QUALITY OF PINK LADY® BRAND APPLE

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ABSTRACT

Apple (*Malus domestica* Borkh, 'Pink Lady® brand') fruit were harvested from one California orchard in 2002, 2003 and 2004 at two or three different maturity stages each year. Fruit were evaluated for background color, firmness, fruit size, percentage of blush, starch index (CTIFL chart), soluble solids, titratable acidity and carbon dioxide (CO_2) production and immediately stored at 33 ºF in air or in controlled atmosphere (CA). In 2003, additional treatments included 1 ppm of SmartFresh® (1-MCP) or 2200 ppm of diphenylamine (DPA). Firmness, CO_2 production, external condition and internal browning were determined after storage in CA or air and 5 days at 68 ºF. Fruit stored in CA conserved higher firmness and produced less CO_2. Internal browning was not seen in fruit stored in air, but appeared in fruit after two months storage in CA. The incidence did not increase after longer storage times. SmartFresh® worked as well as CA in conserving the quality of the fruit. It did not affect the incidence of internal browning, but DPA inhibited internal browning completely. When comparing similar storage atmospheres for all three seasons, the incidence of internal browning was significantly different, being much higher in 2002 and 2004. A mineral analysis of the apple flesh showed differences among the seasons. Concentrations of calcium (Ca), boron (B) and magnesium (Mg) were significantly higher in 2003, corresponding with a lower incidence of internal browning.

INTRODUCTION

The Pink Lady® brand apple was developed in Australia in the late 1960s from a cross between Golden Delicious and Lady Williams. Since then, it has been sought for its brilliant pink color, sweet-tart flavor and crunchy texture. It was introduced in California in the 1990s and today about 1,000 acres are in production. In California, there is some difficulty growing a colorful apple because of the warm climate, and this has resulted in delays in harvest that can affect fruit quality. California Pink Lady® brand apples are marketed all over the United States, mainly in the northeast.

Controlled atmosphere (CA) storage extends the life and preserves the quality of Pink Lady® brand apples. As with many other commodities, reducing oxygen (O_2) and increasing carbon dioxide (CO_2) concentrations retards aging, reduces ripening and maintains titratable acidity (Kader 1986). However, CA can also cause physiological disorders, such as internal browning in Fuji apples (Volz et al., 1998) and Braeburn Browning Disorder (BBD) (Lau 1998). Lau showed that at any given harvest date, the incidence of BBD and internal cavities was greater with higher concentrations of CO_2. Additionally, he showed that late harvests were more susceptible to BBD injury, perhaps due to the increase in respiration rate, increased tissue resistance to gas diffusivity or increased susceptibility to high CO_2 and low O_2 atmospheres.

The internal browning disorder of Pink Lady® brand apples is the result of the interaction of unknown pre- and postharvest factors, as well as the physiological state of the fruit at harvest.

Internal browning generally occurs intermittently and in unpredictable patterns. There are at least two different manifestations of this physiological disorder. One is the diffuse browning, related to senescence breakdown and chilling injury and the other is a CO_2 injury, associated with CA storage.

Results with other varieties suggest that there is more than one factor that predisposes the fruit to internal browning injury. It is widely recognized that variations in mineral composition affect fruit quality after harvest (Bramlage et al., 1980; Sharples 1980; Raese et al., 1989). Mineral composition greatly influences postharvest quality retention, and calcium is dominant in this retention. Trees high in nitrogen are usually vigorous trees with a large crop. However, excess nitrogen can promote poor red color, softer fruit which can be easily bruised, and larger fruit size which can lead to lower concentrations of calcium as this is being diluted (Perring and Jackson 1975). Lau and Looney (1978) investigated differences in mineral content of Golden Delicious apples and found a greater incidence of CO_2 injury associated with higher fruit nitrogen (N), manganese (Mn) and zinc (Zn) and lower potassium (K) and magnesium (Mg), but no association with calcium (Ca) concentrations.

SmartFresh® (1-methylcyclopropene) and diphenylamine (DPA) may prevent internal browning in Pink Lady® brand apples. SmartFresh® benefits in fruit conservation are numerous and some of them remain unknown. Watkins et al. (2000) showed that SmartFresh® reduced superficial scald incidence, and these effects of SmartFresh® were greater in CA than in air storage. If the mechanism that causes the development of internal browning is ethylene-dependent, SmartFresh® has the potential capacity to inhibit internal browning.

DPA is an antioxidant used in the apple industry to inhibit scald injury (Lau 1990). Its antioxidant properties seem to also prevent internal browning. It has been found that DPA treatment markedly reduced the incidence of both external and internal CO_2 injury (Watkins et al., 1997; Fernandez-Trujillo et al., 2001).

MATERIALS AND METHODS

1.1 Fruit Material

On September 21 and October 20, 2002; October 6 and 20 and November 6, 2003; and September 21 and October 5 and 22, 2004, Pink Lady® brand apples were harvested in the early morning from five 40-tree plots in the same orchard near Stockton, California. Approximately 50 apples were harvested per tree, and each tree was harvested once. To determine the progress of starch conversion to sugars over time, a group of 30 apples were collected weekly from the same orchard starting on the first week of September each year.

1.2 Harvest Evaluations

On the day of harvest, three groups of 30 fruit, 6 fruit for each of five replications, were selected randomly among the plots to determine the at-harvest starch disappearance pattern, soluble solids (SS) content, titratable acidity (TA), firmness, percentage of blush, and background color. Ethylene production was also measured during 25 days at 68 ºF (20 ºC). The average fruit size was determined by weighing the entire lot and dividing by the number of apples.

Fruit firmness was measured as resistance to penetration with an 11-mm probe using a Fruit Texture Analyser (Güss, South Africa). The background color was assessed with a CTIFL (Centre technique interprofessionnel des fruits et legumes, association Pink Lady Europe) color

scale (3=green to 7=yellow). The percentage of blush area was visually estimated. Juice was extracted from wedges cut from stem to blossom end from fruit within a replication for determination of SS content and TA. Percent SS was determined by a digital refractometer (Abbe model 10450, American Optical, Buffalo, N.Y.) and TA (citric acid equivalents) by an automatic titration system (TIM 850, Radiometer, Copenhagen, Denmark).

Six fruit from each of five replications were placed together in 1 gallon jar connected to a flow board which supplied a uniform flow of air at 120 mL/min for 24 days at 68 ºF. During ripening, the outlet gases were monitored daily for CO_2 and ethylene to determine production rates.

The second group of 30 apples were cut in half, dyed for two minutes in 3% iodine-potassium iodide and rinsed with fresh water. The starch levels were scored using a 10 point CTIFL scale (Centre technique interprofessionnel des fruits et legumes, association Pink Lady Europe).

1.3 Treatments

The day following harvest, after holding overnight at 50 ºF, fruit were sorted to obtain undamaged fruit of uniform size and color and immediately cooled to 33 ºF in air for 24 hours before starting the CA treatment. Following a determined storage period plus 5 days at 68 ºF, fruit were assessed for flesh browning and other quality attributes.

In 2002, the two harvest maturities, with starch content scores of 3.3 and 6.7 (CTIFL), were stored in air, or 1.5, 3.0 or 21% O_2 in a factorial with 1.0, 3.0 and 5.0% CO_2 at 33 ºF for 2 and 6 months. The high CO_2 atmospheres were included to increase the odds of developing internal browning for research purposes.

In 2003, fruit were harvested at three maturities with starch content scores of 3.8, 6.3 and 8.5 (CTIFL). All fruit were stored in either air, 2% O_2 + 1% CO_2, or 2% O_2 + 3% CO_2 at 33 ºF. In the first experiment, fruit from the three harvests were held at 50 ºF overnight, sorted the following day and pre-cooled at 33 ºF for 24 hours before being placed into air or CA storage for 0.5, 1, 2 or 4 months. For the second experiment, apples from the second harvest were pre-cooled at 33 ºF and placed into stainless-steel tanks for SmartFresh® treatment. A small electric fan was also placed inside each tank to ensure even distribution of SmartFresh® gas around the fruit. SmartFresh® tablets were used to generate 1 ppm of SmartFresh® gas. Apples were treated with SmartFresh® for 24 hours at 33 ºF and then placed into air or CA at 33 ºF. Another set of fruit was treated with a 2200 ppm solution of DPA in water by immersion for 5 minutes, air-dried at 68 ºF, cooled overnight at 33 ºF and then placed into air or CA at 33 ºF. The third set of fruit in experiment two was untreated and placed in air or CA storage at the same time as the other fruit. All fruit were stored for 4 months.

In 2004, fruit were harvested at three maturities with starch content scores of 3.8, 6.2 and 8.5 (CTIFL). All fruit were stored in air or 1.5% O_2 in a factorial with 1.0, 3.0 and 5.0% CO_2 at 33ºF for 2, 4 and 6 months. In the first experiment, fruit from the three harvests were sorted and cooled at 33ºF for 24 h before being placed into CA storage. For the second experiment, a set of fruit from the second harvest was treated with a 2200 ppm solution of DPA in water by immersion for 5 minutes, air-dried at 68 ºF, cooled overnight at 33 ºF and then placed into air or CA at 33 ºF. Fruit were stored for 4 months.

1.4 Quality evaluations

After storage plus 5 days at 68 ºF, 60 fruit were selected to determine firmness, background color and external condition. Ethylene and CO_2 production were also measured during 15 days at 68 ºF in 2003 as previously described.

RESULTS

The rate of starch conversion to sugar varied for the three years, 2002, 2003 and 2004, therefore the harvest dates, which occurred based on starch content, varied (Figure 1). The initial values for SS and TA were similar at equivalent starch levels in 2002, 2003 and 2004 (Figure 2), showing a high correlation with starch content. However, values of percentage of blush, fruit size and firmness were not highly correlated with starch content due to the influence of other factors such as harvest date, crop load, mineral concentration and weather (Table 1).

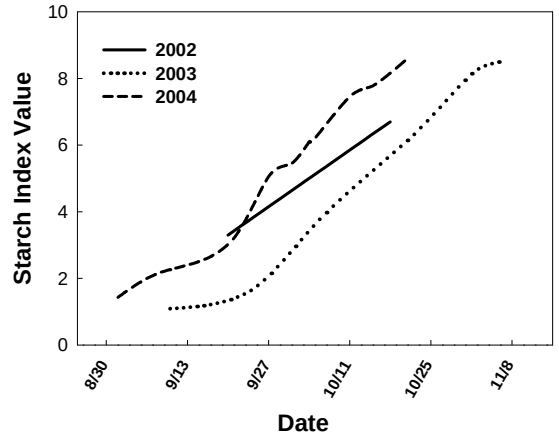

Figure 1. Starch index of apples on the tree versus calendar date for 2002, 2003 and 2004. Starch index value from 1 to 10 (CTIFL) and sample size = 30 apples.

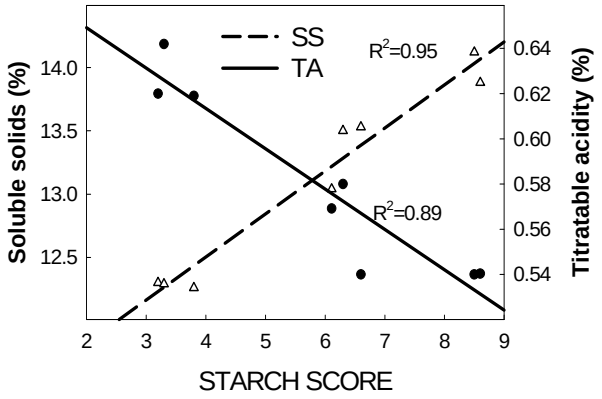

Figure 2. Mean soluble solids and titratable acidity values for each harvest versus starch index for apples harvested in 2002, 2003 and 2004. R^2 corresponds to regression coefficient and sample size = 30 apples.

Table 1. Initial maturity values for 30 apples at each harvest in 2002, 2003 and 2004.

	Starch Score	Blush (%)	Background Color Score[2]	Fruit Wt. (g)	Firmness (lbf)
2002	3.3	29	3.4	153	20.9
	6.7	64	4.4	173	17.8
2003	3.8	36	3.9	172	18.0
	6.3	55	4.5	184	17.4
	8.5	75	5.2	189	15.6
2004	3.2	11	3.2	172	19.8
	6.1	28	3.9	189	18.0
	8.6	54	4.9	190	15.8

[1]Cumulative ethylene production over 10 days at 20°C after harvest.
[2]Background color: scale 3-7

Fruit CO_2 production after storage increased linearly with time in storage and with fruit maturity at harvest (Figure 3). Additionally, the production of CO_2 was lower in CA storage but was not different between the two atmospheres tested. SmartFresh® treated fruit had significantly lower CO_2 production indicating lower respiration rate than fruit stored in air or CA, while DPA did not have a significant effect.

Fruit firmness decreased linearly with time in storage (Figure 4) and fruit stored in air was always softer. There were not differences in firmness among the different concentrations of CO_2 in CA storage; however, there was a trend for fruit kept in 1% CO_2 to be firmer after 4 and 6 months.

For the 2003 season, no internal browning was observed for any of the maturities after 0.5 and 1 month of storage (data not shown). After 2 months of storage in 1% CO_2 and 3% CO_2, 4.8% and 4.6% of fruit showed internal browning (Table 2). A lower percentage of internal browning was observed in fruit from the second harvest, with 1.3% in both atmospheres. Incidence and severity of internal browning after 4 months of storage was not higher than at the 2 month evaluation. SmartFresh® had no effect on the incidence of internal browning. DPA inhibited internal browning completely.

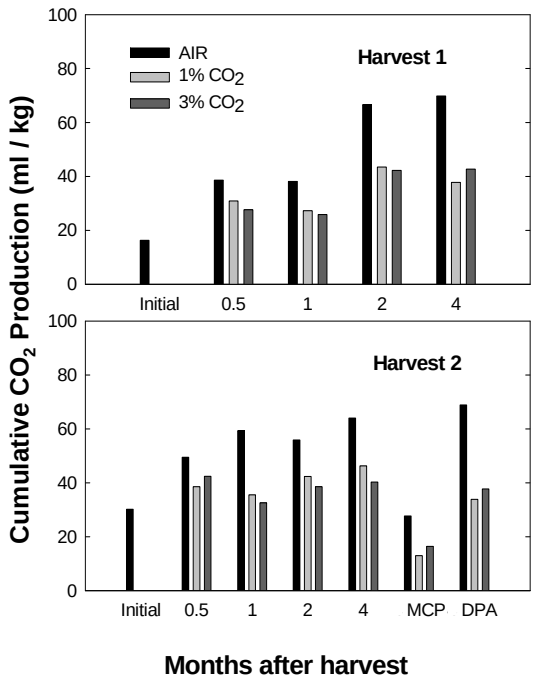

Figure 3. Total CO_2 produced during 10 days at 68ºF after air or controlled atmosphere storage at 33ºF (2% O_2 in combination with 1% or 3% CO_2) for 0, 0.5, 2 or 4 months after harvest in 2003. Harvest 1 and 2 correspond to starch index values of 3.8 and 6.3. The CO_2 production of the fruit with additional treatments: SmartFresh® (1 ppm of 1-MCP) and DPA (2200 ppm of diphenylamine) was measured after 4 months storage in air or controlled atmosphere.

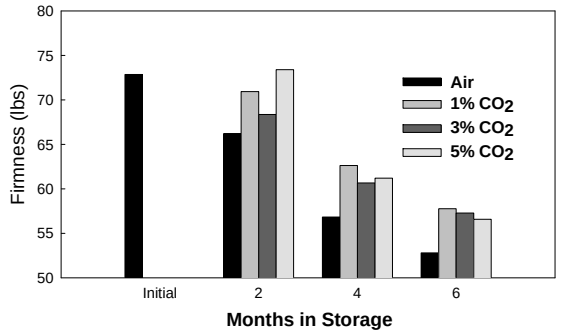

Figure 4. Firmness (lbf) of apples at harvest or after 2, 4 and 6 months of air or controlled atmosphere storage (1.5% O_2 in combination with 1, 3 or 5% CO_2) at 33ºF in 2004; sample size=60 apples, starch index at harvest = 8.5 (CTIFL).

The overall incidence and severity of internal browning among all the treatments were much lower in 2003 as compared to the 2002 and 2004 seasons. The variation between seasons could be due to differences in mineral content of the fruit. The values for the 2003 season, where fruit had less incidence of internal browning, were significantly higher in calcium (Ca), magnesium (Mg) and boron (B) (Table 3). The values for phosphorus (P), nitrate (NO_3), potassium (K) and manganese (Mn) were not statistically different between the seasons.

Table 2. Incidence of internal browning following storage and 5 days at 68 ºF for Pink Lady® brand apples from two harvests in 2003.

	% CO_2[b]	Prestorage Treatment	Internal Browning Incidence (%)[c]	
			Harvest 1	Harvest 2
2 months	0.03	None	0.0	0.0
	1.0	None	4.8	1.3
	3.0	None	4.6	1.3
4 months	0.03	None	0.0	0.0
	1.0	None	1.3	1.3
	3.0	None	2.5	1.3
	0.03	DPA[a]	-	0.0
	1.0	DPA	-	0.0
	3.0	DPA	-	0.0

[a]diphenylamine, 2200 ppm.
[b]All CA atmospheres had 2% O_2
[c]Each value is the mean of 105 apples

Table 3. Mineral analysis of Pink Lady® brand apples.

Mineral	2002	2003	2004
Calcium (Ca)[1]	53.9 a	75.1 b	51.8 a
Magnesium (Mg)[1]	43.8 a	75.9 b	53.8 a
Boron (B)[1]	4.8 a	6.6 b	5.2 a

[1]Values in µg/g fresh weight of flesh tissue.
[2]Values with different letters are significantly different at 5% level (Tukey's test).

DISCUSSION

Pink Lady® brand quality can vary from year to year. The influence of the weather determines the pace of red color development and, consequently, the maturity of the fruit at commercial harvest. The search for a full red color can be a limiting factor for the quality of the fruit. Over mature fruit lose quality faster in storage and may present physiological disorders, fruit firmness may decrease in storage to unacceptable levels and greasiness may develop.

The mineral composition of the fruit and crop load can have a tremendous influence on fruit firmness, development of red color and susceptibility to bruising and other disorders. The balance among crop load and mineral composition of the fruit is a factor to control every season.

SmartFresh® and CA retard aging of the fruit and slow detrimental changes. High concentrations (>1%) of CO_2 in storage do not appear to better maintain Pink Lady® brand firmness or background color and can also cause CO_2-injury disorders such as internal browning. DPA was demonstrated to be an efficient tool to prevent CO_2-induced internal browning. Fruit susceptibility to internal browning cannot be related to only one factor at harvest or in storage. Flesh browning can be associated with concentration of CO_2 in CA; however, other factors

appear to modulate fruit susceptibility because there is seasonal variability susceptibility. Mineral nutrition and seasonal weather may be other important factors.

Our results demonstrate the benefits of CA storage or SmartFresh® treatment to maintain Pink Lady® brand firmness and background color. To prevent CO_2-induced flesh browning (distinct brown spots or patches in flesh), CA atmospheres should not exceed 1% CO_2 and use of DPA may be used to prevent CO_2-related flesh browning. Another type of flesh browning can develop in Pink Lady® brand apples from some growing areas, which appears related to low temperature injury. Storage at slightly elevated temperatures may be warranted in areas where the diffuse browning is observed.

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