Effects of Storage Temperature, Storage Atmosphere, and Growing Region on Internal Browning Disorder of 'McIntosh' Apples

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SUMMARY. Our study found that storage temperature, storage atmosphere and growing region interactively affect the probability of internal browning disorder in 'McIntosh' apples (*Malus domestica* Borkh.). Higher incidence of internal browning occurred in apples stored for 6 months at 1 °C (34 °F) in controlled atmosphere (CA) with 2.5% O_2 + 1.5% CO_2 or in CA with 1.0% O_2 + 0.5% CO_2 than apples stored at 1 °C in air or stored at 3 °C (37 °F) in air or CA conditions. The magnitude of the incidence of internal browning varied among apples harvested from different growing regions. Apples from London, Ontario, Canada were less tolerant to these two storage conditions and therefore greater number of fruit developed internal browning than apples from other regions. In addition, apples from the London growing region and stored at 1 °C in CA with 1.0% O_2 + 0.5% CO_2 had greater probability of internal browning than apples stored at 1 °C in CA with 2.5% O_2 + 1.5% CO_2. However, there was no difference between these two CA storage conditions in causing internal browning among apples harvested from other three growing regions. Few apples showed internal browning when they were stored at 3 °C, no matter of what storage atmosphere was used. Therefore, internal browning disorder can be avoided or significantly reduced by storing apples at 3 instead of 1 °C, in these two CA conditions. Internal browning disorder will not be a risk if apples are stored in air at 1 or 3 °C.

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Commercial storage operators in Ontario delivered apple samples to our research laboratory in March of 1992. These storage operators reported a similar problem in 'McIntosh' apples after removal from commercial CA storage rooms. The apples had developed diffused browning in the flesh, with no definite outline on the affected tissue. This physiological disorder is known as internal browning (Meherick et al., 1994). It has also been called "flesh browning". Internal browning disorder may affect the outer flesh, the tissue around the core, or both. In more advanced stages, browning may encompass most of the internal tissue of the fruit. Researchers in other areas of North America, such as Quebec, Canada and New York, United States, also reported observation of this problem in 1992. This disorder was also reported in British Columbia, Canada, in the spring of 1993 and again in Quebec in the spring of 1997.

Internal browning has been associated with pre- and postharvest conditions. Preharvest conditions include cool growing temperatures, shaded parts of the tree, large fruit, lightly cropped trees, high nitrogen level, low tree vigor, and tree age (Ballard et al., 1922; Henze, 1971; Meheriuk et al., 1984, 1994; Overholzer et al., 1923; Powell, 1909; Schouten, 1986; Winkler, 1923). DeEll and Prange (1993) reported that conventionally grown 'McIntosh' apples had a higher probability of internal browning after 8 months of CA storage than organically grown fruit. Internal browning normally does not develop in 'McIntosh' apples cold stored in air. Postharvest factors associated with internal browning include late harvesting, delayed cold storage, storage temperature that is too cold, high CO_2 level in CA storage, and sometimes, water core (Acki et al., 1981; Meheriuk et al., 1984). Internal browning occurs in many apple cultivars (Meheriuk et al., 1994).

Internal browning often develops in 'McIntosh' apples when they are stored under CA at 0 °C (32 °F). In Ontario, we recommend storing 'McIntosh' apples at 3 °C (37 °F). However, some commercial storage operators store them at 0 or 1 °C (32 or 34 °F) to accommodate mixed varieties of apples stored in the same CA room. These operators do not recognize the risk for developing internal browning in 'McIntosh' apples stored below 3 °C in CA storage.

The objective of this study was to evaluate the effects of storage temperature, storage atmosphere and growing region on the probability of internal browning in 'McIntosh' apples. Information provided in this study will help alert storage operators to the risk of developing internal browning, and enable them to adjust storage conditions accordingly.

Materials and methods

SOURCES OF APPLE SAMPLES. Eight commercial orchards from each of four apple-growing regions in Ontario, Canada (Simcoe, Smithfield, Georgian Bay, and London) participated in this 1994 project. Orchards in the Simcoe area are located at the north side of Lake Erie on the north shore of Long Point Bay close to the city of Simcoe. Orchards in the Smithfield area are located at the north shore of Lake Ontario close to the cities of Trenton and Colborne. Orchards in the Georgian Bay area are located at the southern tip of the Georgian Bay close to the cities of Meaford and Thornsbury. Orchards in the London area are located inland between Lake Huron and Lake Erie close to the cities of London and Woodstock.

Apples were harvested from each orchard at an optimum harvest date that was determined by the commercial grower and the provincial horticulture crop advisor. The apples were transported from the orchard to the Horticultural Products Laboratory at

Table 1. Tests of fixed effects of the probability of internal browning in 'McIntosh' apples after storage for 6 months at 1 or 3 °C (34 or 37 °F) in air, controlled atmosphere (CA) with 2.5% O_2 + 1.5% CO_2, or CA with 1.0% O_2 + 0.5% CO_2, and followed by 7 d at 20 °C (68 °F) in air.

	Tests of fixed effects[z]		
Source	df	Mean square	*P* > F
Growing region (G)	3	14.16	*
Main plot error	28	3.63	
Temperature (T)	1	171.68	**
Atmosphere (A)	2	44.43	**
T × A	2	28.37	**
G × T	3	12.14	**
G × A	6	4.26	*
G × T × A	6	3.34	NS
Subplot error	138	1.85	

[z]Data are transformed to logit values for SAS analysis using PROC MIXED procedure.

Vineland Station on the day of harvest. The apples were not washed or waxed before storage. Apples from all four growing regions were harvested in 1 week.

STORAGE CONDITIONS. Six storage rooms (inside dimension: 1.9 m width × 1.9 m depth × 3.1 m height, with a drop ceiling 2.2 m from the floor [75 inches width × 75 inches depth × 122 inches height, with a drop ceiling 87 inches from the floor]) were used in this experiment (Chu et al., 1985). The rooms are prefabricated walk-in coolers made airtight with Steridex paint on the inside wall, ceiling, and floor surfaces. Apples were stored at 1 or 3 °C (34 or 37 °F) in three different atmosphere conditions: 1) air, 2) CA with 2.5% O_2 + 1.5% CO_2, balance N_2, or 3) CA with 1.0% O_2 + 0.5% CO_2, balance N_2. The storage room temperature was controlled continuously by a computer system (Hantec Controls, Pickering, Ontario) with high and low alarm levels set at 1 °C (2 °F) above and below the preset room temperature. The atmosphere in all CA rooms were automatically monitored and adjusted by a computer-controlled gas sampling system. The atmosphere was controlled by adding nitrogen, carbon dioxide or air; with a computer-controlled gas sampling system (Chu et al., 1985). The atmosphere in each CA room was monitored and corrected twice per day. Atmosphere levels for each room were also checked manually with an oxygen and carbon dioxide analyzer (Nova Analytical Systems Inc., Hamilton, Ontario) sometime during the weekdays by sampling the room atmosphere through a valve on the door in order to verify the computerized system. The relative humidity levels in all storage rooms were maintained at levels between 90% and 95%. Apples were stored in stackable plastic containers, allowing good air circulation through the fruit.

STORAGE DURATION AND LABORATORY EVALUATION OF INTERNAL BROWNING DISORDER IN APPLES. Apples were stored for 4 or 6 months. After each storage period plus additional 7 d at 20 °C (68 °F) in air, 10 apples, randomly sampled from each orchard and storage condition, were evaluated. Data for internal browning was recorded by counting the number of apples showing the symptom. Most apples with the symptom showed only slight severity of internal browning.

STATISTICAL DESIGN AND ANALYSES. A completely randomized split-plot design by each storage duration, with growing region as main plot and storage temperature and storage atmosphere as subplots, was used in the statistical analysis of the data. The eight orchards in each growing region were considered replications. Ten apples in each laboratory evaluation were a sample for each factor. We used PROC MIXED procedure of the Statistical Analysis System (SAS) program package (SAS, 1997) to analyze the data. PROC MIXED procedure uses appropriate error terms consistent to the split plot design. It estimates the standard error of mean and difference between means correctly, whereas most other packages including PROC GLM do not. To make the data approximately normally distributed and account for intrinsic binomial nature of response, data were transformed to logit scale for statistical analysis. The formula used for the data transformation is logit = log((k + 0.05) / (10 – k+0.05)). The value of k is the number of fruit showing internal browning (ranging from 0 to 10). Then the means were back-transformed to probabilities (in percentage) of the internal browning and were presented in results and discussion. This value is calculated according to the following formula: probability of internal browning = exp(lsmean) / (1+exp(lsmean)) × 100.

The lsmean is the least squares mean of the logit data.

Results and discussion

Storage temperature and atmosphere had the greatest impact on internal browning. Growing region and storage period also affected the probability of internal browning. 'McIntosh' apples did not develop internal browning disorder under any storage condition after only 4 months of storage (data not shown, all apples had 0 reading of internal browning). However, we found internal browning disorder in some apples stored after 6 months of storage.

After 6 months in storage followed by one week at 20 °C (68 °F) in air, storage temperature and storage atmosphere within each growing region interacted to affect the probabil-

Table 2. Results of fixed effects of the probability of internal browning in 'McIntosh' apples after storage for 6 months at 1 or 3 °C (34 or 37 °F) in air, controlled atmosphere (CA) with 2.5% O_2 + 1.5% CO_2, or CA with 1.0% O_2 + 0.5% CO_2, and followed by 7 d at 20 °C (68 °F) in air.

	Contrast statement results[z]		
Source	df	F	*P* > F
Growing region (G) at 1 °C	3	9.33	**
Growing region at 3 °C	3	0.44	NS
Atmosphere (A) at 1 °C	2	38.41	**
Atmosphere at 3 °C	2	1.15	NS
G × A at 1 °C	6	4.58	**
G × A at 3 °C	6	1.93	NS

[z]Data are transformed to logit values for SAS analysis using PROC MIXED procedure.

ity of internal browning disorder in 'McIntosh' apples (Table 1). There was very strong interaction between temperature and atmosphere and between temperature and growing region. Also, there was an interaction between atmosphere and growing region. There was a suggestion of an interaction among the three factors (not quite significant at 5% level, though as *P* value is 0.0981). To clarify the interaction among the three factors, CONTRAST statements were used in PROC MIXED to allow independent analysis of 1 and 3 °C (34 and 37 °F) data. The CONTRAST statement results show that when apples were stored at 1 °C, the interactive effect of atmosphere and region was highly significant (Table 2). When apples were stored at 3 °C, the interactive effect of atmosphere and region was not significant. In order to effectively present all two-factorial interactions in Table 1 and the interaction between atmosphere and growing region under 1 °C in Table 2, all simple effects were examined and presented (Fig. 1).

Apples showed internal browning only when they were stored in CA conditions at 1 °C. Since very few or no symptoms were evident after apples were stored at 1 or 3 °C in air (cold storage), internal browning does not appear to be related to chilling injury. Apples stored at 3 °C under all three atmospheres showed very few or no symptoms, so the disorder also does not appear to be related to low-oxygen injury. This suggests that internal browning was caused by an interactive effect between low temperature and low-oxygen atmosphere.

Internal browning appeared most frequently when apples were stored at 1 °C after 6 months in these two CA conditions. The severity of the probability of apples showing the symptom depended upon which growing region the apples were harvested from. Apples from London region had a greater probability of internal browning than apples from the other three regions (Fig. 1, mean separation indicated by uppercase letters). For example, after storage at 1 °C in CA with 1.0% O_2 + 0.5% CO_2, approximately 60% of apples harvested from London region showed the internal browning, while <5% of apples harvested from Simcoe region had the symptoms. In addition, for apples harvested from London region, apples stored at 1 °C in CA with 1.0% O_2 + 0.5% CO_2 had more internal browning than apples stored at the same temperature in CA with 2.5% O_2 + 1.5% CO_2 (Fig. 1, mean separation indicated by lowercase letters).

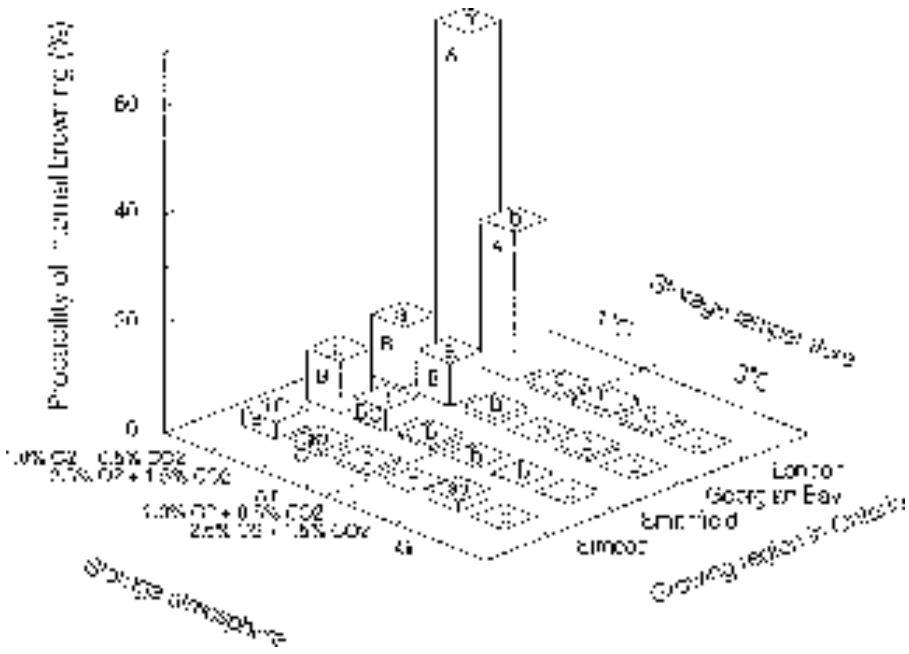
Climate conditions within each region might affect the initiation and development of the internal browning. Meheriuk et al. (1994) and Overholzer et al. (1923) suggested that cool growing temperature might be one of the many possible factors affecting the probability of internal browning disorder. This disorder was not reported by commercial apple growers in Ontario in the spring of 1994 (for the 1993 crop) but was reported in the spring of 1995 (for the 1994 crop), it could be because we had warmer August temperatures in 1993 and colder August temperatures in 1994.

The storage room temperature was maintained within ±0.2 °C (0.4 °F) of the set temperature through the duration of the experiment except for three incidences the temperature of a storage room rose to above the alarm level of ±1 °C (2 °F). The first incidence occurred on 7 Oct. 1994, in the 2.5% O_2 + 1.5% CO_2 CA room, the temperature raised from 3 °C to 13 °C (55 °F) over a 24-h period. The second incidence occurred on 26 Jan. 1995, in the cold storage room, the temperature raised from 3 to 12 °C (54 °F) over a 24 h period. The third incidence occurred on 27 Feb. 1995, in the 1.0% O_2 + 0.5% CO_2 CA room, the temperature raised from 1 to 8 °C (46 °F) over a 24-h period. These incidences were quickly handled by either fixing the refrigeration system or by moving the fruit to another storage room. During the 6 month of storage, the standard deviation of oxygen levels in CA or low-oxygen CA room was ±0.4% or ±0.5%, respectively. The standard deviation of carbon dioxide levels in CA or low-oxygen CA room was ±0.6% or ±0.8%, respectively.

Recommendation to storage operators

During a year when internal browning disorder in apples may occur, a greater probability of this disorder can be expected after 6 months of CA storage if the room temperature is 1 °C (34 °F). Therefore, we recommend that 'McIntosh' apples should be stored at 3 °C (37 °F) in CA rooms. We do not recommend that storage operators store 'McIntosh' apples with

Fig. 1. Probability of internal browning disorder after apples were stored for 6 months at 1 or 3 °C (34 or 37 °F) in air, controlled atmosphere (CA) with 2.5% O_2 + 1.5% CO_2, or CA with 1.0% O_2 + 0.5% CO_2, and followed by 7 d at 20 °C (68 °F) in air. Mean separation (shown in lowercase letters) within each growing region by protected LSD test, 5% level. Mean separation (shown in uppercase letters) within CA storage conditions at 1 °C by protected LSD test, 5% level.



other apple cultivars in the same CA storage room at 1 °C.

Our results have shown that lowering the temperature from 3 to 1 °C during storage in air did not increase the number of apples that developed internal browning. Therefore, 'McIntosh' apples may be stored with other apple cultivars in air at 1 °C.

Apples grown in some region may be less tolerant to extreme storage condition (e.g., CA conditions at 1 °C) and therefore greater number of fruit will develop internal browning than apples from other regions. Storage operators for this region must follow the storage recommendation more closely or develop their own proper apple storage condition for their region.

Apples can show internal browning disorder after 6 months of storage even when there is no symptom after 4 months of storage. Therefore, apples showing no symptom during early sampling from storage does not mean apples will be free from this disorder when storage duration is extended.

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Incorporating Water Harvesting into Plasticulture Production of Muskmelon

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ADDITIONAL INDEX WORDS. water conservation, rainfall capture, trench planting, plastic mulch, water catchments, cucumis melo, cantaloupe, irrigation, seed bed configuration

SUMMARY. Competition for limited water supplies is increasing world wide. Especially hard hit are the irrigated crop production regions, such as the Lower Rio Grande Valley and the Winter Garden areas of south Texas. To develop production techniques for reducing supplemental water needs of vegetable crops, an ancient water harvesting technique called rainfall capture was adapted to contemporary, large scale irrigated muskmelon (*Cucumis melo* var. *reticulatus* L.) production systems. The rainfall capture system developed consisted of plastic mulched miniature water catchments located on raised seed beds. This system was compared with conventional dry land and irrigated melon production. Rainfall capture resulted in 108% average yield increase over the conventional dry land technique. When compared with conventional furrow irrigation, rainfall capture increased marketable muskmelon yield as much as 5355 lb/acre (6000 kg·ha^{-1}). As anticipated,

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