coating on fresh strawberries and raspberries during storage. J. Hort. Sci. Biotechnol. 73, 763–767.