Retention of Quality of 'Golden Delicious' Apples by Controlled- and Modified-atmosphere Storage

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Abstract. 'Golden Delicious' apples (*Malus domestics* Borkh.) were subjected to either 0C controlled-atmosphere (CA) storage or to a postharvest coating of 1.0% to 2.5% Nutri-Save (NS; a polysaccharide derived from shellfish) plus air storage. NS-coated apples were greener and firmer and had higher titratable acidity (TA) and more shrivelled and injured fruit than the control after storage in air at 0C for 5 to 6 months and ripening in air at 20C for 7 days. Poststorage washing increased skin injury, and low relative humidity during ripening increased shriveling of NS fruit. NS applications led to an accumulation of CO₂ and C₂H₄ and a small reduction of O₂ in the fruit core cavities. The use of 1.5% O₂ + 1.5% CO₂ in the storage atmosphere was more effective than NS plus air storage in maintaining flesh firmness (FF) and TA without increasing fruit shrivel or skin injury. NS treatments maintained FF and a green skin in fruit ripened in air at 20C for 2 or 4 weeks following harvest, but some shrivel was evident by 4 weeks. Better retention of skin greenness was the only benefit derived from a poststorage NS treatment of CA-stored fruit during the shelf-life test.

Flesh softening and loss of acidity are the main impediments to successful storage of 'Golden Delicious' apples in air at 0C beyond 3 months. Controlled-atmosphere (CA) storage maintains quality of this cultivar (Lau, 1985), but limited CA storage capacity in many apple-producing regions, including British Columbia, necessitates other alternatives.

Postharvest and poststorage applications of semipermeable sucrose polyesters, such as Pro-long (TAL Chemicals Co., Reading, U. K.) and Semperfresh (Inotek International, Gainesville, Ohio), are promising in quality preservation of apples (Drake et al., 1987; Lowings and Cutts, 1982; Smith and Stow, 1984). Elson et al. (1985) found air-stored 'Golden Delicious' apples coated with 2% Nutri-Save (NS) (Nova Chem Ltd., Armdale, Nova Scotia, Canada) at harvest to be similar in quality to that of fruit held in a 2.5% O₂ + 3.0% CO₂ storage atmosphere.

The present study evaluated quality of 'Golden Delicious' apples stored in CA (1.5% O₂ + 1.5% CO₂) or coated with NS and stored in air at 0C. Also evaluated were the effects of NS treatments on induction of storage disorders and the benefits of NS applications on quality of fruit ripened for 2 or 4 weeks in air at 20C following harvest and on shelf-life extension of fruit following CA storage.

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'Golden Delicious' apple samples [10 fruits for each coating, storage, washing, and relative humidity (RH) treatment] were obtained from each of 10 (1984) or eight (1985 and 1986) random fruit lots at a packing-house in Oliver, B. C., on 26, 21, and 18 Sept. in 1984, 1985, and 1986, respectively. Flesh firmness (FF) and titratable acidity (TA) at harvest were determined on a 10-fruit sample (Lau, 1985).

Fruit for CA were held in 0C air for 2 days and then placed in 1.5% O₂ + 1.5% CO₂ commercial CA rooms (630-t capacity) at 0C and ≈94% RH for 148 (1984), 188 (1985), or 177 (1986) days. Storage O₂ and CO₂ levels were established within 3 days of sealing by the use of atmosphere generators and were monitored daily and maintained within ±0.290 by venting and lime-scrubbing. Storage temperatures were maintained within ±0.2C. Fruit for air storage were dipped for 10 sec in 0%, 1%, 1.5%, 2%, or 2.5% (w/v) NS, dried in air at 20C for 2 h, then placed in unsealed paper bags, and held in air at 0C and ≈90% RH for the same periods as the CA fruit.

After storage, apples from each NS treatment designated for washing (to simulate the washing before packing) were gently wiped with a wet towel for 15 sec under running water. The fruit were then dried and ripened in air at 20C and high or low RH. Low humidities were obtained with a household dehumidifier (≈42% in 1984 and ≈59% in 1985) or in a dry, tissue storage room (≈11% in 1986). High humidities were achieved with a humidifier and a wet floor (≈85% in 1984 and ≈95% in 1985). Fruit in 1986 were ripened in a 20C room with an ambient RH of ≈54%.

To evaluate the benefits of NS coatings on

fruit marketed at ambient conditions following harvest, fruit from 10 grower lots were dipped in 0%, 1%, or 2% NS and held in air at 20C for 14 or 28 days at ≈52% RH. To determine the benefits of NS applications on shelf-life extension of fruit following 6 months of 1.570 O₂ + 1.570 CO₂ storage, fruit from eight grower lots per year were coated with 0%, 1.5%, or 2.5% NS and held in air at 20C for 7 days at 95% or 59% RH (1985) and at 54% or 11% RH (1986).

Each 10-fruit sample was analyzed for skin color, FF, TA, and incidence and severity of disorders upon removal from storage and again after 7 days in air at 20C. Shrivell scores were derived by multiplying the severity ratings (slight = 1, moderate = 2, and severe = 3) by the percentage of shriveled fruit. Concentrations of O₂, CO₂, and C₂H₄ in the fruit core cavities were determined by gas chromatography immediately after storage. Ethanol flavor in the fruit was evaluated on a 1 to 5 scale (Lau, 1985) by 16 to 20 panelists for each treatment after the shelf-life test.

In this 3-year study, the postharvest use of 1.0% or more NS on 'Golden Delicious' apples improved retention of FF and TA in fruit during 0C air storage. Coated fruit were also greener, firmer, and had higher TA than control fruit after the shelf-life test (7 days at 20C in air). The response of fruit quality retention to the concentration of NS was linear (Table 1). The results substantiate previous reports in which postharvest coating treatments were beneficial to retention of FF, TA, and skin color in apples and pears (Drake et al., 1987; Elson et al., 1985; Lowings and Cutts, 1982; Magness and Diehl, 1924; Meheriuk and Lau, 1985). None of the NS treatments were as effective as the 1.5% O₂ + 1.5% CO₂ storage in maintaining FF and TA. NS-coated, air-stored fruit were, however, greener than noncoated, CA-stored fruit after the shelf-life test (Table 1).

The applications of NS resulted in an accumulation of CO₂ and C₂H₄ and a small reduction of O₂ in the fruit core cavities (Table 1). The effects of NS on retention of fruit quality may be a consequence of higher internal CO₂, based on results by Magness and Diehl (1924), Fidler and North (1966), and Lau (1985). Reductions of O₂ to 5% or less are needed to suppress respiration and C₂H₄ production (Burg and Thimann, 1959) and, thus, any NS benefits obtained are not initiated by the small changes in internal O₂ levels. Because NS treatments did not lower O₂ by much, one would not expect as much benefit on retention of FF or TA as found in CA fruit where 1.5% O₂ was used. The 4-fold increase in C₂H₄ accumulation in the coated fruit should not have any effect on fruit quality because high levels of C₂H₄ (101 µl-liter⁻¹) were also found in the noncoated fruit, sufficient to stimulate ripening in all fruit. Noncoated, CA-stored fruit had the lowest internal CO₂ and C₂H₄ concentrations (Table 1), which could be the result of the inhibitory effects of 1.5% O₂ and 1.5% CO₂ in the storage atmosphere on fruit respiration and C₂H₄ production (Burg and Thimann, 1959; Kader, 1986).

Table 1. Fruit quality and concentrations of CO₂, O₂, and C₂H₄ in fruit core cavities of Nutri-Save-coated, air (≈ 90% RH)-stored or noncoated, CA (1.5% CO₂ + 1.5% CO₂, ≈ 94% RH)-stored 'Golden Delicious' apples upon removal from the storage' and after a shelf-life test.

Year	Nutri-save (%)	After storage						After storage and 7 days in air at 20C					
		Flesh firmness (N)	Titratable acidity (mg) ^y	Shrivel score (0-300) ^x	CO ₂ (%)	O ₂ (%)	C ₂ H ₄ (μl·liter ⁻¹)	Flesh firmness (N)	Titratable acidity (mg) ^y	Skin color (0-10) ^w	Percentage of fruit with		Shrivel score (0-300) ^x
											CO ₂ injury	Skin injury	
1984	0	53	314	---	---	---	---	48	284	5.0	0	0	---
	1.0	56	363	---	---	---	---	52	316	3.5	2.5	0	---
	2.0	63	406	---	---	---	---	60	360	3.2	1.0	0	---
	CA storage	72	427	---	---	---	---	66	386	4.0	0.5	0	---
LSD, P = 0.05		3	45	---	---	---	---	2	32	0.7	2.6	0	---
Nutri-Save concn		L*** ^v	L***	---	---	---	---	L***,Q*	L***	L***,Q*	NS	NS	---
1985	0	50	317	24	---	---	---	48	279	5.3	1.3	3	26
	1.0	54	365	60	---	---	---	50	337	3.6	2.5	8	68
	1.5	54	403	86	---	---	---	51	344	3.6	3.1	9	111
	2.0	56	415	91	---	---	---	54	365	3.4	2.5	8	80
	2.5	56	441	121	---	---	---	54	368	3.4	0	20	126
	CA storage	68	500	0	---	---	---	67	428	4.0	0	0	1
LSD, P = 0.05		3	58	6	---	---	---	3	31	0.5	3.3	9	3
Nutri-Save concn		L***	L***	L**	---	---	---	L***	L***	L,Q***	NS	L**	L***,q***
1986	0	47	263	66	0.7	19.3	101	47	284	6.1	5	11	80
	1.0	51	334	121	2.4	17.9	336	46	284	4.2	12	9	92
	1.5	52	341	130	2.8	17.6	326	48	308	4.3	18	14	100
	2.0	53	358	170	3.2	17.2	382	49	341	4.1	6	34	159
	2.5	54	370	185	3.9	16.3	414	52	338	4.2	5	19	174
	CA storage	70	476	0	0.4	19.6	32	67	413	5.1	1	1	17
LSD, P = 0.05		3	41	56	0.4	0.6	57	2	22	0.4	9	14	41
Nutri-Save concn		L***	L***	L***	L***,Q*	L***	L***,Q**	L,Q***	L***,C*	L,Q***	Q*	L*	L***

^xStorage durations were 148.188. and 177 days for 1984 (n = 10), 1985 (n = 8), and 1986 (n = 8; n = 20 for CO₂, O₂, and C₂H₄), respectively.

^yExpressed as milligrams of malate per 100 ml juice.

^zRating: 0 = no shrivel, 1 = slight, 2 = moderate, and 3 = severe shrivel; ratings multiplied by the percentage of shrivelled fruit.

^wHigh values indicate yellow fruit.

^vLinear (L), quadratic (Q), cubic (C), quartic (q), and significant at P = 0.05 (*), 0.01 (**), or 0.001 (***) levels or nonsignificant (NS)

Table 2. Effects of poststorage washing on quality of Nutri-Save-coated 'Golden Delicious' apples (n = 8) after 6 months of air storage (≈ 90% RH) and 7 days in air at 20C.

Nutri-Save (%)	Skin color (0-10) ^z		Percentage of fruit with			
			CO ₂ injury		Skin injury	
	1985	1986	1985	1986	1985	1986
0	5.3	6.1	0.6	5	12	10
1.0	3.6	4.4	1.6	15	17	23
1.5	3.6	4.4	2.5	14	29	28
2.0	3.5	4.4	3.8	11	23	43
2.5	3.4	4.4	0.3	5	37	55
Nutri-Save concn (c)	L,Q*** ^y	L,Q***,C*	NS	Q***	L***,q*	L***
Unwashed	3.9	4.6	1.9	9	10	17
Washed	3.9	4.9	1.6	11	37	46
Washing (w)	NS	**	NS	NS	***	***
c × w	NS	NS	NS	NS	NS	**

^zHigh values indicate yellow fruit.

^yLinear (L), quadratic (Q), cubic (C), quartic (q), and significant at P = 0.05 (*), 0.01 (**), or 0.001 (***) levels or nonsignificant (NS).

Table 3. Effect of a postharvest Nutri-Save treatment on quality of 'Golden Delicious' apples during simulated shelf-life test following harvest (1984, n = 10).

Nutri-Save (%)	Flesh firmness (N)			Skin color (0-10) ^z		Shrivel score (0-300) ^y	
	Days in air at 20C (≈ 52% RH) following treatment						
	0	14	28	14	28	14	28
0	71	58	55	4.8	6.4	0	0
1.0		68	59	3.3	4.6	0	7
2.0		72	67	2.7	3.0	0	18
Nutri-Save concn		L****	L***	L***	L***	NS	L**

^zHigh values indicate yellow fruit.

^yRating: 0 = no shrivel, 1 = slight, 2 = moderate, and 3 = severe shrivel; ratings multiplied by the percentage of shrivelled fruit.

^xLinear (L), and significant at P = 0.01 (**) or 0.001 (***) levels or nonsignificant (NS).

Fruit shrivel was more severe in coated fruit than in noncoated fruit after air storage and the shelf-life test. Severity was increased by higher NS concentrations (Table 1) and lower RH regimes during the shelf-life test (shrivel score = 9 at ≈ 59% RH vs. 5 at ≈ 95% RH in 1985 and 122 at ≈ 11% RH vs. 85 at ≈ 54% RH in 1986). The mechanism by which NS increased water loss from fruit during storage or ripening is not known.

Elson et al. (1985) reported that NS films in RH of 70% or less became impermeable to O₂ and CO₂ at 20C. In this study, a 7-day exposure of fruit to lower RH regimes (11% to 59% RH compared to 54% to 95%) during the shelf-life test had no effect on dessert quality, skin color, skin disorders, and ethanol flavor in NS-coated fruit (data not shown).

Incidence of CO₂ and skin injury was negligible in NS-coated fruit after air storage (data not shown) but evident after the shelf-life test (Table 1). Coating had no consistent effects on ethanol flavor, and values were generally low (data not shown).

Poststorage washing to remove the NS coating slightly increased skin yellowing and also exacerbated skin injury in coated fruit after the shelf-life test (Table 2). NS might have rendered the cells more sensitive to frictional injury resulting from the washing process.

NS at 1% or 2% delayed flesh softening and skin yellowing (Table 3) but had no effect on TA or ethanol flavor (data not shown) of fruit ripened in air at 20C for 14 or 28 days following harvest. Fruit shrivel was not found after 14 days but was a problem after 28 days of ripening (Table 3).

NS at 1.5% or 2.0%, applied to fruit after 6 months of 1.5% O₂ + 1.5% CO₂ storage, had no effect on FF, TA, fruit shrivel, or ethanol flavor (data not shown) but did assist in retention of a green skin (4.6, 3.5, and 3.4 on a 0 to 10 scale for 0%, 1.5%, and 2.0% NS, respectively; $P = 0.001$) during the shelf-life test.

Although NS treatments maintain FF, TA, and green skin color, fruit shrivel and, to a lesser extent, skin injury still remain as serious problems with the commercial use of NS on fresh-market 'Golden Delicious' apples. Also, the coating solution is very viscous and difficult to handle and the cost of dipping can be high. Consumer acceptance of fruit coated with shellfish products may be another obstacle. Storage of fruit in 1.5% O₂ + 1.5% CO₂ at 0°C is simpler, safer, and more effective than NS plus air storage for maintaining high FF and TA in the fruit.

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